Abbe Center | JENA
of Photonics
Friedrich-Schiller-Universität

ABBE CENTER OF PHOTONICS

Status & Perspectives in Science & Education

FRIEDRICH-SCHILLER-
UNIVERSITÄT
JENA

OUR PARTNERS

The Abbe Center of Photonics is an interfaculty center of the Friedrich Schiller University Jena which sustains a dense network with local research institutions.

Fraunhofer IOF
DEUTSCHES OPTISCHES MUSEUM
HELMHOLTZ GEMEINSCHAFT
Leibniz ipht LEIBNIZ INSTITUTE of PHOTONIC TECHNOLOGY

Strategic funding of the Abbe Center of Photonics is provided by governmental and industrial partners.

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Fifth edition
Editorial deadline: 15.01.2024

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FOREWORDS

Photonics brings light into the world – literally and metaphorically. Photonics research plays an important role in the industrial development of solar energy, quantum computing, medical technologies and even space exploration – just to name a few. Without optical technologies, we would not have the means to meet, work, and connect virtually, this latter point becoming especially essential during the COVID-19 pandemic. Clearly, photonics has become the foundation of our modern digital society. It is a key technology today and in the future.

Jena, known as Germany's *City of Light*, has held an appreciation for the light sciences and technologies for a long time. The city's high level of recognition for the subject of light is deeply embedded in the minds and lifes of its inhabitants – probably more so than in anywhere else in the world. The Friedrich Schiller University Jena maintains its commitment to light by choosing the triad LIGHT-LIFE-LIBERTY as its motto. Indeed, as part of this triad, the profile line LIGHT reflects our involvement in light and photonics research and training. Furthermore, the University holds close ties to regional industries, benefiting from their support and cooperation at many levels.

Throughout our University's long history, the tradition of light and photonic studies owes its importance to three individuals in particular: Carl Zeiss, Otto Schott and Ernst Abbe. Ernst Abbe has always been Jena's most notable physicist. By establishing the Carl-Zeiss-Stiftung, he guaranteed the continued existence of our University for many decades to come. From the late 19th century onwards, optics and photonics did not only attain academic recognition, but also great industrial significance.

Giving credit where credit is due, Ernst Abbe was thus chosen in 2010 to be the namesake of our Abbe Center of Photonics (ACP) - the key institution of the University's profile line LIGHT. In recent years, the profile line has been strengthened significantly, with our University very successfully acquiring large-scale, collaborative research projects: the Cluster of Excellence „Balance of the Microverse", the two Collaborative Research Centers NOA and CataLight, and the Max Planck School of Photonics. ACP scientists have contributed considerably to the success of these projects and still do. Furthermore, the university holds close ties to non-university research centers and regional industries, benefiting from their support and cooperation at many levels.

The University of Jena and the ACP are located in Thuringia, Germany's dynamically developing region of technological innovation. This region is also blessed with a rich cultural heritage and attractive natural surroundings. I cordially invite you to immerse in this booklet's pages and discover what *light* means to the city of Jena, its university and its scientific community. If this message sparks your interest and curiosity, it would be our pleasure to welcome you personally in Jena, the *City of Light*.

Prof. Dr Walter Rosenthal, January 2021
President of the Friedrich Schiller University Jena

Jena's deep historical roots in the fields of optics and photonics represent a great challenge, but also a strong stimulus to continue this century-long tradition with equal success in the future. In the past, the combination of efforts from various scientific branches was the main force that nurtured many scientific breakthroughs. Today more than ever, this conviction is shared by scientific and economic communities around the globe. This is undoubtedly true for the field of photonics, a key enabling technology also driving social change on a global scale. Since 2000, nine Nobel Prizes in physics and chemistry have been awarded to photonics scientists. In 2023, the most recent award was given to our dear friends and colleagues L'Huillier, Agostini and Krausz for their breakthrough work in the field of attosecond physics and ultrashort light pulses. This is one of the fields in which Jena also holds world-class expertise.

The Abbe Center of Photonics (ACP), as part of the Friedrich Schiller University Jena, clearly pursues one leitmotif of our Center's namesake, Ernst Abbe: ground-breaking science is only possible if individuals work cooperatively to achieve a higher goal. At ACP, theoreticians and experimentalists, among them physicists, chemists, material scientists, biologists and physicians, have made remarkable headway in establishing the Center as the primary driver of the university's profile line LIGHT within photonics and photonics-related technologies. Since the center's founding in 2010, ACP's members have experienced a remarkable synergetic effect by creating joint novel ideas. We have developed a strategic roadmap regarding our joint research and educational missions. Now in 2024 we have set many of these visions into reality! Our ambitions and goals are seen by viewing Jena's academic curriculum and by society's present and future focus in the fields of optics, photonics and quantum technologies. Our Center's continued pursuit for academic excellence will be the stimulus for a sustaining commitment common to all ACP scientists in the years to come. It has and will continue its promise of becoming Jena's home of multidisciplinary research and innovation.

We are proud that our Center's excellence is not limited solely to research. It is our belief that the highest standards of academic opportunities and qualification can be achieved only through a unified approach of research and education. Our teaching of young scientists has boosted the integration of the Abbe School of Photonics with the nationally pioneering Max Planck School of Photonics. Together, we have become joined into the ivy league of photonics education worldwide. We receive annually over a thousand applications globally for our Master's degree and doctoral programs. The resulting internationalization of ASP's teaching personnel and staff has contributed to its recognition as one of our university's flagship faculties. We also managed to face and to encounter many difficulties associated with the COVID-19 pandemic. With fresh ideas in digitalization and modernized education tools, we are well prepared to effectively continue our educational mission.

With this current 2024 edition of our booklet, we wish to provide you with a fresh summary of our Center's collaborative efforts undertaken during the last several years. The booklet has been updated thanks to ACP's many recent developments particularly related to breakthrough results in research as well as our newly appointed faculty. Unlike an annual report, our aim is to attain a balance between the manifestation of and reflection on our very dynamic progress.

We truly hope that this booklet will provide you with a clear overview of our pursuits and future plans. Feel warmly welcome to immerse yourself in the description of our currently-offered courses and seminars. All of these exude our united opinion that Jena is indeed one of the best places in the world to study and do research in optics, photonics and now also quantum technologies. In the spirit of our namesake, Ernst Abbe, we would be happy to welcome you soon.

ACP Board Of Directors, January 2024

Prof. Stefanie Gräfe
Prof. Thomas Pertsch
Prof. Jürgen Popp
Prof. Christian Spielmann
Prof. Andreas Tünnermann

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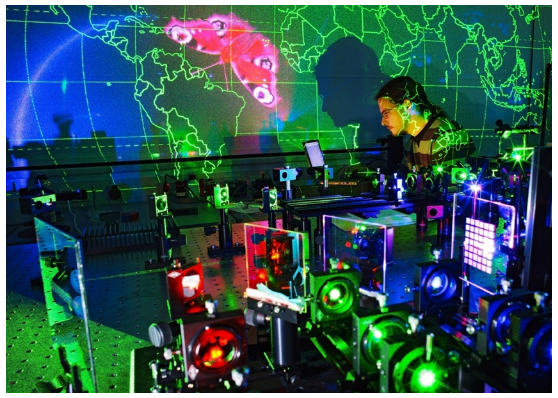
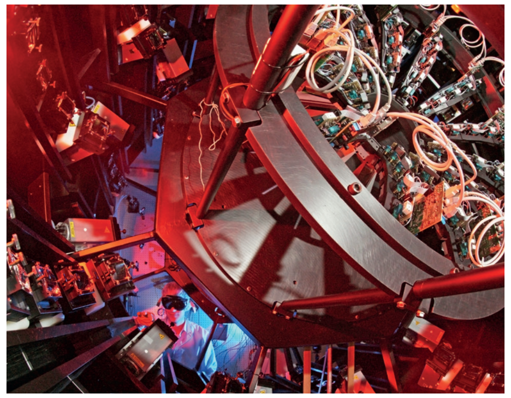
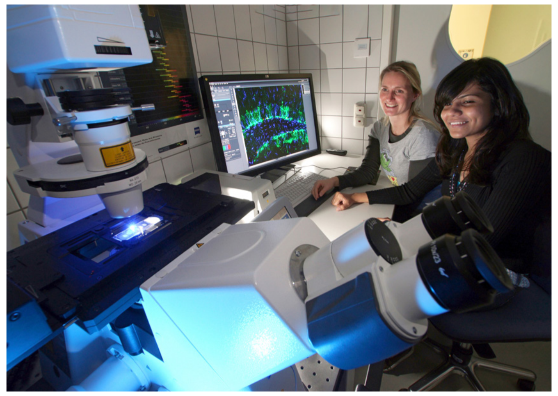






DIRECTOR’S
REPORT

THE ABBE CENTER OF PHOTONICS IS THE ACADEMIC CENTER FOR OPTICS AND PHOTONICS AT THE FRIEDRICH SCHILLER UNIVERSITY JENA.

Our main mission is to promote interdisciplinary research and education, jointly performed by scientists from different subject areas, spanning physics, material sciences, chemistry, biology and medicine.

We are following the vision of positioning ACP and Jena as one of the leading European centers for research and education in optics, photonics and quantum sciences, as well as in the development and transfer of optical and quantum technologies.

Abbe Center of Photonics | JENA
Friedrich-Schiller-Universität

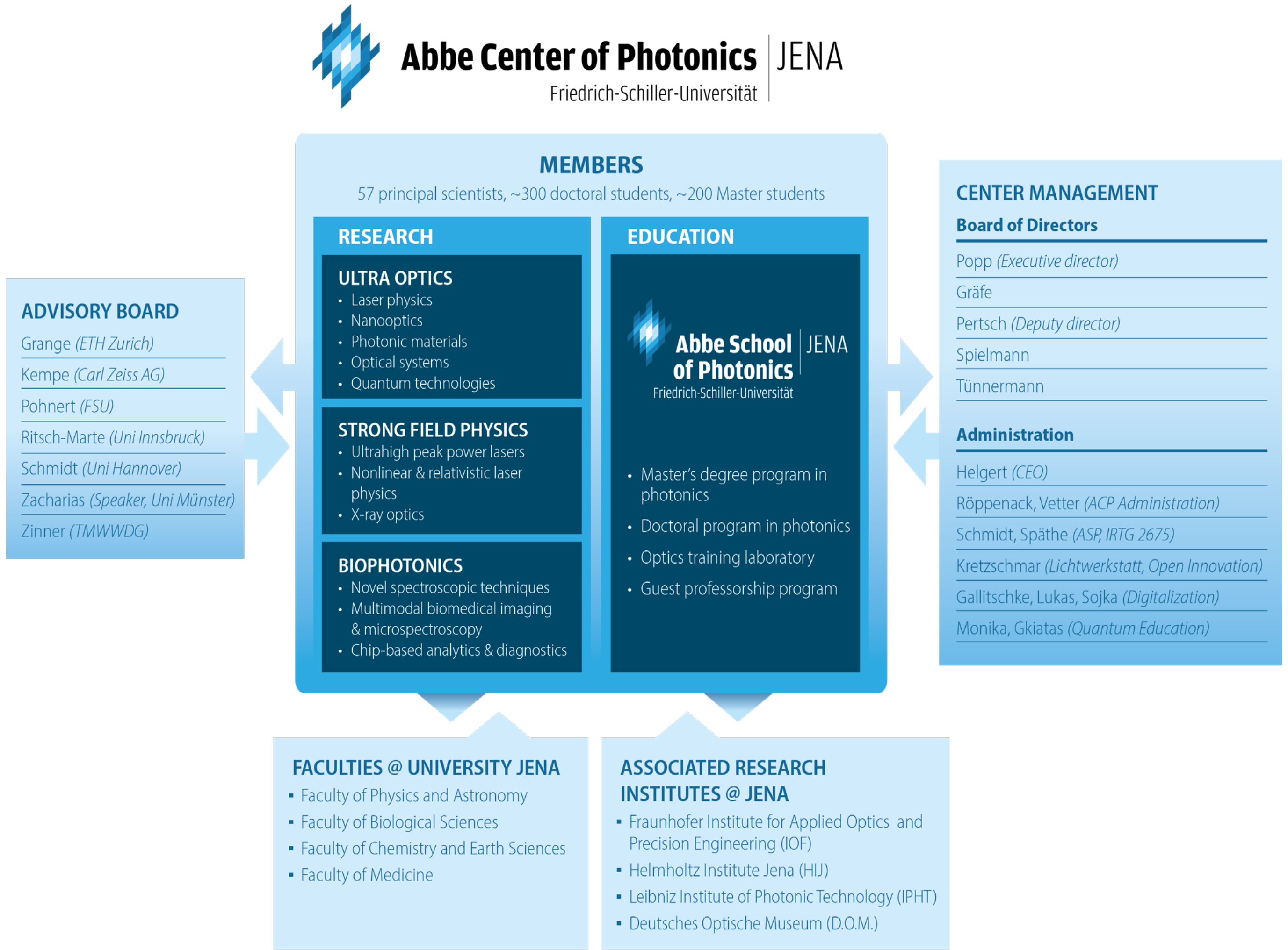
STRUCTURE

The Abbe Center of Photonics (ACP) is the host of major research and educational activities in optics and photonics at the Friedrich Schiller University Jena. As a cornerstone of the University's scientific profile, this interfaculty center forms the core of the University's profile line LIGHT and incorporates major scientific contributions from Jena's non-university optical research institutes.

Based on more than a century of optics and photonics tradition in Jena, ACP was founded in 2010 by the optical scientists of the Friedrich Schiller University Jena to further shape the University's scientific profile. ACP's founding was a milestone in the University's long term institutional strategy to establish the priority research area Optics, Photonics and Photonic Technologies already in 2005. Besides its academic mission, ACP reflects the strategy of the University by forming a close partnership with Jena's prosperous optics and photonics industry.

This fact was also recognized by the German Federal Ministry of Education and Research (BMBF) when it established the Center for Innovation Competence ZIK »ultra optics« that same year, remaining a central pillar of ACP until today.

ACP's legal status as an interfaculty center of the University is sealed by an official statute. The Center is directed by an elected board of four to five scientific directors, one of them being its executive director.



Organization chart of the Abbe Center of Photonics.

A CROSS-FERTILIZING CENTER FOR OPTICAL SCIENCES

In joint research projects, ACP scientists cover both fundamental and applied topics. One of ACP's main goals is to produce synergetic effects between University institutes, the associated non-university research institutes and its industrial partners to enable a scientific and economical added-value. The Center's funding is mainly attracted in competitive third-party funding programs. While encompassing a broad variety of research fields, the ACP concentrates on expertise development in its three strategic domains: **ULTRA OPTICS, STRONG FIELD PHYSICS**, and **BIOPHOTONICS**. Besides ACP's research efforts, the education of young research scientists, represented by the integrated **Abbe School of Photonics (ASP)**, exhibits its fourth profile cornerstone.

ACP membership is open to all members of the Friedrich Schiller University working in the field of optics and photonics and also to externals who are active in ACP's research fields. ACP membership applications are regularly considered and approved by the board of directors. In January 2024, ACP is comprised of 57 high-profile members who, due to the Center's interfaculty character, are affiliated with different departments of the University:

- 32 members from the Faculty of Physics and Astronomy,
- 15 members from the Faculty of Chemistry and Earth Sciences,
- 4 members from the Faculty of Biological Sciences,
- 3 members from the Faculty of Medicine.

There are three further ACP members which are not directly affiliated with either of the University's departments. Moreover, further cross-affiliations of ACP's members with Jena's associated research institutions promote sustainable institutional bonds between the ACP and these institutions. This particularly holds true for the Fraunhofer Institute for Applied Optics and Precision Engineering, the Leibniz Institute of Photonic Technology, the Helmholtz Institute Jena and the Deutsches Optisches Museum (D.O.M.).

ACP is run by a lean but effective management structure. The board of directors is elected by the members every three years. The ACP advisory board, currently formed by seven high-profile personalities from academia, industry and politics, supports the directors in questions of strategic importance. Administratively, the Center is run by a chief executive officer and a specialized team particularly dedicated to the coordination of the Master's degree, doctoral and guest programs s well as other centralized initiatives concerning e.g. digitalization, research infrastructures, science communication and internationalization.

The bust of Ernst Abbe, the first to formulate the diffraction limit for a microscope and the famous eponym of the ACP, is hosted inside a historical monument in Jena.

AN ATTRACTIVE PERSPECTIVE FOR PHOTONICS EXPERTNESS IN ACADEMIA

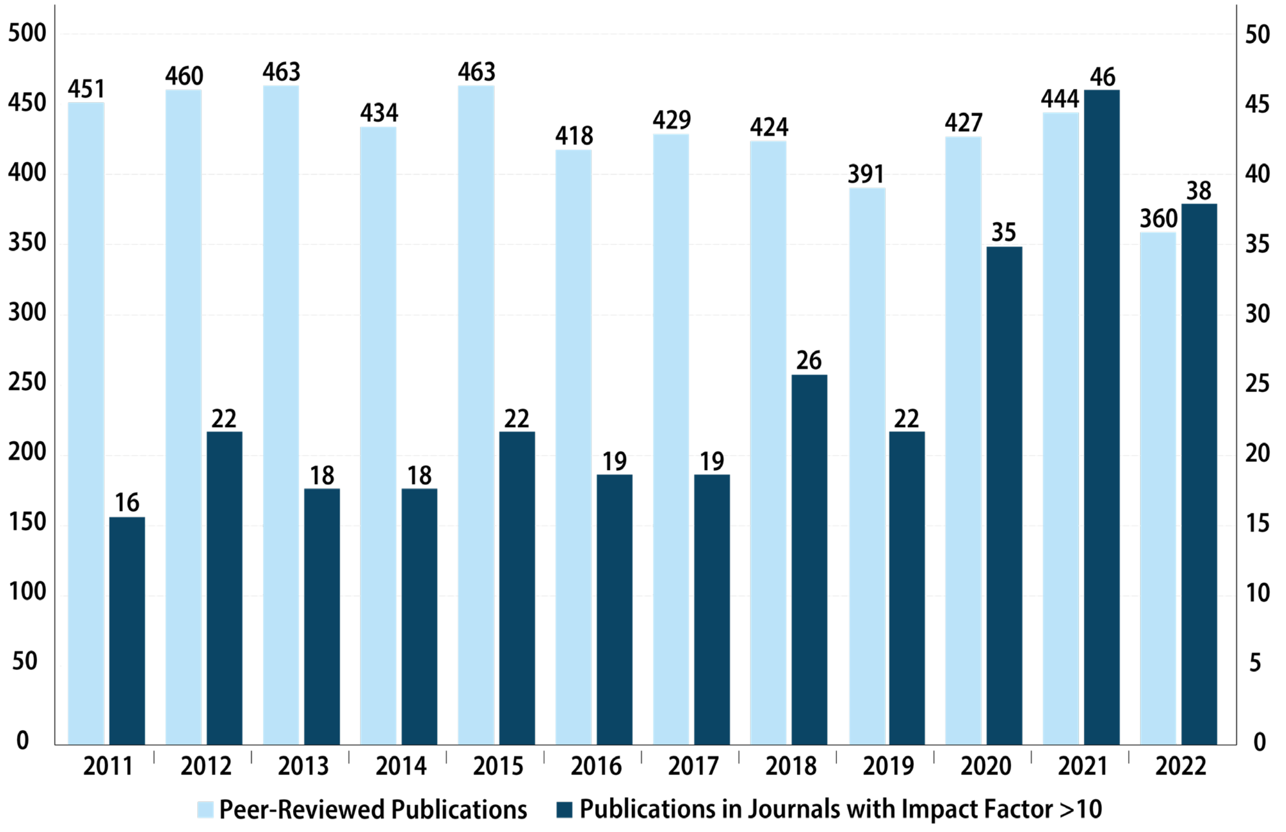
Hand in hand with the University, ACP offers applicants showing excellent academic achievements the maximum opportunities for an academic career in optics and photonics in Jena. In order to provide this scientific and structural development with a broad foundation, ACP members have managed to actively steer strategic appointments, thereby serving to strengthen the Center's core identity and the University's profile line LIGHT. Since 2012, a considerable number of strategic professorship appointments have been achieved: Blahnik (Optical System Design), Dietzek-Ivanšić (Molecular Photonics), Deckert (Nanospectroscopy), Eggeling (High-Resolution Microscopy), Fritzsche (Relativistic Quantum Dynamics), Gärttner (Quantum Information Theory), Gräfe (Theoretical Chemistry), Limpert (Novel Solid-State Laser Concepts), Mappes (Science Communication), H. Schmidt (Quantum Systems), M. Schmidt (Fiber Sensors), Staude (Photonic Nanomaterials), Peschel (Solid State Optics), Röhlsberger (X-ray Physics), Stöhlker (Atomic Physics in Extreme Coloumb & Laser Fields), Turchanin (Applied Physical Chemistry), and Wondraczek (Glass Chemistry).

EQUAL GENDER OPPORTUNITIES AND FAMILY-FRIENDLINESS

ACP strongly and actively pursues gender mainstreaming and family-friendly working conditions. In addition to ACP internal initiatives, a variety of measures at the federal state, local state and municipal level are already in place to promote equal gender opportunities. While gender equality is less an issue in the departments of biology and medicine, there is still – despite all efforts – a severe problem in the current staffing of physics and chemistry departments which reflects the acute shortage of women in these disciplines in Germany in general, and optics and photonics in particular. Currently, eight out of 57 ACP principal scientists are female, namely Delia Brauer, Maria Chernysheva, Stefanie Gräfe, Erika Kothe, Ute Neugebauer, Heidemarie Schmidt, Isabelle Staude and Adriana Szeghalmi.

As part of our institutional strategy, women are strongly encouraged and supported in many respects to achieve group leaderships, junior and full professorships. Moreover, we have demonstrated that the long-term issue can be systematically addressed by supporting women at the earlier stages of their academic careers, incorporating this principle in all aspects of ACP's qualification strategy. In fact, first successes of these efforts can be seen by quantitative indicators at the early-stage academic levels, demonstrating that the coordinated programs at ACP and ASP exhibit a noticeable percentage of women. In November 2023, 31% of all enrolled or graduated students in the ASP Master's degree program were women, and the percentage of women enrolled in the ASP doctoral program is 30%, with a solid trend of increase.

In particular, the competitive support instruments which aim to maximally link doctoral researcher and postdoctoral career stages are considered as optimally designed for promoting gender equality and for balancing structural disadvantages for female candidates. For two prominent cases, our gender equality measures on the junior level have proven to be fruitful. In 2015, former ACP member Rachel Grange was appointed as a professor at ETH Zurich. Following this model, the previous ACP junior research group leader Isabelle Staude was appointed as a full professor at Friedrich Schiller University Jena in 2020. While we will continue to increase our efforts on gender equality, we hope that our already demonstrated success cases will act as a seed for further appointments of female professors in the future. To further promote equal opportunity and family-friendly conditions, ACP has appointed its director Stefanie Gräfe as contact person for gender issues. She provides advice and support for equal opportunity or family-related topics within ACP and ASP. On the administrative level, information regarding financial aid earmarked for the promotion of women in academic careers is distributed at all levels. Clearly, the support of young female scientists is a cross-sectional task for both ACP and the University. It creates and secures conditions of equal opportunity for all its members, independent of gender and background.



Optics and photonics publications by ACP principal scientists according to ISI Web of Science, since 2011. To reflect the dynamics in recent years and to allow for a fair comparison, the numbers take into account the peer-review publications in optics, photonics and related fields for all ACP members since the start of their affiliation with the Friedrich Schiller University.

ACP's new infrastructure, a research and teaching building with more than 2,600 m^2 of laboratory and office spaces for research and teaching was taken into operation in 2016. Since then, the building, its students and scientists have jointly evoked a great impact on the scientific excellence in the whole Jena region, in many respects. The construction has been funded by the State of Thuringia and the German federal government with 26 million Euro.

PUBLICATIONS AND DISTINGUISHMENTS

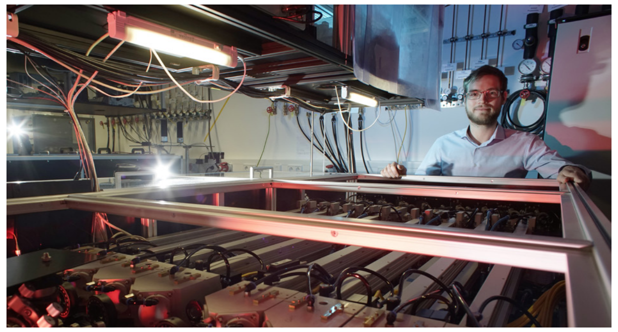
Publications are the main channels of scientific output, but they also serve to generate public awareness and are thus a primary performance indicator, both for the Center's scientific excellence and its visibility. Since ACP was officially founded in late 2010, a regular output of about 400 peer-reviewed publications p.a. has been measured, and a significant rise of high-impact papers was achieved. This rise is mainly attributed to two factors: First, a number of large-scale projects in the optical sciences and adjacent fields led by the ACP principal scientists were put into operation a few years ago. Second, the institutionalization of the profile line LIGHT by the ACP, its key player, has attracted more and more international researchers of the Friedrich Schiller University to the optical sciences. These additional scientists have fused their complementary expertise into combined research efforts in a synergetic way - this fact is also reflected by the recent rise in publication numbers. By November 2023, more than 340 high-impact publications, marked as ACP research highlights, have been published by ACP principal scientists, and at least 124 of them were issued by the Nature Publishing Group (Nature, Nature Photonics, Nature Materials, etc.).

Among the particularly outstanding achievements are the prices and distinguishments, which the Center's members have been awarded in recent years. Just to name a few, the Federal German President's Award for Innovation in Science and Technology was awarded to a team around Stefan Nolte, for their contribution in transferring fundamental research of ultrafast laser processes into an industrial manufacturing tool. The prestigious ERC Grants (Starting, Consolidator and Advanced) were awarded to ACP principal scientists Benjamin Dietzek-Ivanšić, Christian Eggeling, Stefanie Gräfe, Jens Limpert (three times), Andreas Tünnermann, Andrey Turchanin, Ullrich Schubert, Thomas Stöhlker and Lothar Wondraczek. Only for the second time in its longstanding history since 1957, the Pittsburgh Spectroscopy Award was given to a non-American individual, Jürgen Popp for his outstanding contributions to the field of applied spectroscopy. This list may be well continued, and ACP scientists will strive to do so.

FUNDING

The Abbe Center of Photonics (ACP) acquires multiple sources of funding to establish and maintain its research, education and infrastructure program. The larger share of financial aid is for indirect support, attracted by ACP's principal scientists through many different competitive third-party funding schemes. This support comes mainly from substantial large-scale and collaborative research projects.

To obtain maximum benefit from the synergetic effects which ACP provides, its members focus their common acquisition efforts on strategic funding, i.e. on large-scale, interdisciplinary and sustainable collaborative research projects. The following list, sorted by funding sources, is a selection of currently active strategic research projects which have been acquired by ACP's principal scientists through competitive funding programs:



THE GERMAN RESEARCH FOUNDATION

- Excellence Cluster EXC 2051 Balance of the Microverse - strong support to our microbiology partners
- Collaborative Research Center SFB 1375 NOA - Nonlinear Optics down to Atomic scales
- Collaborative Research Center SFB 1278 Polytarget
- Collaborative Research Center SFB TRR 234 Catalight together with the University of Ulm
- International Research Training Group IRTG 2675 META-ACTIVE together with the Australian National University

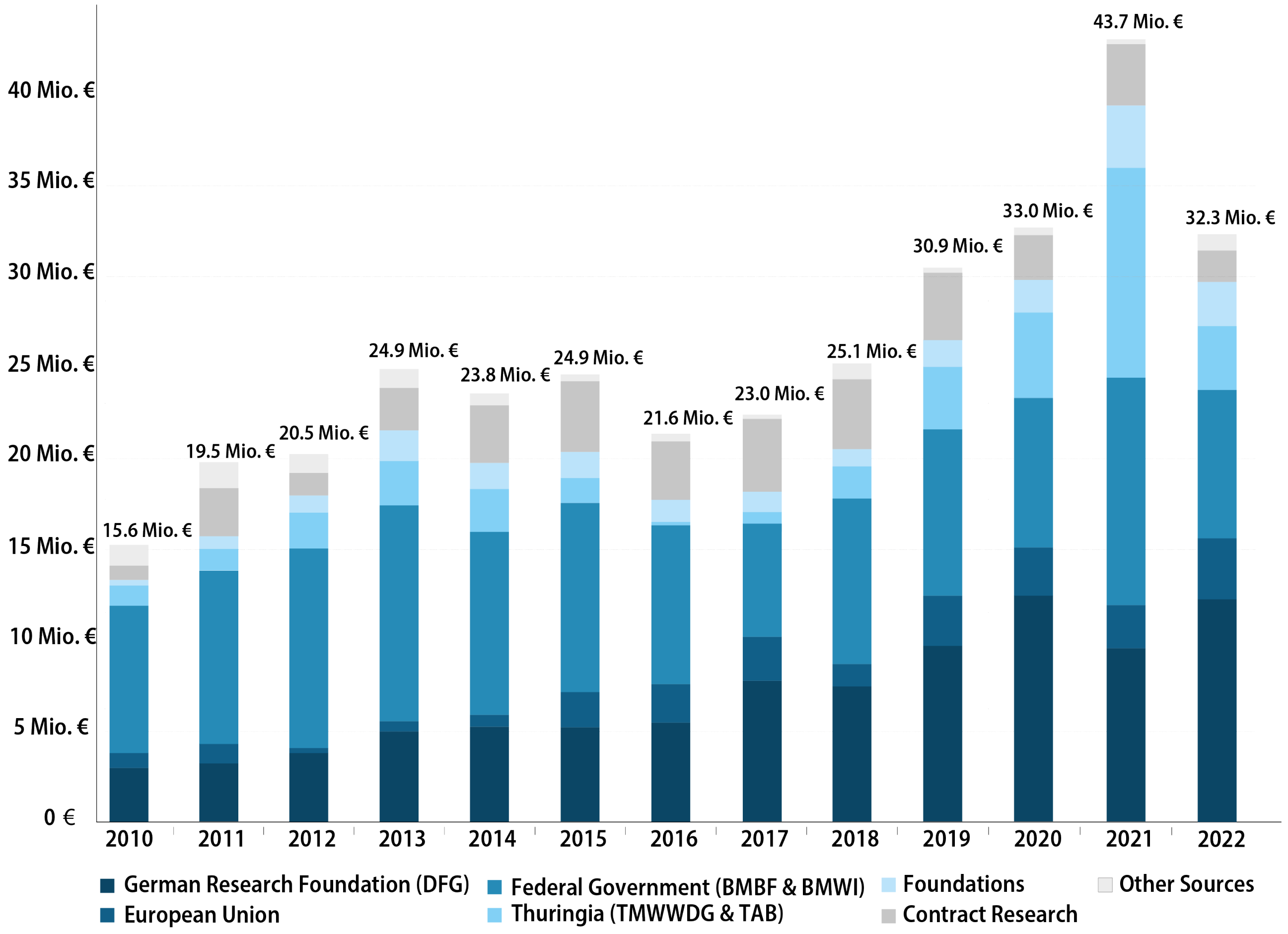
THE EUROPEAN UNION

- Attosecond Chemistry - COST Action (CA18222)
- BioQantSense - Twinning for Excellence with the Serbian National Institute of Physics Belgrade (EU Twinning 101079355)
- EMIMEP - European Master for Industry in Microwave Electronics and Photonics (MSCA-EMJMD)
- FastGhost - Fast quantum ghost microscopy in the mid-IR (FET-OPEN 899580)
- LISA - Laser Ionization and Spectroscopy of Actinide elements (MSCA-ITN 861198)
- METAFAST - Metasurfaces for Ultrafast Light Structuring (FET-OPEN 899673)
- SURQUID - Super-resolving Quantum Imaging and Detection (FET-OPEN 899824)

STATE AND FEDERAL FUNDING

- InfectoGnostics - Federal Research Campus, funded in public-private partnership by the BMBF, the Free State of Thuringia, and more than 20 companies
- InQuoSens - Thuringian Innovation Center for Quantum Optics and Sensor Technology in collaboration with the Technical University Ilmenau, funded by the Free State of Thuringia
- Leibniz Center for Photonics in Infection Research, selected and funded by the National Research Infrastructure Roadmap
- Jena Alliance Life in Focus -a project of the Carl-Zeiss-Stiftung, a multidisciplinary education initiative
- Max Planck School of Photonics - national education excellence initiative, funded by the BMBF
- QOMPLEX - joint project on Complexity Scaling of Quantum Photonic Systems, funded by the BMBF
- QP.TECH.EDU and Quantum Mini Labs, both joint programmes within the Quantum Futur Education Initiative funded by the BMBF
- UKPinho - SME-driven alliance on ultrashort laser pulse technology research
- Carl-Zeiss-Stiftung Center for Quantum Photonics, together with the Universities of Stuttgart and Ulm

In addition to individual grants and fellowships, ACP scientists are also proud to attract an exceptionally high amount of third-party funding for projects aiming to support professional careers within the educational program. Substantial financial support for infrastructure and administration to benefit the Abbe School of Photonics is provided by federal programs (Max Planck School of Photonics), the German Academic Exchange Service (Graduate School Scholarship Programs) and from the Carl-Zeiss-Stiftung (Jena Alliance Life in Focus). In addition, ACP gratefully receives financial support for selected doctoral research projects from different types of scholarships from the European Union and the European Research Council (ERC), the German Federal Ministry of Education and Research (BMBF), the Thuringian Ministry for Economy, Science, and Digital Society (TMWWDG), the Alexander von Humboldt-Foundation, the Carl-Zeiss-Stiftung, as well as from our more than 20 industrial partners, among them ASML, LEICA, JENOPTIK, OSRAM, PHILIPS, TRUMPF, and ZEISS. The following chart lists the annual budgets which ACP scientists have spent on their optics and photonics projects from 2010 to 2022. Since ACP's foundation, an already considerably high level of funding has been continuously increased. Currently, the annual competitive third-party budget has achieved a considerably high and constant level of about EUR 30 million raised by ACP principal scientists. Another solid tendency lies in the fact of a growing amount of funding was attracted from the German Research Foundation (DFG). In sum, and over the last 10 years, ACP's annual budgets have constituted roughly 25 to 35% of the overall sum of third-party funding granted to all scientists of the entire Friedrich Schiller University Jena. These numbers are proof of the vital and sustainable impact of optics, photonics and quantum technology research and education performed by ACP – a reflection of the University's impressive research profile as well as on the strong economic and infrastructural backbone of Jena.



Annual budgets of third-party funding in optics and photonics research and educational projects led by ACP principal scientists from years 2010 to 2022, sorted by funding sources. The numbers for 2023 were not yet available at the editorial deadline of this booklet.

LOCAL PARTNERS

ACP strongly supports the transfer of fundamental research results to applications by a dedicated partner network. To promote strategic partnerships, ACP sustains a multitude of theme-, project- and person-oriented collaboration forms in particular with three local non-university photonics institutes, as well as with the emerging Deutsches Optisches Museum, all of them located in Jena. These prime strategic partnerships are showing a strong societal impact, not only in the Jena region. This strategy has manifested in a dynamic and ever growing exchange of people, ideas, research results, finally leading to new intellectual property, optical system prototypes or start-ups – and has evolved as one of the key distinguishing features of Jena as an internationally unique photonics hub and ecosystem. Particularly, the higher education of our Abbe School of Photonics provides fertile grounds when its graduates are continuing their professional careers at ACP's premium partners, each of them providing an unmistakable scientific and societal profile.

FRAUNHOFER INSTITUTE FOR APPLIED OPTICS AND PRECISION ENGINEERING JENA

Jena's Fraunhofer Institute for Applied Optics and Precision Engineering (IOF) develops solutions for all aspects of light generation, light guidance and light measurement. Current focuses of its research activities include free-form technologies, micro- and nanotechnologies, fiber laser systems, quantum optics as well as optical technologies for safe human-machine interaction. The institute focusses on on the business fields of Sensors & Metrology, Opto-mechanical Systems, and Light Sources & Lasers. It is thereby able to offer the entire process chain or individual process steps for each of these areas – from the design to the production of components as well as the assembly to opto-mechanical or opto-electronic systems and holistic characterization. Fraunhofer IOF can accompany customers from their initial request to the market launch. All research and development processes are carried out in line with market trends. The institute also takes care of translating results and developments into the processes of partners and customers in the form of personnel qualification or technology transfer. In addition to contract research, the institute also offers individual services according to its developed technologies. These services include, for example, the functional coating of surfaces, material and component testing, ultra-precision machining of components, high-speed 3D measurements or the construction of tailor-made special machines. With its "Digital Innovation Hub Photonics" (DIHP), Fraunhofer IOF combines its technical expertise with competence in the field of innovation management and professional training at the highest level, making it one of the leading institutions in the national and international photonics industry.

LEIBNIZ INSTITUTE OF PHOTONIC TECHNOLOGY JENA

How can we support physicians in diagnosing cancer faster, more gently and more accurately? How can we help them to treat patients with life-threatening infections and jointly combat the danger of growing resistance to antibiotics? Which drug residues pollute our water and what is in our food? Scientists at the Leibniz Institute of Photonic Technology (Leibniz IPHT) use light to find solutions to questions and urgent problems in the fields of health, environment, medicine and safety. They research photonic technologies for faster and more precise medical diagnostics, for safe medicines, for a new quality of food and water analysis and for innovative safety technology. They work on the vision to make our lives safer and healthier. Under the motto "Photonics for Life", one focus of research is on optical health technologies. To this end, three program areas are interlinked: Biophotonics, Fiber Optics and Photonic Detection. In 14 research departments and two junior research groups, scientists use four key technologies: Fiber technology, planar micro- and nanotechnology, systems technology and statistical evaluation processes (chemometrics, machine learning and artificial intelligence). Together with partners from research and industry, Leibniz IPHT pushes translation. According with the maxim "From Ideas to Instruments", the institute covers the entire innovation chain – from basic technological research to the implementation of customized, application-ready solutions. The foundation for this is laid by an outstanding technological infrastructure. A technology center allows the production of highly precise and complex optical fibers. They are used as light sources, as fiber optic sensors and in probes and endoscopes. A clean room offers optimal conditions for research into highly sensitive detector and sensor concepts using micro- and nanotechnologies, for example, as well as for providing microfluidic components for lab-on-a-chip systems for medical and life science applications.

HELMHOLTZ INSTITUTE JENA

The Helmholtz Institute Jena (HI Jena) is an outstation of the GSI Helmholtzzentrum für Schwerionenforschung, located on the campus of the Friedrich Schiller University Jena. Additional partners within the Helmholtz Association are the research centers Deutsches Elektronen-Synchrotron (DESY) in Hamburg and the Helmholtz Zentrum Dresden-Rossendorf (HZDR). The institute's research is focused on the borderline between conventional accelerator technolgy and the rapidly developing field of laser-driven particle and photon sources. HI Jena provides important contributions to current and future large-scale research facilities, such as the FAIR project at the Helmholtzzentrum GSI, and the FEL photon sources FLASH and XFEL at DESY. Moreover, it effectively strengthens Jena's research profile by facilitating new areas of research and significantly stimulating cooperation between the participating Helmholtz Centers and ACP principal scientists.

DEUTSCHES OPTISCHES MUSEUM JENA

In a public-private-partnership the foundation "Deutsches Optisches Museum (D.O.M.)" is entirely redesigning all parts of the former museum of optics in Jena, transforming it into a research facility. On a publicly accessible area of about 2,500 m^2 in the city center of Jena, there will open a new and highly interactive permanent exhibition on optics and photonics in 2026. The narrative of D.O.M.'s exhibition is based on the holistic combination of three elements: (1) live optical experiments, allowing the visitors to grasp the basic optical and photonic effects by personal interaction. (2) presenting historic optical devices and instruments that were designed based on those effects, while putting the equipment in the context of its application. And eventually (3) the showcase of optics research – providing a unified platform for young researchers from ACP, MPSP, and ASP to have a very visible public outreach of their latest publications. All this is based on D.O.M.'s outstanding collection of historic optical equipment, the world's largest archive of optical glasses, numerous antique and still working microscopes with thousands of historic objectives, many thousands of historical spectacle lenses since the middle ages, and the largest collection of grey literature on optical instruments. Research at D.O.M. is focused on the understanding of the application of optics. While revisiting historic experiments by combining antique optics with latest (imaging) technology, limitations of the past are revealed, providing impulses for new and innovative solutions to today's tasks. In this context, D.O.M. always puts emphasis on the connection with the present. The work therefore considers both, the contribution to improving our standard of living and the gain in knowledge via the physical laws of optics.

ADVISORY BOARD

The Abbe Center of Photonics (ACP) reinvigorated its management structure with the establishment of an advisory board, which was re-commissioned by the President of the Friedrich Schiller University lately in 2022. ACP is delighted to welcome seven renowned individuals as board members, all with the highest personal achievements in science, industry, and German society with regard to optics and photonics. The board's primary role is to assist the center with the development of a management strategy and vision for future success and to serve as a medium for strengthening linkages between academia, industry, government and community. Dialogue is warranted through regular assessment meetings of the ACP Advisory Board and the ACP Board of Directors. The board's regular meetings take place in Jena every two years.

PROF. HELMUT ZACHARIAS, SPEAKER

He is a full professor in the Department of Physics at the University of Münster.

PROF. RACHEL GRANGE

After a 5-year junior professorship at Friedrich Schiller University, she has been appointed as a full Professor at the ETH Zurich.

DR. MICHAEL KEMPE

He is Head of Department for Medical Technology and Fellow of the Carl Zeiss AG, Oberkochen/Jena.

PROF. GEORG POHNERT

He is Vice-President for Research and professor at the Department for Chemistry and Earth Sciences at the Friedrich Schiller University.

PROF. MONIKA RITSCH-MARTE

She is a full professor in the Department for Physiology and Medical Physics at the Medical University of Innsbruck.

PROF. PIET SCHMIDT

He is a full professor at the Leibniz University Hannover and Director of the Institute for Experimental Quantum Metrology (QUEST) at the PTB in Braunschweig.

MR. BURKHARD ZINNER

He is Head of Division for Research at the Thuringian Ministry for Economy, Science & Digital Society.

OUR TEAM

The operative backbone of the Abbe Center of Photonics (ACP) is a team specialized in professional scientific management. It conducts central projects concerning internationalization, digitalization of education, innovation and transfer, and recruiting campaigns in joint efforts with the regional industry partners. Furthermore, our team runs the Lichtwerkstatt Makerspace and supports the ACP board of directors. All activities are closely coordinated with ACP's principal scientists, the University's central institutions, funding agencies and ACP's industrial partners. Above all, the team provides dedicated support to Abbe School of Photonics (ASP) students and scientists throughout each stage of their academic studies.

Professional science management has become an indispensable key capacity of all players in the areas of research and education, particularly when striving for academic excellence on an international level. The enlarged demands and challenges for the strategic and operative steering of academic processes, both on a conceptual and a personal level, and the increased need for short-term actions lend themselves to a flexible, specialized team.

With regard to this nationally and internationally recognized development, ACP has performed a head-start by forming an operative administration and project team with interdisciplinary expertises already in 2010. Since then, ACP's professional science management stuctures were continuously developed and optimized to face upcoming challenges and trends. Our current staff combines the international experiences and perspectives of individuals with topical backgrounds in physics, business administration, biology, computer sciences, digitalization, academic management, marketing, communication sciences and international relations.

The tasks covered by the team span the general coordination of strategic collaborative projects like, e.g., the **CRC 1375 NOA**, the **IRTG 2675 Meta-Active**, the **Thuringian Innovation Center InQuoSens** and the **CZS Center for Quantum Photonics**. Moreover, we are coordinating and developing the Master's degree and doctoral candidates, junior scientists and guest professors of our **Abbe School of Photonics** and Max Planck School of Photonics, including individual counseling and career development. Further endeavors concern scientific outreach, different strategies for international marketing of our educational programs, the steering of evaluation and selection processes as well as the management of local research, IT and science communication resources, in particular with regard to the ACP research building. The team further ensures for a seamless and efficient interaction with all central administration units of the Friedrich Schiller University Jena.

LICHTWERKSTATT JENA – GERMANY'S OPEN PHOTONICS MAKERSPACE

Moreover, ACP is running a number of projects which are multidisciplinary and cross-linked with ACP's key research areas, for example in the field of open innovation management. One suche project to be highlighted is the **Lichtwerkstatt Jena** - Germany's first and so-far only **Open Photonics Makerspace**. It was build on BMBF-support from 2017 til 2023 and has now become a substantial partner of the entrepreneur and maker scence in the Jena region. Here, citizens, researchers and many companies with an interest in optics and photonics can gain free access to state-of-the-art technical equipment (including AR/VR, 3D scanning, 3D printing, laser cutting, microelectronics) and the necessary know-how to realize own ideas.

By virtue of the Lichtwerkstatt's outreach and impact, many creative minds are supporting Jena's photonics companies to break traditional patterns of thinking, to enrich their innovation projects with inspiration and complement the resources of internal R&D departments. These open innovation processes are fueled by our Lichtwerkstatt Makerspace through various instruments such as hackathons or workshops. In addition to representatives from companies and academia, many enthusiastic students and researchers from physics, photonics, IT sciences and media management are the main Open Photonics Makerspace users.

Booth of the Lichtwerkstatt Makerspace at the LASER World of Photonics Fair in Munich, 2023. F.L.T.R.: Canan Gallitschke, Dr. David Zakoth, Johannes Kretzschmar, Clara Henkel, Dr. Falko Sojka.

EDUCATION – ABBE SCHOOL OF PHOTONICS

BUILDING CAREERS IN PHOTONICS

The Abbe School of Photonics (ASP) is an integral part of the Abbe Center of Photonics. It provides and coordinates the graduate programs in optics and photonics at the University. Thus, ASP serves as a career springboard by promoting academic careers, as well as providing opportunities to gain job experience in the photonics industry. Its interdisciplinary education programs are embedded in ACP's cross-fertilizing research environment. One of the school's core degree programs is the international Master's degree program in Photonics. In order to open up the program to students worldwide, all ASP lectures are taught completely in English.

ASP's concept and philosophy aim at establishing Jena as one of the world's leading educational centers in optics and photonics. ASP has been shaped by our University's traditionally broad spectrum of teaching activities in the light sciences. The School offers outstanding opportunities for high-level qualification at the graduate level in the areas of optics and photonics. Its academic qualification strategy is fully research-oriented and based on the principles of academic freedom, competitive research conditions and internationalization at all levels of education and research.

On the one hand, ASP's training promotes and optimally links career phases of young scientists in academia. On the other hand, the School also recognizes the fact that the large majority of its graduates will continue their careers in companies conducting intensive research. All of our competitive career-development measures are therefore designed to lay the foundation for successful careers in academia as well as in industry.

ASP coordinates and organizes all of ACP's educational activities. The School was founded in 2008 as an essential part of the ProExcellence Initiative issued by the Free State of Thuringia. Since then, the local state and the federal governments, the Carl-Zeiss-Stiftung, Germany's optics industry and the European Union together have provided more than € 16 million in basic funding necessary to support this process. A key factor of the program is ASP's close collaboratory work with its industrial partners. To sustain these business' partners' exceptionally high degree of economic development in the future, and with regard to Germany's demographic development, the constant availability of a substantial number of highly qualified employees is required. ASP graduates are just such potential candidates, trained and well-prepared to shape the future of Germany's next innovations in photonics and high-tech industry.

CAREER TRACKS IN PHOTONICS AND QUANTUM SCIENCES AND TECHNOLOGY

One of the School's core programs is its Master's degree program in Photonics (M.Sc. Photonics). This program's lectures and courses are taught completely in English. The recruitment is based on a global strategy - selecting the best students from around the world. On the Master's degree level, ASP's teaching staff is also strongly engaged in specializing its photonics courses for students in the Master's degree program in physics (M.Sc. Physics) and in medical photonics (M.Sc. Medical Photonics). A new, also international Master's degree (M.Sc. Quantum Science and Technology) is currently in the ramp-up phase. Moreover, our School has established a structured coordinated doctoral program, comparable to a PhD program in the USA, which is directly linked with ACP's strategic research programs.

Further academic courses and career development work are supported by our advanced optics training laboratory and a comprehensive scholarship program for deserving graduate students. In addition to its academic course programs, ASP organizes and carries out joint activities related to business education, run in collaboration with industrial partners and outside academic partners. Importantly, ASP develops a strong, person-oriented global photonics network by sustaining communication with its alumni worldwide.

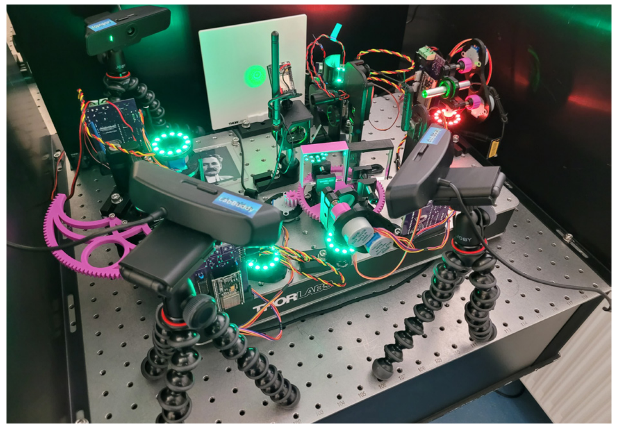
Master's degree and doctoral students at the Jena hub of the international Photonics Online Meetup 2023.

Furthermore, ASP attracts first-class young professional scientists for photonics research work. These gain teaching experience and involve graduate students in their research projects. Other career opportunities available at ASP include the job positions of academic tutors and junior research group leaders. Taken all together, ASP contributes decisively to establish Jena as being one of the world's leading educational centers for photonics and quantum technologies.

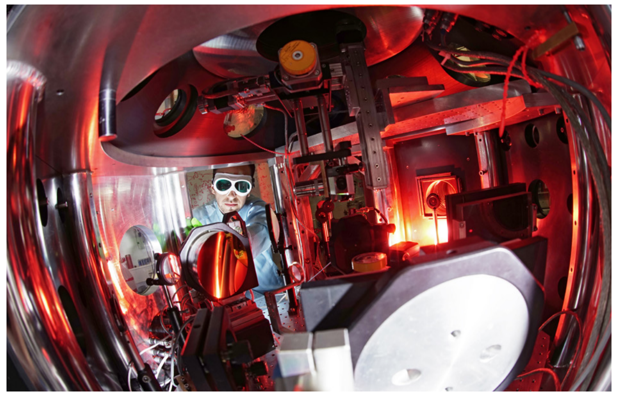
HIGH-LEVEL PHOTONICS TRAINING LABORATORY

Having extensive hands-on experience is one of the most valuable professional attributes by which a true expert in optics and photonics can be distinguished. To strengthen laboratory experience already at the beginning of a student's Master's degree studies, ASP has set up and continuously develops its photonics training laboratory with currently more than 18 dedicated optical and quantum setups. Students are able to perform high-level experiments using strictly research-grade components and equipment. After 2020, some of these setups have been transformed into remotely controllable experiments, so-called Extended Reality (XR) Twin Labs, whose analogue and digital twins are fully synchronized in time and space.

The laboratory's equipment covers continuous-wave and pulsed lasers, interferometry, linear and nonlinear spectroscopy, optical time-domain reflectometry and optical tweezing, to name only a few. The corresponding research techniques were made available with respect to their educational value and designed by ASP's senior scientists and academic tutors. They are fully operated by students. This strong commitment of allowing a maximum of hands-on experience during beginning-stage studies is clearly a distinguishing feature of ASP teaching, as compared to other educational institutions. Moreover, to support our graduate students in their experimental abilities to independently analyze and solve challenges in optics and photonics, they are granted from the beginning of their training full access to ACP laboratories with their respective research equipment. Our photonics training laboratoy is continuously upgraded to incorporate new trends, such us Artificial Reality (AR) and Virtual Reality (VR) techniques.



Remotely controllable Michelson interferometer with digital twin (XR TwinLab) for training and education purposes.



ASP doctoral researcher adjusting a laser in the photonics training laboratory.

PURSUING THE PHOTONICS CAREER

ASP prepares its graduate students for a successful start in their professional careers. For example, in cooperation with the Faculty of Physics and Astronomy, ASP organizes various career events such as job and talent fairs. Here, graduate students are brought into direct personal contact with our local industry partners, many of them specialized in applicational fields. These job and talent fairs provide a setting for the efficient matching of career opportunities and expectations. Furthermore, by means of career-mentoring workshops with scientists and representatives from various businesses, students receive valuable orientation and advice. They can thus better ready themselves for a global job market full of opportunity.

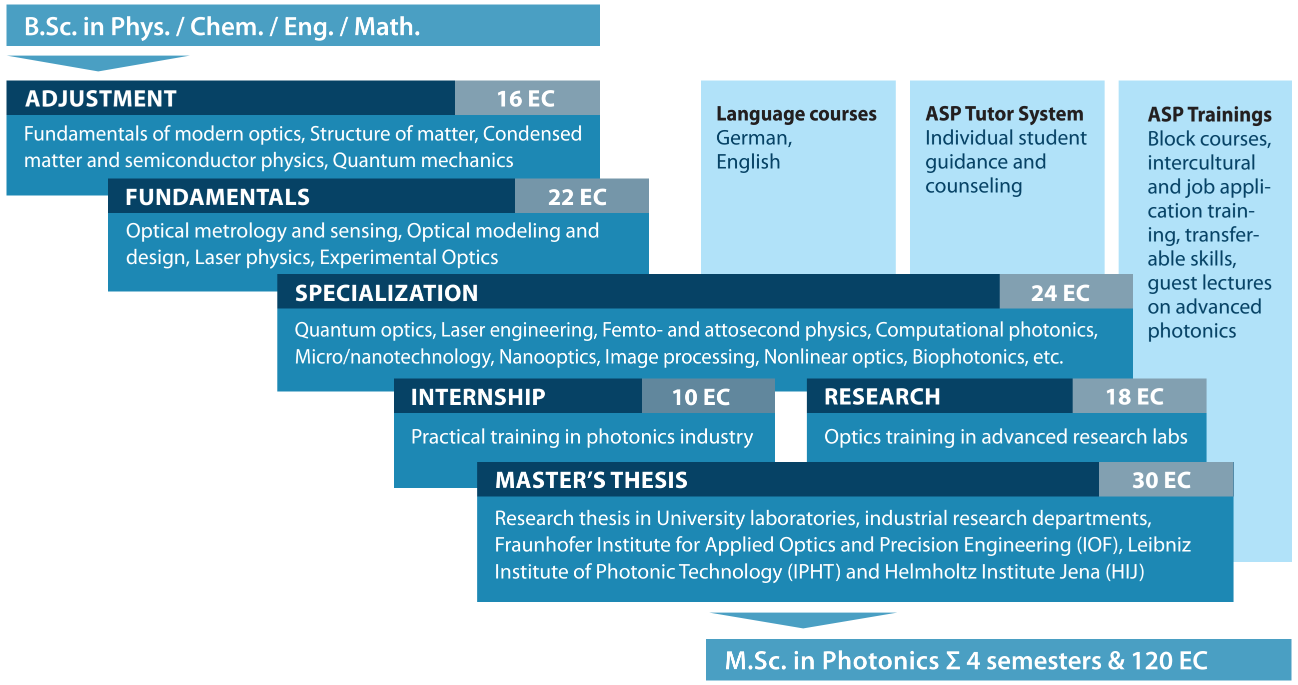
MASTER'S DEGREE PROGRAM

The Master's degree programs of the Abbe School of Photonics (ASP) are the key educational activities within the Abbe Center of Photonics. Their purpose is to train students in the optical sciences via a broad array of courses and hands-on seminars. The programs are designed to provide opportunities for students to attain the necessary skills required to fill today's challenging positions in industry and academia.

