FAU

Friedrich-Alexander-Universität
Erlangen-Nürnberg

Photonics Research in Erlangen

Spotlights

Erlangen Graduate School in
Advanced Optical Technologies
(SAOT)

SAOT

Forewords

Ideas develop best in a climate of openness – this also applies in the world of research. The Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU) respects the cultures of all individual subjects and research is valued equally whether carried out independently or collaboratively. In-depth research and research networks that are initiated via interdisciplinary institutions and programs are particularly welcome. FAU has developed eight interdisciplinary Key Research Priorities that allow researchers to consolidate their expertise, exchange ideas, and form strong research synergies. Each FAU Key Research Priority connects intensive research, academic excellence, international networks, and funding secured for a wide range of projects.

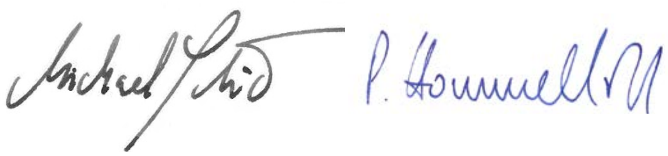
By means of this brochure, we would like to introduce you to **Photonics Research in Erlangen**, which is closely related with, but not limited to, FAU's **Key Research Priority "Optics and Optical Technologies"**. The information is aimed at any person interested in optics and photonics, especially students who are looking for exciting subjects and researchers who would like to get an overview of our academic portfolio. I hope you will enjoy reading this brochure and that it can draw your attention to the innovative activities carried out in the dynamically developing Nürnberg Metropolitan Region. It would be a special pleasure for us to welcome you personally in Erlangen – the place of cutting-edge Photonics Research.

Prof. Joachim Hornegger
President of FAU

The interaction of light and matter is of **outstanding importance** regarding an extensive variety of phenomena in our world. Light allowed life on earth to develop from the very beginning. It allows us to see our world and to perceive the beauty of our planet and beyond. It had also allowed the ongoing technological progress in a multitude of disciplines. For many centuries, our curiosity has been the driving force behind the development of systems which expand the capabilities of our naked eye and harness the benefits of light-matter interaction.

Today, **optical technologies**, also called **photonics**, are considered as a **key technological area** for energy, industry and medicine in the decades to come. Fundamental research in classical optics and quantum optics forms the essential basis. Beyond these fundamentals, the Key Research Priority "Optics and Optical Technologies" at FAU opens new opportunities in teaching and education. We hope to encourage the brightest minds to become leaders in photonics and help shape our future world.

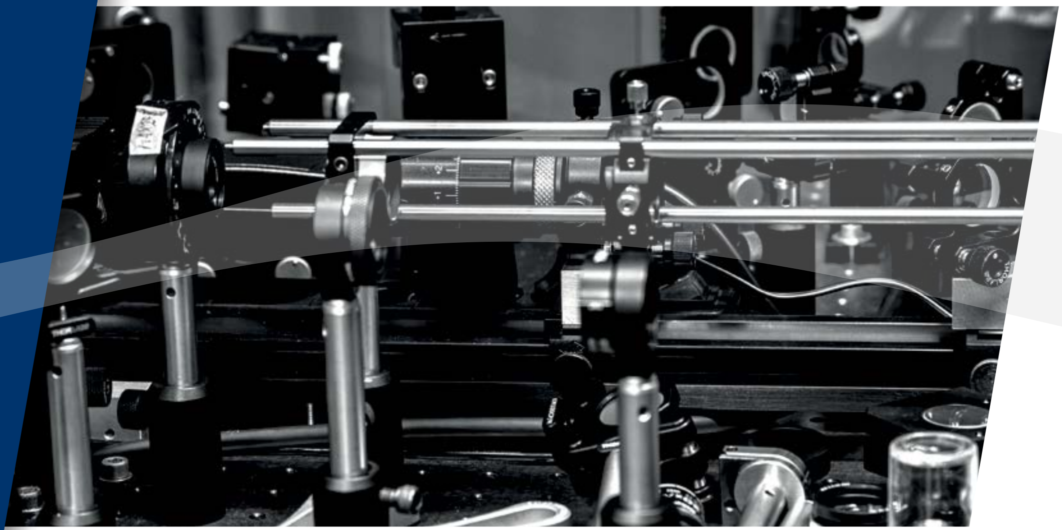
In this brochure, we would like to present you a diverse selection of research topics and the investigators developing **innovative technology and algorithms** in Erlangen. Furthermore, we will introduce you to the associated research institutions and study programs.



Prof. Michael Schmidt and Prof. Peter Hommelhoff
Speakers for the Key Research Priority „Optics and Optical Technologies" at FAU

Michael Schmidt is an expert in processing matter with light. He is working on shaping light for and through processing material. He is the Coordinator of SAOT and vice spokesman of CRC814.

Peter Hommelhoff's research centers on attosecond imaging of electron dynamics inside and at the surface of solids, on quantum-enhanced electron microscopy and on nanophotonics-based particle acceleration.



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SAOT erlangen graduate school in advanced optical technologies

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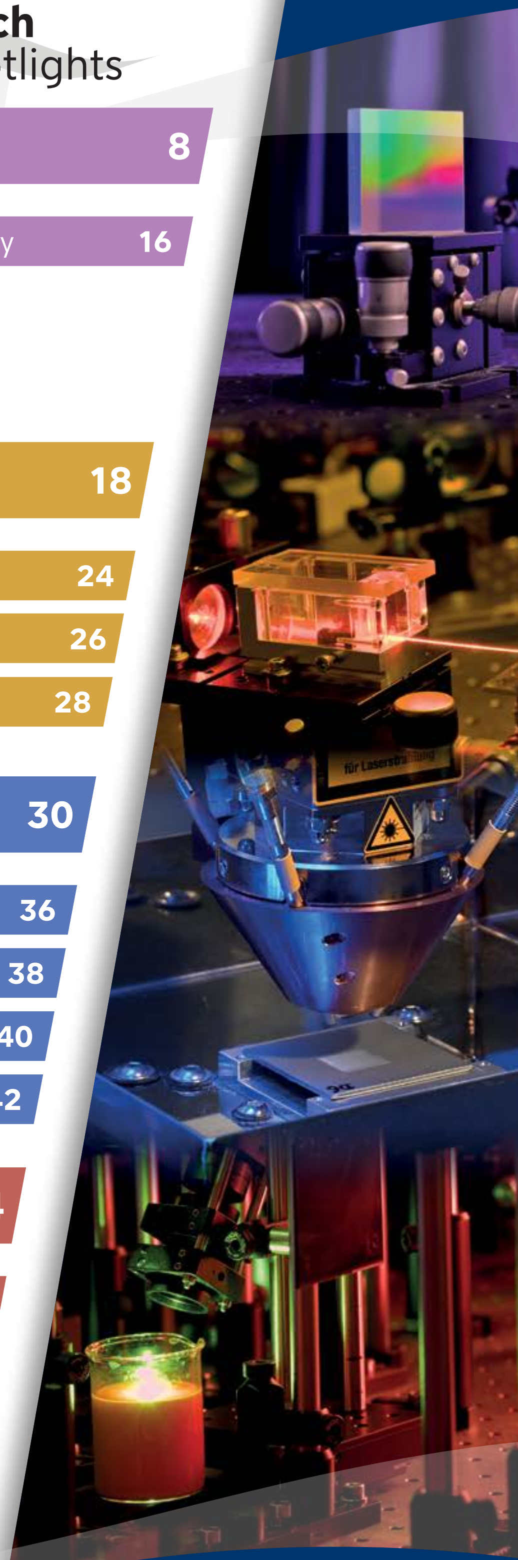
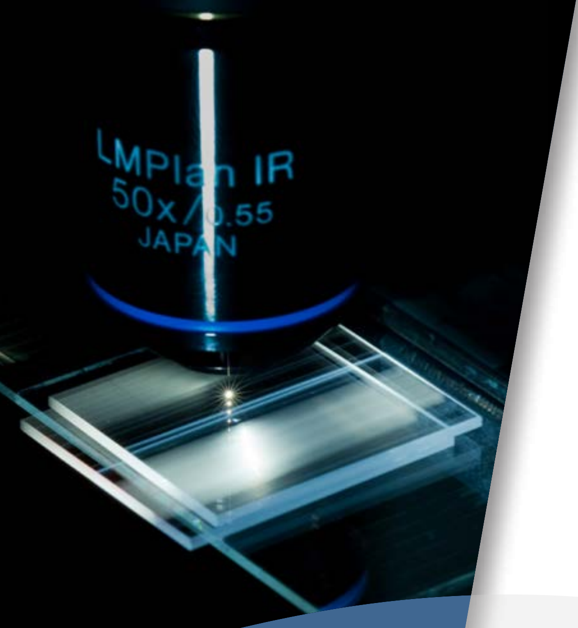




