LICHTGEDANKEN

The Research Magazine

09

INTERVIEW NONLINEAR OPTICS DOWN TO ATOMIC SCALES

INNOVATION SPASER—THE SMALLEST LASERS IN THE WORLD

BREAKTHROUGH THE MOST IMPORTANT PUBLICATION OF THE YEAR

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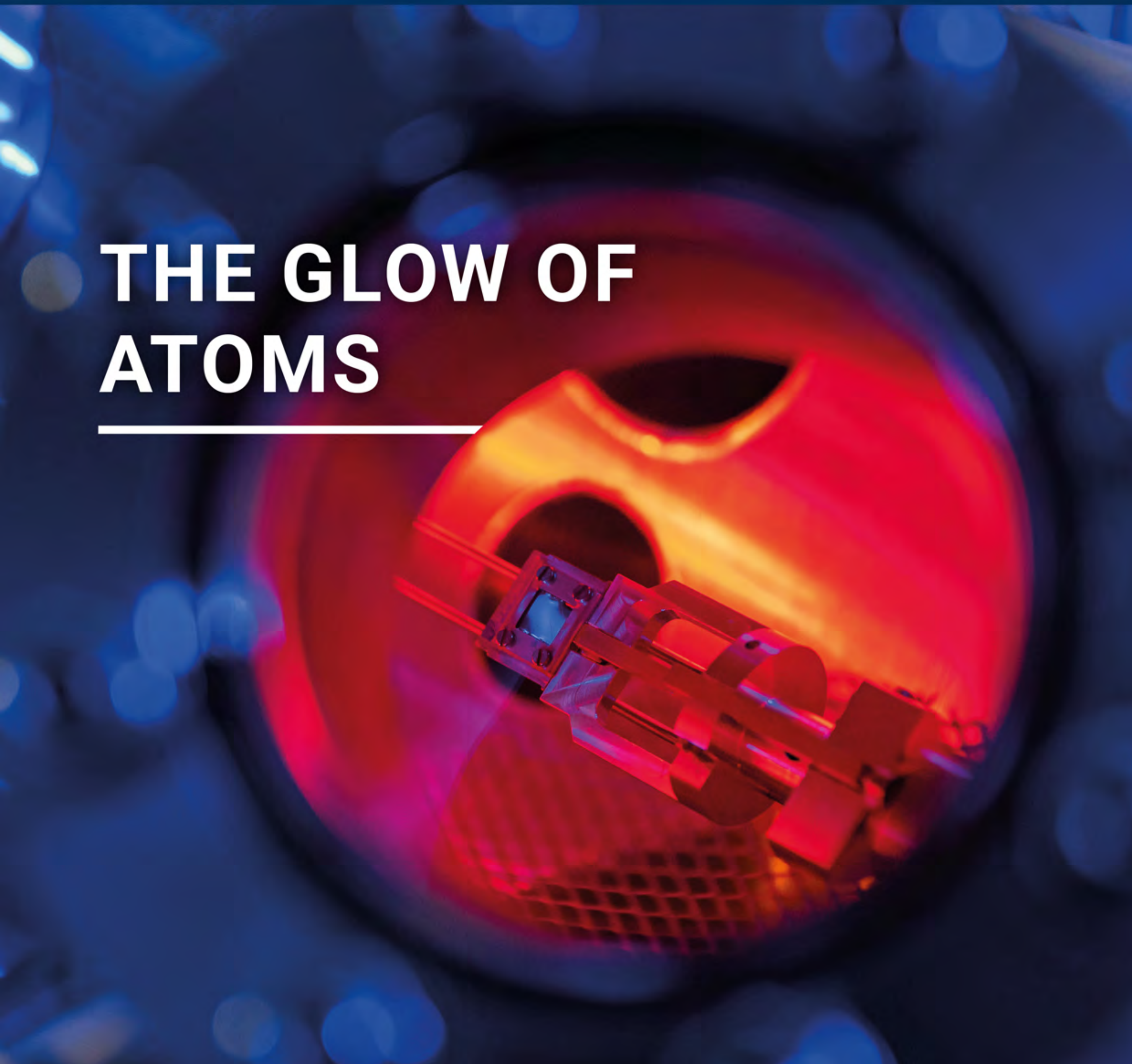

THE GLOW OF ATOMS

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Dr Ute Schönfelder, Editor
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Rays of hope in times of crisis

The year 2021 started where 2020 left off: in the midst of the coronavirus crisis. And as we publish the ninth edition of our LICHT**GEDANKEN** magazine, we just cannot help talking about it. The pandemic has been restricting almost all spheres of life for over a year. The crisis has also left its mark on everyday university life. But despite (or precisely because of) the exceptional situation, we can see shimmering rays of hope in research and teaching after the second ›COVID semester‹. In the LICHT**GEDANKEN** survey, researchers from our University explain how the crisis has boosted their productivity, how they are developing new ideas and forms of communication and cooperation, and what experiences they can take away for their post-crisis careers (pp. 38–41).

A more literal take on ›rays of hope‹ is reflected by our focus on ›the glow of atoms‹. Optical research and development has a rich tradition in Jena, where Carl Zeiss once revolutionized microscopy and Ernst Abbe calculated a microscope's diffraction limit. These resolution barriers have long been broken down, and Jena and its university continue to play an important role in one of the latest optical disciplines, nonlinear optics, which is what this edition of LICHT**GEDANKEN** is all about. The first laser in Germany was developed in 1962 in Jena (p. 12); the first professor of nonlinear optics was appointed here; and in 2020, the University of Jena was involved in a team of researchers who achieved the internationally acclaimed ›Physics Breakthrough of the Year‹ (pp. 36), with possible implications for nonlinear optics.

Our focus on ›the glow of atoms‹ delves into the fascinating world of extremes. When laser light around a billion times more intense than the sun is concentrated on the tiniest material structures, their matter particles begin to glow. Under these extreme conditions, the rules of classic optics no longer apply. We see the emergence of new phenomena and light with completely new properties. Teams of researchers at our collaborative research centre (CRC) ›Nonlinear Optics down to Atomic Scales‹ (NOA) are investigating what happens during these processes, and we present their results in this issue of LICHT**GEDANKEN**. We also take a look at laboratories where physically distanced scientists with face coverings are using lasers to measure, calculate and model the effects of light on nanomaterials. In our interview with the CRC's spokespeople, Prof. Dr Ulf Peschel and Prof. Dr Stefanie Gräfe (pp. 14–16), we learn that a theoretical foundation is still required to comprehend and classify many concepts, while other ideas are already shaping our everyday lives and will continue to play a role in the future.

I hope you will find our research magazine enlightening and I look forward to hearing your feedback, comments or criticism. You can contact the editorial team and me at presse@uni-jena.de.

Stay healthy and hungry for knowledge!

Jena, May 2021

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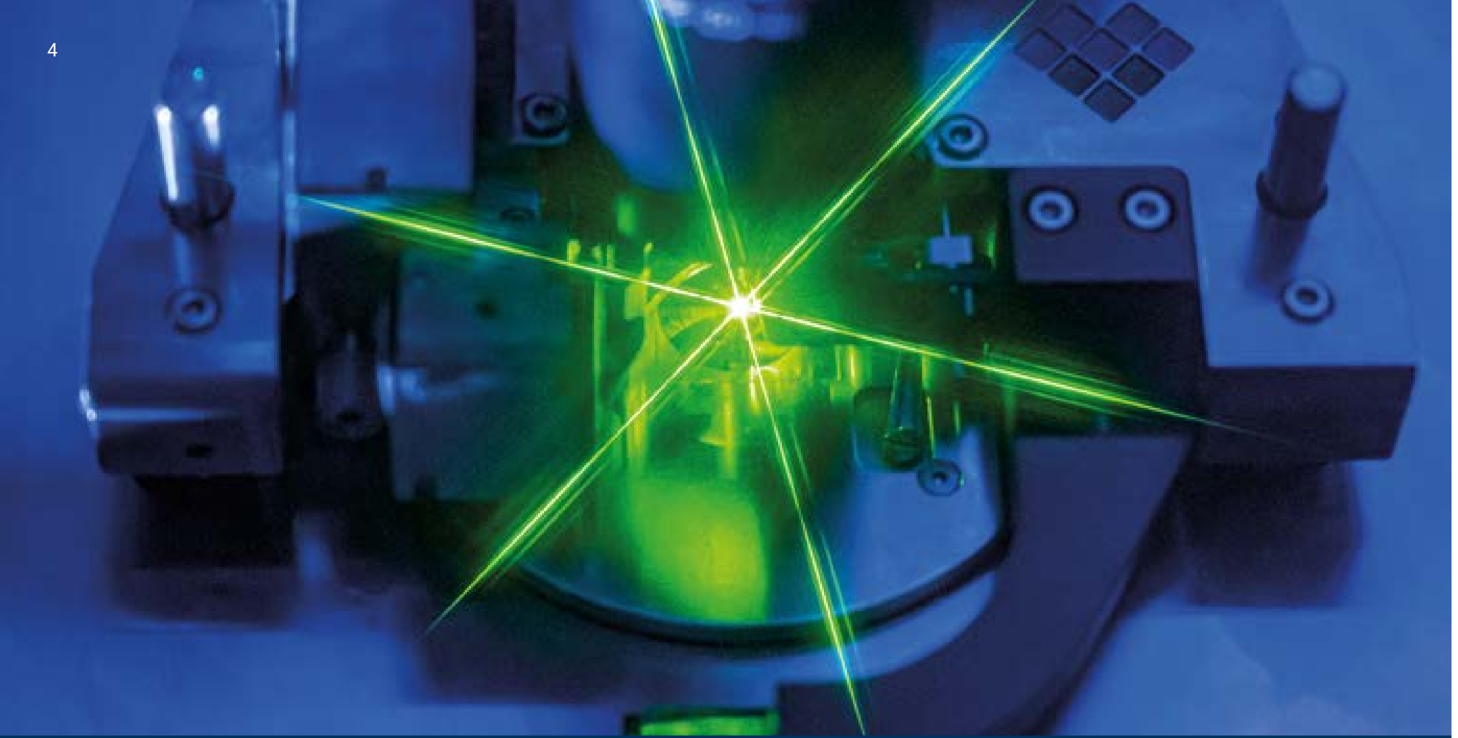
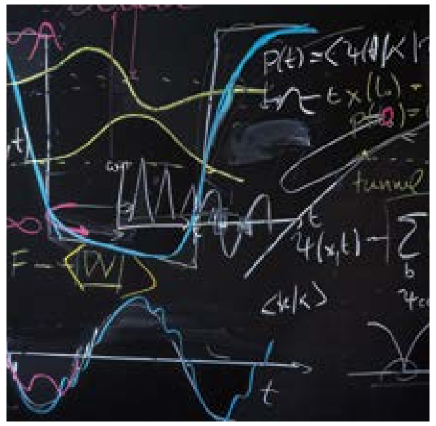


PHOTO: JENS MEYER

FEATURE

The glow of atoms



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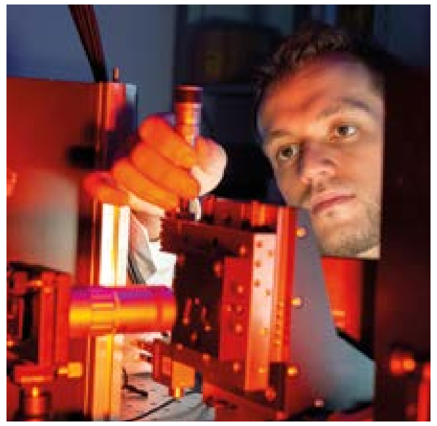

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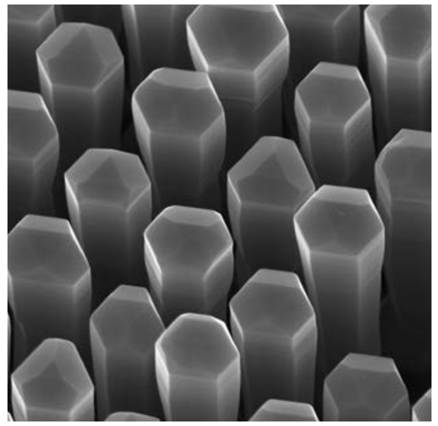

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New algorithms through discretization

ERC starting grant for Jena mathematician

Every year, the European Research Council (ERC) awards starting grants to young scientists looking to carry out pioneering work in science and find answers to future questions, providing up to 1.5 million euros for them to start their own independent research group. Those who receive starting grants can run their own innovative five-year project. Prof. Dr Dietmar Gallistl (pictured above) from the University of Jena was awarded such funding in 2020. In his project entitled ›Discretization and adaptive approximation of fully nonlinear equations‹ (DAFNE), he is investigating new numerical methods for a class of differential equations in order to expand their range of potential applications.
In the years to come, Dietmar Gallistl will be examining how the ›finite element method‹ can be applied to the class of fully nonlinear equations. The finite element method is a method of discretization, a mathematical process in which a complex equation is solved by subdividing it into smaller steps. When calculating a geometrical body, for example, it is divided into many small elements. »This method is often used in engineering, for example to calculate the deformation of elastic solids,« explains Gallistl. sh

Exploring the ›gut-brain axis‹

The human digestive system is closely connected to the brain: Gut microbiota play an important role in mental illnesses and neurodegenerative diseases, and they also influence the brain's ability to learn.
This link is being examined more closely by the ›SmartAge‹ research network led by Prof. Dr Otto W. Witte from Jena University Hospital. His interdisciplinary team of experts from ten European countries is responsible for jointly supervising 15 young researchers. The network has received almost four million euros in funding from the EU's Horizon 2020 innovation programme. vdG

Research Training Group on aging to be continued

The ›ProMoAge‹ Research Training Group (RTG) has been extended for another four years. It has received a further 5.5 million euros in funding from the German Research Foundation. The group's members come from the University of Halle-Wittenberg, the University of Jena, the University hospitals in Halle and Jena, and the Leibniz Institute on Aging in Jena (Fritz Lipmann Institute). The funding will go towards 14 scientific projects and six medical doctorates. The main objectives of the ›ProMoAge‹ RTG are to research the post-translational modifications of cellular proteins as key factors in age progression, to explore their impact on the signal proteins relevant to aging and to investigate their influence on epigenetic and transcriptional regulatory processes. The findings can be used to improve the health of the elderly. vdG

Annual report submitted by commission of experts

Over the past year, Germany's research and innovation have been significantly impaired by the ongoing coronavirus crisis. This was the conclusion drawn by the Commission of Experts for Research and Innovation (EFI) in an annual report that was presented to Angela Merkel on 24 February 2021. The chancellor held a video conference with the commission and its chairman, economist Prof. Dr Uwe Cantner from the University of Jena.
In its annual report, the commission states that companies of all sizes are noting a significant drop in revenue and may be investing less in research and innovation projects. The science system is also suffering from restrictions, as reflected by research output. PR

Virtual submission: Prof. Dr Uwe Cantner (EFI Chair) and Prof. Dr Katharina Hölzle (Deputy Chair) present Dr Angela Merkel (Federal Chancellor) and Anja Karliczek (Research Minister) with the 2020 annual report. · Photo: David Ausserhofer

Wind power: sustainable, but who does it belong to? · Photo: Jan-Peter Kasper

Who owns the wind?

A new collaborative research centre (CRC) / Transregio between the Universities of Jena and Erfurt is investigating changes in ownership structures.

This new major project in Thuringia will receive around ten million euros in funding from the German Research Foundation over the next four years. The CRC ›Structural Change in Ownership‹ brings together researchers from the social, legal, economic and historical sciences.

What is it all about?

While some people's wealth is growing faster and faster, the vast majority of the global population has to get by with less. In today's world, 26 billionaires own as much property as the poorer half of humanity put together.
»In view of the immense economic, environmental and technological challenges of our time, the concentration of wealth and resulting ownership structures are proving to be crisis-prone and highly controversial,« explains Prof. Dr Hartmut Rosa. The sociologist, who researches and teaches in Jena and Erfurt, is the spokesperson for the new CRC. In addition to the redistribution of wealth, Rosa points out some of the other ownership issues in the modern world, such as the question of who owns the sunlight or wind used to generate and sell energy.
The new research network is attempting to systematically analyse these issues and examine changes in ownership structures. Over 30 experts and their teams from both universities and associated institutions are dealing with such changes in ownership structures. US

What does the biological clock say?

An interdisciplinary research team from Friedrich Schiller University Jena, the Leibniz Institute on Aging (Fritz Lipmann Institute) and Jena University Hospital is being funded by the Carl Zeiss Foundation.

As the popular saying goes, ›you are as old as you feel‹—a person is not just as old as the years they have lived.
The aim of the new ›IMPULS‹ research project at the University of Jena is to establish how a person's age can be defined and determined. Over the next five years, the project team will receive around 4.5 million euros in funding from the Carl Zeiss Foundation as part of its ›Breakthroughs‹ programme. ›IMPULS‹ is the German acronym for the ›identification and manipulation of the physiological and psychological clocks in a person's lifespan‹. In other words, the researchers are not just interested in finding out the ›time‹ displayed on a person's biological clock. »We also want to know whether and how the overall aging process can be delayed by manipulating our biological clock,« explains Prof. Dr Christoph Englert, the spokesperson for the collaborative project. The professor of molecular genetics at the University of Jena and research group leader at the Leibniz Institute on Aging says that aging processes are modulated by individual factors, such as a person's diet, lifestyle and attitude towards old age. »We want to combine physiological and psychological approaches to develop a new perspective on ageing.« US

Dr Maria Wächtler (right) and Dr Daniil Kartashov are generating high harmonic optical oscillations on nanoparticles and nanowires. Their analysis is providing the researchers with more information about the dynamic processes within the nanomaterials—with the highest levels of temporal and spatial resolution in the femtosecond and nanometre range. · Photo: Jens Meyer

FEATURE

The glow of atoms

Nonlinear optics in the nanoworld

Nonlinear optics is a human-made branch of physics: If we had not developed high-performance lasers, we would not be able to gather enough protons to combine with electrons and form collective oscillations. If we did not have the intensity of femtosecond laser pulses, we would barely be able to generate light waves with a field strength high enough to make the matter itself glow, to change the colour of light, and to stimulate high harmonic oscillations through interactions with charge carriers. Teams of researchers from the University of Jena are investigating these interactions between light and matter at a collaborative research centre known as ›Nonlinear Optics down to Atomic Scales‹. They are particularly interested in finding out what happens when intense laser light hits individual atoms and tiny nanostructures, thus opening a new window into the nanoworld.

No light without matter

Optics is the oldest discipline in physics. While people in ancient times believed light originated in their eyes in the form of ›rays of vision‹, we now know that light is emitted by matter and registered by the eye. It is a wave and a particle at the same time. Nothing moves faster and what we perceive as visible light is only a small part of a broad spectrum. However, we are yet to fully understand all aspects of the ›theory of light‹. While humans are not the origin of light, they have opened up a whole new chapter of physics in nonlinear optics.

BY UTE SCHÖNFELDER

What is nonlinear optics anyway?

In order to answer this question, it might be useful to start by looking at traditional—linear—optics, which gets its name from the linear relationship between the light that enters and exits a body or medium. If a ray of sunlight falls through a windowpane, for example, a certain amount of light will come out on the other side. If twice as much light shines through the glass, the amount of light on the other side will also double. »And the light's wavelength—that is, its colour—doesn't change in linear optical processes,« explains Prof. Dr Gerhard Paulus, who teaches nonlinear optics at the University of Jena. »Red light is diffracted or refracted as a red ray; if I shine green light at an object, it will reflect green light.«
This is different in nonlinear optics, where a ray of infrared light that hits a crystal suddenly turns into green light. And unlike in linear optics, doubling the incident light will quadruple the amount of light that comes out, with double the frequency.

Why is that?

A crucial condition for such effects is the intensity of the light beam used. »Nonlinear optics can only be achieved with a very high intensity of light waves,« highlights Paulus. After all, nonlinear effects only occur when the rays are at least a billion times more intense than the sun, »so at electric field strengths of light waves that we don't find in our everyday lives.« In order to bundle so many photons (i.e. light particles) into one ray, you need lasers. When uncontrolled, photons move in all directions at the speed of light. Channelling them into a coherent unit (i.e. with a uniform wavelength and identical phase of oscillation) is not possible without laser technology. In short, nonlinear optics was only a theory until the laser was invented in the 1960s.
Paulus explains what happens when matter is exposed to extremely intense light fields: The photons excite the material's charge carriers (usually electrons) and stimulate vibrations. When the radiation intensity is low, Hooke's law applies: The deflection of the charge carriers is proportional to the force applied (i.e. the field strength of the incident light waves). The more intense the radiation, the more the electrons vibrate and emit electromagnetic radiation. The light waves and excited electrons vibrate sinusoidally at low intensities. But when the intensity increases and the electrons are highly deflected from their orbit, their movements are distorted. As a result, the electrons not only emit light in the wavelength of excitation, but also at other frequencies.
Crystals with a certain lattice structure are particularly suitable for producing nonlinear optical effects. »In principle, however, all materials are suitable,« says Paulus. Nonlinear optical effects can even be generated in air.

What nonlinear optical phenomena are there?

Some of the most important effects include frequency doubling (see p. 18) and high harmonic generation (see p. 35), as well as numerous other phenomena involving the multiplication and mixing of frequencies. Prof. Paulus and his colleague Dr Philipp Wustelt have made a video in which they explain a particularly impressive effect known as ›self-phase modulation‹. The essential requirement for all nonlinear optical processes is that light interacts with a suitable medium.

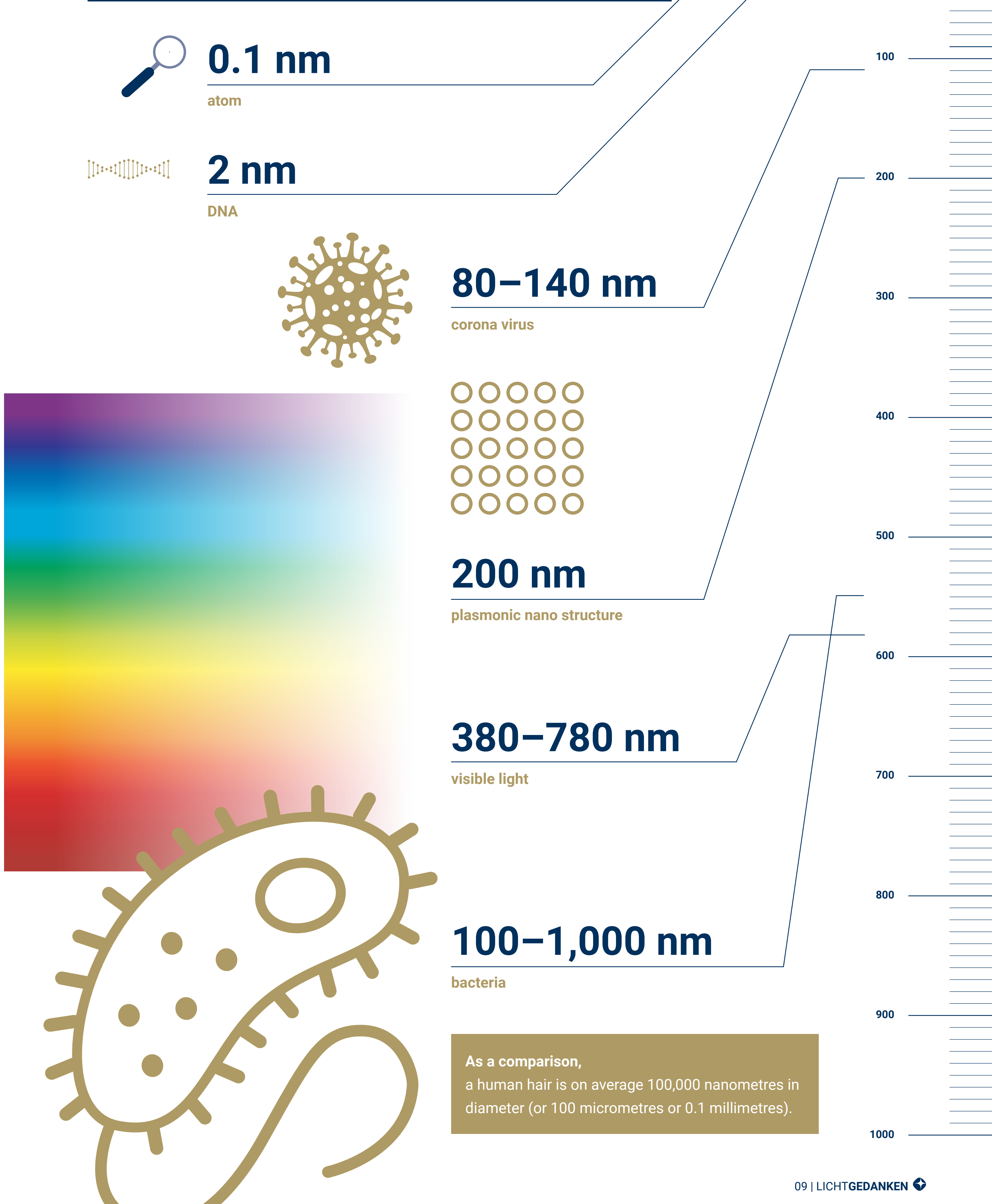
Why are we investigating nonlinear effects on nanostructures?