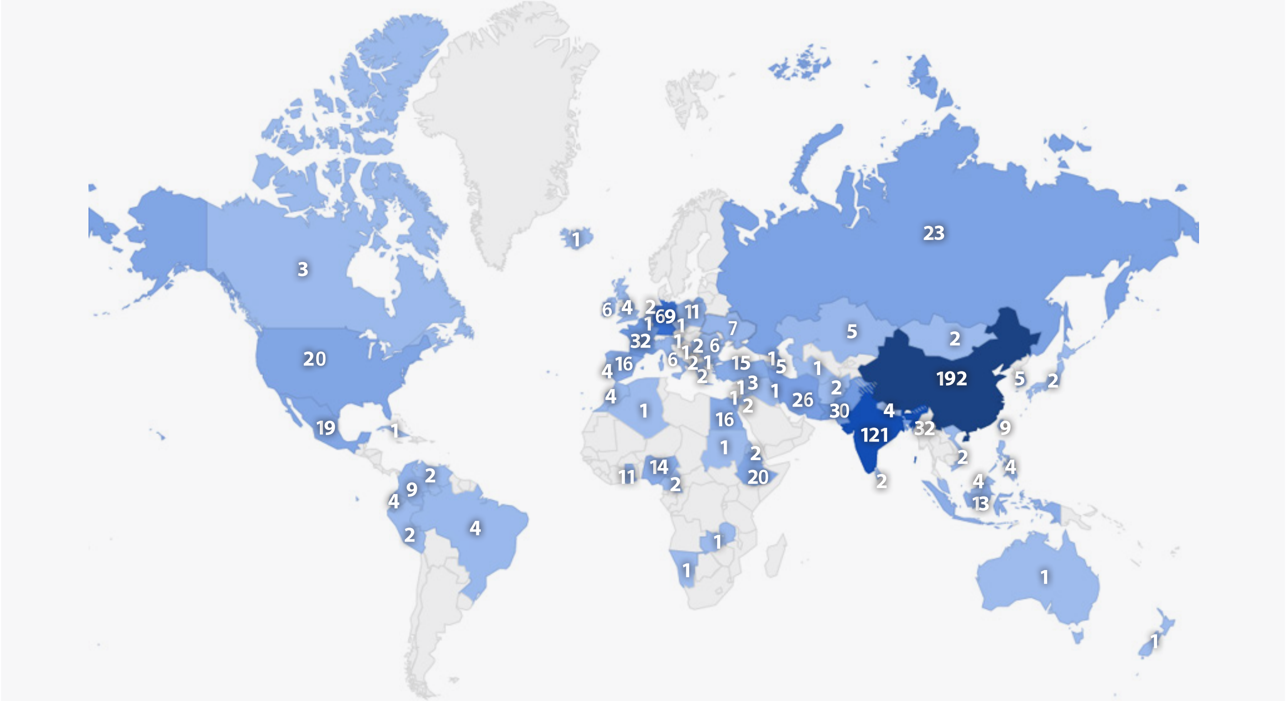
The Master of Science in Physics (**M.Sc. Physics**), with a strong specialization in photonics, continues to be the backbone of Jena's optics and photonics curriculum and meeting top academic standards. It is based upon the long-standing physics teaching tradition provided by our Faculty of Physics and Astronomy. The curriculum consists of mandatory and elective lectures which are either in German or English.

In addition, ASP's Master of Science in Photonics program (**M.Sc. Photonics**) offers an internationally recognized graduate degree providing multidisciplinary coverage in the fields of optics and photonics. This program incorporates upstream scientific aspects in the engineering field along with relevant and important business courses. Students enrolled in this two-year graduate photonics program – featuring lectures and courses exclusively in the English language – are trained for technical or scientific positions in both industry and academia. Since 2019, the M.Sc. Photonics course has gained in importance: together with similar programs at our partner universities in Erlangen and Karlsruhe, the M.Sc. Photonics is now fueling the photonics education of Germany's elite students in the national **Max Planck School of Photonics**. While approximately 70% of our graduate students successfully finishing the program continue on the academic track and accept PhD positions at top-ranking universities worldwide, other alumni often find attractive job positions in the optical industry, many being located in Jena and throughout Germany.

Under the lead of the University Hospital Jena, the Master of Science in Medical Photonics (**M.Sc. Medical Photonics**) is aimed at Bachelor's degree students of medicine, biology, chemistry and physics. Its curriculum is designed to join these disciplines into a group which performs photonics research in the area of applied medicine. Due to these multiple backgrounds, the teaching staff supports interdisciplinary learning endeavors. Starting in 2024, a new program (**M.Sc. Quantum Science and Technology**) will complement the education portfolio of the Abbe School of Photonics.



EC - European Credits



Countries of origin and numbers of M.Sc. Photonics enrolled students from 2009 until 2023. To date, at least 824 students from 70 different countries have enrolled in the program.

STUDYING OPTICAL SCIENCES IN JENA

All four Master's degree programs, M.Sc. Physics, Photonics, Medical Photonics and Quantum Science and Technology, are fully integrated into the course curriculum package of the Friedrich Schiller University Jena. They are directed and taught by the scientific and teaching staff of the faculties of Physics and Astronomy, of Chemical and Earth Sciences, the Faculty of Medicine, and others. These lecturers offer many years of teaching expertise in the areas of optics and photonics, posing great benefits for those students in these programs. At the same time, the programs are embedded in the rich, stimulating research environment of the Abbe Center of Photonics. Thus, students obtain hands-on experience while taking methodology courses which take place in state-of-the-art photonics laboratories. These locations not only access our University's various institutes, but also include the Fraunhofer Institute for Applied Optics and Precision Engineering, the Leibniz Institute of Photonic Technology, the Helmholtz Institute Jena, as well as those of some of ACP's prominent industrial partners such as the world-renowned company ZEISS in Jena.

Our M.Sc. Physics program is open to anyone who has successfully completed a Bachelor of Science program in Physics in the European Union. While the M.Sc. Physics has proven very successful for decades, in 2009 the first students were enrolled and welcomed into the newly established M.Sc. Photonics program. Applying to this is easy to a state-of-the-art online application system which opens already ten months before the actual enrollment.

All applicants are evaluated by ASP's selection committee and, out of more than 1,000 applicants, the top 60...90 students are finally selected for eligibility. Comprehensive financial support is also offered to the best students through national and other scholarship awarded directly by the ASP and also by the Max Planck School of Photonics.

Since 2009, an annual average of 60 students has been enrolled into the M.Sc. Photonics Program, summing up to 824 students from 70 countries until 2023. These student numbers, with respect to their countries of origin, are displayed in the world map. The fact that almost 90% of these students are of non-German nationality fulfills one of ASP's central goals and philosophies – to locally run an international educational program with a sustainable regional impact.

SYSTEMATIC MENTORING SUPPORT

Particularly at the start of all programs, graduate students receive dedicated academic and wide-ranging administrative and mentoring support. The ASP mentoring program involves experienced Master's degree students, doctoral researchers, and qualified postdoctoral scientists. These mentors have the responsibility of coaching and supervising Master's degree freshmen, helping them get used to their new environment and to other fellow students. The mentors act as contact persons for each individual Master's degree student with regard to all questions that may arise, particularly when they enter Germany for the first time. Accordingly, the mentors and their assigned

Creativity workshop for Master's degree students during the Photonics Academy 2019 in Jena.

mentees establish a trusting relationship throughout the entire degree program period, helping to ensure the development of each student's professional and social qualifications.

In addition, Master's degree students are assisted by ASP's coordination office personnel, who help them to get well-acclimated in Germany upon arrival. Further, ASP offers intercultural trainings to enhance the students' intercultural competence and enable them to become an active member of the German society. Professional job training is also provided by our partners in science and industry, as well as with chosen international partner universities. The mentoring program also includes regular participation in selected job fairs, and involves work with online media. Our ultimate goal is to achieve gradual professional and personal advancement for each student, developing students into full-scale, independently thinking and working researchers in optics and photonics.

PHOTONICS EDUCATION WITH STRONG PARTNERS

The ASP Master's degree program in Photonics has its roots in the European educational system and has received considerable funding and stimuli from the Erasmus+ program of the European Union. Accordingly, the M.Sc. Photonics curriculum was jointly designed and is currently supported by some of the leading centers in German and international photonics education, including the Karlsruhe Institute of Technology, the University of Erlangen-Nuremberg, the Australian National University, the Politecnico di Milano, the Technical University Delft, the Université Paris-Saclay, the University of Eastern Finland, the Université Bordeaux, the University of Central Florida, the University of Rochester, the University of Limoges, University of Brescia, University of the Basque Country, the University of Toronto, or the Taiwan National University. These partnerships have led to long-term exchange agreements, enabling ASP students to be highly mobile. For our German students, ASP offers a large network of reputable partner universities under the jurisdiction of the Erasmus+ exchange program.

Moreover, ASP Master's degree students benefit from our German photonics industry partners and their dedicated involvement in our study programs. Our premium partners include, but are not limited to, Active Fiber Systems, AGILENT, ASML, Edmund Optics, JENOPTIK, Jenaoptronik, KARL STORZ, LEICA, OSRAM, SCHOTT, SICK, SONY, Thorlabs, TRUMPF, Vistec, and ZEISS. Every graduate student experiences at least one mandatory internship focused on practical training in optics laboratories of these and more than 80 other partner companies, or at ACP institutes. Moreover, the final Master's degree thesis can be accomplished by successfully completing an industrial project.

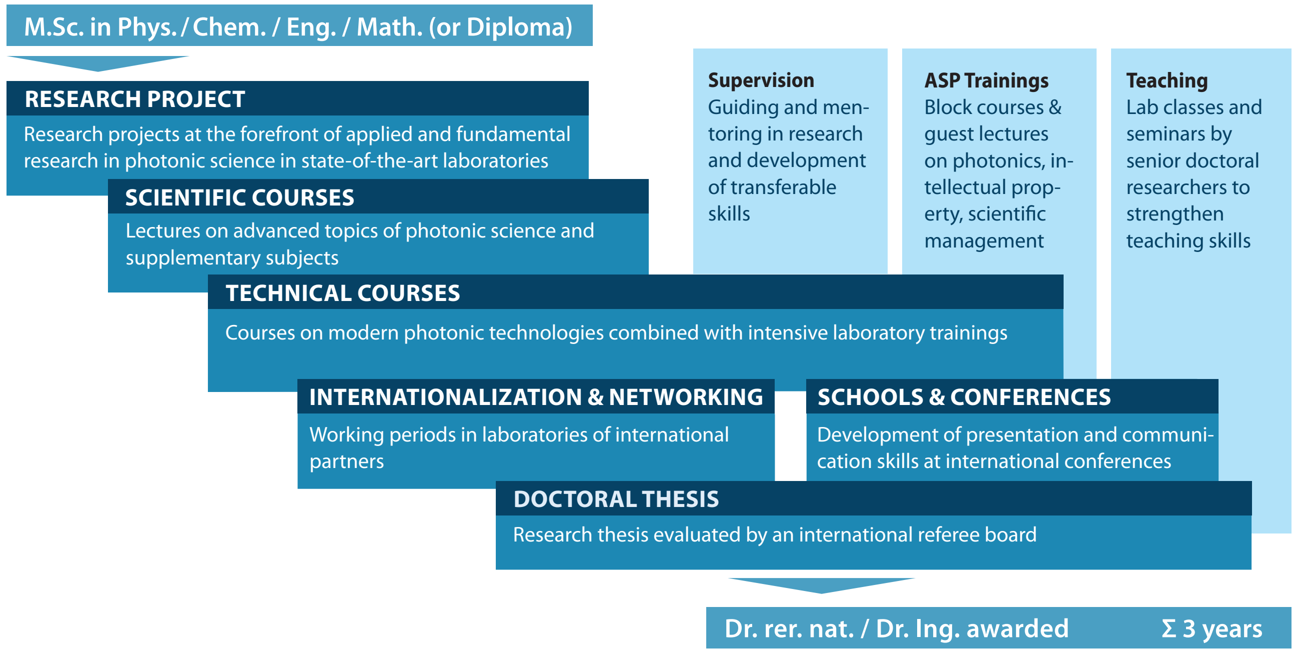
Students from worldwide are enrolled in ASP's international photonics studies.

DOCTORAL PROGRAM

The Abbe School of Photonics (ASP) is strongly committed to the advancement of highly qualified students and their promotion to early-stage researchers. Our doctoral program respects the principle of scientific freedom, but selectively also supports the development of individual science careers, provides professional and practical course opportunities and contributes to individual soft skills development.

In Jena, the roots for an exceptional scientific community specializing in optics and photonics were laid by the breakthrough work of Ernst Abbe in the late 19th century. Because of this unique historical background and throughout the decades, the numerous doctoral researchers who have graduated from Friedrich Schiller University were the inconspicuous but indispensable contributors to the advancement of knowledge in optics and photonics in Jena. Incorporating this rich tradition, the doctoral program of ASP (comparable with a PhD program in the USA) has become firmly institutionalized and sustainably structures the education and interconnection of young academics in optics. Since its start in 2009, ASP's doctoral program has been denoted by a constantly growing number of doctoral candidates pursuing research topics in optics and photonics at the University, reflecting the successful acquisition of numerous funding for light sciences research provided by scientists of the Abbe Center of Photonics (ACP) in recent years. In June 2023, 319 doctoral candidates (among them 97 women) have taken the opportunity to officially register in the ASP doctoral program. While a majority of those who join the ASP doctoral program have a physics background, also chemists, mathematicians and engineers perform their research projects at 11 different institutes under the umbrella of the ASP doctoral program, following both the core optical disciplines and adjacent fields, such as e.g. nanochemistry or material sciences.

Funding of the ASP doctoral program is provided by many different sources. First, substantial financial support is given directly to ASP to cover doctoral scholarships, infrastructure, and the administration of ASP. This direct funding is provided by public-private partnerships through Jena's established local photonics industry and through the Carl-Zeiss-Stiftung by its „Jena Alliance Life in Focus" program. Second, a significant amount of indirect support is obtained by the ACP scientists through various schemes of third-party funding programs on quite different scales. This indirect support comes mainly in the framework of research projects including substantial support of doctoral researchers. An example is the Collaborative Research Center (CRC/SFB) 1375 NOA - Nonlinear Optics down to Atomic scales, running since 2023 in its second funding phase by the German Research Foundation (DFG). ASP functions as the umbrella organization for a multitude of such projects to strengthen the aspects of doctoral education along with individual research and supported by industrial partners.



M.Sc. in Phys. / Chem. / Eng. / Math. (or Diploma)

RESEARCH PROJECT
Research projects at the forefront of applied and fundamental research in photonic science in state-of-the-art laboratories

SCIENTIFIC COURSES
Lectures on advanced topics of photonic science and supplementary subjects

TECHNICAL COURSES
Courses on modern photonic technologies combined with intensive laboratory trainings

INTERNATIONALIZATION & NETWORKING
Working periods in laboratories of international partners

SCHOOLS & CONFERENCES
Development of presentation and communication skills at international conferences

DOCTORAL THESIS
Research thesis evaluated by an international referee board

Dr. rer. nat. / Dr. Ing. awarded Σ 3 years

Supervision
Guiding and mentoring in research and development of transferable skills

ASP Trainings
Block courses & guest lectures on photonics, intellectual property, scientific management

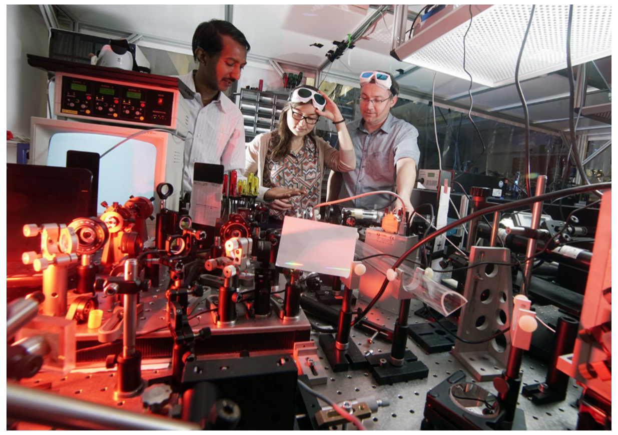
Teaching
Lab classes and seminars by senior doctoral researchers to strengthen teaching skills

ACP's principal scientists serve as topical supervisors for ASP doctoral researchers. The acquisition of new outstanding doctoral researchers is facilitated by choosing among the most excellent alumni of M.Sc. Physics and M.Sc. Photonics from Jena as well as hundreds of external applications, which we receive each year from the entire world. To attract the best candidates to the program, a modern online application system was established. Currently, a share of 41% of ASP doctoral researchers are of foreign origin, reflecting a continuous increase over the last ten years. Emphasizing its strong engagement in the further internationalization of studies, ASP is dedicated to this important primary aim of the institutional strategy of the Friedrich Schiller University Jena.

Workshop on Quantum Photonics in the ACP auditorium in 2021.

SHAPING FUTURE SCIENTISTS

A cornerstone of ASP's philosophy is to regard and value our doctoral candidates as scientists in all respects. Most notable is the conscious and deep involvement of our doctoral researchers in ACP's top-notch research environments. Providing them with full access to the laboratories, they can more readily contribute their individual scientific contributions to globally prevailing research questions. During the work on their individual research project, a maximum of freedom to develop their own ideas and to follow personal scientific interests is allowed of every doctoral researcher. It is our firm belief that this trust in our doctoral candidates' liberties and their abilities to develop is the most distinguished feature in the ACP doctoral program – which in fact renders it most competitive to other comparable optics education schemes worldwide. Our long-term experience has shown that this philosophy translates into a timely advancement in self-reliance and individual responsibility of our graduates, which is essential for the development of their scientific careers at higher levels.



Former ASP doctoral researchers Rudrakant Sollapur and Zhanna Samsonova in the Laser Lab of ACP PI Daniil Kartashov (from left to right).

To further promote the ASP doctoral candidates' scientific skills, participation in international conferences and presentation of their own contributions is encouraged and enabled, whenever possible. In the early stage of the doctoral phase, they can realize their individual professional and personality-forming experiences on international platforms such as, in particular, scientific conferences. Further opportunities to connect with global science communities are offered locally by ASP guest professors. Besides the topical input which doctoral researchers obtain by attending the special lectures of the more than 70 guest professors thus far, these distinguished scientists are available for face-to-face discussions here in Jena, to share their perspectives and expertise directly with our doctoral candidates.

Both opportunities and challenges for the doctoral candidates are gained through different, interfaculty and interdisciplinary seminars. At topical sessions and workshops in international conference style, which take place at least once per month, our doctoral candidates present their research to a larger audience encompassing also ASP supervisors and interested guests. Furthermore, in the framework of the Lichtwerkstatt Makerspace, creativity and hands-on workshops as well as photonics hackathons have become part of the game. These schemes offer an ideal platform to receive concentrated constructive feedback from fellow doctoral researchers, professors and external coaches, to possibly shift the perspective on their work disclosing formerly disregarded aspects, and to prepare for competitive, demanding on-stage performances as young academics. During the COVID-19 pandemic and and its related restrictions, digital research training schemes, for instance by incorporating Artificial (AR) and Virtual Reality (VR) technologies, are significantly gaining in importance with regard to scientific communication, exchange and interaction among our ASP doctoral researchers.

Group picture of ASP and external doctoral researchers at the DokDok 2022 conference in Arnstadt, Thuringia.

Firstly in 2011, ASP doctoral researchers' own initiative has led to the advent of a fully self-organized, but highly professional conference series on optical concepts called DoKDoK. It is the purpose of DoKDoK to bring together young researchers from all disciplines of photonics to create networks, stimulate discussions, exchange methodological skills and share fundamental understanding. As a conference „from students for students", DoKDoK tries to harness the creative power of young researchers, giving them the chance to present and discuss their ideas in a motivating yet relaxed setting. Meanwhile in its seventh edition, DoKDoK has become well established and ultimately a permanent part of ACP's doctoral program. As a cornerstone of ASP's doctoral researchers' networking, it is handed over as an organizational event from one generation to the next. The latest edition of DoKDoK took place in August 2023 in Luisenthal, Germany. On average, more than 60 young researchers and industry professionals attend DoKDoK every year, the majority of them affiliated with ASP, but many of them also from all over Germany and abroad. Moreover, the organizational committee has proven to be able to continuously acquire reputable international keynote speakers as well as to attract considerable funding from the photonics industry. In exchange, by attending DoKDoK, the industry representatives get the chance to approach their high-potential employees of the future in a quite informal atmosphere.

BUILDING PERSONALITY BEYOND SCIENCE

Besides the development of high-standard scientific profiles, the ASP doctoral program supplies a sophisticated combination of scientific exchange and teaching of required skills. In particular transferable skills, which are essential both for scientific and industrial careers. Combining complementary foci, ASP in close collaboration with the Graduate Academy Jena of the Friedrich Schiller University offers a dense annual seminar schedule covering, among other aspects, transferable skills such as scientific presentations, career prospects, entrepreneurship and patent law, creativity, extramural funding, or topics on gender equality and family friendliness. Additional methodological courses are organized by the ACP principal scientists. Moreover, vivid participation of ASP doctoral researchers in partner workshops and seminars is actively promoted. Numerous opportunities are available through the regular seminars of the Max Planck School of Photonics, Fraunhofer Institute Jena, the Leibniz Institute of Photonic Technology and the Helmholtz Institute Jena.

JUNIOR SCIENTIST PROGRAM

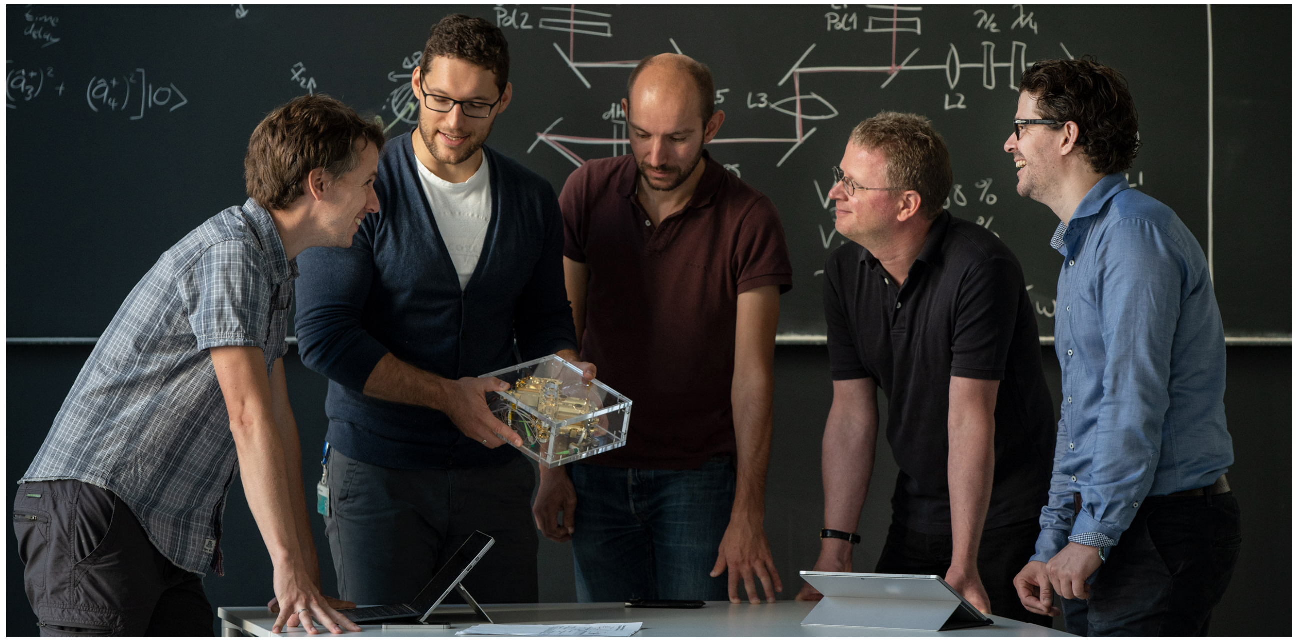
The future of optics and photonics will depend on highly skilled scientists. Hence, the Abbe School of Photonics (ASP) provides a full-scale program for young researchers to develop their scientific knowledge and abilities. Furthermore, ASP offers wide career opportunities to first-class young scientists, who will most likely lead the field in the years to come.

Very early on, ASP realized that, in particular, continuity in supporting scientific careers at all stages is very important if eventually the best people should systematically be elevated into leading positions in science. While Master's degree and doctoral programs can be considered standard ingredients in scientific education, very often the development of scientific careers to higher levels is left to one's individual responsibility. Specifically, the support of scientific careers at this beginning stage can make all the difference in the perspectives and goals of young, highly motivated people in science. Consequently, the ASP has teamed up with the Graduate Academy of the Friedrich Schiller University Jena to create a program supporting and actively developing the careers of those who are going to someday create the perspective and vision of photonics.

Inherent to the program is the idea that, at this stage, young researchers need individual support, which allows for their own unique development. Hence, instead of rules and structures, a key factor in their growth is to establish early their independence and self-confidence in research and education. In addition, these young scientists will receive the continued support they need by the ASP to help them on their way to top positions in science, e.g. by providing a world-class research infrastructure, supportive funding, a skills program devoted to research and excellent teaching, as well as guidance and encouragement through comprehensive mentoring.

TUTORS

While normally a postdoc concentrates on a dedicated research project supervised by an individual senior scientist, ASP offers particularly qualified young scientists the chance to participate extensively in teaching and supervision by becoming tutor of ASP. These tutors work very closely with Master's degree students by following them continuously throughout the two years of their Master's degree program. They give seminars, tutorials for professors' lectures and supervise practical labs as well as supervise periods of student research and training. This way they remain in close contact with these students throughout their entire educational program and take responsibility for developing their qualifications while developing their own managerial skills. This continuous and responsible involvement in scientific education provides tutors with invaluable experience, from which they will profit in their future as independent scientists.



Selected beneficiaries of ACP's junior scientist program, from left to right: Dr. Falk Eilenberger, Prof. Markus Gräfe, PD. Dr. Frank Setzpfandt, Dr. Erik Beckert und Prof. Fabian Steinlechner, and Dr. Fabian Steinlechner.

JUNIOR RESEARCH GROUP LEADERS

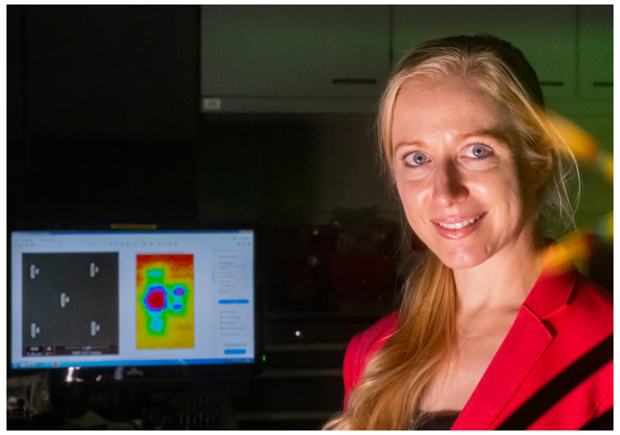
Young researchers who have already demonstrated their extraordinary abilities to conduct high level research can join ASP as Junior Research Group Leaders. In this way, they become increasingly independent in their research by running their own projects and labs as well as by taking responsibility in the supervision of students and young researchers within their labs. Junior Research Group Leaders usually have the status of a principal scientist within ACP. Currently, the following young scientists run their independent junior research groups enabled by individual funding from external resources:

-
- Dr. Maria Chernysheva - Junior Group Leader of Ultrafast Fiber Laser Systems funded by the European Union
- Dr. Falk Eilenberger – Junior Group Leader of Optics in 2D Materials funded by the Federal Ministry of Education and Research (BMBF)
- Dr. Matthias Kübel - DFG-funded Emmy-Noether Junior Group Leader of Molecular Movies funded by the German Research Foundation
- Dr. Jan Rothhardt – Leader of a Helmholtz Young Investigator Group on Soft x-ray spectroscopy and microscopy funded by the Helmholtz Association
- Dr. Sina Saravi - Junior Group Leader of Nonlinear Neuromorphic and Quantum Photonics funded by the Carl-Zeiss-Stiftung

JUNIOR PROFESSORS

The flagship program to support young scientists who have already shown great distinction in their academic development is the Junior Professorship. This career track is exclusively for those who can be entrusted with full academic rights to pave their predetermined way into a permanent position in science. ASP attracts exceptionally innovative young scientists to a career in Jena, at an early stage. Junior Professors have the status of principal scientists within ACP. Since 2010, already seven Junior Professors in optics and photonics have become tenured and are strongly involved at teaching within ASP, while three others have gained permanent positions at other universities. For example, in 2016 former ACP Junior Professor Alexander Szameit was appointed at the University of Rostock; and in 2019, former ACP Junior Professor Isabelle Staude received and accepted the call for a permanent professorship at the Friedrich Schiller University Jena.

Lately, Dr. Giancarlo Soavi, Dr. Christian Franke and Dr. Mario Chemnitz from the University of Cambridge, the Max Planck Institute of Molecular Cell Biology and Genetics Dresdenand the Leibniz Institute Jena, respectively, have joined ACP as Junior Professors with tenure options.



Isabelle Staude, appointed as full professor at the University of Jena, is an internationally renowned expert in optical metasurfaces.

GUEST PROFESSORSHIP PROGRAM

The Abbe School of Photonics acquires international first-hand teaching experience by inviting internationally renowned experts in optics and photonics to lecture for a period up to three months here in Jena. The program has been established to provide our students with an overview of top-level research and to offer leading researchers the opportunity to share their work through direct contact with ACP members.

The successful ASP Guest Professorship Program (including the prestigious Carl Zeiss guest professorship) has become a truly international brand. To date, ACP principal scientists and their students have benefitted from special lectures held by more than 40 distinguished experts from all over the world. Both principal scientists and students have strongly contributed to the educational values of ASP on several levels, a contribution, which is going to be continued. First, many ASP guest professors give regular lectures within the M.Sc. Photonics program. Second, they share their perspective and expertise with the doctoral students, ACP principal scientists, and representatives from our industrial partners in devoted special lectures on the most current topics in their research fields. Last but not least, our guest professors continuously prove to open up an enormously inspiring source of novel ideas by fruitful and mostly long-term collaborations.

Since 2006, more than 70 top-ranked optics and photonics scientists have accepted our invitation to lecture in Jena for visits up to three months. With their vast experience and their cosmopolitan background in science, ASP visiting scholars regularly offer valuable feedback on our curriculum based on their personal perspectives. Some of these impressions are given here.

PROF. DR. IGOR LEDNEV

STATE UNIVERSITY OF NEW YORK
ALBANY, USA

“I find my visit to Jena most productive, intellectually stimulating and hope to develop long-term collaborations based on new contacts made here.”

PROF. YURI. S. KIVSHAR

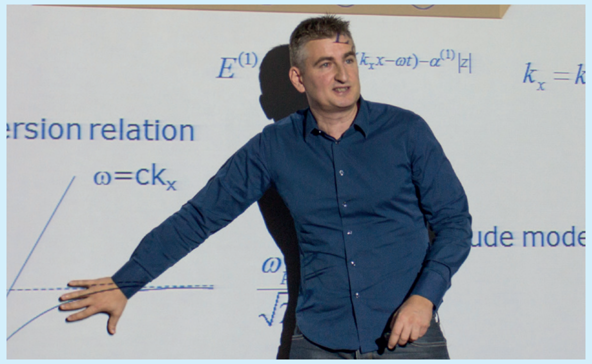
AUSTRALIAN NATIONAL UNIVERSITY
CANBERRA, AUSTRALIA

“I visited Jena many times and I believe Jena is a unique town not only as a special place for history of optics in Germany and the world. I believe the Abbe Center of Photonics has the largest number of enthusiastic young researchers I ever met, who will definitely drive its bright future!”

PROF. FEDERICO CAPASSO

HARVARD SCHOOL OF ENGINEERING & APPLIED SCIENCE CAMBRIDGE, MASSACHUSETTS, USA

“I was enthusiastic to come to Jena – a very significant connection of science, technology, and industry exists at this place which is very fruitful. I was impressed by the broad range of ideas and their integration into practice, and by the variety and level of expertise of the doctoral students here in Jena. Their abilities to assemble complex optical setups and to develop their own scientific ideas are rarely found nowadays. So I can really say the Abbe Center is a world-class operation, that’s for sure.”



PROF. JAVIER AIZPURUA

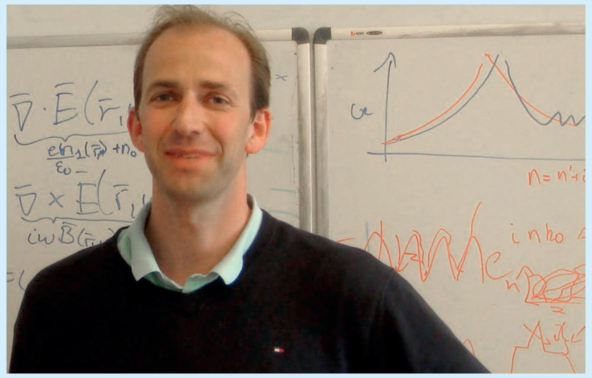
UNIVERSITY OF THE BASQUE COUNTRY
ST. SEBASTIAN, SPAIN

“It is really encouraging to be immersed in an atmosphere of cooperation and collaboration within optics, being exposed to a multidisciplinary effort that covers aspects of biochemistry, optical signaling, image formation, or chemical physics, at a very high level. It has been a privilege to visit this pole of optics!”

PROF. ANDREW BERGER

UNIVERSITY OF ROCHESTER, NY, USA

“Jena is a world-class hub for optics, and I will certainly be spreading the word back in the USA that this is a place for collaborations, visits, and student exchange.“



PROF. N. ASGER MORTENSEN

UNIVERSITY OF SOUTHERN DENMARK,
SØNDERBORG, DENMARK

“My stay at the Abbe School of Photonics has been highly rewarding and a truly exciting experience for me. Being invited to spend a sabbatical in the‚Lichtstadt’ during the International Year of Light has been a great honour for me!”

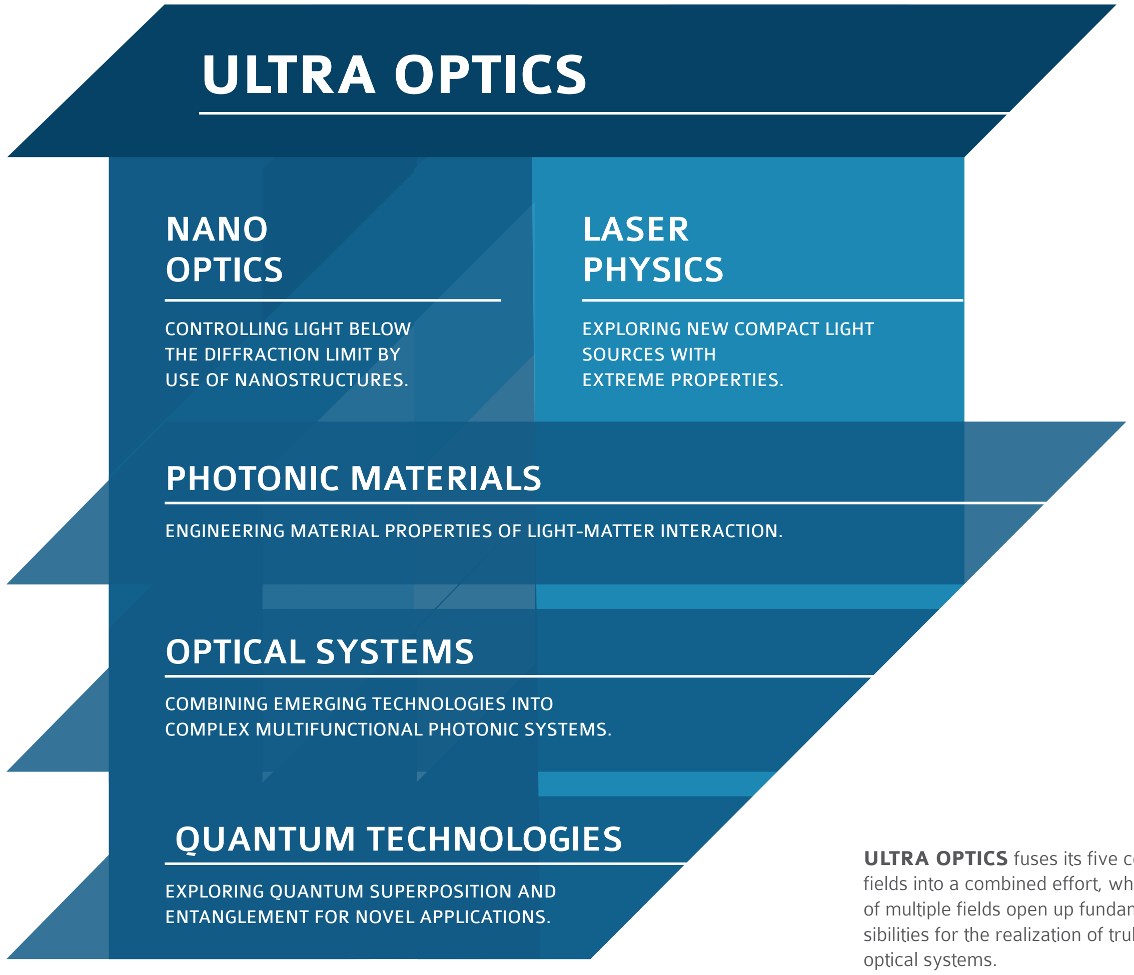
KEY
RESEARCH AREA
ULTRA OPTICS

KEY RESEARCH AREA ULTRA OPTICS

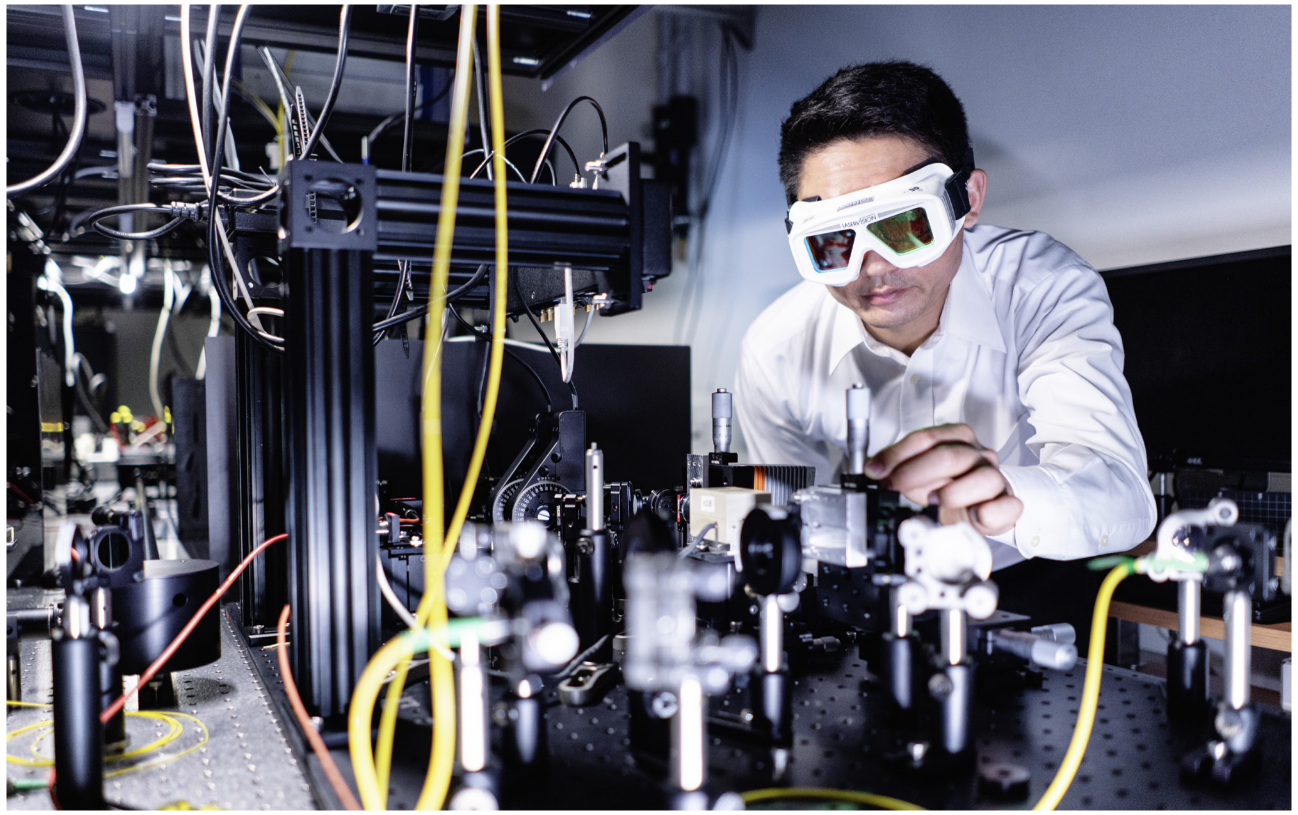
Optical technologies form an indispensable basis for addressing pressing tasks of our society. Hence they are researched, developed, and provided by the Abbe Center of Photonics (ACP). This requires complete control of light in all its properties. Firstly, this control makes it possible to initiate processes with light. Secondly, it enables the use of light as an instrument, tool or information carrier. ACP's key research area **ULTRA OPTICS** takes on this challenge as a synergistic combination of two fields of modern optics, **Nano Optics** and **Laser Physics**, with major contributions from the enabling fields **Photonic Materials, Optical Systems** and **Quantum Technologies**.

The objective of the key research area **ULTRA OPTICS** is to thoroughly control light with extreme parameters – in terms of wavelength, pulse duration, spatial concentration, and power – from basic research all the way to applications.

Initiated by the German Federal Ministry of Education and Research, **ULTRA OPTICS** was originally founded in 2005 as a Center for Innovation Competence (ZIK). **ULTRA OPTICS** was the major driving force to found ACP in order to integrate Jena's research on optics and photonics with a much wider scope. Today **ULTRA OPTICS** is a successful and mature center of research and innovation for optical technologies. At the same time, it forms an integral part of ACP to combine with the key research areas **STRONG FIELD PHYSICS** and **BIOPHOTONICS** in a synergetic way.



ULTRA OPTICS fuses its five complementary fields into a combined effort, where the synergy of multiple fields open up fundamentally new possibilities for the realization of truly multifunctional optical systems.



Spectrocsopic characterization of artificial, nanostructured photonic materials.

NANO OPTICS

Nanotechnology is an approach to understand and master the properties of light and matter at the nanoscale. It is considered to be a major factor of innovation in science and economy of this century, since it will enable to shrink and integrate optics to make it compatible to the size of electronics and to realize truly opto-electronic systems. Within this strongly interdisciplinary development, **ULTRA OPTICS'** research field **Nano Optics** conducts major efforts to provide fundamental understanding as well as key solutions to ground breaking applications, such as light harvesting, nanosized single photon sources, biophotonic sensors, nanoelectronics, and nanomedicine.

State-of-the-art nanofabrication technologies allow for the realization of optical structures with sub-wavelength and therefore sub-micron dimensions. These structures can be either tiny photonic components, such as, e.g. waveguide bends, apertures, microdiscs, and nanoantennas, or they can exhibit periodic arrangements as e.g. diffraction gratings, photonic fibers, artificial crystals and metamaterials. In close collaboration between theory, technology, and experiments, fundamental effects of **Nano Optics** are examined by ACP's scientists. Relevant, producible nanostructures are designed, modeled and characterized with the aim of realizing and using optical systems with new functionality. Examples of recent research activities of ACP's scientists targeted the strong coupling of plasmonic nanoantennas to quantum systems, the light-induced self-organization of photonic nanostructures, the synthesis of nano-scaled multiphoton light sources, or the generation and control of diffractionless plasmonic beams, just to mention a few.

LASER PHYSICS

Together with the global photonics community, ACP's principal scientists celebrated the 50th anniversary of the invention of the laser in 2010. Based on the quantum-mechanical effect of stimulated emission, which was postulated by Albert Einstein in 1917, the laser has enabled a number of seminal discoveries in modern science over the last decades. Moreover a considerable market for laser devices has been developed, which is revolutionizing industrial production and has broad impact on our daily life.

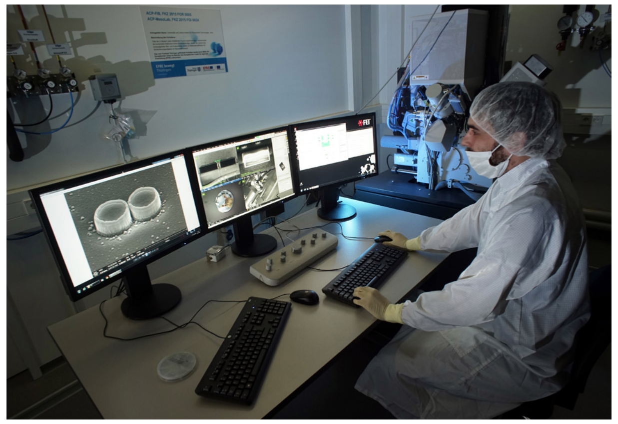
ULTRA OPTICS' research area **Laser Physics** covers activities ranging from the development of lasers able to create extreme intensities (>10^{20} W/cm^2) or ultra-high average powers above the kW barrier. It includes the control of laser radiation at ultrafast time scales as well as theoretical and experimental studies on light-matter interactions under extreme conditions and in novel structures. The research programs run by **ULTRA OPTICS** result in the invention and implementation of innovative light sources. These novel sources of light are at the same time highly integrated by the use of novel multifunctional components, as they offer some truly remarkable parameters along with flexible properties tailored to applications' needs. However, ACP's research is not limited to light sources – it also comprises the fundamental exploration of light-matter interaction, which can be accessed by them. The final aim is to develop new schemes for spectroscopic measurements, material processing, medical treatment, remote sensing, as well as to study the spatio-temporal dynamics of extreme light states.

PHOTONIC MATERIALS

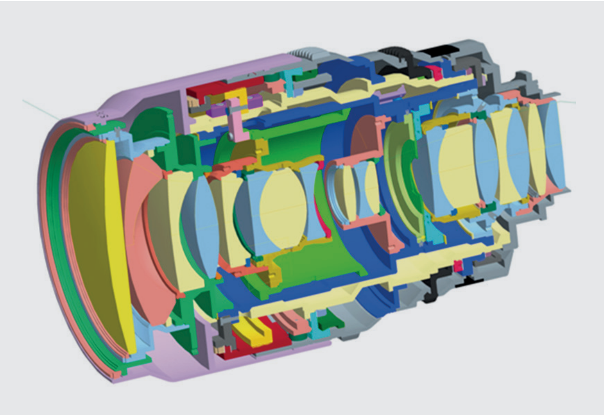
Similar to a car without a steering wheel, light would be of little use without the appropriate means to control it. With the goal of realizing complex optical systems, **ULTRA OPTICS'** expertise comprises a wide range of optical materials, including their processing into sophisticated geometric shapes, thin films, or nanostructures, as well as their combination, tailoring, and integration. Moreover, **ULTRA OPTICS** runs extensive research programs to set new trends in innovative **Photonic Materials**. In addition to the currently dominant silicon-based optics, **ULTRA OPTICS** establishes organic and inorganic carbon-based photonic materials, as well as hybrid photonic nanomaterials.

These newly emerging material platforms prospectively enable us to realize entirely novel optical, optoelectronic and mechanical properties. Among them are regimes which are unparalleled by natural materials and accordingly of fundamental interest – but must also be specifically tailored to application needs.

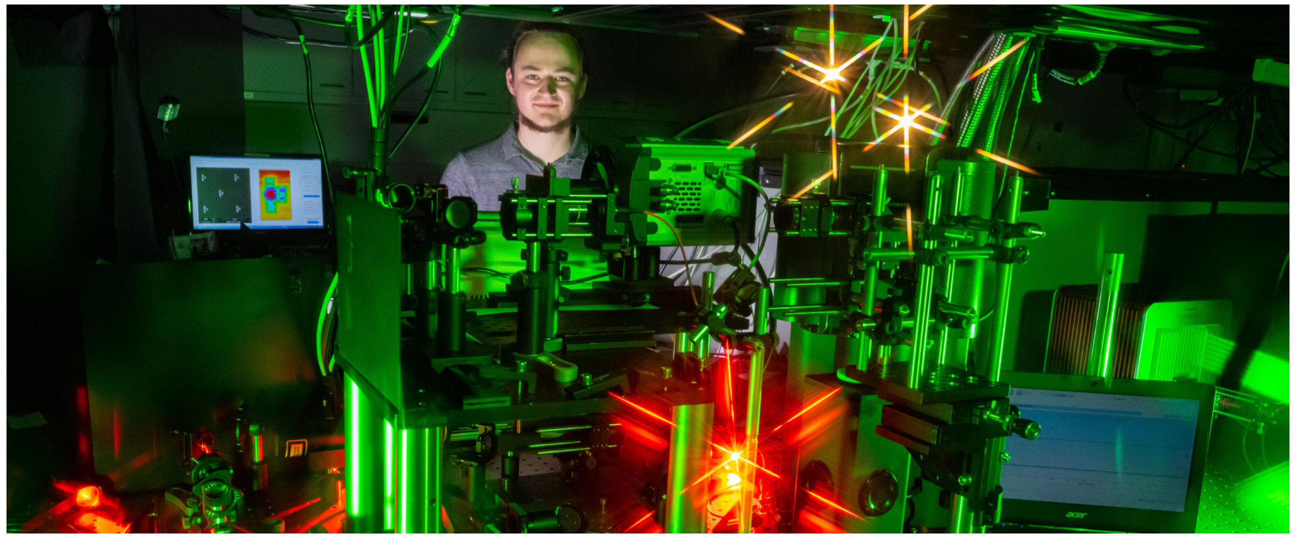
With research on novel 2D materials into opto-electronics, such as transition-metal dichalcogenides (TMDs), which naturally form mono-molecular and semiconducting sheets thinner than a nanometer but with an enormous degree of optical activity, **ULTRA OPTICS** enters an exciting area at the beginning of its development, but to which a high potential for innovation is attributed. Another class of matter, by which **ULTRA OPTICS** expects to push a fundamental perspective shift to the field of optics, is constituted by photonics metasurfaces. Their optical properties are rather determined by sophisticated nanostructures than by the original constituents of which these structures are composed. Hence, photonics metasurfaces' properties can be widely tailored to cover a wide range by changing the geometrical topographies at the nanoscale level. Consequently, they can access parameter ranges unavailable by existing materials so far. As an example, ACP's researchers have realized optical metamaterials which exceed the optical activity of any other available matter by several orders of magnitude. Technologies to fabricate these materials and surfaces range from sophisticated and high-resolution lithographic tools to approaches involving lithographically controlled chemical synthesis, which is only possible by the interdisciplinary collaborations between ACP principal scientists.



Doctoral student operating the combined focused ion beam - scanning electron microscope to visualize and characterize optical nanoresonators.



High-performance camera system for movie applications, showing the complexity of the mechanical mounting and movement kinematics.



PhD student Tobias Bucher in the nanolabs for characterizing optical metasurfaces.

OPTICAL SYSTEMS

The success of ACP is inherently connected to the ability to carry new ideas from fundamental studies all the way through to application-oriented developments. On the one hand, this is possible due to the broad expertise of ACP's scientists in many fields of photonic applications. On the other hand, it requires substantial expertise to design and realize complex **Optical Systems** from the macroscopic to the microscopic scale which include the new approaches.

Consequently, it is not only due to the local history of Ernst Abbe, Otto Schott, and Carl Zeiss that the ACP is one of the strongest places for the design and realization of modern **Optical Systems**. This involves enabling fields such as lens design, aberration theory, system metrology, and performance evaluation as well as novel approaches for electromagnetic wave-based rigorous modeling. The latter is necessary when the applications require pushing the limits of classical optics, i.e. when including diffractive elements in the system. Similarly, the given infrastructure and expertise allows ACP's scientists to realize **Optical Systems** based e.g. on lithographically defined diffractive elements, microstructured fibers produced by sophisticated drawing technologies, laser written waveguides, free-form surfaces, extreme thin-film technologies and optoelectronic signal processing. The resulting optical systems find regular use in such extraordinary applications as real time 3D shape recognition, astronomic instruments for space missions, or in next-generation instruments for gravitational wave detection.

QUANTUM TECHNOLOGIES

The emergence of quantum technologies, using the fundamental quantum effects of superposition and entanglement, is holding solid promise for a range of breakthrough applications with high societal impact. Specific examples are the encoding of unbreakable messages using quantum cryptography or orders-of-magnitude faster quantum computers. These potentials are recognized worldwide, leading to strategic funding initiatives like the Quantum Technologies Flagship of the European Union. Also within **ULTRA OPTICS**, the development and promotion of optical **Quantum Technologies** have become a major field of research. ACP's strength lies in its demonstrated ability to fuse multiple expertises to integrate available enabling technologies into a combined research effort to open up new platforms and integrated systems exploiting **Quantum Technologies**. One example is the generation of non-classical states of light, e.g. photon pairs, by spontaneous nonlinear processes in nonlinear photonic systems ranging from bulk crystals over different waveguide structures to nanostructured or atomically thin surfaces. This understanding can be used to tailor the properties of the generated two-photon quantum states, like spectrum, spatial distribution, and entanglement, to meet the demands of specific applications. Another very active research focus is the development of novel quantum light sources for applications in quantum communication and sensing, efficient processing and detection schemes for high-dimensional quantum information, as well as scalable methods for the transmission of quantum states over long distances.