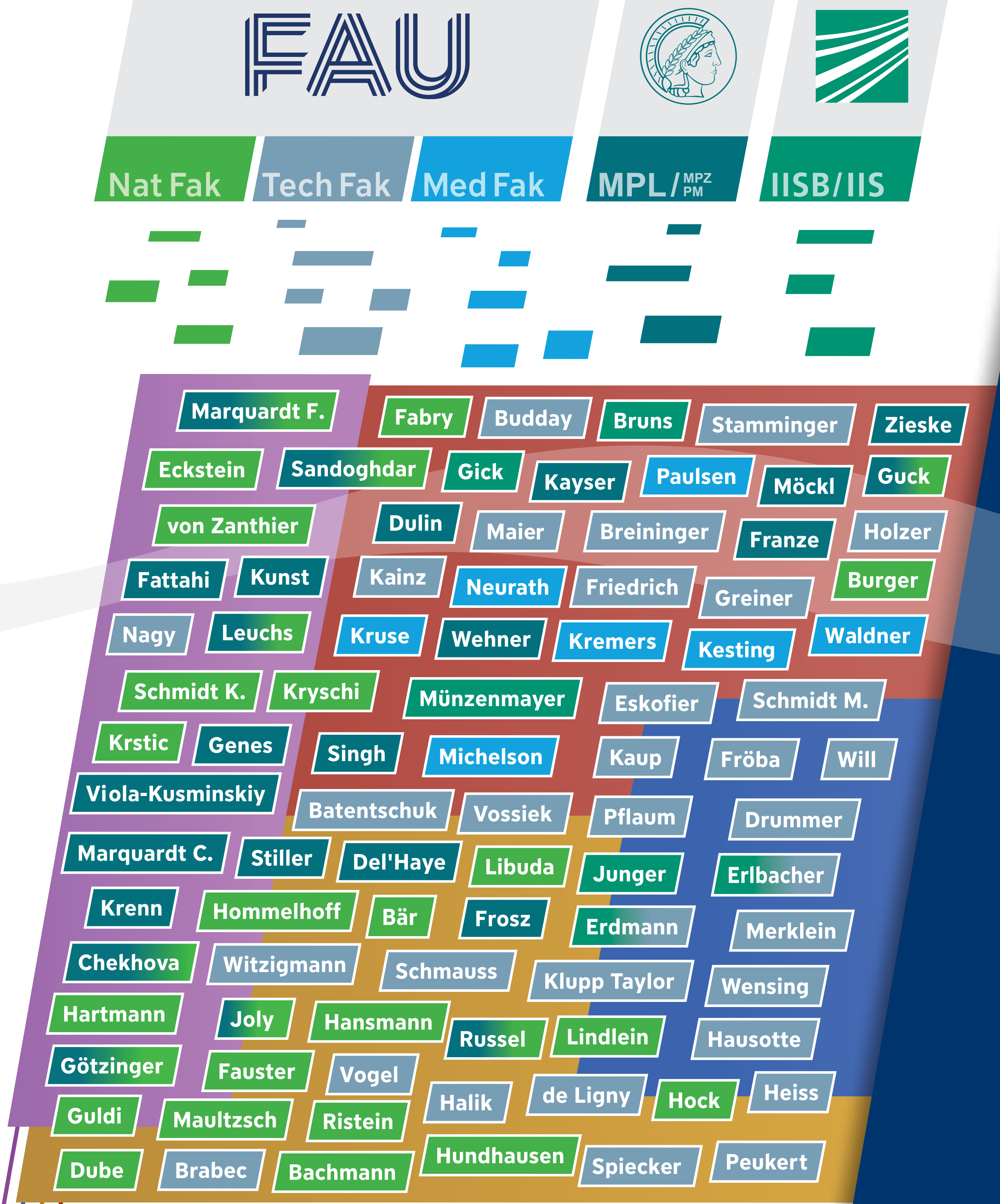
> *Photonics is the science of the harnessing of light. Photonics encompasses the generation of light, the detection of light, the management of light through guidance, manipulation, and amplification, and most importantly, its utilization for the benefit of mankind.*
>
> **Pierre Aigrain** · French physicist · 1924 – 2002

Today, there are about **90 groups** and principal investigators in Erlangen whose research focus is connected to photonics and optical technologies. With about two thirds of that, **Friedrich-Alexander-Universität Erlangen-Nürnberg** accounts for the largest share, consisting of scientists from the **Faculty of Sciences** (NatFak), the **Faculty of Engineering** (TechFak), and the **Faculty of Medicine** (MedFak). Current activities at FAU span from fundamental research on photonics and optical technologies to cutting-edge applications in both the academic and the industrial context. Scientific questions are addressed by sophisticated experimental setups and measurement techniques as well as by state-of-the-art data processing algorithms, theoretical calculations and simulations.

In addition, research conducted at the **Max Planck Institute for the Science of Light** (MPL) and the **Max-Planck-Zentrum für Physik und Medizin** (MPZPM) includes biological optomechanics, photonic crystal fibers, nano-optics, optics and information as well as theory of quantum optics. These activities are complemented by research groups from the **Fraunhofer Institute for Integrated Circuits** (IIS) as well as the **Fraunhofer Institute for Integrated Systems and Device Technology** (IISB).

This diverse research on photonics in Erlangen can be classified into four main fields:

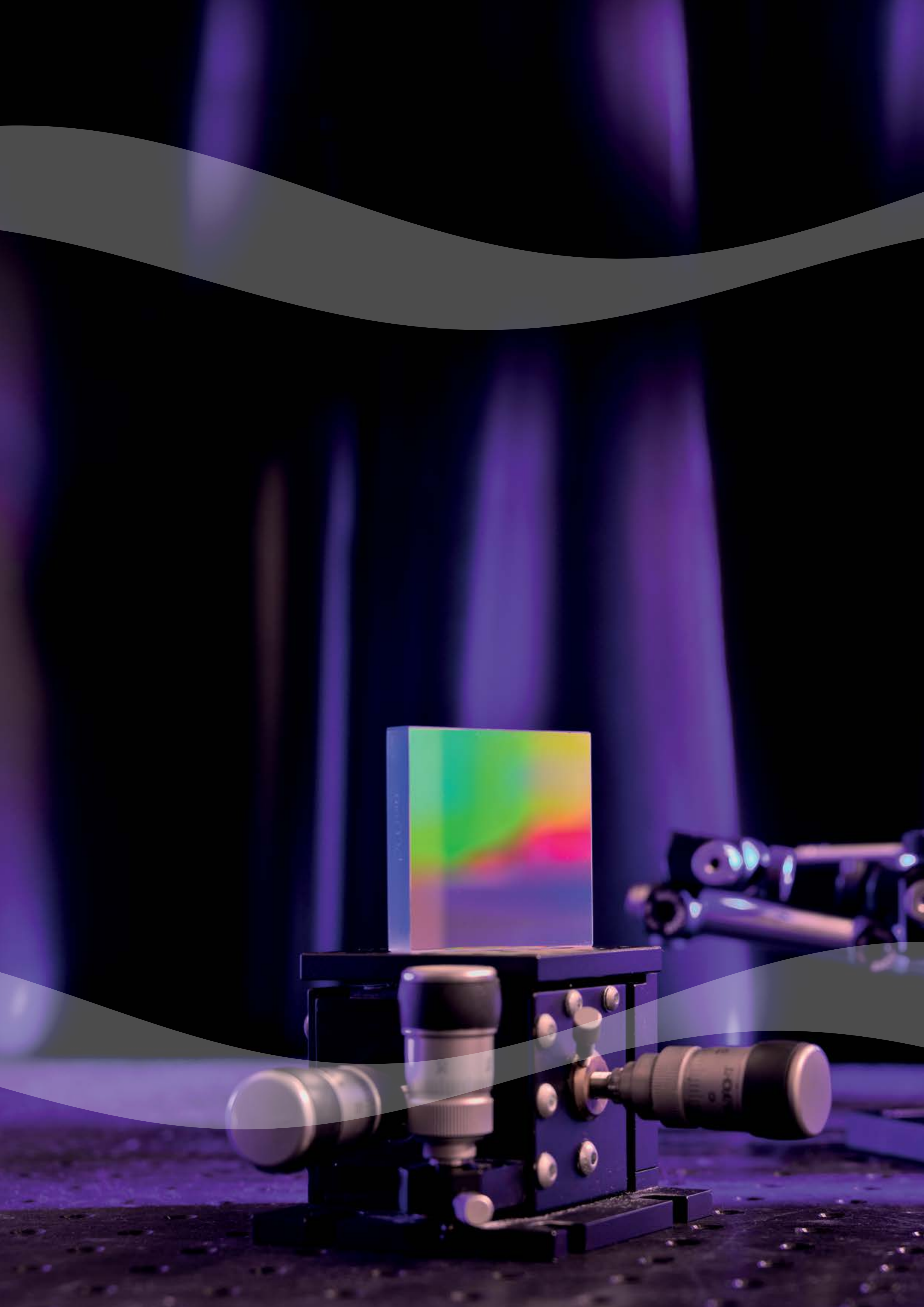
- Quantum Optics and Ultrafast Dynamics
- Photonics in Production and Process Technology
- Photonic Fibers, Materials and Devices
- Biomedical Photonics and Data Processing



An assignment of the research groups to the four main fields is shown in the scheme above. As can be seen, several interdisciplinary groups show overlap into multiple fields to a certain extent. A digital reference to an **up-to-date listing of all involved investigators and their main topics** is available online.

To give an insight into photonics research in Erlangen, selected **research topics and scientists are spotlighted** in this brochure, thematically ordered and color coded by the respective main field. In addition, information on **graduate schools, further participating institutions**, and **latest publications** on photonics is provided.