The processes involved in the interaction between light and matter particles are being examined in detail by teams of scientists at a collaborative research centre dedicated to ›Nonlinear Optics down to Atomic Scales‹. The researchers are particularly focusing on what happens when intense laser light interacts with nanostructures. Their aim is to gain a comprehensive understanding of such processes to enable the production of nanomaterials with tailor-made properties, which could be used as sensors, semiconductors or optoelectronic components.

Click here for the video:

www.lichtgedanken.uni-jena.de/Ausgabe_09_Audio_und_Video

What does ›nano‹ actually mean?



Milestones in nonlinear optics

BY UTE SCHÖNFELDER

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The roots of optics, the oldest discipline in physics, can be traced back to the ancient world, where philosophers such as Pythagoras, Ptolemy and Plato advocated the theory of ›rays of vision‹, whereby light was thought to originate in the eye itself and—similar to a lighthouse beam—scan the outside world. The mathematician **Euclid** (3rd c. BC) described these ›rays of vision‹ as emanating linearly from the eye and being reflected by the outside world.

When the Arab scholar **Alhazen** (965–1040) took a closer look at the structure of the eye, he identified the importance of the lens for sight and refuted the theory of ›rays of vision‹ in various scientific experiments. Some of his analysis included the reflective properties of curved mirrors, the refraction of light in the atmosphere and the magnification qualities of lenses.

The Dutch astronomer, mathematician and physicist **Christiaan Huygens** (1629–1695) established wave theory as an approach to various properties of light such as reflection, refraction and diffraction. Huygens posited that light required a transmission medium—just like sound needs air—and postulated the ›aether‹ for this. This was countered by the theory expounded by **Isaac Newton** (1643–1727), who envisaged light as a stream of particles. The wave hypothesis was only proven many years later by **Thomas Young** (1773–1829) and **Augustin Fresnel** (1788–1827).

19th century

In the 19th century, **James Clerk Maxwell** (1831–1879) presented his theory of electromagnetism, according to which light is an electromagnetic wave that is propagated at the speed of light. **Heinrich Hertz** (1857–1894) became the first person to generate the electromagnetic waves postulated by Maxwell in the laboratory, showing that they behave like light (i.e. they can be reflected, refracted or diffracted).

Albert Einstein (1879–1955) proposed that light consisted of the smallest energy quanta—photons—and was awarded the Nobel Prize in Physics in 1922 for discovering the law of the photoelectric effect and proving that light had the properties of both, waves and particles.

1930

The German-American physicist **Maria Goeppert-Mayer** (1906–1972), who would go on to win the Nobel Prize, developed the theory of ›two-photon absorption‹ in the 1930s. This is the process by which molecules or atoms simultaneously absorb two photons and enter an excited state.

When the American engineer and physicist **Theodore Maiman** (1927–2007) developed the first functioning ruby laser in 1960, he laid the foundations for nonlinear optics. After all, the field strength required for nonlinear effects can only be produced by intense laser light.

1960

In 1961, the German physicist **Wolfgang Kaiser** (*1925) was able to measure the two-proton absorption predicted by Maria Goeppert-Mayer. In the same year, **Peter Alden Franken** (1928–1999) became the first person to demonstrate frequency doubling, which is now the most important process in nonlinear optics.

1980

When **Anne L'Huillier** (*1958) discovered high harmonics in 1988, the French physicist opened up the field of extreme nonlinear optics, the effects and theory of which are fundamentally different to those which had previously been discovered.

JENA

Reinhart Neubert (*1935) built the first gas laser in Germany—in Jena—in 1962. Exactly 50 years later, the University of Jena awarded the laser pioneer an honorary doctorate.

1963

The first chair of nonlinear optics in Germany was held by **Max Schubert** (1926–1998), who was appointed to the University of Jena in 1964. Together with his student, the physicist **Bernd Wilhelmi** (1938–2018), Schubert wrote the ›Introduction to Nonlinear Optics‹, a textbook that subsequently became an international standard work.

Six years after Anne L'Huillier had discovered high harmonics, **Gerhard Paulus** (*1966), who was appointed to the University of Jena in 2007, demonstrated the corresponding effect in photoionization. In 2015, Anne L'Huillier became the first female honorary doctor of the Faculty of Physics and Astronomy at the University of Jena.

2015

As it stands, the most advanced school of thought in nonlinear optics is the field of relativistic laser physics. When the laser fields are so strong that the electrons are accelerated to almost the speed of light, a whole new class of characteristic effects is produced. The first chair in this field is currently held by **Malte Kaluza** (*1974) at the University of Jena.

Prof. Dr Ulf Peschel has been teaching theoretical physics and solid-state optics at the University of Jena since 2014. His research work combines theoretical and experimental approaches. For example, he is exploring how targeted structuring can give light particles completely new properties. As the spokesperson for the ›NOA‹ CRC, he is working with Prof. Dr Stefanie Gräfe and her team to develop theoretical models to describe the generation of high harmonics (see box on p. 35). · Photo: Jens Meyer

Physical limits aren't the end of the road

The ›NOA‹ collaborative research centre (CRC) has been based at the University of Jena since 2019. NOA stands for ›Nonlinear Optics down to Atomic Scales‹. The CRC is run by physicist Prof. Dr Ulf Peschel and chemist Prof. Dr Stefanie Gräfe. In this interview, they describe the questions addressed by the research network and explain why scientific knowledge needs a theoretical foundation.

INTERVIEW: UTE SCHÖNFELDER

What is NOA all about?

Peschel: We're investigating the fundamental processes of light-matter interaction—right down to the atomic level. In other words, we're seeing what happens when light particles (photons) interact with matter particles (electrons). The light fields we use are so strong that the matter is changed by the light. The nonlinear processes involved depend on the intensity of the light (see p. 10).
The interesting thing about the interaction is the fact that the matter isn't just affected by the light; the light itself is also affected by the excited matter. So, we can practically use light to control light. We're looking at both aspects at the CRC: We're manipulating matter with intense light; and we're generating and controlling light by letting it interact with the matter. And we're studying everything on very small scales.

What specific questions do you want to answer?

Gräfe: We're interested in a number of fundamental questions. For example, we've long known how nonlinear interactions between light and matter work (e.g. in nonlinear crystals); for these effects, it seems to be important that the materials have a very homogeneous structure (i.e. a very regular, evenly distributed atomic structure). We're now interested in finding out how small these homogenous structures can be to enable a nonlinear interaction, and how this interaction is influenced by unevenness, roughness and individual defects. If I have a material that only consists of one atomic layer, for example, each additional atom has an enormous impact.
We're also interested in effects that can only be achieved on these extremely small scales. For example, electrons can tunnel from atomically small metal tips to neighbouring tips and then overcome energy barriers, which would not be possible according to the theories presented in classical physics. And we want to investigate how this phenomenon can be controlled or even operated in a targeted manner using

Prof. Dr Stefanie Gräfe has been a professor of theoretical chemistry at the University of Jena since 2013. Some of her main research fields include the theoretical description and simulation of the interactions between intense light fields, atoms and molecules. She is the deputy spokesperson for the ›NOA‹ CRC, where she studies effects such as nonlinear interactions in plasmons and molecules on tiny metal tips. Gräfe is working with Prof. Dr Volker Deckert and his team of experimental scientists (see p. 27) to describe the diffraction limit of spectroscopic methods.

The Abbe diffraction limit

In 1873, Ernst Abbe developed his famous formula to describe the diffraction limit of a microscope, $d = \lambda / 2n \cdot \sin\alpha$.
In his formula, d is the achievable resolution as the minimum distance required between two lines for them to be discernible as two separate lines under a microscope, λ is the wavelength of light, n is the refractive index of the medium between the object and objective, and α is the half-angle of the cone of light entering the objective from one point of the object.
For the term $n \cdot \sin\alpha$, Abbe introduced the concept of numerical aperture (NA), which describes a system's ability to focus light. Abbe's formula is therefore often written as $d = \lambda / 2\,NA$. The maximum numerical aperture for the air between the object and objective is 1. For visible light with a wavelength of $\lambda \approx 400$ nm, the maximum achievable resolution is therefore $d \approx 200$ nm.
However, numerous methodological approaches have since enabled resolutions well below the limit established by Ernst Abbe.

light. If we can understand and control such processes, we might even be able to use them for specific purposes in the future.

Why are nanomaterials so interesting and important in research?
Peschel: Technical components have been getting smaller and smaller for a long time—to save material and increase efficiency—but we're interested in much more than just this aspect. Nanostructured materials simply have completely new properties. For example, we can use nanostructures to make materials ›invisible‹ or give them new colours and so on. These metamaterials have been researched and developed for around 20 years, but our materials are now even smaller—far below the wavelength of visible light. In these dimensions, at the atomic level, quantum mechanical effects are playing an increasingly prominent role. We want to understand how these effects determine the properties of the materials.

Gräfe: One highly specific application of nanomaterials is chip technology, where we now have standard structure sizes of 13 nanometres—that's about 130 atoms. The latest chips are just seven nanometres wide, so only 70 atoms. And 3-nanometre technology is expected from 2022—only 30 atoms wide. The smaller these structures become, the more relevant and influential each atom becomes. For such applications, we have to know how the atomic geometries affect the material properties and how we can control them.

How small are the structures you are examining in your CRC projects?
Peschel: The metallic, plasmonic nanostructures that we're using in various projects at our CRC (see pp. 17, 20, 24) are around 200 nanometres in size. The important factor for nonlinear optical effects is usually the distance between the nano-antennas, where we work within a range of up to five nanometres—that's the thickness of a lipid bilayer, the basic structure of biomembranes. If we magnified this distance to one centimetre to get a better idea of the size, it would be like a centimetre along the route between Jena and Weimar.

Why do we need nonlinear optical methods to examine such small structures?
Peschel: Nowadays, a number of methods are being used to research atomic and other very small structures. The advantage of nonlinear methods is that they fall well below the resolution limits of common optical methods that depend on the wavelength of the radiation used. In other words, we can now ›see‹ much smaller structures.
In addition, much more information about the structures can be obtained by observing nonlinear interactions between the light field and material than by studying simple linear interactions. So, we're practically expanding our range of information sources.

Gräfe: What's more, there are usually fewer disturbing background effects with nonlinear methods.

Are there also resolution limits for nonlinear optical methods?
Gräfe: Yes, there are. But they're not as absolute as their linear counterparts, such as the Abbe diffraction limit (see box on the left). On the atomic scale on which we work, quantum effects play a role that affects the interactions with light. However, we don't yet know this in detail. This is one of the questions we want to answer at our CRC.

Peschel: The answer to this question isn't so much about the physical resolution limits; the limitations of our theoretical models and understanding of the phenomena on such scales are much more important for what we can see and identify. After all, we can no longer ›observe‹ the phenomena directly; we obtain information from various spectra of light and have to interpret them.

We've only been able to experiment with nonlinear optical phenomena since the invention of lasers that can bundle light in the required intensity. In addition to laser technology, what role does theoretical research play?
Peschel: As we've already mentioned, an essential one. The challenge at the moment is to consistently describe light-matter interactions at the atomic level, considering both the optical and quantum mechanical effects. As theorists, we develop models and our experimentally working colleagues provide data. Together we then see whether we can use the models to plausibly explain the data.
Our findings are always made in small steps and the purpose of theory is to generate a basic understanding. That's why we need simple models to give us an idea, so that we can develop simulations and test them experimentally. Theory is absolutely essential for our basic understanding of the physics involved. ■

Prof. Dr Isabelle Staude (right) and physics doctoral candidate Tobias Bucher are developing tiny optical antennas. This allows to effectively focus light on ultra-thin 2D materials. · Photo: Jens Meyer

Ultra-thin: semiconductors made of one atomic layer

Maximum surface area, minimum thickness: Research teams from materials science and physics are growing ultra-thin, inorganic materials consisting of only one single layer of atoms. In combination with nanoscale optical antennas, they are tailoring 2D materials to form photonic nanomaterials.

BY UTE SCHÖNFELDER

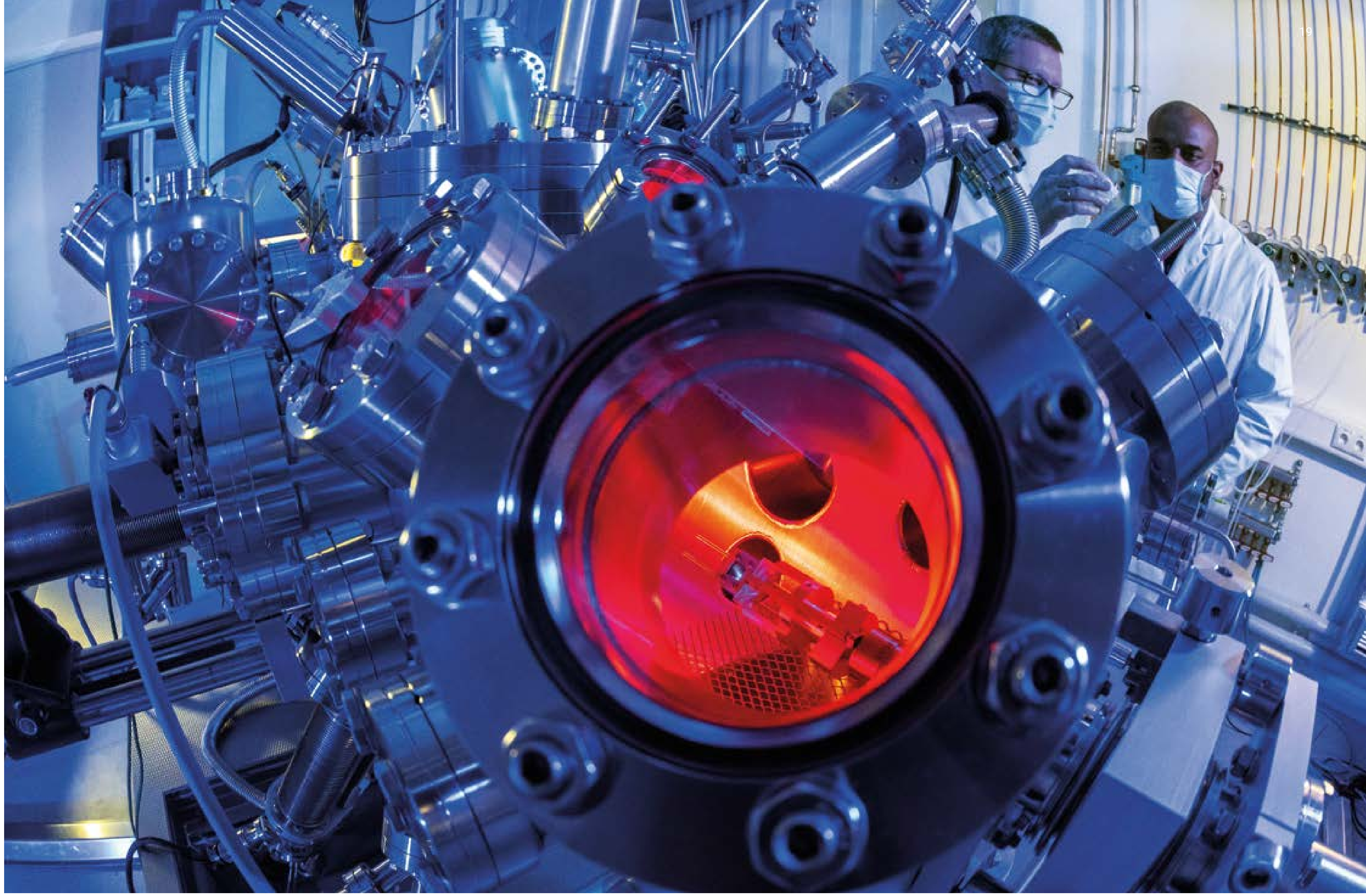
Despite the fact that the crystals are less than one nanometre thick, they are incredibly robust. As they hardly have any volume, they are usually just referred to as ›2D materials‹. Similar to graphene, the first 2D material to be artificially produced, the ultrathin molybdenum or tungsten disulphide sheets have a number of extraordinary properties. »These ultimately thin semiconductor materials are suitable for various applications, such as new types of electronic and optoelectronic components, chemical sensor components and catalysts,« explains Andrey Turchanin.

Perfectly equilateral triangles: The 2D crystals made of tungsten disulphide are less than one nanometre thick. Each side of the triangle is around 30 micrometres long.

Turchanin synthesizes the 2D materials in his laboratory by heating and evaporating the precursor materials at over 700°C. These materials are transported through a glass tube in a stream of argon and hydrogen gas at a defined pressure and temperature, which causes a reaction. The material crystallizes on a substrate within the tube, similar to the way in which water forms frostwork on a cold window pane. The ›ice crystals‹ made of tungsten disulphide are shaped like equilateral triangles (picture on the left), while other 2D materials crystallize in the shape of

Nonlinear frequency doubling

When laser light interacts with a nonlinear material (e.g. a crystal with a certain non-centrosymmetric lattice structure), radiation is generated with twice the frequency of the incident light. When the frequency is doubled, the light's wavelength is halved. In this way, for example, green light with a wavelength of 532 nm can be produced from the infrared radiation of an Nd:YAG laser with a wavelength of 1,064 nm. This phenomenon is used in laser pointers. The effect is caused by the oscillations of charge carriers in the crystal, which are produced through interactions with intense laser light.
As nonlinear frequency doubling is also referred to as ›second-harmonic generation‹, it is often abbreviated as SHG.



Prof. Dr Andrey Turchanin (left) and Dr Antony George are working on the ›Ultra-High Vacuum (UHV) Multiprobe System‹ at the Institute of Physical Chemistry. The system enables more than ten different highly sensitive microscopic and spectroscopic methods for analysis of ultra-thin material samples. A high accuracy of measurements in the system, which was built especially for Prof. Turchanin and his team, is achieved by generating an ultra-high vacuum during measurements; when the machine is running, there are fewer gas particles in the Multiprobe System than there are in the vacuum between the earth and moon. · Photo: Jens Meyer

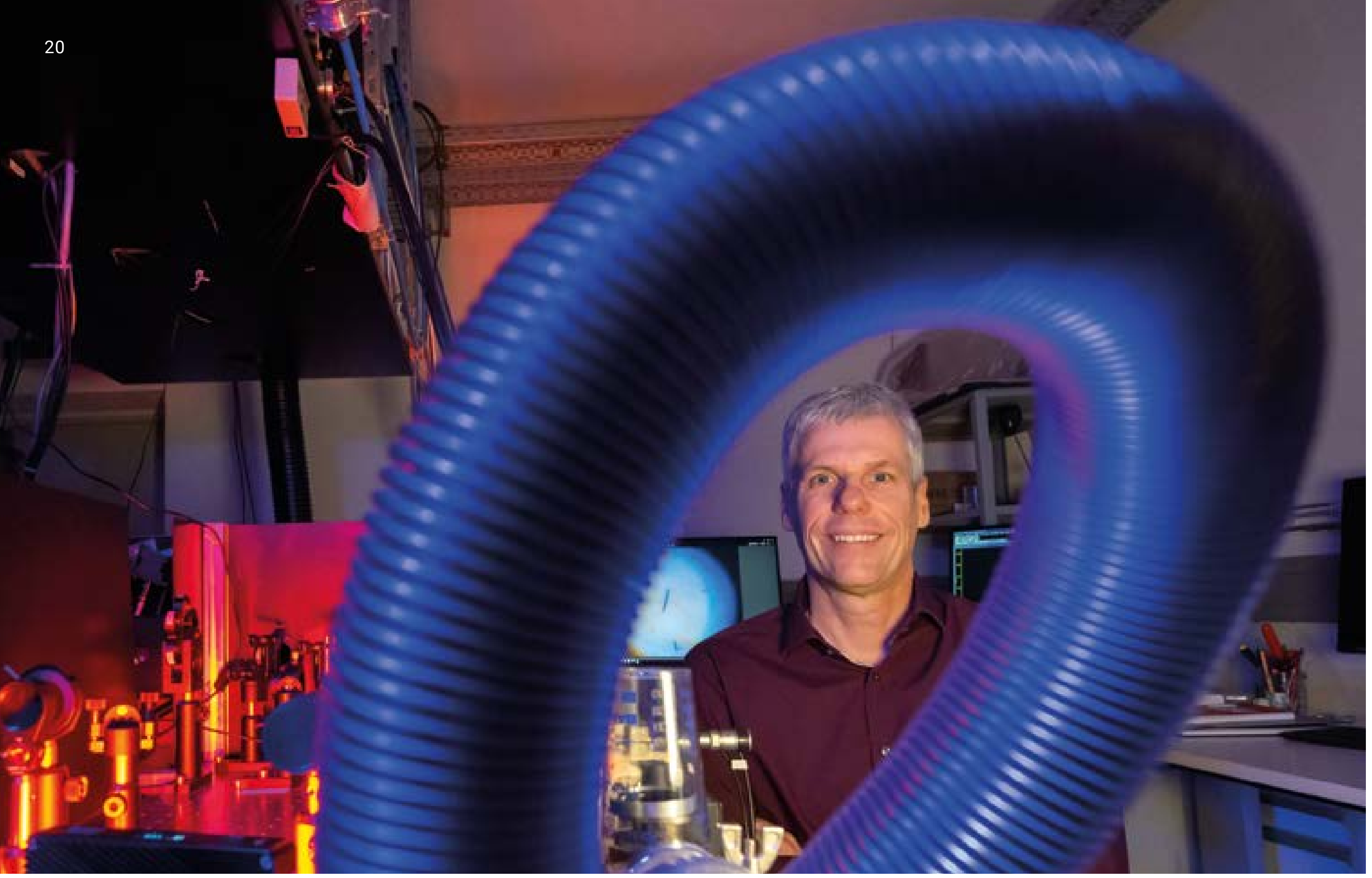
stars or snowflakes. Andrey Turchanin and his colleagues at the Institute of Physical Chemistry are producing 2D materials to develop ultrathin photonic structures with which to investigate nonlinear optical phenomena. The two-dimensional crystals are highly suitable for this, because of their symmetry-broken crystal structure, which is necessary for strong second-order nonlinear optical effects to occur.
However, the 2D layers are so thin that they would be almost invisible to incident laser light, as they are much less thick than the wavelength of the light used. In order to enable the 2D material to interact efficiently with light, the researchers are therefore also equipping the membranes with tiny antennas that focus light in the near field to fall below the diffraction limit (see box on p. 16).

2D material combined with a silicon layer equipped with nano-antennas

This step is done in Prof. Dr Isabelle Staude's laboratory. The nano-antennas are made as a thin layer using electron-beam lithography. In this process, custom shapes are drawn onto a mask by exposing a ›resist‹ to a beam of electrons and the nanostructure is then transferred to the material (e.g. silicon) via an etching process. The nano-antennas created in this way measure between a few tens and a few hundreds of nanometres in size. When a layer of lithographed antennas is examined under an electron microscope, it looks like a piece of bubble wrap. »Both layers can be combined to create a hybrid system with optical properties that cannot be found in natural materials,« says Prof. Dr Isabelle Staude from the Institute of Solid-State Physics. In the future, the hybrid systems could be used as miniaturized sources of single or entagled light particles. This makes them suitable for applications in quantum technology, such as the encryption of optically transmitted information.