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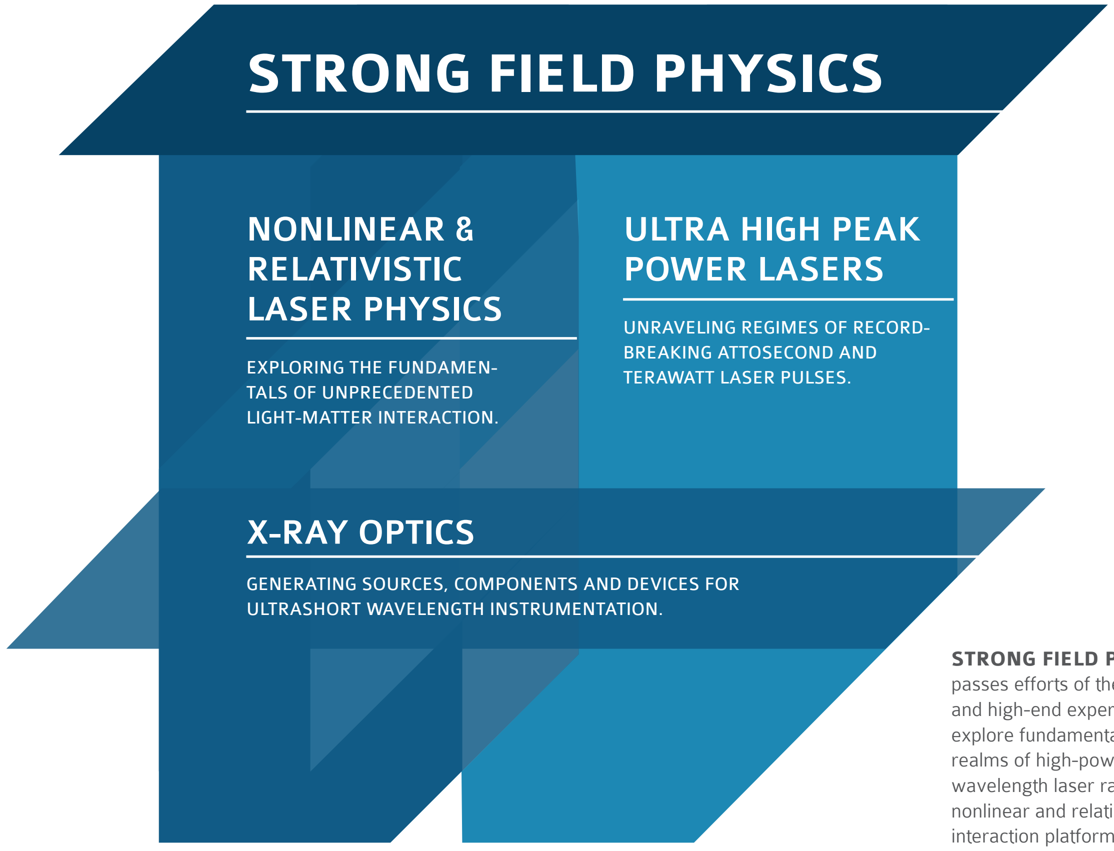
KEY
RESEARCH AREA
STRONG FIELD PHYSICS

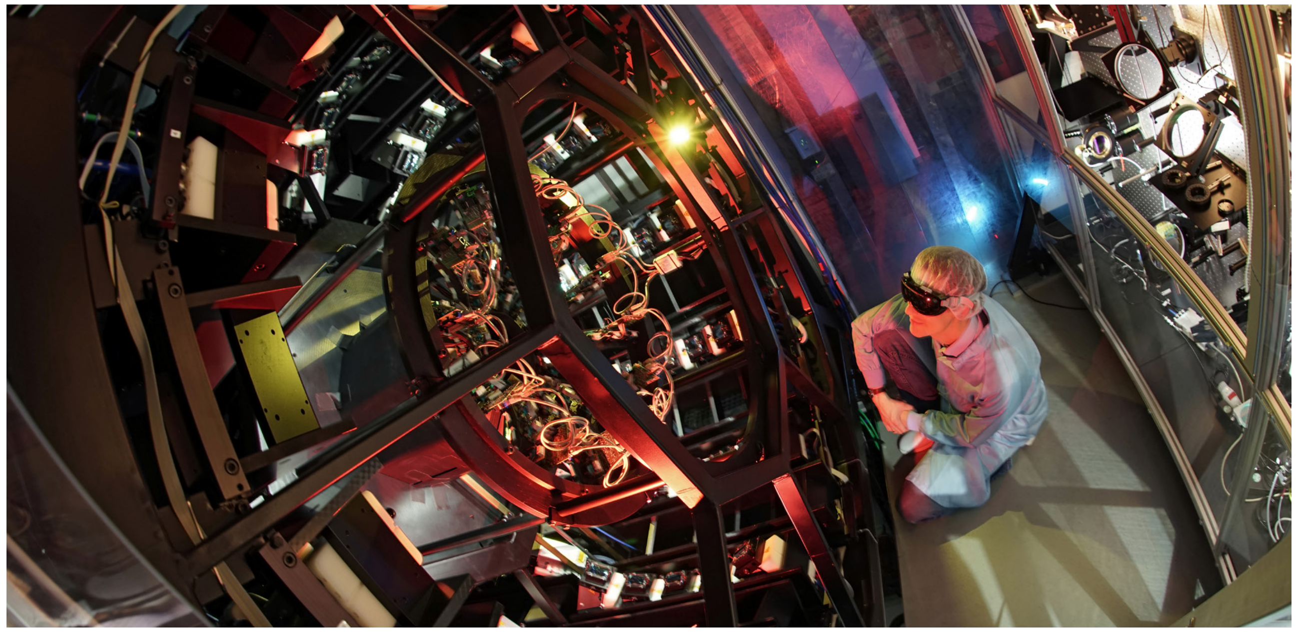
KEY RESEARCH AREA STRONG FIELD PHYSICS

The interaction of matter, ranging from atoms to solids, with laser fields stronger than 10^{14} W/cm^2, has opened new opportunities in atomic, molecular and optical physics. In the early years of nonlinear optics when strong lasers became available, laser-matter interaction could be successfully described by assuming the laser field as a perturbation, where e.g. low order harmonic generation and parametric processes were manifested. With the development of more powerful lasers, experimentation could reveal new phenomena. To explain these results, new theoretical approaches were necessary. Due to the now accessible strong field regime, the laser field strength becomes comparable to the binding field strength in an atom, thus making the perturbative description obsolete. Consequently, our physical intuition concerning optical phenomena built upon perturbative approaches needs to be re-examined. Furthermore, in order to adequately study such phenomena, more powerful lasers, as well as alternative theoretical methods, are necessary.

STRONG FIELD PHYSICS is, on its own, very well suited for answering fundamental physical questions. However, **STRONG FIELD PHYSICS** is also becoming increasingly important for a wide range of applications. These include realizing novel particle accelerators, studying plasma dynamics, paving the way for innovative x-ray sources, and functioning as the basis of attosecond science.



STRONG FIELD PHYSICS encompasses efforts of theoretical modeling and high-end experimental setups to explore fundamental effects in the realms of high-power and ultrashort wavelength laser radiation, including nonlinear and relativistic light-matter interaction platforms.



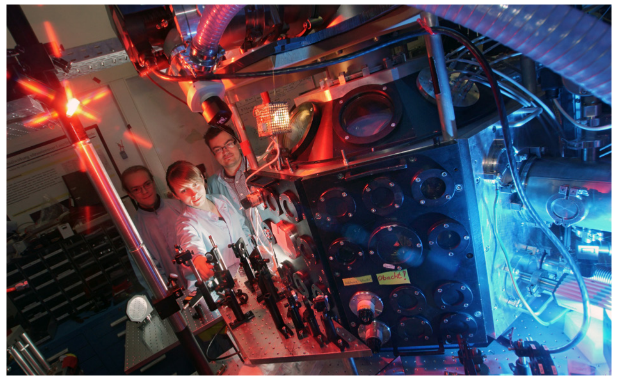
Penultimate power amplifier of the POLARIS laser system.

In particular, attosecond science is an emerging interdisciplinary research area in strong field physics centered around the study of atomic dynamics within the natural time scale of atoms. Thus, it will, for the first time, allow for the resolving and control of electronic motion in an atom including the tracking of bound electrons or investigating the electron emission process. In all of these new intriguing possibilities, the scientists at the Abbe Center of Photonics are contributing highly significant results in a variety of research fields, including the realization of new optical tools along with their study of strong field light-matter interactions. The branches addressed by ACP's key research area **STRONG FIELD PHYSICS** are the fundamental fields of **Ultrahigh Peak Power Lasers, Nonlinear & Relativistic Laser Physics**, and **X-ray Optics**.

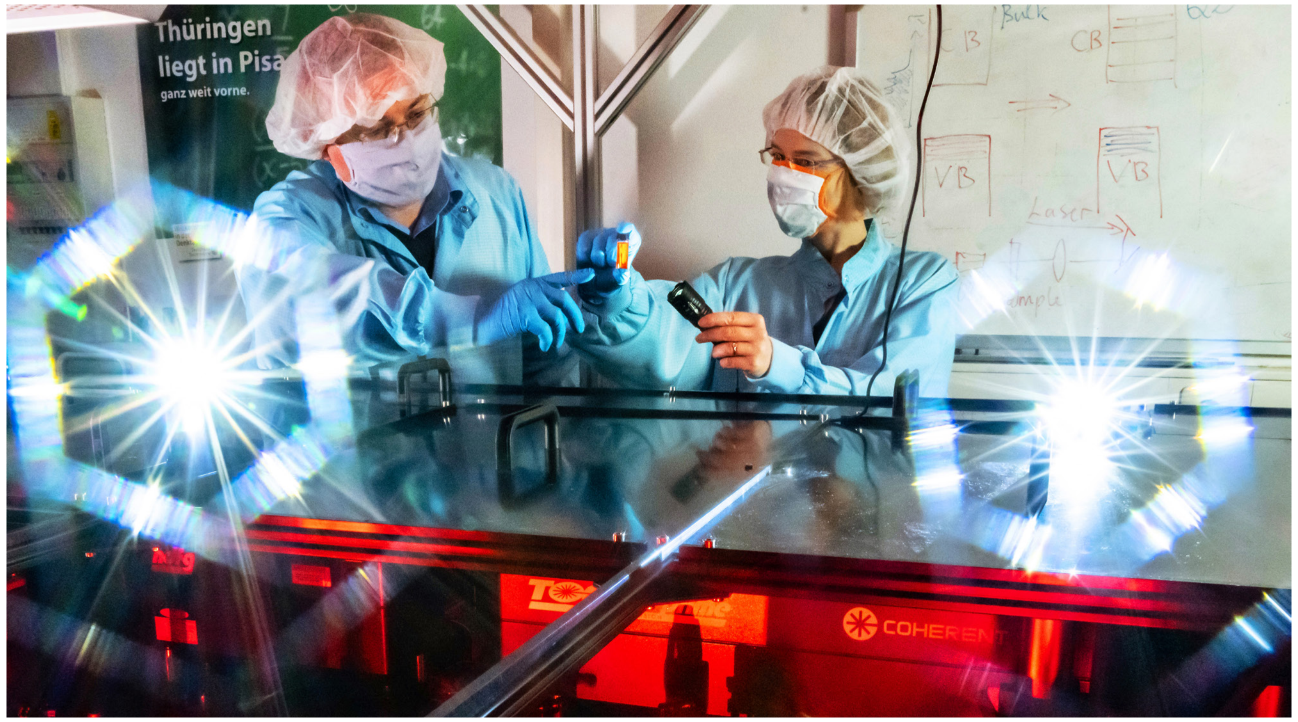
ULTRAHIGH PEAK POWER LASERS

The progress in strong field physics is inherently linked to the availability of high-power laser sources, i.e. **Ultrahigh Peak Power Lasers**. At ACP, the high-power laser systems JETI and POLARIS are in operation. While JETI is a conventional Titanium:Sapphire laser, the fully diode-pumped system POLARIS has been entirely designed, developed and commissioned by ACP principal scientists and is currently the most powerful, diode-pumped system worldwide. Both systems generate laser pulses reaching peak powers in the range of more than several 10 TW to more than 100 TW. Both JETI and POLARIS are constantly upgraded and further developed at ACP and are co-operated by the Helmholtz-Institute Jena. When focusing these laser pulses onto any kind of matter, relativistic laser-plasmas are generated which allow for state-of-the-art experiments on particle acceleration, the realization of secondary radiation sources, the study of x-ray sciences and other applications.

In the field of laser-driven particle acceleration, considerable progress has been made to boost the energy of electrons and ions. Besides increasing the final particle energy, major emphasis has been put on tailoring particle energy distribution using the laser and target parameters. Such well defined energy distributions are indispensable for significant future applications including laser-based particle accelerators for medical radiation therapy.



Setup of a new target chamber for the high-power laser system POLARIS.



Investigation of High Harmonic Generation (HHG) in nanoscale semiconductors, reveiling ultrafast charge and electron dynamics.

NONLINEAR & RELATIVISTIC LASER PHYSICS

Spectroscopy on highly charged ions is ideally suited for answering fundamental questions about atomic structure. In order to comprehend experimental observations, theoretical modelling including nonlinear light-matter interactions, quantum electrodynamics (QED) as well as relativistic correlations must be applied. Within the field of **Nonlinear & Relativistic Laser Physics**, ACP theoreticians are among the leading experts in this field. Moreover, the theoretical predictions are applicable for an extended laser intensity regime, to be reached in the next generation of laser sources which are currently under development at the European level with strong involvment of ACP's expertise.

X-RAY OPTICS

During strong field interaction with matter, secondary radiation is also emitted. Depending on the laser intensity and the kind of matter, the emitted radiation ranges from the THz to the x-ray region. Major advantages of laser-based sources are their spatial and temporal coherence. Whereas THz emission is studied at ACP on a mainly theoretical basis, there are many activities within the Center which concentrate on the generation and application of novel sources for **X-ray Optics**. Applications include the lens-less imaging of nanostructures and the study of structural dynamics with time-resolved x-ray diffraction or spectroscopy. To realize such demanding experiments, ACP scientists are also involved in the development of new x-ray optical components, encompassing polarimeters, spectrometers, and detectors. Based on developmental progress of the new x-ray instrumentation, ACP scientists are, in cooperation with the GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt, at the forefront in applying x-ray spectroscopy on highly charged ions.

Extreme light-matter interaction experiments, for instance the access to ultrashort wavelengths, are performed by studies of femtosecond laser radiation in a vacuum or in a noble gas environment.

WORLDWIDE STRONG FIELD PHYSICS COLLABORATIONS

Both the experimental and theoretical work done by ACP scientists involved in the key research area of **STRONG FIELD PHYSICS** are highly demanding and require collaborative efforts. Hence, ACP researchers are strongly involved in many national and international research alliances which grant access to large-scale research infrastructures including high-power lasers and accelerators. Besides several national and international synchrotron sources, equipment includes the x-ray free electron lasers in Hamburg and at Stanford University (USA), as well as particle accelerators in Darmstadt and Lanzhou (China).

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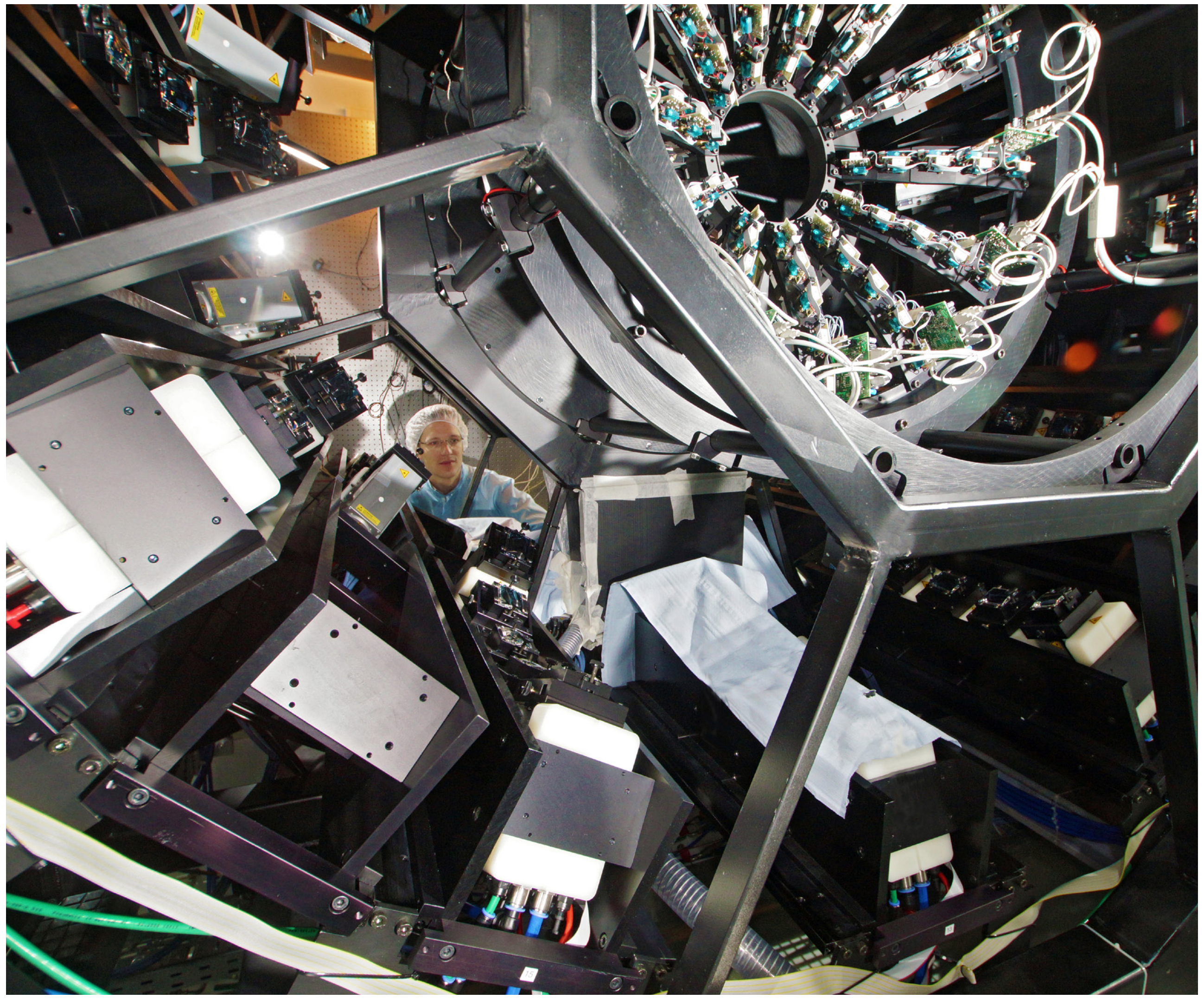


Installation of the final power amplifier of the POLARIS laser system.

KEY
RESEARCH AREA
BIOPHOTONICS

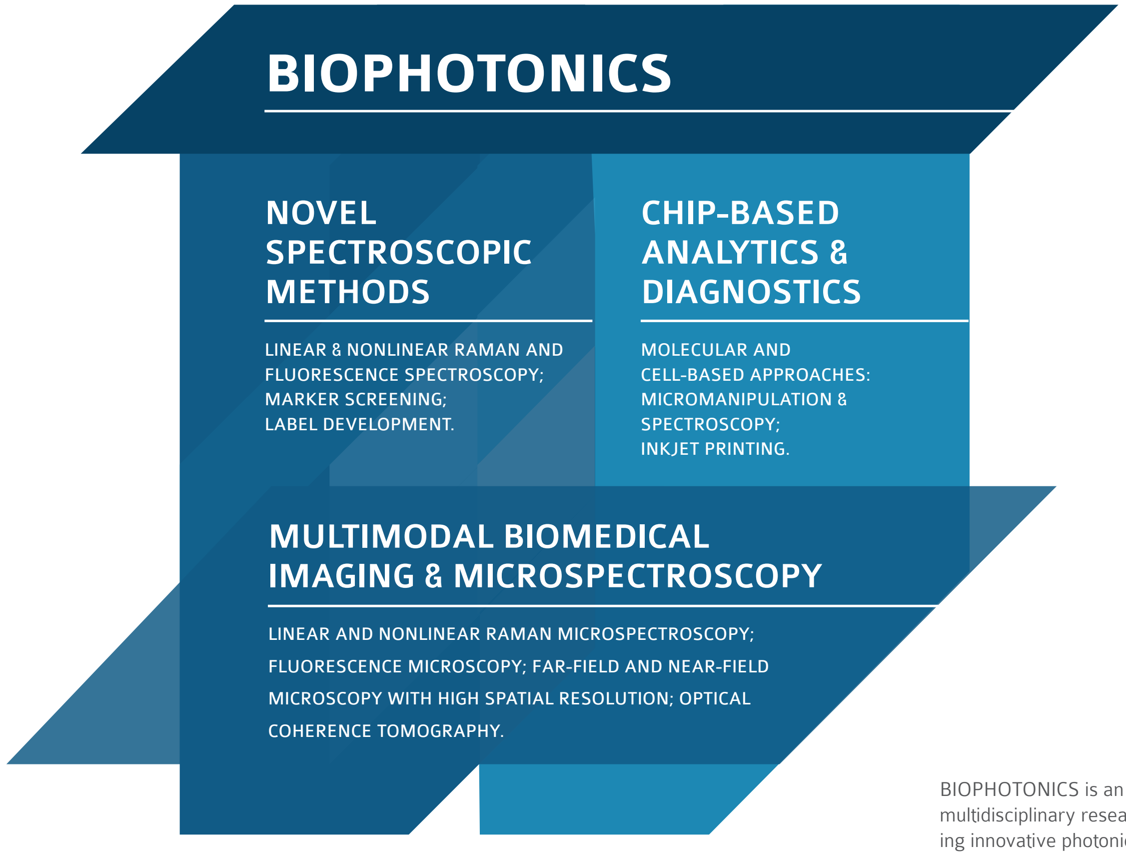
KEY RESEARCH AREA BIOPHOTONICS

Understanding the origins of diseases, diagnosing them early, and curing them with targeted therapies – these are the visions of contemporary biomedicine. In ACP's key research area **BIOPHOTONICS**, light is utilized as a tool to turn these visions into reality. Light enables the examination of life processes in cells, cellular networks and tissues down to the molecular level and can serve as an ideal tool for in vivo diagnosis and therapy, paving the way towards minimally invasive medicine. Throughout the last decade, **BIOPHOTONICS** has developed into a coherent scientific discipline of high societal and economic importance.

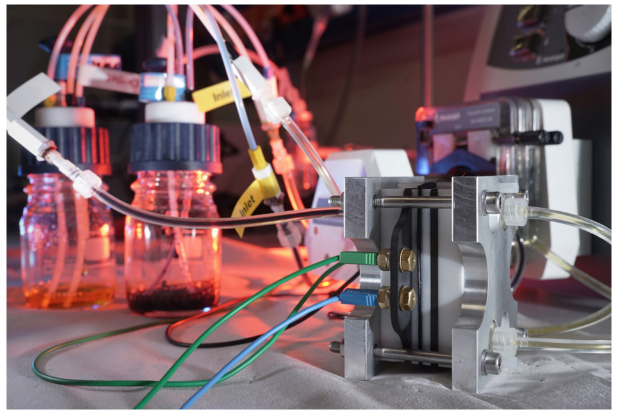
RECOGNIZING DISEASES AT THE MOLECULAR LEVEL

From a global perspective, **BIOPHOTONICS** has already provided major innovations for biomedical research and clinical routine. In biomedical research, the recent development of ultrahigh resolution microscopy is providing novel insight into the nanoworld. Now processes in living cells and the development of diseases can be studied in greater detail. Spectroscopic and multimodal imaging methods contribute complementary information on cell function and metabolism. These findings help in developing targeted therapies that treat diseases right at their origin – possibly even before manifest symptoms appear. **BIOPHOTONICS** research at the Abbe Center of Photonics explores methods that provide deeper insights into complex biological samples of different size, starting from organs via tissue sections, cells, viruses, down to DNA and RNA.

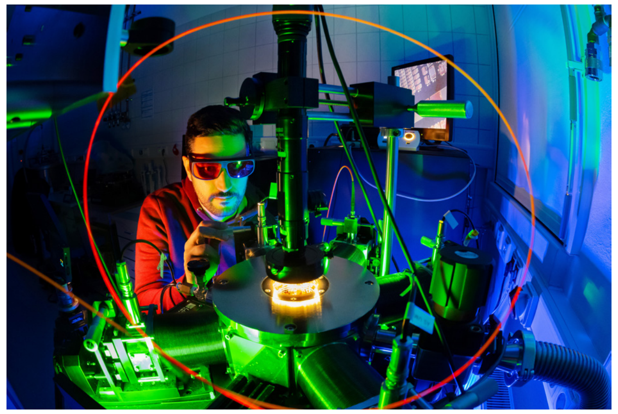
In clinical routines, photonic technologies enable early and sensitive and accurate recognition of diseases, as well as their gentle treatment. Fluorescent imaging has become an important method in the in vivo detection of cancer and can guide the surgeon with greater precision while operating. Current research aims to refine these techniques and detect tumors as small as one millimeter in diameter. Marker-free imaging methods, like Raman and near-infrared spectroscopy, are also developing towards *in-vivo* application and will provide even more detailed diagnostic information. The research performed by ACP scientists utilizes and develops these methods according to the needs of pathology, oncology, and sepsis research. In the field of sepsis, the fast and unambiguous identification of pathogens, their resistances and the specific host response is urgently needed to save lives in intensive care units. Thus photonic technologies hold great promise in addressing this challenging task.



BIOPHOTONICS is an emerging, highly multidisciplinary research area embracing innovative photonic tools applied to the life sciences and medicine.



In nutritional sciences, biochips are developed to identify the genetic footprint of particular bacteria.



PhD student Emad Najafidehaghani characterizing optoelectronic properties of nanomaterials at his laser setup.

PROVIDING LIGHT-BASED TOOLS FOR MEDICINE AND THE LIFE SCIENCES

The **BIOPHOTONICS** research at ACP is based on three complementary fields of technology: **Novel Spectroscopic Techniques, Multimodal Biomedical Imaging & Microspectroscopy**, and **Chip-based Analytics & Diagnostics**. The platform of **Novel Spectroscopic Techniques** covers, among others, linear and non-linear Raman spectroscopy and fluorescence spectroscopy. By nature, these spectroscopic methods are strongly cross-linked with a second enabling technology field, namely that of **Multimodal Biomedical Imaging & Microspectroscopy**. Biomedical imaging delivers spatially and temporally resolved information on the distribution of biomolecules in living cells or their environment (molecular imaging). Promising solutions include far-field and wide-field techniques of super-resolution microscopy, Raman and fluorescence microscopy as well as optical coherence tomography. Additionally, questions concerning statistical data and image analysis are in the focus. The field of **Chip-based Analytics and Diagnostics** includes lab-on-a-chip biosensors based on microfluidic and optofluidic technology, miniaturized spectroscopy, and molecular diagnostics. In combination with the **Novel Spectroscopic Techniques**, such biosensing technologies are utilized for the highly sensitive and selective detection of biomarkers and pathogens from biological samples, like tissue sections or bodily fluids. The target molecules indicate specific biological states, e.g. diseases like cancer or sepsis. An important task is the provision of suitable labels, i.e. of molecules that specifically couple to the target molecule and thus enable their detection. Especially fluorescence spectroscopy requires these labels, as many biomolecules do not show sufficient autofluorescence, but also Raman spectroscopy can benefit from the use of labels, like e.g. in surface-enhanced Raman spectroscopy (SERS). The applied technologies in **BIOPHOTONICS** hold great promise to reveal correlations between the metabolic state of cells with the pathophysiological state of tissues.

RESEARCH DRIVEN BY USERS' NEEDS

BIOPHOTONICS research at ACP benefits largely from the scientific and industrial expertise gathered in Jena, ranging from optics and photonics to medicine and the life sciences. Along with potential technological innovations, users' needs are essential research drivers at ACP, and end users as well as suppliers are involved right from the start. In particular, clinical biophotonic research is becoming focused on technology-driven solutions, which should address both the pressing unmet medical needs of hospitals and patients, as well as the potential of transferring solutions to industry. Therefore, ACP's efforts toward valuable development continually overlook the real-world application of routine clinical diagnostics and therapy.

Through intensive preclinical testing, the quality of the newly developed diagnostic and therapeutic approaches is evaluated, prompting the transfer of results to industry as well as the initiation of formal clinical trials. This strategy helps overcome a typical bottleneck in **BIOPHOTONICS** research, which nowadays generally seems too technology-driven, and generates significant innovations at the interface of optical analysis, photonic technology, and biomedical diagnostics.

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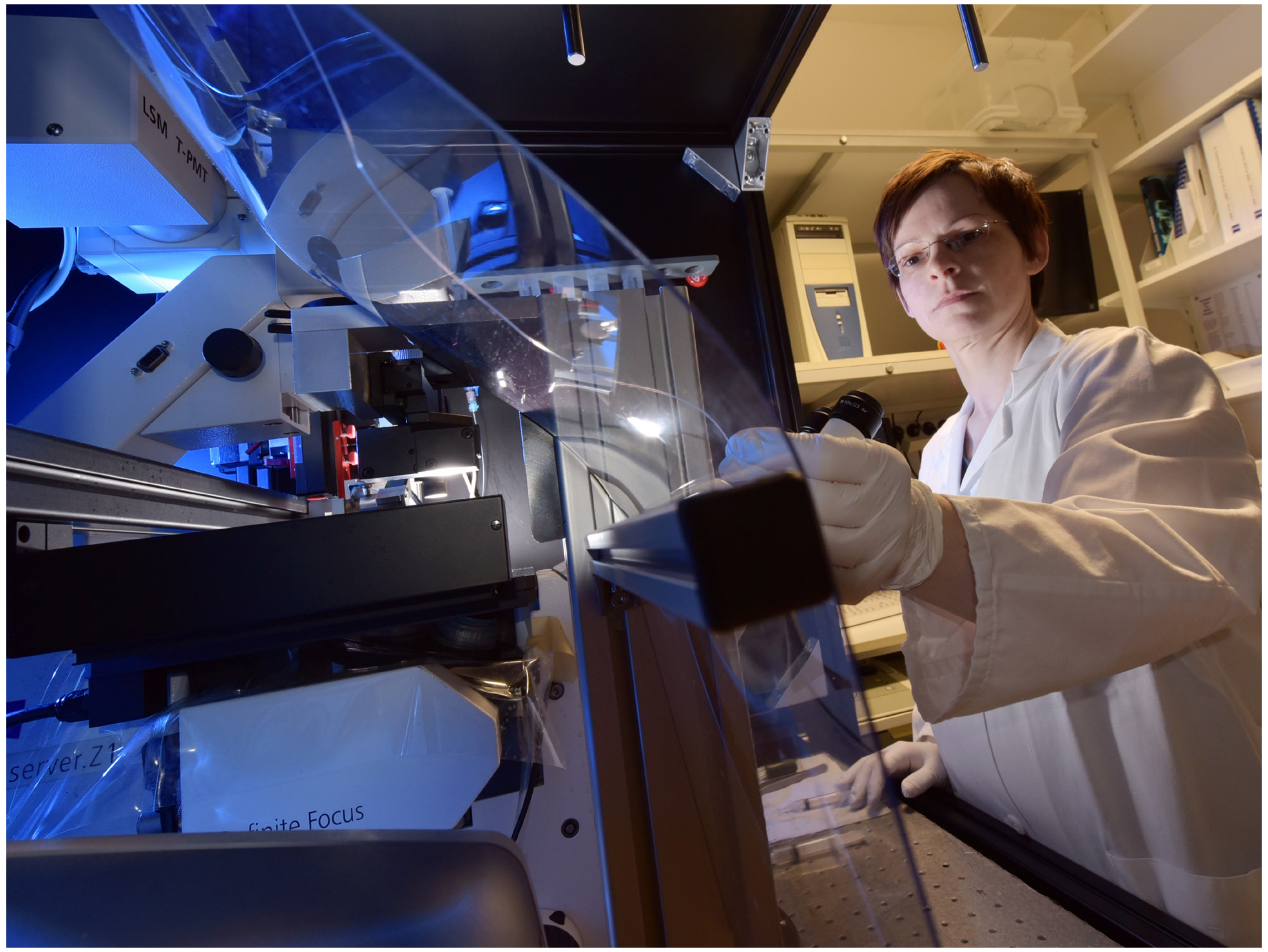

BIOPHOTONICS explores the potential of light in life sciences and medicine, for instance by biomedical imaging techniques to identify cancerous tissue.

Raman microspectroscopy is applied, among others, for cancer diagnosis.

PRINCIPAL SCIENTIST PROFILES

MICHAEL BAUER

PROFESSOR FOR ANESTHESIOLOGY & INTENSIVE CARE AT DEPT. OF ANESTHESIOLOGY & INTENSIV CARE MEDICINE

Prof. Bauer is a member of several collaborative research groups in particular the LPI addressing the use of biophotonics for pathogen detection. They also study cellular functions in the continuum of infection, host response and the development of organ failure. He is chief-executive director of the Center for Sepsis Control Care (CSCC) at the Jena University Hospital.

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RESEARCH AREAS

Prof. Bauer heads a group addressing molecular mechanisms and prevention of organ failure in life-threatening infections. Key components of this research reflect strategies for early detection of pathogens and the ensuing immune response. Research interests include:

- Culture-independent pathogen detection (in cooperation with Prof. Popp)
- *In vivo* visualization of cellular redox state and function(s), such as dye uptake and excretion
- Nanomedicine
- Plasmonics to describe the host reponse

TEACHING FIELDS

Prof. Bauer's teaching covers aspects of pathophysiology and molecular aspects in critical care medicine with a focus on life-threatening infections:

- Fundamentals of oxygen transport, energy metabolism and redox state
- Systems biology of infection, sepsis and organ failure

RESEARCH METHODS

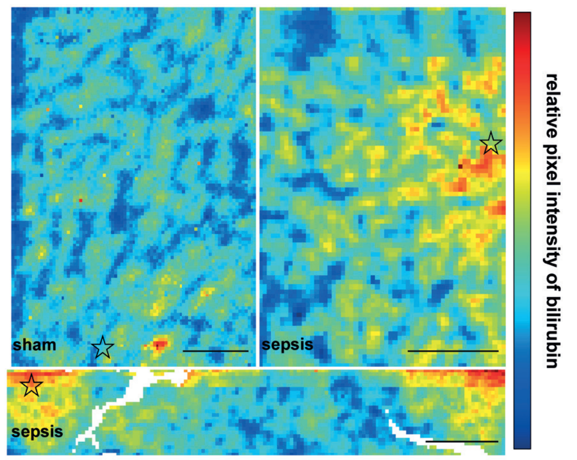
The laboratories led by Prof. Bauer offer a full range of molecular biology techniques with special emphasis on multi-omics and in vivo microscopy of solid organs, including:

- *In vivo* (fluorescence) microscopy to study cellular redox state, function and integrity
- Complementary application of Raman spectroscopy (in cooperation with Prof. Popp)

RECENT RESEARCH RESULTS

The group focuses on changes in metabolism, functionality and signal transduction in various tissue and cell types, such as macrophages and hepatocytes, that control progression or resolution of host defense and organ failure. Extensive characterization of the host response to bacterial and fungal infections, in particular through immunophenotyping and metabolomics, carried out by combination of biophotonic with ‚Omics'-approaches and subsequent modeling is used to define subtypes of the host response to life-threatening infections. This approach allows us to apply innovative therapies, in particular nanostructured carriers for delivery of kinase inhibitors as cargos to restore central cellular signalling functions.

MICRO-RAMAN SPECTROSCOPY TO STUDY HEPATIC METABOLISM AND EXCRETORY FUNCTION



Concentrations of endogenous bilirubin were studied in the various regions of the hepatic acinus using micro-RAMAN spectroscopy (see figure) along with a detailed characterization of its export machinery and potential molecular regulators. Transcripts encoding the transporter were among those mRNAs related to biotransformation that showed a strong association with the predicted outcome of sepsis. As opposed to current thought, liver dysfunction was identified as an early and commonplace event in sepsis disease, in which signaling events amenable to drug therapy play a crucial role. Effector mechanisms of hepatic biotransformation can be visualized by Raman spectroscopy at the subacinar level. These observations carry important implications for the diagnosis, monitoring and pharmacotherapy of the critically ill.

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[2] Press et al., NPG Asia Materials 9, e444 (2017).
[3] Schaarschmidt et al., Theranostics 8, 3766 (2018).

CHRISTOPH BISKUP

PROFESSOR OF BIOMOLECULAR PHOTONICS, JENA UNIVERSITY HOSPITAL

Prof. Biskup is head of the Biomolecular Photonics Group at the Jena University Hospital. He is a member of the board of directors of the Jena Center of Medical Optics and Photonics (CeMOP) and head of the examination committee of the interdisciplinary M.Sc. program Medical Photonics.

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RESEARCH AREAS

One of the aims of the Biomolecular Photonics Group is to establish new photonic techniques and to incorporate them into biologiccal research. The focus is to develop and apply new quantitative multidimensional fluorescence microscopy techniques. Research interests include:

- Multidimensional fluorescence lifetime imaging
- Optical protein-protein and protein-DNA interaction assays
- Structure-function relationships of ion channels
- Indicators and nanosensors for ions and biomolecules

TEACHING FIELDS

Prof. Biskup is head of the examination committee of the interdisciplinary M.Sc. program Medical Photonics. He gives lectures and courses in:

- Anatomy and physiology (for students of Medical Photonics)
- Microscopic techniques (for students of Medicine , Molecular Medicine and Medical Photonics)
- Image processing

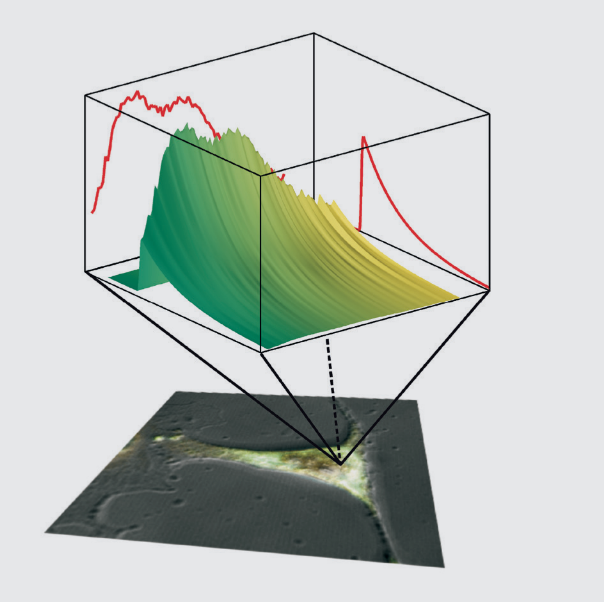
RESEARCH METHODS

The laboratories of the Biomolecular Photonics Group offer a wide range of methods used at the interface of physiology, physics and chemistry, including

- Standard molecular biology techniques, cell culture
- Fluorescence and confocal laser scanning microscopy
- Fluorescence spectroscopy
- Spectrally resolved fluorescence lifetime measurements based on time-correlated single photon counting and streak camera measurements
- Patch-clamp fluorometry

RECENT RESEARCH RESULTS

In conventional fluorescence microscopy, solely information conferred by the fluorescence intensity is used to delineate microscopic structures or perform quantitative measurements by using fluorescent indicator dyes. However, a fluorophore is not only characterized by the intensity of the emitted light, but also by its absorption and emission spectra, by its lifetime in the excited state and by the polarization of the emitted light. The Biomolecular Photonics Group has established several techniques that allow several of these parameters to be recorded simultaneously from a microscopic sample.



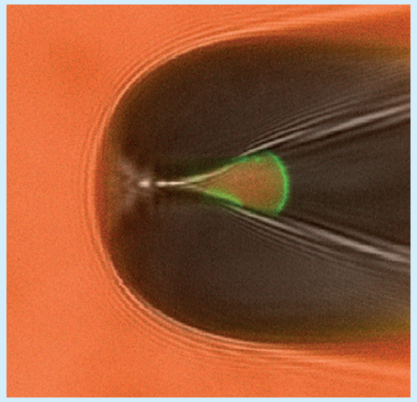
Fluorescence decay surface recorded by using multidimensional fluorescence microscopy techniques. For each voxel of a cell a time-resolved fluorescence spectrum is recorded.

Techniques to record time-resolved fluorescence spectra are based on a streak camera system [1] or on the time-correlated single photon counting (TCSPC) technique [2, 3]. Instead of a single fluorescence decay curve, which is obtained by conventional techniques, a fluorescence decay surface can be reconstructed from the data ob-tained by these techniques (see figure).

These techniques can be used to prove the molecular vicinity of proteins by exploiting Förster resonance transfer (FRET). FRET between appropriately labeled proteins occurs only when the labels are in close vicinity (< 10 nm) to each other. Despite a light microscope's limited resolution, protein interaction can be visualized in this way [4]. The interaction of key players in cellular signal transduction cascades can be investigated, and the effectiveness of pharmaceuticals to stimulate or inhibit a signal transduction cascade can easily be assessed in high throughput assays.

CONFOCAL PATCH-CLAMP FLUOROMETRY

By combining optical and electrophysiological techniques, the gating of ion channels can be correlated to other events such as the binding of ligands or conformational changes. By using fluorescently labeled cyclic nucleotides, ligand binding and activation of CNG- and HCN channels was studied. This technique will now be applied to other ligand-activated channels. The figure on the right, reproduced from Biskup et al., Nature 446, 440 (2007), shows a confocal image of an excised membrane patch containing olfactory CNG channels. The ligand cGMP was coupled via a spacer to the green fluorescence dye DY-547 and stains the patch membrane by binding to the channels. The bath solution was counterstained with the homologous red dye DY-647.



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THOMAS BOCKLITZ

HEAD OF LEIBNIZ-IPHT DEPARTMENT "PHOTONIC DATA SCIENCE"

PD Dr. Thomas W. Bocklitz studied physics and earned his PhD in Chemometrics from the Friedrich Schiller University Jena, Germany. He is head of a research department "Photonic Data Science" at the Leibniz Institute of Photonic Technology. His research agenda is closely connected with the translation of physical measurements into bio-medical relevant information. Dr. Bocklitz received the Kowalski-award in 2015 and the Kaiser-Friedrich research award in 2018 together with the CDIS team. In 2024, he was appointed full professor at the Institute of Physical Chemistry at the Friedrich Schiller University Jena.

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RESEARCH AREAS

Dr. Bocklitz's research interests are focused on the application of data science methods:

- Machine learning (ML) for photonic image data
- Chemometrics and ML for spectral data
- Correlation of different measurement methods and data fusion of the measurement data

TEACHING FIELDS

Dr. Bocklitz teaches undergraduate courses in mathematics for chemist (B.Sc.) as well as classes in fundamental physical chemistry (M.Sc. Chemistry). He is give lectures in chemometrics for M.Sc. Medical Photonics students and workshops in the JSMC.

RESEARCH METHODS

The department headed by Dr. Bocklitz is theory-oriented. While the calculation equipment is constantly upgraded, computational methods are developed in-house and include:

Machine learning for photonic image data:

- Classical machine learning methods
- Deep learning methods, like image classifiers, methods for semantic segmentation and GANs
- Data preprocessing and data standardization based on inverse modelling

Chemometrics and ML for spectral data:

- Multivariate statistics and machine learning methods for spectral data
- Deep learning models for pretreatment and spectral analysis
- Data preprocessing and data standardization based on inverse modelling

Correlation of different measurement methods and data fusion of the measurement data:

- Data fusion of various data type combinations
- Co-registration and spatial correlation of measurements

RECENT RESEARCH RESULTS

The Bocklitz research group investigates the entire data life cycle of photonic data, which extends from data generation to data modelling, data learning and archiving. The data life cycle is considered in a holistic approach and methods and algorithms for experiment planning, sample size planning [1], data pre-treatment and data standardization [2] are investigated. These procedures are combined with chemometric procedures [3], model transfer methods [4] and artificial intelligence based techniques [5] in a data pipeline. This holistic approach allows the use of data from various photonic processes for material characterization and medical diagnostics. Further focal points of the research department are the data fusion of different heterogeneous data sources [6], the simulation of different measurement procedures in order to optimize correction procedures, methods for the interpretation of analysis models [7] and the construction of data infrastructures for different photonic measurement data, which guarantee the FAIR principles [8].

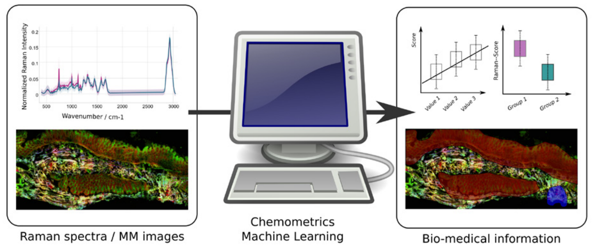
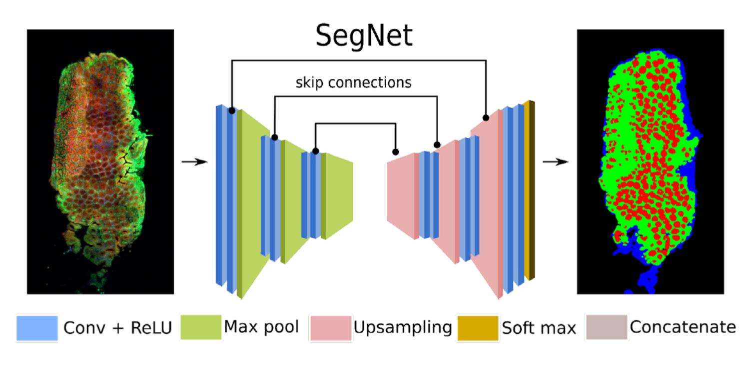


Figure 1: Translation of physical measurements (Raman spectra and multimodal images) on the left side into biomedical information like diagnostic markers on the right side.

SEMANTIC SEGMENTATION OF NON-LINEAR MULTIMODAL IMAGES FOR DISEASE GRADING OF INFLAMMATORY BOWEL DISEASE – A SEGNET-BASED APPLICATION



Non-linear multi-contrast microscopy is the combination of coherent anti-stokes Raman scattering (CARS), two-photon excited fluorescence (TPEF) and second harmonic generation (SHG), and it has shown its potential to diagnose different inflammatory bowel diseases (IBDs). Non-linear multi-contrast microscopy can quantify biomolecular changes in the crypt and mucosa region, which serve as a predictive marker for IBD severity. To use the multi-contrast images for IBD severity determination, an automatic segmentation of the crypt and mucosa regions must be performed. In the presented study, we semantically segment the crypts and the mucosa region using a deep neural network, i.e. a SegNet. The semantic segmentation based on the SegNet architecture is compared to a classical machine learning approach, which revealed that the trained SegNet model achieved an overall F1 score of 0.75 and outperformed the classical machine learning approach for the segmentation of the crypts and the mucosa region (Pradhan et al. ICPRAM 1, 396 [2019]).

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[3] Guo et al., Chemometrics in Raman Spectroscopy, Molecular Sciences and Chemical Engineering, Elsevier (2020).
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[5] Pradhan et al., J. of Biophotonics 13, e201960186 (2020).
[6] Ryabchykov et al., Frontiers in Chemistry 6, 257 (2018).
[7] Bocklitz et al., ICPRAM 1, 874 (2019).
[8] Steinbeck et al., Research Ideas and Outcomes 6, e55852 (2020).

MICHAEL BÖRSCH

PROFESSOR OF MICROSCOPY METHODS, JENA UNIVERSITY HOSPITAL

Single-molecule spectroscopy and super-resolution fluorescence imaging of membrane proteins are the topics of our Biophysics Group at the Faculty of Medicine. As a Professor of Microscopy Methods, Michael Börsch has applied single-molecule FRET for nearly 25 years to monitor individual biological nano-machines at work. He is an Adjunct Assistant Professor at SUNY Upstate Medical University (NY, USA) and was a visiting scholar at Stanford University from 2012 to 2014, concentrating on single-molecule research with Prof. W. E. Moerner (Nobel Prize in Chemistry 2014). Prof. Börsch is a member of SPIE and of the Biophysical Society.

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RESEARCH AREAS

Our Single-molecule Microscopy Group investigates conformational dynamics of single cellular nano-motors, pumps and receptors, for example the enzyme FoF1-ATP synthase. We attach two dye molecules specifically to subunits of these machines and measure their distances continuously within the single protein using Förster resonance energy transfer (FRET). The distance changes manifest the sequences of conformations during either catalysis or transport. Recently, we started super-resolution microscopy with structured illumination (SIM) and single-molecule localization (STORM/PALM) for the imaging of single bacterial and yeast proteins. Stimulated emission depletion (STED) microscopy with FLIM and homoFRET complements our high-resolution microscopy work.

TEACHING FIELDS

My areas of teaching include

- Interdisciplinary lectures on proteins, bio-membranes, single-molecule spectroscopy and super-resolution microscopy
- Directing research labs on single-molecule FRET analysis of proteins
- Practical courses on membrane protein purification, protein-labeling and activity measurements, diffusion- and mobility analysis
- Supervising internships and Master's theses spanning topics from optics to biophysics

RESEARCH METHODS

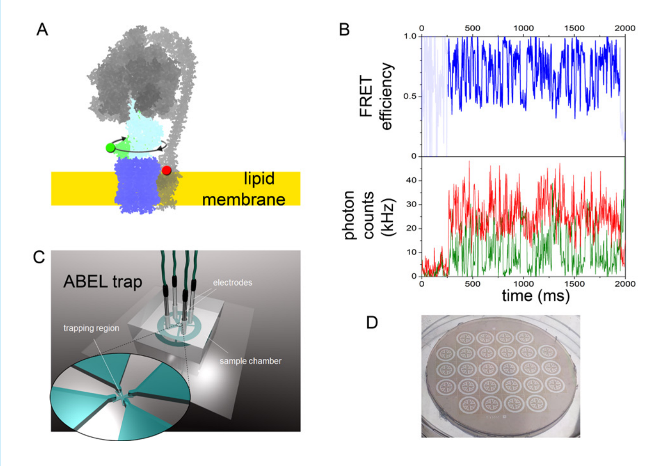
- Nikon N-SIM / N-STORM super-resolution microscope
- Abberior STED microscope combining 7 pulsed lasers between 440 nm and 660 nm, 2-photon laser system and 4 STED lasers

RECENT RESEARCH RESULTS

We use custom-built confocal microscopes for in vitro single-molecule FRET measurements in solution, equipped with 3D piezo scanners. Lasers provide continuous-wave excitation at 473 nm, 488 nm, 514 nm, 532 nm, 594 nm, 658 nm and 785 nm. Picosecond-pulsed lasers exist from 405 nm to 635 nm, and a super-continuum laser covers the spectrum from 450 nm to 2200 nm. TCSPC electronics count photons simultaneously for up to 6 avalanche photodiodes. Data-acquisition and analysis software was written by our group and includes calculation of fluorescence lifetimes, auto- and cross correlation functions [2], anisotropy and FRET efficiencies at arbitrary time intervals, as well as Hidden Markov Models for analysis of sequential dynamics. One microscope is dedicated for single-molecule FRET and two more for Anti Brownian Electrokinetic trap (ABEL trap) setups [3].

Our biochemical laboratory in Jena is fully equipped to perform cell growth (10-L fermenter system), enzyme purification (FPLC for Ni-NTA, ion exchange and size-exclusion columns, [1]), fluorescence-labeling and ATP-synthase activity measurements [4]. Additional equipment is accessible through central research facilities of the Jena University Hospital (i.e., ultracentrifuges, ultrasonifier systems and fluorescence spectrometers), located in the same building. In our chemistry lab, we produce PDMS microfluidic devices for the ABEL trap in collaboration with the Leibniz Institute of Photonic Technology Jena.

MONITORING CONFORMATIONAL DYNAMICS OF SINGLE MEMBRANE ENZYMES AT WORK



We applied a single-molecule biophysics approach to study conformational dynamics of individual membrane enzymes FoF1-ATP synthase using Förster resonance energy transfer (smFRET) in a confocal microscope [4]. We modified the enzyme by introducing cysteines at two sites and labeled FoF1 with two fluorophores (see green and red dots in Figure 1A). FRET-labeled FoF1 molecules were reconstituted as single proteins in artificial lipid membranes (liposomes) with diameters ranging from 120 to 150 nm. FoF1 subunit rotation upon ATP hydrolysis was observed as distance fluctuations between the two marker dyes (see blue FRET efficiency trace in Figure 1B). To extend observation times for these proteoliposomes in solution, we used a microfluidic device called the Anti-Brownian electrokinetic trap (invented by A. E. Cohen and W. E. Moerner at Stanford). In collaboration with the Leibniz Institute of Photonic Technology Jena, we produced these devices using PDMS polymers (see Figures 1C and D).

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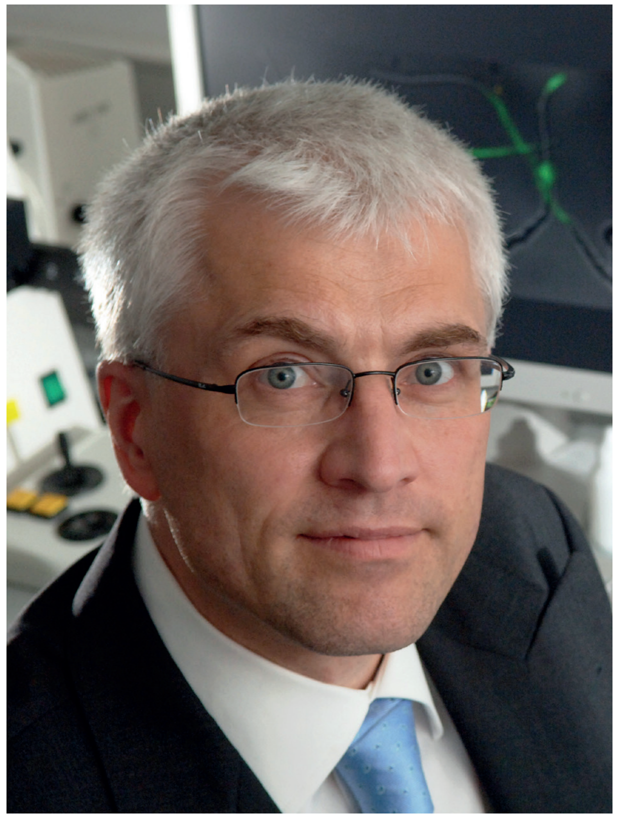
[1] Weiss et al., Nature Materials 17, 89 (2018).
[2] Günther et al., Acc. Chem. Res. 51, 1911 (2018).
[3] Dathé et al., Proc. Spie 10884, 108840N (2019).
[4] Sielaff et al., Molecules 24, 504 (2019).

AXEL BRAKHAGE



PROFESSOR OF MICROBIOLOGY AND MOLECULAR BIOLOGY, INSTITUTE OF MICROBIOLOGY

Axel Brakhage is the scientific director of the Leibniz Institute for Natural Product Research and Infection Biology (HKI) and head of the department of Molecular and Applied Microbiology. Since 2004 he holds a Chair of Microbiology and Molecular Biology at the Institute of Microbiology. He coordinates the Excellence Cluster "Balance of the Microverse", the CRC/TR 124 "Pathogenic fungi and their human host – FungiNet" and the BMBF consortium InfectControl. He is a member of the board of the Leibniz Institute for Photonic Technologies in Infection Research (LPI). He is an elected member and senator of the National Academy of Sciences Leopodina. Currently, he serves as vicepresident the German Research Foundation (DFG). He is member of several scientific advisory boards.

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RESEARCH AREAS

Prof. Brakhage's research focuses on all aspects of the pathobiology of the human pathogenic fungus Aspergillus fumigatus and on the molecular biology/ biotechnology of fungal natural products and related microbial communication, including: pathogenicity determinants, interaction with the immune system, immune evasion, systems biology of fungal infection, proteome and transcriptome analyses, transcription factors, the activation of silent gene clusters using genetic engineering, drug discovery and antibiotics, histone modifications, microbial communication such as interaction of fungi and bacteria leading to the activation of silent gene clusters with the production of novel compounds; molecular mechanisms of cross talk.

TEACHING FIELDS

Prof. Brakhage's teaching is devoted to the early involvement of young scientists in research, as well as to the education of postgraduates. He gives courses in:

- Applied microbiology and molecular biology
- Molecular biotechnology/ infection biology of lower eukaryotes

RESEARCH METHODS

The laboratory led by Prof. Brakhage offers methods for the characterization of immune effector cells, the molecular biology of fungi, biochemistry and biotechnology:

- 2D-gel electrophoresis and MALDI-TOF/ TOF mass spectrometry, proteomics
- Fluorescence and confocal laser scanning microscopy, cell culture techniques
- Plasmon resonance spectroscopy
- Murine infection models, analysis of immune cells
- Isolation of compounds, transcriptome analyses

RECENT RESEARCH RESULTS

Axel Brakhage's group has been investigating the pathobiology of the human-pathogenic fungus Aspergillus fumigatus for which the first pathogenicity determinant, dihydroxynaphthalene (DHN) melanin, was discovered. This determinant has major effects on the intracellular processing and apoptosis of human immune effector cells, at least in part by modifying lipid rafts of the phagolysosomal membrane. During this work, the group also contributed to the discovery of a human receptor sensing DHN melanin and of Th17 cells directed against A. fumigatus, that are induced almost exclusively by cross-reactivity to Candida albicans. Recently, it was also found that A. fumigatus induces the formation of extracellular antifungal vesicles in human neutrophils [1, 2, 3, 4].

His group has been working on the regulation of the biosyntheses of fungal natural products, many of them being important drugs. His group showed that fungal silent gene clusters are induced by microbial communication, i.e., triggered by a specific bacterium [5]. His work has opened up the possibilities for further investigation of these thus far untapped reservoirs for drug development purposes. This research also contributes to the understanding of how microorganisms communicate with each other. The group has been applying methods of functional genome analysis such as proteome and transcriptome analyses.