Online Edition



Quantum Optics **and** Ultrafast Dynamics

The discovery of the quantum nature of light more than 100 years ago represented a paradigmatic change in physics. The fact that light is not only a wave but also has particle properties clarified the physics of unexplained phenomena such as the photoelectric effect and blackbody radiation. This discovery marked the birth of quantum mechanics and served as a basis for innumerable technologies reaching into our everyday life of today, including computers, smartphones, lasers, and much more. The quantized light particles are called photons. Quantum features of photons often are counter-intuitive, but all the more exciting. More than 20 groups from Erlangen work on a deeper understanding and novel application concepts of quantum optics and ultrafast processes. With nano-scale optics and attosecond light-matter interaction, research on quantum optics in Erlangen is at the edge of space and time limits.

Scientist Spotlight

"I am really amazed by the interdisciplinary scientific environment in Erlangen"

Hanieh Fattahi

Research Group

Hanieh Fattahi received her PhD in Physics at Ludwig-Maximilians-Universität München. After graduation in 2016, she received the Minerva fast-track scholarship of the Max Planck Society, which allowed her to establish a research group within the chair of Prof. Ferenc Krausz at Max Planck Institute of Quantum Optics. Her research in Munich has been focused on synthesis of intense controlled waveforms of laser light, design and development of ytterbium thin-disk lasers and optical parametric amplifiers. She has also been a visiting scientist at the Chemistry department of Harvard University and University of Oxford, where she investigated various label-free microscopy techniques to study soft matter. Since 2020, she is leading an independent research group at Max Planck Institute for the Science of Light in Erlangen. She is also affiliated to FAU, Max Planck center for Extreme and Quantum Photonics in Ottawa, and Max Planck School of Photonics.

Latest Publications

Her latest publications cover nonlinear laser pulse compression down to a few femtoseconds as well as broadband multi-octave terahertz pulses.

What are the future questions you are working on and what are the particular challenges?

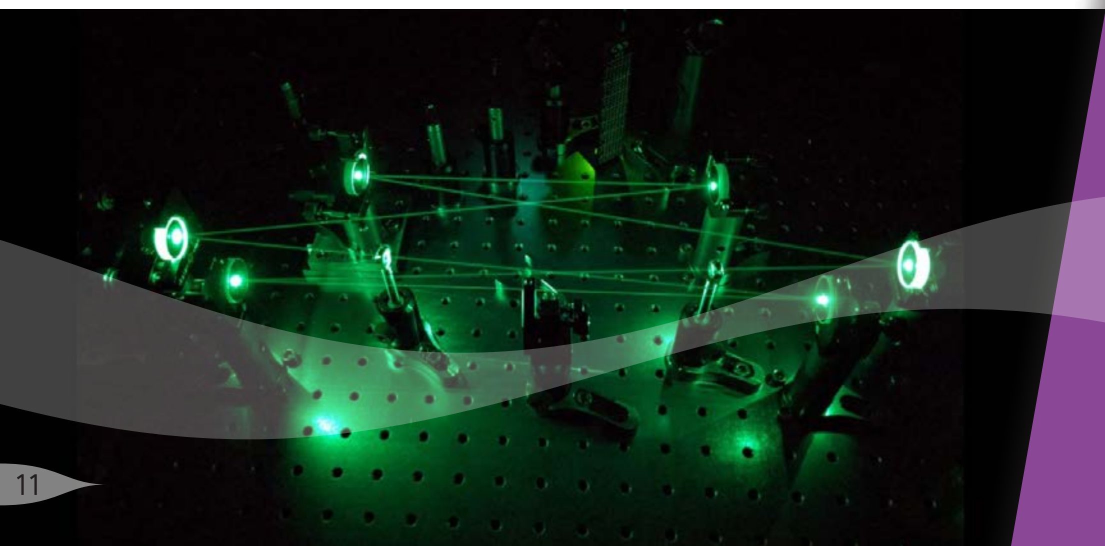
Our group has expertise in the generation of bright ultrashort pulses at various spectral ranges, and the development of highly sensitive detection metrologies. Equipped with these unique tools, we are exploring the application of ultrafast physics in: i) high-resolution label-free spectro-microscopy of molecules in soft matter; ii) monitoring and detection of climate-related atmospheric gases at short wavelength and in the mid-infrared spectral range with superb sensitivity iii) establishing a link between strong-field physics and solotronics as they are of great interest for quantum technology but still require considerable additional fundamental study.

What do you particularly appreciate about Erlangen as a research location?

I am really amazed by the interdisciplinary scientific environment in Erlangen and most importantly how scientists are keen to collaborate. The existing unique facilities available at the university and the research institutes here are also very special and has allowed my group to have access to unique samples for research, from unique optical fibers and nanostructure to biological samples. Moreover, Erlangen is a university town, with excellent students, which is the pre-requisite for the success of any research project.

What advice can you give to young people who are interested in studying optics-related subjects in Erlangen?

Learn the basics of optics and photonics well! As it is very well said in Germany: the devil is in the details. Also, for those students, who are interested in experimental physics, I highly recommend them to experience the laboratory work in the frame of small projects, or HiWi positions, before starting their BSc or MSc project. This also helps to better understand the fundamentals.



Scientist Spotlight

Erlangen - a melting pot for new ideas!

Joachim von Zanthier

Research Group

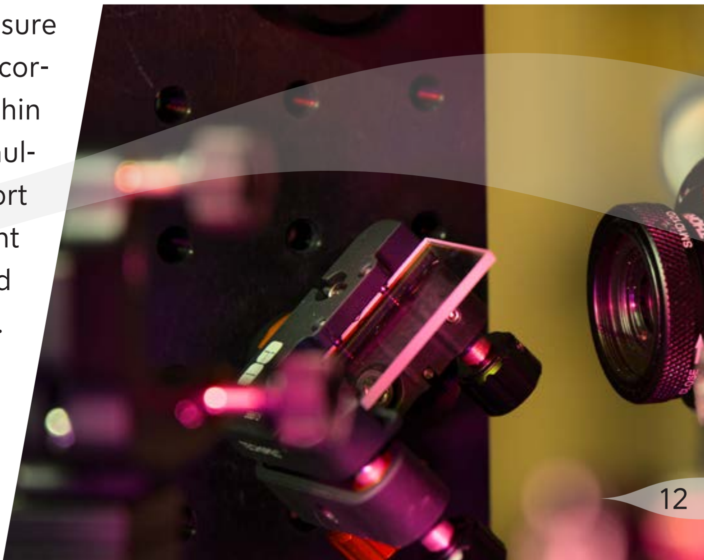
Joachim von Zanthier leads the group Quantum Optics and Quantum Information at the Physics Department of FAU. His group investigates multi-photon states, fragile states of light which carry additional information about the emitting sample. Multi-photon interferences can be used, for example, to image a light source with higher resolution than a common microscope. The technique is versatile so that it can be employed in, e.g., microscopy, astronomy, as well as x-ray structure analysis.
The group also uses multi-photon interferences to transfer the light emitting atoms into particular quantum states, for testing the foundations of quantum mechanics or for quantum information science.

Latest Publications

His latest publications include quantum interference with many-particle states and different types of quantum coherence in dipole radiation.

What are the future questions you are working on and what are the particular challenges?

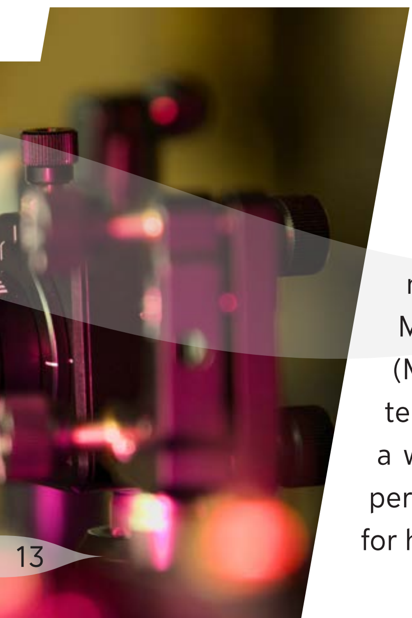
Presently, we push the technique to measure multi-photon interferences to the limit, recording for example photons coincidentally within a few picoseconds. This is needed because multi-photon states mostly live only for very short times. We also investigate the collective light emission of many atoms brought into entangled quantum states via multi-photon interferences. This is explored, amongst others, within the newly established Collaborative Research Center *Quantum Cooperativity of Light and Matter* (QuCoLiMa).



What do you particularly appreciate about Erlangen as a research location?

The conditions for doing research in Erlangen are very favorable. One the one hand, there is the large Physics Department covering a broad range of topics, a melting pot for new ideas. On the other hand, I see in Erlangen a particular openness for activities across borders to other departments and faculties, what is particularly advantageous for interdisciplinary cooperations.

What advice can you give to young people who are interested in studying optics-related subjects in Erlangen?



Erlangen is one of the largest centers for optics-related research and study programs in Germany. Optics and quantum optics is one out of three research foci of the Physics Department. At the same time, it is central to the master's program of Advanced Optical Technologies (MAOT) and the research focus of the Max Planck Institute for the Science of Light (MPL). There are four graduate schools devoted to optics related subjects. Thus, there is a wide range of options and it is up to each person to choose the most suitable program for his or her studies.