Nonlinear frequency doubling in nano-antennas

One of the nonlinear optical effects that can be produced and analysed with 2D membranes equipped with nano-antennas is nonlinear frequency doubling (see information box on p. 18). In this process, photons are generated that oscillate at twice the frequency of the incident light. Isabelle Staude explains the effect: »We expose the sample to laser pulses with a wavelength of 850 nm and, apart from the incident frequency, we also obtain laser light with a wavelength of 425 nm.« The light generated in this process is detected and analysed. The researchers are not only interested in the intensity of the radiation generated in this way, but above all in the light's polarization properties. Polarization is one of the key properties of light and can be used, for example, to encode information. In naturally occurring materials such as phosphate or borate crystals, there is a fixed relationship between the polarization of the incident light and the laser light created; by contrast, the hybrid systems present completely new possibilities for tailoring the polarization properties of nonlinear light. That's exactly what the researchers want to exploit.
Staude, Turchanin and their teams are conducting experiments to investigate how different geometric nanostructures influence the nonlinear optical effects; they are looking to design the nano-antennas in such a way that they can be used to control certain effects in a targeted manner. Another long-term goal is the production of optically switchable components. For this purpose, the 2D materials will be functionalized to enable them to react independently to changing ambient conditions such as light. ■



When light and electrons shine together

Over the past 20 years, semiconductor nanowires have evolved into flexible devices in optoelectronics, where they are now used as light-emitting diodes (LEDs), in photovoltaic cells and in other areas. They can also be used as tiny lasers: The incident light is reflected at the facet ends of the wire, which is approximately 200 nanometres thick, and is amplified as it passes through, thus creating a laser. As it stands, lasers made of semiconductor nanowires are the smallest in the world—but they could be even smaller…

BY SEBASTIAN HOLLSTEIN

Prof. Dr Carsten Ronning and his team of physicists at the Institute of Solid State-Physics are working with Prof. Dr Thomas Pertsch from the Institute of Applied Physics to investigate a new method that could be used to produce lasers with even smaller diameters. In this method, the semiconductor nanowires only serve as a source of light and a tool. Their project, which is entitled ›Nonlinear dynamics in plasmonic hybridized semiconductor nanowires‹, is being carried out at the ›Nonlinear Optics down to Atomic Scales‹ collaborative research centre (NOA CRC).
The scientists' approach involves placing a semiconductor nanowire on a metal surface, which is separated by a dielectric intermediate layer that is less than ten nanometres thick. »When the wire and metal are excited with light, a so-called spaser is created in the intermediate layer,« explains Carsten Ronning. »This phenomenon is caused by the oscillation of different waves. While the semiconductor nanowire produces what is known as an optical mode, a wave of light particles, the electrons also oscillate in the metal and form a plasmonic mode.« Both waves react with each other in the intermediate layer and create a hybrid mode.
Once the incident light has been amplified in this field, it acquires the properties of a laser—a plasmonic laser or ›spaser‹. With a diameter of only five to ten nanometres, however, the spaser is significantly smaller than the light beam emitted by the semiconductor—and much faster and more intense.

Specifying the properties of the ›spaser‹

As part of the project, the researchers are attempting to manipulate the spaser's properties in a targeted manner by altering various parameters, particularly by defining the qualities of the plasmonic nanostructures on the substrate. If these structures are modified, the light can be captured more strongly within individual points. The substrate also allows the researchers to manipulate the frequency and wavelength, which should have an impact on the speed and intensity of the laser.

Comparing the effects of plasmonic nanostructures

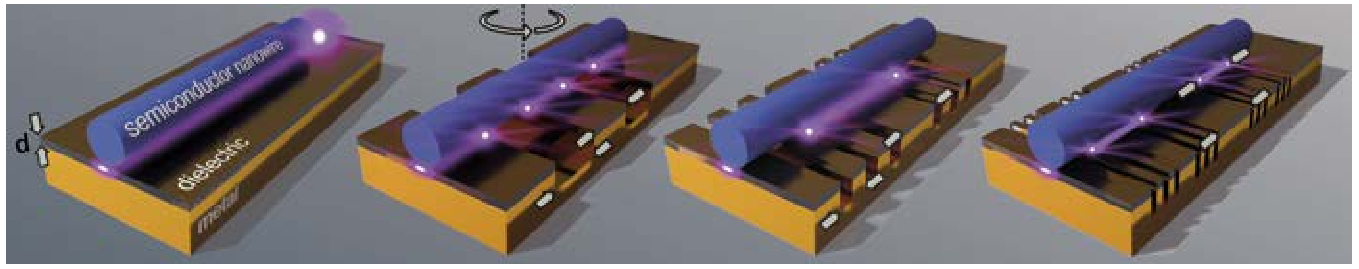
That's why Ronning and his team are first focusing on the structure of the substrate. »As part of their bachelor's dissertations, young researchers and Francesco Vitale, a doctoral candidate involved in this project, have drafted various schemes and developed a method with which we can write the necessary structures on the substrate. Other researchers have been focusing on how to place the semiconductor nanowire in certain positions on the substrate,« explains Ronning. »As we're working on the nanoscale, these processes are extremely complicated. We've even bought a special tool—a nanoManipulator—to place the wires onto the surface and move them around in a targeted manner.« More set screws are required due to various factors, such as the higher intensity of the spaser. This produces nonlinear effects which, among other things, enable the light to change colour.
As the project progresses, the team will be looking to gather more information as to what happens inside the field between the semiconductor and metal. Thanks to the spectroscopic measurements carried out by Thomas Pertsch, the physicists are able to observe how quickly and how far the wave that becomes a spaser is propagated. Such valuable information helps to functionalize the mini laser and thereby explore its potential for various applications.

Faster chips that transfer data via light

»The range of applications is generally very broad, because microelectronic components are also getting smaller, such as microchips in smartphones,« explains Carsten Ronning. »This type of laser is a highly promising step towards developing optical-based chips that would be able to transfer data even faster, because light moves faster than electrons.« In addition, the spaser could be used as a spectroscopy unit on a ›lab on a chip‹ (i.e. on tiny analysis tools for chemical and biological investigations).
By working with scientists from other specialist fields at the collaborative research centre, the laser experts will be able to further explore the range of potential applications, such as to enable the spectroscopy of a single protein. ■

Picture left: Prof. Dr Carsten Ronning at an experimental set-up for photoluminescence spectroscopy in order to determine the optical properties of semiconductor nanowires. · Photo: Jens Meyer

Picture below: The graphic design of various ›spasers‹ with differently structured plasmonic substrates. · Graphics: Martin Hafermann



Plasmonic nanostructures

Nano-sized cones, pyramids and rings made of metals are tiny optical antennas. Such as radio or television antennas, optical antennas can also be used to capture, focus and emit electromagnetic waves. The length of the antenna is adapted to the wavelength of the electromagnetic radiation. While radio waves have a wavelength of several metres, the wavelength of visible light varies from only 380 to 780 nanometres. In other words, optical antennas have to be extremely small.
When plasmonic nanostructures are illuminated, the electromagnetic light waves interact with the moving conduction electrons in the metal. The electrons start to oscillate collectively and propagate themselves; these oscillations are referred to as ›surface plasmon polaritons‹ (or ›plasmons‹ for short). As a result, much smaller structures can be illuminated and detected than with the original incident light and the Abbe diffraction limit can be bypassed.

Stroboscopic imaging of ultrafast dynamics in nanomaterials

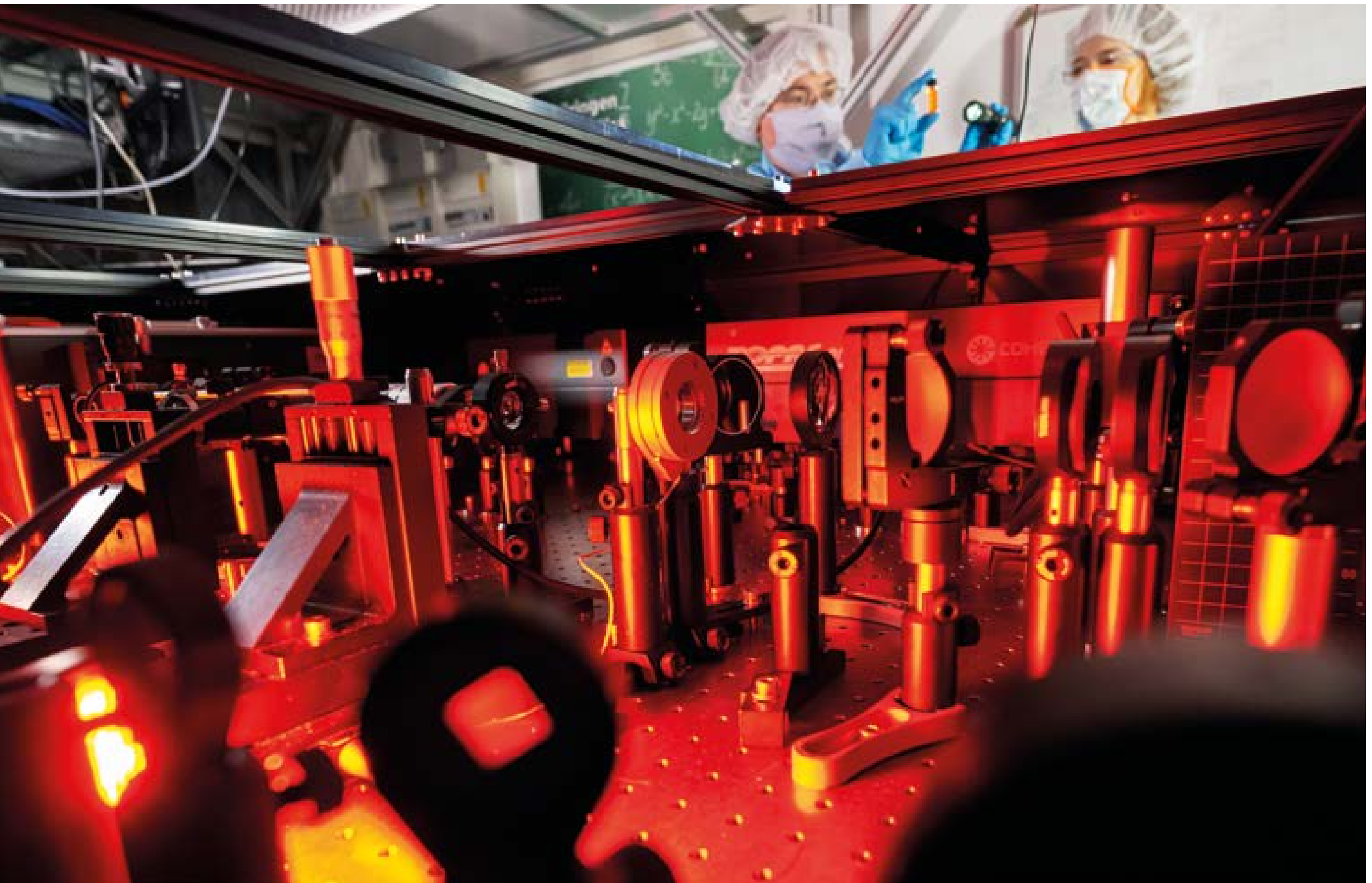
As sprinters cross the finish line at the end of a 100-metre race, the winner is not always immediately clear; the event often ends in a photo finish and the viewers are unable to make out the exact order of the athletes, as they are simply moving too fast for the unaided eye. However, their movements can be captured and temporally resolved using stroboscopic imaging. This principle is being used by physicists to image extremely quick processes in nanomaterials (pump-probe spectroscopy).

BY UTE SCHÖNFELDER

Dr Maria Wächtler and Dr Daniil Kartashov are running a research project within the collaborative research centre ›Nonlinear Optics down to Atomic Scales‹ (NOA CRC) to gain insights into the tiny structures that make up matter. The researchers are using nonlinear optical methods to study the basic building blocks of semiconductors, focusing not only on spatially resolving the atomic structures, but also on imaging the dynamic processes that happen inside them, such as the oscillations of charge carriers in atomic lattices which only last a few hundred femtoseconds.

In order to examine extremely fast processes in extremely small dimensions, two challenges have to be solved at the same time: »First of all, we need the right material for our investigation,« says Maria Wächtler. For this purpose, the chemist and her team are producing useful nanoscale semiconductors in their laboratory at the Leibniz Institute of Photonic Technology. »Secondly, we have to develop methods that are sensitive enough to detect interactions with such small structures while being able to image ultra-fast processes,« adds Daniil Kartashov, who works at the Institute of Optics and Quantum Electronics at the University of Jena as a specialist in time-resolved spectroscopic methods.

Dr Daniil Kartashov (left) and Dr Maria Wächtler investigate the nonlinear optical effect of high harmonic generation in nanoscale semiconductors. · Photo: Jens Meyer



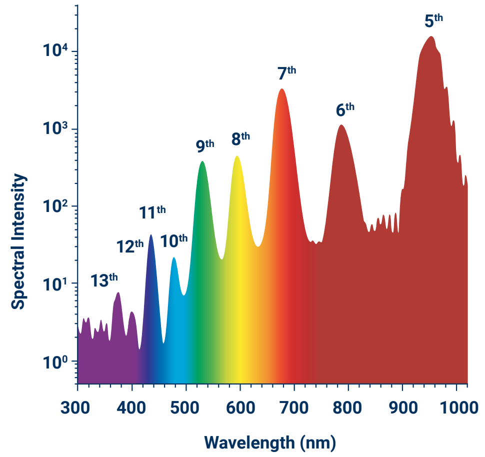


Diagram left: Here you can see the intensities of the 5th to 13th harmonics generated by nonlinear interactions between an infrared laser pulse with nanoscale semiconductors. Picture above: solution of quantum dots made of cadmium selenide. · Photo: Jens Meyer

As part of their project, the researchers are examining different sizes, shapes and complexities of nanoscale semiconductor materials. The simplest objects are quantum dots: spherical lattices measuring only a few nanometres in size and consisting of a few hundred to a thousand atoms. »These are sometimes referred to as artificial atoms, because their electronic properties behave like single atoms,« explains Wächtler. Due to their low spatial dimensions, their charge carriers—the electrons—cannot move freely in the spheres and are fixed to very specific energy values, which means their properties are determined by quantum effects.

The quantum dots are made of cadmium selenide and measure between two and eight nanometres in diameter. To give you a rough idea of how small a nanometre is, it might help to draw a comparison: The difference between a nanometre (one millionth of a millimetre) and a metre is proportionally the same as the difference between the diameter of a one-penny piece and the diameter of the earth. Such structures are practically ›invisible‹ for linear optical methods.

From infrared radiation to visible light

In order to learn how such nanoscale semiconductors work (e.g. how charges are transported in them and how vibrations are propagated within the atomic lattice), a novel, highly sensitive diagnostic method is required. For this purpose, Daniil Kartashov and his team of researchers are generating high harmonic optical oscillations (see box on p. 35). »These oscillations are caused by interactions between laser light and the examined material; their frequency is many times greater than that of the incident light,« says Kartashov. However, high harmonics can only be created if the incident light has a very high field strength. The laser used to excite the quantum dots has an output power of 300 billion watts per square centimetre. In order to prevent the material from immediately evaporating, the laser is pulsed so that the material is only exposed to the light for approximately 100 femtoseconds (100 millionths of a billionth of a second).

»This short period is sufficient for the laser light to interact with the electrons in the atomic lattices and generate high harmonics,« says Kartashov. The excitation laser emits pulses with a wavelength of approx. 4,800 nm in the mid-infrared spectrum, which are invisible to the human eye. The generated harmonics have wavelengths fractional to the laser wavelength: The 3rd harmonics measure 1,600 nm, the 5th harmonics measure 960 nm and so on. »We record the spectra of the rays generated between the 5th and 13th harmonics,« says Kartashov. As the signals are extremely weak, however, approximately 1,000 pulses a second are shot at the sample and the individual shots are accumulated (see figure at the top left). This is how the researchers obtain initial snapshots from the material. Another laser beam enables the scientists to trigger the material's inner dynamics before the laser pulses generating harmonics. This excitation laser sets the electrons and the lattice in motion, and then the second laser pulse comes with a variable delay to take snapshots of these dynamics. Recording spectra of the generated harmonics results in a series of images of the lattice dynamics which are similar to those found in sports photography, when very fast movements are resolved into individual images, such as a photo finish of sprinters crossing the finish line.

The researchers are applying this method, known as ›pump-probe spectroscopy‹, to various nanomaterials. In addition to quantum dots, they are investigating nanowires and also single-atomic-layer membranes produced by Prof. Turchanin and his team (see p. 17). »This provides information about how different structures and geometries affect the optical properties of semiconductor materials at nanoscale,« says Maria Wächtler, who explains that this area of research is still very much in its infancy but is already showing considerable potential for a range of practical applications. »This knowledge could enable us to develop photonic semiconductors for photonic computer chips,« says Kartashov. In contrast with electronic chips, the great advantage of photonic technology is that information could be processed at a significantly higher rate, as the speed of light is at least 1,000 times faster than the electron transport chain. ■

The researchers are conducting their experiments with nanostructures that are etched into nanometre-thin, smooth gold surfaces. This is where the metal is applied to silicon wafers in a vacuum as part of a thin-film deposition process. · Photo: Sven Doering, Agentur Focus

Raman spectroscopy

In 1928, the Indian physicist Chandrasekhara Venkata Raman, who would go on to win the Nobel Prize, discovered the ›Raman effect‹: When monochromatic light particles hit molecules, the light is scattered. While most of the light retains its wavelength and frequency (i.e. the scattering is elastic), approximately every millionth photon is scattered inelastically (i.e. energy is transferred from the light field to the molecule or from the molecule to the light field). In each case, the scattered photons have a different wavelength (frequency, energy) to that of the incident light.
This inelastically scattered radiation is used in Raman spectroscopy, where oscillation energy is transferred; as this energy is unique to each atom or molecule, Raman spectra are like chemical fingerprints that provide unique information about the composition of the sample examined.

Chemical reaction close-ups

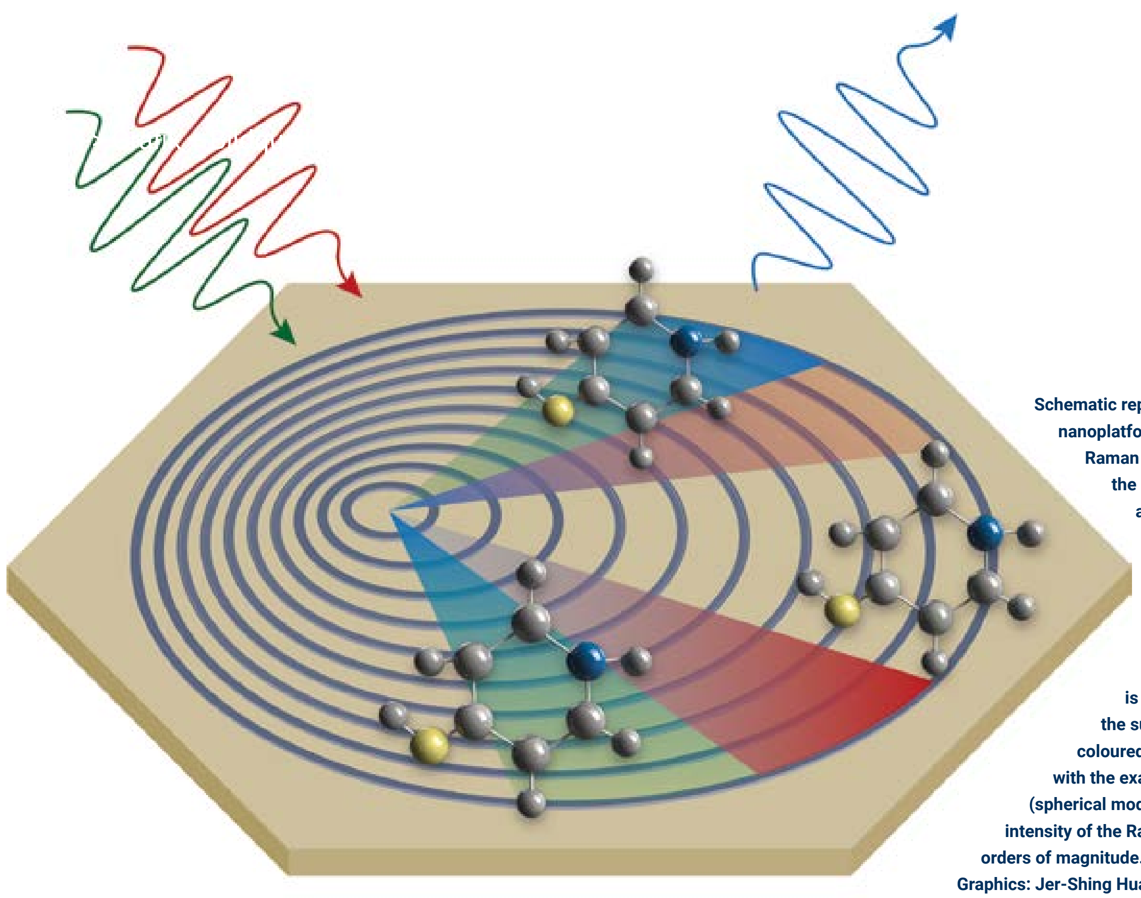
Until now, scientists have not been able to directly observe what happens between individual atoms and molecules when they react with one another. The signals generated by the interaction between light, atoms and molecules are too weak to be detected by conventional light-based methods. However, a team of researchers based at the University of Jena has developed a strategy to enhance the weak signals with plasmonic and nonlinear optical effects, which is the first step towards being able to directly observe chemical reactions in individual molecules.

BY UTE SCHÖNFELDER

We bring secrets ›to light‹. We want to ›shed light‹ on the nature around us. When we have an idea, ›a lightbulb goes off in our head‹… There are countless metaphors about the enlightening effect of light—and for good reason: »If we want to learn something about our environment, the matter and molecules around us and the fundamental processes occurring within them, we need light,« says Prof. Dr Jürgen Popp, a chemist at the University of Jena. »Light is the key to what we see, from the simplest of microscopes (like the ones we remember from school) to state-of-the-art imaging processes based on interactions between laser light and matter.«
Popp and his teams from the Institute of Physical Chemistry of the University Jena and the Leibniz Institute of Photonic Technology (Leibniz-IPHT) are researching spectroscopic methods that might enable us to take a closer look at a chemical reaction. To do this, they are optimizing Raman spectroscopy (see box above), an analytical form of spectroscopy with a wide range of applications, such as the analysis of drinking water and foodstuffs or the clinical detection of pathogens. Raman spectroscopy is a contactless method that can be used to uniquely identify any material or molecule. »The spectrum of a sample is like a chemical fingerprint,« highlights Prof. Dr Michael Schmitt, who is a member of Popp's team.
However, the Raman signal, which is based on an inelastic scattering of light, is a very weak process; if the researchers want to look at individual molecules, the Raman signals therefore have to be enhanced to be able to measure them at all.
And that's exactly what Jürgen Popp and Michael Schmitt are working on together with PD Dr Jer-Shing Huang from the Leibniz-IPHT at the ›Nonlinear Optics down to Atomic Scales‹ collaborative research centre. The researchers have just made a first important step: in a paper published in ›ACS Nano‹ they combine two methods with partners from Taiwan to effectively enhance the weak Raman signal.

Plasmonic enhancement of weak Raman signals

On the one hand, they are using plasmonic nanostructures (see box on p. 21) as optical nanoantennas to concentrate light onto even nanometre-sized areas and thereby increasing the interaction between light and matter. In this case, the researchers are using plasmonic structures to enhance the weak Raman signal: The electrons in the nanostructures are excited by a laser to form surface plasmons, thus creating a strong electrical field with which molecules absorbed at the hotspots can interact much effectively with light. This intensifies the interaction between the Raman excitation light and the molecules examined, thus increasing the intensity of the Raman scattering effect. This method, which is known as ›surface-enhanced Raman scattering‹ (SERS), can be used to enhance the Raman signal by orders of magnitude compared with normal Raman spectroscopy.
The researchers are conducting their experiments with nanostructures made of gold, which are cut into highly smooth, individual crystals known as ›gold flakes‹ which are around 300 nanometres thick. »We're using differ-



Schematic representation of the nanoplatform used to enhance Raman spectroscopy: Both, the excitation rays (green and red) and the Raman scattering (blue) are coherently bundled by the ring-shaped nanostructures. This coherent bundling is further enhanced by the surface plasmons in the coloured areas, which interact with the examined molecules (spherical models) to increase the intensity of the Raman signal by twelve orders of magnitude. Graphics: Jer-Shing Huang

ent shapes and sizes of nanostructures, as we want to find out how the design affects the plasmonic enhancement effect,« explains Jer-Shing Huang.