HOST IMMUNE EVASION TACTICS OF PATHOGENIC FUNGI

Human pathogenic microorganisms have evolved a multitude of different immune evasion strategies for establishing their pathogenic lifestyle inside the host. The pathogen mimics or alters host structures, thereby preventing or at least diminishing the host structure's immune response. Professional phagocytes are often the target of manipulation by intruding microorganisms. Only little is known about how filamentous fungi avoid intracellular killing by phagocytes. Aspergillus fumigatus represents an important airborne fungal pathogen: it is the primary causative agent of invasive aspergillosis in immunocompromised patients. In lung alveoli, resident alveolar macrophages belong to the first line of defence against inhaled conidia. We could show that, depending on dihydroxynaphthalene (DHN)-melanin, the grey green conidial pigment, A. fumigatus prevents formation of flotillin-dependent lipid rafts in phagolysosomal membranes. This leads to reduced vATPase assembly on phagolysosomal membranes and thus reduced acidification of phagolysosomes, in which the pathogen can then survive for a certain time. Our data suggests that pathogenic fungi manipulate host cells to generate a niche, allowing them to survive.

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[2] Shopova et al., mBio 11, e00596-20 (2020).
[3] Bacher et al., Cell 176, 1340 (2019).
[4] Stappers et al., Nature 555, 382 (2018).
[5] Stroe et al., eLife 9, e5254 (2020).

DELIA BRAUER

PROFESSOR OF BIOACTIVE GLASSES

Delia Brauer is Professor of Bioactive Glasses. She is a Fellow of the Society of Glass Technology and member of its Board of Fellows. She chairs Technical Committee 04 (Glasses as Biomaterials) of the International Commission on Glass (ICG) and is a member of the Basic Sciences and Technology Committee of the Society of Glass Technology. In 2015, she was awarded the Gottardi Prize of the International Commission on Glass (ICG), which is presented annually to a young person with outstanding achievements in the field of glass in research and development, teaching, writing, management or commerce. She is also a member of the Jena Center for Microbial Communication (JCMC).

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RESEARCH AREAS

Professor Brauer's research focuses on the materials chemistry of inorganic, non-metallic materials, especially glasses and glass-ceramics, with a particular focus on the interaction between materials and water. She is also interested in how glass composition, structure and properties are connected, particularly in glasses having a highly disrupted structure. Current research areas include:

- Improving the hydrolytic stability of phosphate glasses
- Glass-based cement systems
- Bioactive glasses with improved processing
- Morphology and topography of glass-ceramic surfaces
- Synchrotron applications for glasses and glass-ceramics
- Characterisation of archaeological glasses, glazes and ceramics
- 3D-µCT in bioactive glass research

TEACHING FIELDS

Prof. Brauer teaches students of the courses Materials Science, Chemistry and Chemistry of Materials at the Bachelor and Master level. Her courses include:

- General and inorganic chemistry
- Materials science (courses on glass, ceramics, glass structure and ceramics in medicine)
- Materials synthesis and characterization

RESEARCH METHODS

Prof. Brauer's research group prepares and characterizes glasses and glass-ceramics. Techniques include:

- Equipment for glass melting
- High-temperature characterization including DSC, heating microscopy,
- Structural characterisation including x-ray diffraction, FTIR and Solid-State (MAS) NMR spectroscopy, 3D x-ray microscopy
- Equipment for dissolution experiments and analysis

RECENT RESEARCH RESULTS

Bioactive Glasses

Bioactive silicate glasses are used clinically to regenerate bone and as dentifrices to re-mineralize teeth. Prof. Brauer's group investigates how glass structure controls ion release, dissolution and crystallisation; and how a structure-based glass design allows for optimisation of properties.

Structure and mechanical properties of aluminosilicate glasses

Aluminosilicate glasses are used for various applications where mechanical performance is key, e.g. as for mobile phone displays for fibres in glass fibre composites. We have shown that incorporation of phosphate, as an additional network former, offers unique opportunities for fine-tuning glass properties, e.g. elastic properties and hardness, via changes in glass structure and polymerization. [2]

Surface crystallisation and topography

As glasses are thermodynamically not stable, heat-treatment causes crystallization. Using a barium titanium silicate system as an example, we study the influence of atmosphere composition (moisture, air, argon or vacuum) on surface crystallisation of fresnoite crystals.

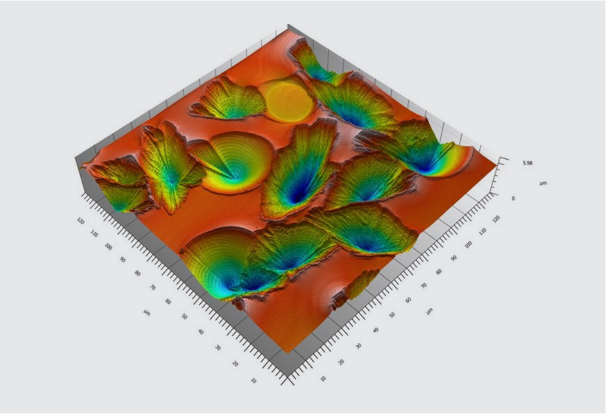

Figure: LSM picture of fresnoite crystals on a glass surface with the crystals sinking into the bulk (blue is deep, red is the surface).

3D X-RAY MICROSCOPY IN MATERIALS RESEARCH

With our new 3D-µCT (X-ray microscopy Xradia 620 Versa, Zeiss; jointly with the group of Applied Geology) it is possible to analyse both large items like archaeologically interesting ceramics (Figure A) or small items like a glass powder (Figure B). The technique allows for non-destructive analysis, being able to differentiate between phases of different density.

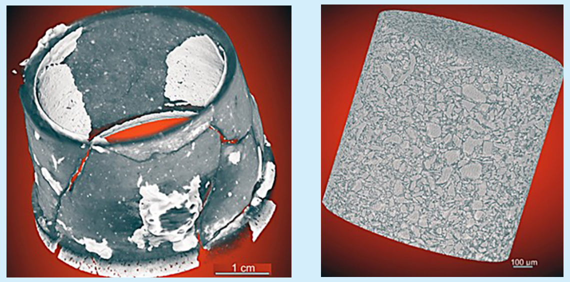

Figure: (a) Upper part of an antique vase (16-17th century, Collegium Jenense): the white part is the preserved glazing, grey is the ceramic and the light dots are mainly quartz grains. The binding agent that was used to glue the individual shards together was numerically removed. (b) Glass powder (<0.125 mm): the challenge here was to prevent the particles from moving during rotation and to find a holder material that is X-ray transparent compared to the target material.

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[1] Wetzel et al., Sci. Rep. 10, 15964 (2020).
[2] Grammes et al., Front. Mater. 7, 115 (2020).

MARIO CHEMNITZ

PROFESSOR FOR INTELLIGENT OPTICAL SYSTEMS

Dr. Chemnitz holds a PhD in Physics from the FSU in 2019 and pursued his postdoctoral studies at the INRS-EMT in Montreal, Canada. In 2022, he became an independent research group leader at the Leibniz Institute of Photonic Technology, specializing in nonlinear optics and photonics. He holds a professorship for Intelligent Optical Systems in Jena since 12/2024. With over ten years of research experience, he focuses on harnessing nonlinear optical functionalities in optical fibers and integrated photonic devices for applications in biophotonics and neuromorphic information processing. He has received a NEXUS Nachwuchsgruppenförderung from the Carl-Zeiss Stiftung, to build up a dedicated research laboratory and a highly interdisciplinary team at the interface of physics, computer sciences, and engineering.

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RESEARCH AREAS

The research group of Dr. Chemnitz investigates the application potential of emerging programmable optical devices in combination with machine learning algorithms and nonlinear photonics. Through the exploration and functionalization of novel nonlinear wave dynamics, the research group thrives in the exploration of new imaging and sensing solutions, new nonlinear states of light, and neuromorphic (brain-like) processor hardware.

Current topics include:

- Complex nonlinear phenomena in waveguides and their coherent control.
- Liquid-core optical fibers and optofluidic platforms.
- Neuromorphic information processing using nonlinear wave dynamics.
- Hyperspectral sensing and imaging techniques.

TEACHING FIELDS

Dr. Chemnitz aims to introduce students to the foundations of machine learning and their applications in optics. Courses will cover the mathematical foundations of various regression, optimization, and learning algorithms as well as their applications in optics, focusing on design strategies for programmable optics, autonomous devices, and optical neural networks.

RESEARCH METHODS

- Design and fabrication of hybrid-material optical fibers and waveguides with specific linear and nonlinear properties.
- Nonlinear phenomena in all-fiber and on-chip systems with a specific focus on optical soliton dynamics and modulation instabilities.
- Machine learning algorithms in conjunction with programmable optical devices and reconfigurable waveguides for advanced nonlinear system control.

RECENT RESEARCH RESULTS

Dr. Chemnitz' research has been groundbreaking in several key areas:

- **Reconfigurable optical fibers**, where the PI matured liquid-core fibers as a dynamic platform for nonlinear optics featuring local dispersion tunability, advanced mode control, and non-local nonlinearity [1].
- **Smart photonics**, where the PI demonstrated autonomous on-chip multi-path interferometry for reconfigurable picosecond waveform shaping empowered by meta-heuristic optimization algorithms and an all-optical sampling scheme [2].
- **Neuromorphic computing**, where the PI showcased fission-based broadband frequency generation as a resource to replicate the computational capabilities of simple neural networks in the optical domain [3].
- **Soliton dynamics**, where the PI experimentally demonstrated the impact of temporal non-locality in nonlinear media leading to unique noise-resilient localization effects that significantly differ from the soliton phenomena known from glass fibers [4].

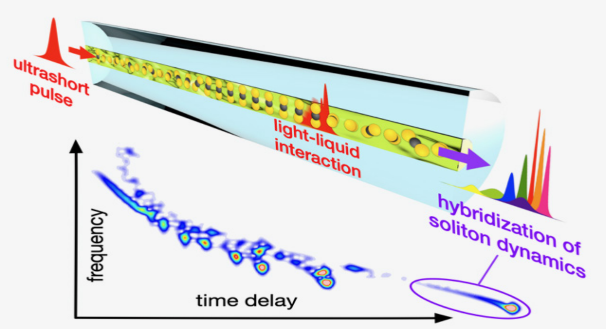


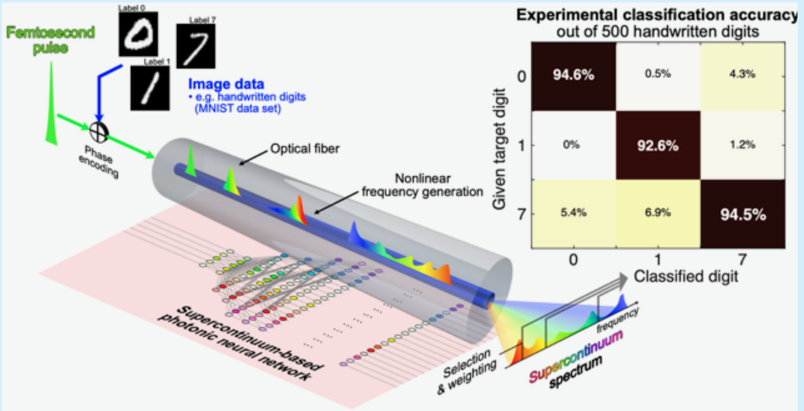
Illustration of the non-instantaneous light-matter interaction leading to a modification of the classical soliton decay known as supercontinuum generation. Resulting hybrid states exhibit dispersive characteristics in time-frequency space.

HARNESSING NONLINEAR OPTICAL DYNAMICS FOR NEUROMORPHIC COMPUTING

In the age of rapidly advancing artificial intelligence, energy efficiency is of global interest. Dr. Chemnitz and his team recently presented a non-intuitive way of how nonlinear optics may be used for low-power emulation of not only one artificial neuron but entire neural networks within a single optical fiber.

Unlike electronic hardware that evolves by adding computational units, their system is characterized by its unique scalability of optical wave dynamics: By increasing the nonlinearity of the optical wave dynamics, the computational power increases within the same fiber. Such scaling of computations within a single physical unit may not only solve energy and scalability problems of neuromorphic hardware but also open new avenues of research on processing optical information directly in the optical domain.

The figure shows the operating principle of the fiber processor exemplarily for handwritten digit recognition – a key benchmark for neural networks. Images of various handwritten digits are encoded on the phase of the input pulse, projected by spectral broadening inside a fiber, and read out from selected spectral windows. The plot shows a classification result of three types of digits predicted by the experimental system from over 500 handscripts.



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[2] Fischer et al., Optica 8, 1268-1276 (2021).
[3] Fischer et al., Adv. Sci., 2303835 (2023).
[4] Chemnitz et al., Nat Commun 8, 42 (2017).

MARIA CHERNYSHEVA

JUNIOR RESEARCH GROUP LEADER FOR ULTRAFAST FIBER LASERS, LEIBNIZ INSTITUTE OF PHOTONIC TECHNOLOGY

Maria Chernysheva studied laser physics at the Fiber Optics Research Center of the Russian Academy of Sciences and, since 2019, has been leading the Junior Research Group for Ultrafast Fiber Lasers, Leibniz Institute of Photonic Technology. Prior to this position, she worked as a Marie Skłodowska-Curie research fellow and Royal Academy of Engineering research fellow at Aston University, UK. Her main research direction has been nonlinear dynamics and new generation regimes in ultrafast fibre lasers.

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RESEARCH AREAS

The research of her group concentrates on the enhancement of ultrafast fibre laser technology. Specific focus is currently placed on:

- Investigation of novel fast nonlinear modulating techniques and advanced broadband material saturable absorbers
- Investigation of fundamentals of ultrashort pulse dynamics in laser cavities, for example, instability-driven phenomena or formation and interaction of ultrashort pulses
- Research on novel soft-glass fibres, design of fibre-based components and fibre structures
- Innovative laser sources at Short-wave and Mid-infrared wavelength regions

TEACHING FIELDS

Dr Chernysheva teaches a course on "Ultrafast Fiber Laser: Technology and Applications" for the M.Sc. Photonics and for the M.Sc. Physics.

RESEARCH METHODS

The Group of Ultrafast Fibre Lasers combines different techniques for the fabrication and characterisation of fibre-based laser components and resonators and ultrashort pulses in the wavelength range spanning from 1 to 5 µm:

- Numerous laser sources, pump diodes and pulse-shaping techniques
- Dispersion Fourier transformation-based real-time spectral measurements, optical spectrum analysers
- 33-GHz Digital storage oscilloscope, FROG and autocorrelations
- Optical fibre post-processing and functionalisation

RECENT RESEARCH RESULTS

One of the research directions of the group was focused on the interaction- and collision-driven bidirectional generation of ultrashort pulses in ring mode-locked lasers. The results experimentally demonstrated a plethora of phenomena, such as the formation of synchronised and unsynchronised dispersion waves, Q-switched instabilities, and wavelength drift with the consequent pulse annihilation [1,2]. The developed bidirectional lasers offered the flexibility of the single laser system to generate a controllable dual-frequency comb. Its combination with real-time spectral acquisition techniques based on dispersive Fourier transformation opens up spectroscopy and rotation sensing applications, reaching phase retrieval of ~7 mrad at tens of MHz data acquisition rates [3].

Aiming to expand beneficial fibre optics platforms towards the Mid-IR wavelength range and enable shaping of the ultrashort dynamics, the group investigates unique soft-glass fibres, which feature drastically different material, thermal and chemical properties compared to conventional silica. The research activities, therefore, have included designing a full set of soft-glass fibre-based laser components, such as beam combiners operating via evanescence field interaction and fibre Bragg grating structures. Thus, the recent fundamental studies of fibre Bragg grating optical properties have paved the way to mastering the inscription process for individual soft-glass composition [4] and achieving controllable refractive index modification [5, 6].

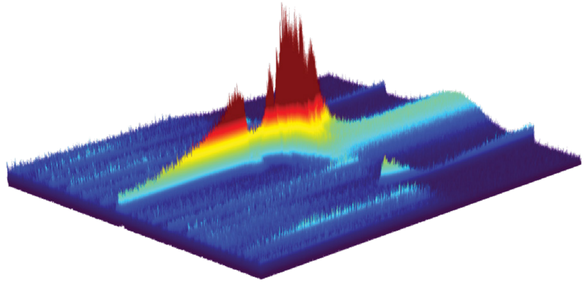

Figure: Experimental observation of real-time spectral evolution during ultrashort pulse formation in mode-locked fibre laser over a sub-microsecond time span.

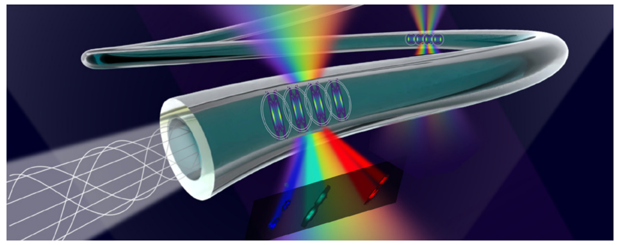

Figure: Large angle light scattering on fibre Bragg gratings in soft-glass multimode fibres.

BROADBAND TUNEABILITY AND ULTRASHORT PULSE GENERATION IN TM-DOPED FIBRE LASER OMITTING FILTERS AND SATURABLE ABSORBERS

The recent findings of the Ultrafast Fibre Lasers junior research group have confirmed the possibility of creating a Thulium-doped ultrafast fibre laser with a ~90 nm wavelength tuneability range around 1900 nm. The demonstrated concept is simple and elegant in two respects: neither a spectral filter nor a saturable absorber had to be applied as extra laser components. Precisely designed and controlled excitation dynamics of Thulium ions in active optical fibre solely guided the ultrashort pulse generation [7]. Such instabilities are generally considered parasitic, but their control and manipulation offer a new avenue of opportunities to establish tailored ultrafast generation.

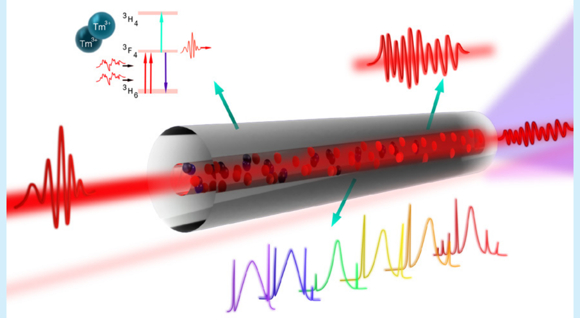

Figure: Concept of the exploitation of rare-ions pair excitations for self-mode-locked ultrashort pulse generation in fibre lasers.

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[3] Kudelin et al. Advanced Photonics Research 3 (8), 2200092 (2022).
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[5] Ruepert et al. ACS Photonics 10(8) 2765–2773 (2023).
[6] Becker, J. Lightwave Technol. 39, 2956-2960 (2021).
[7] Kirsch et al. Communications Physics 5, 219 (2022).

VOLKER DECKERT

PROFESSOR OF NANOSCALE STRUCTURAL INVESTIGATIONS OF BIOLOGICAL AND BIOMEDICAL SYSTEMS, INSTITUTE OF PHYSICAL CHEMISTRY

Professor Deckert holds a joint position at the Institute of Physical Chemistry and the Leibniz Institute of Photonic Technology where he heads the Nanoscopy Department. His main research field deals with investigations of molecular structures within the nanometer range. In 2020, he received the Ellis R. Lippincott Award Spectroscopy for his achievements in high resolution Raman spectroscopy and the realization of tip-enhanced Raman spectroscopy.

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RESEARCH AREAS

Prof. Deckert research interest in general covers fundamentals, method developments, and application of near-field optical spectroscopy. The main target is to use the optical properties of nanoscale metallic structures to reveal the structural conformation and composition of molecules at the highest possible spatial resolution and also understand the underlying principles of high spatial resolution spectroscopy. Research interests include:

- Near-field optics
- Electromagnetic and chemical interactions on the nanometer scale
- Raman spectroscopy
- Structural investigation of proteins and protein aggregations
- Membrane-protein interaction
- Virus surface characterisation
- Single-site catalysis
- Limits of lateral resolution

TEACHING FIELDS

Prof. Deckert is involved in the teaching of general physical chemistry and advanced characterization tools.

RESEARCH METHODS

Prof. Deckert's laboratories are dedicated to the molecular-level investigation of surface structures, in particular of biomolecules and heterogeneous catalysis using ultra-high resolution:

- Tip-enhanced Raman scattering (TERS) microscopy
- Scanning probe microscopy (standard, force-distance, high speed, PiFM, …)
- Fabrication of thin layers (evaporation/sputtering/ALD)
- AFM-coupled transient absorption spectroscopy
- Non-linear optical spectroscopy

RECENT RESEARCH RESULTS

Recent experimental evidence made clear that the generally assumed lateral resolution limits in near-field optics have to be revisited. In cooperation with other groups we developed two models to explain tip based near-field spectroscopy results that demonstrate sub molecular resolution recently. Both models are based on the fact that a plasmonically active nanoparticle can never be a perfect sphere but eventually must show atomic scale features at edges and corners. Such a model is well accepted and used in scanning tunneling microscopy. As for near-field optics, firstly, we could theoretically demonstrate that such features affect the plasmon resonance dramatically in terms of enhancement and field confinement, i.e. lateral resolution.[1] Secondly, if an atomic sized probe is scanning across a molecule, it affects the electronic structure of the molecule depending on the exact location of the probe with respect to the molecule. This so-called chemical effect predicts probe site dependent changes in the vibrational structure of the molecule that are readily detected experimentally as "intensity and spectral position fluctuations" but eventually are related to lateral resolution.[2] Our group also develops new methods to exploit either new information on a specimen, or to improve near-field optical techniques regarding speed or sensitivity. Recent developments are related to laser mode dependent enhancement optimization using a correlated photo-induced force microscopy, a TERS approach and the direct and simultaneous assessment of the tips plasmon resonance and actual temperature directly from a Stokes/anti-Stokes comparison.[3,4] In terms of applications, our main interest is related to bio-related specimen and soft-matter. Based on the experience on bio-spectroscopy with nanometer resolution, the long-term research focus lies on the investigations of dynamic systems, i.e. protein-lipid interactions, immobilized photocatalysts, and drug release of core-shell particles. The latter is a nice example to show how the combined application of different scanning probe techniques provides fast and also structurally specific information about block-copolymer structures used as potential drug carriers.[5] Particularly the correlation of mechanic (force-distance spectroscopy) and near-field Raman (TERS) data allows for a rapid surface pre-characterization based on elasticity and adhesion parameters while subsequent specifically targeted TERS experiments result in nanometer resolved structural sensitive information about surface composition, compound mixing ,and even unexpected reaction products. This also a good example how specific experimental requirements drive the method development and ultimately also the fundamentals of the underlying theoretical concepts.

NANOSCALE STRUCTURE BASED VIRUS DISCRIMINATION

Based on previous high-resolution Raman data on protein crystals and single virions we demonstrate that the direct distinction of mixed virus particles is possible via TERS experiments. The results demonstrate that a near-field spectroscopy-based classification is possible also for specimen sizes below the diffraction limit. Furthermore, also specific virus properties like the presence of a lipid shell can be clearly observed. To address the potential pitfalls by a "too high" lateral resolution a resolution decrease was achieved by spectral acquisition during scanning. This ensures that the entire virion surface contributes to the spectra and consequently dramatically improves reproducibility.

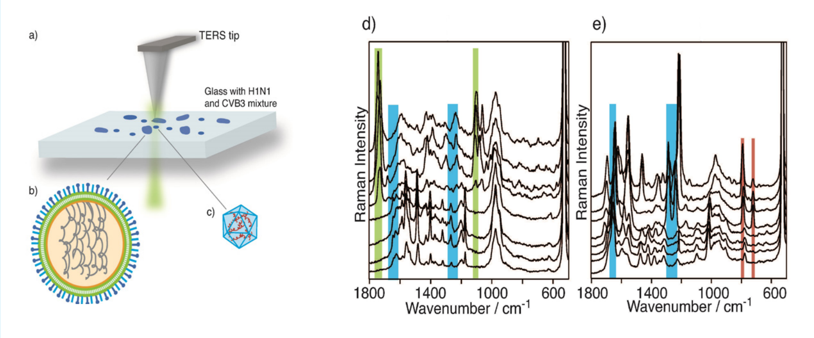

Figure: Scheme of nanometer scale plasmon and temperature assessment via modelling Stokes/anti-Stokes ratios

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[1] Trautmann et al., Nanoscale. 9, 391 (2017).
[2] Latorre et al., Nanoscale. 8, 10229 (2016).
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[4] Richard-Lacroix et al., Light Sci Appl. 9, 3922 (2020).
[5] Höppener et al., Small. 112, 1907418 (2020).

BENJAMIN DIETZEK-IVANŠIĆ

PROFESSOR FOR PHYSICAL CHEMISTRY AT INSTITUTE OF PHYSICAL CHEMISTRY

Benjamin Dietzek-Ivanšić, Fellow of the Royal Chemistry Society, is professor of Physical Chemistry, head of the research department Functional Interfaces and Deputy Scientific Director at the Leibniz Institute of Photonic Technology. He is a member of the executive board of the Abbe School of Photonics and member of the Board of Directors of the Jena Center for Soft Matter. He is co-spokesperson of the SFB/TRR 234 CATALIGHT and chair of the ITN LOGICLAB. His research was awarded with the Thüringer Forschungspreis für Angewandte Forschung in 2013 and the Prix Forcheurs Jean-Marie Lehn in 2018.

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RESEARCH AREAS

Prof. Dietzek-Ivanšić's research in the field of molecular photonics focuses on understanding the relationship between structure, photoinduced dynamics and the function of molecules and molecular materials, including:

- Electron transfer reactions in molecules in solution and in molecule-bulk interfaces
- Photoinduced processes in drugs for photodynamic therapy and molecular sensors
- Photoinduced processes in molecular sensors
- Photophysics underlying molecular photocatalytic water-splitting
- Developing experimental tools to characterize structural and electronic intermediates in (photo)catalytic cycles and the impact of local environment on the photophysics of molecules

TEACHING FIELDS

Benjamin Dietzek-Ivanšić is actively involved in the education of young developing researchers. His teaching includes classes in:

- Physical Chemistry
- Molecular Spectroscopy

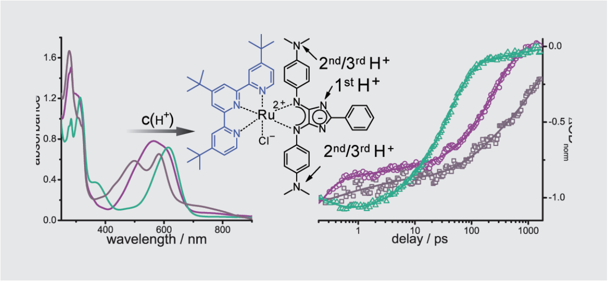
RESEARCH METHODS

Prof. Dietzek-Ivanšić's group uses a variety of spectroscopic methods to study the photoinduced function-determining processes in molecules and molecular materials:

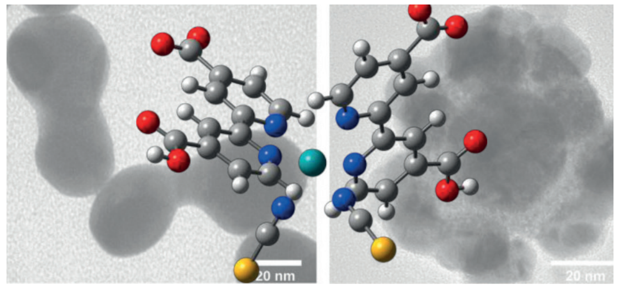
- Ultrafast time-resolved pump-probe spectroscopy spectroelectrochemistry
- Time-resolved luminescence spectroscopy
- Resonance-Raman spectroelectrochemistry
- Ultrafast pump-probe microscopy
- Vibrational sum-frequency generation
- Time-resolved EPR spectroscopy

RECENT RESEARCH RESULTS

The group has recently been working on the photophysical mechanisms underlying structural changes in light-responsive polymer nanocarriers for target drug release. This work is performed in the context of the SFB 1278 POLYTARGET. Here we could demonstrate low-intensity upconversion in a noble-metal free polymer [1]. Furthermore, we investigated the photoacidity and photostability of a new class of naphtol-based polyermic photoacids [2, 3]. In collaboration with the Schacher group we investigated the impact of the local polymer environment on the light-activated reactivity of polymer-integrated photobases as a novel material to device light-responsive polymer nanostructures [4].



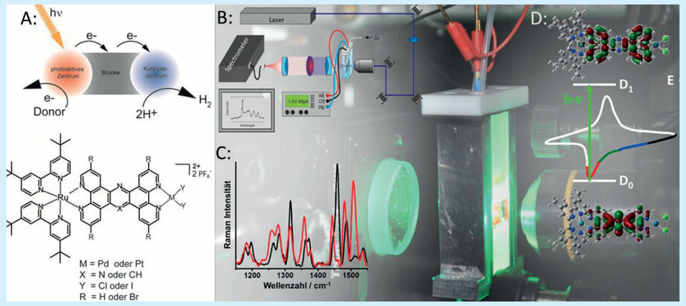
Photoinduced dynamics of terpyridine 4H-imidazole-ruthenium complexes.



SERS Enhancement in the Spectra of Ruthenium Dye-Metal Nanoparticle Conjugates.

ECTRONIC INTERMEDIATES DURING SUPRAMOLECULAR PHOTOCATALYTIC WATER SPLITTING

Recent research was devoted to studying the electronic intermediates in heterodinuclear transition-metal complexes, which serve as homogeneous photocatalysts for the production of molecular hydrogen as an environmentally clean fuel. The work performed in the context of the SFB/TRR 234 CATALIGHT combined ultrafast time-resolved optical pump-probe spectroscopy, with resonance Raman spectroscopy, electrochemistry and in-situ X-ray absorption near-edge structure spectroscopy to elucidate the impact of structural variations on the mechanism of charge transfer and of proton reduction. We identified a molecular vibrational mode efficiently coupling various excited electronic states and thereby facilitating electron transfer from the photoactive, i.e. light-absorption center of the molecule, to the catalytically active metal center. [Chem. Eur. J. 21, 7668 (2015)]. In-situ-XANES spectroscopy under catalytic conditions has aided the identification of the catalytically active species and has shown that the Pd-version of the molecular photocatalysts forms Pd-colloids under catalytic conditions, which the present the active species. However, exchange of the Pd-ion by Pt leads to a stable molecular photocatalyst [Angew. Chem. Int. Ed. 54, 5044, 2015] the catalytic efficiency of which can be tuned by exchanging the co-ligand structure at the Pt center [Angew. Chem. Int. Ed. 54, 6627, 2015]. Notably, the first ultrafast photoinduced electron transfer (two subsequent light-induced electron transfer processes are required to accumulate a sufficient number of redox equivalents on the catalytically active metal center for Hydrogen formation) are only minorly affected by the structural changes of the structural framework of the molecular catalyst. Introducing ultrafast time-resolved transient absorption spectroelectrochemistry to investigate molecular photocatalysts, we identified the excitation-wavelength specific excited state relaxation pathways, which lead to light-driven deactivation of a key intermediate of the catalytic cycle [Angew. Chem. Int. Ed. 58, 13140, 2019]. Further insight into the mechanism [Chem. Commun. 50, 5227, 2014] revealed a strong dispersion in the intermolecular charge transfer-characteristics upon electrochemical reduction of the molecular bridge connecting the photocenter of the complex with the catalytically active center.



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[2] Wendler et al., Macromol. Rapid Commun. 41, 1900607 (2020).
[3] Wendler et al., Chem. Eur. J. 26, 2365 (2020).
[4] Sittig et al., Chem. Eur. J. 27, 1072 (2020).

CHRISTIAN EGGELING

PROFESSOR FOR SUPERRESOLUTION MICROSCOPY AND INSTITUTE DIRECTOR, INSTITUTE OF APPLIED OPTICS AND BIOPHYSICS AND PROFESSOR OF MOLECULAR IMMUNOLOGY

Dr. Eggeling holds a PhD in Physics from the University of Göttingen, was then a research scientist at the biotech company Evotec, Hamburg, before joining the department of Professor Stefan Hell (2014 Nobel Laureate in Chemistry) at the Max-Planck-Institute for Biophysical Chemistry in Göttingen. In 2012, he started as a principal investigator in the MRC Human Immunology Unit and as the scientific director of the newly established Wolfson Imaging Centre Oxford at the Weatherall Institute of Molecular Medicine, University of Oxford, and was appointed Professor of Molecular Immunology in 2014, positions which he still holds today. In 2017, he started as a Professor of Superresolution Microscopy and director of the Institute of Applied Optics and Biophysics (IAOB) at the Friedrich Schiller University Jena, and as the Head of the Department of Biophysical Imaging at the Leibniz IPHT Jena.

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RESEARCH AREAS

The research group of Christian Eggeling is focused on the development of advanced microscopy for the investigation of molecular organization and dynamics in cells, especially on the cellular plasma membrane. Highlights are the optimization of superresolution STED microscopy and its combination with single-molecule fluorescence spectroscopy tools such as fluorescence correlation spectroscopy (FCS), use of adaptive optics for deep-tissue investigations, advancements in single-particle tracking (using fluorescence, interferometric scattering (iSCAT) and novel superresolution MINFLUX microscopy), the detailed investigation of lipid membrane heterogeneity such as lipid rafts, and biological applications of all of these tools for investigations of multiple biomedical issues such as within the Excellence Cluster "Balance of the Microverse", the Collaborative Research Center 1278 PolyTarget, infection diagnostics or immunology. Further, fully serviced user microscope facilities have been set up and are being optimized.

TEACHING FIELDS

Main teaching activities include bachelor biophysics lectures and exercises, master applied laser technology lectures and exercises as well as support of physics teaching practical. Further, student assistants, master and bachelor as well as PhD students are welcome and supported through various research projects.

RESEARCH METHODS

The Eggeling group is specialized on advanced fluorescence microscopy techniques, especially superresolution STED microscopy in combination with fluorescence correlation spectroscopy (STED-FCS), and has access to multiple microscopes including confocal, wide-field/TIRF/MINIFLUX superresolution, structured illumination and STED microscopes, but is also using complementary approaches such as single-particle tracking and intereremetric Scattering (iSCAT) microscopy. In addition to that, the group has access to biochemical wet labs, cell culture and optical labs (up to biosafety level 2).

RECENT RESEARCH RESULTS

Recent research includes the use of artificial intelligence algorithms for an optimized fluorescence microscopy/spectroscopy analysis [1], advanced microscopy of molecular interactions involved in virus infection [2-4], use of adaptive optics for optimized inner-cellular and tissue observations [5, 6], and the biophysical characterization of immune responses [7, 8].

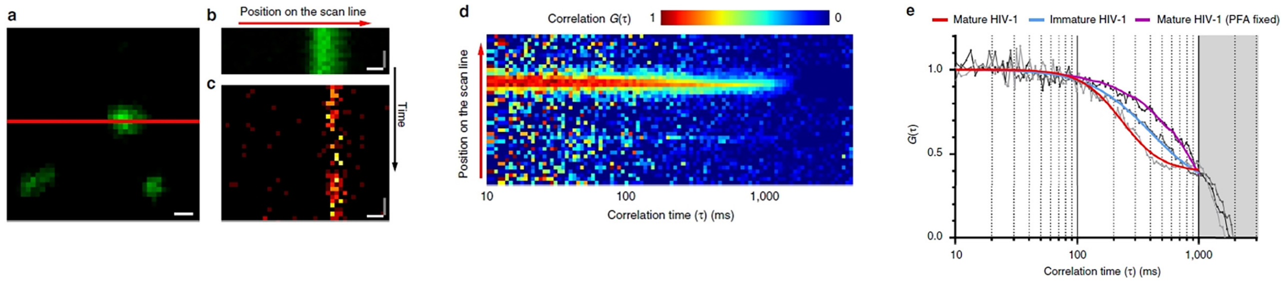

Figure: STED-FCS measurements of the diffusion of the viral protein ENV on HIV-1 virus particles. a Live confocal imaging was used to locate individual HIV-1 virus particles in a 2 micron × 2 micron imaging window using the signal from a labeled viral protein (green) as a guide and to align them with the position of a beamscanning line (red). Scale bar: 200 nm. b, c Representative signal for each point along the scanned line over time (intensity carpet) for the viral protein (green) in confocal mode and the Env surface protein (orange) in superresolution STED mode on wild-type mature HIV-1 particles. Image x- and y-axis correspond to the position on the scan line and signal intensity at each time point, respectively. Scale bars: x-axis (white) = 200 nm, y-axis (grey) = 4.4 ms. d FCS correlation curve for each point of the scanned line (correlation carpet) generated from signal intensity carpet shown in c. Image x- and y-axis correspond to correlation time tau and the position on the scan line, respectively. Colour code corresponds to the normalised FCS autocorrelation curves G(tau) at each position on the scan line. e Representative normalised autocorrelation curves of Env diffusion (grey and black lines) obtained from individual positions on the scan line within correlation carpets. Autocorrelation curves were fitted (coloured lines) for mature (red), immature (blue) and completely fixed HIV-1 particles (purple) using generic two-dimensional diffusion model. Greyed out area corresponds to the photobleaching-only portion of the correlation data. The data highlights faster diffusion on mature compared to immature viruses, with fully fixed viruses showing the correlation curve decay due to pure photobleaching.

DEVELOPMENT OF STED-FCS

The Eggeling group has developed and in applications further advanced the combination of superresolution STED microscopy with fluorescence correlation spectroscopy (STED-FCS) to in more detail investigate molecular interactions, especially in the cellular plasma membrane, elucidating long-standing problems such as lipid membrane heterogeneity, e.g. lipid rafts. See for example Eggeling et al., Nature 457, 1159 (2009) or Sezgin et al., Nature Protoc. 14, 1054 (2019).

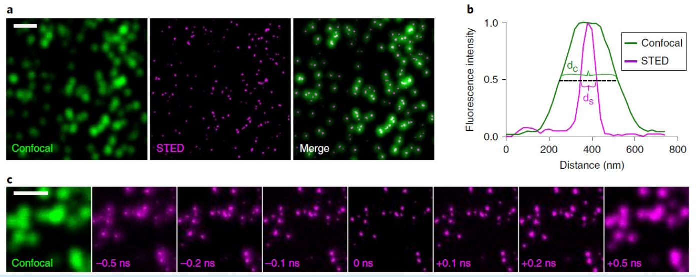

Figure: a, Representative confocal and STED microscopy images of immobilized 40-nm fluorescent beads. The confocal and STED laser beams are well aligned when these images are perfectly centered. b, A representative intensity line profile for a single isolated bead from the images in a (green: confocal; magenta: STED), confirming the optimized alignment. These profiles can be used to obtain the diameters (full-width-half-maximum [FWHM] values) of the imaged spots (d). c, Representative confocal (left, green) and STED (right panels, magenta) images of fluorescent beads for different time delays between the excitation and STED laser pulses; perfect timing is at 0 ns.

[1] Waithe et al., J. Cell Biol. 219, e201903166 (2020).
[2] Favard et al., Science Adv. 5, eaaw8651 (2019).
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FALK EILENBERGER

HEAD OF THE RESEARCH GROUP PHOTONICS IN 2D-MATERIALS AT THE INSTITUTE OF APPLIED PHYSICS AND HEAD OF THE DEPARMENT FOR NANO- AND MICROTECHNOLOGY AT FRAUNHOFER IOF

Falk Eilenberger Head of Department for Nano- and Microtechnology at the Fraunhofer IOF Jena. In parallel, he is leading an academic Research Group called "Photonics in 2D-Materials" at the Institute of Applied Physics where the physics of nano materials by integrating them with optical nanostructured systems is explored. Prior to this, Falk Eilenberger received his PhD on ultrafast nonlinear photonics from the University of Jena and was a visiting scholar at the University of Sydney.

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RESEARCH AREAS

We structure matter on the nanoscale to induce and investigate quantum light matter interaction down to the atomic scale. To achieve this we utilize materials which are intrinsically nanoscopic, such as 2D-Materials and we create nanostrucutures on a large scale using state of the art lithography tools. This approach yields a unique bottom-up / top-down toolset, which we use to create nanostructure empowered optical components. Among these are metasurfaces, spectroscopic solutions, quantum light sources, and photonic sensing devices alike.

TEACHING FIELDS

- Introduction to Nanooptics
- Quantum Computing
- Nanotechnology Lab

RESEARCH METHODS

The team and its collaborators are operating tools to experimentally realize and study optical with nanostructures:

- Nanocharacterization tools: SEM, AFM, optical near fields microscopy
- Quantum-optical characterization tools: HBT- and HOM-spectrometer, high order interference experiments
- Tools for large scale (12") fabrication of nanostructures (e-beam lithography, photolithography, etching tools
- Wafer scale characterization equipment for quantum integrated circuits

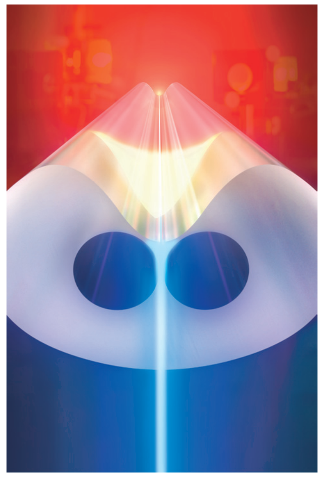
RECENT RESEARCH RESULTS

Two-dimensional materials can be integrated with almost all optical systems. Among these we have focus on optical resonators, metasurfaces, and guided wave systems, all of which can be used to enhance the light-matter interaction strongly and in a scalable manner.

Guided wave systems enhance light-matter interaction by increasing the interaction length from sub-nanometer to possibly the length scales of meters for optical fiber or to chip-scale for semiconductor waveguide. We have recently demonstrated that 2D-materials can be grown at high quality directly on the core of optical fibers, functionalizing those into active photonic systems. Such 2D-functionalized fibers are shown to exhibit second order nonlinearity [1] and environmentally sensitive photoluminescence properties [2].

Optical resonators and resonant surfaces on the other hand can be used to enhance and tailor light matter interaction on specific modes; leading directly into the strong coupling regime where the role of light and matter can no longer be distinguished and new hybrid quantum systems are formed. Among these are room temperature Bose-Einstein-Condensates [3] and single photon sources with extremely high diffraction efficiency [4].

Besides photonic research in 2D-materials we are investigating quantum computers for their ability to simulate complex states of light and to demonstrate their usability in interferometric sensing schemes [5].



LARGE SCALE METASURFACES

We use a set of lithographic tools to fabricate large scale nanophotonic surfaces, which draw their functionality from subwavelength structures in various highly functional materials. Our lithography tools set is centred on an ultrafast 12" maskless character-projection machine, which is able to pattern arbitrary optical surfaces in a very short amount of time. We recently demonstrated a 300 mm metasurface grating; highlighting our technological capabilities [6].

Using lithographic processes we pattern standard optical materials such as glass or silicon but also high active materials, such as $LiNbO_3$, TiO_2 or diamond. As such we are able to create near-arbitrary optical surfaces, which operate from the EUV to the far Infrared. Many projects are application-driven, for example in projects for astronomy, earth observation, high intensity laser systems but also customer electronics and the semiconductor industry.

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CHRISTIAN FRANKE

JUNIOR-PROFESSOR (WITH TENURED TRACK) FOR DIGITIZED EXPERIMENTAL MICROSCOPY

Christian Franke holds a PhD from the University of Würzburg working with Prof. Markus Sauer on the development of methods for quantitative super-resolution microscopy (SRM). In 2017 he joined the MPI of Molecular Cell Biology and Genetics in Dresden as a postdoctoral fellow in the department of Prof. Marino Zerial, focusing on the application of SRM to cell biological questions, specifically endosomal trafficking. End of 2020, he started his own research group at FSU as a Professor for Digitized Experimental Microscopy. He is a member of the Abbe Center and School of Photonics, the Jena Center of Soft Matter, member of the Studies Affairs Committee and Board of Examiners of the international "Medical Photonics" Master program and the Co-Organizer of the "Physikalisches Kolloquium".

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Additionally, Prof. Franke established an advanced practical module in "Applied Super-Resolution Microscopy" for Master of Physics students. Since 2024, he is also active in teaching physics to students of medicine & dentistry in lectures and practical courses.

RESEARCH AREAS

- Super-Resolution Microscopy methods development (Localization Microscopy for highest spatial resolution, Structured Illumination Microscopy for in vivo imaging)
- Super-Resolution Microscopy application in life and material sciences
- Computational Microscopy
- Application to cellular trafficking (e.g. endocytosis)
- High-Fidelity optical 3D Scanning with Structured Illumination
- High-Resolution multi-scale optical measurement of living systems

TEACHING FIELDS

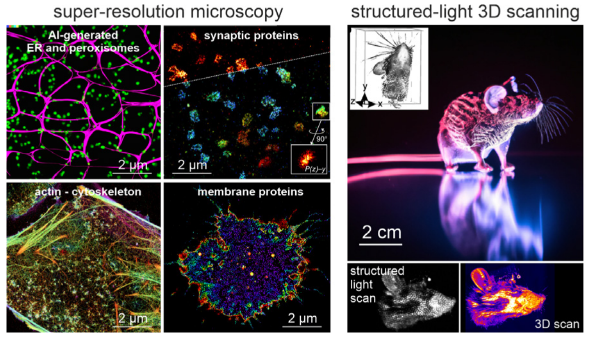
Main teaching activities lay in the international Master of Medical Photonics program lectures & according seminars in Physical Optics and Optical Engineering – these lectures are also open to Master students in Physics and Photonics.

RESEARCH METHODS

- Quantitative Single-Molecule Localization Microscopy, e.g. dSTORM, PALM, (DNA-) PAINT
- Random Pattern Structured Illumination (Speckle-SIM)
- 3D super-resolution microscopy by PSF engineering, wave-field measurements & computational approaches
- AI-based data & image analysis (ML-based image segmentation & multiplexing, Computational Phenotyping)
- Various applications of SRM to cell biology & clinical research, as well as nanoparticles-based drug delivery
- Quantitative 3D stereophotogrammetry for scanning of whole animals (e.g. mouse models)

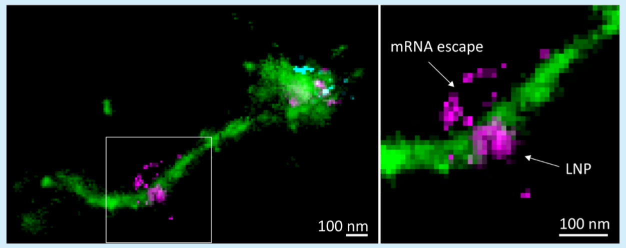
RECENT RESEARCH RESULTS

Seeing is believing. The newly established Franke research group is focused on the development of advanced optical and computational tools for the quantitative study of biological and clinical questions. On one side, we work to advance super-resolution microscopy methods like **single-molecule localization microscopy** (SMLM, e.g. d**STORM, PALM**) and random structured illumination microscopy (nanoSpeck3D) to quantitatively study the structure-function relationship of sub-cellular (trafficking) organelles, e.g. endosomes, with three-dimensional nanometer resolution. Fpr this, we create **novel hard- and software tools**. Recent efforts to push the limits of 3D volume, colour and time resolution, include the development of quantitative tools for novel 3D SMLM approaches [1-3], correlative multi-colour SMLM and volumetric electron tomography (superCLEM)[4] and their application to cell-biological questions [3, 4-6]. For example, we could visualize for the first time the molecular escape of mRNA molecules, delivered by lipid nanoparticles from endosomal recycling tubules at the nanometer scale with multi-colour dSTORM [5] and help to understand part of the fine-structure in developing liver tissue [6]. Led by our excellent postdoctoral researcher, Dr. Andreas Stark, we recently branched out into macroscopic measurements of 3D volumes by high-fidelity stereophotogrammetry also utilizing structured illumination, with which we can now measure objects on the centimeter to micrometer scale, thus bridging dimensions between the macro- and nanoscopic world. Using this approach, we contributed identifying the intricate relationship between the visual and tactile cortex of mice [7]. We also found a novel way of performing macroscopic 3D measurements with a monocular, miniaturized structured-illumination system [8], which completes our array of optical tools to probe life across 9 orders of magnitude.



SINGLE-MOLECULE LOCALIZATION MICROSCOPY AS TOOL IN DRUG DEVELOPMENT

In recent years, nanoparticles (NPs) as delivery vehicles for therapeutic cargo, such as small sized DNAs and RNAs, amongst others, have emerged as potentially powerful therapeutics. An increasing number of RNA-based therapeutics have proven effective for clinical treatment. More recently, optimization of chemical and physical properties of NPs have focused the attention on mRNA-based therapeutics, e.g. in the context of vaccines. Major improvements towards clinical application have come from chemical modifications of therapeutics that increase stability and reduce immunogenicity. Nevertheless, efficacy remains a crucial challenge due to limited or poor delivery. Using multi-colour dSTORM we investigated how lipid nanoparticles (LNPs, magenta) are trafficked inside cells and how they deliver their cargo, e.g. mRNA or pharmaceuticals, with nanometer resolution. For the first time, we could visualize their intracellular fate in never-seen detail and could unravel a new way of cargo delivery/escape via transferrin-positive recycling tubules (green), pointing towards optimized designs for future NPs.



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TORSTEN FRITZ

PROFESSOR FOR APPLIED PHYSICS / SOLID-STATE PHYSICS INSTITUTE OF SOLID-STATE PHYSICS (IFK)

Torsten Fritz studied physics and mathematics at the TU Dresden and is currently professor and chair of Applied Physics / Solid State Physics at the Institute of Solid-State Physics (IFK) at the Friedrich Schiller University Jena. Currently, he is appointed as IFK's institute director. Since 2019 he is also Visiting Professor at the Department of Chemistry and Biochemistry at the University of Arizona at Tucson, AZ, USA. In 2015 and 2016, he was appointed as Specially Appointed Professor at the Department of Chemistry, Graduate School of Science, Osaka University, Osaka, Japan.

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RESEARCH AREAS

The surface science group of Prof. Fritz is involved in the research of organic molecules which in the form of thin films possess semiconducting properties. We specialize in the preparation and characterization of highly ordered (epitaxial) layers on single-crystalline substrates in ultra-high vacuum, placing emphasis on the structure-property-relations. Further research topics include 2D-materials (epitaxial graphene, hexagonal boron nitride (h-BN), transition metal dichalcogenides) and organic superconductors. The diversity of complementary experimental methods (optical spectroscopy, photoelectron spectroscopy, electron diffraction, scanning probe microscopy at 1.2 K, and many more) is a key aspect of this group.

TEACHING FIELDS

- Solid-state physics
- Advanced solid-state physics and materials science
- Organic and inorganic semiconductors
- Surface science

RESEARCH METHODS

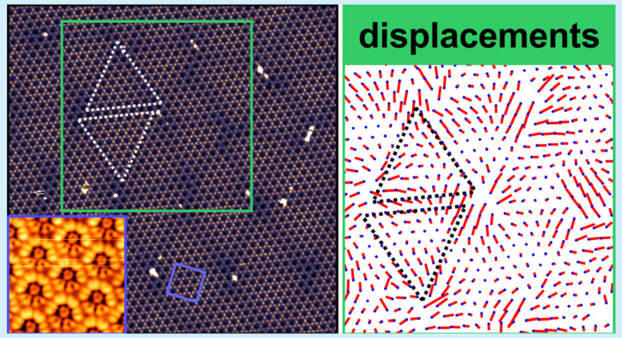
- Low-temperature scanning probe methods at 1.2 K (STM, AFM, STS)
- In-situ optical spectroscopy (Differential Reflectance Spectroscopy [DRS], PL)
- All variants of photoelectron spectroscopy (ARPES, XPS, PMM, AES, XPD)
- Quantitative distortion corrected electron diffraction (LEED, RHEED)
- Joule-Thomson STM/AFM (specs: T control <20 K [MCP-LEED, DRS] or 1.2 K [STM, AFM], H-field ~3 T, 4-probe-measurements, organic molecule crucibles, Ar sputter gun and e-beam heating, doping, QMS,)
- Surface analysis system (specs: T control down to 20 K [XPS, UPS, ARUPS], monochromatic UV source, crucibles for organic molecules, Ar sputter gun and e-beam heating, doping with alkali metals and alkaline earth metals, MCP-LEED, AES, DRS, QMS)

RECENT RESEARCH RESULTS

- In-depth characterization of the potassium doping of PTCDA monolayers, including the direct observation of the K adsorption sites [1-3].
- First direct observation of static distortion waves (SDWs) in flexible 2D crystals of organic molecules, see Research highlight" [4].
- Study of dielectric background effect on optical transition energies of isolated molecular monomers and weakly interacting two-dimensional aggregates [5].
- Development of a full and most comprehensive classification scheme of the epitaxial types in reciprocal and real space, including both, rigid and flexible lattices [6].
- Development of a new consistent model for the interpretation of different spectroscopic results (including ARPES, IPES, 2PPE, and optical spectroscopy) which takes into account the perturbations of the different measurement processes on a molecular system [7].

STATIC DISTORTION WAVES (SDWS) IN FLEXIBLE 2D CRYSTALS OF ORGANIC MOLECULES

The epitaxy of many organic films on inorganic substrates can be understood within the framework of rigid lattice epitaxy. However, there are cases where this concept fails, and tiny shifts in molecular positions away from ideal lattice points, so-called static distortion waves (SDWs), are responsible for the observed orientational epitaxy. Using LEED and STM, we were able to directly detect SDWs in organic adsorbate films. They manifest themselves as wave-like sub-Angstrom molecular shifts (on average only 0.5 Å) away from an ideal adsorbate lattice. Using a DFT-based model, we show that due to the flexibility of the adsorbate layer the resulting total energy in the domain is indeed minimal.



The left part of the image shows an STM image of the static distortion waves observed for a monolayer of the organic molecule HBC on a graphite single crystal. The inset shows the sub-molecular structure of the layer. On the right, the extracted molecular shifts are shown, exaggerated by a factor of 15. From [4].

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STEPHAN FRITZSCHE

PROFESSOR OF THEORETICAL PHYSICS AND CORRELATED QUANTUM SYSTEMS IN INTENSE FIELDS, HELMHOLTZ INSTITUTE JENA

He is a board member at the Helmholtz Institute Jena and head of the Theory Group at this institute. Prof. Fritzsche also serves as Principal Editor for Computer Physics Communications, a peer-reviewed international journal with focus on the numerical analysis and software design in physics and physical chemistry.

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RESEARCH AREAS

Prof. Fritzsche's research interests deal with the structure and dynamics of finite quantum systems for applications in atomic and optical physics. Current research topics are:

- Multi-photon ionization dynamics in intense FEL radiation
- Excitation, auto-ionization and decay cascades of atomic and molecular systems
- Light-matter interactions and light scattering in strong Coulomb fields
- Particle beams carrying quantized orbital angular momentum
- design and implementation of community tools for atomic, astro and plasma physics

TEACHING FIELDS

Prof. Fritzsche´s teaching has as its focus the behavior of correlated quantum systems and includes courses in:

- Atomic structure and collision theory
- Light-matter interactions in strong and short pulses
- Computational quantum physics

RESEARCH METHODS

Various concepts and theoretical techniques are applied by Prof. Fritzsche's group for studying the structure and light-matter coupling of finite quantum systems, including:

- Relativistic atomic & many-body theory
- Numerical simulation techniques and code development
- Time-independent and time-dependent density matrix theory
- Computer-algebraic techniques
- Concepts and protocols from quantum information theory and quantum state estimation
- Concepts and protocols with quantum walks

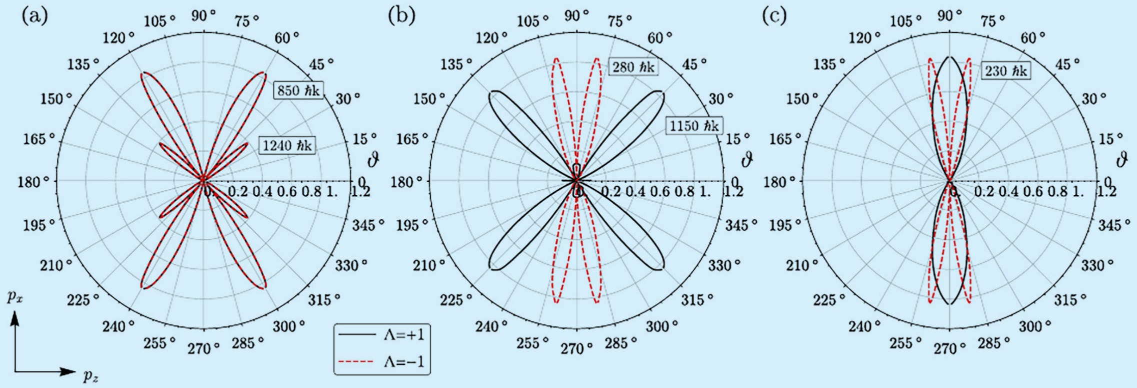
RECENT RESEARCH RESULTS

In recent years, the atomic density matrix theory has been successfully applied to model the excitation, ionization and recombination dynamics of neutrals and multiple-charged ions, and with applications in nuclear, atomic and plasma physics as well as x-ray science. Emphasis has been especially placed on the quantum-electrodynamical (QED) treatment of the emitted photons and electrons in order to explore the relativistic light-matter coupling in strong Coulomb fields. It was shown, for example, that magnetic contributions of the radiation field often lead to strong modifications in the emission and scattering of photons by atoms and highly-charged ions [1, 2]. Moreover, many of these photon-atom interactions are enhanced by resonances due to the excitation of inner-shell electrons [3-5].