"Keep your eyes open to novelty"

Maria Chekhova

Research Group

Maria Chekhova obtained her PhD at the Lomonosov University Moscow in 1989, for a work on polariton spectroscopy, and stayed there as a researcher and a group leader. Her habilitation thesis in 2004 dealt with the polarization and spectral properties of two-photon light. From 1997 to 2009, she worked as a visiting professor at the University of Maryland (USA) and in the Metrology Institute (Turin, Italy). Since 2009 she leads an independent research group at the Max Planck Institute for the Science of Light (MPL) and since 2020, she also holds a part-time professor position at FAU. Her list of publications includes more than 200 scientific papers and a book. Since 2021, she is a fellow of Optica. She leads several European and German scientific projects, collaborating with researchers in France, Israel, Czech Republic, Denmark, USA, and Singapore.

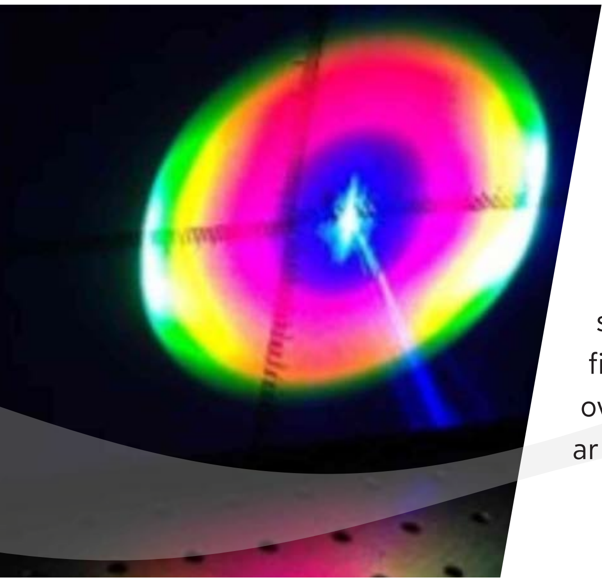
Her central research topic is the generation and application of quantum light, with a special focus on bright light that shows quantum behavior. She is also actively working on pairs of entangled photons generated through different nonlinear effects, mainly spontaneous parametric down-conversion and four-wave mixing. Her recent works also address nanoscale quantum nonlinear optics, including the generation of entangled photons in subwavelength layers and 2D arrangements of nano-particles, called metasurfaces.

Latest Publications

Her recent publications include biphotons generated by a metasurface and overcoming detection loss and noise in sub-shot noise quantum metrology and sensing.

The first experimental work pioneered spontaneous parametric down-conversion in a metasurface, providing two orders of magnitude enhancement compared to an unstructured film of the same material. The second one demonstrated that squeezing, a powerful but fragile quantum resource, can be used much more effectively if parametric amplification is applied prior to the detection.

What are the future questions you are working on and what are the particular challenges?



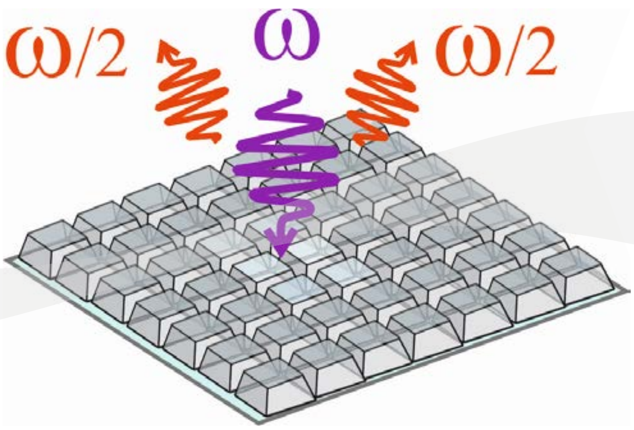
My most recent and most ambitious project is to develop nonlinear quantum optics at the nanoscale. This is part of the so-called 'flat-optics paradigm': passing from bulk optical elements to ultrathin - ultimately monoatomic - layers or metasurfaces. My goal is to make such ultra-thin sources produce quantum light: photon pairs and squeezed states. The main challenge is the low efficiency of these tiny sources. But we are going to overcome this problem by using strongly nonlinear materials and resonances.

What do you particularly appreciate about Erlangen as a research location?

Erlangen has perfect scientific infrastructure, involving FAU, MPL, and the facilities available at both institutions, among them fiber fabrication and nanostructuring. Absolutely fascinating is also the recent development of research at the boundary of optics and medicine, although I am so far not working in this field. For me, it is also very important that the city is small, so that it takes us very little time to get to the laboratories. And I enjoy walking and biking in the forests around Erlangen; it helps me to stay fit and in good mood.

What advice can you give to young people who are interested in studying optics-related subjects in Erlangen?

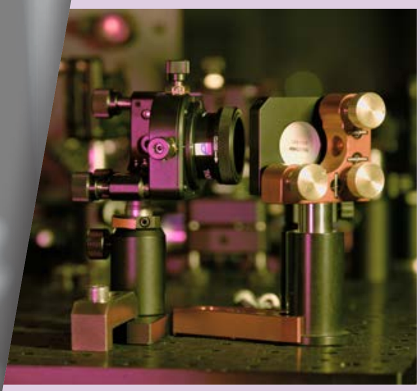
Keep your eyes open to novelty. You have a unique possibility to work and study at the cutting edge of photonics. Try to join an actively working group: whatever your background, if you are motivated and surrounded by motivated people, if you work hard and keep learning, you will succeed.



Quantum Technology

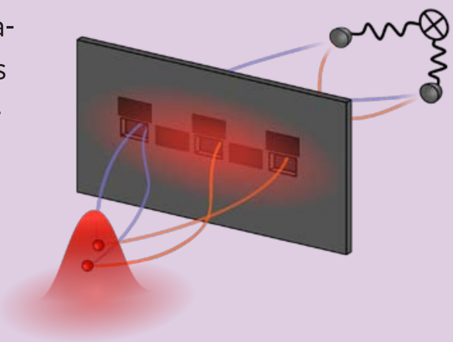
– by Joachim von Zanthier –

Optical quantum technologies will shape the 21st century and have a profound impact on technological and economic developments worldwide. They are used in quantum communication, but also in quantum metrology and quantum computing. In Erlangen, the Department of Physics at FAU and the Max Planck Institute for the Science of Light are primarily active in this field.

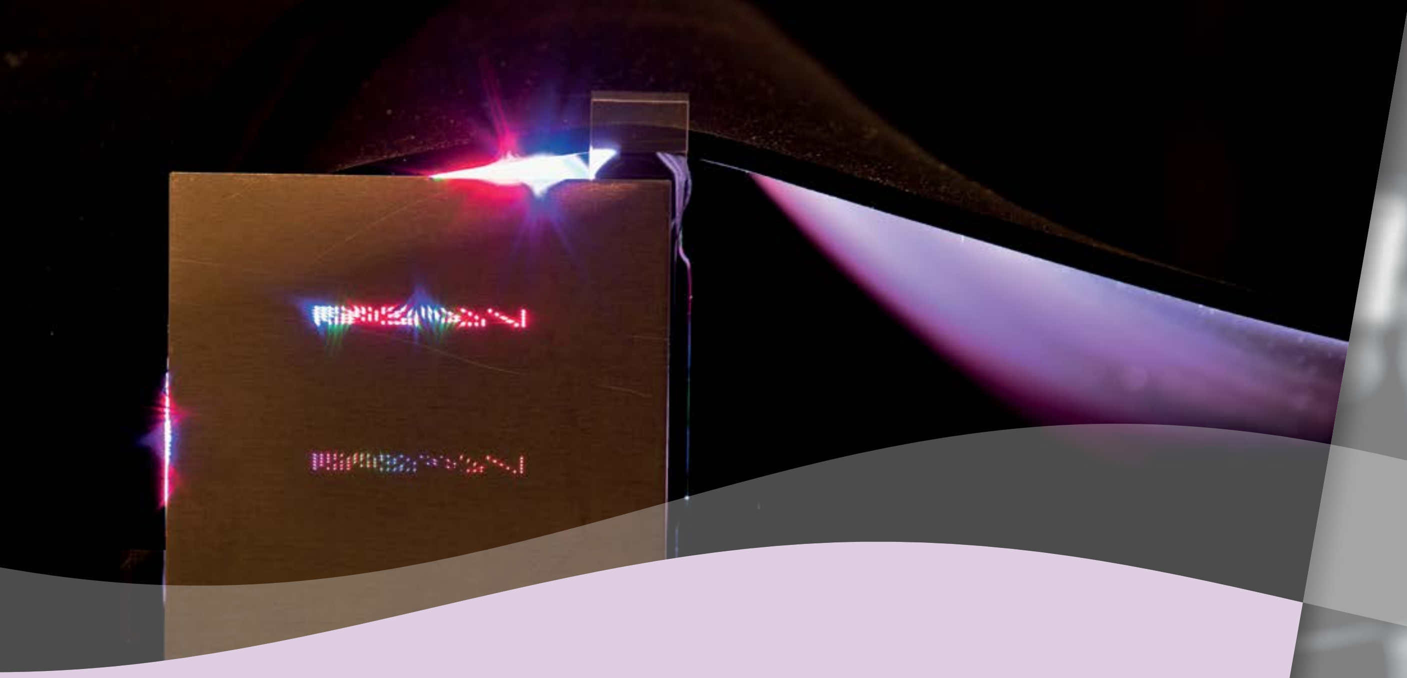


One focus is on **quantum communication**. Here, in recent years, the groups of Gerd Leuchs and Christoph Marquardt have set milestones, especially in the field of satellite-based quantum key distribution. While many researchers pursue quantum communication with single-photon detection, these groups were early to focus on quantum communication detecting the field of coherent laser light. In this way, quantum states could be studied for the first time emitted from a geostationary satellite.