Gold nanostructures act as antennas for laser light

The nanotechnology expert and his colleagues are taking a targeted approach. Theoretical groups led by Prof. Dr Stefanie Gräfe and Prof. Dr Ulf Peschel from the collaborative research center (see interview on p. 14) first model the interaction of the structures with light on the computer in order to derive the optimum design parameters for the desired effect. In addition to the SERS method, the study published by the researchers from the University of Jena and Leibniz-IPHT also features another way to enhance the weak Raman signal: by utilizing nonlinear light matter interactions the Raman scattered light excited by intense short-pulse lasers is coherently bundled. This method, known as ›coherent anti-Stokes Raman scattering‹ (CARS), also results in enhanced Raman signals. In their recent publication, the researchers created a gold surface structured with nanoscale rings (see figure above) and used this to plasmonically enhance both the incident laser light and the coherent Raman signal. The resulting process, known as ›nonlinear surface-enhanced coherent anti-Stokes Raman scattering‹ (SECARS), combines the enhancement mechanisms of both CARS and SERS to enhance the Raman signal by up to twelve orders of magnitude.
The researchers concluded that their findings could be used to considerably shift the limit of detection for Raman spectroscopy. »In addition to the existing advantages of the process, such as the fact that sample molecules can be used directly without the need for dyes, the method is now highly sensitive,« explains Jürgen Popp. Michael Schmitt adds that the aim is to refine the method to the point where chemical reactions can be directly observed in individual molecules: »every chemist's dream«. ■

Original publication:
Spatially Resolving the Enhancement Effect in Surface-Enhanced Coherent Anti-Stokes-Raman Scattering [...], ACS Nano 2021,
DOI: 10.1021/acsnano.0c07198

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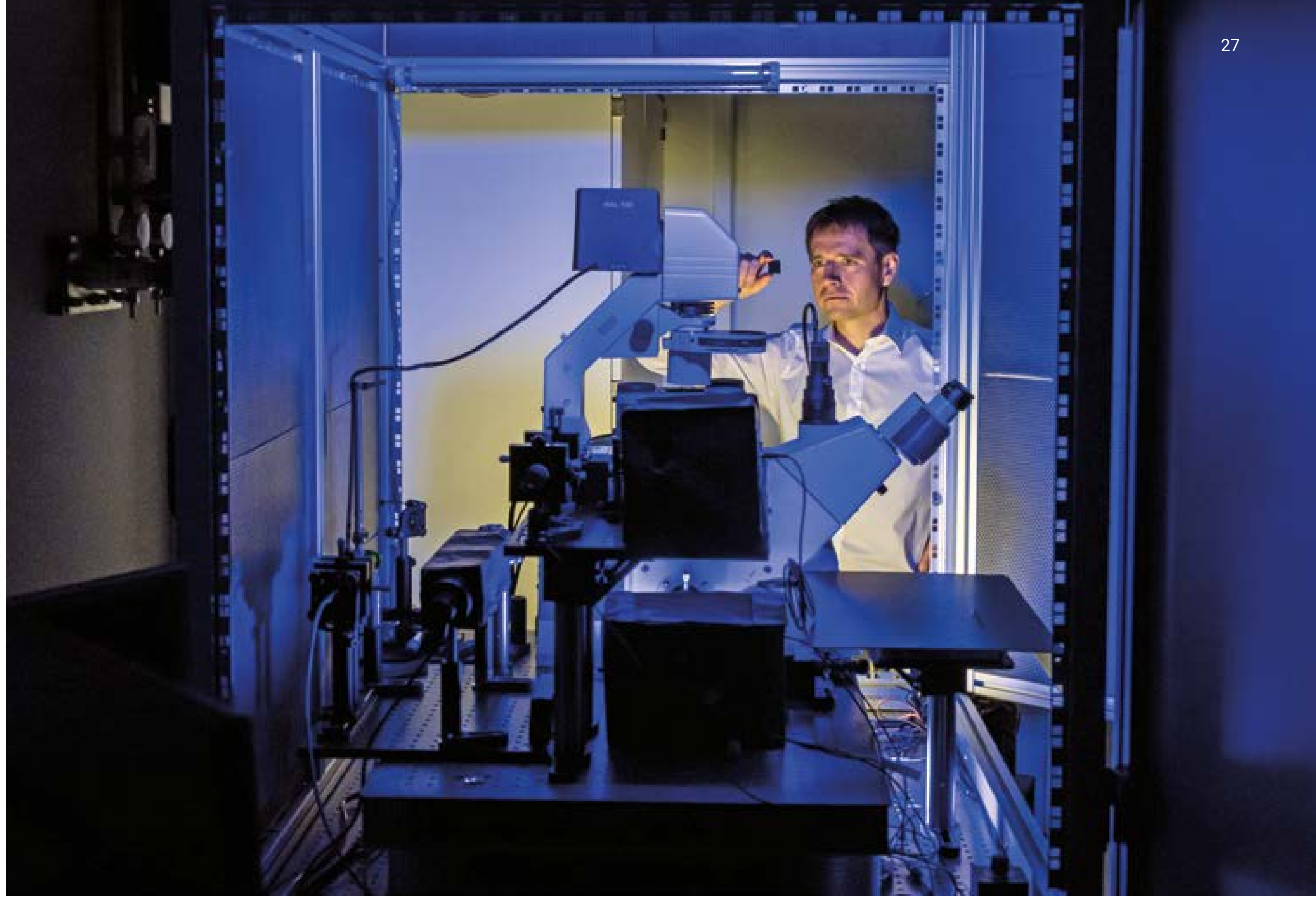


Prof. Dr Thomas Pertsch examines nanostructured surfaces under a near-field microscope. · Photo: Jens Meyer

Top-level research with nanolight

Teams of researchers from the fields of chemistry and physics are developing ultra-sharp metal tips and optical fibres to scan and analyse the finest surface structures. When combined with intense laser light, the metal tips become super-focusing nanolights that are able to detect various features of surface structures, such as their spatial dimensions, chemical composition and optical properties.

BY UTE SCHÖNFELDER

The research teams directed by Prof. Dr Volker Deckert and Prof. Dr Thomas Pertsch are investigating light-matter interactions using a high-resolution optical method that incorporates nonlinear optical effects within the established principle of scanning probe microscopy. »To put it simply, a scanning probe microscope works like a turntable,« explains Thomas Pertsch. A tiny metal tip scans the surface of the material sample and transmits information about its topography to a detector via a moving arm. »This method is so sensitive that metal surfaces can be resolved down to individual atoms in the metal lattice,« says Pertsch.
But that's not sensitive enough for the physicists… As part of a collaborative project, the researchers are combining scanning probe microscopy with optical methods to obtain information on the optical and chemical properties of samples in addition to their surface structure. Volker Deckert and Thomas Pertsch have each been pursuing different approaches, which will be combined into a common measurement method at the ›NOA‹ CRC.

Silver droplets make silicon needles more sensitive

Deckert and his colleagues from the Institute of Physical Chemistry are using tiny silicon needles to scan the samples. The needles themselves are around 50 micrometres long, which is less than the thickness of a sheet of paper. The tip of the needle that interacts with the sample is over 1,000 times smaller, measuring just five to ten nanometres in diameter. But even that's not small—and therefore sensitive—enough… »The silicon needles are also coated with silver vapour, which is deposited on the silicon surface as tiny droplets,« explains Deckert. The individual silver droplets increase the effective needle point only insignificantly by around 10 nm, which roughly equates to the thickness of a cell membrane.

By preparing the needles in this way, the tiny probes are still able to scan details of the sample, revealing the smallest intricacies of its structures and defects. In addition, once irradiated with laser light and coupled to a Raman spectrometer, the light scattered by the needles can also be used to detect the surface structure and its properties.

The main objective of the researchers, however, is actually something else: »The concentration of high-intensity light particles in the very small volume of the metal needles causes nonlinear effects between the light and material,« says Deckert. The needle tips become a source of light, so to speak, locally concentrating the light particles so strongly that the sensitivity of the Raman spectroscopy process is significantly enhanced. Similar to the team directed by Jürgen Popp and Jer-Shing Huang (see p. 24), Deckert is using linear and nonlinear light-matter interactions to coherently bundle the Raman scattering excited by intense short-pulse lasers (›coherent anti-Stokes Raman scattering‹), enhancing the Raman signals as a result.

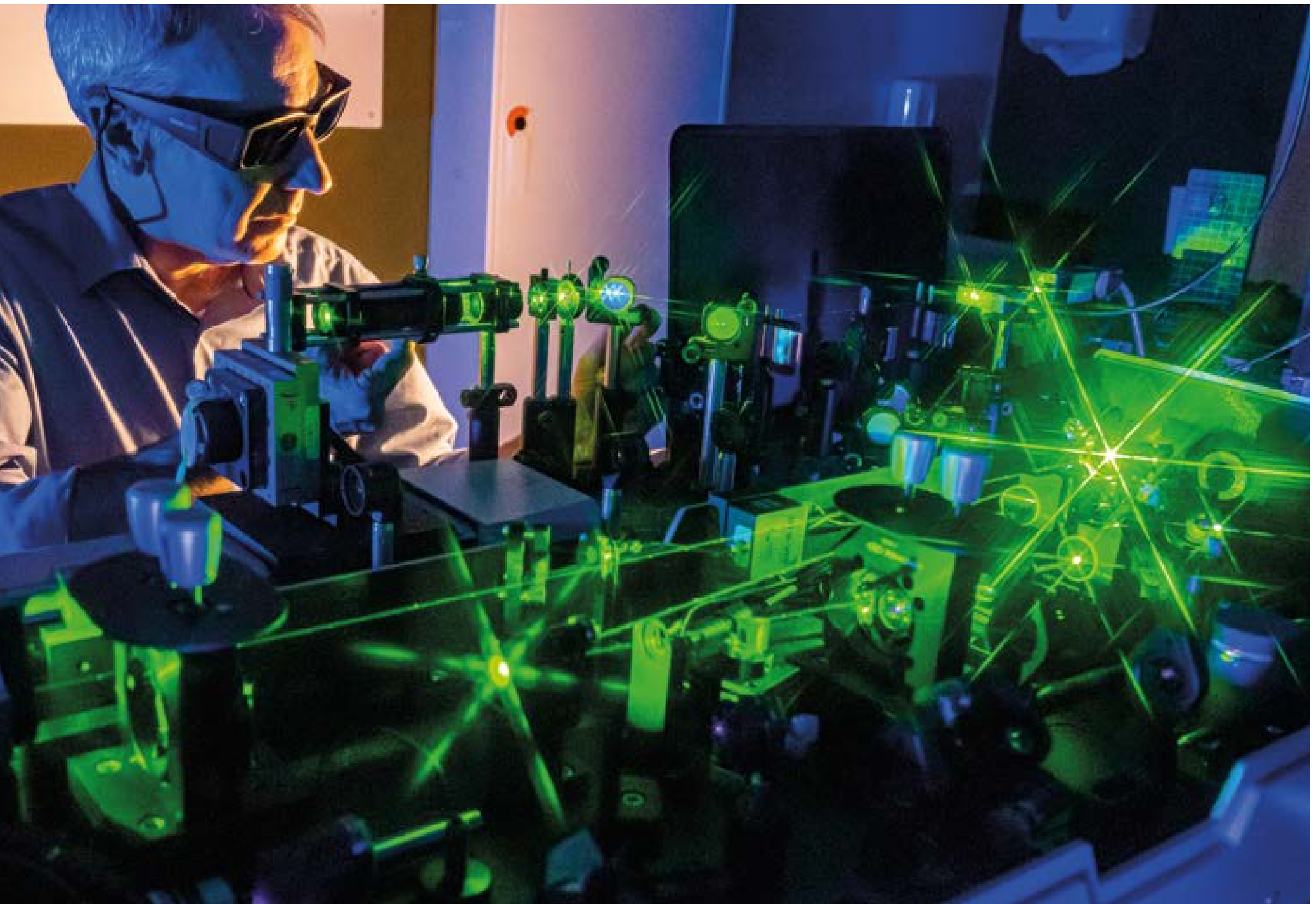
In a recent study published in cooperation with their US colleagues, the researchers from the University of Jena demonstrated the highly practical potential applications of these methods. They presented their results in ›Proceedings of the National Academy of Sciences‹, showing that tip-enhanced Raman spectroscopy can be used to detect virus particles in clinical samples and even identify the respective virus type—all in the time of a few minutes. While the study focused on influenza and coxsackieviruses, the method would theoretically also be suitable for detecting other pathogens, such as SARS-CoV-2, emphasizes Volker Deckert.

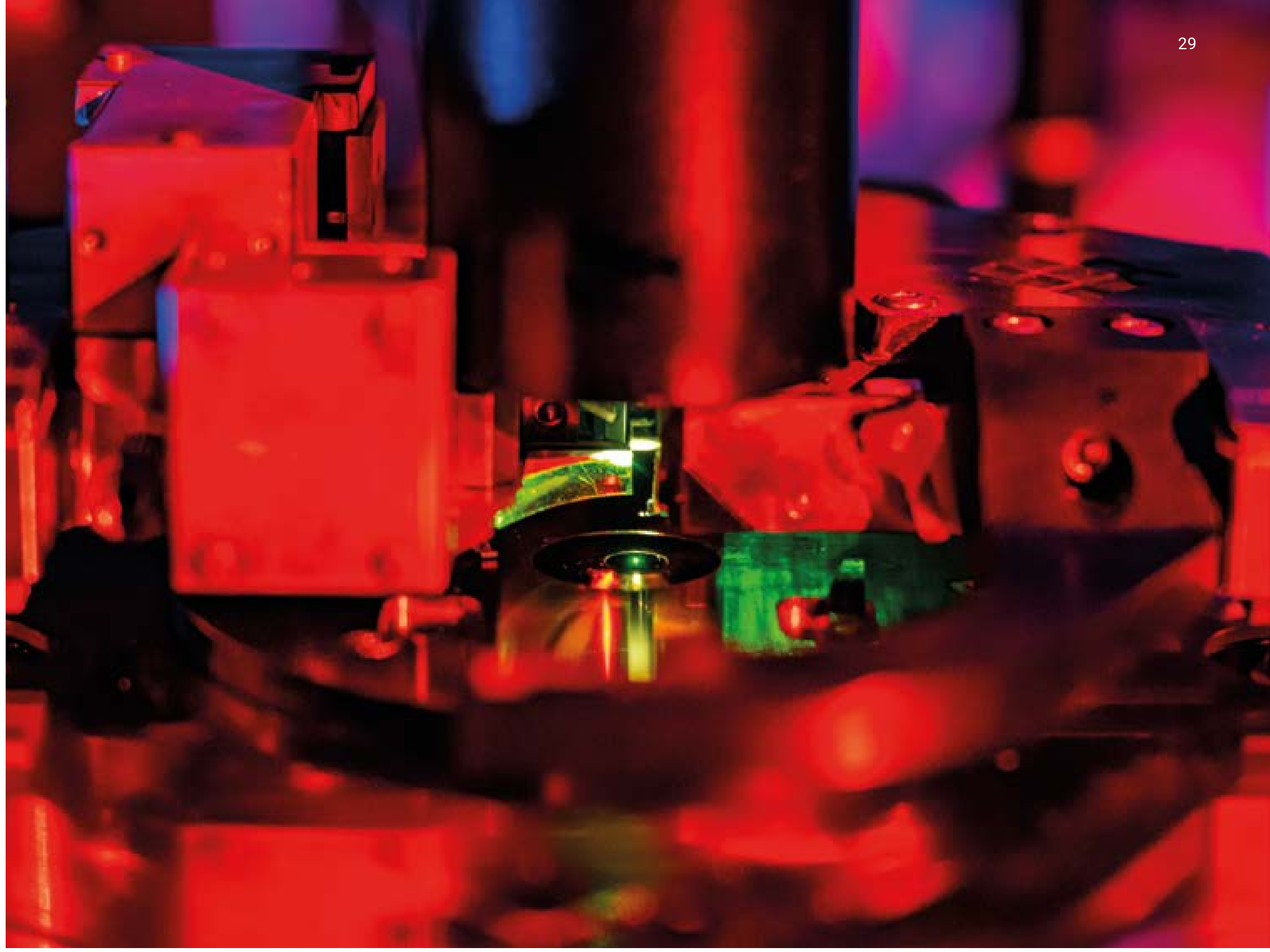
Light particles concentrated by gold-plated fibres

When it comes to producing light-focusing needles for nonlinear optical investigations, Thomas Pertsch and his team at the Institute of Applied Physics are taking a different approach: »We're using optical fibres coated with a thin layer of gold at the tip,« explains Pertsch.

The fibre itself is a ›kitten's whisker‹, measuring 125 micrometres in diameter—and therefore slightly thicker than a human hair. Its tip is approximately 50 micrometres long and tapers to a few nanometres. When laser light passes through the fibre at the appropriate wavelength, the light particles engage in a resonant interaction with the gold coating's electrons at the gold-plated tip. This creates a ›surface plasmon‹—the collective excitation of electrons along a metal surface—which interacts with the light particles. »The light focused at the tip of the needle is practically trapped there due to the interaction with the electrons—it can't escape,« says Pertsch. The sample can be scanned with the shining needle as it interacts with the light. At the same time, the fibre returns the light reflected by the sample and transmits it to a detector.

Prof. Dr Volker Deckert sets up a laser to examine nanoscale surfaces and their nonlinear optical properties. · Photo: Jens Meyer





Here we can see a silver-plated silicon tip used to scan surfaces and materials. The metal tip significantly increases the sensitivity of Raman spectroscopy. · Photo: Jens Meyer

Optical properties determined by nanostructures

These methods are providing the researchers with extensive and rich information about the samples examined. »The data allows us to draw conclusions about the optical properties produced by each sample structure,« says Deckert, who adds that their eventual target is to produce nanostructures in a targeted manner so that the materials have the exact optical properties required for a specific application.

The aim of the current research project at the ›NOA‹ collaborative research centre is to carry out basic research to establish the investigation methodology on well characterized reference materials. »Another key ingredient of our success is our close cooperation with research partners who are creating theoretical models of light-matter interactions,« emphasizes Thomas Pertsch. This is essential for both, the development of nanoscale tips and the evaluation of nonlinear optical effects. ■

Original publication:
Laser spectroscopic technique for direct identification of a single virus I: FASTER CARS, Proc Natl Acad Sci U S A. 2020, DOI: 10.1073/pnas.2013169117

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Jena on its way to the Quantum Valley

Quantum physics might not get the publicity it deserves, but quanta and their properties have been shaping our everyday lives for quite some time. As early as the 1950s, the ›first quantum revolution‹ laid the physical foundations for the development of computer chips and lasers. Now the ›second quantum revolution‹ is already upon us: Our scientists are on the verge of a breakthrough with new applications that will be some of the most important technologies of the 21st century. Prof. Dr Andreas Tünnermann tells us what the future has in store—and how Jena has a part to play.

INTERVIEW: TILL BAYER

Mr Tünnermann, you're leading a project at the ›NOA‹ collaborative research centre to investigate the non-linear properties of nanomaterials. What is it about and what does quantum technology have to do with it?
On the one hand, we're researching basic phenomena in quantum physics; on the other hand, we're already applying some of our research results. Ever since quantum physics was founded almost 100 years ago, it's produced many technologies such as computer chips, microelectronic components and lasers as novel sources of light. The scientists at our collaborative research centre are drawing on our knowledge of these three areas.
My team's project is about studying light-matter interactions in systems that only consist of a few atomic layers. We're particularly interested in quantum phenomena like tunnelling, where light enables a particle to penetrate a potential energy barrier that actually prevents the transfer of electric charge. This can only be achieved by using quantum mechanical phenomena on an atomic scale.

What other projects are taking place in Jena to advance research into quantum technologies?
In the modern age, quantum researchers have succeeded in controlling even individual quantum particles with high precision. We're building on these achievements by carrying out a series of projects at the Fraunhofer Institute for Applied Optics and Precision Engineering (IOF) and at the University of Jena's Institute of Applied Physics. A prominent example is QuNET, a major cooperative initiative funded by the Federal Ministry of Education and Research, where we are researching the use of quantum phenomena to develop highly secure communication technologies, including the encryption and transmission of information.
Our second major field of research is imaging, where we're investigating analytical methods based on the quantum effects of photon entanglement. Such methods enable us to analyse samples that react sensitively to certain types of radiation and cannot be achieved with conventional systems. These methods can be particularly useful in medicine, where they can be used to reduce radiation exposure during tissue imaging.

What do you find so fascinating about the quantum world?
I find it particularly interesting that the precise control of quantum systems is opening up new applications in the fields of sensor technology, communication and computing. I'm driven by the challenge of developing these technologies to the extent where we can generate added value for the economy. I was lucky enough to put the results of the first quantum revolution into practice, and I even had the opportunity to participate in the development of laser technology in the 1980s and 90s, when we managed to establish a community in Germany and turn companies into global market leaders. Nowadays, almost 50% of all high-power lasers for industrial production and medical technology come from Germany.
I hope we can pool the knowledge of universities and non-university research institutions—and focus the innovation potential of companies—to shape the second quantum revolution in a similar way and create added value for society and the economy.

Quantum computers make people sit up and take notice, because they can be better than conventional computers in terms of their processing power. What is the state of development in this field?
There's a lot of hype about quantum computers and we have to curb our expectations. In theory, they're superior to conventional computers for certain computational tasks because of their different scaling behaviour. As the prime factorization of very large numbers is easier with quantum computers, for example, encryption systems can be broken. What's more, quantum computers will pave the way for completely new developments, such as in the field of materials research.
In practical terms, however, there's still a great deal to be done before we can develop a universal quantum computer. I imagine we'll first see a conventional computer with a quantum accelerator slot that enables special computing operations—but we should assume that many years of development are ahead. However, this is certainly the technology with the greatest long-term potential.

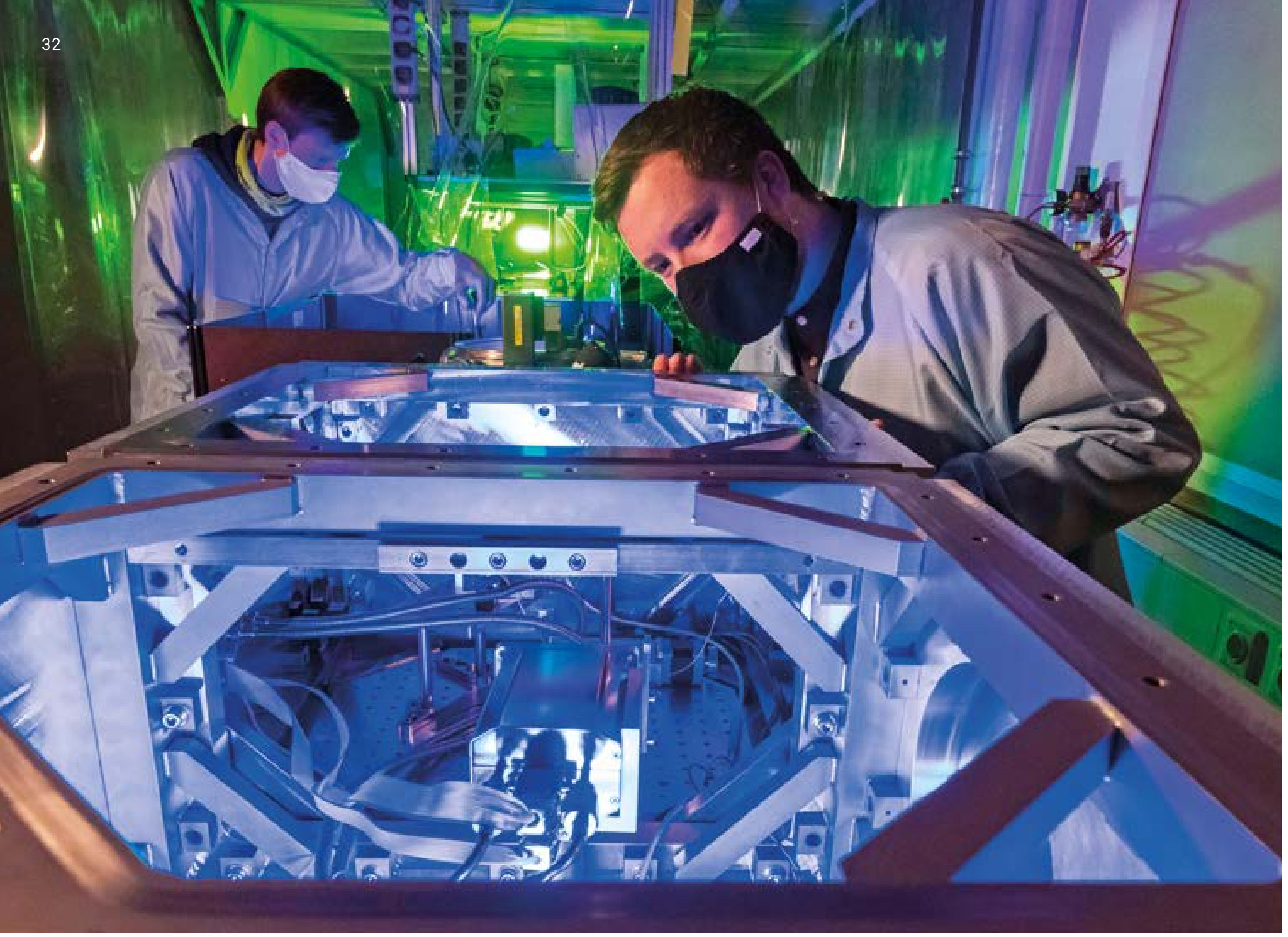
How long will it take for us to notice quantum technologies in our everyday lives?
We'll all come into contact with new quantum technologies—directly and indirectly—in just a few years. The most obvious change will emerge in the field of data encryption, which concerns our basic social rights, and modern systems are already using ›quantum number generators‹. However, we shouldn't forget that various quantum mechanical phenomena can already be found in our society. A classic example is the CD, which requires a laser to be played.