Apart from the interaction of atoms with plane-wave photons and electrons, recent interest was placed upon the role of the orbital angular momentum in atomic processes. Today, twisted beams of photons and electrons can be generated with energies of up to keV and with quite high topological charges. In our group, we explore the interaction of such beams at both, medium and strong intensities, and for which nonlinear interactions become prominent [6]. With the well-known JAC toolbox [7], moreover, a new atomic code is presently established for the computation of (many-electron) interaction amplitudes, properties as well as a large number of excitation and decay processes for open-shell atoms and ions across the whole periodic table.

POLARIZATION-DEPENDENT HIGH-INTENSITY KAPITZA-DIRAC EFFECT IN STRONG LASER FIELDS

The deflection of photoelectrons in intense elliptically polarized standing light waves, known as the high-intensity Kapitza-Dirac effect, has been studied in order to understand the observed longitudinal momentum transfer in above-threshold ionization experiments. The figures displays the calculated angular distributions of low-energy photoelectrons for (a) linear, (b) elliptical, and (c) circular polarizations of the standing wave. Results are shown for standing waves with I = 15 × 10^{13} W/cm^2 and for both orientations of the incident circularly-polarized light; taken from Phys. Rev. 101, 031401(R) (2020).



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WOLFGANG FRITZSCHE

EXTERNAL LECTURER

Apl. Prof. Dr. Wolfgang Fritzsche is head of the Department Nanobiophotonics at the Leibniz-Institute of Photonic Technology (Leibniz-IPHT).

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RESEARCH AREAS

The Nanobiophotonics group develops innovative methods for molecular detection based on the optical properties of plasmonic nanoparticles in combination with molecular components. This so-called Molecular Plasmonics includes passive approaches, such as the development of optical markers, and is focused on application of plasmon nanostructures for bioanalytics. On the other hand, in active plasmonics, plasmonic effects are used to manipulate biomolecules or for catalysis.

- Passive Molecular Plasmonics: LSPR (localized surface plasmon resonance)-based bioanalytics
- Active Molecular Plasmonics: plasmonic (nano)manipulation

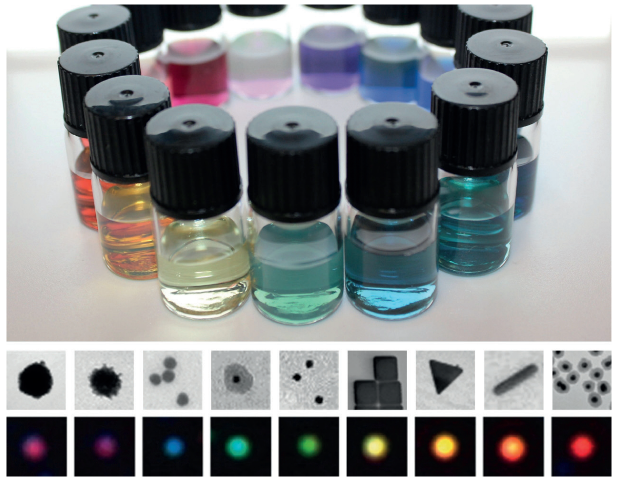
TEACHING FIELDS

Dr. Fritzsche is involved in teaching Physical Chemistry as well as Instrumental Analytics for pharmacists, Optical Sensors/Microfluidics in the master's degree programme Medical Photonics, and Nanobiophotonics in the master's degree programme Chemistry of Materials.

RESEARCH METHODS

- Colloidal metal-nanoparticles, hybrid plasmonic nanostructures and plasmonic microarrays
- Molecular techniques: self-assembly monolayers, biofunctionalization and conjugation of nanoparticles and nanostructures
- (Imaging) spectroscopy of single plasmonic nanostructures and microarrays
- Scanning Force Microscopy
- Micro/nanointegration
- Nanobiomanipulation (laser-irradiation of plasmonic antennas for manipulation of biomolecules) and plasmonic catalysis
- DNA and protein detection using LSPR sensorics

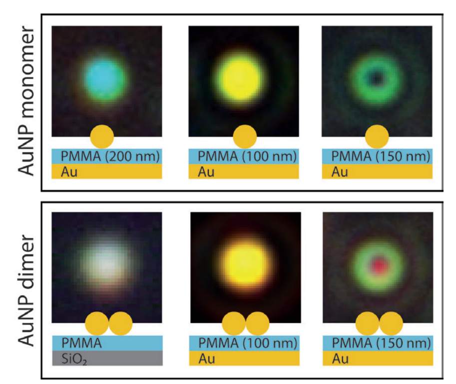
RECENT RESEARCH RESULTS



Plasmonic nanoparticles in spectral range UV-NIR, available from the Fritzsche Group.

The group's research is focused on molecular plasmonics, as the interaction between molecular structures and metal nanostructures, and nanooptics. The main applications are in bioanalytics, where metal nanoparticles provide a label-free and quite sensitive detection using its property of localized surface plasmon resonance (LSPR). Besides composition, size and shape of the nanoparticle, the LSPR is also influenced by the refractive index of the surrounding matrix. Therefore, measurements of the shift of the LSPR wavelength allow for monitoring processes like biomolecular binding events at the level of individual gold nanoparticles. Nanoparticles of various materials, sizes and shapes are synthesized as well as characterized regarding structural and optical/spectroscopic properties, also at the single particle level. A variety of surface modification techniques including surface silanization have been established in order to bind these particles onto certain surfaces (chip substrates, but e.g. also inside hollow glass fibers), and to attach biomolecules, such as DNA or proteins. DNA nanotechnology is utilized to generate larger (>100 nm) superstructures (DNA origami) in order to allow for a more defined relative positioning of plasmonic particles and fluorophores. On the technical side, developments for a multiplexed readout of plasmonic properties of nanoparticles, to be realized by an imaging spectrometer based on a Michelson interferometer principle, are under way. Besides analytics, the interaction of laser light with particles is investigated regarding a manipulation of molecules (DNA) on a sub-molecular level, like DNA-restriction. An interesting effect was thereby discovered, which is based on electrons leaving the nanoparticle when excited by fs-laser pulses, and the transfer of this excitation along DNA nanowires over several micrometers. It clearly exceeds the generally accepted electron conductance of DNA of a few (maybe tens) of the nanometers, and is still the focus of ongoing investigation.

FINETUNING PLASMONIC RESONANCES



The localized surface plasmon resonance (LSPR,) as the resonant oscillation of conduction electrons in metal nanostructures upon light irradiation, is widely used for sensing as well as nanoscale manipulation. The spectral resonance band position can be mainly controlled by nanoparticle composition, size, and geometry and is slightly influenced by the local refractive index of the near-field environment. Here we introduce another approach for tuning, based on interference modulation of the light scattered by the nanostructure. Thereby, the incoming electric field is wavelength-dependently modulated in strength and direction by interference due to a subwavelength spacer layer between nanoparticle and a gold film. Hence, the wavelength of the scattering maximum is tuned with respect to the original nanoparticle's LSPR. The scattering wavelength can be adjusted by a metallic mirror layer located 100 – 200 nm away from the nanoparticle, in contrast to nearfield gap mode techniques that work at distances up to about 50 nm in the nanoparticle environment. We have demonstrated, for the first time at the single nanoparticle level that depending on the interference spacer layer thickness, different distributions of the scattered signal can be observed, such as bell-shaped or doughnut-shaped point spread functions (PSF). The tuning effect by interference is furthermore applied to anisotropic particles (dimers), which exhibit more than one resonance peak, and to particles which are moved from air into the polymeric spacer layer to study the influence of the distance to the gold film in combination with a change of the surrounding refractive index.

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MARTIN GÄRTTNER

PROFESSOR OF QUANTUM INFORMATION THEORY

Martin Gärttner is Professor for Quantum Information Theory at the Friedrich Schiller University Jena. He is leading the Quantum Information and Quantum Many Body Dynamics group at the Institute for Condensed Matter Theory and Optics (IFTO). Prof. Gärttner is active in networks on Quantum Technologies across Germany and Europe. He is coordinating student networks within the European Quantum Science and Technology Master program DigiQ (www.digiq.eu). Within the network EFEQT (www.efeqt.eu) he is organizing workshops and online quantum meetups for Master students.

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RESEARCH AREAS

Emerging quantum technologies will potentially transform important technological areas such as computing, communication, and sensing. What fascinates us as physicists is that many phenomena that arise when many particles interact at the quantum level are still poorly understood. Nevertheless these phenomena, such as entanglement, are what actually makes quantum devices potentially so powerful, and their better understanding is thus key. Towards this goal we develop analytical and numerical tools to model and simulate quantum many-body systems and search for efficient ways to prepare and probe interesting quantum states of matter. The Gärttner group focusses on

- Efficient methods to extract information form data generated by quantum simulation experiments, for example entanglement detection or quantum state tomography
- Machine learning assisted ab-initio methods for simulating the dynamics of strongly interacting quantum many-body systems
- Thermalization of closed quantum systems, specifically of disordered spin systems

TEACHING FIELDS

Martin Gärttner gives specialized lectures on Quantum Information Theory, Quantum Technologies, Quantum Computing, and Computational Methods in Quantum Physics. His teaching is research oriented and he includes interactive elements like quizzes and small programming exercises in his lectures.

QUANTUM OPTICS RESEARCH METHODS

We use and develop many different numerical techniques for simulating the dynamics of quantum many-body systems. This includes exact diagonalization and semiclassical methods like the truncated Wigner approximation, but also variational methods using neural networks to approximate quantum many-body states.

To improve the readout of quantum devices we develop entanglement witnesses, and use detector tomography and quantum state tomography, combined with Bayesian methods for parameter estimation.

RECENT RESEARCH RESULTS

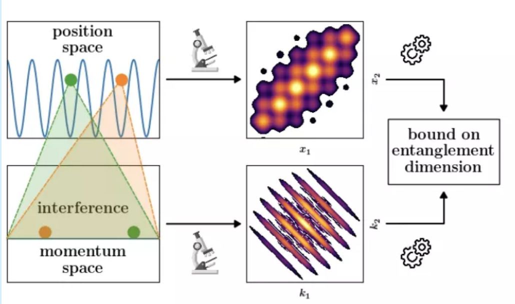
Machine learning for complex quantum systems: Artificial neural networks have proven extremely successful for machine learning tasks such as computer vision and speech recognition. In quantum many-body physics they can help speeding up ab-initio simulations or processing of data from quantum experiments. For instance, generative models can be trained to approximate probability distributions based on data samples. Quantum states are represented by high-dimensional probability distributions, inviting the use of generative models for finding efficient state representations. We use this approach to develop numerical tools for calculating the time evolution of quantum many-body states [1] and to do quantum state tomography [2].

Entanglement detection: Entanglement, which Erwin Schrödinger coined the characteristic treat of quantum mechanics, is the resource that renders many quantum technologies superior to their classical counterparts. At the same time entanglement is at the heart of many physical phenomena. For example, it explains why interacting quantum systems, even when perfectly isolated from their environment, can relax to thermal equilibrium. Thus, techniques for detecting and quantifying entanglement based on experimental data are direly needed. We develop such techniques taking into account the concrete measurement capabilities of quantum simulation platforms including cold atoms and photonic systems [3,4].

Thermalization in disordered spin systems: Disorder is present in many natural systems from glasses and amorphous solids to social networks with seemingly random connections. Such systems often show surprising emergent dynamical effects. In the realm of quantum many-body systems disorder can lead to hierarchical relaxation and glassy behavior. We study relaxation dynamics and transport in quantum spin systems where the inter-particle interactions are to some degree random. Such systems can be realized by cold atoms excited to Rydberg states. In these highly excited states the atoms interact via strong dipole-dipole interactions. We model these systems numerically [5] and try to come up with new ways for experimentally probing their properties [6].

DETECTING HIGH-DIMENSIONAL ENTANGLEMENT IN COLD-ATOM QUANTUM SIMULATORS

Quantum entanglement has been identified as a crucial concept underlying many intriguing phenomena in condensed matter systems such as topological phases or many-body localization. What remains a challenge is the experimental detection of such fine-grained properties of quantum systems. The development of protocols for detecting entanglement in cold atom systems, which are one of the leading platforms for quantum simulation, is thus highly desirable and will open up new avenues for experimentally exploring quantum many-body physics. In a recent work, we have developed a method to bound the width of the so called entanglement spectrum, or entanglement dimension, of cold atoms in lattice geometries, requiring only measurements in two experimentally accessible bases and utilizing ballistic time-of-flight (ToF) expansion (see figure). We could show that this methods allows high dimensional entanglement certification under experimentally realistic conditions and using currently available experimental techniques [7].



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HOLGER GIES

PROFESSOR OF QUANTUM THEORY AT INSTITUTE OF THEORETICAL PHYSICS

Prof. Gies is the spokesperson of the research unit FOR 2783 on "Probing the Quantum Vacuum at the High Intensity Frontier" and of the research training group GRK 2522 on "Strong Dynamics and Criticality of Quantum and Gravitational Systems", both funded by the German Research Foundation (DFG). He serves as a member of the extended directorate of the Helmholtz Institute Jena and on the board of the Helmholtz Research School of Advanced Photon Science.

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RESEARCH AREAS

Prof. Gies investigates the potential of using light as a probe for fundamental physics. Research thrusts include:

- Properties of light induced by quantum or thermal fluctuations
- Quantum phenomena at highest laser intensities
- Light-induced particle production
- Light propagation in modified quantum vacua
- Optical searches for exotic particles
- Light-matter interactions out of equilibrium

TEACHING FIELDS

Prof. Gies provides advanced theory courses, supporting the training of young developing researchers during their early project phases. He gives courses in:

- Quantum field theory and quantum mechanics
- Strong-field and quantum vacuum physics

RESEARCH METHODS

Prof. Gies develops and applies a wide range of theoretical methods to describe quantum correlations of light and matter including:

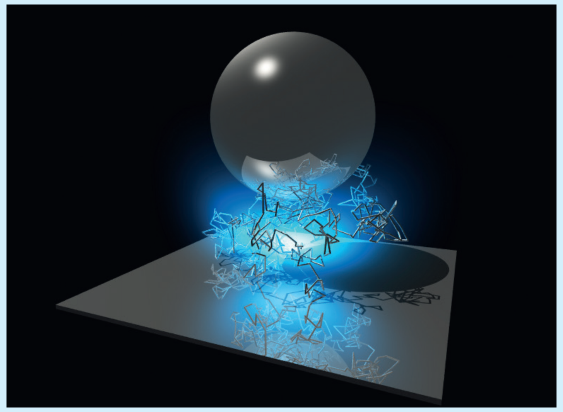
- Perturbative effective actions and correlation functions
- Analytical and computer-algebraic field theory methods
- Numerical worldline algorithms for inhomogeneous electromagnetic fields
- Non-equilibrium quantum transport equations
- Non-perturbative renormalization flows

RECENT RESEARCH RESULTS

Dealing with quantum processes in realistic inhomogeneous fields requires a thorough understanding of quantum fluctuations in general field profiles. The quantum theory group is strongly involved in method development for the efficient determination and prediction of salient signatures of the quantum world in upcoming strong-field experiments. For instance, the group has developed the worldline Monte Carlo technique which currently is the only theoretical tool in practice which is capable of determining quantum properties of light in general strong-field backgrounds. A main topic deals with the potential of upcoming high-intensity laser facilities as discovery machines of fluctuation induced vacuum nonlinearities. In close collaboration with experimental colleagues, the group has developed general purpose methods to efficiently describe quantum vacuum phenomena in focused laser pulses [1], which has lead to the proposal of a new experimental detection scheme [2], suggesting novel inelastic processes as a key signature. This potential signature of light scattering off a high-intensity region is a prototypical example of a new kind of all-optical phenomena at the high-intensity frontier that has the potential to explore this new regime of physics for the first time. The group also addresses issues of theoretical consistency of quantum electrodynamics (QED) as the currently most fundamental description of light-matter interactions. This has lead to a recent proposal of a novel high-energy completion of QED by means of a scenario based on the concept of asymptotic safety [3]. This new line of research has provided first evidence for the existence of a so far undiscovered universality class that features the existence of high-energy complete "lines of constant physics" and has the potential to solve a decades-old consistency puzzle of QED.

QUANTUM ENERGY DENSITIES OF THE PHOTON FIELD IN MICRO- AND NANOSTRUCTURES

Photonic quantum fluctuations in structured geometries can be investigated with the worldline Monte Carlo method, developed by the Quantum Theory Group. Quantum fluctuations are mapped out by their random spacetime trajectories inside a given geometric configuration, such as the experimentally often used sphere-plate configuration. The number of interactions between the quantum trajectories of the photon field and the material are a quantitative measure for the fluctuation-induced energy density inside the geometry (blue shining region). Recent algorithmic developments make it now possible to study the quantum-modified propagation properties of light within such a geometry.



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STEFANIE GRÄFE

PROFESSOR OF THEORETICAL CHEMISTRY, INSTITUTE FOR PHYSICAL CHEMISTRY

Prof. Gräfe has joined the Friedrich Schiller University Jena in 2013 and is the head of the Theoretical Chemistry group at the Institute for Physical Chemistry. Based on her research in strong field molecular physics, she is also associated with the Faculty of Physics and Astronomy. Since 2023, she is the spokesperson of the SFB/CRC 1375 NOA - Nonlinear Optics down to Atomic scales.

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RESEARCH AREAS

Prof. Gräfe's research covers a wide range of topics in quantum chemistry and molecular dynamics with strong emphasis on the theoretical description and modeling of processes involving the interaction of weak and intense ultrashort laser pulses with atomic, molecular and other quantum systems:

- Strong-field atomic and molecular physics
- Femtosecond chemistry and attosecond physics
- Time-resolved spectroscopy
- Photophysics of electron transfer systems
- Electronic and spectroscopic properties of molecular systems
- Quantum chemistry

TEACHING FIELDS

Prof. Gräfe is teaching basic and advanced topics of physical and theoretical chemistry for both undergraduate and graduate students. She aims at introducing students to modern research areas and supporting their education towards young researchers. Current topics include:

- Quantum mechanics and molecular dynamics
- Theoretical and quantum chemistry
- Light-matter interaction
- Symmetry and chemistry

RESEARCH METHODS

The research group lead by Prof. Gräfe applies state-of-the-art quantum chemical methods and develops numerical schemes to describe various aspects of light-matter interaction:

- Numerical solution of the time-dependent Schrödinger equation
- Non-adiabatic (quantum and classical) dynamics
- Time-dependent density functional theory (TD-DFT)
- Ab-initio quantum chemistry

RECENT RESEARCH RESULTS

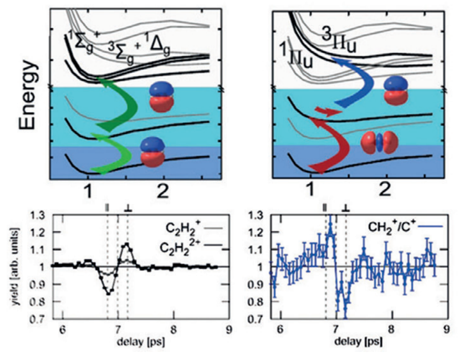
Our research activities have been focused on the theoretical description and simulation of ultrafast internal, ionization and fragmentation dynamics of atomic and molecular systems in intense and ultrashort laser fields.

Strong-field physics and chemistry: While in the last decades strong field physics was mainly focused on atoms and small diatomic molecules, now also larger and chemically more interesting molecules are increasingly investigated. In these strong laser fields, ionization and fragmentation dynamics play an important role besides rotational dynamics. It is a great challenge for theoretical modeling to describe the interaction of polyatomic molecules with intense laser fields completely numerically, because many degrees of freedom on many different temporal and spatial scales are involved. For the theoretical description, we pursue different approaches, from multi-physics approaches to quantum and/or (semi-)classical dynamics. This way, we are able to describe the ionization of triatomic and pro-chiral molecular systems [1], the complex strong-field dynamics of HeH^+ [2], or the symmetry breaking (Renner-Teller effect) of CS^2 in strong fields [3, 4]. Our group often works in close collaboration with experimental groups. Locally, we collaborate with the group of Prof. Gerhard Paulus.

Molecular-plasmonic hybrid systems: Novel hybrid materials of metallic nanoparticles and organic molecular aggregates offer one of the most versatile architectures for the design and implementation of functionality at the nanoscale. These hybrid materials combine the light collection properties of the aggregates with the fast and efficient charge transfer dynamics of nanoparticles and are therefore very good as model systems for e.g. dye sensitized solar cells and artificial photosynthesis complexes. We are developing methods to investigate for the first time the interaction of the excitonic dynamics of the aggregates with the plasmonic dynamics of the nanoparticles. Recently, we have started to investigate the "chemical effects" in molecule-nanoparticle hybrid systems interacting with external laser fields, which are the result of the close proximity of the metallic nanoparticle and the molecule. To this end, we simulated the experimental setup of tip-enhanced Raman scattering (TERS) and calculated the influence of the relative position of the metallic tip to the sample molecule on the molecular properties and thus on the spectroscopic observables using quantum chemical methods [5]. We found that the presence of a single Ag atom (or a small Ag cluster) leads to strong changes in the Raman spectrum. Together with electrodynamic calculations, our calculations provide an indication as to why a TERS setup allows experimental (sub-)nanometer resolution [6].

FRAGMENTATION DYNAMICS OF POLYATOMIC MOLECULES

In a joint project with the group of Dr. Kitzler (Vienna), we have demonstrated experimentally and theoretically for the first time that molecular alignment can be used for controlling the relative probability of individual reaction pathways in organic molecules, such as fragmentation and isomerization reactions. Aligning the molecular axis with respect to the polarization direction of the ionizing laser pulse does not only allow us to enhance or suppress the overall fragmentation yield of a certain fragmentation channel but, more importantly, to determine the relative probability of individual reaction pathways starting from the same parent molecular ion. This constitutes a novel and effective tool to steer fragmentation dynamics of polyatomic molecules [Xie et al., Phys. Rev. Lett. 112, 163003 (2014)].



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STEFAN H. HEINEMANN

PROFESSOR OF BIOPHYSICS, CENTER FOR MOLECULAR BIOMEDICINE

Prof. Heinemann is the head of the Department of Biophysics at the Friedrich Schiller University Jena and of the Jena University Hospital. Dr. Heinemann serves as a speaker of the interdisciplinary Research Group FOR 1738 Heme and Heme Degradation Products of the German Research Foundation (DFG). Within ACP, he contributes to research and teaching at the joint meeting point of biomedical sciences and photonics.

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RESEARCH AREAS

In his research, Dr. Heinemann focuses on the structure, function and pharmacology of ion channels. In particular, he investigates cellular systems under optical control and uses photonics for targeted cellular manipulations. Research interests include:

- Voltage-gated ion channels
- Cell signaling via redox processes and heme
- Neurotoxins and pain signaling
- Photonic manipulation of living cells
- The biophysics of ion transport
- Frequency upconverting material

TEACHING FIELDS

Dr. Heinemann teaches students at various levels of proficiency – Bachelor's degree students in biology and biochemistry, Master's degree students in molecular life science and molecular medicine, biochemistry and photonics.

He gives courses in:

- The fundamentals of biophysics
- Molecular medicine and pharmacology
- Biomembranes and cellular sensors
- Biophotonics

RESEARCH METHODS

The laboratories run by Dr. Heinemann offer methods of modern electrophysiology, microscopy, molecular biology and cell physiology including:

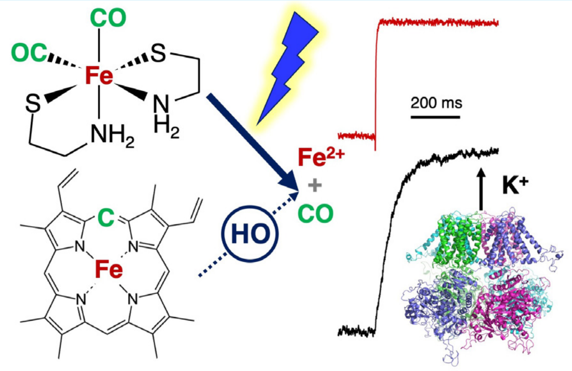
- Patch clamp
- Recombinant DNA technology
- Transgenic mice and cell preparations
- Laser scanning microscopy
- Real-time fluorometry and live cell imaging

RECENT RESEARCH RESULTS

Our Department focuses on the research of ion channels, their structure, function and pharmacology. The function of such membrane proteins can be monitored at real time on a single-molecule level with a combination of molecular biology, electrophysiology and photonic technologies. We are studying how ion channels contribute to the function of cells and organs, and are investigating how they can be manipulated by toxins and drugs. The overall aim is to better understand the molecular mechanisms underlying various diseases and to devise therapeutic strategies. An important area of study is the so-called Ca^{2+}- and voltage-activated potassium channel BK_{Ca}. It plays important physiological roles in smooth muscle relaxation and in neurotransmitter release. Malfunctions of this channel lead to an array of diseases such as epilepsy, urinary incontinence, and hypertension. Since drugs that open BK_{Ca} channels could be useful in disease treatment, we elucidated how low-molecular weight molecules interact with the channel protein to induce conformational changes that finally open the ion-conducting pore. We described the molecular mechanism by which omega-3 fatty acids from oily fish activate BK_{Ca} channels [1]. The gating of BK_{Ca} is modulated by the surrounding lipid molecules [2]. Further research focuses on how heme and heme degradation products, such as Fe^{2+} and CO, regulate voltage-gated ion channels. We demonstrated that heme binds to the N-termini of various K^+ channel proteins and their beta-subunits that give rise so-called A-type currents [3]. Heme binding interferes with the process of rapid channel inactivation and, therefore, has an impact on cellular electrical signaling. For the detection of free heme in the cytosol, we work on the optimization of fluorescent heme sensors. BK_{Ca} channels are also targets of heme; in addition, we showed that Fe^{2+} is a potent channel activator. Together with partners, we demonstrated how CORM-S1 rapidly releases Fe^{2+} and CO upon illumination, thus providing access to quantitative studies on Fe^{2+}-mediated gating in a biological setting [4]. Further research areas are related to the photonic modulation of living cells. Based on voltage-gated Na^+ channels, we developed gated and ratiometric molecular sensor systems for phototoxicity by incorporating selenocysteine in Na^+ channel proteins [5]. Such tools will help to evaluate and control living systems by photonic stimuli. Furthermore, we are studying the photoelectric coupling at cellular plasma membranes as an alternative to optogenetic cellular manipulations, and we develop fluorescent sensors for the measurement of the electrical membrane potential. In collaboration with the Leibniz IPHT Jena, we devise novel approaches for local light generation with molecular targeting of frequency up-converting nanoparticles.

A LIGHT-TRIGGERED HEMEOXYGENASE MIMIC

Catabolism of the blood pigment heme by heme oxygenase results in the liberation of carbon monoxide (CO) and iron ions (Fe^{2+}). Although this process is known for long, the physiological impact of these heme breakdown products largely remained elusive. Studying the impact of both mediators is not straightforward because of rapid diffusion and limited stability. We demonstrated that CORM-S1 (dicarbonyl-bis(cysteamine)iron(II)) is a useful chemical that precisely delivers CO and Fe^{2+} when illuminated with blue light. Fe^{2+}, rapidly released from CORM-S1 in a flash-photolysis setting, activates BK_{Ca} channels with an efficacy much higher than CO. BK_{Ca} channels are therefore downstream targets of heme oxygenase and may connect heme signaling with electrical cell signaling. Physiologically relevant micromolar Fe^{2+} concentrations activate BK_{Ca} channels as much as unphysiologically high (> 2 mM) Mg^{2+} concentrations.



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RAINER HEINTZMANN

PROFESSOR OF NANOBIOPHOTONICS, INSTITUTE OF PHYSICAL CHEMISTRY

As a professor of physical chemistry, Rainer Heintzmann is a member of the Faculty of Chemistry and Earth Sciences and the Faculty of Physics and Astronomy. He also heads a research unit at the Leibniz Institute of Photonic Technology in Jena. His main research direction has been high resolution optical microscopy and microscopy image processing.

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RESEARCH AREAS

The research of his group concentrates on the improvement of optical microscopy. Specific focus is currently placed on:

- Modern optical microscopy for biomedical research
- Research and implementation of super-resolved fluorescence microscopy through linear and non-linear structured illumination (SIM) and localization microscopy (dSTORM, DNA-PAINT)
- Hyper-spectral Raman-imaging for combined spatial and spectral information in medical research
- Affordable microscopes based on 3D-printig and smartphones for education and research
- Advanced image processing in microscopy
- Solving inverse problems in microscopy (e.g. image deconvolution and 3D-reconstruction)

TEACHING FIELDS

Prof. Heintzmann teaches undergraduate courses in physical chemistry and also specialized courses on optics and image processing. Specialized courses currently are:

- Light microscopy
- Biophotonics
- Image processing in microscopy

RESEARCH METHODS

The methods developed in Prof. Heintzmann's laboratories are applied, in collaboration with biologists, to biomedical problems. Available methods are:

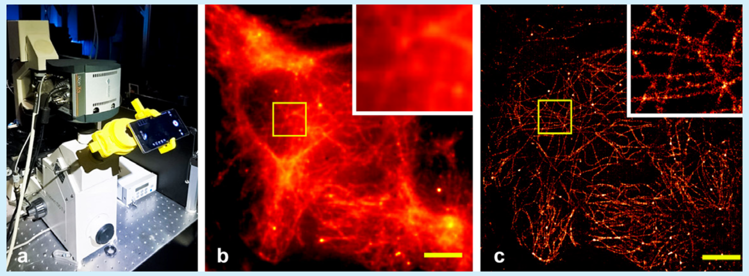
- Fast structured illumination microscopy
- Localization microscopy (dSTORM, DNA-PAINT)
- Confocal microscopy
- Hyper-spectral Raman microscopy
- Affordable and flexible microscopes through 3D-printing and off-the-shelf electronics

RECENT RESEARCH RESULTS

The Nanobiophotonics group has a long tradition working on aspects of structured illumination. It remains a strong focus of research in our group. Recently, in cooperation with the group of Dr. Thomas Ach, we have used our SIM-system for fast, multi-color imaging of age-related macula-degeneration (AMD) [1]. Optimization of SIM-reconstruction remains an important topic for us [2,3], e.g. related to identification and avoidance of motion artifacts [4]. Another line of research concentrates on pointillistic or single-molecule localization (SML)-based imaging modes. With dSTORM and DNA-PAINT, we use two SML methods, which rely on the precise localization of individual fluorescent dyes in the sample and are able to resolve structural details below 25 nm. In cooperation with external partners, these methods are employed e.g. in cancer research. We currently also develop approaches for a further resolution improvement through novel holographic illumination techniques [5], as well as sequential staining techniques for super-resolved imaging of many different colors. Spectroscopy based on Raman-scattering offers high molecular specificity without the necessity for staining or other marking steps. However, the integration into normal confocal imaging modalities limits speed and quality of the measurement due to low efficiency and heating effects [6]. We are thus working on hyperspectral Raman-imaging by combining integral-field spectrometry with light-sheet illumination. Our system enables parallel recording of 50×50 spectra, reaching a 50-fold enhancement in speed compared to standard confocal systems [7]. A similar method is employed in the visible spectral range for studies on AMD. Our project UC2 [8] is an open-source general-purpose modular framework for making interactive projects with optics and electronics. Relying on the basic principles makes UC2 particularly easy to use and flexible to adapt for a wide range of applications. Building an optical setup is simplified using 3D-printed cubes, each holding a specific component (e.g. lens, mirror) on a magnetic square-grid baseplate. The use of widely available consumables, together with open documentation and software, offers an extremely low-cost and accessible alternative for both education and research areas. The UC2 concept serves as a base for building microscopes and thanks to 3D printing it is ideal for rapid. The examples of many of the applications and some results are shown in the UC2 manuscript [9].

AFFORDABLE MICROSCOPY FOR RESEARCH AND EDUCATION

Recently we could demonstrate with "cellSTORM" that the camera module of a commercial mid-range smartphone is sufficient for achieving dSTORM images with a resolution of better than 80 nm [10] . With further developments, we have adapted this approach to a compact incubator microscope suited for imaging of live cells inside incubators for cell culture. The small device allows long-term measurements, greatly enhanced resolution through light-intensity fluctuation- or localization-based super-resolution techniques. Due to compact dimensions and the affordable price, it lowers the entry-barriers for high-end microscopy and is well suited for high-risk biosafety areas, which we have showcased by imaging SARS-CoV2 viral particles in cooperation with the university hospital Jena [11].



CellSTORM – affordable localisation microscopy on a smartphone:
a) 3D-printed adapter on the microscope stage. b) wide-field equivalent image. c) reconstruction from complete experiment. Scale bar 3 mikrometer.

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JER-SHING HUANG

HEAD OF RESEARCH DEPARTMENT OF NANOOPTICS, LEIBNIZ INSTITUTE OF PHOTONIC TECHNOLOGY

Dr. Jer-Shing Huang is the head of the Research Department of Nanooptics at the Leibniz Institute of Photonic Technology (Leibniz-IPHT). He is also an adjunct professor at the Department of Electrophysics at National Chiao Tung University (NCTU) and an adjunct research fellow at the Research Center for Applied Sciences (RCAS) at the Academia Sinica in Taiwan. Before Dr. Huang moved to Jena in 2016, he was an associate professor at the Department of Chemistry of National Tsing Hua University in Taiwan. Since 2016, Dr. Huang has been a member of the Editorial Advisory Board of ACS Photonics and SPIE Visiting Lecturer.

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RESEARCH AREAS

Dr. Huang's research focuses on the engineering of nanoscale optical fields and light-matter interactions. The research is based on fundamental sciences in physics and chemistry, and extends to interdisciplinary applications in the fields of optics, spectroscopy, microscopy, materials sciences, and sensors. Current research topics include:

- Nanoantennas and nanocircuits
- Optical trapping
- Chiral spectroscopy and imaging
- Plasmonic nanosensors
- DNA origami-based plasmonic devices
- Fluorescent polymer micro-resonators

TEACHING FIELDS

Dr. Huang's teaching covers basic and advanced topics for graduate students to gain sufficient knowledge in light-matter interaction. Dr. Huang's courses include:

- Physical chemistry
- Analytical chemistry
- Instrumental analysis
- Light-matter interaction

RESEARCH METHODS

Dr. Huang's research group exploits modern computer simulations and nanotechnologies to design and fabricate high-definition nanostructures and applies linear and nonlinear microscopic and spectroscopic methods to characterize the optical response of the nanostructures and study the interaction between light and matter. Specific research methods include:

- Numerical simulations (COMSOL and FDTD Solutions)
- Microscopy and spectroscopy
- E-beam lithography and focused-ion beam milling
- Scanning electron and atomic force microscopy
- PL and dark-field scattering spectroscopy
- Circular-dichroism spectroscopy
- Evanescent-wave cavity ring-down spectroscopy

RECENT RESEARCH RESULTS

The interaction between light and matter is usually limited by the size mismatch between light wavelength and molecular size in the matter. The goal of Dr. Jer-Shing Huang's group is to understand, control, and utilize nanoscale light-matter interactions through the application of rationally designed nanostructures. In particular, the group focuses on nanoplasmonics, which studies and controls the fundamental processes of the interaction of light with matter at the nanoscale. Fields of application include the sensitive detection of molecular chirality, nanoscale integrated optical circuits, plasmon-enhanced spectroscopy, and nanoobjects manipulation by the optical field. For optical nanosensors, we have developed a spectrometer-free plasmonics sensing platform, the plasmonic Doppler grating (PDG) [1]. A PDG consists of a series of circular grooves on a gold film that mimics the wavefront of a moving point source exhibiting the Doppler effect. We demonstrate PDG's ultimate sensitivity for direct quantification of the peculiar and tiny refractive index enhancement due to hydrogen bonds in water-ethanol mixtures. The PDG has also been applied to spatially resolve the plasmonic enhancement effect in coherent anti-Stokes Raman scattering [2]. Another type of optical nanosensors are based on bottom-up chemically synthesized nanoparticles. For example, we prepared high-definition bimetallic Au–Pd–Au nanobricks as an archetype of robust nanoplasmonic hydrogen sensors. We achieved the highest spectral shift of the resonance peak upon the absorption of hydrogen gas at a very low concentration [3]. For optical nanocircuits, we developed, for the first time, deep sub-wavelength mode conversion at the frequency of 194 THz (vacuum wavelength =1,545 nm). The field is confined into a nanogap with a width of only λ/15 of the operational optical signals. We show that by controlling the symmetry of the fundamentals modes in the waveguide, second-harmonics can be effectively generated in a centrally symmetric structure made of gold materials. [4]. Regarding chiral light-matter interaction, we have developed a one-step nanofabrication method to effectively fabricate a metasurface consisting of 3D chiral units, which exhibit superior chiral dissymmetry, stable field localization, and broadband near-field optical chirality [5]. We also study the generation of optical chirality patterns using interference of far-field beam and plasmonic waves [6]. These optical chirality patterns have many potential applications including super-resolution chiral imaging [7]. Figure 1 shows the representative images from the mentioned research projects.

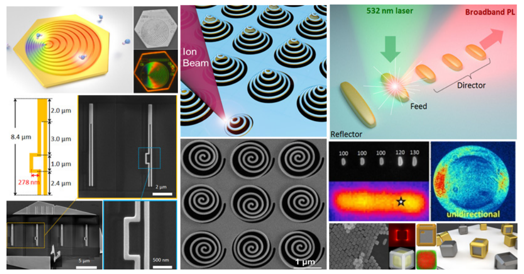

Figure 1. Graphical summary of selected research results.

BROADBAND DIRECTIONAL TRANSMITTING OPTICAL NANOANTENNAS OPERATING AT 400 THZ

Optical nanoantennas for next-generation wireless communication in the visible range (400-750 THz) feature a miniaturized footprint and ultrahigh operational frequency. The realization of broadband and directional transmitting optical nanoantennas with tunability is, however, technically challenging because multiple emitters at different wavelengths need to be precisely positioned at different antenna elements separated only by ~100 nm. This renders the implementation of "transmitting" directional nanoantennas very difficult. Recently, we have successfully overcome this challenge by exploiting the photoluminescence from the antenna material as a unique optical source to drive the nanoantenna. We experimentally demonstrated broadband directional transmitting nanoantennas operating at frequencies higher than 400 THz (λ = 750 nm). The opportunity of using photoluminescence from the antenna's material as the power source is unique for optical nanoantennas and finds no counterparts in their RF counterparts. The significance is not only about wireless communication at ultrahigh frequency but also that the operational frequency enters the regime of electronic transition in typical materials, allowing for the manipulation of light-matter interaction.

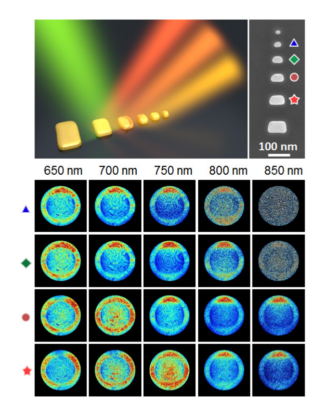

Figure 2. Broadband directional optical nanoantennas driven by photoluminescence of gold.

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MALTE C. KALUZA

PROFESSOR OF EXPERIMENTAL PHYSICS/ RELATIVISTIC LASER PHYSICS, INSTITUTE OF OPTICS AND QUANTUM ELECTRONICS

Prof. Kaluza is director of the Institute of Optics and Quantum Electronics. He is a member of the extended board of directors of the Helmholtz Institute Jena, member of the Senate of the Friedrich Schiller University Jena and the coordinator of the Erasmus Program of the Faculty of Physics and Astronomy. Dr. Kaluza is the head of the High-Intensity Laser Physics Group at the Center for Innovation Competence »ultra optics«.

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RESEARCH AREAS

Prof. Kaluza's research focuses on the generation and application of electromagnetic pulses from the THz to the x-ray regime with extreme parameters, reaching peak powers up to Terawatt or Petawatt for the study of various phenomena in non-linear relativistic optics. These studies also include:

- Development of laser systems with peak powers from TW to PW
- Laser-based particle acceleration
- Secondary electromagnetic pulses with ultra-short duration
- High-resolution probing of transient states of matter with optical pulses and particle beams
- Development, characterization, and application of novel materials for laser operation

TEACHING FIELDS

Prof. Kaluza's teaching is devoted to young scientist education from their first year onward to the doctorate level using state-of-the-art research.

He gives courses in:

- 1st year experimental physics
- High-intensity, relativistic optics
- Plasma physics

RESEARCH METHODS

In Prof. Kaluza's group's laboratories, a wide range of methods is developed and used to generate and apply high-intensity laser pulses. These methods include:

- Operation of the POLARIS laser system
- Cryogenic cooling for laser amplifiers
- Operation of burst-mode lasers both with high peak and high average power
- High-resolution spectroscopy and characterization of laser materials
- Few-cycle optical probing techniques
- High-resolution characterization of ultra-short high-energy particle and photon pulses

RECENT RESEARCH RESULTS

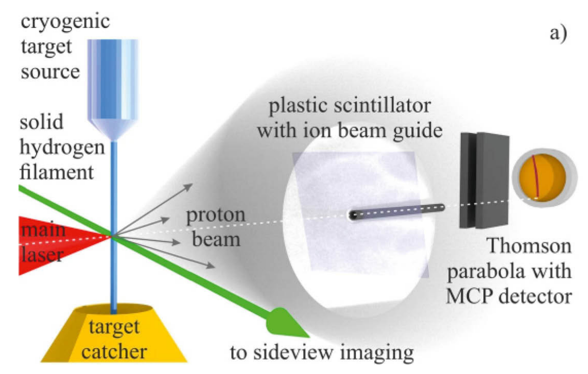
The Relativistic Laser Physics Group has recently achieved considerable progress in the field of laser-driven particle acceleration. Both the generation of electron [1] and ion pulses [2] from relativistic laser-plasma interactions and the possibility to actively tailor the energy distribution of the particles offer a number of important applications for the future. Here, the application of these particle pulses, both for the realization of ultra-short x-ray pulses and for the future development of a laser-based particle accelerator for radiation therapy in medicine, are the subject of our ongoing research.

In addition, the development and application of optical probing techniques by the Relativistic Laser Physics Group has led to the first observation of transient structures in laser-generated plasmas on µm- and fs-scales. Both the observation of the plasma wave, the transient acceleration structure in the plasma responsible for the generation of monoenergetic electron pulses, and the determination of the electron pulse duration with these techniques, have led to an insight into the acceleration mechanisms with unprecedented temporal and spatial resolution [3].

Furthermore, new approaches for the generation and amplification of high-power laser pulses have been studied by the Relativistic Laser Physics Group. These include the development and characterization [4] of new laser materials, especially Yb^{3+}-doped CaF_2, which is well suited for diode-pumping as used in the operation of the POLARIS laser which is currently the most powerful, diode-pumped system worldwide. To enhance the performance of such laser systems, novel cryogenic cooling techniques are being developed with the aim of increasing the repetition rate of the laser pulses.

EFFICIENT LASER-DRIVEN PROTON ACCELERATION FROM A CRYOGENIC SOLID HYDROGEN TARGET

Using cryogenically cooled, solid hydrogen filaments as a novel type of targets for laser-driven proton acceleration at the POLARIS laser system, the Relativistic Laser Physics Group could demonstrate a significant enhancement of the conversion-efficiency from laser pulse energy to protons up to the level of several percent. Furthermore, a detailed analysis of the laser and target conditions has shown that the protons with the highest kinetic energies are accelerated by a novel laser-acceleration mechanism for protons: the acceleration due to the formation of collisionless shocks. These results may help to significantly improve the prospects of laser-accelerated proton pulses for future applications. Image taken from [2].



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DANIIL KARTASHOV

POSTDOCTORAL SCIENTIFIC RESEARCHER

Dr. Daniil Kartashov holds a senior researcher and teaching position at the Institute for Optics and Quantum Electronics at the Friedrich Schiller University Jena. He is a Principal Investigator in the DFG Collaborative Research Center (CRC) 1375 "Nonlinear Optics down to Atomic Scales (NOA)" and leads the research group on Strong Field Nanophotonics.

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RESEARCH AREAS

Dr. Daniil Kartashov's research areas include ultrafast nonlinear optics and spectroscopy, nonlinear nanophotonics, nonlinear dynamics of ultrashort intense laser pulses in transparent media, strong field phenomena in gases and solids, relativistic plasma physics. His work is currently focused on extreme optical nonlinearities and high-order harmonic generation in nanoscale solids.

TEACHING FIELDS

Dr. Kartashov teaches Bachelor's and Master's degree students in physics and photonics. His teaching activity includes supervision of Bachelor/Master diploma work, lectures and seminars in XUV and x-ray optics, Physics of Optical Discharge and Filamentation. He further contributes to the supervision of internship research student work and physical practicum at the Faculty of Physics and Astronomy.

RESEARCH METHODS

Dr. Kartashov and his group develop experimental time-resolved ultrafast spectroscopy methods in solids based on highly nonlinear interaction with ultrashort laser pulses. The experimental research is carried out using top level femtosecond laser system, optical parametric amplifier and broad range of spectral and temporal diagnostics including high resolution spectrometers for different spectral ranges, frequency up- and down-conversion methods like FROG, X-FROG etc.

RECENT RESEARCH RESULTS

The Strong Field Nanophotonics group works in the very novel research field of nonlinear nanophotonics with special focus on extreme nonlinearities of interaction. When intensity of ultrashort laser pulses approaches the optical breakdown limit of the material, the nonlinear laser-matter interaction proceeds in a new regime beyond standard perturbative nonlinear optics. One of the unique characteristics of this regime of interaction is the significant population transfer of carriers from the valence band to the conduction band in semiconductors mediated by multiphoton absorption or tunneling. As a result, two major effects are experimentally detected and investigated: off-resonance optically pumped population inversion and high-order harmonic generation. Combining new pumping mechanism, based on interaction with strong off-resonance optical fields, and the geometry of a nanowire, naturally forming a cavity due to spatial mode confinement and high reflectivity of facets, a single semiconductor nanowire laser was demonstrated (see Fig. 1). It is shown that in this novel strong field pumping regime population inversion and lasing can be achieved with arbitrary pumping wavelength ranging from 0.8 micron (near-IR) to 4 micron (mid-IR) and switching the pumping mechanism from multiphoton absorption to tunneling. Excitation of electrons to the conduction band enables generation of high-order harmonics (HHG), based on two different mechanisms: nonlinear Bloch oscillations, i.e. nonlinear currents, driven by the laser field, of electrons in the conduction band and holes in the valence band, and interband electron-hole recombination, analog of HHG in gases. The group is conducting experimental investigation of this extreme nonlinear optics effect in bulk and nanoscale semiconductors like 2D materials, thin films, quantum dots and nanowires (see Fig. 2) with special focus on ultrafast carrier and lattice dynamics and its dependence on dimensionality.

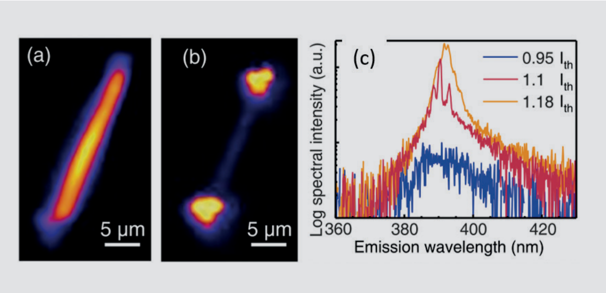


Figure 1: a) Spontaneous and b) lasing emission from a single ZnO nanowire pumped by 3.9 micron intense femtosecond laser pulses. c) The emitted spectrum at different pumping intensities measured relative to the threshold lasing value 0.7 TW/cm^2.

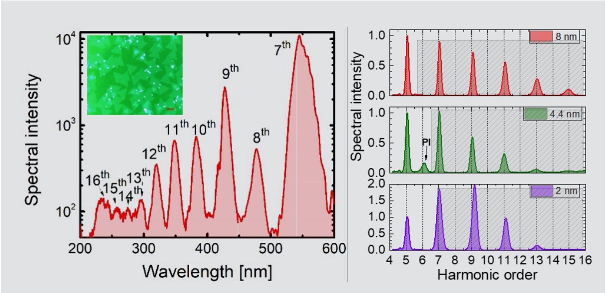
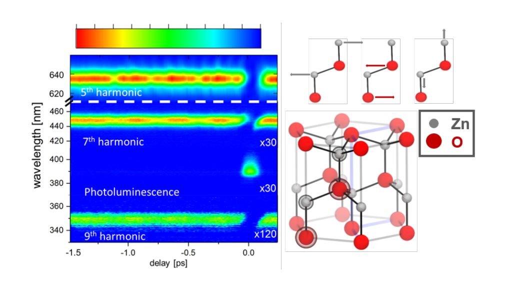


Figure 2: HHG spectrum measured in a single atomic layer semiconductor WS2 (left) and in layers of quantum dots of different diameter (right). The shaded area shows harmonics with energy of quanta above the bandgap.

HIGH-ORDER HARMONIC GENERATION BASED SPECTROSCOPY OF ULTRAFAST LATTICE DYNAMICS IN SEMICONDUCTORS

In collaboration with colleagues from Vienna University of Technology, we demonstrated in pump-probe experiments on ZnO crystals that high-order harmonic generation in semiconductors can be used for a new type of time-resolved spectroscopy of ultrafast lattice dynamics. We show that lattice motion can be reconstructed from modulation of harmonic intensities caused by different phonon modes, including silent modes not detectable for linear or Raman spectroscopy.



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ERIKA KOTHE

RESEARCH AREAS

With a particular focus on the visualization of morphological changes during mating interactions, her research interests are:

- Mating type genes and sexual development in the white rot fungus *Schizophyllum commune*
- Mutually beneficial symbiotic interactions of basidiomycetes in ectomycorrhizae
- Heavy-metal resistance in fungi and streptomycetes
- Applications to improve bioremediation

TEACHING FIELDS

Professor Kothe teaches at the basic and advanced levels, including the coordination of the M.Sc. program Master's degree in Microbiology and she is involved in the Bachelor's and Master's degree programs in Biogeosciences. Additionally, she is involved in many graduate teaching programs.

PROFESSOR OF MICROBIAL COMMUNICATION, INSTITUTE OF MICROBIOLOGY

Professor Kothe is, among other affiliations, speaker of the Graduate School Jena School for Microbial Communication within the Excellence-Cluster Balance of the Microverse. In addition, she is coordinator of the profile line LIFE of the Friedrich Schiller University Jena and president of the German University Association for Advanced Graduate Training.

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Subjects taught are:

- Basic and advanced microbiology
- Bio-geo-interactions
- High level microbial interactions, cell biology and development

RESEARCH METHODS

The group offers all research-oriented teaching in the fields of microbiology and cell biology of bacteria and fungi. Nanostructures and minerals are covered with special emphasis on nanoparticles, biominerals and microbial investigation involving:

- Fluorescence video-imaging
- High resolution microscopy
- Omics techniques
- Characterization of mutations
- Characterization of native consortia
- High resultion imaging

RECENT RESEARCH RESULTS

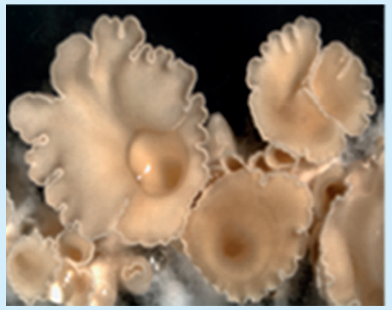
The research on mating type loci covers pheromone response in mushroom forming fungi. We undertook a functional characterization and transcriptome analysis that enabled a comprehensive study of the mating reaction and intracellular signal transduction pathways involved [1]. Production of volatiles weathering of Corg-rich rock and wooden material, and the interaction with other fungi and bacteria is investigated using the model basidiomycete Schizophyllum commune [2].

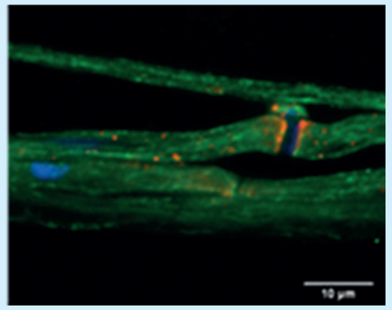
Colonization strategies and host specificity of ectomycorrhizal fungi are examined with Tricholoma vaccinum. The sequenced genome of Tricholoma vaccinum and Agrobacterium tumefaciens mediated transformation enable functional analyses. The influence of co-occuring microorganisms on mycorrhiza is investigated [3], incluing heavy metal contaminated habitats.

Streptomycetes from a heavy metal containing site of the former uranium mining site Wismut in Eastern Thuringia are used to determine the mechanisms of heavy metal resistance in this group of important soil microbes and questions of bio-geo-interactions [4,5]. The bacterial diversity is assessed for bioremediation approaches.

CONTROL OF DEVELOPMENT IN MUSHROOMS

The small G protein Ras regulates different cellular processes in eukaryotes. This highly conserved protein contains several GTP/GDP-binding domains. Its ability to hydrolyze GTP allows Ras to activate different effector molecules and function as a binary molecular switch, controlling intracellular signaling networks. To analyze the Ras function in *S. commune*, different mutant strains are investigated for their physiology, fruitbody formation and cytoskeleton phenotypes.





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JENS LIMPERT

PROFESSOR FOR NOVEL SOLID-STATE LASER CONCEPTS AT INSTITUTE OF APPLIED PHYSICS

Jens Limpert leads the Laser Development Group at the Institute of Applied Physics. Furthermore, he is a scientific member of the Helmholtz Institute Jena and a member of the directorate of the Fraunhofer Institute for Applied Optics and Precision Engineering, Jena. He was distinguished with a European Reseach Council (ERC) Starting Grant in 2009, a Consolidator Award in 2014 and an Advanced Grant in 2019.

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RESEARCH AREAS

In his research, Prof. Limpert investigates novel laser source concepts. Research thrusts include:

- Innovative laser sources, high power lasers
- Novel fiber structures
- Propagation effects of short laser pulses
- Light matter interaction at high intensities
- Nonlinear optics, parametric amplifiers
- Ultrafast lasers
- Coherent combination of lasers
- Cavity enhancement of femtosecond pulses
- High harmonic generation (HHG) and attosecond pulse generation
- THz generation

TEACHING FIELDS

Prof. Limpert teaches courses in the fundamentals of laser physics both for the M.Sc. Photonics and for the M.Sc. Physics.