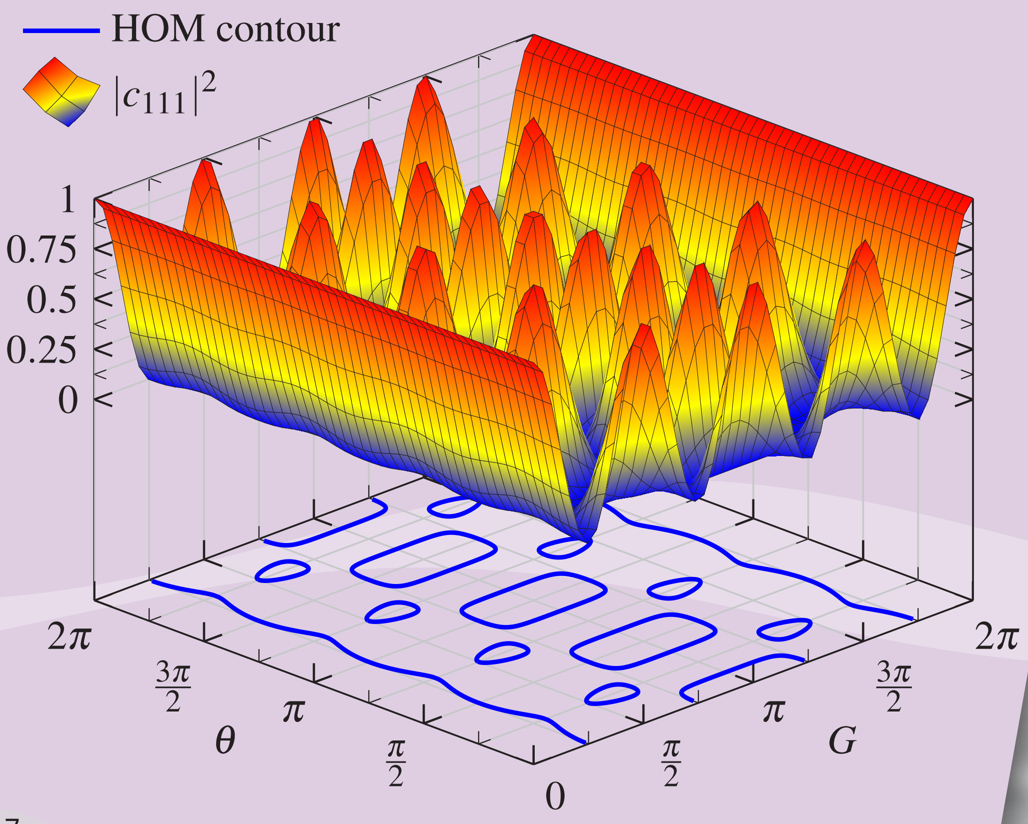
In the field of **quantum metrology**, the group of Maria Chekhova is a pioneer in the generation and characterization of bright squeezed vacuum, which finds applications in ultrasensitive interferometers below the classical sensitivity limit and quantum imaging. In addition, the group of Joachim von Zanthier has recently proposed the technique of Incoherent Diffraction Imaging, which uses quantum measurement methods to enable new imaging techniques in microscopy, X-ray structure analysis and astronomy.

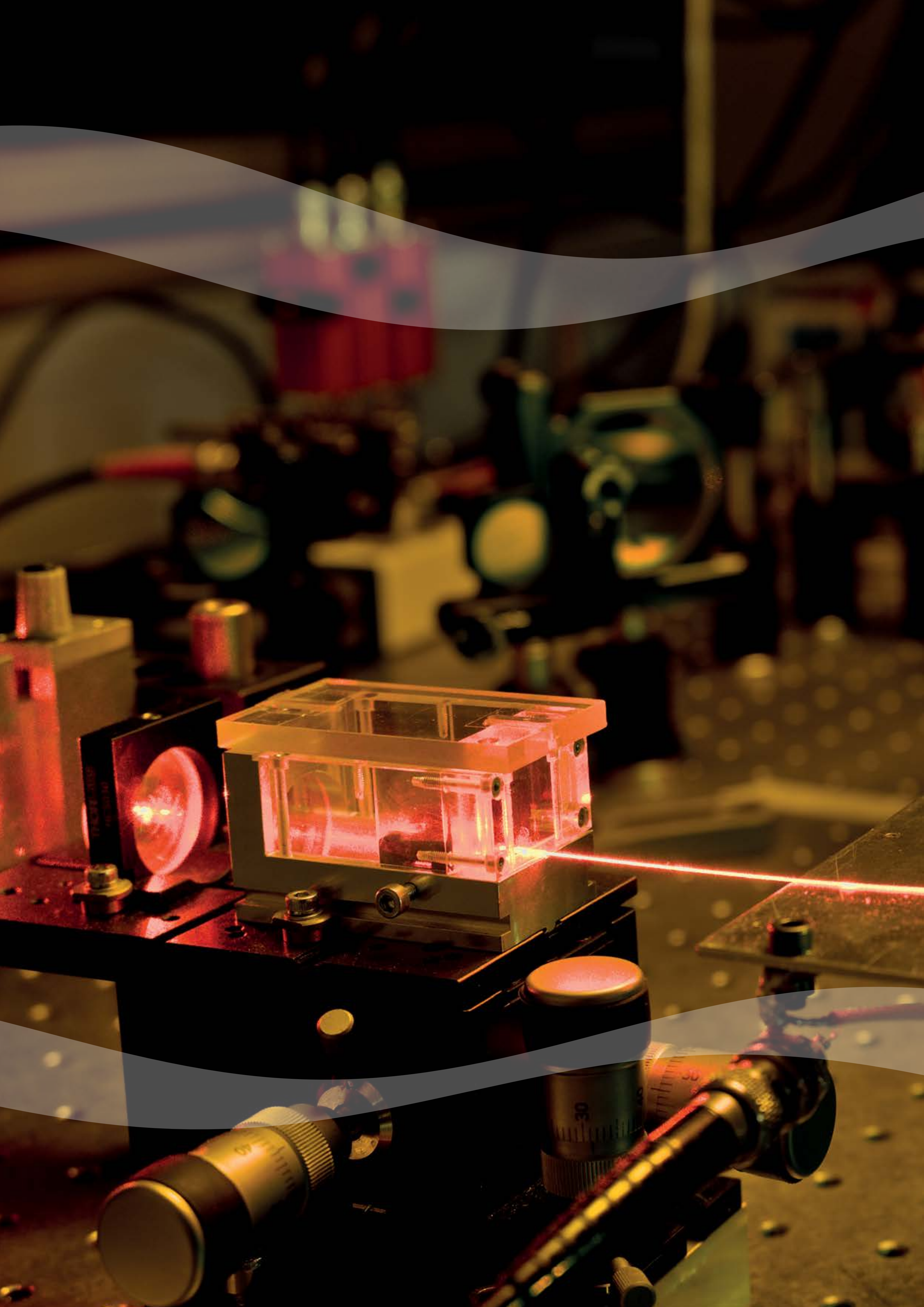


With respect to **quantum computing**, the theory groups of Michael Hartmann, Florian Marquardt, Martin Eckstein and Kai Phillip Schmidt develop new quantum algorithms, among others in close collaboration with the recently founded Munich Quantum Valley. With the appointment of Christopher Eichler in 2022, quantum computing is also investigated experimentally, using the plattform of superconducting circuits.



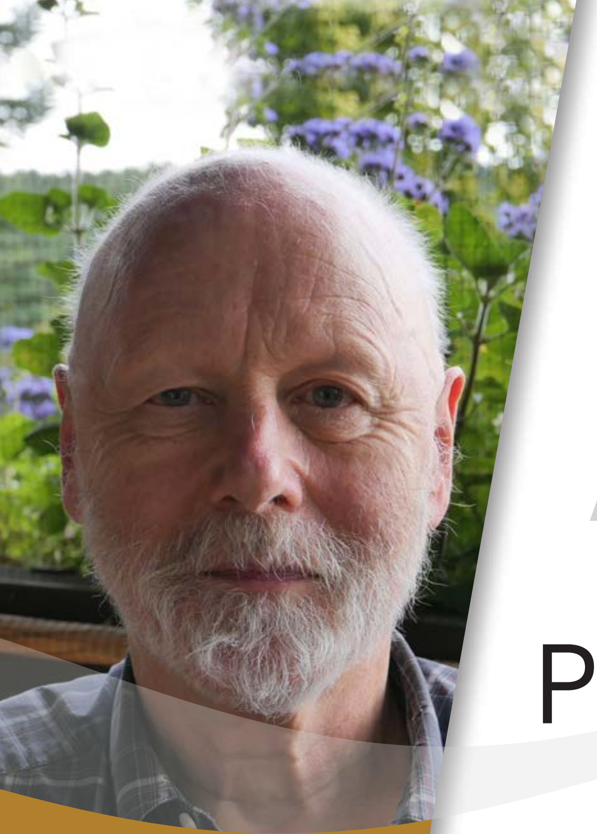
Above all, the Department of Physics has recently established the research focus **„Physics of Light and Matter“** at the interface between quantum optics and solid-state physics. Here, the foundations for tomorrow's quantum technologies are being researched. This area is strengthened by the recently granted Collaborative Research Center Transregio 306 „Quantum Cooperativity of Light and Matter“ (QuCoLiMa). QuCoLiMa bridges the gap between basic research on the one hand and applications in the field of quantum technologies on the other hand. All activities together will forge the future development of quantum technologies in Erlangen.