Prof. Dr Andreas Tünnermann has been teaching applied physics at the Friedrich Schiller University Jena and directing the Institute of Applied Physics since 1998. He conducts research in the fields of photonics and quantum technologies. He also heads the Fraunhofer Institute for Applied Optics and Precision Engineering IOF in Jena. Andreas Tünnermann has been a member of the board at the Helmholtz Institute Jena and the Abbe Centre of Photonics since 2009. · Photo: Fraunhofer IOF

With the current economic package alone, the German government is investing two billion euros in the development of quantum technologies. Is Germany in a good position to promote quantum research?
Our basic research infrastructure is excellent—Germany certainly holds its own against other countries around the world. This is mainly due to the long-term funding campaigns we've seen over the past few decades, such as those run by the German Research Foundation and the Federal Ministry of Education and Research.
The objective of all current funding programmes is to transfer knowledge into the development of new applications, particularly by promoting qualified young talents. The federal government is pursuing this target by launching special programmes designed to network science and business, improve education and promote specific areas such as quantum engineering.
If we want to remain competitive on the international stage, it's important that we implement all of these measures as quickly as possible. But I'm optimistic, because Germany's key advantage lies in its innovative small and mid-sized enterprises that can quickly bring new applications to market.

But is there anything that can be done to improve our infrastructure?
Science isn't just about competition; it's also about cooperation. At the moment, however, there is a noticeable reduction in cooperative projects around the world. This is having an impact not only on quantum research, but also on other fields of research. This is a worrying development. We have to enable and facilitate cross-border cooperation. In the long term, nationalist endeavours will only end up slowing down scientific progress and the development of society as a whole.
Like many of my colleagues around the world, I'm trying to counteract this by developing networks. In Jena, my research teams are made up of young people from Europe, Asia, Africa and America. We're also working closely with other research groups within Europe. We've opened a graduate school with Canada and applied for another with Australia.

Many people are helping to develop quantum technologies in Jena, not least you and your teams at the university and the Fraunhofer Institute. How do you see the future development of Thuringia and the region in terms of quantum research?
Thuringia has a large number of competitive groups and Jena has already become a hotspot for photonics and quantum technologies. We're planning a new physics professorship at the University of Jena with a focus on research and teaching in applied quantum physics.
We're in a good position, but I still think we need to establish an even tighter network. I would be delighted to see the Free State of Thuringia support activities at multiple locations to really put the region's quantum research on the map. It will be important to synergize our skills and capacities in Thuringia and also to involve local businesses. ■



Picture left: Dr Frederik Tuitje (right) and Tobias Helk (left) are members of the team directed by Prof. Dr Christian Spielmann at the Institute of Optics and Quantum Electronics; here they are preparing the laser plasma source for their experiments. · Photo: Jens Meyer

Optical harmonics

Optical microscopy has its limits—Ernst Abbe proved this in Jena by calculating the resolution limit of a microscope which is for visible light in the order of one micrometre. However, scientists are now attempting to shift this limit by looking for novel approaches. Among them are lens-less microscopes illuminated with short wavelength radiation (e.g. x-rays) resulting in images with nanometre resolution. A promising light source for this method is based on high harmonics generation of ultrashort lasers pulses in gases.

BY SEBASTIAN HOLLSTEIN

High harmonics based sources emit spatially coherent light pulses at short wavelengths. These properties are necessary for spatially resolving objects measuring only a few nanometres and for observing dynamic processes. High harmonics are generated by shooting very high-intensity laser pulses into a noble gas. This results in a nonlinear interaction between the light and gas atoms: The electrons start oscillating in the light field and emit short-wavelength radiation—the high harmonics (see box on p. 35). If this extreme ultraviolet (XUV) light interacts with an unknown sample, the light's properties will change. These changes provide information about the examined object. As the light has a very short wavelength, it can also be shone through samples that are not transparent to visible light (e.g. plasma).

What makes stars shine

Plasma is a highly excited state of matter consisting of ions and free electrons. This physical state is adopted by almost all visible matter in space, including stars, galaxies and interstellar matter. So, if we want to unearth the secrets of our universe, research into plasma is essential. Although plasma can be generated in the laboratory, we are still trying to understand the processes that take place in the ›turbulent‹ interior of this highly dense cloud of ions and free electrons. Prof. Dr Christian Spielmann and his team from the Institute of Optics and Quantum Electronics are cooperating with colleagues around the world to take a closer look at this special physical state and literally ›shed light on the matter‹. And high harmonics are their most important tool.

The researchers have already had their first taste of success. In a paper published in ›Light: Science & Application‹, the team present a method that enables physicists to directly observe the formation and interaction of highly ionized krypton plasma with coherent ultraviolet light in the femtosecond range. »We first turned krypton gas into plasma by exciting it with a laser, and then we sent a coherent XUV probe pulse—a high harmonic—through the plasma. Its wavelength was so short that the XUV probe pulse was able to penetrate the plasma,« explains Spielmann. »As this second beam propagated through the plasma, it acquired the properties of the plasma.« Using a new X-ray scattering process, the researchers were able to read out the information and create an image of the spatial distribution of electrons and ions in the plasma.

How to make photovoltaic cells more efficient

High harmonics are also providing insights in other, more practical fields, and are even helping to combat climate change. For example, Spielmann is collaborating with Prof. Dr Michael Zürch from the University of California in Berkeley and colleagues from other disciplines on the ›QUESTforENERGY‹ project, where he is investigating new nanomaterials for use in photovoltaic cells. »As the efficiency of single-layer, silicon-based photovoltaic cells can hardly be increased, they're not our best weapon when it comes to meeting rising energy demands,« he says. »We need alternatives«. By combining various two-dimensional materials with different absorption spectra, we may be able to create photovoltaic cells which could cover a greater solar spectrum and would be able to convert more light into electrical energy.

In order to find suitable materials, scientists must first investigate how their optical and electronic properties change when they are optically excited and how these optoelectronic properties can be controlled. How are charge carriers propagated in the material and what happens to the structure of the materials?

To observe these processes with temporal resolution in the femtosecond range, the researchers are shooting high harmonics pulses through the excited sample and analysing the beam on the other side of the sample to follow the transient changes of the properties in in the two-dimensional material. From the changes they can find out how electrons made their way through the sample and how much time they need to cross the material.

Ghost imaging of biological samples

High harmonics could also be used when analysing biological samples under the microscope, because the short wavelength allows finer details to be resolved compared to illumination with visible light. However, there is a risk of damaging or even destroying organic samples due to the intense radiation. Although scientists have developed measuring methods with X-ray lasers, where information can be collected before the objects are damaged, these processes are very complex. That's why the scientists are exploring the possibility of an XUV ghost imaging process within the ›Balance of the Microverse‹ cluster of excellence.

In this process, the objects are not placed directly between the XUV light source and a camera. This is done by splitting the XUV beam into one intense beam, which creates the image in a camera without an object, and one weak beam, which simultaneously illuminates the object to be examined and then falls onto a photodiode. As both rays are correlated with each other, the object can be fully reconstructed by combining the information from both rays. ■

Original publication:
Nonlinear Ionization Dynamics of Hot Dense Plasma Observed in a Laser-Plasma Amplifier, Light: Science & Applications (2020), DOI: 10.1038/s41377-020-00424-2

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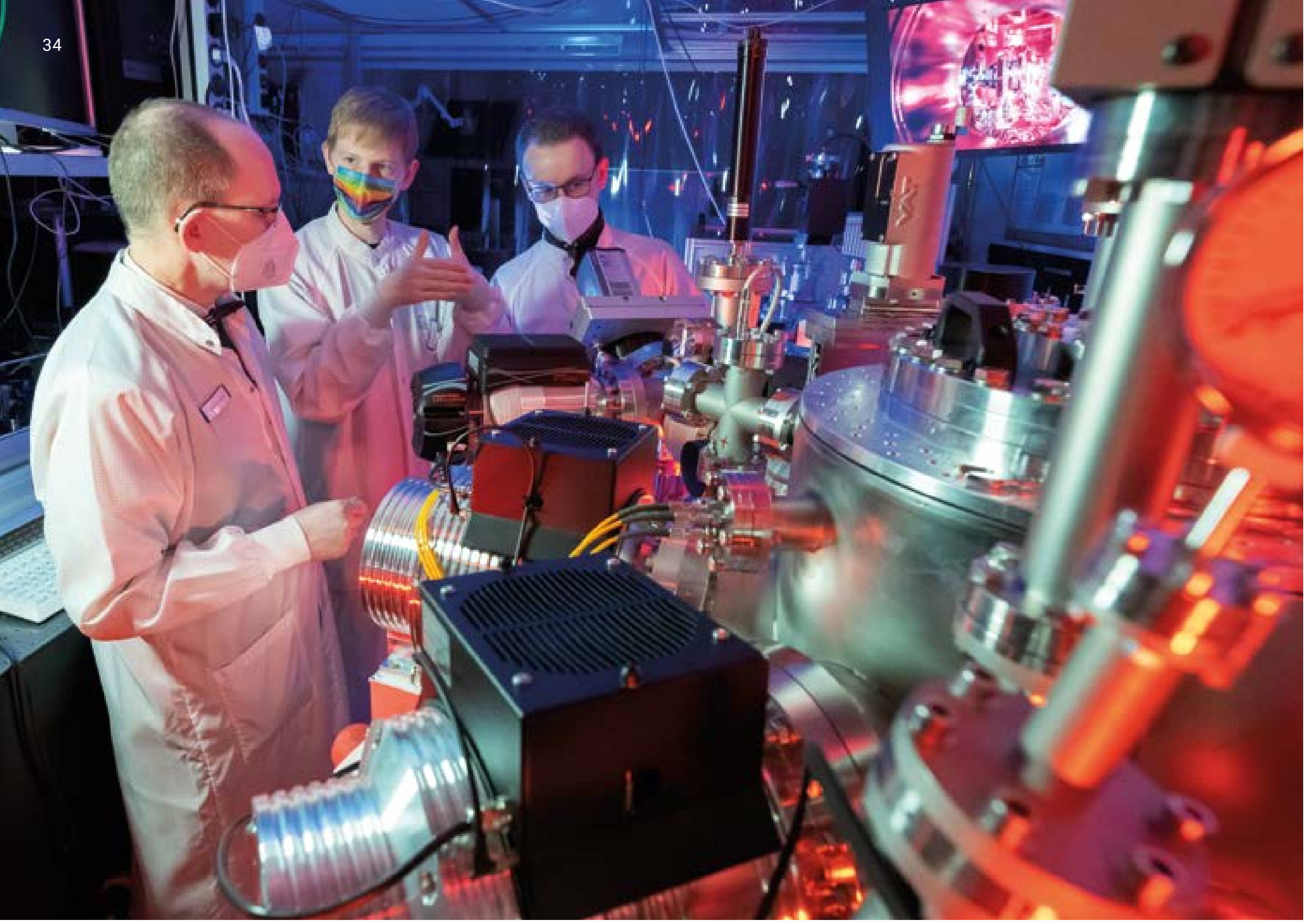

A closer look inside semiconductors

Although XUV light can be used to image nanoscale structures, generating coherent light with a wavelength of only a few tens of nanometres has so far only been achieved in major research facilities. Researchers at the University of Jena are using nonlinear optical effects to generate such radiation—at a conventional laser laboratory—to non-destructively determine the inner structure of materials and their chemical composition with nanoscale precision.

BY UTE SCHÖNFELDER

Images provide insights. What we can observe with our own eyes enables us to understand. Constantly expanding the field of perception into dimensions that are initially hidden from the naked eye, drives science forward. Today, increasingly powerful microscopes let us see into the cells and tissues of living organisms, into the world of microorganisms as well as into inanimate nature. But even the best microscopes have their limits. »To be able to observe structures and processes down to the nanoscale level and below, we need new methods and technologies,« says Dr Silvio Fuchs from the Institute of Optics and Quantum Electronics at the University of Jena. This applies in particular to technological areas such as materials research or data processing. »These days, electronic components, computer chips or circuits are becoming increasingly small,« adds Fuchs. Together with colleagues, he has now developed a method that makes it possible to display and study such tiny, complex structures and even ›see inside‹ them without destroying them. The researchers recently presented their method—coherence tomography with extreme ultraviolet light (XCT)—in ›Optica‹, where they demonstrated its potential applications in research and other areas.

Light penetrates the sample and is reflected by internal structures

The imaging procedure is based on optical coherence tomography (OCT), which has been established in ophthalmology for a number of years, explains doctoral candidate Felix Wiesner, the lead author of the study. »These devices have been developed to examine the retina of the eye non-invasively, layer by layer, to create 3-dimensional images.« At the ophthalmologist, OCT uses infrared light to illuminate the retina. The radiation is selected in such a way that the tissue to be examined does not absorb it too strongly and it can be reflected by the inner structures. However, the physicists in Jena use extremely short-wave UV light instead of long-wave infrared light for their OCT. »This is due to the size of the structures we want to image,« says Felix Wiesner. In order to look into semiconductor materials with structure sizes of only a few nanometres, light with a wavelength of only a few nanometres is needed.

Nonlinear optical effect generates coherent XUV light

Generating such extremely short-wave UV light (XUV) used to be a challenge and was almost only possible in large-scale research facilities. Jena physicists, however, generate broadband XUV in an ordinary laboratory and use what are called high harmonics for this purpose (see box above). This is radiation that is produced by the interaction of laser light with a medium and it has a multiple of the frequency of the original light. The higher the harmonic order, the shorter the resulting wavelength. »In this way, we generate light with a wavelength of between 10 and 80 nanometres using infrared lasers,« explains Prof. Dr Gerhard Paulus, Professor of Nonlinear Optics at the University of Jena. »Like the irradiated laser light, the resulting broadband XUV light is also coherent, which means that it has laser-like properties.«

In their experiments, the physicists exposed nanoscopic layer structures in silicon to the coherent XUV radiation and analysed the reflected light. The silicon samples contained thin layers of other metals, such as titanium or silver, at different depths. Because these materials have different reflective properties from the silicon, they can be detected in the reflected radiation. The method is so sensitive that not only the deep structure of the tiny samples can be displayed with nanometre accuracy, but—due to the differing reflective behaviour—the chemical composition of the samples can also be determined precisely and, above all, in a non-destructive manner. »That's what makes coherence tomography an interesting application for inspecting semiconductors, solar cells or multilayer optical components,« says Paulus. It could be used for quality control in the manufacturing process of such nanomaterials, to detect internal defects or chemical impurities. ■

Picture left: Prof. Dr Gerhard Paulus, doctoral candidate Felix Wiesner and Dr Silvio Fuchs (from left to right) in a laser laboratory. · Photo: Jens Meyer

High harmonics

The term ›harmonic‹ is used in physics to refer to an oscillation whose frequency is an integer multiple of the fundamental frequency. In music, harmonics appear as overtones. However, harmonics can also be formed by light and other electromagnetic waves. In nonlinear optics, the term ›high harmonics‹ is used to refer to light waves whose frequency is approximately 10 times that of the original laser frequency or greater.

In order to generate high harmonics, extremely intense laser light is required: Laser pulses with an intensity of 10^{14} W/cm^2 (one hundred trillion watts per square centimetre) are concentrated on matter (diluted gas). The electrical field strength of these pulses is so great that they tear the electrons out of their shell. As the direction of the electrical field in a light wave switches back one trillion times a second, however, the electrons are accelerated back to their original atom just as often. This is where they give off their kinetic energy in the form of harmonic light waves.

Original publication:
Material-specific imaging of nanolayers using extreme ultraviolet coherence tomography, Optica (2021),
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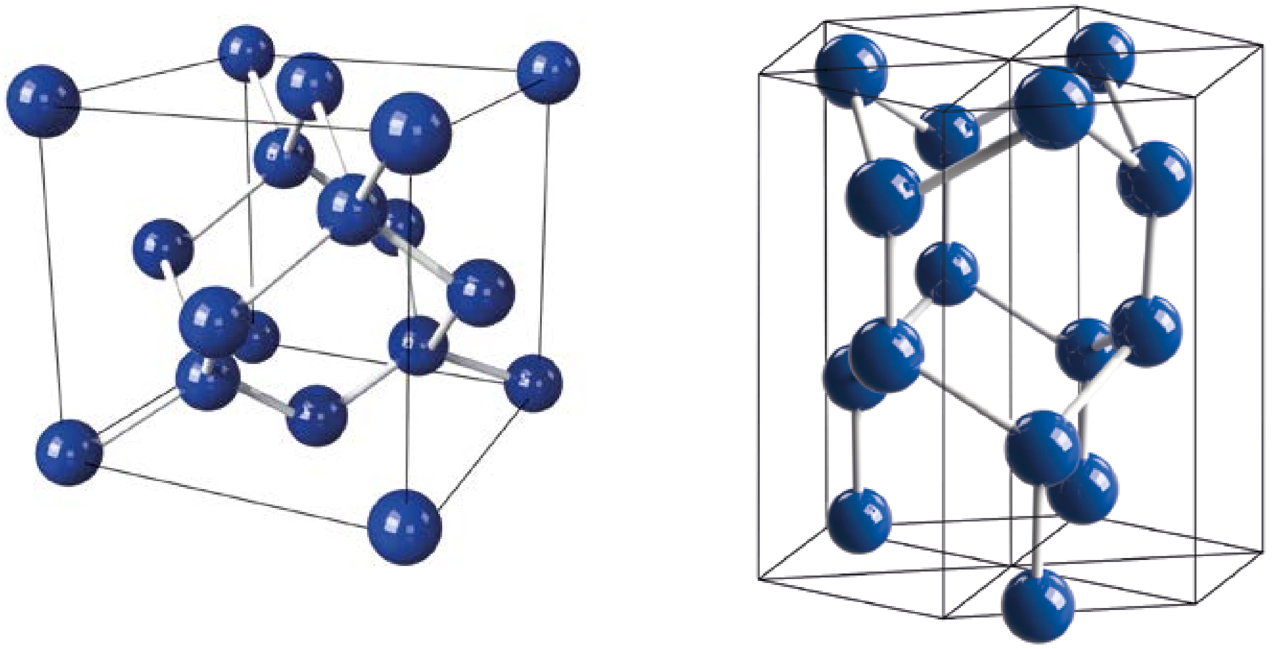
Here is a model representation of silicon's crystal structure: cubic (left) and hexagonal (right). Graphics: Silvana Botti



Physics World: Breakthrough of the Year

A team of researchers from Eindhoven University of Technology and the University of Jena—and their partners from the University of Linz and the Technical University of Munich—have been awarded the ›Physics World: Breakthrough of the Year 2020‹ award for creating a silicon-based alloy that emits light. Their award-winning work could revolutionize optical data processing in the coming years, as it enables the development of photonic computer chips for the first time.

BY UTE SCHÖNFELDER

The team, whose members include Jens Renè Suckert and Prof. Dr Silvana Botti from the University of Jena, published a study in April 2020, demonstrating for the first time that silicon alloys are suitable for emitting a significant number of photons. Their findings are paving the way towards silicon lasers that could revolutionize optical data processing. The magazine ›Physics World‹ has been honouring international scientists with the ›Breakthrough of the Year‹ award since 2009.

Prof. Silvana Botti underlines the importance of the development: »Our work enables the creation of silicon-based photonic computer chips that are much faster and more energy-efficient than existing electronic chips.« Such microchips, which communicate with light particles (photons) instead of electrons, need an integrated laser that produces the data signals directly on the chip. However, silicon is a semiconductor material that was previously seen as an extremely weak emitter of light due to the symmetry properties of its electronic energy states. In order to emit photons (i.e. light), the electrons in the semiconductor have to ›jump‹ from an excited state (conduction band) to a lower-energy state (valence band). »In silicon crystals, however, these two bands are offset in such a way that it is difficult for the electrons to pass from one to the other,« explains Jens Renè Suckert, one of the first authors of the award-winning paper. This ›indirect band gap‹ had previously prevented photons from being efficiently emitted by silicon.

Silicon changes its crystal structure in a nanowire geometry

The team managed to overcome this problem by reconsidering a 50-year-old theory and modifying the silicon's crystal structure in such a way that the indirect band gap was eliminated. The researchers became the first team to master the growth of silicon with the semiconductor germanium in an alloy with a hexagonal crystal structure (above right) instead of its cubic structure (above left), thus facilitating the transition from conduction to valence band. In their paper, which was published in ›Nature‹, the researchers demonstrated that silicon effectively emits light in such a crystal structure.

A team of physicists from the University of Jena contributed to the study by calculating the electronic properties of the silicon-germanium nanowires. »Accurate calculations are essential to prove that the light emission actually comes from the direct band transition within the alloy and to rule out any other sources,« explains Silvana Botti. The calculations were so precise that they even allowed the researchers to predict the efficiency and colour of the light emission depending on the amount of germanium.

Prof. Dr Silvana Botti and doctoral candidate Jens Renè Suckert are members of the award-winning team of international researchers who are paving the way to silicon lasers with their most recent breakthrough. · Photo: Jürgen Scheere

Theory enables precise predictions for experiments

»Being recognized for the most important breakthrough in physics research is fantastic and just goes to show how important innovations can emerge from the combination of theoretical and experimental research,« says Silvana Botti, who adds that the recent study demonstrates how experimental physics is enriched by the calculations provided by theoretical physics: »The combination of theory and experimentation can lead to real breakthroughs,« she says. ■

Original publication:
Direct-bandgap emission from hexagonal Ge and SiGe alloys, Nature (2020), DOI: 10.1038/s41586-020-2150-y

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How has 2020 changed the scientific landscape?

The year of crisis 2020 may have ended a few months ago, but the coronavirus pandemic rages on. Almost all walks of life are affected by the situation—from the economy to culture and society—and teaching and research are still running in ›COVID mode‹ at universities. What does this mean for scientists at the University of Jena? How do they look back on 2020 and what experiences have they taken away from it? We asked all ten faculties for their opinion.

SURVEY: VIVIEN BUSSE

PHOTO: PETER SCHEERE

Anna Leisner-Egensperger

PROFESSOR OF PUBLIC LAW AND TAX LAW

The science of public law faced considerable challenges in 2020. While it was the hour of the executive in spring, the importance of our parliamentary democracy returned to the fore in summer. I'm currently involved in the federal government's vaccination strategy as an external expert, which is proving to be an unexpectedly exciting task. With regard to my science and research, the past year has been productive and fulfilling in a way I am usually denied through my commutes on overcrowded trains and my work for equality committees—from commentaries on the German constitution and articles in various guides to the digital acceptance of many dissertation procedures.

A personal challenge has been looking after our four children, who are aged 11 to 15 and have had to be home-schooled during certain terms. As I've spent much time with them, I've had quite a few sleepless nights. I miss seeing lecture theatres full of people and having personal exchanges with students. That said, Zoom and Cisco are pretty good inventions.