RESEARCH METHODS

The laboratories run by Prof. Limpert offer a wide range of complex setups and characterization methods to establish and study novel optical components:

- Fiber optics and fiber technology
- Numerous laser sources and pump diodes
- Setups for spatial and temporal shaping of ultrashort pulses
- Ultrashort optical pulse characterization devices

RECENT RESEARCH RESULTS

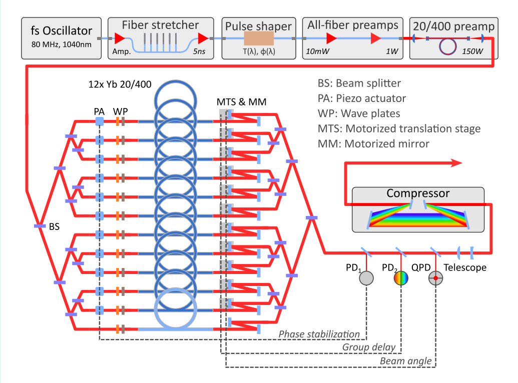
The Fiber and Waveguide Laser Group has demonstrated a significant performance scaling of fiber-based laser systems in recent years. Based on a fundamental knowledge of waveguide optics and laser physics, novel fiber designs such as the rod-type large pitch photonic crystal fiber have been invented. This fiber design is based on a novel mechanism, the delocalization of higher order transverse modes, and allows for single-mode extraction from a core size of ytterbium-doped fibers as large as 135 µm, 135 times larger than the guided wavelengths. This record mode area has enabled an enormous performance increase in ultrafast fiber laser systems. Gigawatt peak power, in combination with several 100 W of average power, constitutes unique laser parameters [1, 2].

To extract a performance which is beyond the capabilities of a single aperture emission, the approaches of spatially separated amplification, followed by the coherent addition of amplified femtosecond pulses, are pursued. These concepts are based on the idea of distributing the load or challenges, respectively, to more than just one amplifier channel. In this regard, an amplifying interferometer is constructed. Besides producing a careful numerical analysis, the group has been able to extract parameters beyond the capabilities of a single channel emission [3], demonstrating a new and promising scaling concept for ultrafast lasers. Based on this work, fiber based laser systems are now considered potential drivers for laser wake-field particle accelerators. Besides performance scaling fundamental effect in amplifying fibers are investigated. Among them thermally induced modal instabilities. This new affect is a serious issue for high average power fiber laser system. Over the recent years the group has contributed to the understanding of that effect and proposed most efficient mitigation strategies [4].

Transferring the performance of high-repetition rate fiber lasers to new wavelength regions would enable a number of novel applications. We have revealed an unprecedented potential of Thulium-doped fiber lasers most recently. The favorable scaling when shifting the emission wavelength to 2 µm of mode area and nonlinear effects are the basis for a push in obtainable peak power, whereas the higher thermal robustness of long-wavelength fiber lasers hold the promise for high average powers. In addition, the provided gain bandwidth of thulium-doped silica would support pulses as short as 60 fs. In terms of optical cycles that would correspond to a 25 fs emission at 800 nm. The group has demonstrated multi-GW peak power and kW average power ultrafast thulium-based fiber laser systems [5,6]. Therefore, 2 µm fiber lasers might be considered as the long-wavelength counterpart of Titanium:Sapphire lasers in the future, but in an average-power scalable platform, which is most beneficial for an inexhaustible number of applications.

GENERATION OF FEMTOSECOND PULSES WITH MORE THAN 10 KW AVERAGE POWER

In lasers, waste heat is generated in the process of light emission. Laser geometries with a large surface-to-volume ratio, such as fibers, can dissipate this heat very well. Thus, an average power of about 1 kilowatt is obtained from today's high-power lasers. Beyond this power, the heat load degrades the beam quality and poses a limit. To circumvent this limitation, the we have created a new laser that externally combines the output of 12 laser amplifiers. They showed that the laser can produce 10.4 kW average power without degradation of the beam quality [7]. Thermographic imaging of the final beam combiner revealed a marginal heating. Thus, power scaling to the 100-kW level could be accomplished by adding even more amplifier channels. In the future, high-power combined lasers not only will accelerate industrial processing, but also enable formerly visionary applications such as laser-driven particle acceleration and space debris removal.



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STEFAN LORKOWSKI

PROFESSOR FOR NUTRITIONAL BIOCHEMISTRY AND PHYSIOLOGY AT THE INSTITUTE OF NUTRITIONAL SCIENCES

Prof. Lorkowski is the director of the Institute of Nutritional Sciences and heads the Chair of Nutritional Biochemistry and Physiology at this institute. He is coordinator of the Competence Cluster for Nutrition and Cardiovascular Health (nutriCARD) Halle-Jena-Leipzig and serves as a member of the scientific executive committee of the German Nutrition Society. Prof. Lorkowski is a member of the scientific advisory board of the DACH Society for the Prevention of Cardiovascular Disease and of the executive board of the German Atherosclerosis Society.

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RESEARCH AREAS

In his research Prof. Lorkowski investigates the function and plasticity of human monocytes and macrophages, which are the phagocytic cells of the immune system, in physiological processes and in pathophysiological conditions. He is also interested in unraveling the physiological importance of metabolites of vitamin E as signaling molecules. Research interests include:

- Cellular lipid transport and metabolism
- Targeted delivery into human cells
- The regulation of cellular metabolism and function by nutrients and metabolites
- Molecular mechanisms of atherosclerosis and dyslipidemia

TEACHING FIELDS

Prof. Lorkowski's teaching is aimed at the theoretical and practical training of undergraduate and graduate students, as well as young scientists. He gives courses on:

- Fundamentals of biochemistry and nutritional biochemistry
- Principles of cellular transport processes
- Molecular basics of age-related diseases
- State-of-the-art techniques of life science research

RESEARCH METHODS

The laboratories led by Prof. Lorkowski offer a wide range of techniques for investigating cellular processes at the molecular level which include:

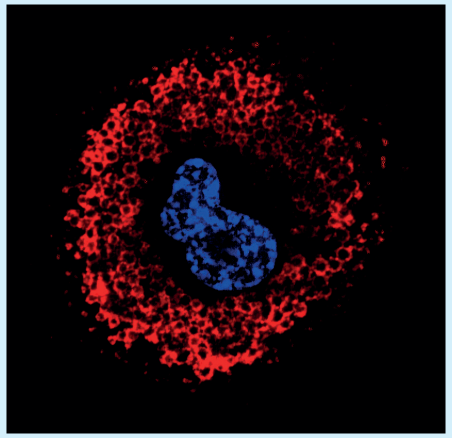
- Confocal laser-scanning fluorescence microscopy
- Isolation and culture of human cells
- Targeted delivery of cargos into human cells
- Cell and animal models of atherosclerosis
- Expression profiling and flow cytometry
- Fatty acid analysys

RECENT RESEARCH RESULTS

Prof. Lorkowski and his research group have contributed to the unraveling of molecular mechanisms of lipid droplet formation in macrophages [1, 2]. The storage of neutral lipids such as triglycerides and cholesteryl esters in cytosolic lipid droplets is a complex process. In contrast to previous assumptions, studies by Lorkowski's group and others indicate that the lipid droplets of eukaryotic cells are by no means static cellular structures used only for intermediate- or long-term storage of lipids. Lipid droplets, for example in macrophages, are in a dynamic state of continuous and tightly regulated esterification and hydrolysis. In addition, the group developed several state-of-the-art techniques to achieve a deeper insight into the spatio-temporal dynamics of lipid droplet formation and into the molecular constituent parts of the lipid droplet protein machinery [3-5]. In particular, the group developed a simple and rapid approach for efficiently transfecting macrophages with different types of cargo for in-depth functional studies [6-8]. Transfection of macrophages is usually accompanied by a progressive loss of cell viability and functionality. By contrast, the technique developed by Lorkowski's group maintains cell viability and functionality, thus allowing efficient genetic modification of these hard-to-transfect cells. Furthermore, this research group has contributed to the characterization of the complex picture of macrophage plasticity by adding a new dimension to macrophage heterogeneity. Macrophages derived from blood monocytes perform many tasks related to tissue injury and repair. The main effect of macrophages on the extracellular matrix is generally considered to be destructive in nature, because macrophages secrete metalloproteinases that degrade and destabilize the surrounding extracellular matrix. Macrophages ingest foreign material as part of the remodeling process that occurs in wound healing and other pathological remodeling conditions. By contrast, the group discovered that macrophages may promote tissue integrity and contribute to the extracellular matrix and hence to tissue stabilization both indirectly, by inducing other cells to proliferate and release matrix components, and directly by secreting components of the extracellular matrix such as fibronectin and different types of collagen [9].

NONINVASIVE IMAGING OF INTRACELLULAR TRANSPORT PROCESSES

The appearance of cytosolic lipid droplets is a hallmark of macrophage foam cell formation, a key event in the atherosclerosis process. In this context, the intracellular fate of individual lipid species such as fatty acids or cholesterol is of particular interest. We utilize Raman and fluorescence microscopy techniques to visualize the intracellular metabolism of such lipids and to trace their subsequent storage. The combination of microscopic information with Raman spectroscopy allows for imaging at the diffraction limit of the employed laser light and biochemical characterization through associated spectral information. In order to spectroscopically distinguish the molecules of interest from other endogenously occurring lipids, deuterium labels are used. This approach enables the investigation of the cellular trafficking of other molecules such as nutrients, metabolites, and drugs.



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TIMO MAPPES

RESEARCH AREAS

Experimental revisiting historic milestones in optics and photonics

- Performance of immersion microscopy with high numerical aperture pre 1900
- High-resolution widefield microscopy at 275 nm and the discovery of microscopic fluorescence in 1903
- Beginning of light-sheet microscopy in 1904

Physical characterization of vintage optical solutions

- Performance of historical objectives, applying correlative microscopy to evaluate the intra- and extrapolation of historic microscopic drawings
- Lens-mapping of spectacle lenses made prior to 1800
- Tolerances and stability in production of optical glass

Edutainment as science communication

- Developing educational kits for optics & photonics

PROFESSOR FOR HISTORY OF PHYSICS WITH FOCUS IN SCIENCE COMMUNICATION

Prof. Mappes is the founding director of Deutsches Optisches Museum (D.O.M.). In 2018 he joined Friedrich Schiller University after having run global R&D for the spectacle lens business of ZEISS. There, in addition to numerous technical innovations, he introduced edutainment as a compelling format of science communication at the point of sales. In parallel to latest technology, Prof. Mappes' private passion for more than 25 years are antique optical instruments. This passion is now his profession - in Jena he is creating a new type of museum by merging science center elements with historic artefacts of optics, combining it with the showcase of the latest research results in optics and photonics.

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TEACHING FIELDS

In the course "Milestones in Optics" Prof. Mappes is reflecting on the physics of optical systems and instruments, as well as their application, economics and relevance. He also shares his industrial background in workshops on science communication.

RESEARCH METHODS

Research at D.O.M. is developed from scratch with focus on its research areas. The museum's collection is a unique source of entire systems or optical glass:

- World's largest collection of optical glass with about 95,000 samples
- Huge collection of spectacle lenses dating back to the 1600s, among them the largest collection of Nuremberg master spectacles
- Major collection of antique microscopes starting in the late 1600s, as well as a large collection of historical microscope objectives
- Scientific equipment to analyze these systems

RECENT RESEARCH RESULTS

There are several fields D.O.M. team members are or have been working on recently:

(1) Evaluation of historic or current optical solutions

- Experimental characterization of UV-protection with clear ophthalmic lenses [1]
- UV-microscopy at λ = 275 nm with quartz-optics of 1903. Experimentally we proved the limitations of the historic results being the contrast of photographic plates. Modern CCD, applied with the historic optics, convey details of the test objects at the respective widefield resolution limit in this UV-C regime of d = 145 nm.

(2) Edutainment

Developing didactic workflows to enable laymen to prove optical performance. For industrial applications a sales process was designed, along with the matching robust optical test system to compare optical parameters beyond the visible spectrum [2].

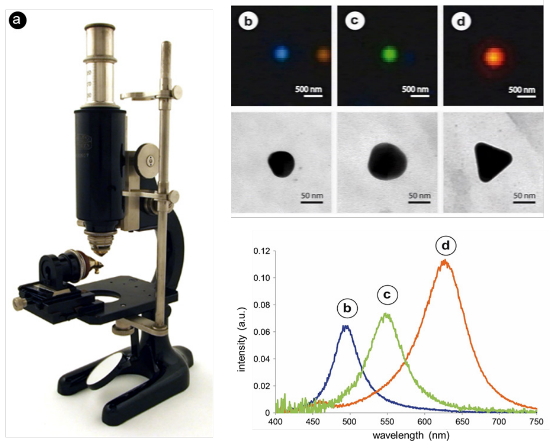
(3) Overcoming classical limits in the performance of optical systems

Transforming the challenges of classical optical limits to a none-optical regime and re-transforming the solutions to address basic technical limitations [3, 4].

REVISITING HISTORICAL MICROSCOPY RESEARCH

Research at D.O.M. aims at revisiting major findings in optics and photonics. As such the team is probing historic speculations with recent methods. One example in this very direction was the validation of the theory on the shape and behavior of metallic nanoparticles in solution by Siedentopf and Zsigmondy in 1902 [5]. Color imaging back then was not available yet. Thus, Zsigmondy could describe the colors of the Tyndall cones of the moving nanoparticles in written text only. In addition, he could only speculate about the distinct shape of the nanoparticles, because they were too small to be resolved by any means during his lifetime.

Consequently, the historic optical equipment (a) was applied and Zsigmondy's findings were evaluated. The photonic response of the particles could be documented (first row on the right, micrographs b through d) and correlated this with the shape of the particles by using TEM images (second row on the right). Eventually single-particle spectra (bottom graph on the right) could be evaluated. Eventually Zsigmondy's approach to develop models beyond accessible physical regimes could be experimentally proved having been successful [6].



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UTE NEUGEBAUER

PROFESSOR FOR PHYSICAL CHEMISTRY, CLINICAL SPECTROSCOPIC DIAGNOSTICS

Ute Neugebauer is professor of Physical Chemistry and head of the research department Clinical Spectroscopic Diagnostics at the Leibniz Institute of Photonic Technology (Leibniz-IPHT). She is deputy scientific director of the Leibniz-IPHT, leader of the Core Unit Biophotonics of the Center for Sepsis Control and Care at Jena University Hospital and involved in the Executive Committee of the Core Facility Jena Biophotonic and Imaging Laboratory (JBIL).

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RESEARCH AREAS

The main research interest of the group of Prof. Neugebauer is the investigation, development and application of novel spectroscopic tools and methods for medical diagnostics and the characterization of physiological interactions in particular in the context of infections and sepsis. This includes the detailed characterization of the pathogen causing the infection, its localization within the host cells, the elucidation of its interaction with drugs and with the host, and the analysis of the host response to the infection, here with a special focus on immune cells.

TEACHING FIELDS

Prof. Neugebauer gives lectures for students in chemistry and the interdisciplinary Master's degree course Medical Photonics. Her courses include:

- Physical chemistry
- Light-matter interaction
- Applied physical chemistry

Her teaching is devoted to the early involvement of students and young scientists in state-of-the-art research.

RESEARCH METHODS

In our research we use advanced biophotonic tools with a focus on Raman- and fluorescence-based methods. To allow optimal handling of biological samples and in order to shorten the time required for diagnosis, we integrate label-free and non-destructive photonic methods into bioanalytical chip systems.

RECENT RESEARCH RESULTS

Photonic methods hold a high potential to improve medical infection diagnostics, in particular shorten the time-to-diagnosis [1]. The optical-spectroscopic method developed in the last years can spectroscopically characterize the interaction of antibiotics with bacteria. Characteristic changes in the bacterial spectrum and morphological changes indicate effective action of the antibiotic, but also help to identify antibiotic resistance. Using statistical data analysis algorithms antibiotic susceptibility of patient isolates can be determined within only a few hours [2]. In times of rising antibiotic resistances this is of utmost importance. The spectroscopic characterization takes only a few hours and the result can be qualitative, i.e. to differentiate between sensitive and resistant behavior, or quantitative [3], i.e. to determine the minimum inhibitory concentration (MIC: concentration of antibiotics that visibly inhibits bacterial growth). These research activities are continued in collaboration with Prof. Dr. Jürgen Popp and his group. Furthermore, the spectroscopic methods to study drug-bacteria interaction can be translated to follow the interaction of bacteriophages and their host [4]. Once, the pathogens enter the host, they are attacked by the immune system. Important cells of the immune system are leukocytes. They fight off pathogens by phagocytosis or with antibodies and coordinate the specific and non-specific immune response. In defined in-vitro stimulation experiments, we were able to follow the reaction of monocytes to the bacterial cell wall component lipopolysaccharide (LPS) in a time-resolved, marker-free and non-destructive manner using Raman spectroscopy. The spectral changes can be easily explained by the biological changes in the cell [5]. The spectroscopic method can also be applied to immune cells obtained after in-vivo stimulation in a mouse model [6]. With novel technical developments in the research department of Prof. Dr. J. Popp, high-throughput Raman measurements (>2,000 cells/hour) are now possible and enabled revealing the specific spectroscopic signatures of immune cells after stimulation with different pathogens [7] (see Research highlight).

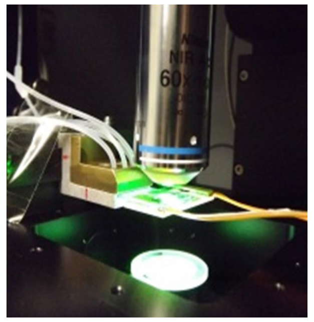
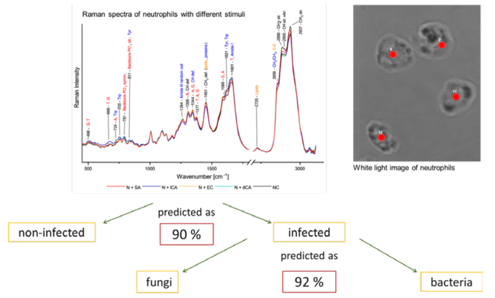


Figure 1:
Microfluidic system under the Raman microscope for the spectroscopic characterization of antibiotic susceptibility.

DIFFERENTIATION OF BACTERIAL AND FUNGAL INFECTION USING THE RAMAN SPECTROSCOPIC FINGERPRINT OF NEUTROPHILS

Neutrophils, the most abundant white blood cells, are among the first responders to infection. We established a Raman spectroscopy-based method for label-free neutrophil phenotyping and infection diagnosis [7]. Neutrophils without pathogen contact served as negative controls (NC) while infectious conditions were simulated by bringing neutrophils into contact with bacteria (*S. aureus* (N+SA) and *E. coli* (N+EC)) and fungi (heat-inactivated (N+dCA) and viable Candida albicans (N+ICA)). Random forest classification models enabled differentiation of infected and non-infected cells with high accuracy (90%). Among the neutrophils challenged with pathogens, even the cause of infection, bacterial or fungal, was predicted correctly with 92% accuracy. This Raman-based method holds the potential to save precious time in bloodstream infection diagnostics, where currently, pathogen isolation is based on time-consuming microbiological cultivation.



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STEFAN NOLTE

PROFESSOR OF EXPERIMENTAL PHYSICS/ LASER PHYSICS, INSTITUTE OF APPLIED PHYSICS

Prof. Nolte is the head of the Ultrafast Optics group at the Institute of Applied Physics and Deputy Director of the Fraunhofer Institute for Applied Optics and Precision Engineering IOF, Jena. He is a member of the executive board of the Abbe School of Photonics, a fellow of the Max Planck School of Photonics, and a member of the Center of Medical Optics and Photonics (CeMOP). In December 2013, he has been awarded the Federal German President's Award for Innovation in Science and Technology together with Bosch and Trumpf for transferring ultrashort pulse laser processing into industrial mass production.

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RESEARCH AREAS

The research topic of Prof. Nolte is ultrashort laser pulses inclucing ultrashort pulse micromachining and material modification for industrial and medical applications, areas where he is engaged in since the field's inception in the mid-1990s. Current research interests include:

- Linear and nonlinear interaction of light and matter
- Micro- and nanostructuring by ultrashort laser pulses
- Ultrashort pulse laser cutting and welding
- 3D-volume structuring of glasses and crystals
- Fiber and volume Bragg gratings
- Linear and nonlinear optics in discrete systems
- Additive manufacturing using ultrashort laser pulses
- Applications of ultrashort lasers in ophthalmology
- Nonlinear spectroscopy

TEACHING FIELDS

Stefan Nolte is teaching courses ranging from fundamental aspects of physics to state-of-the-art research. He is also responsible for the ASP optics training laboratory, including labwork internships. He gives courses in Atomic and Molecular Physics and Ultrafast Optics.

RESEARCH METHODS

The laboratories led by Prof. Nolte are equipped with a wide variety of lasers, handling equipment and characterization technology. These include:

- High repetition rate ultrashort pulse laser systems (7 fs to 20 ps) including wavelength conversion (300 nm to 10 µm), and average powers up to 500 W
- High-precision positioning and laser scanner systems
- Equipment for sample preparation and characterization (optical microscopes, electron microscope, Raman microscope, etc.)
- Characterization of spectral and spatial properties of micro- and nanostructured samples
- Characterization of nonlinear spatio-temporal dynamics

RECENT RESEARCH RESULTS

The Ultrafast Optics group has extensive capabilities to precisely structure virtually any material on a micrometer scale. This includes the defined modification of the optical properties within the volume of transparent materials, which is e.g. used to realize complex coupled waveguide array structures of various three-dimensional geometries. Its potential is exploited for tailoring the flow of light in artificially structured glass. By combining this with the localized generation of so-called nanogratings acting as artificial birefringent structures, integrated optical quantum gates can be realized for quantum optical operations [1].

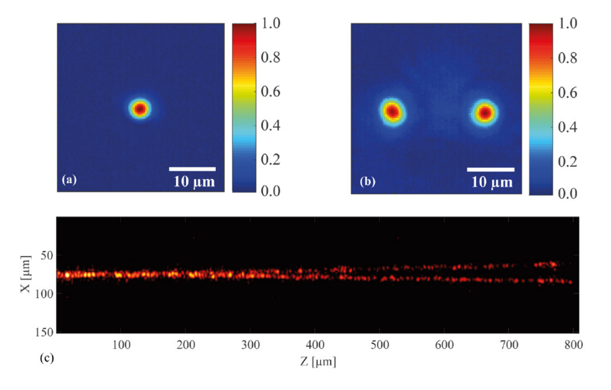
In addition, we use ultrashort laser pulses to inscribe highly periodic structures into transparent materials. This way we are able to realize Bragg gratings in various fibers, which can be used as efficient fiber-integrated laser mirrors withstanding even highest powers [2]. In addition, the inscription of aperiodic fiber Bragg gratings allows for a precise spectral filtering as required e.g. in astrophotonic applications [3]. When this technique is extended to bulk material, volume Bragg gratings can be generated. We recently managed to inscribe such highly efficient gratings into fluoride glasses, targeting applications as lasers or hyperspectral imaging in the mid-infrared spectral range [4]. For optimizing the laser processing, a detailed spatio-temporal analysis of the laser-glass interaction is essential [5].

Apart from structuring and ablation, we apply ultrashort laser pulses for additive manufacturing. The high peak power of these pulses allows to process a large variety of different materials. Currently, we focus on copper, glass as well as lightweight alloys. Here, the ultrashort pulse duration results in extremely fast heating and cooling cycles, allowing e.g. the laser powder bed fusion of hypereutectic alloys [6].

A promising spectroscopic approach for the process analysis of chemical reactions is the coherent anti-Stokes Raman scattering using femtosecond laser pulses (fs-CARS). The short pulse durations enable the excitation of molecular states of a gas, before detrimental molecular collisions take place. This feature makes fs-CARS ideally suited for thermometry and gas concentration measurements under high temperature and high pressure conditions. We recently investigated two-beam fs/ps CARS for effective concentration and temperature measurements in gas mixtures [7].

LASER-WRITTEN INTEGRATED OPTICS DEEP INSIDE SILICON

Silicon is the backbone of today's semiconductor industry. Despite electronics, silicon photonics plays an increasing role due to the large interest of integrating photonic and electronic devices on the same chip. However, conventional approaches are limited to the surface resulting in 2D planar photonic solutions. Recently, we directly inscribed highly localized single mode waveguides into the bulk of crystalline silicon by using infrared ultrashort laser pulses [Kämmer et al., Laser Photonics Rev. 13, 1800268 (2019)]. Microstructural analysis revealed that defects and dislocations are induced in the crystalline matrix. The resulting strain is expected to be responsible for the positive refractive index changes of up to 5x10^{-3} enabling waveguiding with losses below 8.7 dB/cm [Alberucci et al., Phys. Rev. Applied 14, 024078 (2020)]. In order to demonstrate the 3D writing capabilities, a buried Y-splitter was fabricated with an exact splitting ratio of 50:50 [Matthäus et al., Opt. Express 26, 24089 (2018)].



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GERHARD G. PAULUS

PROFESSOR OF NONLINEAR OPTICS, INSTITUTE OF OPTICS AND QUANTUM ELECTRONICS

Dr. Paulus holds the Chair of Nonlinear Optics. In addition, he is a member of the board of directors of the Helmholtz Institute Jena and serves on several scientific advisory committees at major laser facilities all over Europe.

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RESEARCH AREAS

The central theme of Dr. Paulus's research is strong-field and attosecond laser physics. Current projects include:

- Phase-dependent ionization and dissociation of fundamentally important atomic and molecular systems
- Relativistic ionization dynamics
- Strong-field QED
- X-ray polarimetry with an extinction ratio of 10^{10}
- Nanoscale XUV imaging
- High-precision X-ray polarimetry

TEACHING FIELDS

- Introductory physics
- Fundamentals of modern optics
- Nonlinear optics
- Strong-field and attosecond laser physics
- X-ray physics and free-electron lasers
- Renewable energies

RESEARCH METHODS

- Photoelectron spectroscopy
- Momentum spectroscopy
- XUV spectroscopy
- Polarimetry
- Vortex laser beams

RECENT RESEARCH RESULTS

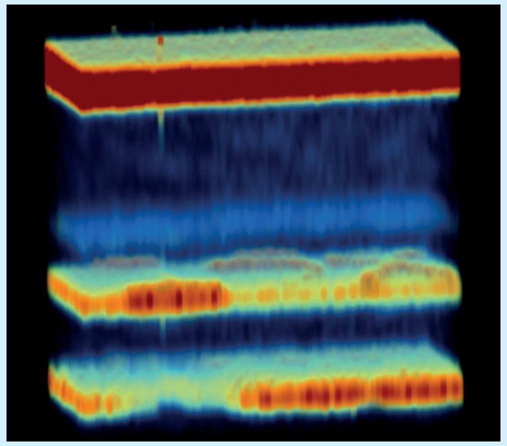
Dr. Paulus' research group has invented and developed XUV Coherence Tomography (XCT) as a novel method for non-destructive cross-sectional imaging with nanoscale resolution. Similar to Optical Coherence Tomography (OCT), the scheme is based on white-light interferometry, however using ultra-broadband extreme UV radiation. In addition to high resolution, the method affords very high material contrast and ultrafast temporal resolution.

The XUV radiation used for XCT is generated via high-harmonic generation, i.e. via the interaction of intense femtosecond pulses with atoms or molecules. Dr. Paulus uses an unique approach to investigate the fundamental physics of the respective processes, namely a fast ion beam of fundamentally important systems such as He^+, $H2^+$, or HeH^+. The latter is in fact considered to be the first molecule after the Big Bang. We have performed the first measurements on the strong-field dissociation and ionization dynamics of this intriguing molecule.

Last but not least the group works on high-precision X-ray polarimetry. The ultimate goal is to measure the birefringence of vacuum polarized by a strong laser field. To this end, an X-ray polarimeter with an extinction ratio of 10^{-11} or better is required. In the past ten years, a series of world records in polarization purity were established and the state-of-the-art advanced by three orders of magnitude such that the required extinction ratio is in reach. The unprecetended sensitivity of the polarimeters has found applications for a number of other applications in plasma physics, solid-state physics, and X-ray quantum optics.

XUV COHERENCE TOMOGRAPHY

The figure shows a coherence tomogram of a silicon sample with two embedded gold layers in depths of 200 and 300 nm. In addition, a silicon dioxide layer in 160 nm depth was detected. The latter has inadvertently formed during the production of the sample. The remarkable sensitivity of XCT is underlined by the fact that this layer could only be verified by a transmission electron microscope after cutting out a thin slice of the sample.



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THOMAS PERTSCH

PROFESSOR FOR APPLIED PHYSICS AT INSTITUTE OF APPLIED PHYSICS

Prof. Pertsch is a member of the board of directors of the Abbe Center of Photonics and the spokesman of the Abbe School of Photonics. He is a fellow of the Max Planck School of Photonics and associated investigator in the clusters of excellence "Balance of the Microverse" and "Transformative Meta-Optical Systems". He serves in the board of directors of the Thuringian Innovation Center for Quantum Optics and Sensing and is the head of the Nano & Quantum Optics Group at the Institute of Applied Physics. Since 2024, he is the spokesperson of the profile line LIGHT of the Friedrich Schiller University Jena.

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RESEARCH AREAS

Prof. Pertsch's research targets the control of light at the nanoscale and at the quantum level using nanostructured materials and ultrafast nonlinear optical effects. Research interests include:

- Ultrafast light-matter interactions and optical quantum phenomena in nanostructured matter, as e.g. photonic nanomaterials, metamaterials, photonic crystals, and 2D semiconductors (TMDCs)
- Nonlinear spatio-temporal dynamics, plasmonics, near field optics, high-Q nonlinear optical microresonators, opto-optical processes in integrated optics, and all-optical signal processing
- Integrated quantum optics, quantum imaging, and quantum sensing
- Multi-tip scanning nearfield optical microscopy (SNOM) and photoemission electron microscopy (PEEM)
- Application of photonic nanostructures for multi-functional diffractive optical elements, for efficiency enhancement of photovoltaic elements, and for astronomical instruments

TEACHING FIELDS

Prof. Pertsch's teaching is devoted to the early involvement of young scientists in modern research topics. He gives Master-level courses in:

- Fundamentals of Modern Optics
- Computational Physics and Photonics
- Nanooptics and Quantum Optics

RESEARCH METHODS

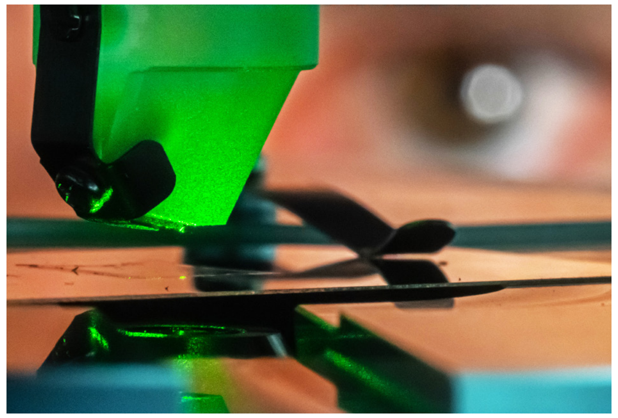
The laboratory run by Prof. Pertsch offers a wide range of methods for the experimental characterization of photonic nanostructures, which include:

- Scanning nearfield optical microscopy (SNOM)
- High-resolution micro-spectroscopy (UV-VIS-IR)
- Time-resolved single photon detection and correlation
- Photoemission electron microscopy (PEEM)
- Ultrafast time-resolved characterization of nonlinear spatio-temporal dynamics

RECENT RESEARCH RESULTS

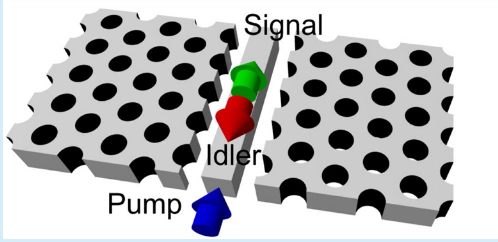
The Nano & Quantum Optics Group studies the nonlinear interaction of light with nanostructured matter [1]. Our research ranges from the single photon level to ultrahigh intensities, from the XUV to the MIR, from ultranarrow linewidth to few cycle fs pulses. Despite this diversity, our research has in common, that modifying the geometry of matter at the nanoscale allows to control fundamental interactions, giving rise to new phenomena for extreme excitation parameters. Our research approach incorporates a comprehensive range of methods, from theory, numerical modelling, nanotechnologies, to experimental characterization.

Together with our major collaborators from within the ACP and the Australian National University, the Université de Paris, the National Central University Taiwan, the Lomonosov Moscow State University, as well as the Karlsruhe Institute of Technology, we could recently achieve exemplary demonstrations of the strength of networking to achieve breakthroughs in fundamental science, e.g.: merging top-down and bottom-up approaches to fabricate artificial photonic nanomaterials with a deterministic electric and magnetic response [2], disorder-induced phase transitions in the transmission of dielectric metasurfaces [3], hybrid dielectric metasurfaces for enhancing second-harmonic generation in chemical vapor deposition grown MoS2 monolayers [4], pinhole quantum ghost imaging [5], or ultrafast all-optical tuning of direct-gap semiconductor metasurfaces [6]. Our fundamental expertise on the optical properties of nanostructures also allows us to operate an application-oriented research stream with several international industry partners on the basis of joint PhD projects. Recent results of these collaborations include: hybrid refractive holographic single vision spectacle lenses [7], dispersion-engineered nanocomposites enable achromatic diffractive optical elements [8], sub-micrometer nanostructure-based RGB filters for CMOS image sensors [9], or flat optics in high numerical aperture broadband imaging systems [10].



Exploring nonlinear light-matter interactions at the nanoscale to tailor the quantum properties of light requires also research on novel experimental methods, like superfocusing scanning nearfield optical microscopy.

PHOTONIC CRYSTAL WAVEGUIDES AS SOURCES OF COUNTERPROPAGATING FACTORIZABLE BIPHOTON STATES



Nanostructured nonlinear photonic crystal waveguides can generate counterpropagating photon pairs by spontaneous parametric down-conversion (SPDC). Particularly spectrally unentangled biphoton states are highly desired for heralding of single photons as the basis of quantum computing and quantum communication. Our configuration is an ideal integrated source of such heralded single photons, as it spatially separates the photons of a pair directly at the source without any extra components, while allowing for generation of spectrally narrow photons on a very short length scale [11]. Using the unique properties of Bloch modes, we furthermore show that two counterpropagating phasematching conditions can be fulfilled simultaneously, allowing for the generation of path-entangled Bell states in a single periodic waveguide [12]. The feasibility of our approach is demonstrated by a design of a photonic crystal slab waveguide made of lithium niobate on insulator (LNOI).

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ULF PESCHEL

PROFESSOR OF THEORETICAL PHYSICS AND SOLID STATE OPTICS

In 2014, Ulf Peschel became a chairholder at the Institute of Solid State Theory and Optics, where he is currently the Institute's director. Prof. Peschel is a Senior Fellow of the Optical Society of America and Dean of the Faculty of Physics and Astronomy.

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RESEARCH AREAS

Ulf Peschel has been working in the field of optics for more than 20 years, both theoretically and experiment-ally, with a focus on integrated optics, nanophotonics, nonlinear dynamics and electromagnetic modelling. He theoretically investigates the interaction between light fields and quantum systems on the nanoscale leading to nonlinear optical effects as higher harmonics generation or exciton-polariton condensation in semiconductor nanostructures. He also performs experiments on the field evolution in optical fiber systems, in which discreteness is realized in the temporal domain, and where gain, loss and phase modulation can be tuned to experimentally realize new phenomena as topological protection, parity-time symmetry, entanglement or superfluidity of light.

TEACHING FIELDS

Prof. Peschel is currently giving lectures in the theoretical physics including the linear and nonlinear aspects of optics and light-matter interaction.

RESEARCH METHODS

A computer cluster including respective software and licenses is hosted and maintained in Ulf Peschel's group. The group has vast experience in the numerical solution of various optical problems and uses a lot of standard methods of electromagnetic modeling, including the beam propagation method, finite difference time domain (FDTD) codes and eigenmode solvers.

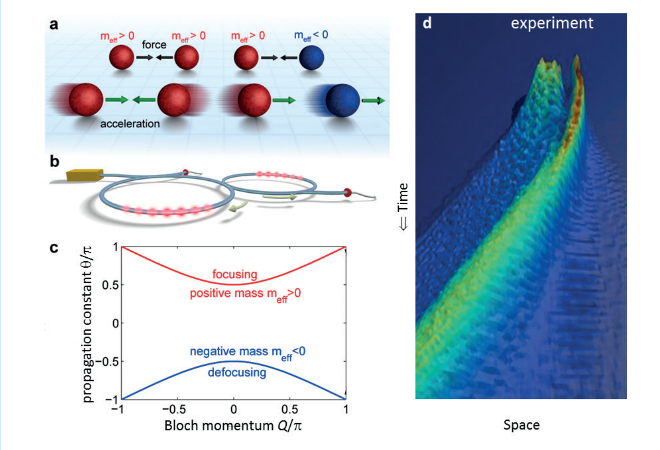
A running fiber loop setup is available for proof-of-principle experiments on linear and nonlinear dynamics in optical systems.

RECENT RESEARCH RESULTS

Some of Prof. Peschel's current research activities focus on the time evolution of optical pulses in fiber systems. Together with his group, he for the first time realized a discrete system in the time domain and investigated time discrete temporal solitons [1]. He could demonstrate that the dimensionality of a fiber system can be increased by will thus allowing for the demonstration of genuine two-diemnsional effects in originally one-dimensional settings [2]. He currently studies optical systems with balanced gain and loss, which obey parity-time (PT) symmetry, which allow for sudden phase transitions and unidirectional invisibility [3]. The group observed the first PT-symmetric optical solitons in one [4] and two transverse dimensions [5]. Studies on topological effects resulted in the first experimental measurement of the Berry curvature in an optical system [6]. Prof. Peschel is modelling activities focus on the efficient investigation of exciton-polariton dynamics in resonantly excited semiconductor resonators, in particular on condensation and soliton formation in these structures [7] implementation of codes simulating light-matter interaction in semiconductor nanostructures based on finite-difference time domain (FDTD) codes coupled with semiconductor Maxwell-Bloch equations [8]. Ulf Peschel is currently the speaker of the cooperative research center SFB 1375 „Nonlinear Optics down to Atomic scales (NOA)". His research activities focus on the modeling of quantum effects stimulated by strong light fields.

OPTICAL DIAMETRIC DRIVES

Newton's third law demands that, for every action, there is an equal and opposite reaction. If for some reason, one of the masses of two mutually attracting particles is negative as $m_1=-m_2$, both bodies will indefinitely accelerate in the same direction while keeping a constant distance among themselves (see Figure a). Quite recently, we have reported the first experimental demonstration of this intriguing effect for pulses propagating in a nonlinear optical mesh lattice. Pulses circulating in two coupled fiber loops of different lengths (see Figure b) experience a band structure with two bands of opposite curvature or group velocity dispersion (see Figure c). Similar to two particles with opposite masses, pulses from different bands accelerate in the same direction due to the action of nonlinear cross-phase modulation (see Figure d). As a result, a bound state experiencing perpetual acceleration is established, provided that the power in both field distributions is appropriately chosen [Wimmer et al. Nature Phys. 9, 780 (2013); Batz and Peschel, Phys. Rev. Lett. 110, 193901(2013)].



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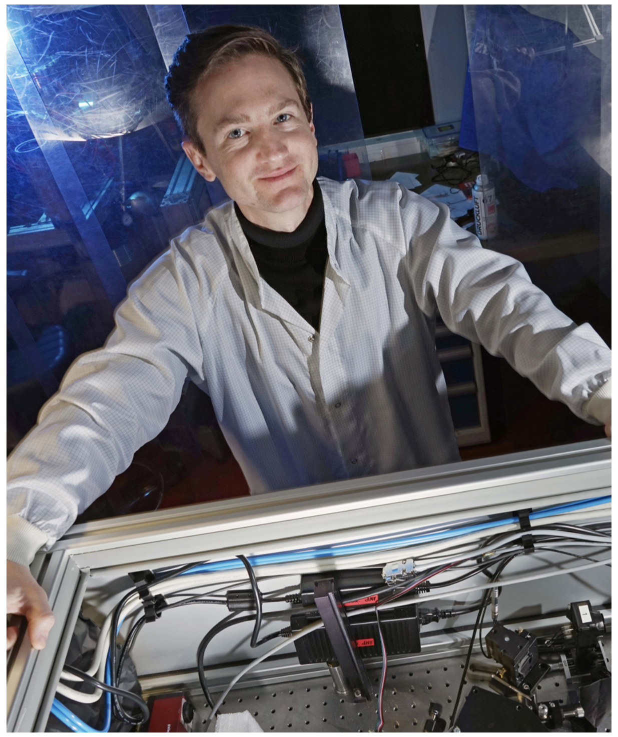
ADRIAN N. PFEIFFER



GROUP LEADER OF ATTOSECOND LASER PHYSICS, INSTITUTE OF OPTICS AND QUANTUM ELECTRONICS

Dr. Pfeiffer is the head of the Attosecond Laser Physics Group of the Institute of Optics and Quantum Electronics, Friedrich Schiller University Jena.

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RESEARCH AREAS

In his research, Dr. Pfeiffer aims to gain scientific insights into ultrafast physics and to develop new technologies in ultrafast optics. Research interests include:

- Novel technologies for high-field physics and attosecond science
- Time-resolved deep UV spectroscopy, interferometry and microscopy
- Strong-field driven electron dynamics in the condensed phase, bulk media, nanostructures, quantum-confined structures and at interfaces
- Optical spectroscopy and control of high-field and attosecond phenomena

TEACHING FIELDS

Dr. Pfeiffer's teaching includes introductory lectures in experimental physics for Bachelor students and advanced courses in modern optics for Master students:

- Experimental Physics 1 (classical mechanics and thermodynamics)
- Experimental Physics 2 (electrodynamics and optics)
- Attosecond Laser Physics

RESEARCH METHODS

The experimental methods aim at the characterization and manipulation of bulk media, nanostructures, quantum-confined structures and interfaces on the attosecond time scale. Examples include:

- Harmonic concatenation
- Transient absorption and dispersion spectroscopy with miniature beamlines
- Non-collinear spectroscopy
- Macroscopic laser pulse propagation using semiconductor Bloch equations

RECENT RESEARCH RESULTS

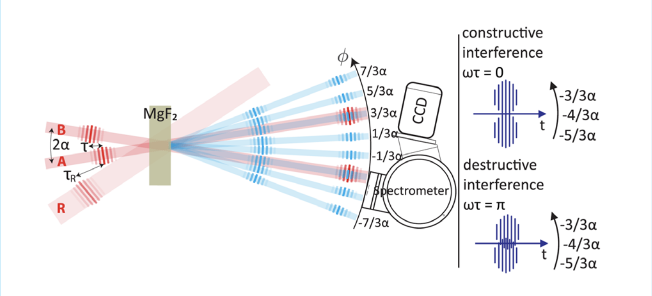
The group studies the interaction of laser light and matter at intensities above the limit that can be described by traditional nonlinear optics. The intensity is too high for the power series expansion of nonlinear optics to converge, but still low enough for quantum coherences to prevail. This field of research, which is called strong field physics or extreme nonlinear optics, leads to phenomena that occur on the attosecond time scale, and at the same time offers the possibility to generate light bursts of attosecond duration. Scientific findings on ultrafast physics and the technological development of ultrafast light sources go hand in hand.

In recent years, promising progress has been made in strong-field light matter interaction in solid materials. Due to their higher density, the generation of high-order harmonics (HHG) from solids could surpass gas-phase sources in terms of conversion efficiency. In addition, the required intensity for HHG from solids is much lower compared to the gas-phase, thus easing the demands on the drive laser. Together with the avoidance of the vacuum beam lines required for gas-phase HHG, solid-state attosecond technology could be applied more widely with simpler and more compact experimental setups. One goal of the group is to develop new methods of laser pulse generation. Up to now, laser pulses with a duration of one femtosecond or shorter could only be generated in the Vis-IR as well as in the extreme UV, but the deep UV is a spectral range in which such extremely short laser pulses were not available before. Harmonic concatenation is our new method for the synthesis of ultrashort pulses, which delivers record short deep UV waveforms of only 1.5 fs.

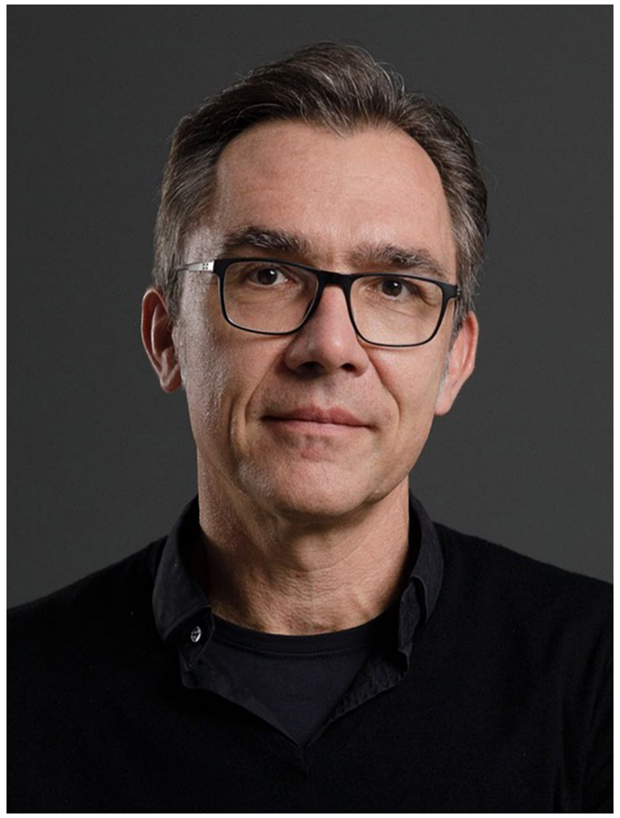
Another goal is to understand the physics on the electronic time scale by attosecond spectroscopy. For the manipulation of pump and probe pulses in the Vis-IR and extreme UV, beamlines of several meters in length are normally required. We have developed beamlines on a centimeter scale which facilitate transient absorption and dispersion in the deep UV range. The aim of this project is to measure the nonlinear reaction time of thin glasses, crystals and liquid films to explore the limits of light-induced signal processing.

HARMONIC CONCATENATION OF 1.5-FEMTOSECOND-PULSES IN THE DEEP ULTRAVIOLET

Harmonic concatenation is our new method for the synthesis of ultrashort pulses. The principle is the concatenation of spatial and temporal harmonics that are created by two noncollinear Vis-IR pulses. Cascaded processes of frequency conversion and self-diffraction in a thin dielectric plate yield a multifaceted emission pattern of temporal and spatial harmonics. The emission angle of the harmonic orders depends on the frequency. This spatiotemporal coupling is exploited to concatenate two neighboring spatial harmonics by adjusting the crossing angle of the fundamental pulses. Using temporal harmonics of third order, the concatenation of two spatial harmonics synthesizes record-short deep UV waveforms of only 1.5 fs.



JÜRGEN POPP



PROFESSOR OF PHYSICAL CHEMISTRY, INSTITUTE OF PHYSICAL CHEMISTRY

Prof. Jürgen Popp is the director of the Institute of Physical Chemistry, the scientific director of the Leibniz Institute of Photonic Technology and a member of the board of directors of the Abbe Center of Photonics. He is the spokesperson of the "Leibniz Center for Photonics in Infection Research" one out of three projects that the German government has put on the national roadmap for research infrastructures. In 2016 he was awarded with the Pittsburgh Spectroscopy Award. 2018 Juergen Popp won the third prize of the Berthold Leibinger Innovationspreis and received the Kaiser-Friedrich-Forschungspreis. In 2019 he was awarded the Ralf-Dahrendorf-Preis für den Europäischen Forschungsraum.

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RESEARCH AREAS

The core research focus of the group of Prof. Popp is biophotonics, i.e. the development and implementation of innovative optical/photonic methods and tools for multiscale spectroscopy and multimodal imaging together with particle- and chip-based molecular point-of-care concepts for biomedical diagnostics. In this context, these biophotonic approaches are utilized and developed according to the needs of pathology, oncology, and infection/ sepsis.

TEACHING FIELDS

Prof. Popp gives courses in:

- Fundamentals of physical chemistry
- Innovative spectroscopy and imaging approaches for biophotonics
- Raman spectroscopy for biomedical diagnostics

RESEARCH METHODS

The laboratories led by Prof. Popp offer a wide range of laser (micro)spectroscopic methods, at which almost the complete value chain of Raman-based approaches is available:

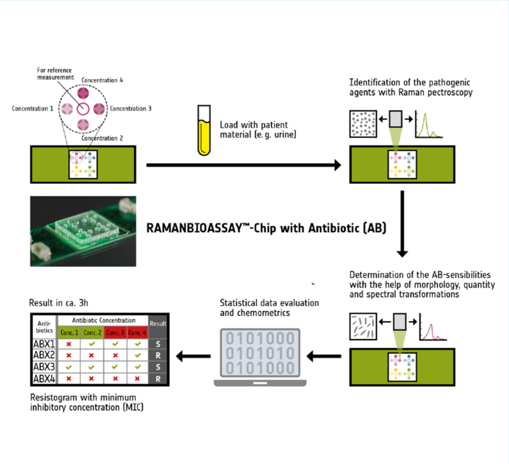
- Raman (micro)spectroscopy with excitation wavelengths ranging from the UV into the NIR
- Resonance Raman (micro)spectroscopy
- Surface enhanced Raman spectroscopy (SERS)
- IR absorption/ ATR-IR spectroscopy
- Coherent Raman microscopy (coherent anti Stokes Raman scattering (CARS) and stimulated Raman scattering (SRS))
- Second harmonic generation (SHG) microscopy
- Multi-photon excited fluorescence microscopy
- Fluorescence life-time imaging microscopy (FLIM)
- UV/ Vis absorption spectroscopy
- Steady state fluorescence spectroscopy
- Optical coherence tomography

RECENT RESEARCH RESULTS

Over the last few years, the Biophotonics group has been investigating a multimodal nonlinear imaging approach that has the potential to reliably assess tumour tissue and the success of surgery directly in the operating theatre. The approach combines different nonlinear imaging techniques such as two-photon excited autofluorescence (TPEF), second harmonic generation (SHG) and coherent anti-Stokes Raman scattering (CARS) [1,2]. For a clinical application this approach was transferred into a compact microscope suitable for clinical use. In order to further extend the applicability of this multimodal microscopy approach for in vivo tissue screening, various endoscopic probe concepts were also realized [3,4,5]. The core of all these setups are robust and alignment-free fiber laser concepts developed by the groups of Prof. Limpert and Prof. Tünnermann in close cooperation with the Biophotonics group [6]. Together with the group of PD Dr. Thomas Bocklitz, innovative image evaluation algorithms for the translation of multimodal images into quantitative diagnostic markers were developed [7,8,9]. Recently, the Popp group was able to show that the realized multimodal imaging approach (I) can be combined with laser tissue ablation for tissue-specific laser surgery and (II) is suitable for the visualization of cold atmospheric plasma-induced tissue alterations for online monitoring of wound or cancer treatment [10,11]. Another focus of the Biophotonics group is an automated high throughput screening of biological cells. The Popp group has developed a high-throughput Raman spectroscopy platform for the automated analysis of cells [12]. This was achieved by completely automating the process chain, i.e. cell detection, Raman spectrum acquisition and chemometric analysis for online cell classification in e.g. multiwell plates or microfluidic environments. Using this automated platform, a large number of cells, e.g. 10,000, can be measured on a time scale of 30 minutes without sample preparation. The applicability of this platform has been demonstrated with several examples, such as (I) differentiated determination of white blood cell counts; (II) identification of circulating tumor cells in a leukocyte mixture; (III) label-free characterization of drug-induced changes [13,14,15].

SPECTROSCOPIC INVESTIGATIONS OF INFECTIONS

The most important aspect in the treatment of infectious diseases is the timely identification of the type of pathogen and its resistance to antibiotics in order to select the appropriate antibiotics as quickly as possible. In close cooperation with the group of Prof. Neugebauer the Popp group has investigated a new method called RAMANBIOASSAY™, which enables the simultaneous identification of bacteria, the characterization of antibiotic resistance and the determination of the minimum inhibitory concentration [15]. The basis of RAMANBIOASSAY™ is the combination of chip-based Raman micro spectroscopy with classical imaging, which allows the label-free, non-destructive and culture-free optical and spectroscopic characterization of a very small number of bacteria in only 2 to 3.5 hours. Statistical evaluation algorithms allow for an automated classification and identification of bacteria and resistance to antibiotics.



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RALF RÖHLSBERGER

PROFESSOR FOR X-RAY SCIENCE, INSTITUTE OF OPTICS AND QUANTUM ELECTRONICS AND HELMHOLTZ INSTITUTE JENA

Prof. Röhlsberger is member of the directorate of the Helmholtz Institute Jena and head of the x-ray Science Group at this institute. He also leads a research group on Magnetism and Coherent Phenomena at the Deutsches Elektronen-Synchrotron DESY in Hamburg, and he is member of the Cluster of Excellence CUI – AIM (Centre for Ultrafast Imaging – Advanced Imaging of Matter) at the University of Hamburg as well as a principal investigator in the SFB-TRR QuCoLiMa (Quantum Cooperativity of Light and Matter) of the DFG. Moreover, he currently is the chair of the International Board on the Applications of the Mössbauer Effect.

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RESEARCH AREAS

Prof. Röhlsberger's research is focused on the interaction of x-rays with matter to reveal its fundamental aspects and to develop new applications of x-ray scattering and spectroscopy with accelerator driven sources of hard X-rays. In particular these are:

- Development of photonic nanostructures for controlling the interaction of x-rays and matter
- Pump-probe experiments to study the non-equilibrium dynamics of matter
- Applications of high-purity polarimetry for nuclear quantum optics and materials science
- Experiments towards establishing a nuclear clock based on the isotope Scandium-45

TEACHING FIELDS

Prof. Röhlsberger's teaching activities are focused on the applications of highly brilliant x-rays from synchrotrons and x-ray lasers in solid state physics, materials science and quantum optics. He gives lectures and seminars in:

- Introduction to modern x-ray physics and advanced x-ray spectroscopies with synchrotron radiation
- Fundamentals and applications of Mössbauer spectroscopy in the natural sciences

RESEARCH METHODS

Prof. Röhlsberger's research methods comprise laboratory-based methods for preparation and characterization of multilayers and thin films, as well as the use of advanced instrumentation and x-ray scattering methods at synchrotrons and x-ray lasers.

- Development and applications of high-purity polarimeters at synchrotrons and x-ray lasers
- Laser pump – x-ray probe spectrometers
- Advanced sputter deposition setup for preparation of new functional materials
- High-resolution x-ray diffractometry for characterization of thin films and multilayers

RECENT RESEARCH RESULTS

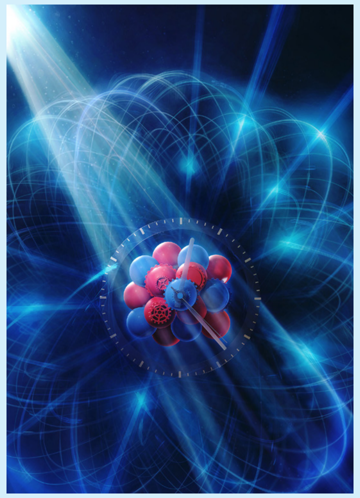
Polarization analysis of x-rays bears an enormous potential for fundamental studies of anisotropies in nature. We have recently achieved record extinction ratios of 10^{-10} that allow for probing tiniest optical acitivities, surpassing any kind of polarimetry in the optical regime. At these extreme levels of polarization purities, it is indispensable to distinguish between the contributions of dichroism and birefringence to the total optical activity. In a recent study we have demonstrated for the first time how x-ray dichroism and x-ray birefringence can be disentangled via high-purity polarimetry. Both effects play an important role in fundamental studies of condensed matter, especially in correlated materials. A striking example are spectroscopic measurements in the vicinity of atomic absorption edges to reveal the electronic occupancy of selected orbitals, e.g., in materials like CuO and La_2CuO_4, that are highly relevant as mother compounds for high-Tc superconductors [1].