Photonic Fibers, Materials and Devices

From photovoltaics and semiconductors to microstructured devices, glasses and molecular assemblies, Erlangen is a widely-known site for photonic material technologies. Research activities comprise the fabrication and the characterization of innovative photonic structures and their implementation into prototype as well as large-scale applications. Around 30 research groups focus on the design of light-absorbing and emitting materials, laser-treated glasses, microresonators and molecular machines, as well as on their investigation using approaches such as state-of-the-art spectroscopy, electron microscopy, or X-ray tomography. In addition, Erlangen is one of the world's leading spots for research on photonic crystal fibers.



Make the effort to visit research group websites

Philip Russell

Research Group

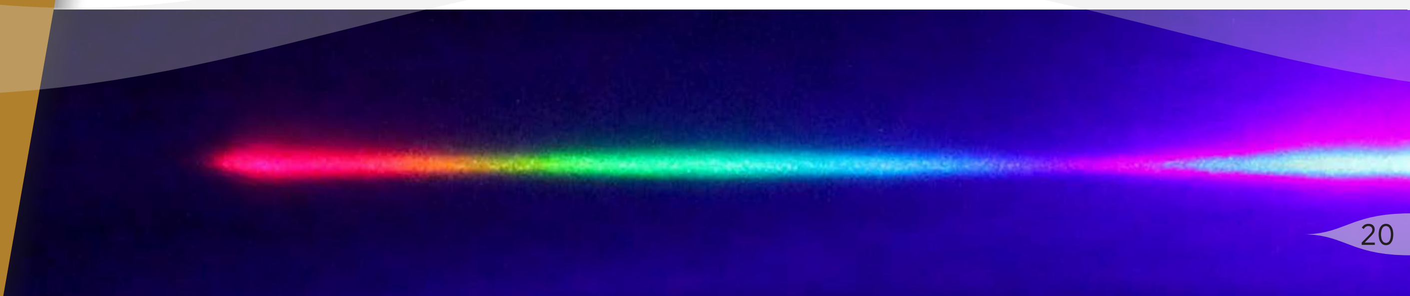
Philip Russell is an emeritus founding Director at the Max-Planck Institute for the Science of Light and was formerly Krupp Professor of Experimental Physics at the Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU). He obtained his doctorate at the University of Oxford in 1979, and has worked at universities and research establishments in Germany, the USA, the UK and France. His research interests focus on photonic crystal fibers (PCF), which he first proposed in 1991, and their myriad scientific applications.
His awards include the 2005 Körber Prize for European Science, the 2013 EPS Prize for Research into the Science of Light, the 2014 Berthold Leibinger Zukunftspreis, the 2015 IEEE Photonics Award and the 2018 Rank Prize for Optoelectronics.

Exemplary Publications

Recent publications include efficient quantum up-conversion of single photons, and mid-IR fibre lasers delivering sub-two-cycle pulses. His first paper on photonic crystal fibers goes back to 1996, and since then his publications on PCF and its applications have been cited some 40,000 times.

What are the future questions you are working on and what are the particular challenges?

Photonic crystal fibers (PCF)—thin strands of glass with an intricate array of hollow channels running along their length—offer an unprecedented degree of control over light, making possible e.g. efficient generation of multi-octave-spanning supercontinuum light.

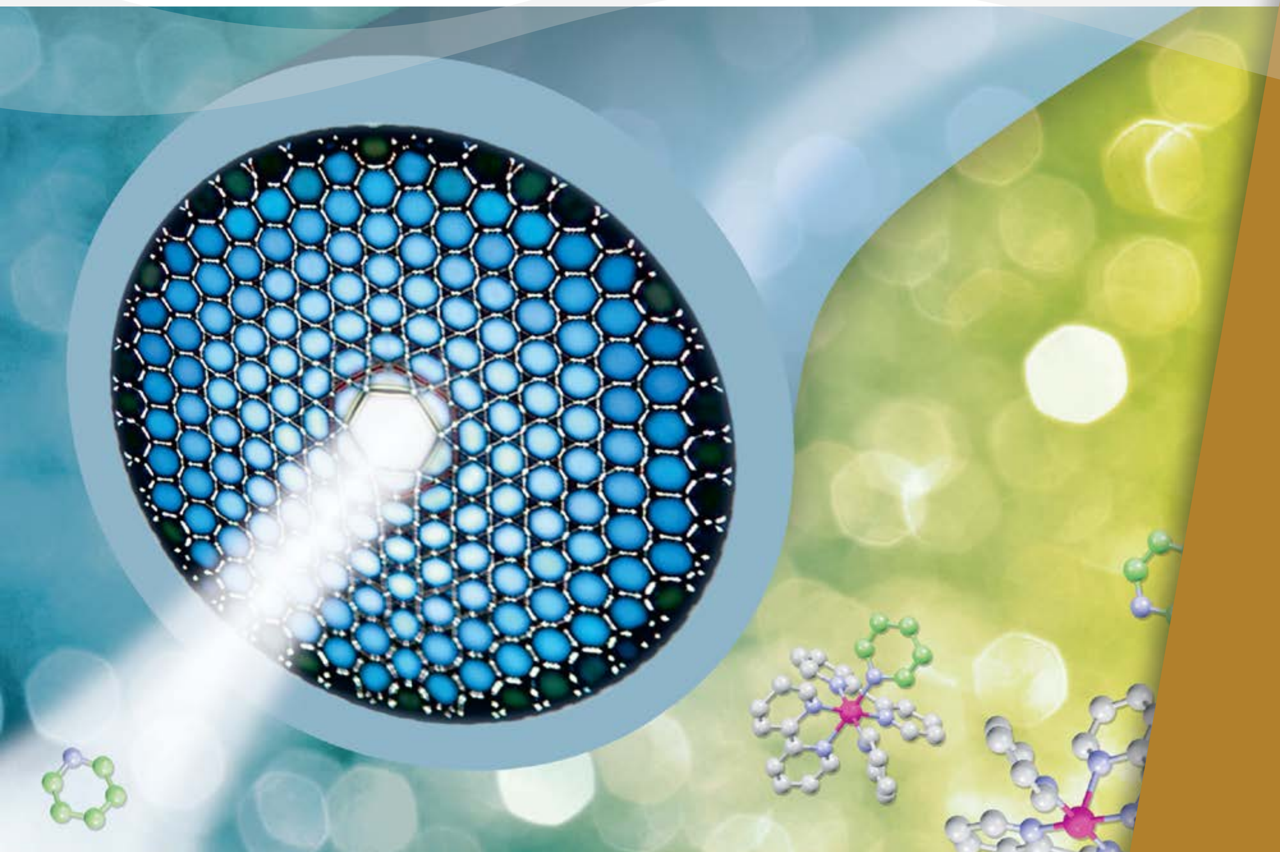


Chirally twisted PCF supports optical vortices and in some cases strong circular dichroism. The dispersion in gas-filled hollow-core PCF can be adjusted by varying the pressure, providing a simple means of compressing pulses to single-cycle durations, as well as underpinning a range of unique sources of tunable deep and vacuum ultraviolet light.

Particles optically tweezered inside hollow core PCF can be used to sense physical quantities with high spatial resolution. Strong optomechanical effects in solid-core PCF can be used to robustly mode-lock fiber lasers at few-GHz frequencies. All these applications present significant experimental and theoretical challenges.

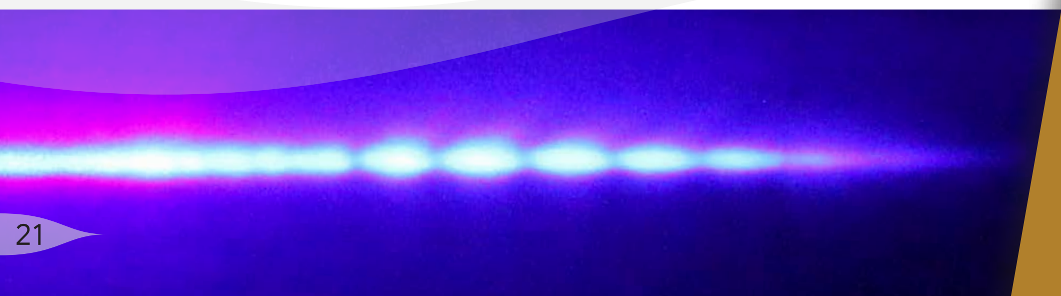
What do you particularly appreciate about Erlangen as a research location?

Erlangen has the advantage of being a relatively small town, so that everything is within easy cycling or walking distance. In addition to excellent science and engineering departments it has the Max Planck Institute for the Science of Light, which offers many Master's and PhD projects and excellent research funding.