Since its beginnings at the Platonic Academy, the study of ethics has thrived on personal exchange. COVID-19 has therefore presented a huge challenge for the teaching staff and students involved in our master's programme in ›Applied Ethics and Conflict Management‹ and our interdisciplinary course in ›Ethics (with History and Theory) of Medicine‹.

After all, the study of ethics isn't just about putting forward our own moral opinions; it's about communicating with others and learning to understand their arguments and views—and it's even about having our own opinions questioned. The best possible argument ultimately has to be convincing and we have to find suitable, value-based solutions to morally relevant conflicts in particular historical situations. That's why classroom-based teaching is so important in ethics—and that's why I often find our digital classes so impoverishing, but I suppose this decision was inevitable when it came to balancing our interest in good health and classroom-based teaching in 2020.

Nikolaus Knoepffler

PROFESSOR OF APPLIED ETHICS

PHOTO: ANNE GÜNTHER

PHOTO: ANNE GÜNTHER

Anke Lindmeier

PROFESSOR OF MATHEMATICS EDUCATION

Ever since the coronavirus reached our shores in March 2020, we've seen another example of how understanding mathematical concepts is so important for society. As a mathematics educator, I know that a maths lesson on exponential functions doesn't necessarily guarantee that we can actually estimate growth correctly. It even took the most prominent branches of the media quite some time to develop suitable ways to represent the development of the pandemic. Some even dared to experiment briefly with logarithmic scales, but they were probably too mathematically demanding for many readers.

It's difficult to predict the long-term effects of the coronavirus pandemic on research into maths education. Our studies with and at schools have practically come to a standstill. In view of the challenge posed by digital teaching methods, I fear that the research landscape will remain difficult for a long time, because computer-based surveys are still difficult to conduct at German schools (to name just one example). However, I hope that society recognizes the importance of research when it comes to learning mathematics.

The year 2020 affected science like no other. As in many other fields, the pandemic has presented us with unprecedented challenges in science and teaching—and we're still feeling the effects today.

At the same time, the public debate surrounding the COVID-19 pathogen has generated interest in scientific processes and highlighted the importance of infection research in a globalized world. One of the key lessons to be learned from the pandemic is that scientific findings should play a central role in political decision-making processes. It remains to be seen whether this principle will be implemented in the ›post-COVID world‹.

Kai Papenfort

PROFESSOR OF GENERAL MICROBIOLOGY

PHOTO: ANNE GÜNTHER

PHOTO: ANNE GÜNTHER

Corinna Dahlgrün

PROFESSOR OF PRACTICAL THEOLOGY

Since March 2020, the scientific world has largely been banished to the confines of book-heavy offices displayed in little boxes in the corner of our Zoom calls. My field of research concerns the Church, which is trying to respond to many acute needs as well as possible and developing a creative touch in the process. As a practical theologian, it's my job to reflect on the current developments and suggest courses of action. One such attempt is a homiletics seminar entitled ›Preaching for the Internet‹. In the first half, we looked at worship formats from various German and English churches to find criteria for good practice. This was followed by films made by our students, who had their difficulties but learnt a lot.

Such positive experiences of online teaching are leading to further ideas. Next winter, for example, we'll be holding a seminar on Jesus films in cooperation with the Bonn New Testament scholar Hermut Löhr—interdisciplinary, nationwide and digital.

Martin Walter

PROFESSOR OF PSYCHIATRY AND PSYCHOTHERAPY

PHOTO: MICHAEL SZABO

Six months after starting my position as director of the University Hospital for Psychiatry and Psychotherapy, the coronavirus pandemic has revealed the strengths and weaknesses of my new institution like a magnifying glass and my search for practical solutions has put me in touch with some amazing people. Instead of setting up a new scientific department, we had to deal with the crisis and take responsibility for the special demands placed on our employees and patients. It's been impressive to see my colleagues excel themselves and grow together as teams. New technical solutions have suddenly emerged, such as those developed in the field of digital psychotherapy.

Our MRI research on people has been postponed for the time being. As we're lacking results from our own experiments, we're cooperating with international teams to evaluate existing data sets and benefiting from our teamwork in the age of social distancing. New problems such as ›post-COVID fatigue‹ have given rise to novel initiatives and large-scale cooperative projects on inflammation and mental health in Jena.

The coronavirus pandemic presents a wide range of challenges in everyone's private and professional lives. Many economic issues are closely related to the pandemic, such as the effects on the economy and especially on public finances.

However, the coronavirus pandemic is too complex to be adequately evaluated from the perspective of one discipline alone; an interdisciplinary approach is helpful. As a member of the Scientific Council for Pandemic Management of the Thuringian State Government, I have the opportunity to discuss the complexity of the situation with other scientists in an interdisciplinary setting to develop recommendations for political decisions. Let's hope we can work together to gradually overcome the pandemic in 2021 and take a step back towards normality.

Silke Übelmesser

PROFESSOR OF ECONOMICS / PUBLIC FINANCE

PHOTO: ANNE GÜNTHER

Andreas Tünnermann

PROFESSOR OF APPLIED PHYSICS

PHOTO: ANNE GÜNTHER

2020 was also an opportunity to develop new approaches to research and teaching. For example, the University of Jena worked with the Max Planck School of Photonics and the Fraunhofer IOF to inaugurate a ›Digital Teaching Lab‹, where students can conduct experiments via augmented reality (e.g. a Fourier optics test). This means we're creating new settings for research-oriented teaching, even beyond the coronavirus situation.

2020 was the year in which we came together digitally: As part of our ›lecture series‹, for example, Nobel laureate Stefan Hell held a virtual talk for our doctoral candidates. People from all over the world also discussed their research during our open ›coffee breaks‹. This is a huge opportunity for science! Nevertheless, virtual meetings are no long-term replacement for personal contact and I look forward to seeing people in classrooms again soon.

One of the key focuses of intercultural research is the constructive handling of unfamiliar, unsafe and disruptive situations. With this in mind, analysing public communication practices in the coronavirus pandemic can provide extremely useful insights when it comes to understanding the roots of social and ›cultural‹ polarizations and developing proposals for action aimed at creating a more ›cosmopolitan‹ and ›cohesive‹ society.

The extraordinary circumstances of the pandemic have given us new impetus in teaching. The idea of global virtual collaboration is especially challenging in an intercultural context. The forced development of digital action plans with video conferencing systems has resulted in significant technological leaps, such as the development of intercultural simulations in the IVAC project or the cross-border, cooperative initiative for virtual teaching on glocal-campus.org. It's particularly encouraging to see a steady rise in the acceptance of virtual collaboration.

Jürgen Bolten

PROFESSOR OF INTERCULTURAL BUSINESS COMMUNICATION

PHOTO: ANNE GÜNTHER

Mirka Dickel

PROFESSOR OF DIDACTICS OF GEOGRAPHY

PHOTO: ANNE GÜNTHER

Facing the state-imposed lockdowns, social distancing, uncertainties and unpredictabilities associated with the socio-political global corona crisis, questions about human self-assurance in modernity became pressing. For sure, we live in times of ›transcendental homelessness‹ (Georg Lukács).

My questions literally got to me, left me no peace, drove me to research. Specifically, I was concerned with the question of what it means to speak of scientific responsibility. What does it mean for me and for us scientists to bear responsibility for life and survival on our planet? What human-nature relationship is worth to convey in scientific and societal discourse? Which human-nature relationship can we truly advocate? In other words, what good reasons are there for our research and how can they be argued? Good reasons, philosophically speaking, are reasons that stand up to argumentative scrutiny and thus point to reflection. In 2020, I questioned the presuppositions of research in modernity and addressed the relationship between epistemology (knowledge theory) and ontology (logos) with respect to scientific responsibility.

Fish larva helps with research into ageing

The brain structures of a zebrafish larva are examined under a fluorescence microscope: As part of the ›IMPULS‹ project, a team of researchers at the University of Jena, the University Hospital and the Leibniz Institute on Aging (Fritz Lipmann Institute) are investigating the factors that influence the complex ageing process in humans (p. 7).

PHOTO: JENS MEYER

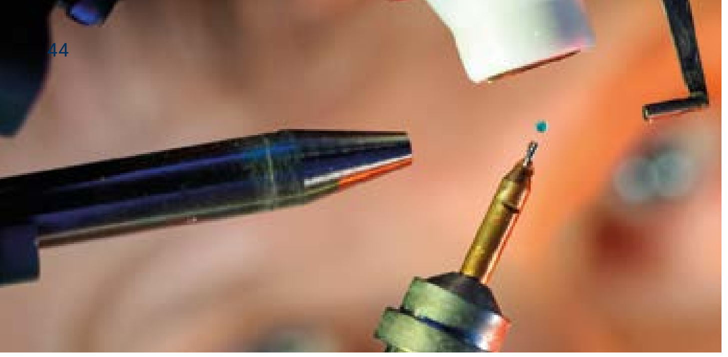

PHOTO: JENS MEYER

Molecular teamwork

Everyone knows we can achieve more as a team. Chemists at the University of Jena have applied this everyday knowledge to a compound containing two gallium atoms, which work together in such a way that they can break the particularly strong bond between fluorine and carbon in other substances (DOI: 10.1021/jacs.0c12166). With the help of X-ray structure analysis, junior professor Dr Robert Kretschmer and his team of researchers were able to prove that one gallium atom bound the fluorine during the cleavage reaction while the other gallium atom bound the rest of the hydrocarbon compound. »Now that we've taken this step, we can develop the concept further,« says Kretschmer. »It would be ideal if the reaction could be continued to form a full catalytic cycle.« MK

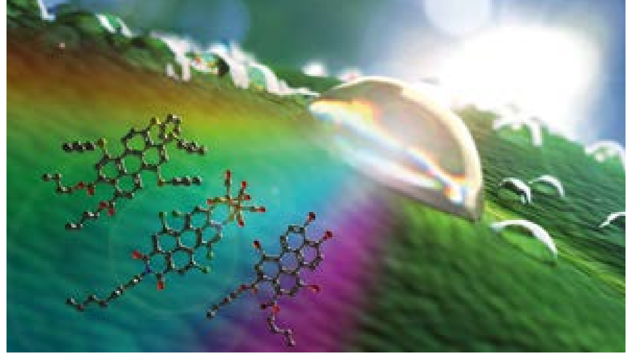

IMAGE: PENEVA GROUP

From sunlight to hydrogen

A team of researchers at the ›CataLight‹ collaborative research centre, including scientists from the University of Jena, have combined novel organic dyes with base metal catalyst molecules that release hydrogen gas when exposed to light in water (DOI: 10.1002/chem.202004326). The researchers used rylene dyes, which are particularly stable in relation to light and chemical processes. »The light-absorbing metal complexes used in research often contain ruthenium or iridium. However, these metals account for under 0.1 millionth of a percent of the mass in the earth's crust and therefore have their limitations,« explains Prof. Dr Kalina Peneva, who adds that the use of photoactive, organic chemical compounds is much more sustainable than using heavy metals. sl

PHOTO: HELGE BRUELHEIDE

Plant diversity on the decline

29 million pieces of data on the distribution of vascular plants have been evaluated for a study carried out by the German Centre for Integrative Biodiversity Research Halle-Jena-Leipzig (iDiv)—that's the most comprehensive analysis of plant data from Germany to date (DOI: 10.1111/gcb.15447). »The results paint a very bleak picture of the state of plant diversity in Germany,« says Dr David Eichenberg, who led the study. After dividing the whole of Germany into a grid, the researchers found that biodiversity had declined, on average, by around 2% per decade in each box on the grid (approx. 5 x 5 km). Some of the biggest losers include archaeophytes (non-native species that were introduced to Germany before the discovery of America). In contrast, many neophytes (species that have arrived in Germany since 1492) have managed to spread. iDiv/ST

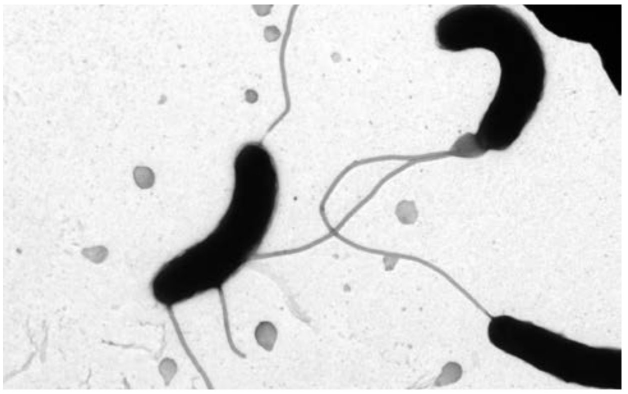

PHOTO: KAI PAPENFORT

Antibiotic resistance

The effectiveness of antibiotics such as penicillin lies in the fact that they attack the cell wall of bacteria by hindering their synthesis. However, bacteria are not always helpless in the face of such attacks. A team of researchers from the University of Jena have now discovered a molecule—VadR—which has a significant impact on the antibiotic resistance of *Vibrio cholerae*, the bacterium that causes cholera (DOI: 10.1038/s41467-020-19890-8). VadR inhibits the synthesis of a bacterial protein which, among other things, controls the curvature of the rod-shaped *V. cholerae* (picture above). »However, VadR is only one of many molecules that can interfere with gene expression. If we understand all these molecules, their functions and their interactions, it will help us to develop new therapeutic approaches,« says Prof. Dr Kai Papenfort, who is leading the study. AG

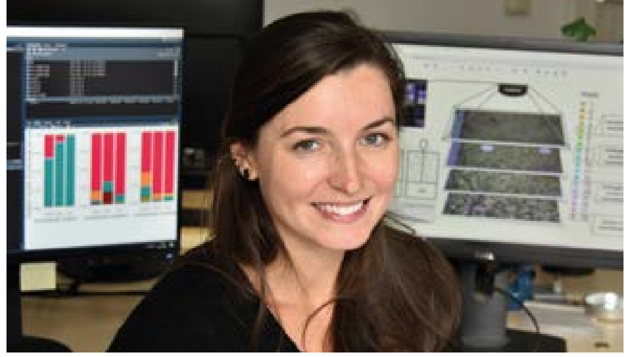

PHOTO: ANNE GÜNTHER

Altered flowering phases in plants

Insects have a significant impact on biodiversity and the flowering phases of plants. This is one of the findings made by researchers from the University of Jena and the German Centre for Integrative Biodiversity Research Halle-Jena-Leipzig (iDiv) (DOI: 10.3389/fpls.2020.542125). If there is a lack of insects in a plant's environment, its flowering behaviour changes. »These alterations can lead to a time gap between the emergence of plant and animal species which, in turn, has negative consequences for the ecosystem,« says Josephine Ulrich (pictured), who led the study. Some of the adverse effects include the reduced food supply for insects and the decreased success of pollination. This deterioration in ecosystem function could lead to more species being lost. viv

PHOTO: JENS MEYER

Intelligent nanomaterials

2D materials are highly versatile products consisting of only one layer of atoms. In combination with optical fibres, the ultra-thin materials are opening up new applications in the field of sensor technology, nonlinear optics and quantum electronics. However, combining the two components used to be an incredibly complicated process, as the ultra-thin layers had to be transferred to the waveguide by hand. A team of researchers from Australia and the University of Jena have succeeded in growing 2D materials directly on optical fibres for the first time ever (DOI: 10.1002/adma.202003826). The success of the project hinged on a novel growth method developed by Prof. Dr Andrey Turchanin and his team at the Institute of Physical Chemistry. sh

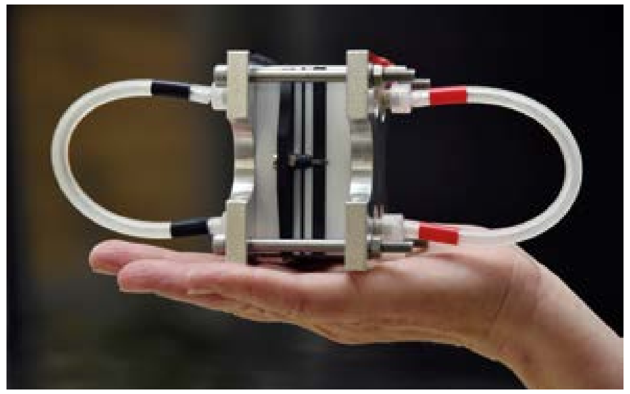

PHOTO: ANNE GÜNTHER

More efficient energy storage

If we want to enable the long-term use of renewable energies, we need suitable power storage systems. This can be achieved through redox flow batteries, where the energy-storing components are dissolved in a solvent and stored at various locations. However, these energy storage systems had previously exhibited two major weaknesses that had prevented their widespread use: On the one hand, environmentally harmful and toxic heavy metal salts such as vanadium were often used as electrolytes; on the other hand, they required a complex cooling system. A team of researchers from the University of Jena have now developed new polymer electrolytes for redox flow batteries that are efficient and environmentally friendly (DOI: 10.1002/aenm.202001825). The project is led by Prof. Dr Ulrich S. Schubert. sh

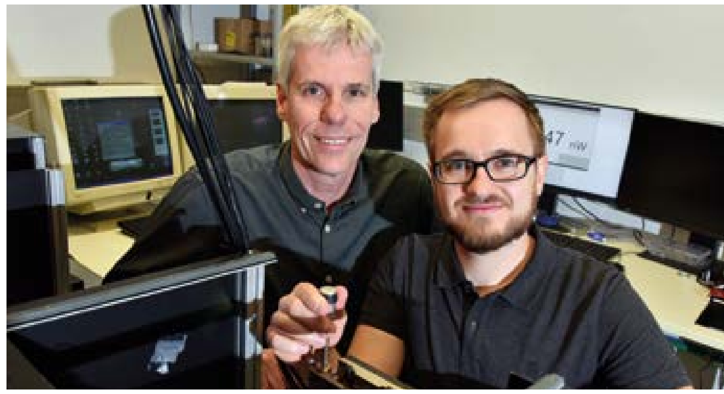

PHOTO: ANNE GÜNTHER

Nanoscale X-rays

A team of physicists from Duisburg, Grenoble, Madrid and the University of Jena have recently developed one of the smallest X-ray detectors in the world with a resolution of just 200 nm (DOI: 10.1038/s41467-020-18384-x). The high resolution of the detector is due to the small size of the semiconductor nanowire.
The detector is not intended to be used in the medical field; instead, the method could provide valuable information when investigating materials. »Many components, such as those in chip-based sensors or physical light sources, are getting smaller and smaller,« says Maximilian Zapf (in the picture on the right). »Our detector could be used to test such nanoscale elements and characterize their material,« adds Prof. Dr Carsten Ronning (in the picture on the left). sh

Life in the wild is full of dangers and risky decisions that are critical to an animal's survival. Left: An Adélie penguin jumps off an ice floe while his comrades look on. Above: A blacktip reef shark swims through a shoal of fish. · Photos: Oliver Krüger

Hunger encourages risk-taking

Animals that experience prolonged hunger at a young age take greater risks in later life. This was one of the findings of a meta-study carried out by a team of researchers from the Universities of Bielefeld and Jena, who compared the risk behaviour of more than 100 animal species and revealed major individual differences. An animal's willingness to take risks is partly innate, but it is also influenced to a large extent by the conditions in which it grows up.

BY UTE SCHÖNFELDER

The lives of animals in the wild are full of risky situations with uncertain outcomes. Whether they are exploring new habitats in unfamiliar terrain or searching for new food sources, they run the risk of being caught and killed by a predator. In many instances, their very survival depends on a single decision. Whether an animal decides to take a risk or prefers to avoid danger varies greatly from one individual to another.

»Just as there are humans who are more cautious and others who take more risks, among animals of a particular species there are also individuals that are more or less risk-averse,« says Prof. Dr Holger Schielzeth. The population ecologist from the University of Jena explains that these differences are to some degree innate, but to a considerable extent they also depend on an individual's development.

Study results compared for more than 100 animal species

As shown by the extensive meta-study conducted by the research teams directed by Holger Schielzeth and his colleague from the University of Bielefeld, Prof. Dr Klaus Reinhold, an animal's nutritional condition in its early years has a significant impact on its willingness to take risks in later life. The researchers have published their results in ›Biological Reviews‹.

The researchers, working with lead author Nicholas Moran, analysed more than 120 experimental studies involving over 100 animal species and the results. Species studied included spiders, insects, crustaceans, fish, amphibians and birds. Common to all the studies was the fact that the animals had experienced phases of good and bad nutrition, and that their risk appetite was measured later in life.

The scientists had suspected that an animal's living conditions and experiences would have an influence on its behaviour and even shape its willingness to take risks, but they had conflicting hypotheses on the exact nature of the influence: »On the one hand, one could assume, that animals that have always enjoyed good circumstances and are therefore in a better condition, would have more to lose and would therefore be more risk-averse,« explains Klaus Reinhold, an evolutionary biologist from the University of Bielefeld. On the other hand, he adds, a better nutritional status could mean that an animal would escape more easily from a risky situation, and would therefore be more likely to take a risk

Clear effect among all examined species

The analysis of the results of all the studies has now made things clear. An insufficient food supply causes animals to engage in higher-risk behaviour: the willingness to take risks rises by an average of 26 per cent in animals that have experienced hunger earlier in their lives.

»We were surprised that this result was so clear and unambiguous,« says Holger Schielzeth. The correlation applied to virtually all the behavioural contexts studied, such as exploration behaviour, migration and risky searches for food. There were of course variations in the strength of the effect.

At the moment, the ecologists can only speculate as to whether there might be a similar connection between fearlessness and individual development in humans. Holger Schielzeth would back that hypothesis; after all, humans are just another animal species. ■

Original publication:
Poor nutritional condition promotes high-risk behaviours: a systematic review and meta-analysis, Biol. Rev. (2020), DOI: 10.1111/brv.12655

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Search engine for metabolites

The metabolism of every organism—from unicellular microbes to the complex human system—produces thousands of chemical compounds. As these molecules are the starting, intermediate and end products of chemical processes, they can provide information about the physiological state of living beings and their organs, tissues and cells. For this to work, however, these molecules (metabolites) actually have to be detectable. Such analyses involved an extremely high degree of complexity, because it was only possible to clearly identify metabolites whose structures were already known. However, bioinformaticians at the University of Jena are now using artificial intelligence methods to detect all metabolites in a sample—even those which are unknown.

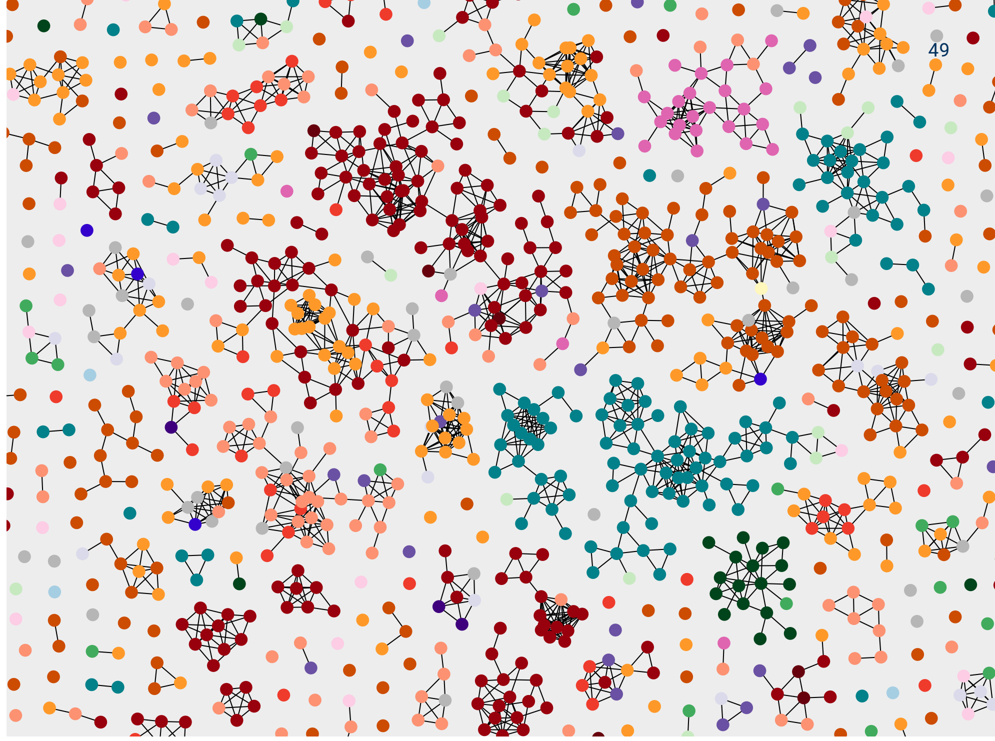
BY SEBASTIAN HOLLSTEIN

Everything that lives has metabolites, produces metabolites and consumes metabolites. They can be used as ›chemical markers‹ to detect diseases or investigate drinking water samples, to name just a few of their applications. However, the diversity of these compounds causes difficulties in scientific research. Scientists have only managed to identify and define the structure of a relatively small number of molecules. Therefore, whenever a sample is analysed, only a relatively small part of it can be identified, while the majority of molecules remain unknown.