An important branch of our group is to employ nuclear resonances of Mössbauer isotopes in materials science as well as in quantum optics at energies of hard x-rays. In the latter field we could recently realize a photonic control scheme for quantum systems embedded in a solid-state host that works at room temperature. Efficient control schemes for such systems are one of the major goals of contemporary condensed matter quantum technologies. Our scheme contrasts with established laser control schemes. Its striking feature is that it relies on the excitation of a solid's quasi-particle to tune the interactions of the solid with the quantum system to achieve a precise quantum phase control of the scattered x-rays. This constitutes a completely new approach in the field of photonic quantum technologies. We could demonstrate the coherent manipulation of a collective nuclear excitation and show that this new control scheme does not destroy its coherence, a prime prerequisite for quantum technologies [2].

In another recent experiment we could achieve coherent control of atomic nuclei via suitably shaped near-resonant x-ray fields. By tuning the phase between two x-ray pulses we could switch the nuclear exciton dynamics between coherent enhanced excitation and coherent enhanced emission. This was facilitated by shaping single pulses delivered by state-of-the-art x-ray facilities into tunable double pulses, for which we could demonstrate a temporal stability of the phase control on the few-zeptosecond timescale [3]. Our results unlock coherent optical control for nuclei, which should not only advance nuclear quantum optics, but also enable time-resolved studies of nuclear out-of-equilibrium dynamics, which is a long-standing challenge in Mössbauer science.

RESONANT X-RAY EXCITATION OF THE NUCLEAR CLOCK ISOMER SCANDIUM-45

Resonant oscillators with stable frequencies and large quality factors help us to keep track of time with high precision. The search for more stable and convenient reference oscillators is continuing. Nuclear oscillators have significant advantages over atomic oscillators because of their naturally higher quality factors and their higher resilience against external perturbations. One of the most promising cases is an ultra-narrow (1.4 femto-eV) nuclear resonance transition in the isomer Scandium-45 between the ground state and the 12.4-keV isomeric state with a long lifetime of 0.47 s. High-brightness x-ray sources for direct excitation of the resonance have become available only recently. In a recent experiment we could excite the Scandium-45 isomeric state by irradiation with 12.4-keV photon pulses from a state-of-the-art x-ray free-electron laser, the European XFEL near Hamburg. This enabled us to determine the transition energy as 12,389.59 eV with an uncertainty that is two orders of magnitude smaller than the previously known values [4]. Our findings now open applications of this isomer in extreme metrology, nuclear clock technology, ultra-high-precision spectroscopy and similar fields.



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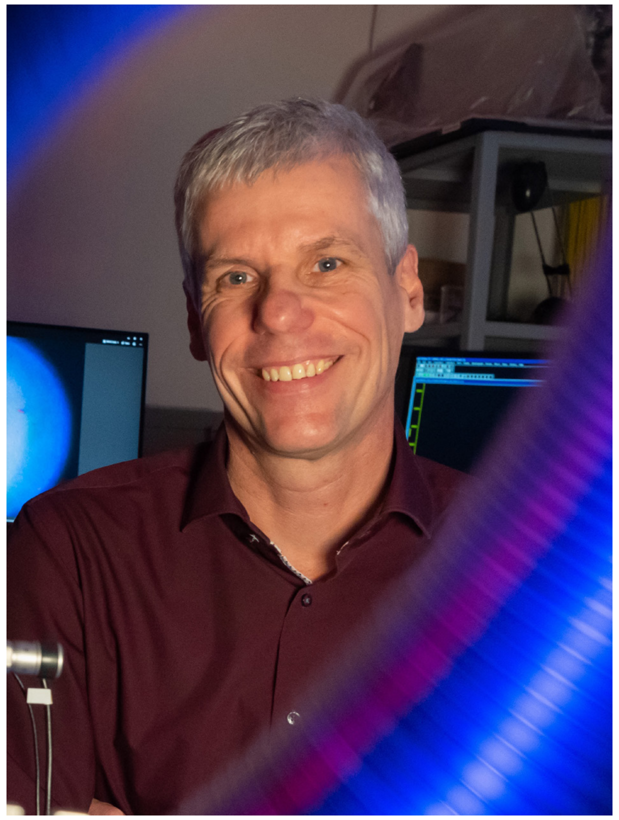
CARSTEN RONNING



PROFESSOR FOR EXPERIMENTAL SOLID-STATE PHYSICS, INSTITUTE OF SOLID STATE PHYSICS

Carsten Ronning joined Friedrich Schiller University Jena in 2008 as a chair professor at the Institute of Solid State Physics. He serves as a member on the managing board of the collaborative research center CRC 1375 "NOA", in the research council of the University Jena, as well as in the standing reviewer panel 307 of the German Research Foundation (DFG), where he has been reelected in 2020.

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RESEARCH AREAS

Carsten Ronning's research interests address nano-scale solids, photovoltaics, ion-solid-interactions, metasurfaces, as well as light-matter-interactions. Research thrusts include:

- Semiconductor nanowires: synthesis, functionalization, manipulation, optical characterization as well as lasing properties
- Photovoltaics: characterization of Cu(In,Ga)(Se,S)- and Kersterite solar cells using synchrotron und electron beam methods
- Ion solid interactions: ion beam modification of materials, effects by nanostructures, Monte Carlo simulations
- Metasurfaces: masked or focused ion beam irradiation, ion beam irradiation of phase change materials, oxides or silicon
- X-ray nanoanalysis: of functional nanomaterials and solar cells at the synchrotron ESRF in Grenoble, France

TEACHING FIELDS

Carsten Ronning covers the full curriculum of experimental physics, which includes mechanics, optics, nuclear physics, solid-state physics, atomic physics, etc. Furthermore, he offers specialized courses on nuclear solid-state physics as well as nanomaterials and nanotechnology.

RESEARCH METHODS

The laboratories lead by Carsten Ronning offer a wide range of methods for the synthesis, modification and characterization of materials.

- Ion beam doping, modification of solids and deposition, magnetron sputtering of thin films
- Structural characterization by high-resolution electron beam and X-ray methods, as well as ion beam analysis techniques
- Optical characterization of semiconductors using divers luminescence techniques
- Advanced electrical characterization, e.g. of solar cells

RECENT RESEARCH RESULTS

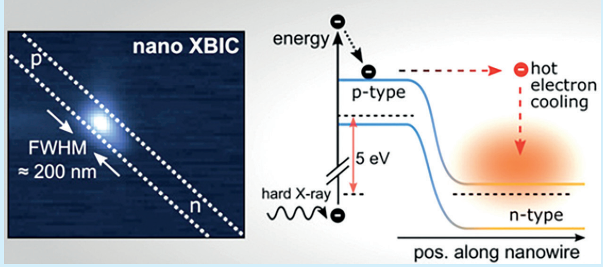
Metasurfaces are artificially structured and optical thin layers that can be precisely constructed to manipulate the amplitude, polarization, or phase of light. Metasurfaces thus enable flat optics and will revolutionize photonics, as conventional lithography and processes such as ion implantation can be used to fabricate complex optical devices. We realized metasurfaces by either selectively irradiating or doping materials with ions through masks. Alternatively, we introduced doping elements or defects using a focused ion beam and thus write the metasurfaces „directly" into the material. [1,2]

We also produce, conduct, and investigate the properties of semiconductor light-conducting wires. [3,4] The tiny wires, which are only about ten to five hundred nanometers in diameter, are so thin that the wavelengths of visible light optimally fit in them. Perfect light guide, then. In addition, three other features make the wires remarkable: they are an „active medium" that can emit photons, they can be pumped, and reflect the light at their ends, thus acting as a resonator. These properties make them tiny lasers. In order to exploit the full potential of such small lasers, it is especially important to find out how and how fast the laser light is emitted. We have succeeded in investigating both: for very thin wires, the light is emitted as a Gaussian beam, while the HE11 mode is dominant within the wire. This also leads to fast emissions in the range of a few ps. However, if the wires are thicker, this changes quite considerably: then the wires radiate more strongly at the edges and less at the center, and are also much slower.

Finally, our goal is to also understand the transport and recombination mechanisms of charge carriers in polycrystalline thin-film solar cells - such as e.g. $Cu(In, Ga)Se_2$ (CIGS) solar cells. With such findings, the efficiency can be increased in cooperation with our industrial partners and a process window optimal for the industry will be found. Today it is well known that alkali elements can lead to a significant increase in the efficiency of CIGS solar cells, but their role is largely unknown. Therefore, we extensively investigate thin film solar cells and sublayers using high-resolution synchrotron and electron beam based methods in a combinatorial approach and revealed the beneficial effects of alkali decorated grain boundaries. [5,6]

HOT ELECTRONS IN A NANOWIRE HARD X-RAY DETECTOR

Nanowire chip-based electrical and optical devices such as biochemical sensors, physical detectors, or light emitters combine outstanding functionality with a small footprint, reducing expensive material and energy consumption. The core functionality of many nanowire-based devices is embedded in their p-n junctions. To fully unleash their potential, such nanowire-based devices require – besides a high performance – stability and reliability. We investigated an axial p-n junction GaAs nanowire X-ray detector that enables ultra-high spatial resolution (~200 nm) compared to micron scale conventional ones. In-operando X-ray analytical techniques based on a focused synchrotron X-ray nanobeam (nano XBIC) allowed probing the internal electrical field and observing hot electron effects at the nanoscale. Finally, we also studied the device stability and found a selective hot electron induced oxidization in the n-doped segment of the p-n junction. Our findings demonstrate capabilities and limitations of p-n junction nanowires, providing insight for further improvement and eventual integration into on-chip devices. [7]



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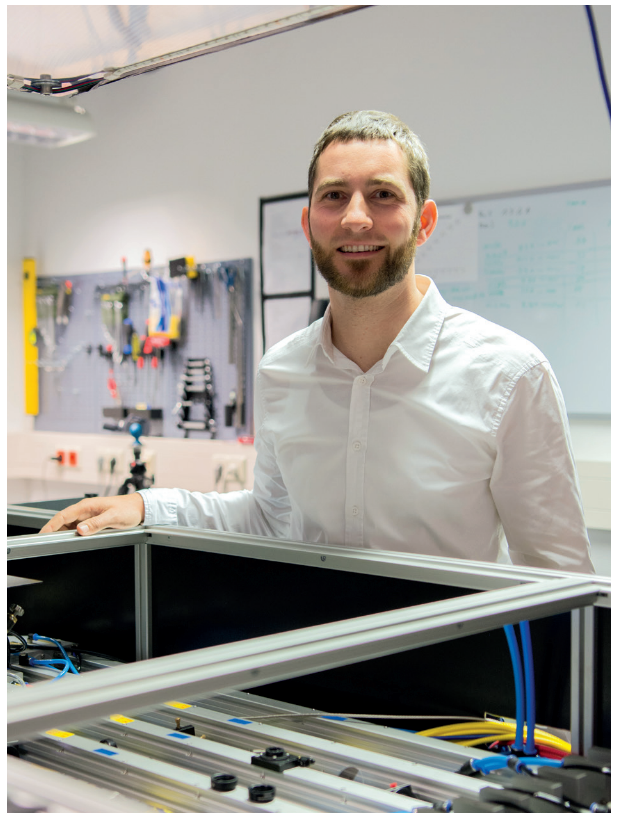
JAN ROTHHARDT



GROUP LEADER AT THE HELMHOLTZ INSTITUTE JENA AND AT THE INSTITUTE OF APPLIED PHYSICS

Dr. Rothhardt is head of the Soft X-ray Spectroscopy and Microscopy Group at the Helmholtz-Institute Jena and a member of the extended board of directors of the Helmholtz Institute Jena.

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RESEARCH AREAS

Dr. Rothhardt investigates matter on smallest spatial and temporal scales by using modern laser-based XUV and soft x-ray sources. His research interests include:

- Laser-based short wavelength sources
- Nanometer scale imaging techniques
- Ultrafast XUV spectroscopy of molecules and highly-charged ions

TEACHING FIELDS

Dr. Rothhardt's teaching activities cover Nonlinear Optics, Laser Physics and Ultrafast Laser Spectroscopy.

RESEARCH METHODS

Dr. Rothhardt's group utilizes a variety of modern imaging and spectroscopy techniques including:

- Coherent diffraction imaging and holographic techniques
- XUV Laser spectroscopy & XUV Fourier-Transform spectroscopy
- Ultrafast pump-probe spectroscopy

The group utilizes modern experimental equipment including:

- High average power femtosecond lasers
- High photon flux table-top XUV and soft x-ray sources
- XUV and soft x-ray spectrometers and detectors
- High performance computers and clusters for image processing

RECENT RESEARCH RESULTS

Recent research of Dr. Rothhardt has been focused on the development and applications of high photon flux XUV and soft x-ray sources. This included the demonstration of phase matching and efficient high harmonic generation at high repetition rates in the tight focusing regime [1], resonant enhancement of the macroscopic yield of high harmonic generation by Fano-resonances [2], the demonstration of a high photon flux XUV sources delivering up to 1 mW of average power per harmonic in the XUV [3, 4]. These unique sources have recently been employed for lensless imaging at the nanoscale.

WAVELENTH-SCALE LENSLESS XUV IMAGING

Short wavelength radiation in the extreme ultraviolet (XUV) and soft X-ray spectral region enables high contrast and high-resolution imaging. In our group, we utilize the highly coherent radiation of table-top high harmonic sources to perform lensless imaging with wavelength-scale resolution down to only a few nanometers. This novel method offers insights into e.g biological samples, which is so far not possible with other techniques. The employed lensless imaging methods are based on computational image formation by "digital optics". Hence, the image forming lens is replaced by an iterative algorithm or neural network, which completely eliminates aberrations and losses. This approach enables high resolution, high contrast images with a minimized dose on the sample.

In our latest experiments we used a high photon flux, 18 nm wavelength, laser-like high-order harmonic source to achieve record imaging performance by different lensless methods. A record resolution of 13 nm has been achieved using coherent diffractive imaging on isolated samples [5]. Waveguiding effects in nanoscale structures have been observed with wavelength-scale resolution via Fourier-transform holography [6]. Recently, we achieved 45 nm resolution on an extended Siemens-Star test object by employing Ptchography, a scanning lensless imaging technique [7], which enables real-world applications e.g. in EUV metrology and biology.

Our current research is focused on pushing resolution limits to the few-nm range [8], exploring broadband (potentially material-selective and ultrafast) lensless imaging, and enabling imaging in the so-called water window for biological and solid-state applications.

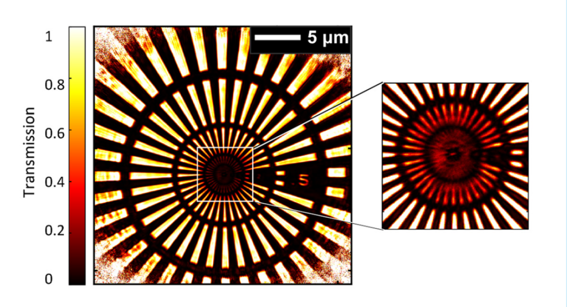

Figure 1: Large field of view XUV image of a Siemens-Star test pattern recorded with Ptychography. The obtained resolution is as small as 45 nm [7].

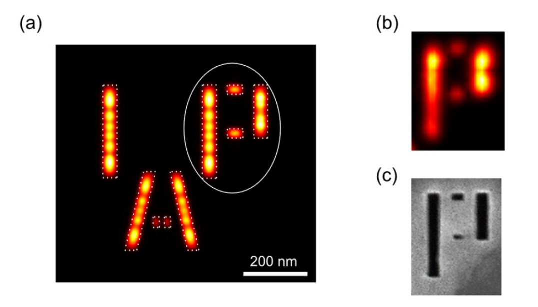

Figure 2: a) Simulation of the transmitted XUV light field behind a test sample. b) XUV image of the letter P obtained via Fourier-Transform-Holography (FTH). c) Helium-ion microscope image of the sample structure [6].

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SINA SARAVI

JUNIOR RESEARCH GROUP LEADER FOR NONLINEAR NEUROMORPHIC & QUANTUM PHOTONICS

Dr. Saravi leads a junior research group at the Institute of Applied Physics of the Friedrich Schiller University Jena. His research activities focus on utilizing linear and nonlinear nanophotonic systems for realization of diffractive optical neural networks for image recognition/inference applications and sources of quantum light for application in optical quantum technologies.

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RESEARCH AREAS

Dr. Saravi's research focus on the development of all-optical diffractive neural networks, designed by machine-learning algorithms, and utilizing the unique capabilities of nanostructured metasurfaces as the implementation platform. Furthermore, he investigates novel sources of quantum light (e.g. entangled photon pairs) in nonlinear nanophotonic systems, especially ones that are hybridized with atomic/atom-like systems. In summary, his research focuses on:

- Diffractive optical neural networks and machine learning
- Nonlinear metasurfaces
- Hybrid nonlinear quantum optical systems

TEACHING FIELDS

Dr. Saravi has taught master-level courses on:

- Quantum Optics
- Advanced Quantum Optics

RESEARCH METHODS

Dr. Saravi uses the following theoretical and experimental methods in his research:

- Classical and quantum nonlinear parametric interactions are formulated using Green-function methods, quasinormal-mode expansions, and Lindblad master equation.
- FDTD and FEM methods are used for rigorous simulation of the linear and nonlinear optical properties of nanophotonic systems.
- Customized microscopy setups are used for characterizing the properties of light generation and scattering in nanophotonic systems.

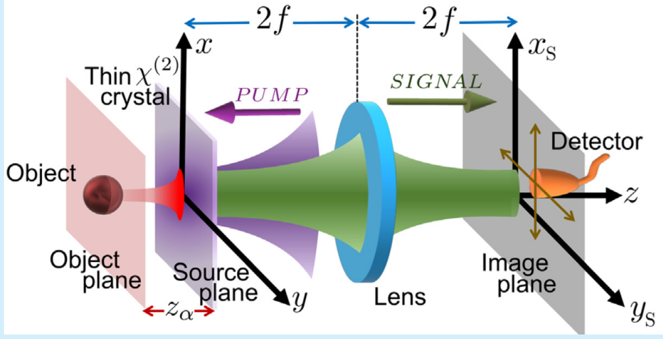
RECENT RESEARCH RESULTS

Previous works of Dr. Saravi and coworkers have experimentally demonstrated that nonlinear metasurfaces are ideal platforms to both enhance the efficiency [1] and control the emission properties [2] of the second-harmonic-generation process. More recently, they pushed these results into the quantum regime [3], showing that nonlinear nanoresonators (the constituting elements of a nonlinear metasurface) have unique properties for generation of entangled photon-pair states, where both the directionality and polarization state of the biphoton state can be controlled by simple tuning of the system parameters. These results motivate the utilization of metasurfaces for realizing engineered scattering responses and efficient nonlinear activation elements in our development of all-optical diffractive neural networks.

Furthermore, Dr. Saravi and his team pursue the design of novel sources of quantum light, where nonlinear sources of photon pairs/squeezed light are hybridized with atomic/atom-like systems, where they have already shown that the presence of the atom-like system fundamentally modifies the dynamics of quantum light generation in such systems [4]. Moreover, they also developed theoretical formulations, based on the Green-function method, to study the dynamics of high-gain parametric down-conversion processes, which is capable of treating nanostructured systems with inherently complex dispersive and lossy properties [5].

NONLINEAR QUANTUM IMAGING UTILIZING NEAR-FIELD INTERACTIONS

The optimal realization of diffractive optical neural networks requires a deep understanding of nonlinear imaging. Dr. Saravi's team have investigated such physics in the context of quantum imaging, where quantum light is generated in a sub-wavelength-thin nonlinear slab, which interacts with a near-field absorptive nanoparticle [6]. The focus of this investigation was to predict the image of the object, specially to find the limit of spatial resolution achievable in such quantum imaging systems that involve light beams of two different wavelengths: one photon is interacting with the object, and the other photon in the pair, with a different wavelength, is imaged onto a camera. In this case, it was found that the resolution of imaging is only limited by the diffraction limit of the shorter-wavelength photon in the pair. To treat this problem, special attention was given to near-field and non-paraxial formulation of light generation and propagation.



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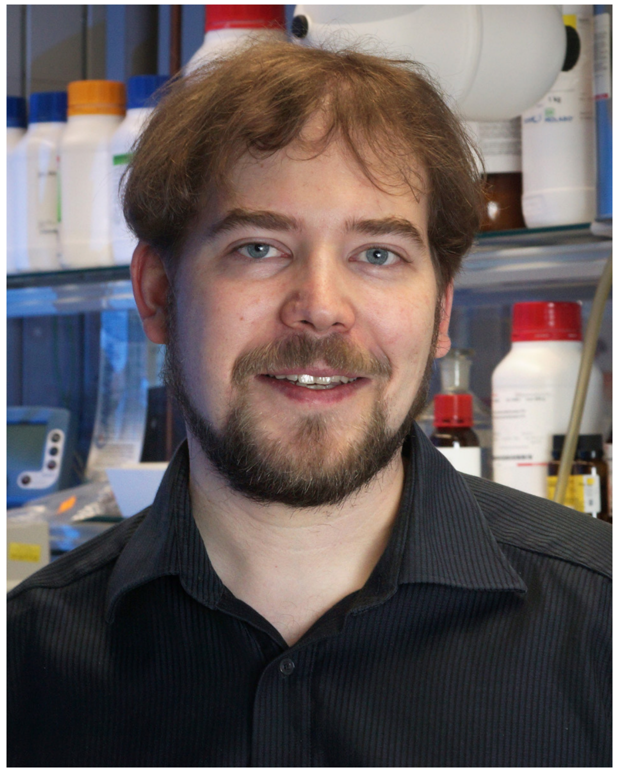
FELIX SCHACHER



PROFESSOR AT THE INSTITUTE OF ORGANIC AND MACROMOLECULAR CHEMISTRY (IOMC)

Since 2010, Prof. Schacher's research group at the Friedrich Schiller University Jena operates at the interface of organic, physical, and macromolecular chemistry. He has received the Hermann-Schnell-Fellowship of the German Chemical Society (GDCh) in 2013, the Carl-Duisberg-Award of the GDCh in 2020, and is also a member of the Jena Center for Soft Matter (JCSM). He is active in the Sections Makromolekulare Chemie and Chemie des Waschens of the German Chemical Society (GDCh).

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RESEARCH AREAS

His research is focused on the synthesis and self-assembly of block copolymers into nanostructured materials in the bulk and in solution. Research interests include:

- Controlled/ living polymerization techniques
- Stimuli-responsive block copolymer membranes
- Hierarchy and compartmentalization in block copolymer materials
- Design and manipulation of interfaces, in particular within organic/inorganic hybrid materials
- Morphological investigations using a combination of imaging and scattering techniques

TEACHING FIELDS

Prof. Schacher's teaching includes various aspects of macromolecular chemistry. He gives courses in:

- The fundamentals of polymer chemistry
- The synthesis and characterization of block copolymers
- Self-assembly and supramolecular chemistry
- Polymers in materials science

RESEARCH METHODS

Prof. Schacher's research group utilizes different methods for the synthesis and morphological characterization of block copolymers which include:

- State-of-the-art synthetic equipment, including gloveboxes for working under inert conditions or under controlled temperature/humidity
- Dynamic and static light scattering (DLS/ SLS)
- Small and wide angle x-ray scattering (SAXS/ WAXS)
- Equipment for UV irradiation
- (Cryo) ultramicrotome for sample preparation in electron microscopy

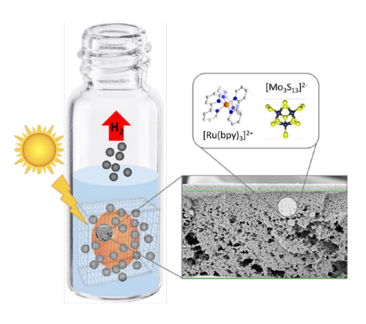
RECENT RESEARCH RESULTS

We demonstrated that multicompartment micelles of about 150-200 nm size from stimuli-responsive triblock terpolymers, polybutadiene-block-poly (methacrylic acid)-block-poly (N,N-(dimethylamino) ethyl methacrylate) (BMAAD), are promising candidates for non-viral gene delivery into different cell lines. The structures exhibit a patchy shell, consisting of amphiphilic (interpolyelectrolyte complexes, MAA and D) and cationic patches (excess D), generating a surface reminiscent to those of certain viruses and capable of undergoing pH-dependent changes in charge stoichiometry. After polyplex formation with plasmid DNA, superior transfection efficiencies can be reached for both adherent cells and human leukemia cells. Compared to the gold standard PEI, remarkable improvements and a number of advantages were identified for this system, including increased cellular uptake and an improved release of the genetic material, accompanied by fast and efficient endosomal escape. Furthermore, high sedimentation rates might be beneficial regarding in vitro applications [1].

In another study, we use thiol-terminated, polyether-based amphiphilic block copolymers with a hydrophilic poly(ethylene oxide) (PEO) segment and a second crosslinkable block of either poly(furfuryl glycidyl ether) (PFGE) or poly(allyl glycidyl ether) (PAGE) as ligands for Au nanoparticles. In both cases, direct reduction of suitable precursors in N,N-dimethylacetamide (DMAc) leads to Au NPs with a block copolymer shell which can be crosslinked using either Diels–Alder reactions for the PFGE segment or hydrosilylation chemistry targeting the PAGE segment. In this way, shell-crosslinked Au-NPs with enhanced stability against ligand exchange reactions in the presence of competitive ligands like alkyl thiols could be prepared [2]. Besides ligands, we also design polymeric templates for metal and metal oxide nanoparticles, e.g. where net charge and charge density of the template determines nanoparticle composition [3]. Further, we use amphiphilic diblock terpolymers for the preparation of free-standing integral asymmetric membranes via nonsolvent induced phase separation (NIPS) processes. The diblock terpolymers consist of a hydrophobic poly(styrene-co-isoprene) block and a hydrophilic segment of poly(N,N-dimethylaminoethyl methacrylate). The materials are synthesized either via nitroxide mediated polymerization or living anionic polymerization. The NIPS process is used for the fabrication of porous diblock terpolymer membranes where the membrane morphology can be influenced by several parameters such as the applied solvent mixture, open time, or relative humidity. The resulting anisotropic membranes exhibit pH- and temperature-dependent water flux and pore sizes. UV-induced crosslinking of the isoprene part of the membrane matrix can be used to enhance membrane stability against solvents or to simply improve handling [4]. One intriguing application field for such materials is heterogeneous (photo) catalysis, as we could recently show for oxidation of thiophene under flow conditions [5] or photocatalytic hydrogen evolution after immobilization of catalytically active polyoxometalates and/or photosensitizers [6].

HETEREGENOUS PHOTOCATALYSIS WITHIN BLOCK COPOLYMER MEMBRANES

Electrostatic adsorption of thiomolybdates and Ru-based photosensitizers to the (charged) surface of block copolymer membranes leads to the formation of free-standing heterogeneous photocatalysts for the hydrogen evolution reaction. We could show that immobilization of catalyst and photosensitizer leads to prolonged catalytic activity and also elucidate potential repair mechanisms for degraded catalytic sites.



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HEIDEMARIE SCHMIDT

PROFESSOR FOR SOLID STATE PHYSICS/QUANTUM DETECTION, IFK

Prof. Dr. Heidemarie Schmidt received the "NanoFuturPrize" from BMBF in 2002 (1.7 Mio. Euro) and led the Young Scientist Group "Nano-Spintronics" at Uni Leipzig (2003-2007), HZDR (2007-2011), and TU Chemnitz (2011-2016). She was awarded a Heisenberg Fellowship from DFG (2012-2017), won an ATTRACT grant (2.1 Mio. Euro) from Fraunhofer-Gesellschaft, and since 2016 she is leading the ATTRACT group BFO4ICT at Fraunhofer ENAS Chemnitz. Since 2017 she is Professor (W3) for Solid State Physics and Quantum Detection at Friedrich Schiller University Jena and Head of the Research Department Quantum Detection at the Leibniz-IPHT, Jena.

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RESEARCH AREAS

- Detectors for application in the life sciences and medical technology: impedance biochips
- Cryogenic single photon detectors for applications in quantum optics, safety, and security
- High-sensitivity, robust detectors and detector systems for applications in life science, medical technology, and environmental monitoring: IR sensors
- AI hardware with analog and digital functionality for application in neuromorphic computing, sensor-near data analysis, and trusted electronics: analog, electroforming-free memristors and digital, electroforming-free memristors
- Light-matter interaction in external fields: magnetooptics and electrooptics
- Bound magnetic polaron formation in transparent oxide thin films: magnetotransport

TEACHING FIELDS

- Lectures on solid state optics in external fields I and II

RESEARCH METHODS

- Optical properties: IR spectrometer and UV-ViS spectral ellipsometer measurements
- Magnetooptical properties: vector magnetooptical generalized ellipsometry (VMOGE) measurements and modelling
- Transport properties: magnetoresistance measurements and modelling, Impedance measurements and modelling, current-voltage measurements and modelling
- Thermoelectric properties: Seebeck coefficient measurements, thermal conductivity measurements
- Scanning probe microscopy: Kelvin Force Probe Microscopy (KPFM), Photo Induced Force Microscopy (PiFM)

RECENT RESEARCH RESULTS

Magnetic oxide thin films with bound magnetic polarons (BMP) for transparent spintronics: We have fabricated magnetic, n-type conducting ZnO thin films and controlled the formation of BMP with huge collective spins by means of a structured metallization of the ZnO surface. The transport properties [DE102013209278B4] depend on concentration and species of magnetic ions and intrinsic defects [1]. Increased static dielectric constant [2] has been shown for magnetic ZnO thin films with BMP.

Multilayer structures in magnetic thin films for magnetooptics: We have set-up a vector magnetooptical generalized ellipsometer (VMOGE) with an octupole magnet [3] and examined the magnetooptical response of multilayer structures with magnetic thin films. We have developed the 4×4 Mueller matrix method to extract the magnetooptical dielectric constant from the magnetic thin films. For magnetic metals (Fe, Co, Ni, Ni20Fe80 [4], Ni80Fe20, Co90Fe10, Co40Fe40B20) the extracted magnetooptical constants can be related with the results of spin DFT calculations.

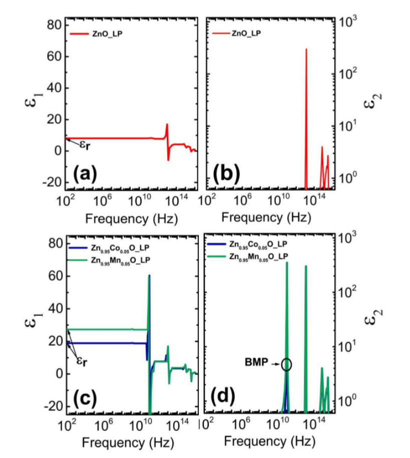
AI hardware for Neuromorphic computing, Sensor-near data analysis, and Trusted Electronics: Multiferroic thin film materials, e.g. $BiFeO_3$ [5] and $YMnO_3$ [6], with top electrode and bottom electrode are well-known as memristors, where the resistance state can by reconfigured into high resistance state (HRS) and low resistance state (LRS) by applying an appropriate voltage bias to or pushing an appropriate current through the memristor. We have analyzed the physical mechanism underlying the non-volatile resistive switching in $BiFeO_3$ and $YMnO_3$ memristors and have developed them into a novel AI hardware element [US9520445B2, DE102012104425B4, DE102014105639B3, US9583704B2, DE102016205860B4, US10,388,370B2, CN000109074842B, DE 10 2019 203 288, DE 10 2018 125 270.6, DE102018112605A1].

Charged silicon for use as electrostatic carriers and impedance biochips in biotechnology:Surface-near electrostatic forces above charged silicon have been measured using Kelvin Probe Force Microscopy (KPFM) and modelled using a model developed for the interpretation of KPFM data recorded on doped semiconductors [7]. Doped silicon is potentially useful [US201402911143A1, DE102018107810A1, DE 102020200470.6] as an electrostatic carrier [19] in bioreactors, in implants, and in impedance biochips for cell counting [8].

BOUND MAGNETIC POLARONS IN N-TYPE CONDUCTING, MAGNETIC, OXIDE THIN FILMS

Bound magnetic polarons (BMP) strongly influence transport, magnetization, and magnetooptical properties in magnetic semiconductors within the confined volume of BMPs formation. The radius of BMP is directly proportional to the static dielectric constant. If BMPs are coalescing, strong effect of BMPs can be expected on the transport, magnetization, and magnetooptical properties of magnetic semiconductors, even at room temperature.

We have measured and modelled room temperature impedance of metal/(ZnO or ZnMnO or ZnCoO)/insulator/semiconductor (MSIS) capacitive structure and modelled the static dielectric constant of ZnO and of ZnMnO and ZnCoO. We have confirmed the dielectric constant of ZnO in the range from 8.64 to 9.97. We consider the observed increase of static dielectric constant in ZnMnO and in ZnCoO with decreasing fraction of Mn and Co, respectively, as the key result of our work [Vegesna et al., Sci. Rep. 10, 6698 (2020)].



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MARKUS A.SCHMIDT

PROFESSOR OF FIBER OPTICS AT THE LEIBNIZ INSTITUTE OF PHOTONIC TECHNOLOGY

Markus A. Schmidt owns a full professorship for Fiber Optics at the Friedrich-Schiller University Jena and is head of the research department Fiber Photonics at the Leibniz Institute for Photonic Technologies (IPHT), leading the working group Hybrid Fibers.

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RESEARCH AREAS

Prof. Schmidt currently focusses his research on fibers and waveguides with applications in areas such as biophotonics, optofluidics, and nonlinear optics. Current research interests include:

- Propagation of light in novel waveguides implemented by 3D nanoprinting or fiber drawing (e.g. hollow-core light-cages)
- Beam manipulating by functionalizing optical fibers with metasurfaces or plasmonic nanostructured
- Nano-object detection (e.g., viruses etc.) inside waveguides for biosensing via measuring Brownian motion
- Ultrafast nonlinear light generation (e.g., soliton-based supercontinuum generation)

TEACHING FIELDS

Prof. Schmidt's teaching is devoted to the early involvement of young developing scientists in state-of-the-art research. Currently, he holds two courses in:

- Fiber optics (summer semester)
- Active Photonics Devices (winter semester)

RESEARCH METHODS

The infrastructure at the Leibniz Institute of Photonic Technology and the laboratories led by Prof. Schmidt offer a wide range of methods for the fabrication and characterization of all kinds of optical fibers, including:

- Ultrashort pulse lasers
- Microscopic tracking setup, image processing tools
- 3D nanoprinting (Nanoscribe)fiber-drawing tower
- Various spectrometers, transmission setup, lasers and other light sources

RECENT RESEARCH RESULTS

Markus A. Schmidt has focused his research on fibers and waveguides with applications in areas such as biophotonics, optofluidics, and nonlinear optics. One large fraction of the research of the group of Prof. Schmidt targets nano-object detection [1-3]. Here the Brownian motion of objects which are substantially smaller than the diffraction limit of light is statistically analyzed, which represents a key technology in modern bioanalytics (e.g., virus ensemble characterization). In the group of Prof. Schmidt, freely diffusing nano-scale objects are introduced into the holey channel of microstructured fibers and the trajectory of the diffusion is analyzed via side-wide microscopic detection. One recent research examples includes the three dimensional recovery of the trajectory of the diffusion of a gold nanosphere inside a modified step index fiber (top left). Another key research area in the group of Prof. Schmidt addresses nonlinear frequency conversion within highly confining hybrid waveguides [4-6]. Currently the group is intensively working on soliton-based supercontinuum generation in liquid core fibers, which via the non-instantaneous response of the liquid core material yields novel type of nonlinear excitations (e.g., hybrid solitons) and temporally stable broadband spectra. Moreover novel kind of dispersions tuning schemes (e.g., resonance mediated tuning via nanofilms (bottom left)) are employed to desirably shape nonlinear processes and output spectra. The development of novel types of hollow waveguides also represents one intensively followed research directions. Here 3D nano-printing is used to realize waveguides such as light cages (top right) which allow guiding light inside an array of freely suspended strands which unique give side-wise access to the hollow core [7-9]. This project which is carried out in close collaboration with our partner group at LMU Munich (Prof. Stefan Maier) allows for the integration of novel types of nonlinear and sensing devices as being demonstrated. Metasurfaces represent a promising pathway to manipulate the flow of light via defined scattering of an ensemble of nano-engineered scatteres [10-12]. Within this project, metasurfaces are created on the end faces of optical fiber by means of either nano-printing or electron beam lithography (bottom right). This leads to effects such as fiber-integrated focusing for optical trapping applications or highly sensitive optical responses for bioanalytics.

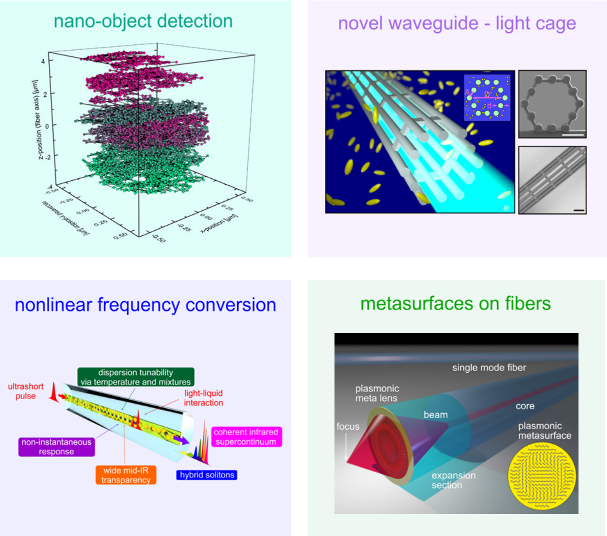

Figure 1: Schematic of research areas followed: top left: in-fiber nano-object by means of analyzing Brownian motion of diffusing nano-objects such as viruses. Bottom left: Key features of nonlinear frequency conversion in liquid core fibers.
Top right: Optofluidic light cage, representing an example of a 3D-nanoprinted hollow waveguide structure. Bottom right: Example of fiber-integrated plasmonic metasurfaces mediated light focusing

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MICHAEL SCHMITT

APL. PROFESSOR FOR PHYSICAL CHEMISTRY AT INSTITUTE OF PHYSICAL CHEMISTRY

Apl. Prof. Michael Schmitt is research associate at the Institute of Physical Chemistry at the chair for Physical Chemistry of Prof. Popp. He serves as assistant Editor of the Journal of Biophotonics.

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RESEARCH AREAS

Dr. Schmitt's research interests are focused on linear and non-linear laser microspectroscopy for:

- Biomedical and life sciences analysis
- Characterization of the interaction between low molecular molecules and biological target molecules
- Derivation of structure-property and structure dynamic relationships of biomolecules and innovative materials

TEACHING FIELDS

Dr. Schmitt teaches classes in fundamental physical chemistry (B.Sc. and M.Sc. Chemistry) and spectroscopy and imaging (M.Sc. Chemistry, M.Sc. Chemical Biology).

RESEARCH METHODS

The laboratories run by Dr. Schmitt at the chair of Prof. Popp offer possibilities for linear and non-linear laser spectroscopy by utilizing the following equipment:

- Resonance Raman spectroscopy
- Non-linear multimodal imaging combining:
  - Coherent anti-Stokes Raman (CARS) microscopy
  - Stimulated Raman scattering (SRS) microscopy
  - Second harmonic generation (SHG) imaging
  - Multi-photon excited autofluorescence imaging
  - Multi-photon excited fluorescence life-time imaging microscopy (FLIM)

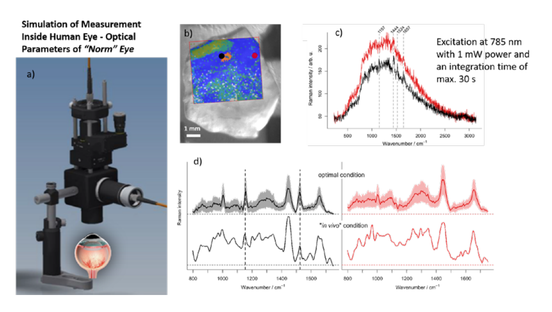
RECENT RESEARCH RESULTS

Multimodal nonlinear microscopy has matured during the past decades to one of the key imaging modalities in life science and biomedicine due to its unique capabilities of label-free visualization of cell and tissue structure and chemical composition, high depth penetration, intrinsic 3D sectioning, diffraction limited resolution and low phototoxicity. Within the last years the non-linear imaging unit within the chair of Prof. Popp headed by Dr. Schmitt utilized the combination of various non-linear imaging modalities like coherent anti-Stokes Raman scattering (CARS), multi-photon-excited fluorescence (MPEF) or second harmonic generation (SHG) to study disease processes in organs like e.g. liver [1,2,3] or chemical processes in plants [4]. Furthermore, new technological concepts of image acquisition and sample illumination to further speed up the image acquisition have been realized [5].

Another focus of the work of Dr. Schmitt is the spectroscopic characterization of innovative materials like e.g. self-healing polymers. The main goal of this work, which was carried out in close collaboration with the group of Prof. Schubert, was the characterization of the healing mechanism of self-healing polymers on a molecular level, which is an important prerequisite for the targeted development of self-healing materials [6-9]. In this context it could be shown for the first time that the healing of a crack in a self-healing polymer observed by CARS microscopy takes place on a different time scale than the simultaneous observation of crack healing by conventional reflection microscopy [8]. These investigations, which for the first time allowed for the simultaneous acquisition of morphological reflection and molecular CARS images, show very well that it is not sufficient to characterize the healing „only" morphologically, but that molecular aspects, which can only be detected by molecular spectroscopic methods such as CARS microscopy, play a decisive role.

RAMAN SPECTROSCOPY OF HUMAN RETINA SAMPLES COMPLYING WITH LASER SAFETY REGULATIONS FOR IN VIVO MEASUREMENTS

Retinal diseases are leading causes of vision impairment, increasing worldwide due to an aging society. If diagnosed early, most cases could be prevented. In contrast to standard ophthalmic diagnostic tools, Raman spectroscopy can provide a comprehensive overview of the biochemical composition of the retina. In a proof of concept study, we could show, that Raman spectroscopy can provide information on the chemical structure of human retina samples under in-vivo like conditions [10]. The challenges of in vivo Raman studies due to laser safety limitations and predefined optical parameters given by the eye itself are explored. This work highlights that Raman-based investigations can add important value to retinal diagnostic even under laser safety regulations and the optical restrictions of a human eye.



Raman setup to simulate the optical pathway in the eye; bottom: bright-field image with overlaid molecular Raman cluster image and average cluster Raman spectra of a human retina sample (adapted from [10]).

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ULRICH S. SCHUBERT

PROFESSOR AT THE LABORATORY OF ORGANIC AND MACROMOLECULAR CHEMISTRY AND JENA CENTER FOR SOFT MATTER

Prof. Schubert is director of the Jena Center for Soft Matter (JCSM), spokesperson of the DFG CRC 1278 PolyTarget, PI and Research Area Coordinator of the Cluster of Excellence "Balance of the Microverse", Coordinator of EU ITN "POLYSTORAGE" and coordinator of the SPP 2248 "Polymer-based Batteries". The Schubert group currently has about 100 members from 12 different countries. He is one of the world's leading chemists and materials scientists and listed as "highly cited researcher" since 2014. In addition, he is a scientific member of the Max Planck Society (MPG) and a Fellow of the National Academy of Inventors. He received numerous prestiguous awards, including the German Federal Cross of Merit with Ribbon.

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RESEARCH AREAS

Prof. Schubert is working on innovative materials for healthcare, sustainability and energy. His laboratory covers organic synthesis, macromolecular and supra-molecular chemistry, combinatorial and material research, advanced characterization and nanoscience, including:

- Metallo-supramolecular polymers and batteries
- Tailor-made functional polymers and nanoparticles
- Responsive materials and optical metamaterials
- Organic solar cells and polymer LEDs
- High-throughput experimentation, inkjet-printing and nanolithography

TEACHING FIELDS

Prof. Schubert's teaching includes undergraduate courses as well as graduate courses involving state-of-the-art research:

- Organic and macromolecular chemistry
- Polymers and energy
- Nanoengineering and nanostructured polymers

RESEARCH METHODS

The Laboratory of Organic and Macromolecular Chemistry features a wide range of methods for the experimental characterization of functional materials including:

- Size exclusion chromatography (SEC), high pressure liquid chromatography (HPLC) and gas chromatography (GC) systems
- Biological cell culture facilities with Live cell imaging microscopy (Confocal-Laserscanning microscopy with superresolution, High-content microscopy), Flow cytometry and molecular biology equipment including RT-PCR and gel electrophoresis
- Mass spectrometry (ESI-TOF, MALDI-TOF MS/MS, ESI/APCI-TOF, MALDI-imaging
- (Cryo)transmission and scanning electron microscopy
- Asymmetric flow field-flow fractionation (AFFFF) and analytical ultracentrifugation (AUC)
- Atomic force microscopy (AFM) & Nanoindentation

RECENT RESEARCH RESULTS

The Schubert group's research is based on a highly interdisciplinary background of its group members which consists of chemists, physicists, biologists and material scientists.

In the field of **materials for life sciences**, Schubert group focuses on the development of tailor-made polymers for the transport of genes and drugs, respectively. In particular, polymeric nanoparticulate materials are investigated (within the framework of DFG CRC 1278 – Polytarget). Moreover, the interaction between polymeric materials and cells is studied. With the recently completed cleanroom facility at the ACP on the Beutenberg Campus, it is now possible to transfer research results of suitable cell and organ-specific nanoparticle formulations into clinical test samples for targeted delivery of active pharmaceutical ingredients produced under GMP conditions. [1-4]

The **nanochemistry** labs synthesize nanoparticles or carbon nanotubes by non-classical methods (e.g., by microwave irradiation). Moreover, surfaces can be functionalized on the nm-level by electro-oxidative lithography.[5-8]

Various **advanced characterization techniques** allow the detailed analysis of the different polymeric materials providing information on the (absolute) molar mass (e.g., by analytical ultracentrifugation, mass spectrometry), sizes of polymer assemblies up to other polymer properties (e.g., thermal proper-ties). In particular, electron microscopy (cryo-TEM, SEM) allows a deeper insight into polymeric as-semblies, particles etc. [9-14]

A great interest of the Schubert group display the **self-healing, self-organization and self-assembling materials and systems**. Supramolecular interactions (metal complexes, ionic interactions, hydrogen bonding) are utilized for the design of molecular building blocks (e.g., for energy and electron transfer) as well as of supra-molecular polymers. Latter materials are also studied in the context of self-healing polymers. These materials are also fabricated based on reversible covalent interactions. [15-21]

With **polymers for energy**, new battery technologies as alternative to the classical lithium batteries are investigated – these systems are based on organic materials and polymers. Redox-active polymers are used as active materials within thin batteries (e.g., printable bat-teries, solar batteries) as well as in redox-flow batteries. The usage of organic materials allows the abstention of critical metals (like cobalt or vanadium). [22-26]

High-throughput experimentation and tailor-made macromolecules are another topic of the group of Prof. Schubert. In order to obtain well-defined polymers (with tailor-made properties), living and controlled polymerization methods are utilized (e.g., RAFT polymerization or CROP of oxazolines). For instance, LCST-type polymers were synthesized by these methods. Moreover, high-throughput experimentation methods allow the fabrication of polymer libraries in order to elucidate structure-property relationships.[27-29]

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FRANK SETZPFANDT

RESEARCH GROUP LEADER QUANTUM OPTICS

Since 2016, Dr. Setzpfandt leads a Research Group focused on quantum optics, especially targeting quantum imaging and sensing approaches as well as integrated quantum optics. Before, he was a PostDoc at the Institute of Applied Physics of the Friedrich Schiller University and the Nonlinear Physics Centre of the National University Canberra, Australia. He currently serves as CEO of the Thuringian Innovation Center for Quantum Optics and Sensors.

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RESEARCH AREAS

The research of Dr. Setzpfandt focuses on the generation of tailored classical and nonclassical states of light using nanostructured and integrated optical systems as well as the use of nonclassical light for imaging and sensing.

This includes the following research fields:

- Integrated quantum optics
- Nonlinear optics in waveguide and nanostructures
- Photon-pair generation
- Quantum imaging and sensing

TEACHING FIELDS

Dr. Setzpfandt currently teaches master-level courses on:

- Quantum Optics
- Quantum Imaging and Sensing
- Integrated Optics
- Experimental Quantum Technologies

RESEARCH METHODS

Dr. Setzpfandt uses a number of state-of-the-art characterization techniques, e.g.:

- Nonlinear frequency conversion and nonlinear spectroscopy
- Photon-pair correlation measurements
- Quantum ghost imaging
- Integrated optical circuit characterization

RECENT RESEARCH RESULTS

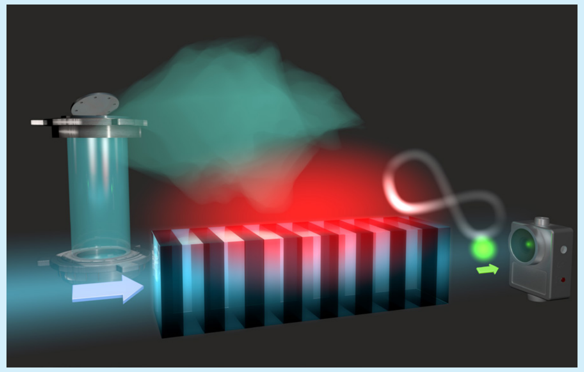
Photon pairs, quantum states of light containing exactly two photons, are the basis for many quantum phenomena and quantum applications in computing, communication, and sensing. They are often generated using spontaneous down-conversion (SPDC), a second-order nonlinear conversion process where a short-wavelength pump photon decays into a pair of signal and idler photons. The properties of these photon pairs can be controlled to a large extent by the properties of the nonlinear optical material they are generated in. One focus of our research is to use structured nonlinear materials in the form of waveguides or nanophotonic resonators to generate tailored photon pairs, where we could show the generation of spatially entangled pairs in nanostructured waveguides [1] and develop a complete understanding of the states that can be generated in coupled waveguide systems [2]. Furthermore, we could show that waveguide sources of photon pairs can be directly used as a spectroscopic sensor, where, using quantum correlations, spectroscopy in the mid-IR can be performed by measuring only photons in the visible [3, 4].

We also investigate the applications of photon pairs for quantum imaging, where we recently found a lensless quantum imaging method reminiscent of a pinhole camera [5].

Whereas nonlinear waveguides are an established platform for generating photon pairs, nanostructured nonlinear surfaces are currently emerging and enable precise control of the emission direction of photon pairs by lateral structuring. The potential of this approach was demonstrated for a surface of monomolecular thickness using classical frequency conversion, which follows the same rules as SPDC [6].

WAVEGUIDES FOR QUANTUM SPECTROSCOPY

Nonlinear waveguides enable the generation of photon pairs with largely different wavelengths, e.g. with one wavelength in the mid-IR and the other in the visible. This renders them promising devices for quantum spectroscopy, where the mid-IR photon can interact with substances in the waveguide surrounding and its absorption can be sensed by measuring only the visible partner photon. This enables IR spectroscopy using cheaper and more sensitive detectors for visible light. We recently could experimentally demonstrate the feasibility of this concept be generating photon pairs with one photon in the mid-IR in a waveguide and inferring waveguide properties in this spectral range from measurements of the short-wavelength partner photon only.



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GIANCARLO SOAVI

JUNIOR PROFESSOR FOR SOLID STATE PHYSICS AND OPTICAL PROPERTIES OF TWO-DIMENSIONAL MATERIALS

Giancarlo Soavi is a Junior Professor at the Institute for Solid State Physics of the Friedrich Schiller University Jena, where he leads the Group of UltraFast Optical Spectroscopy (GUFOS). He received his PhD in Physics in 2015 from Politecnico di Milano and he worked as a Visiting Scientist at the University of Konstanz (Germany) in 2014 and as a Research Associate at the Cambridge Graphene Centre (University of Cambridge, UK) from 2015 to 2018. He is the leader of the "Lasers and Sources" working group of the 1b€ European project Graphene Flagship.

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RESEARCH AREAS

The research group of Dr. Soavi focuses on the study of the ultrafast opto-electronic and nonlinear optical properties of nanoscale and quantum confined systems, including carbon nanotubes and graphene nanoribbons, metallic nanoparticles, 2D perovskites and 2D materials. Research interests include:

- Ultrafast electron and exciton dynamics in 2D materials and related heterostructures
- Nonlinear optical imagining and harmonic generation in quantum confined systems
- Fabrication of opto-electronic devices based on 2D materials
- Development of novel methods for the study of ultrafast dynamics at the nanoscale

TEACHING FIELDS

Dr. Soavi teaches two elective courses designed for MSc students in physics and photonics:

- Graphene: electronic and optical properties
- Nonlinear optical properties of 2D materials

RESEARCH METHODS

The Group of UltraFast Optical Spectroscopy (GUFOS) combines different techniques for the fabrication and characterization of devices based on 2D materials and for the study of the ultrafast dynamics and nonlinear optical properties of nanoscale systems. These include:

- Microscope for deterministic transfer of 2D materials
- 10K clean room for nano-fab and device fabrication
- Custom-built Raman and photoluminescence microscope
- MHz repetition rate pump-probe spectroscopy
- Custom-built nonlinear optical microscope
- Cryostat for optical measurements from room temperature to 4K

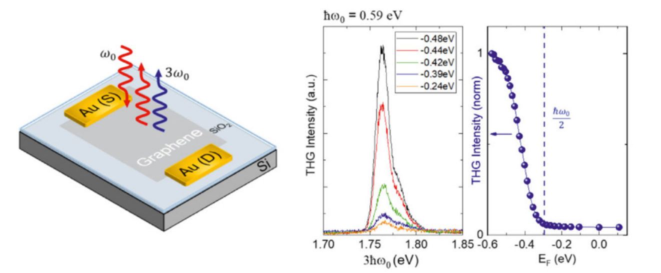
RECENT RESEARCH RESULTS

In the last years, the research of Dr. Soavi focused on two major activities. The first deals with the study of the ultrafast dynamics and coherent phonons excitation in quantum confined systems. Experiments in this field were performed with custom-built pump-probe systems, with temporal resolutions ranging from 10fs to 100 fs. In pump-probe experiments, a first ultrashort pulse (pump) triggers a dynamical process which is subsequently detected by looking at the changes in the absorption or transmission of a second ultrashort pulse (probe). By changing the delay between the pump and the probe it is possible to follow in real time the evolution of the excited state of the system under investigation. This technique can be applied to a vast range of samples and it is widely used in chemistry, biology and solid-state physics. In particular, Dr. Soavi designed and implemented experiments to study the ultrafast optical response of quantum confined systems, including the investigation of the pseudo-spin dynamics in graphene [1], the inter- and intra-valley scattering and spin-flip in semiconducting 2D materials [2], the out-of-plane heat transfer in layered heterostructures [3], the ultrafast mechanism of exciton-exciton annihilation and the subsequent formation of biexcitons in graphene nanoribbons [4] and the ultrafast response and charge carrier photogeneration in semiconducting carbon nanotubes [5]. Besides the ultrafast dynamics of electrons and excitons, pump-probe experiments have been performed to study the coupling between excitons and phonons in 2D materials [6] and the mechanical coherent oscillation of metallic nanoparticles [7].

More recently, the research of Dr. Soavi focused on the fundamentals and applications in the field of nonlinear optics, harmonic generation and frequency conversion. In this context, he achieved the first experimental demonstration of ultra-broadband and gate-tuneable third harmonic generation in graphene [8] and studied the impact of hot-electrons in harmonic generation with ultrashort pulses [9]. Dr. Soavi also designed and implemented four-wave-mixing experiments for ultra-sensitive gas detection using graphene integrated photonic devices [10] and second harmonic generation experiments to study symmetry breaking in layered perovskites [11].

ULTRAFAST NONLINEAR OPTICS WITH GATE GRAPHENE

In single layer graphene the THG intensity can be tuned over more than one order of magnitude by externally applied gate voltages [8]. This enhancement is due to logarithmic resonances in the imaginary part of the nonlinear optical conductivity arising from multiphoton resonant transitions. This result highlights new possibilities for the realization of on-chip integrated nonlinear devices based on single-layer graphene, such as broadband gate tuneable nonlinear optical switches and ultra-sensitive gas detectors [10]. However, a major limiting factor for applications is the increase of the graphene's electronic temperature that follows from interaction with ultrashort (fs-ps) pulses [9]. Possible configurations to control the hot electron recombination dynamics include interlayer electron-phonon interactions [3] and gate tuning of the SLG chemical potential due to phase-space suppression of the hot electron scattering with optical phonons.