What advice can you give to young people who are interested in studying optics-related subjects in Erlangen?

Make the effort to visit research group websites and read a few recent papers on optics-related research carried out in Erlangen. Even if you don't fully understand all the science, this will give you a good feel for the range of different research topics on offer.



Scientist Spotlight

Look beyond the border of your specialty

Bernd Witzigmann

After finishing a doctoral program at ETH Zurich in 2000, Bernd Witzigmann has spent 4 years in industrial research in the US, which then was followed by an assistant professorship at ETH Zurich in the electrical engineering department again. From 2008 to 2021, he has been heading the Computational Electronics and Photonics Group at University of Kassel. In April 2021, he came to Friedrich-Alexander Universität Erlangen-Nürnberg, to the department EEI in the Faculty of Engeneering.

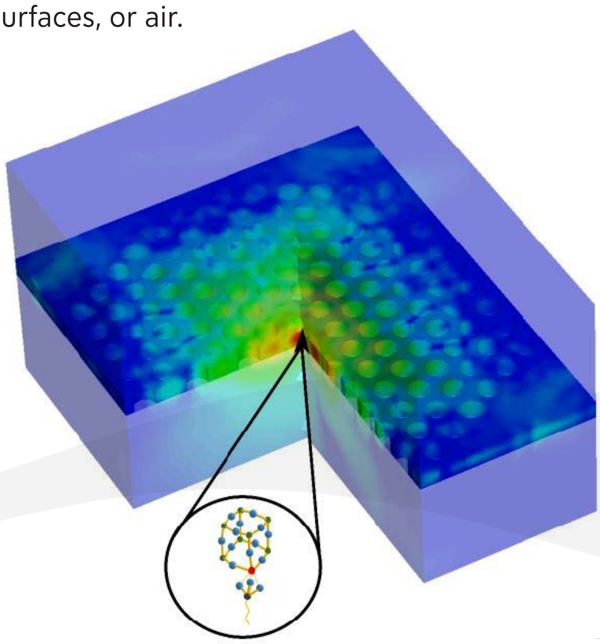
There, Witzigmann is heading the Institute for Optoelectronics, where his main research field is the interaction of electrons and photons and its application to technologies such as sensing, energy conversion, and communications.

Research Group

Latest Publications

His recent publications include optimization of deep UV LEDs/Lasers, including the understanding of the luminescent mechanisms of AlGaN/GaN quantum wells, and the development of theoretical models for light-matter interaction. The aim ist the realization of light sources for disinfection of water, surfaces, or air.

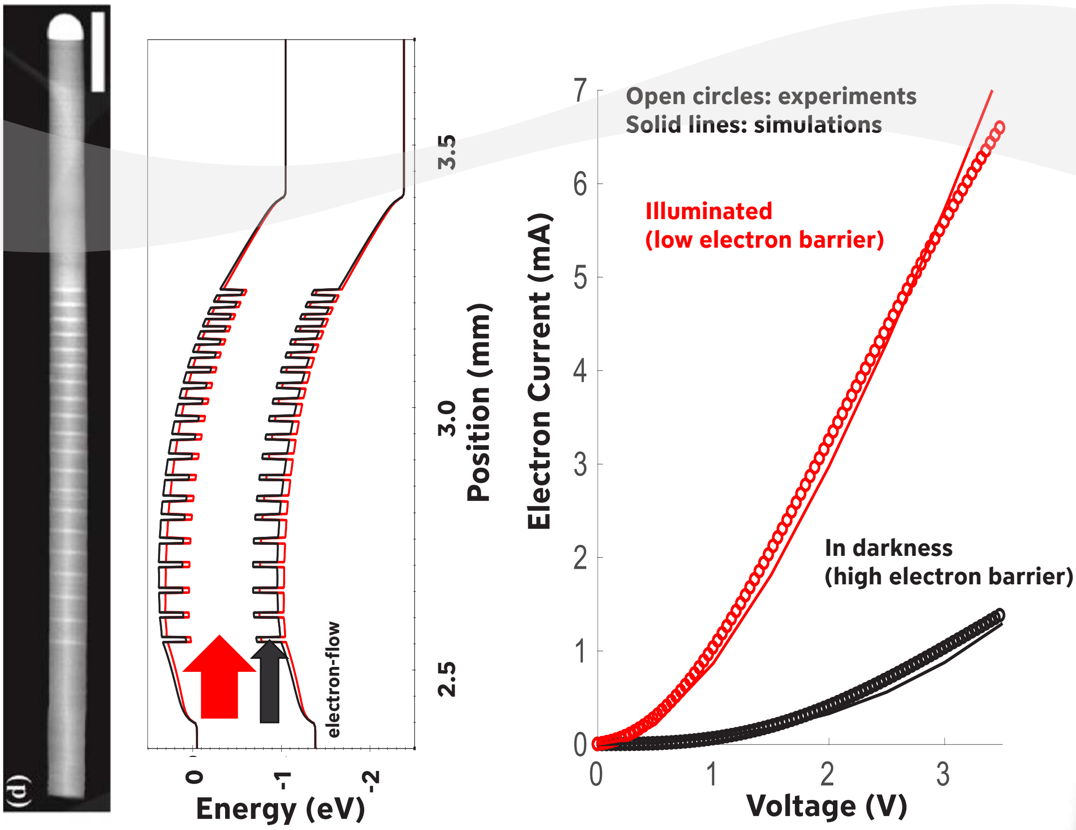
Another research direction deals with nanowire photodetectors for quantum photonic systems: here his group uses photogating in semiconductor nanowires in order to build detectors with highest sensitivities, for bioimaging or quantum communications applications.



What are the future questions you are working on and what are the particular challenges?

Currently, we are working on high-efficiency semiconductor LEDs and lasers which emit in the deep ultraviolet (UV) spectral range, mainly for disinfection applications. Current devices have electro-optical efficiencies of below 1%, and we want to increase this by at least one order of magnitude.

Photons also play a major role in future quantum technologies, and we are investigating architectures for quantum information processing which require less cooling than current implementations. This can be a major step towards a broader application of quantum technologies.



What do you particularly appreciate about Erlangen as a research location?

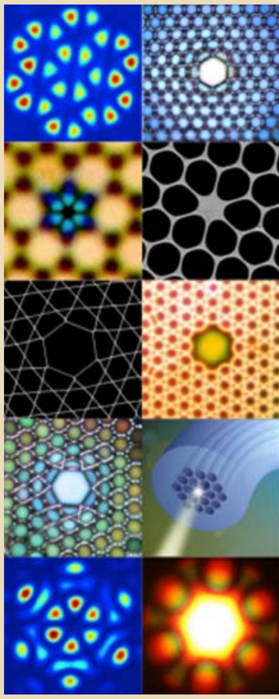
Erlangen has a stimulating mixture of academia, research institutes and industry which are active in science and engineering. This creates an attractive environment for collaborations.

What advice can you give to young people who are interested in studying optics-related subjects in Erlangen?

Optics and photonics are wide spread across disciplines - ranging from physics, biology, chemistry, to the engineering disciplines. My advice would be: look beyond the border of your specialty, and be curious about the possibilities this brings along. Different disciplines can learn from each other!

Fiber Technology

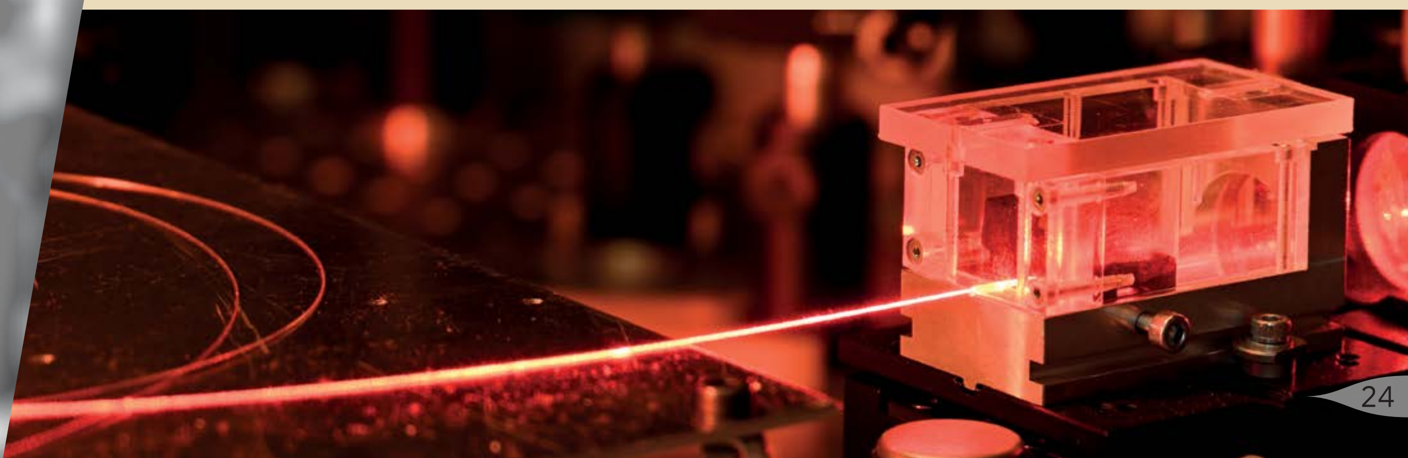
– by Nicolas Joly, Michael Frosz and Bernhard Schmauss –