Bioinformaticians at the University of Jena have been working with their colleagues from Finland and the USA to develop a unique method with which all metabolites in a sample can be taken into account, thus considerably increasing the knowledge gained from examining such molecules. The team reports on its successful research in the scientific journal ›Nature Biotechnology‹.

»Mass spectrometry, one of the most widely used experimental methods for analysing metabolites, identifies only those molecules that can be uniquely assigned by matching them against a database. All other, previously unknown, molecules contained in the sample do not provide much information,« explains Prof. Sebastian Böcker from the University of Jena. »With our newly developed method, called CANOPUS, however, we also obtain valuable insight from the unidentified metabolites in a sample, as we can assign them to existing compound classes.«

CANOPUS works in two phases: first, the method generates a ›molecular fingerprint‹ from the fragmentation spectrum measured by means of mass spectrometry. This contains information about the structural properties of the measured molecule. In the second phase, the method uses the molecular fingerprint to assign the metabolite to a specific compound class without having to identify it.



Picture left: Dr Kai Dührkop presents the visualization of a data set with the CANOPUS software. · Photo: Jens Meyer

Picture right: A section of the molecular network showing the metabolites in a mouse's digestive system, where each coloured node represents a measured molecule. Nodes are connected when their mass spectra are very similar. Although the majority of these molecules are completely unknown, CANOPUS predicts the substance class of each unknown molecule (amino acids in orange, glycerophospholipids in brown, triterpenoids in dark green and bile acids in turquoise).

Analysis simplified by two-stage learning process

»Machine learning methods usually require large amounts of data in order to be trained. In contrast, our two-stage process makes it possible in the first step to train on a comparatively small amount of data of tens of thousands of fragmentation mass spectra. Then, in the second step, the characteristic structural properties that are significant for a compound class can be determined from millions of structures,« explains Dr Kai Dührkop.

The system therefore identifies these structural properties in an unknown molecule within a sample and then assigns it to a specific compound class. »This information alone is sufficient to answer many important questions,« Böcker emphasises. »The precise identification of a metabolite would be far more complex and is often not necessary at all.« The CANOPUS method uses a deep neural network predicting around 2,500 compound classes.

The bioinformaticians have already used their method to compare the intestinal flora of mice in a study where a test group had been treated with antibiotics. Their experiments provide information as to which classes of substances are produced by the mouse itself and which by its intestinal flora. Their research results may provide important insights into the human digestive and metabolic systems. The study also presented two more possible applications of the new method, which further proves its functionality and informative value.

Jena's molecular search engine used millions of times

With the new method, the bioinformaticians from Jena are expanding the possibilities of the search engine for molecular structures—›CSI: FingerID‹—which they have been making available to the international research community for around five years. This service is now used thousands of times a day by researchers looking to compare a mass spectrum from a sample with various online databases in order to determine a metabolite with greater precision. Over a hundred million requests have been submitted.

The new process strengthens the field of metabolomics—that is, research on these omnipresent small molecules—and increases its potential in many research areas, such as pharmaceuticals. Many active pharmaceutical substances in use for decades are metabolites; others could be developed with their help. ■

Original publication:
Systematic classification of unknown metabolites using high-resolution fragmentation mass spectra, Nature Biotechnology (2020), DOI: 10.1038/s41587-020-0740-8

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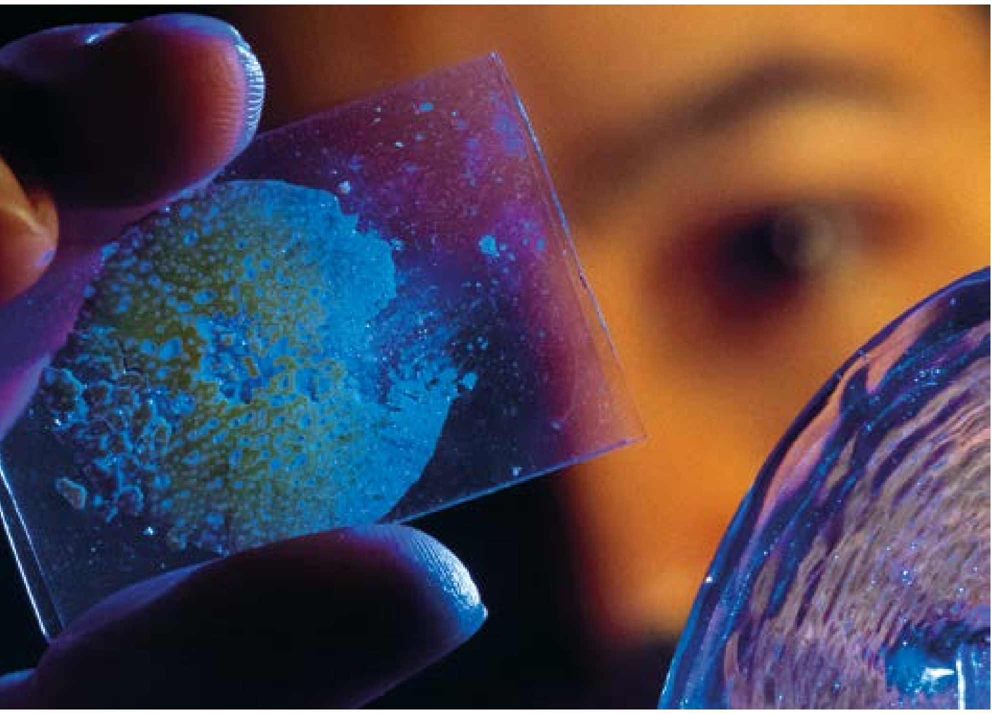
The best of both material worlds

A team of materials scientists from Jena and Cambridge develops hybrid glass materials with novel combinations of properties. The researchers are combining organometallic and inorganic glass to produce composite forms of glass that are impact-resistant and break-proof like plastic while retaining the hardness of glass.

BY UTE SCHÖNFELDER



Picture left: The two starting materials for the new composite material: organic glass (left) and inorganic glass (right). · Photo: Jens Meyer

Picture right: The bond structures of the new composite glass are being determined with the help of a nuclear magnetic resonance spectrometer operated by a team of materials scientists, including Dr Courtney Calahoo from the University of Jena (pictured here).· Photo: Jens Meyer

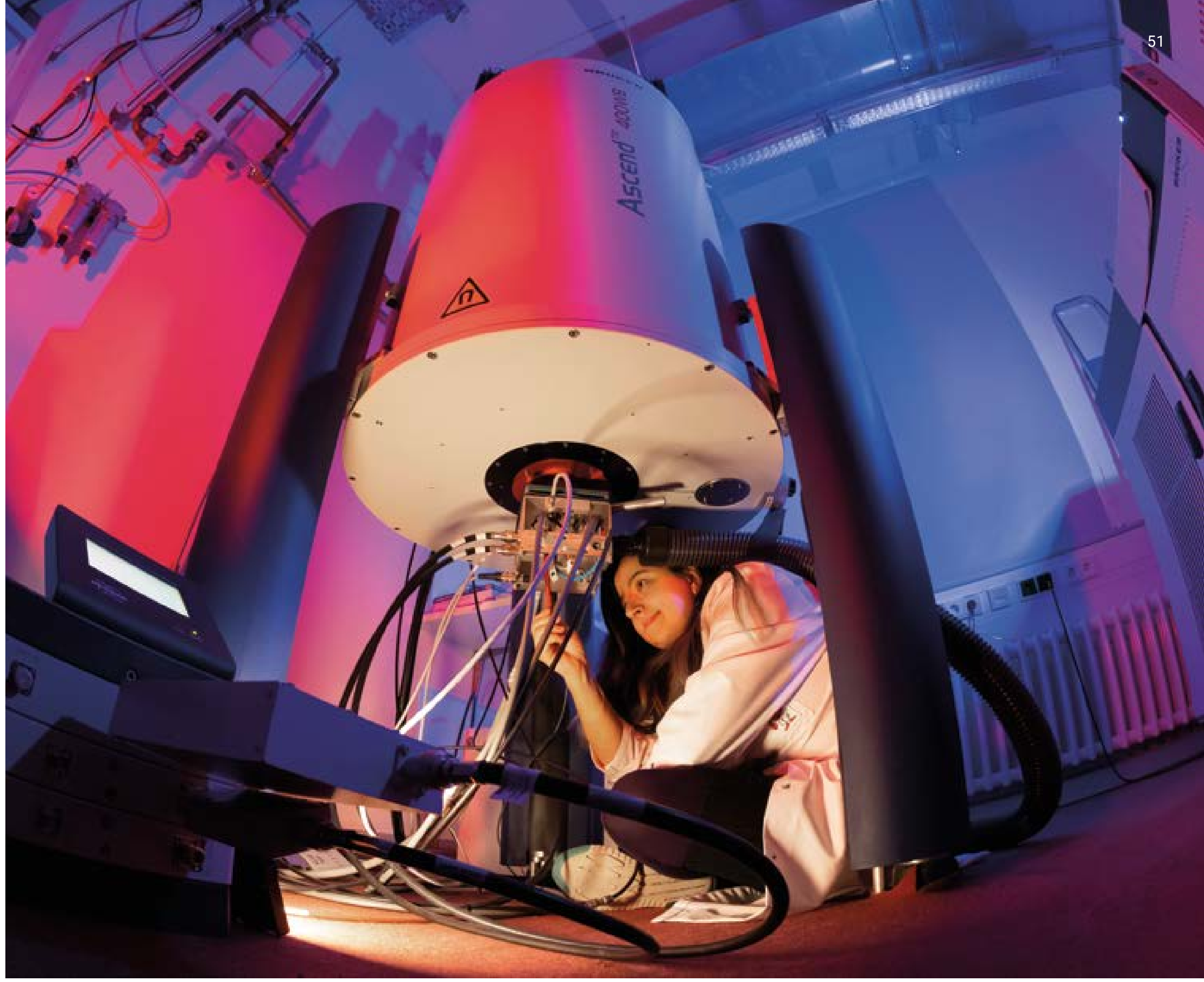
Composites of organic and inorganic materials are a common phenomenon in nature. For example, bones consist of collagen (an organic structural protein) and apatite (an inorganic mineral) what makes bones flexible yet strong. Composites enable combinations of properties that could not be achieved with just one type of material.
When it comes to producing hybrid materials with such properties, however, the natural creation of such technological materials is still far superior; the artificial production of similarly functional hybrid materials is still a major challenge today. However, a team of researchers from the Universities of Jena and Cambridge has succeeded in producing a new class of hybrid glass materials that combines organic and inorganic components that gives the materials very special mechanical properties.
They have achieved this using combinations of materials in which organometallic and inorganic glasses are chemically bonded. The researchers have presented their work in the renowned journal ›Nature Communications‹.

Organometallic framework as the basic structure of the new material

In recent years, an increasing amount of research has been conducted into materials consisting of metal-organic frameworks (or MOF materials for short). They can be used, for example, as separating diaphragms, for storing liquids and gases, as catalyst supports, and for storing electrical energy.
The advantage of MOF materials is that their framework structures can be configured in a targeted manner, from the length scale of individual molecules up to a few nanometers. In this way, for example, the porosity achieved can be adapted to a large number of applications, both in terms of the size of the pores and their permeability, and in terms of the chemical properties prevailing on the pore surfaces.
»The chemical design of MOF materials follows a modular principle, according to which inorganic nodes are connected to one another via organic molecules to form a three-dimensional network,« explains Louis Longley from the University of Cambridge. This results in an almost infinite variety of possible structures, some of which could be transformed into a glassy state through heat treatment. »While crystalline MOF materials are typically synthesized in powder form, the liquid and glass states open up a wide range of processing options and potential shapes.«
»By combining MOF-derived glass with classic, inorganic glass materials, we can get the best of both worlds,« says Courtney Calahoo from the University of Jena.

New properties created through chemical bonding with inorganic glass

Such composite glass has much better mechanical properties than previous types of glass, as it combines the impact resistance and fracture toughness of plastics with the hardness and rigidity of inorganic glass.
These properties are ensured by the fact that the materials involved are not simply mixed with one another, but real chemical bonds are formed in the contact area between the metal-organic frameworks and conventional glass. »This is the only way to create truly new properties, such as electrical conductivity and mechanical resistance,« adds Prof. Dr Lothar Wondraczek, the glass chemist who led the study at the University of Jena. ■



Original publication:
Metal-organic framework and inorganic glass composites. Nature Communications (2020), DOI: 10.1038/s41467-020-19598-9

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Nanostructures to fight blood clots

While artificial heart valves and vascular prostheses can save lives, the implants also put patients at risk, because blood clots can form on their surfaces and cause thrombosis. That's why materials researchers in Jena are now developing thrombosis-resistant surfaces with nanostructures made from polymer crystals that can be used to control blood clotting.

BY AXEL BURCHARDT

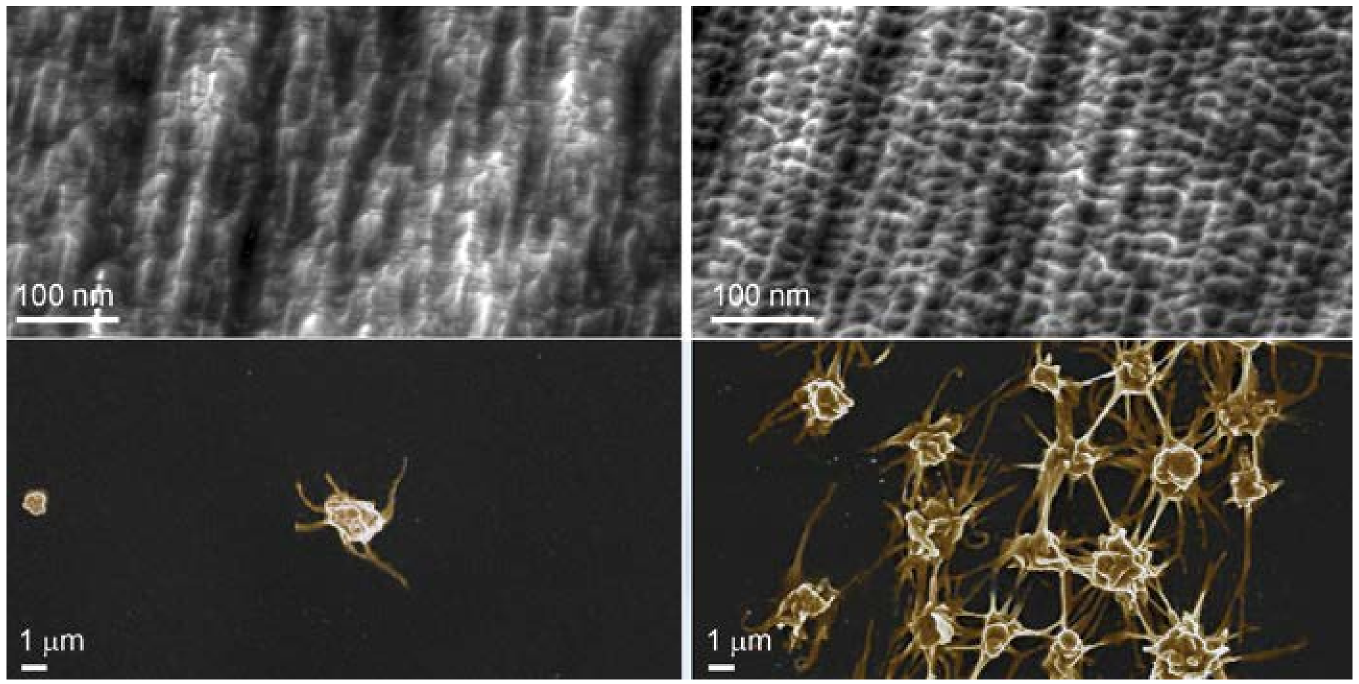
When blood vessels are badly damaged or the heart valves are no longer functioning as they should, they have to be replaced. In Germany alone, around 190,000 vascular prostheses and 30,000 heart valve replacements are implanted every year.

These little lifesavers are usually made of plastics, which offer many advantages but have one major disadvantage when they come into contact with blood: They can cause blood clots formation on the surface of the implants which, when detached, can lead to life-threatening complications such as thrombosis and embolisms. In order to counteract this, patients with such implants often have to take anticoagulants for a lifetime and suffer from their side effects.

Highly ordered patterns of polymer crystals

A team of researchers at the University of Jena recently developed a new approach to this issue by creating special, nanostructured polymer surfaces. Dr Izabela Firkowska-Boden, the physicist and materials scientist who led the project, explains how it was done: »When these materials are cooling down after melting, very fine and highly ordered patterns of polymer crystals can form on their surfaces under the right conditions. These crystalline structures only measure a few tens of nanometres—or a few billionths of a metre,« says Firkowska-Boden. The results of her research have been published in the journal ›Langmuir‹.

Atomic force microscopy images of nanostructured polymer surfaces (top); scanning electron microscopy images of thrombocytes on nanostructured surfaces (bottom). Different surface structures (left and right) lead to a different adhesion of platelets due to the surface-induced bioactivity of the fibrinogen. · Figure: Izabela Firkowska-Boden



Dr Izabela Firkowska-Boden, a materials scientist at the University of Jena, holds a fibrinogen protein model. Photo: Anne Günther

Fibrinogen aligned along the patterns

The key to this process is the fact that the ordered patterns are about as small as fibrinogen, a protein molecule that plays an important role in blood clotting. Due to this size match and the physical forces involved in the process, the fibrinogen aligns itself along the patterns.

When blood platelets (thrombocytes), which are another important factor in blood clotting, come into contact with the polymer samples treated with fibrinogen, they change. »The changes in the blood platelets depend heavily on the structure of the polymer patterns,« explains the scientist from the University of Jena.

While the thrombocytes changed dramatically on one polymer pattern, thus increasing their potential for clotting, the team found that the blood platelets hardly reacted on other polymer patterns.

New design of thromboresistant surfaces of biomaterials

»From a biomedical point of view, our work shows that structuring material surfaces within the nanoscale range may allow us to fine-tune and manipulate fibrinogen bioactivity and platelet activation, which is very promising when it comes to designing new thromboresistant surfaces for biomaterials,« says Dr Firkowska-Boden. This is an important step towards making implant materials made of polymers less susceptible to blood clotting in the future. ■

Original publication:
How nanotopography-induced conformational changes of fibrinogen affect platelet adhesion and activation, Langmuir (2020), DOI: 10.1021/acs.langmuir.0c02094

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Prof. Dr Aletta Bonn is a Professor of Ecosystem Services at the Friedrich Schiller University Jena and the Head of the Ecosystem Services Department at the Helmholtz Centre for Environmental Research (UFZ), which is part of the German Centre for Integrative Biodiversity Research (iDiv). · Photo: Bernhardt, iDiv

Picture right: Trees are not just important for the climate; they also make a significant contribution to human health. · Photo: Anne Günther

Economic packages for biodiversity and climate change

Has the debate surrounding biodiversity and climate change become a distant memory during the coronavirus crisis? Prof. Dr Aletta Bonn asks this question in her opinion piece. The biologist warns that politics and society need to look past the ongoing pandemic and do more to protect and preserve biological diversity to ensure human health in the long term.

The past year has been challenging! We've all had to come to terms with the new situation of a pandemic, adapt our ways of working and find new ways to collaborate, teach and organize. At the same time, some of us have been confronted with challenging situations in our personal lives, having to balance our professional commitments with home-schooling or other care duties. In doing so, however, we have found many creative solutions and possibly even a renewed focus on the truly important aspects of teamwork.

The coronavirus pandemic has also drawn attention to biodiversity and its importance for human health; zoonotic diseases such as COVID-19 are partly linked to the destruction of habitats. When we observe the serious consequences of unsustainably managing our natural resources, we can clearly see our responsibility for conserving biodiversity—both in Europe and in other parts of the world, in protected areas and in agricultural landscapes. We are sadly heading in the wrong direction with our current agricultural policy and our weak insect conservation law.

It is understandable that the tangible and urgent coronavirus pandemic has turned our attention to the here and now, but we must not lose sight of the drastic and urgent situation with respect to climate change and biodiversity loss! The effects of these changes are far more serious than the current pandemic. For example, Germany has seen a dramatic decline in plant species over the past 60 years—more than two thirds of over 2,000 species examined have been affected by such changes.

More than just good intentions

That means we urgently have to act on our good intentions and put our ideas into practice: There are important decisions to be made at this year's UN Summit on Biodiversity, and the European ›Green Deal‹ has to be implemented.

The biodiversity and climate crisis are related and should be tackled together with health issues. The economic packages introduced in Germany to cushion the coronavirus crisis now have to be appropriately combined with sustainable biodiversity and climate action to ensure human health and well-being in the long term. The coronavirus pandemic has also given us the opportunity to think about our own working styles. As researchers, we have certainly reduced our carbon footprint in 2020, finding interactive ways to communicate with one another, and organizing and attending virtual workshops and conferences. Our iDiv conference, ›Biodiversity Post 2020‹, was also held online. We should definitely keep hold of our environmentally friendly research style after the pandemic.

And last but not least, many people now appreciate the positive impact of local biodiversity on our well-being since going into lockdown. Indeed, our urban parks and green spaces have become very popular. We recently carried out a study that demonstrates that urban green spaces play a central role for our health and well-being: The more roadside trees were in people's immediate living environment, the fewer antidepressants were prescribed, especially for people from weaker socio-economic backgrounds. At the same time, trees can make a major contribution to climate action by binding CO_2, cooling the atmosphere and filtering air pollutants. Our policy-makers and planners should therefore actively expand investments into biodiversity, both in urban and remote areas, as nature-based solutions to tackling both climate change and public healthcare.

The winner takes it all?