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CHRISTIAN SPIELMANN

PROFESSOR FOR QUANTUM ELECTRONICS AT INSTITUTE OF OPTICS AND QUANTUM

Prof. Spielmann is member of the board of directors of the Abbe Center of Photonics and of the executive board of the Abbe School of Photonics. Further, he is the spokesperson of the Graduate School for Advanced Photon Science at the Helmholtz Institute Jena. Besides his duties at the University, he serves as elected deputy speaker of the scientific advisory board of the IPHT, member of the board of the HED@FAIR plasma physics collaboration, and was co-founder of Femtolasers GmbH, one of the premiere manufacturers of ultra-fast laser systems. From 2019 on Prof. Spielmann serves as the elected dean of the Faculty for Physics and Astronomy.

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RESEARCH AREAS

Prof. Spielmann's research of is focused on the generation and application of ultra-short pulses from the infrared to the x-ray regions, including:

- Generation and amplification of ultrafast optical pulses and application in medicine
- Nonlinear optics in structured materials
- Generation of spatially and temporally coherent XUV radiation
- Laser plasma physics for studying matter under extreme conditions
- Application of XUV radiation for functional imaging of nanoscale materials

TEACHING FIELDS

His lectures center on:

- Atomic and molecular physics
- Fundamentals of modern photonics
- XUV and x-ray optics
- Modern methods of spectroscopy

RESEARCH METHODS

The equipment of Prof. Spielmann's laboratories allows for studying the structural dynamics of atomic and solid systems as well as imaging nanostructures:

- Novel approaches for quantum imaging with short velength sources
- Spatial and temporal shaping of ultrashort pulses
- Tunable mid-IR femtosecond sources for time-resolved spectroscopy of solids
- Nonlinear optics for coherent XUV generation
- Laser-based XUV and x-ray spectroscopy with high temporal resolution
- Setup for high resolution XUV imaging in reflection and transmission geometry

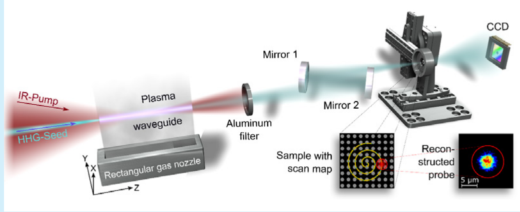
RECENT RESEARCH RESULTS

Spectral broadening and compression of laser pulses is of central importance for many applications. Here, the laser-matter interaction is confined to gas-filled novel anti-resonant hollow-core fibers (ARHF), which enable efficient guiding of intense light inside the fiber. Our experiments with Kr-filled ARHF have shown more than an octave spectral broadening [1]. Major advantages of ARHF are low loss, large-mode field diameter with effective single mode guidance from near IR to deep UV. This project tackles fundamental physical questions concerning the interaction of intense ultrashort mid-IR pulses with matter and provide a tunable ultrashort (down to a single optical cycle) source of near- to mid-IR radiation, which has applications in diverse areas of imaging. In another collaboration, we investigated experimentally interaction of sub-relativistic and relativistic femtosecond laser pulses with nanostructured solid dielectric targets. Interaction of ultra-intense laser radiation with nanostructured targets is a hot topic in modern strong field physics [2], like the generation of high harmonics in solids up to ultra-hot and ultra-dense plasmas for applications in particle acceleration and hard X-ray generation. Experiments were carried out with different types wide-band gap, nanostructured semiconductors. Experiments at relativistic (about 1018 W/cm2) intensities were conducted at Jena's JETi-40 multi-TW laser system. Both the characteristic X-ray emission from transitions in high charge state ions generated in the targets [3] and the emitted particles were measured and simulated. Besides large-scale facilities such as synchrotrons and free electron lasers, only few approaches for brilliant XUV sources exist. The process of high harmonic generation (HHG) provides an elegant alternative for generating photons within the XUV and soft x-ray spectral region. Due to its outstanding properties the generated radiation is ideal for applications in spectroscopy, imaging and time-resolved studies. Beside further increasing the conversion efficiency, we will address the bandwidth of the harmonics, which is crucial for high resolution imaging. Our bright HHG sources emit narrow bandwidth harmonics with are essential for all high-resolution lens-less imaging techniques such as digital in-line-holography, coherent diffraction imaging and ptychography. In joint experiments with Prof. U. Kleineberg (MPI Munich), we demonstrated our capabilities to image close to highest possible resolution in a reasonable exposure time. In another cooperation with industry and the university hospital, we demonstrated a novel approach for rapidly classifying cell types: we measure the pattern of coherently diffracted extreme ultraviolet radiation and demonstrated that it is possible to distinguish different single breast cancer cell types.

More recently, we started to explore other XUV sources such as laser-driven plasma sources and x-ray lasers for high resolution imaging [4]. They offer a higher flux and/or shorter wavelengths which is of great interest for approachig single-shot, table-top imaging in the water window. In parallel we work on realizing a proof of principle experiment for quantum ghost imaging [5] in the XUV. This ansatz holds promise for element specific sub-μm resolution imaging of biological samples without substantial radiation damage.

NONLINEAR IONIZATION DYNAMICS OF HOT DENSE PLASMA OBSERVED IN A LASER-PLASMA AMPLIFIER

Understanding light-matter interaction under extreme conditions, such as in high-density plasmas, is important for our identification of cosmologic objects. Together with researchers at the University of California, Berkeley, the Universidad Politécnica de Madrid, and the Institut Polytechnique de Paris, we succeeded in directly observing the formation and interaction of highly ionized krypton plasma using fs coherent UV light and a novel 4D model [4]. We employed a laser-plasma amplifier that uses eight-fold ionized krypton ions as laser medium. A coherent extreme ultraviolet probe pulse was launched into this plasma and picks up signatures of the plasma conditions as it propagates through the laser-generated plasma column. This XUV probe pulse is then analyzed by diffracting it off a nanoscale target. This method, known as coherent diffraction imaging, together with ptychography, allows for measurement of the properties of the probe pulse carrying information about the plasma with very high resolution. Using an adapted ab initio theory modelling the plasma-light interaction in 4D across multiple scales, we found excellent agreement with experimental data. This allowed to ascribe the observed signal to a strongly nonlinear behavior in laser-plasma interaction generating the highly ionized krypton plasma.



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ISABELLE STAUDE

PROFESSOR AT THE INSTITUTE FOR SOLID STATE PHYSICS

Prof. Dr. Isabelle Staude joined the Abbe Center of Photonics in 2015. Initially, she established a junior research group on functional photonic nanostructures, before becoming a professor for photonic nanomaterials in April 2020. Before that, she was a postdoc at the Nonlinear Physics Centre, Australian National University. She received her Ph.D. degree from the Karlsruhe Institute of Technology, Germany. She received an Emmy-Noether Grant from the German research Foundation as well as the Hertha Sponer Prize 2017 from the German Physical Society. She is the speaker of the International Research Training Group "Tailored Metasurfaces - Generating, Programming and Detecting Light, and a member of the Management Board of the Collaborative Research Center (SFB) "Nonlinear Optics Down to Atomic Scales (NOA)".

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RESEARCH AREAS

Dr. Staude's research focuses on the use of designed photonic nanostructures which are to control the emission, absorption, and propagation of light at the nanoscale level. Her research topics include:

- Nanophotonics, -plasmonics, and -antennas
- High-index dielectric nanoparticles
- Hybrid quantum systems and quantum emitters
- Nanofabrication technology
- Subwavelength optics
- Metamaterials and photonic crystals
- Two-dimensional materials

TEACHING FIELDS

During her course lectures, she is committed to sharing not only her knowledge, but also her fascination for optics at the nanoscale.

She gives courses in:

- Introduction to Nanooptics
- Semiconductor Nanomaterials
- Optical Metrology and Sensing

RESEARCH METHODS

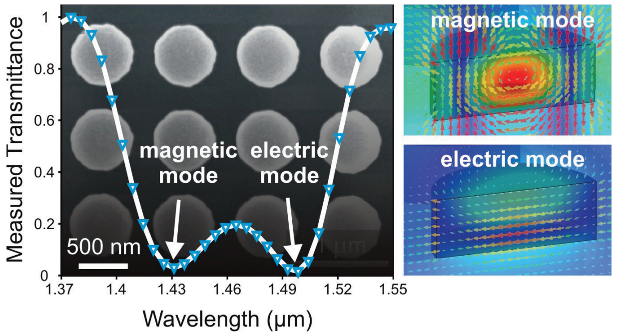
For the experimental realization and study of functional photonic nanostructures, the research group on Photonic Nanomaterials led by Dr. Staude employs a range of state-of-the-art nanotechnology and optical characterization techniques, including:

- Electron-beam lithography based nanofabrication
- Linear and nonlinear optical spectroscopy
- Time-resolved photoluminescence spectroscopy
- Back focal plane imaging
- Assembly of hybrid nanostructures via dry transfer
- Assembly of hybrid quantum systems by selective surface functionalization

RECENT RESEARCH RESULTS

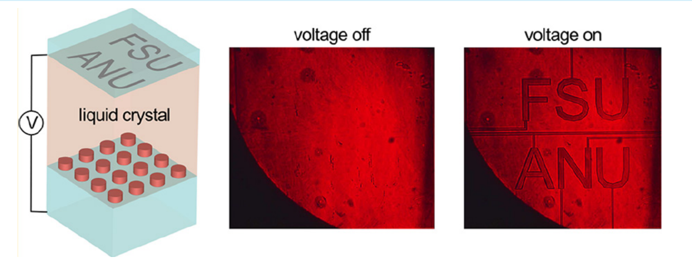
Resonant nanoparticles and their assemblies can show complex and often surprising interactions with light, giving rise to phenomena such as „magnetic light", directional scattering, Fano resonances, and strong near-field enhancements. Using the capabilities of modern nanotechnology, these interactions can be tailored by the size, shape, material composition, and arrangement of the nanoparticles. Resonant nanoparticle structures are a versatile research platform for investigating fundamental light-matter interactions and nanoscale coupling phenomena. Furthermore, they provide unique optical functionalities, opening new opportunities for applications like next-generation (quantum) light sources, optical communications, and truly flat optical components. In our research we combine top-down and bottom-up nanofabrication approaches to experimentally realize composite photonic systems. Using these systems, we strive to control the emission, propagation, and absorption of light - and all of its properties at the nanoscale.

Recently we have focused on nanoparticles composed of highly transparent, high-refractive-index dielectrics. Such nanoparticles support localized electric and magnetic Mie-type resonances (see image), thereby providing a low-loss alternative to plasmonic nanostructures [1]. Most prominently, highly efficient functional nanosurfaces [2], e.g., for resonant wavefront shaping [3] and nonlinear frequency generation [4] can be created by dedicated arrangements of designed dielectric nanoresonators on a plane. Active tuneability of dielectric nanosurfaces has been achieved using liquid crystals [5]. Furthermore, we have studied the use of Mie-resonant all-dielectric nanoparticles as high-radiation efficiency nanoantennas for spontaneous emission control [6, 7].



TUNABLE METASURFACE DISPLAYS IN THE VISIBLE

In recent years, tunable metasurfaces and metadevices have attracted extensive research efforts, aiming at pushing optical metasurfaces towards practical applications. Infiltrating metasurfaces with nematic liquid crystals (LCs) is an attractive approach due to its high compatibility with the existing industrial technologies and optical devices. Recently, we demonstrated a LC-infiltrated metasurface with large electrically controlled transmittance modulation in the visible spectral range and showed its suitability for display applications. In contrast to conventional LC displays, the transmittance modulation takes place inside the subwavelength metasurface, rather than in the bulk LC layer. Additionally, for the first time we used a dedicated photoalignment material to define the pre-alignment of the liquid crystal molecules. Our demonstration shows that LC tunable metasurface displays hold the potential for largely reducing the LC layer thickness, display pixel size, and thus to significantly reduce the device response time, power consumption and to improve the display resolution.



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FABIAN STEINLECHNER

PROFESSOR FOR EXPERIMENTAL QUANTUM INFORMATION AT THE INSTITUTE OF APPLIED PHYSICS

Dr. Fabian Steinlechner received his PhD in 2015 from ICFO (Barcelona, Spain) where his doctoral research focused on the development of quantum light sources for applications in Space. As a postdoctoral fellow at the Institute for Quantum Optics and Quantum Information in Vienna, he contributed to the application of entangled photons in loophole-free tests of non-locality, quantum sensing, high-dimensional quantum information processing, and long-distance quantum communication in free-space and fiber links. In 2018, he established the "Quantum Communication Technologies" and "Photonic Quantum Information" groups at Fraunhofer IOF Jena. In 2023, Fabian Steinlechner was appointed as a full professor for Experimental Quantum Information at the Institute of Applied Physics at the University of Jena.

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RESEARCH AREAS

Entangled photons are a key resource in quantum technology. They act as low-noise probes in imaging and sensing, as versatile information carriers in information processing and communication networks or as tamper-proof padlocks for cryptography. Dr. Steinlechner's research focuses on photonic technologies for generating and manipulating complex quantum states of light for applications in remote sensing, long-range quantum communication, quantum information processing and distributed quantum networks. Research topics include:

- Tailoring the spatial- and spectral structure of biphotons generated via downconversion
- High-dimensional quantum information processing in the spatial and temporal domain
- Generating non-classical states of light for applications in ranging and remote sensing
- Quantum hardware and adaptive optics for satellite-based quantum communication
- Distributed quantum information processing enabled by high-dimensional photonic entanglement and hyperentanglement

TEACHING FIELDS

- Quantum communication

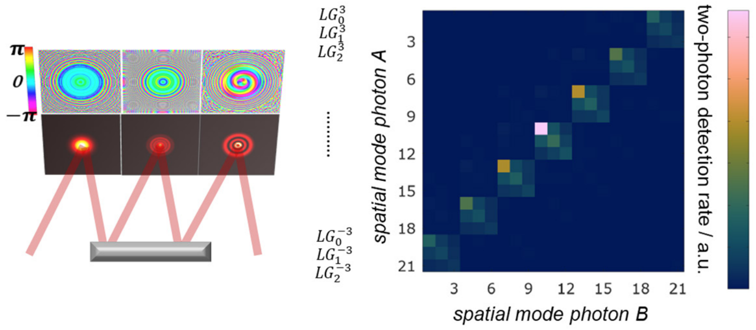
RESEARCH METHODS

The group utilizes modern experimental equipment including:

- Ultra-bright entangled photon sources
- Pulsed and cw-lasers at different wavelengths
- Wavelength-division multiplexing technology
- Single photon detectors and time-tagging electronics
- Ultra-fast electro-optic modulators and pulse shapers
- Spatial light modulators and adaptive optics

RECENT RESEARCH RESULTS

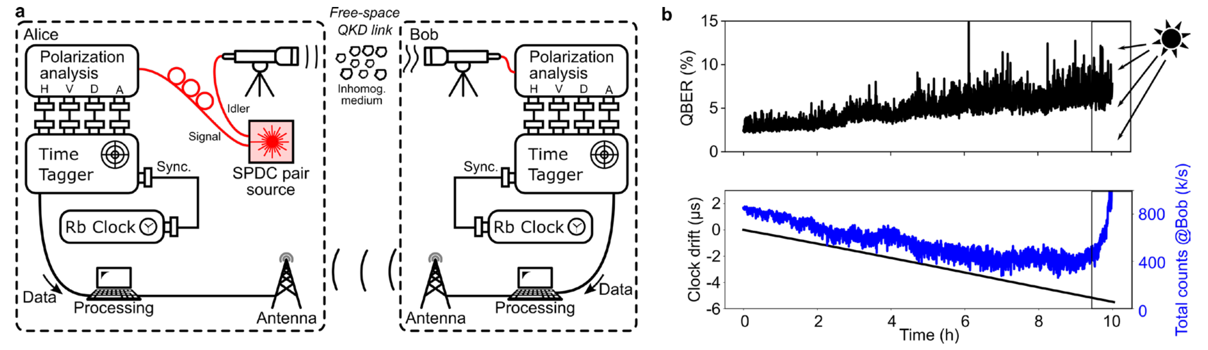
Recent research results include the demonstration of polarization-entangled photon sources with world record pair generation rates [1], the manipulation and detection of spatially-encoded [2-3] and frequency-encoded quantum states [4] for high-dimensional quantum information processing, novel approaches in quantum-enhanced sensing [5], as well as the exploitation of high-dimensional entanglement in noise-resilient quantum communication [6]. The group is also involved in collaborative efforts aimed at advancing quantum technology from laboratory to commercial application, in particular the design of quantum payloads for satellite deployment [7] and quantum communication systems for metropolitan free-space [8] and fiber networks [9].



(left) Schematic representation of multi-plane light conversion for efficient manipulation and analysis of high-dimensional quantum states. (right) Spatial correlations of entangled photon pairs generated via parametric down conversion in a Laguerre-Gauss detection basis.

ENTANGLEMENT-BASED QUANTUM KEY DISTRIBUTION

The group recently established a quantum-secure communication testbed, thereby showcasing local competences along the entire quantum photonics process chain: Figure a) Polarization-entangled photons (photon A and photon B) are generated in a spontaneous parametric down conversion process (SPDC). Photon A is sent to Alice via an optical single-mode fiber, and Photon B is guided to a large-aperture folded mirror telescope and transmitted to Bob via an optical free-space link. The link transmission is continuously monitored and optimized using fast beam steering mirrors. The polarization of individual photons is analyzed continuously and detection events are timestamped with respect to a local Rubidium clock. Residual clock drift is compensated for by continuously tracking the two-photon correlation peak. Figure b) Starting the measurements around midnight, the quantum bit error rate (QBER) slowly increases due to polarization misalignment and abruptly peaks at sunrise due to increased background counts. Ongoing R&D addresses autonomous long-term polarization tracking, optimized spatial filtering for daylight operation, as well as adaptive optics wave front correction for efficient coupling of photons into optical fiber networks.



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THOMAS STÖHLKER

PROFESSOR OF THE PHYSICS OF HIGHLY CHARGED IONS, INSTITUTE OF OPTICS AND QUANTUM ELECTRONICS AND HELMHOLTZ INSTITUTE JENA

Prof. Stöhlker is the director of the Helmholtz Institute Jena and the representative of the APPA research branch (Atomic Physics, Plasma Physics, Materials Research) at GSI, Helmholtz Centre for Heavy Ion Research in Darmstadt. He also serves as speaker of the research programme "From Matter to Materials and Life" of the Helmholtz Association. In addition, he is a member of the research programme "From Matter to Materials and Life" of the Helmholtz Association.

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RESEARCH AREAS

Prof. Stöhlker's research interests are focused on electron dynamics in strong and extreme fields, with particular emphasis of the effects of quantum electrodynam-ics (QED):

- Experiments on bound-state QED and the atomic structure of few-electron ions at high-Z
- Radiative processes in collisions of relativistic particles (ions and electrons)
- Collision dynamics involving heavy ions
- Light-matter interaction in the strong-field regime
- Application of advanced x-ray and electron-detector and spectrometer concepts

TEACHING FIELDS

Prof. Stöhlker's teaching is focused on the physics of simple atomic systems, including the atomic structure, atomic collisions, and fundamental aspects such as QED and parity violation.

He gives courses and seminars in:

- Key experiments in modern atomic physics
- The interaction of high-energy radiation with matter
- Photonic processes in highly ionized matter

RESEARCH METHODS

Prof. Stöhlker runs sophisticated setups for photon, x-ray, electron, and ion spectroscopy which are used for the experiments at storage rings, traps and synchrotrons, including:

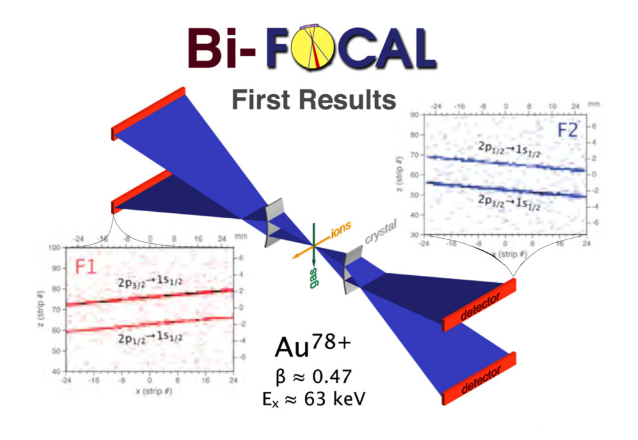
- Energy, time and spatially resolving detectors for x-ray imaging and polarimetry of hard x-rays
- X-ray spectrometers of transmission and reflection type
- Micro calorimeters
- Dense-cluster targets for H_2, He, N_2, Ne, Ar, Xe

RECENT RESEARCH RESULTS

One- and two-electron ions provide an ideal testing ground for fundamental atomic structure theories, for the investigation of QED (self energy and vacuum polarization) as well as relativistic and correlation effects [1]. A new experiment at CRYRING@ESR, the first installation to be made available at the FAIR accelerator and storage ring complex currently under construction near Darmstadt, aims to determine the ground-state Lamb shift in hydrogen-like uranium with an accuracy that substantially exceeds 1%. This will provide the most stringent test of bound-state QED for one-electron systems in the strong field regime approaching the Schwinger limit (1016 V/cm). At extreme magnetic fields, meanwhile, substantial progress was made in 2017 when an experiment conducted on ^{209}Bi$^{82+,80+}$ improved the experimental precision of the so-called specific difference between the hyperfine splittings by more than an order of magnitude while finding a still-unexplained 7-σ deviation from theoretical predictions [2]. Current activities in these fields focus on the application of novel low-temperature bolometers for the hard X-ray regime. For polarization studies of hard x and γ radiation, the application of Compton scattering is another promising approach. Experiments utilizing novel 2D strip or pixel detectors focus on the study of photonic electron transitions and scattering processes in the strong-field domain (characteristic radiation, Rayleigh scattering, electron bremsstrahlung and recombination radiation) where spin effects are important and provide detailed information about the quantum dynamics in the strong-field domain [3].

HIGH-PRECISION CRYSTAL SPECTROSCOPY FOR STRONG FIELD QUANTUM ELECTRODYNAMICS

A breakthrough has been achieved very recently during the investigation of the Lamb shift in the largely unexplored regime of extremely strong electric fields. In an experiment performed at the ion storage ring ESR in Darmstadt, the Lyman-α transitions of H-like gold (Au78+) have been measured with substantial statistical significance by applying the high-resolution transmission crystal-spectrometer system FOCAL [Gassner et al., New J. Phys. 20, 073033 (2018)]. In the figure, the FOCAL spectrometer setup used in this experiment is shown. The resolution of this setup outperforms conventional solid-state germanium detectors by almost one order of magnitude. Up until the present, such detectors have been used in all previous experiments, addressing the topic of strong-field QED via the spectroscopy of the ground-state transitions in high-Z ions. In order to achieve the desired goal of a critical benchmark of the present theory of QED for the realm of extreme fields, such a high-resolution setup like FOCAL is mandatory for an accurate determination of the transition energies and for a further substantial improvement in experimental results. A further refinement of the results is, however, hampered by the systematic accuracy of the setup. The latest efforts of the large international collaboration team, including the Institute of Optics and Quantum Electronics at the Friedrich Schiller University Jena and the Helmholtz Institute Jena, therefore strive to commission an Electron Beam Ion Trap (EBIT) as a compact X-ray source for tests and characterizations of novel detectors. These will facilitate a high-profile experiment currently being installed at CRYRING@ESR, and expected to be performed in 2021.



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ADRIANA SZEGHALMI

EMMY NOETHER GROUP LEADER FOR ATOMIC LAYER DEPOSITION OF OPTICAL COATINGS, INSTITUTE OF APPLIED PHYSICS

Dr. Adriana Szeghalmi is head of the Emmy Noether research group Atomic Layer Deposition of Optical Coatings and head of the ATTRACT research group Atomic Layer Deposition for Optics at the Fraunhofer Institute for Applied Optics and Precision Engineering (IOF) Jena.

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RESEARCH AREAS

The Atomic Layer Deposition Group aims to establish this technology for the development of novel and improved optical elements. We currently focus on devel-oping atomic layer deposited coatings for:

- Low and high refractive indices
- Porous materials
- Advanced nanostructuring technologies
- Interference coatings
- Functional coatings for diffractive optical elements
- Space & laser technology, spectrometry, UV-VIS, DUV, EUV, BEUV, x-ray optics
- Understanding chemical reactions during nucleation and film growth

TEACHING FIELDS

Dr. Szeghalmi currently mentors three doctoral students and a postdoctoral scientist. Graduate students interested in hands-on experience in optical coatings and optical design are welcome to join the group. A course on inorganic and organic materials in photonics is in preparation.

RESEARCH METHODS

The ALD facility led by Dr. Szeghalmi has two plasma-enhanced atomic layer deposition reactors at hand. Both are located in a clean room environment and are equipped with ***in situ*** monitoring techniques for experimental characterization by means of spectroscopic ellipsometry in the 245 nm to 1700 nm spectral range. The equipment comprises:

- OpAL PEALD, Oxford Plasma Technologies
- Sunale R200, Picosun Oy
- J. A. Woollam spectroscopic ellipsometer

RECENT RESEARCH RESULTS

Atomic layer deposition (ALD) is a cyclic, self-limiting chemical deposition technique. The thickness of ALD films is controlled with sub-nanometer precision by the number of ALD cycles. The films manifest high uniformity and low roughness. Most importantly, conformal coating can be achieved on nanostructured materials. A wide range of materials, including oxides, nitrides, fluorides, sulfides, metals and hybrid organic-inorganic composites, can be deposited via the ALD and molecular layer deposition (MLD) techniques. The above-mentioned materials find numerous applications in the fields of photovoltaics, electronics, catalysis, biotechnology, display technology, and photonics.

High and low refractive index dielectrics are essential for refractive and diffractive optics. High optical quality and excellent reproducibility have been achieved for SiO_2, Al_2O_3, HfO_2, Ta_2O_5, and TiO_2 coatings. The deposition of titanium dioxide (TiO_2) using/via ALD was thoroughly investigated [1] and the optical properties are depicted in Figure 1.

Encapsulated gratings show higher efficiency levels than do binary gratings. An improved encapsulation process was developed based on atomic layer deposition and microstructuring. A detailed description of the process is published in [2]. Figure 2 shows a cross-sectioned FIBSEM image of an encapsulated grating designed for TM-polarized light at wavelengths of 1000…1064 nm. The first SiO_2 layer on top of the grating is realized via/using ALD deposition to ensure a high degree of chem-ical bonding to the substrate. Fortunately, no boundary is visible between the grating top and the encapsulation layer. The Ta_2O_5 and SiO_2 layers serve as antireflection coatings made via PVD. The system is in accordance with the ISO:9211-4:2007-03 norm pertaining to the adhesive strength of the layers. The grating efficiency is 97.5% at 1030 nm. The encapsulated grating has a much higher efficiency (up to 8%) than conventional binary gratings in the given spectral range.

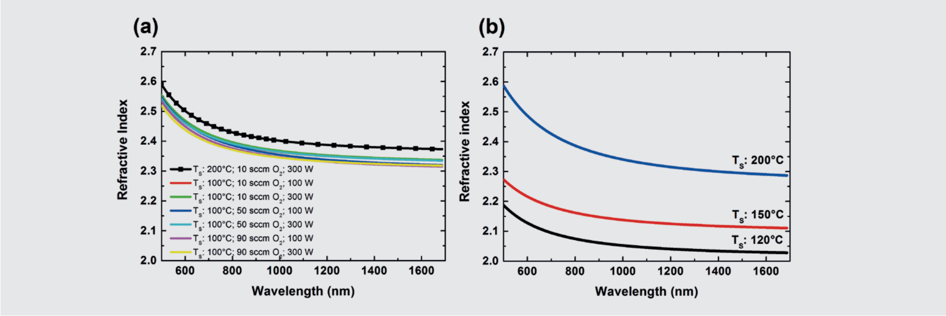


Figure 1: Dispersion of TiO_2 layers deposited (a) via plasma enhanced atomic layer deposition (PEALD), and (b) thermal atomic layer deposition (thermal ALD) at different deposition conditions. The plasma-enhanced atomic layer deposition of TiO_2 was performed at different oxygen gas-flow rates, plasma powers and deposition temperatures T_S. Thermal depositions were carried out at deposition temperatures of 120 °C, 150 °C and 200 °C. Refractive indices are based on the Cody-Lorentz model, chosen for its suitability to the obtained ellipsometric data.

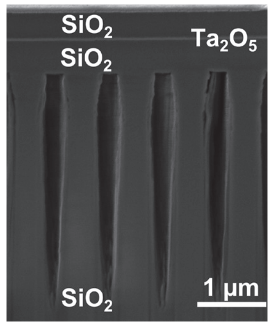
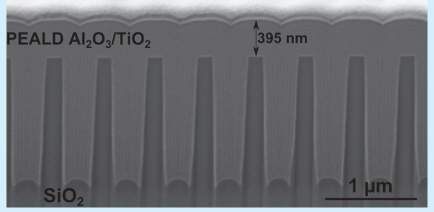


Figure 2. A FIB-cut SEM cross-section image of an encapsulated grating. The three layer system on the grating is only 700 nm thick for use as an antireflection coating.

EMBEDDED GRATING

Another approach to enhance the diffraction efficiency of transmission gratings is by embedding silica gratings into a high refractive index material. During this study, the TiO_2/Al_2O_3 nanolaminate has been applied to functionalize a binary-fused silica grating for highly efficient transmittance gratings between 1000-1060 nm wavelengths which are designed for TM or TE-polarized light. Figure 3 depicts a FIB-cut SEM cross-section image of an embedded grating designed for TM-polarized light. The nanolaminate's fine structure can be viewed in the cross-section image, and proves that a pinhole-free embedment is possible via ALD. This is essential due to the fact that even tiny air pockets will drastically reduce the grating's efficiency. The transmission efficiency at the -1st diffraction order is 95% at the 1030 nm wavelength, being confirmed using RCWA simulations with the real grating parameter. The grating's period of 543 nm is nearly half of the incident wavelength for very high dispersion of fs-pulses using the chirped pulse amplification method (CPA).



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ANDREAS TÜNNERMANN

PROFESSOR OF APPLIED PHYSICS, INSTITUTE OF APPLIED PHYSICS

Prof. Tünnermann is the director of the Institute of Applied Physics, and the Fraunhofer IOF. He is a member of the board of directors of the Helmholtz Institute in Jena and of the Abbe Center of Photonics. Andreas Tünnermann has been distinguished with many prizes and awards, among them the Gottfried Wilhelm Leibniz Award of the DFG, the Schott Award of the Carl-Zeiss-Stiftung, the Leibinger-Innovation award of Trumpf Laser, the Lothar-Späth-Award, and the Thuringian Order of Merit. In 2015 he was awarded with a prestigious European Research Council (ERC) Advanced Grant for boosting novel concepts of fiber lasers. Since 2019, he is the spokesperson of the national Max Planck School of Photonics.

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RESEARCH AREAS

Andreas Tünnermann is leading one of the most creative research groups in modern optics and photonics world-wide. His main research interests include scientific and technological aspects associated with the tailoring of light. Research topics are the design and manufacturing of novel photonic devices and their application for light generation, amplification, guiding and switching, including:

- Functional optical surfaces and coatings
- Micro-, nano- and quantum optics
- Optical fibers, waveguides, and fiber lasers
- Imaging and projection systems

TEACHING FIELDS

Prof. Tünnermann teaches students in the courses B.Sc. Physics, M.Sc. Physics and M.Sc. Photonics. He offers lectures in:

- Atomic and molecular physics
- Laser and ultra-short physics
- Structure of matter

RESEARCH METHODS

The laboratories of the Institute of Applied Physics and of the Fraunhofer IOF offer world-unique facilities, including the following to name only a few:

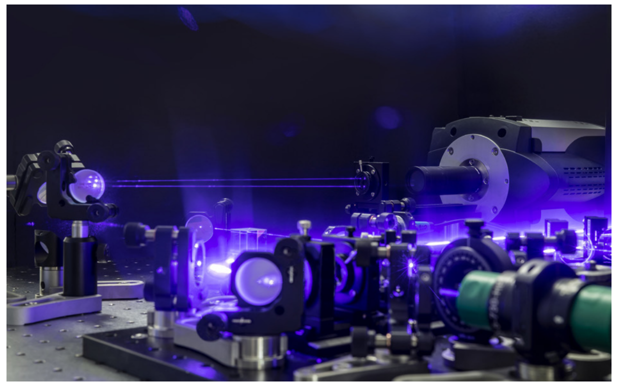
- 1.115 m^2 class 10,000 to 10 clean room area
- Electron beam lithography (Vistec SB350) and related nanostructure technology
- Ultra-precise diamond tools for 3D pattern generation
- Glass chemistry and fiber drawing tower

RECENT RESEARCH RESULTS

The Institute of Applied Physics headed by Andreas Tünnermann carries out fundamental and applied research in the fields of micro-, nano- and quantum optics, as well as fiber- and waveguide engineering. It develops novel optical materials, elements and concepts for information and communication technology, process technology, life science and medicine, environment and enery, as well as material processing and optical measurement techniques.

Current research topics - dealt with by over 150 scientists - concern function, design and fabrication of micro-and nano-optical elements. Those are e.g. resonant nanometric structures, polarizers from IP to DUV range, 3D nano-structuring of crystals with ion beam and Atomic Layer Deposition of optical coatings. Also, light propagation and nonlinear light-matter interaction in e.g. photonic nanomaterials, including metamaterials, photonic crystals, as well as effective media, quantum phenomena and integrated quantum optics, application of photonic nanomaterials and advanced photonic concepts for astronomical instruments are investigated. Further research fields are the applications of femtosecond laser pulses, such as material processing and spectroscopic analyses, as well as micro- and nanostructuring, medical (laser) application and additive manufacturing usage of ultrashort laser pulses. For further aims, new concepts for solid-state lasers with focus on fiber laser technology are to be developed.

In addition, the employees of the Fraunhofer Institute for Applied Optics and Precision Engineering IOF conduct application-oriented research in the field of optical system technology for industry and as part of publicly funded joint projects. The various work groups represent the entire process chain from system design to the production of prototypes for optical, optomechanical and opto-electronic systems. Close cooperation with the Institute for Applied Physics within the Center of excellence in Photonics is of strategic importance in scientific projects as well as in training young scientists.



Quantum-based table-top demonstrator for cryptographically secure communication.

TECHNOLOGIES FOR APPLIED QUANTUM PHOTONICS

In recent years, Andreas Tünnermann's research groups have made significant contributions to establishing applied quantum photonics as a focus and beacon in development, research and teaching in Jena. These works can be seen in the light of the second quantum revolution and can already look back on important scientific and technological contributions, especially in the areas of quantum communication and quantum imaging. Understanding photonic technologies as an enabler for excellent fundamental research and a driver for breakthrough innovations is the backbone of this important strategic direction. Recent research highlights are the development of space-suitable sources for entangled photons, research work on scalable and space-suitable sources for single photons, the integration of quantum optical systems in waveguides and nano-optics as well as the demonstration of novel, highly sensitive imaging systems with exotic states of light. These results were backed by substantial support of different projects. These include the QuNET project, which implements quantum-encrypted connections, and also the project QUILT, in which quantum based imaging technologies are systematically developed.

ANDREY TURCHANIN

PROFESSOR OF PHYSICAL CHEMISTRY, FACULTY FOR CHEMISTRY AND EARTH SCIENCES

Professor Andrey Turchanin received his Ph.D. in Solid State Physics (1999) from the National University of Science and Technology in Moscow. In 2000, he was awarded a Humboldt Research Fellowship at the University of Karlsruhe (now KIT). In 2010 he completed his habilitation on„Novel phenomena and materials in two-dimensional (2D) inorganic and organic systems" at the University of Bielefeld. In 2012, Prof. Turchanin was awarded a Heisenberg Fellowship from the DFG, and in 2013 the Bernhard-Heß-Prize from the University of Regensburg for his research achievements in the field of emerging 2D materials. Since 2014, Prof. Turchanin is leading the Group of Applied Physical Chemistry and Molecular Nanotechnology at the Institute of Physical Chemistry of the Friedrich Schiller University Jena. In 2017, Prof. Turchanin was elected to the board of directors of the Center of Energy and Environmental Chemistry Jena (CEEC Jena); and since 2018 he is chairman of the Thuringia MiT-Group "2D Materials" and editor of the IOP "Journal of Physics: Materials".

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RESEARCH AREAS

Professor Turchanin's research interests are focused on the following topics:

- Tailored growth of 2D materials (e.g., graphene, TMDs)
- Molecular self-assembly and molecular nanosheets
- Electron irradiation induced materials synthesis
- Stimuli-responsive surfaces and interfaces
- Nanolithography and microfabrication
- Nanoelectronic and nanophotonic devices
- Chemical and biological sensors
- Energy storage and energy conversion devices
- Advanced characterization tools
- Surface science
- Nanolithography and microfabrication

TEACHING FIELDS

Professor Turchanin gives courses in:

- Basic physical chemistry
- Molecular nanotechnology and nanobiotechnology

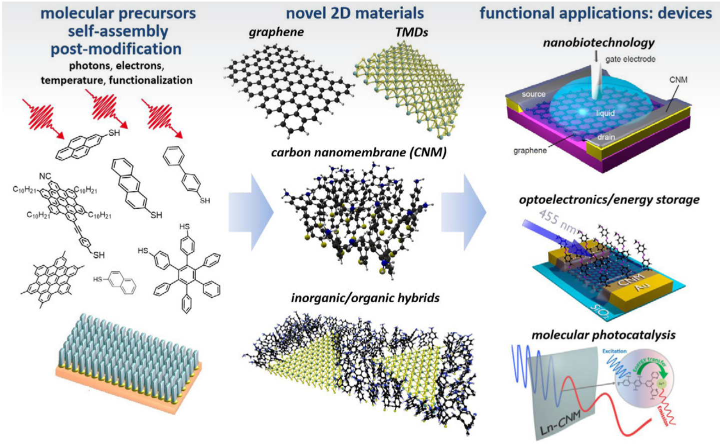
RESEARCH METHODS

In the Turchanin's lab as well as in collaboration with partners the following techniques and methods are employed:

- Photoelectron and Auger spectroscopy (XPS/UPS, AES), Raman spectroscopy, polarisation modulation infrared reflection absorption spectroscopy (PM-IRRAS), second harmonic generation (SHG), surface plasmon resonance (SPR) measurements
- Scanning probe microscopy (STM/AFM), scanning/transmission electron microscopy (SEM/TEM), helium ion microscopy (HIM), optical microscopy
- Low energy electron diffraction (LEED)
- Extreme UV interference lithography (EUV-IL), electron beam lithography (EBL), photolithography
- Electric and optoelectronic transport measurements

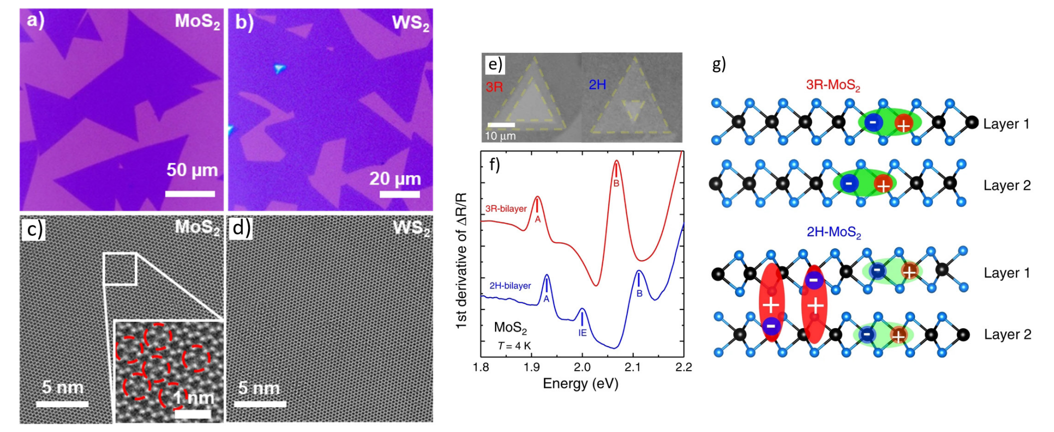
RECENT RESEARCH RESULTS

Andrey Turchanin's current research activities are focused on 2D materials (graphene, transition metal dichalcogenides, molecular nanomembranes, organic monolayers) and their hybrids with other low-dimensional materials for basic studies and novel applications in nanoelectronics, nanophotonics, nanobiotechnology, sensors as well as energy storage/conversion, see Figure 1. These interdisciplinary activities embrace (i) tailored materials synthesis [1-2], (ii) in depth characterization by spectroscopy and microscopy methods down to the nanoscale [3-4], (iii) nanolithography and microfabrication [5-6], (iv) studying of fundamental electronic, optic and optoelectronic properties [7-8], (v) implementation of 2D materials in devices, stimuli-responsive surfaces and interfaces [9-10].



ADVANCED CHEMICAL VAPOR DEPOSITION (CVD) GROWTH OF TRANSITION METAL DICHALCOGENIDE MONOLAYERS (TMDS) FOR STUDYING NOVEL ELECTRONIC AND PHOTONIC PHENOMENA, AND APPLICATIONS

Turchanin's group has recently developed an advanced method for the CVD growth from solid state precursors of large area TMD monolayers (e.g., MoS_2, WS_2, $MoSe_2$, WSe_2, etc.) on various substrates such as SiO_2/Si and sapphire wafers [11], Figure 2a-d. The resulting CVD grown monolayers possess high structural, optical and electronic properties which are comparable to the monolayers obtained by mechanical exfoliation of the TMD bulk crystals [12]. The development methodology significantly facilitates implementation of TMD monolayers in studies of novel physical phenomena, such as, e.g., properties of the interlayer excitons in van der Waals heterostructures of 2D materials (see Figure 2e-g) [8], engineering of novel photonic metasurfaces [13], non-linear optical elements [10, 14], field-effect transistors [11, 15] and functional nanostructures [14, 16].



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LOTHAR WONDRACZEK

PROFESSOR OF GLASS CHEMISTRY, OTTO-SCHOTT-INSTITUTE

Professor Wondraczek is Chair of Glass Chemistry II at the Otto Schott Institute of Materials and Research (OSIM) and coordinates the priority program 1594 of the German Research Foundation (DFG). He is Chair of the committees Glass Transition of the International Commission on Glass (ICG) and Glasses and Optical Materials of the Germany Society of Materials Research, and is also council member of the German Society of Glass Science and Technology.

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RESEARCH AREAS

Prof. Wondraczek's research activities span all areas of experimental glass science with particular focus on the exploration and development of new glass and glass ceramic compositions and surface modification techniques. His main thrusts are the optical and mechanical properties of multi-component oxide, oxynitride and oxyhalide materials. He is exploring structure-property relations with the ultimate objective of providing topology-based tools for the description of non-crystalline solids. Research interests include:

- Glasses for applications in optics and energy technologies
- Photoluminescence, magneto-optical materials, and fiber optics
- Relaxation processes in complex systems

TEACHING FIELDS

Prof. Wondraczek teaches interdisciplinary materials science where he connects materials engineering, physics and chemistry.

He gives courses in:

- Solid state kinetics and thermodynamics
- Composite and nanocomposite materials
- Glasses and optical materials

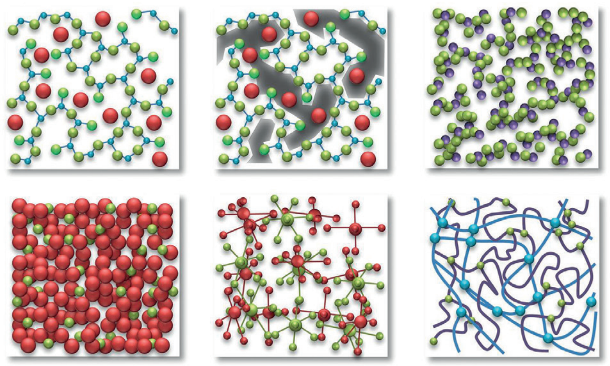
RESEARCH METHODS

The laboratories led by Prof. Wondraczek offer state-of-the-art equipment for the fabrication and experimental characterization of glasses and other optical materials, including:

- Extensive glass melting capabilities
- High resolution static and dynamic luminescence spectroscopy, Raman and FTIR spectroscopy
- Advanced high-temperature processing (< 2200 °C), including nitridation and hydration
- Extensive thermoanalytics, including STA-MS, DSC, DTA, TGA, HP-TGA, DDSC
- Extensive nanomechanical testing, including indentation, nano-scratching, nano-bending, lateral nanotesting and tribological analyses

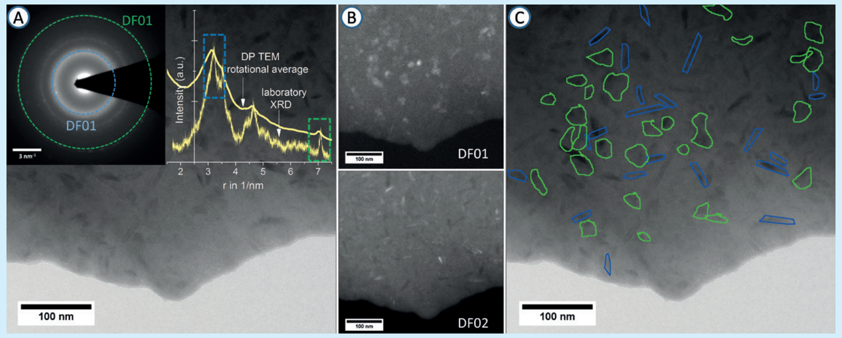
RECENT RESEARCH RESULTS

The primary mission of Prof. Wondraczek's team is to explore topology-based tools for the design of new inorganic glasses, glass ceramics and surface modification techniques. Thereby, the term topological engineering refers to a bottom-up approach of acquiring and applying knowledge of the short- and mid-range structural architecture to derive tools for materials design. Such tools are, e.g., potentials and spatial relations between constituents at the atomistic level [1, 2], the generic design of specific short- and mid-range topology, packing density, molecular interactions occurring at surfaces and their consequences on meso- and macro-scale processes. These tools are aimed at targeting material applications in the fields of optics and photonics, as well as in energy technologies, architecture and for the automotive industry. Specifically, we are exploring and developing strategies with the goal of attaining glassy materials with superior mechanical resistance [1], optical fiber glasses and magneto-optical glasses [2, 4] and glasses for light conversion purposes [5]. At present, optical amplification for broadband telecommunication and new fiber lasers, solar spectral conversion for improved harvesting of sunlight and inorganic materials for transient optical storage via spectral hole burning techniques represent the thrusts of the group's activities in optics.



ULTRABROAD LUMINESCENCE FROM NI^{2+}-DOPED GLASS CERAMICS

Nanocrystalline Ba-Al titanate precipitates from supercooled TiO_2-BaO-SiO_2-Al_2O_3 melts via catalyzed volume nucleation in the presence of Ni^{2+}, forming a $BaAl_2Ti_6O_{16}$ hollandite-type lattice. Ni^{2+}-species are incorporated into the crystalline environment in octahedral co-ordination. Hollandite formation is accompanied by precipitation of tetrahedrally distorted $BaTiO_3$ as a secondary crystal phase, where crystal species and habitus can be clearly distinguished by dark-field transmission electron microscopy. The resulting photoluminescence due to spin-allowed relaxation of $^3T_{2g}(^3F)$ to $^3A_{2g}(^3F)$ in $^{VI}Ni^{2+}$ occurs from three distinct emission centers. Photoemission spans the spectral range of 1.0 to 1.6 µm. Besides red and IR laser excitation, NIR photoemission can be excited with conventional near UV light sources, i.e. in the spectral range of 350-420 nm. Decay kinetics as well as the position and shape of the emission band can be adjusted by dopant concentration and synthesis conditions [5].



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MATTHEW ZEPF

PROFESSOR FOR HIGH FIELD PHYSICS AND LASER PARTICLE ACCELERATORS

Prof. Zepf is a director of the Helmholtz Institute Jena and head of the Research Group for High Field Physics and Laser Acceleration at the University of Jena. He is a member of the Royal Irish Academy and serves on several scientific advisory committees at major international laser facilities.

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RESEARCH AREAS

Prof. Zepf's research focuses on the applications of ultra-intense lasers to applications and fundamental science. Particular areas of interest are

- The development of laser driven and plasma based particle accelerators
- Testing high field QED with ultra-intense lasers
- Development and operation of high-power lasers
- Ultrafast radiation sources

RESEARCH METHODS

In Prof. Zepf's group, research is conducted using a wide range of advanced methods are applied and developed for application in high power laser science.

- The development and operation of multi-100TW lasers and their diagnostics
- Numerical simulations of plasmas
- Ultrafast optical and X-ray probe pulses
- Particle detector development

TEACHING FIELDS

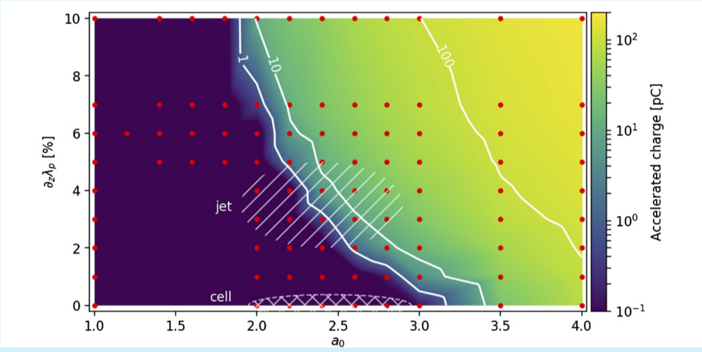
Professor Zepf teaches High Field Laser Science, Plasma Physics and Specialist courses on Plasma Driven Radiation Sources. Bachelor and Master's degree topics are available both experimentally and numerically.

RECENT RESEARCH RESULTS

Prof. Zepf's Group has made notable achievements across the areas of high field physics and particle acceleration. Recent successes are important steps to achieving controlled injection in laser driven electron accelerators [1], where femtosecond probing elucidated the role of microscopic turbulence in the gaseous media on so-called self-injection. The ability to generate such electron beams with high power lasers allows the fundamental dynamics of electrons in electromagnetic fields to be tested with first results in the so-called radiation reaction regime demonstrated using the Astra Gemini laser in the UK [2, 3]. This work is currently continuing with collaborations based at the the Stanford Linear Accelerator, XFEL in Hamburg and a DFG consortium including CALA in Munich. Since our seminal work at the outset of laser driven proton and hadron accelerator research [4] we have developed new concepts [5] and continued to advance the field [6]. These particle radiation sources are complemented by research into intense X-ray and XUV sources exploiting the unique physical regimes accessible with ultra intese lasers [7], [8].

CONTROLLING MM-SCALE ELECTRON ACCELERATORS

Controlling the parameters of a laser plasma accelerated electron beam is a topic of intense research with a particular focus placed on controlling the injection phase of electrons into the accelerating structure from the background plasma. An essential prerequisite for high-quality beams is controlled acceleration (i.e., no electrons accelerated beyond those deliberately chosen to be accelerated). We show that small-scale density ripplesin the background plasma are sufficient to cause the uncontrolled (self-)injection of electrons. Background free injection with substantially improved beam characteristics is demonstrated in a gas cell designed for a controlled gas flow. The image shows the experimentally and numerically derived regions of operation for laser driven accelerators with the self-injected charge being a function of microscopic turbulence (vertical axis) and laser strength (horizontal axis).



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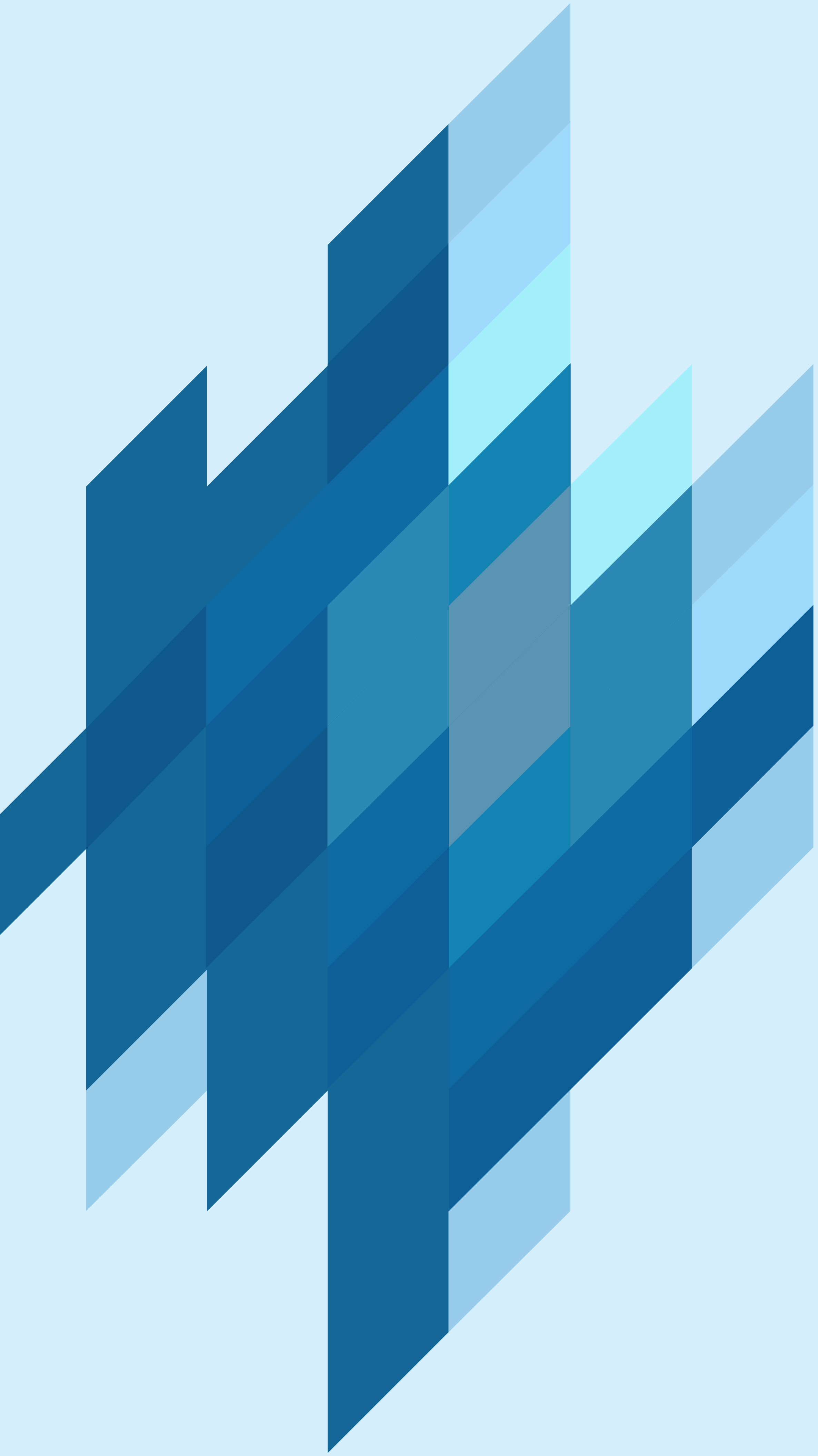

Abbe Center of Photonics | JENA
Friedrich-Schiller-Universität

Imprint

Fifth edition (2024)

Editor
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Dr. Christian Helgert
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Editorial deadline
15.01.2024

Graphic design
timespin
Digital Communication GmbH
Sophienstraße 1
D-07743 Jena, Germany
www.timespin.de

Photo acknowledgements
Page 15, 23: Christoph Worsch
Page 18: Fraunhofer IOF, Leibniz IPHT
Page 21: David Zakoth
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