Competition in higher education studied by new research group

There is increasing competition amongst institutions of higher education as they fight for students, staff and grants. This competition amongst public institutions of higher education—and the role played by different actors—is being investigated by Prof. Dr Uwe Cantner (pictured), an innovation researcher who is a member of a new research group called ›Multiple Competitions in Higher Education: Stakeholders, Coordination and Consequences‹, which is based at the International Centre for Higher Education Research in Kassel. Cantner is working with Prof. Dr Thomas Grebel from Ilmenau University of Technology to study the ›dynamic competition amongst (autonomous) institutions of higher education‹. The project will receive 520,000 euros in funding from the German Research Foundation over the next three years. viv/AB

PHOTO: ANNE GÜNTHER

Between liberty and security

A European research group is studying how the urban atmosphere is shaped by the threat of terrorism

How do people in Europe see the threat of terrorism? How do counter-terrorism measures change their attitudes and how does this affect their social coexistence? These are the questions asked by researchers as part of the project ›Atmospheres of (Counter)Terror in European Cities‹. In addition to the team of researchers led by social geographer Prof. Dr Simon Runkel from the University of Jena, the project will also involve the Universities of Birmingham, Plymouth and Cergy-Pontoise and L'Institut Paris Region. Over the next three years, the project will receive around 1.2 million euros in funding from the German Research Foundation and similar organizations in Great Britain and France—and 290,000 euros will go to Jena. Runkel (pictured) will be investigating how policy-makers and urban planners are dealing with crowds. ch

PHOTO: ANNE GÜNTHER

20th-century philosophy

DFG-funded project examines overlaps between philosophical movements

What is the relationship between critical theory, philosophical anthropology and logical empiricism? These three key philosophical movements of the 20th century will be studied over the next three years by a team of philosophers at the University of Jena: Prof. Dr Christoph Demmerling (pictured), Max Beck and Nicholas Coomann. Their collaborative project entitled ›Post-Metaphysical Philosophizing‹ will receive around 350,000 euros in funding from the German Research Foundation (DFG). Their focus is on the main exponents of each school of thought: Max Horkheimer and Theodor W. Adorno for critical theory; Max Scheler, Arnold Gehlen and Helmuth Plessner as the voices of philosophical anthropology; and Rudolf Carnap and Hans Reichenbach as the protagonists of logical empiricism. sl

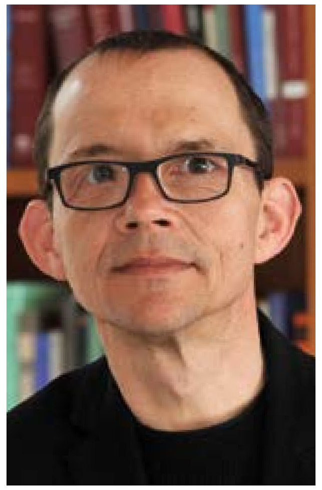


PHOTO: ANNE GÜNTHER

Interculturality on Twitter

New project launched by Intercultural Business Communication

Can virtual reality still be separated from the real world? And, if not, how can this complexity be explored? This question is being investigated by a network known as ›Researching Digital Interculturality Co-operatively‹, which is being coordinated by the University of Jena. Dr Luisa Conti (pictured) and PD Dr Fergal Lenehan are working on part of the project in Jena. Their focus, ›Cosmopolitanism, Nationalism and Intercultural Competence in Online Contexts‹, has been granted 1.1 million euros in funding from the Federal Ministry of Education and Research. They are studying intercultural communication on Twitter around Europe. Their partners investigating the issue of interculturality in a digitalized society are based at institutions of higher education in Mainz, Potsdam, Ireland, Brazil and Israel. viv/AB

PHOTO: ANNE GÜNTHER

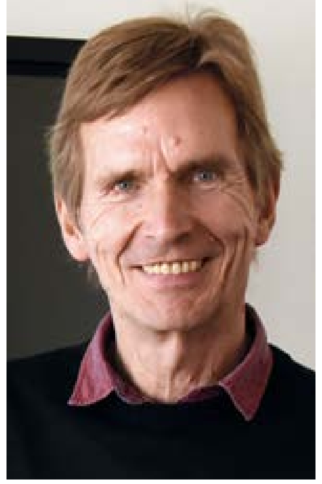


PHOTO: ANNE GÜNTHER

Virtual games

A project to promote intercultural communication

Prof. Dr Jürgen Bolten (pictured), a communication expert at the University of Jena, regularly gets students and teachers from around the world to conduct simulated negotiations in virtual classrooms to enhance their experience and awareness of digital and intercultural settings. Bolten and his team are working on a new project to develop the concept of digital collaboration. The project is part of the ›International Virtual Academic Collaboration‹ funding programme of the German Academic Exchange Service and will receive around 130,000 euros in funding from the Federal Ministry of Education and Research. The aim is to anchor the digitalization initiatives introduced at institutions of higher education during the coronavirus pandemic. The team from the University of Jena is collaborating with institutions of higher education in Poland, China, Finland, Romania, France and Canada. US

PHOTO: ANNE GÜNTHER

Art circa 1800

An art historian is examining depictions of the sublime

Comparisons are part of our everyday tools to orientate ourselves in the world. However, we sometimes reach the limits of what is comparable. Prof. Dr Johannes Grave (pictured) wants to explore one of these limits. As part of his research project entitled ›Picture Comparisons. Practices of Incomparability and the Theory of the Sublime‹, the art historian from the University of Jena wants to analyse images to discover how the sublime was depicted in art circa 1800. His starting point is Kant's understanding of the sublime as something that evades comparison due to its immeasurable size.

The project forms part of the collaborative research project 1288 at the University of Bielefeld: ›Practices of Comparing. Ordering and Changing the World‹. The four-year project will receive a total of around 300,000 euros in funding from the German Research Foundation. sl

PHOTO: JAN-PETER KASPER

Paleoseismology

A project on tectonic activities in the history of the earth

The border region between South Tyrol, East Tyrol, Carinthia and Slovenia is particularly exciting for geologists. It is home to the eastern Periadriatic Fault System, which is a region with some of the most important tectonic structures in the Alps. The historic earthquakes in this area are being investigated by a team of scientists from the Leibniz Institute for Applied Geophysics in Hanover and the Institute of Geosciences at the University of Jena. Prof. Dr Kamil Ustaszewski (pictured), a geoscientist from the University of Jena, is involved in the project which will receive a total of 187,000 euros in funding from the German Research Foundation. The team is using new dating methods that allow earthquakes to be detected from the Quaternary Period, the most recent geological period in the earth's history from 2.4 million years ago to the present day. LIAG/GC/AB

PHOTO: JAN-PETER KASPER

COVID-19 therapy

InfectControl network brings together experts to fight coronavirus

A team of researchers from the Leibniz Institute for Natural Product Research and Infection Biology—Hans Knöll Institute—(Leibniz-HKI), the University of Jena, the University of Würzburg and the Leibniz Institute for Experimental Virology in Hamburg are combining their expertise to combat the coronavirus pandemic. The project will receive around 2.3 million euros in funding from the Federal Ministry of Education and Research as part of the InfectControl consortium directed by Prof. Dr Axel Brakhage (pictured). The researchers want to develop a novel therapeutic approach where the SARS-CoV-2 virus is eliminated from a person's immune system in a targeted manner.

The findings made in the project could also help to accelerate the development of treatments for other pathogenic outbreaks in the future. InfectControl/MK

The dreaming realist

Climbing, running, researching… Dr Oliver Werz is a pharmacy professor with plenty of interests. He pursues every single one with a great deal of passion but always keeps his feet on the ground. We portray a scientist who simply can't sit around twiddling his thumbs and who reveals what bouldering and scientific experiments have in common.

BY TILL BAYER

»This boy is hyperactive!«. Oliver Werz can't help laughing as he recalls his mother's words. Ever since his childhood in the Swabian city of Reutlingen, he's been passionate about pretty much everything to do with sports and science. He was enthusiastic about reptiles and amphibians from an early age; and he played handball, went swimming and did gymnastics. Werz was always on the move. At the same time, he developed an interest in horticulture and started growing cacti. While his friends raved about rock music and motorcycles, Oliver Werz joined a cactus club at the age of 17.
After finishing secondary school, Werz initially wanted to pursue a career as a horticultural engineer. But things turned out differently… He made a spontaneous decision to study pharmacy in the nearby city of Tübingen in 1988; he wanted to become a pharmacist to pursue his interest in science but with secure job prospects. He is now a Professor for Pharmaceutical Chemistry at the Friedrich Schiller University Jena. He has been teaching and researching here for the best part of ten years. The now 55-year-old hasn't outgrown his ›hyperactivity‹—but it does him good.

Controlling the inflammation process with natural products

This also applies to his work as a scientist. Werz is involved in no fewer than three collaborative research centres at the University of Jena and is advancing a research topic that he has painstakingly established over the years: the formation and biology of ›lipid mediators‹. These are tissue hormones that control inflammation processes in the human body. If these substances could be regulated by pharmaceutical agents, one may improve the treatment of inflammation. But it's a complex matter: »Inflammations are the body's natural defensive reactions to viruses, fungi or bacteria,« explains Werz. On the one hand, lipid mediators make sure the pathogens can be cleared and the damage to the body can be healed; on the other hand, they cause pain, swelling or even organ damage. That's why Werz is looking for active ingredients that enhance the positive effects of the hormones while curbing their negative side effects; he is focusing on natural products, which can often have a broader effect than synthetic substances and also trigger fewer side effects. »There's still a lot of research to be done in this field,« says the pharmacy expert. »I'm motivated by the fact that inflammation is the driving force behind so many common disorders such as heart attacks, cancer, arthritis and back pain.«

A Swedish research idol

Werz's interest in lipid mediators—and his decision to embark on a scientific career—are thanks to a Nobel laureate. After graduating in 1992, he wrote his doctoral thesis on 5-lipoxygenase, an enzyme that converts unsaturated fatty acids into inflammatory messengers. This was his first step on the road to inflammation research. His second step took him to the renowned Karolinska Institute in Stockholm, Sweden, where he had the opportunity to work in a group led by Bengt Samuelsson. Samuelsson had won the Nobel Prize in Medicine in 1982 for discovering 5-lipoxygenase. This was a huge chance that Werz simply had to take—even if, in hindsight, it meant the end of his beloved cactus collection. He'd amassed hundreds of specimens and couldn't just take them with him to Stockholm. Most of the plants wouldn't have survived the cold climate and different lighting in Sweden.
»It was undoubtedly one of the most important decisions of my life,« recalls Werz. »Up to that point, I could still see myself working in a white apron at a pharmacy. But during my time in Sweden, I realized that my true passion was research.« That was also due to Samuelsson. He encouraged Werz to deepen his research topic, try out new types of experiments and ultimately train as a professor. Werz still sees him as his scientific role model: »I was particularly impressed by his sharp thinking and down-to-earth manner,« he recalls. »He always made time for me and offered to call him by his first name. I'd imagined a Nobel laureate to be more distant.«

From the desk to the running track

Werz stayed in Sweden for two years before returning to Frankfurt and then moving to Tübingen, where he was appointed as a professor at the university in 2005. He moved to the University of Jena in 2010, by which time he had started a family. The family-friendly environment—and the many opportunities to collaborate with other scientific fields—persuaded him to take this step. These are the reasons why he has always remained loyal to Jena to this day—with one little exception… In 2015, he moved with his whole family to Boston in the USA to conduct research at Harvard Medical School.
Oliver Werz also likes the fact that the University of Jena is just a stone's throw away from nature. He goes running in the surrounding hills three times a week—as a healthy contrast to all the hours he spends at his desk. He even runs half-marathons with his friend at the weekends: from the ›Fuchslöcher‹ in the east of the city, through the ›Paradies‹ park and all the way to Lobeda and back. It only takes him a little over 90 minutes to cover the 21-kilometre route.

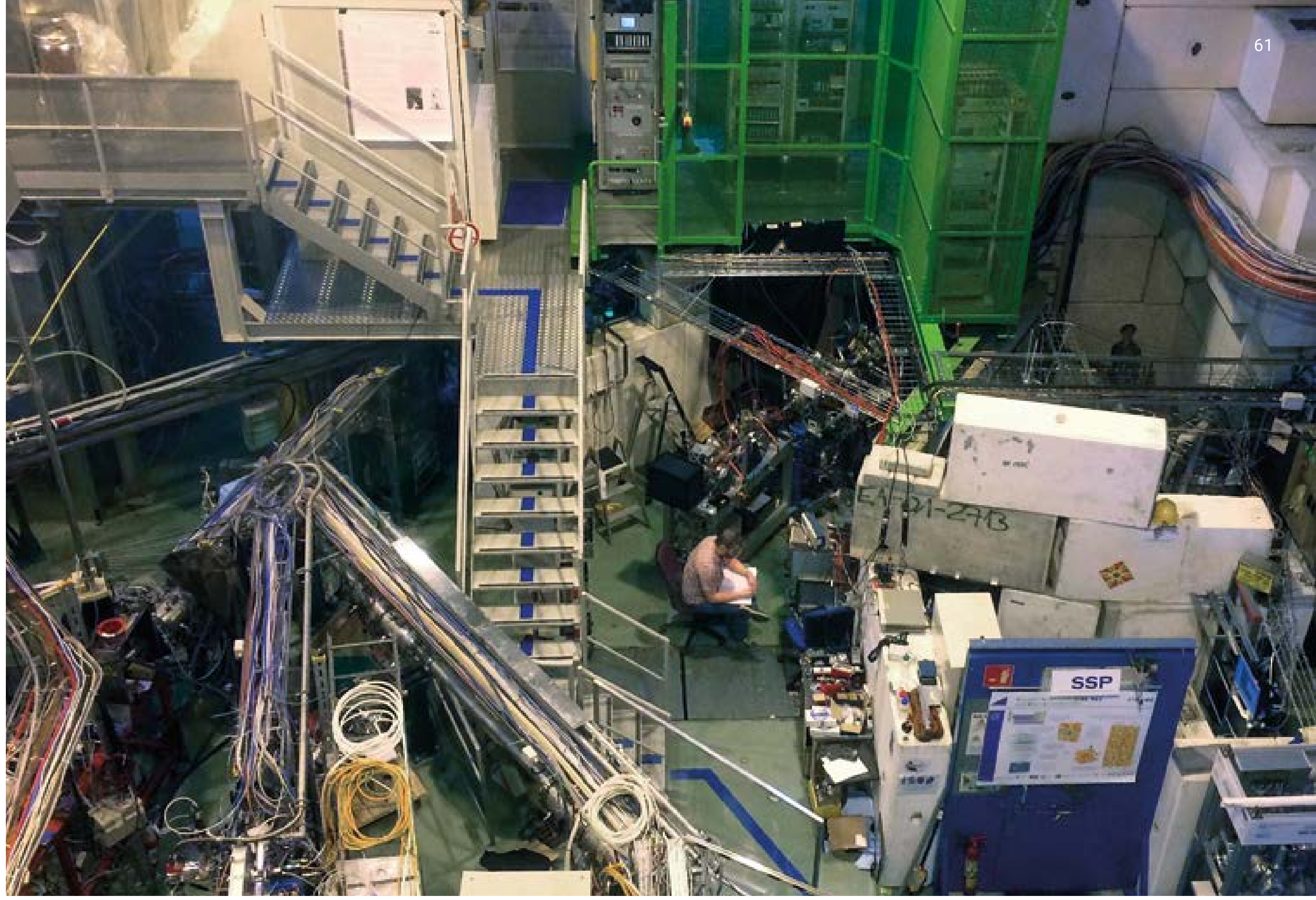
Aerial acrobatics: In the climbing hall that Prof. Dr Oliver Werz visits regularly, the key to success is strength, climbing technique and good planning. · Photo: Jens Meyer

The science of bouldering

Werz is also ambitious when it comes to another hobby that he came across in Jena: bouldering. This is a type of climbing near the ground without ropes and harnesses. As the ›bouldering grandpa‹, as Werz is kidding, he shows many younger people how it's done and even conquers the most challenging walls. As he moves smoothly from grip to grip, he makes the most of his low body weight and climbing experience. He's been rock climbing for over 20 years—that's even how he met his wife. The thing he finds most appealing about bouldering is the complexity of the trendy sport: »It's like a scientific experiment,« explains Werz. »You have to try a difficult bouldering route over and over again, changing the parameters each time until it works.« A tiny detail, such as changing the way you angle your foot or shift your weight, can determine whether you reach the next grip.
Running, bouldering, all his commitments as a professor… it's a miracle that Werz manages everything. But he's got an answer for that as well: »I try to structure my life in such a way that my job, family and hobbies are connected as good as possible.« For example, he often takes his running gear to the office to fit in some training on the way home. And bouldering also means spending time with his family, as his 13-year-old son is also a talented climber and joins him at the bouldering arena at the weekends.
Always keep moving and try out weird and wonderful things now and then—those are the words Oliver Werz has lived his life by since he was little and he wants to keep to that way of life in the future. He also wants to conduct research abroad again—provided he can return to Jena afterwards. After all, the professor has come to appreciate a little peace and quiet—at least at home and at work. ■

Picture left: Dr Oliver Forstner in front of the ›Globe of Science and Innovation‹ at CERN. · Photo: Silvia Scharbert

Picture right: An experimental set-up in the ISOLDE hall. The researcher stands in front of the experimental set-up where laser beams are shot at astatine ions. The lasers are located in the grey room on the first floor of the stairway. The researcher is using an oscilloscope to monitor the signals of neutral astatine atoms coming from a detector and is making notes in an analogue logbook. · Photo: Oliver Forstner



I'll take the beamtime, please!

Astatine is a halogen and one of the rarest elements in the world—there are less than 50 grams of it in the earth's crust. It is produced when radioactive heavy metals (e.g. uranium) decay and only exists for a few minutes before decaying itself. Due to this volatility, it takes a great deal of technical effort for physicists like Oliver Forstner to artificially produce and study the ›unstable‹ element, as it is translated from the Greek. The large-scale equipment required for such purposes is available at the CERN research centre. But how do researchers even work with such a scientific machine?

BY SEBASTIAN HOLLSTEIN

»First of all, it's very important that you aren't overawed by such facilities if you want answers to your questions,« says Oliver Forstner. And nobody knows this better than the physicist from the University of Jena, who spent three years conducting research at CERN during his doctoral thesis. He returned for a few experiments in 2019, joining an international team of scientists who wanted to learn more about astatine. The European Organization for Nuclear Research (CERN) near Geneva is home to the Isotope Mass Separator On-Line Device (ISOLDE), which can be used to produce various isotopes. For example, if a proton beam produced by a particle accelerator is directed onto the element bismuth, its atomic nuclei are split up. This creates astatine isotopes that can be passed on for further experiments.
However, such a project requires a lot of preparation. The scientists first have to apply for beamtime for the large-scale equipment. »You have to explain the preliminary work that has been done and outline the current state of research,« says Forstner. »You should also have detailed plans for the experiment you want to conduct with the equipment, because you have to indicate a specific number of eight-hour shifts for the equipment.« The researchers have to estimate as precisely as possible how long they will need to set up and carry out their experiments and how many runs they will need to obtain a meaningful result. The selection process also includes an oral presentation before the committee, which ultimately assigns appointments based on the scientific relevance of the proposed project. This application phase took approximately six months for the astatine project.

Places of experimentation and exchange

Once the schedule has been approved, the next stages of the preparation work are more practical. As part of the extensive registration process, for example, those who are going to use the equipment must submit medical documents to prove they are fit enough to work under such strain. They also have to complete radiation protection courses beforehand. »After putting in this effort, you can put all your focus on your scientific experiments on site,« says Forstner. »There is usually an atmosphere of full concentration at the facilities, because everyone obviously wants to obtain new and valuable data that will further their research and not waste precious beamtime.«
Centres like CERN are not just places of experimentation, but also places for sharing thoughts and experiences. »An international group like ours doesn't get the chance to meet up that often, so our experiments are a good opportunity for this and lay the foundations for the next steps to be discussed,« explains Forstner. »The facilities and institutions connected to such large-scale equipment usually provide the ideal infrastructure for such meetings. You can really feel the international atmosphere at CERN.« The Swiss research centre also offers a good networking environment—not so much during working hours but certainly in the canteens and restaurants on campus, where scientists can make new contacts and sometimes find valuable impetus for current and future projects. They often sit together late at night and discuss their experiments or even chat about football and other things.
Forstner's team needed around ten days of beamtime. His teammates worked around the clock in several shifts and and due to good teamwork everything went smooth. »We first set up our experiment on the particle accelerator itself,« explains the physicist. »This installation is checked again by a safety engineer. When the equipment starts operating, you mainly stay in the monitoring room to control certain values that tell you whether the experiment is generally working.« The researchers then process this data, which fills up a few hard drives, to come up with scientific findings at their own desks. Oliver Forstner is even benefiting from his past experiments during his current work. And his next date with ISOLDE has already been made. ■

Astatine's electron affinity

Forstner and his team observed as negative astatine ions, which had been produced previously, were exposed to laser light of different wavelengths in the specially developed machine. The researchers were able to measure the amount of energy needed to separate the additional electron from the ion and turn it into a neutral atom. This experiment enabled the scientists to precisely determine astatine's electron affinity and electronegativity. This information can be combined with its ionization potential to ultimately determine the halogen's chemical properties. This will not only help to advance basic research; it could also pave the way for astatine to be used in the fight against cancer. In conjunction with organic proteins, medical professionals could direct it to specific tumours, which would then be destroyed by the element's alpha decay. This way, the ›unstable‹ element could even save lives (DOI: 10.1038/s41467-020-17599-2).

The ›world soul‹ in Jena

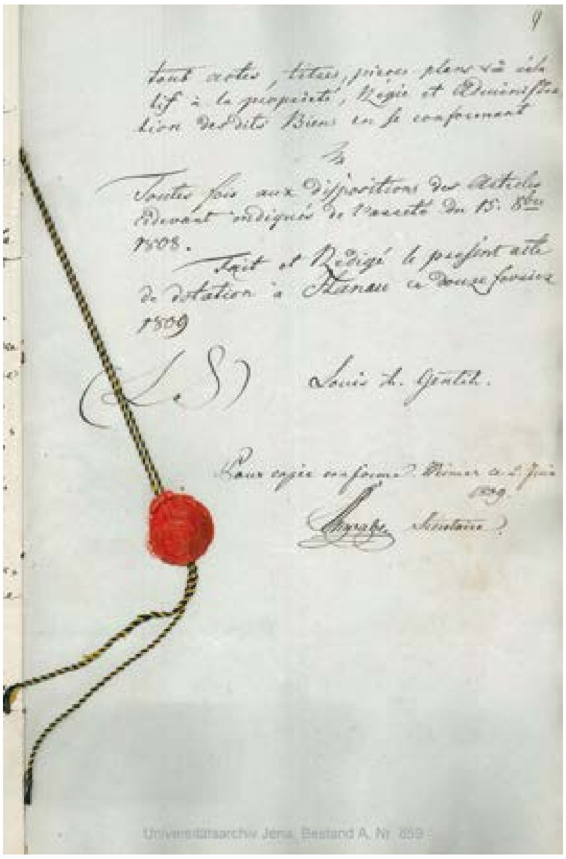
This year marks the 200th anniversary of Napoleon Bonaparte's death. The General and Emperor of the French left his mark all over Europe—even in Jena. After being revered by philosopher Friedrich Hegel in the autumn of 1806, dissident voices soon arose at the university during French rule. We take a look back at that era.

BY STEPHAN LAUDIEN

Emperor of the French, Napoleon Bonaparte, rode through Jena on horseback on 13 October 1806. The next day, it was time for the weapons to do the talking during the Battle of Jena and the Battle of Auerstedt. However, the scholars at the ›Salana‹ university hardly took any notice of the infamous man. There is a simple reason for this: It was a midterm break and most of the students were out of town.

However, one of their professors met the emperor and was seriously impressed. The philosopher Georg Wilhelm Friedrich Hegel saw Napoleon on Johannisstraße: »I saw the emperor—this world soul—ride out through the city to reconnoitre; it truly is a wonderful sensation to see such an individual who is concentrating here on one point as he sits astride his horse, encompassing and dominating the world.« While the emperor was inflicting a serious defeat on the larger armies of Prussia and Saxony the next morning, heralding the end of old Prussia, Hegel was focusing on his manuscript. He had just revised the final pages of ›The Phenomenology of Spirit‹ and sent the book to Bamberg. Woe betide if the pages didn't arrive—there was no duplicate.

The University of Jena was largely spared from the warfare in the autumn of 1806; looting and fire resulted in 4,005 thalers of lost assets—plus 8,722 thalers in private assets. However, teaching could start again on 3 November by virtue of an imperial letter of protection. As compensation for the lost assets, the university was given a plot of land: the ›Lindenstück‹ in Blankenhain. An honorary doctorate was also awarded to five Frenchmen: medics who had been involved in the war.



The university archives contain this decree, issued on 12 February 1809 by Imperial Domain Inspector Louis Alexandre Gentil, stating that the ›Lindenstück‹ was to be donated to the university by Napoleon and outlining the finer details of the transaction.

Teaching at the university was affected by French rule. From the winter semester of 1808 onwards, for example, the curriculum included lectures on the ›Napoleonic Code‹. There were two objectives behind this: On the one hand, the university had to remain appealing to students whose homeland was now part of France; on the other hand, the law graduates in Saxony-Weimar-Eisenach had to be familiar with the legal framework in case it ever entered into force in the local territory. After the French Revolution, a bourgeois interpretation of the law had even caught on amongst Jena's legal scholars.

However, resistance was also starting to emerge against the foreign rulers in Jena, including the historian Heinrich Luden. His lecture entitled ›On the History of the Fatherland‹ put the focus on the Nation, and his anonymous work entitled ›Views of the Confederation of the Rhine‹ was an anti-Napoleonic manifesto. However, the road to the German nation should by no means lead back to the old feudal state.

As for Napoleon, he basked in a long string of victories from his stronghold in Jena before his Grande Armée finally suffered a bitter loss at the hands of the Russian Army in 1812. The Germans, Swedes, Austrians and Russians inflicted another defeat on the emperor at the ›Battle of the Nations‹ near Leipzig in 1813. The Corsican was banished; when he made his return, he was definitively beaten at Waterloo in 1815. Napoleon Bonaparte died on the island of St. Helena on 5 May 1821, 200 years ago. ■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