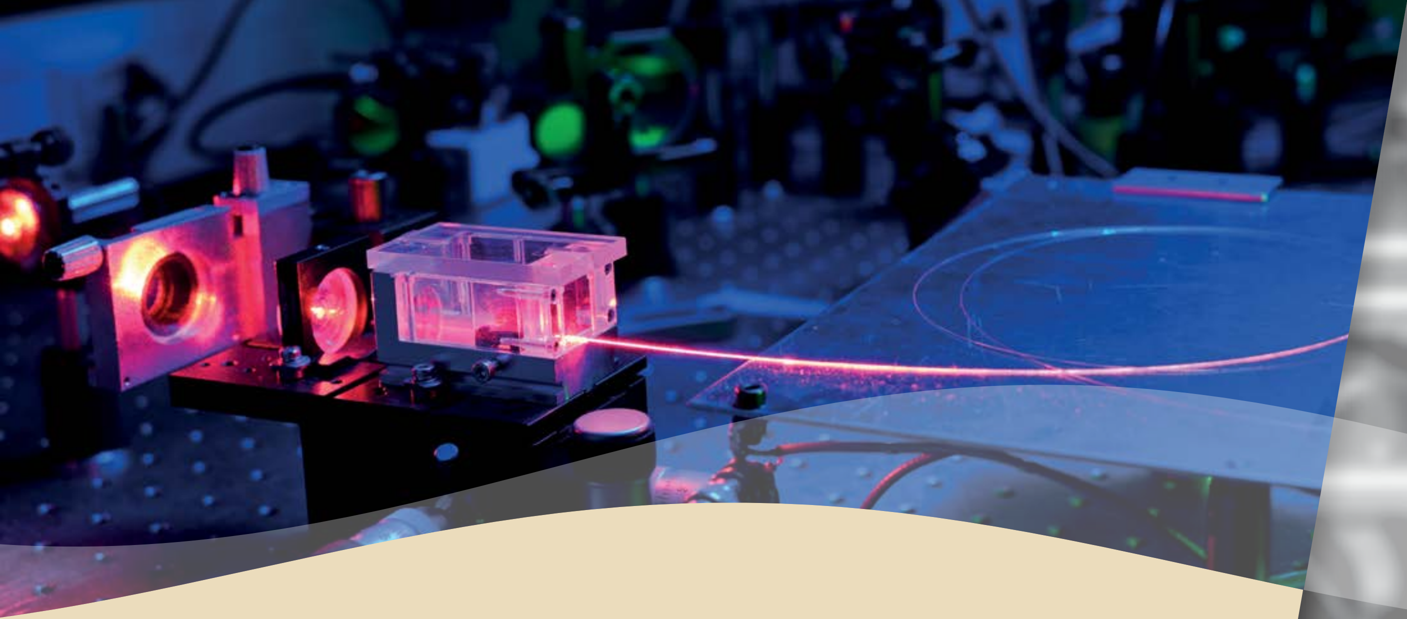


The year 2021 was the 30th anniversary of the initial proposal by Philip Russell for a novel type of optical fiber that would guide light by the newly-proposed photonic bandgap effect: **photonic crystal fibers** (PCF). Compared to conventional step-index fibers, the very first solid-core PCF, with arrays of tiny hollow channels running along their length, offered enhanced control of dispersion, higher optical nonlinearities and birefringence, and so-called „endlessly single-mode“ behavior.

Russell's group reported the first working PCF in 1996 at Southampton University. After a series of papers that are amongst the most highly cited in the entire field of photonics, Phillip Russell arrived in Erlangen in 2005. Since then Erlangen has become recognized as the **world-leading center of research** not only on PCF itself, but also on its myriad applications.

In addition to telecommunications, faster optical interconnections between computers, quantum key distribution, biomedicine, environmental sensing, and laser manufacturing, PCF play an increasingly important role in the development of all kinds of novel laser-based light sources. Within Germany, there are only two non-commercial locations where these optical fibers are drawn: Jena and Erlangen.



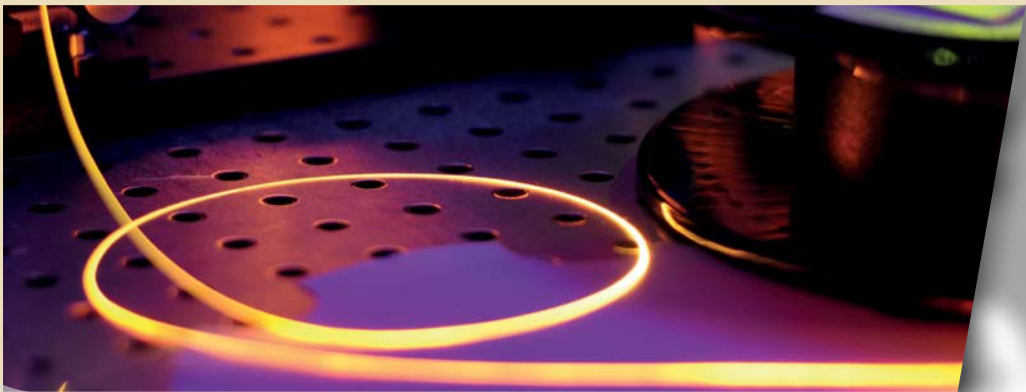


Today, the Max Planck Institute for the Science of Light (MPL) in Erlangen is the site of a world-leading fiber fabrication facility that develops and manufactures photonic crystal and microstructured optical fibers. In collaboration with companies, academic research groups and government agencies from all over the world, many highly cited publications were released over the past 17 years: since 2005, the Web of Science records more than **240 journal publications on PCF from Erlangen**, with about 10,000 citations and an h index of 50.

One exemplary application of PCF is ultra-broad-band **supercontinuum generation** pumped by near infrared pulses. An immediate success ensued in frequency metrology, where PCF were used to generate octave-spanning femtosecond frequency combs. Such controllable sources of non-classical light can also be used for quantum optics technology. The group of Nicolas Joly aims at engineering a source of pairs of photons with extreme frequency separation so as to access regions of wavelength that are not conventionally accessible while keeping the quantum properties of the source.

A second renaissance followed with gas-filled **hollow-core PCF**, especially the anti-resonant reflecting (ARR) variety. ARR-PCF, offering ultra-broad-band guidance, a very high damage threshold, and pressure-tunable dispersion, have opened up a new world for gas-based nonlinear optics. Breakthroughs include soliton self-compression to few-cycle pulses, widely-tunable deep and vacuum UV light sources and multi-octave supercontinuum sources extending deep into the vacuum UV.

A further use of PCF is to utilize them as **micro-reactors for chemistry**. It is then possible to monitor chemical reactions.



Functional Nanoparticles

– by Wolfgang Heiß –

The i-MEET, namely the Institute Materials for Electronics and Energy Technology, is dedicated to the functional aspect of electronic properties and applicability of different material classes. One research focus is the synthesis, characterization and processing of **nanocrystals for optoelectronic device applications**.

The synthesis of nanocrystals with various compositions, controlled shapes and sizes provides **novel materials** for developments in electronics, photocatalysis, and biointerfacing. The material's physical properties are not only tailored during synthesis but also post synthetic by application of galvanic exchange reactions. Tuning the nanocrystals properties in solution is a tool to replace high-effort growth techniques based on expensive equipment, high temperature, and ultra-high vacuum.

A special focus is put on **infrared-optical devices** as well as on **detectors for the X-ray spectral region**. As a necessity for nanocrystal devices with sufficient electronic conductivity, the surface functionality is tailored by ligand exchange methods, performed in solution. As an example, zero-dimensional perovskites are attached to nanocrystal cores with the rock-salt structure to form a quasi-epitaxial shell, with advantageous electrical properties.

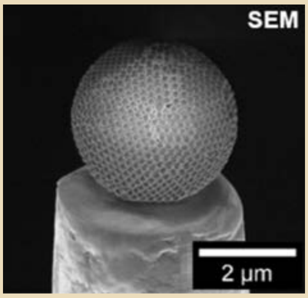
An aim of nanoparticle research at i-Meet is to **provide nanocomposite materials** with properties which are hardly achievable otherwise. An example are metal-oxide nanocrystals with electrically tunable plasmon resonances. Such materials are of interest in smart windows, exhibiting dimming properties for visible light as well as for heat radiation. An important topic for these applications is the up-scaling of the synthesis to obtain sufficient amounts for large area printing of smart windows.

Besides the classical inorganic semiconductor and metal-oxide nanocrystals, also **organic pigments** can be synthesized in the form of colloidal nanocrystals. They are of interest due to their environmental stability, low toxicity, and low price, and thus can be considered as an alternative to inorganic nanocrystals. Besides their electronic properties, they exhibit also advantageous photocatalytic activity, which are pioneered in i-MEET for selective oxidation reactions, for the photo-electrochemical splitting of water, or for the photocatalytic reduction of heavy metal salts applied for water cleaning. The same materials are also applied in the form of hierarchical nano-architectures with nature inspired shapes as **electronic interfaces to bio-materials**.

CRC 1411 – Design of Particulate Products

– by Johannes Walter –

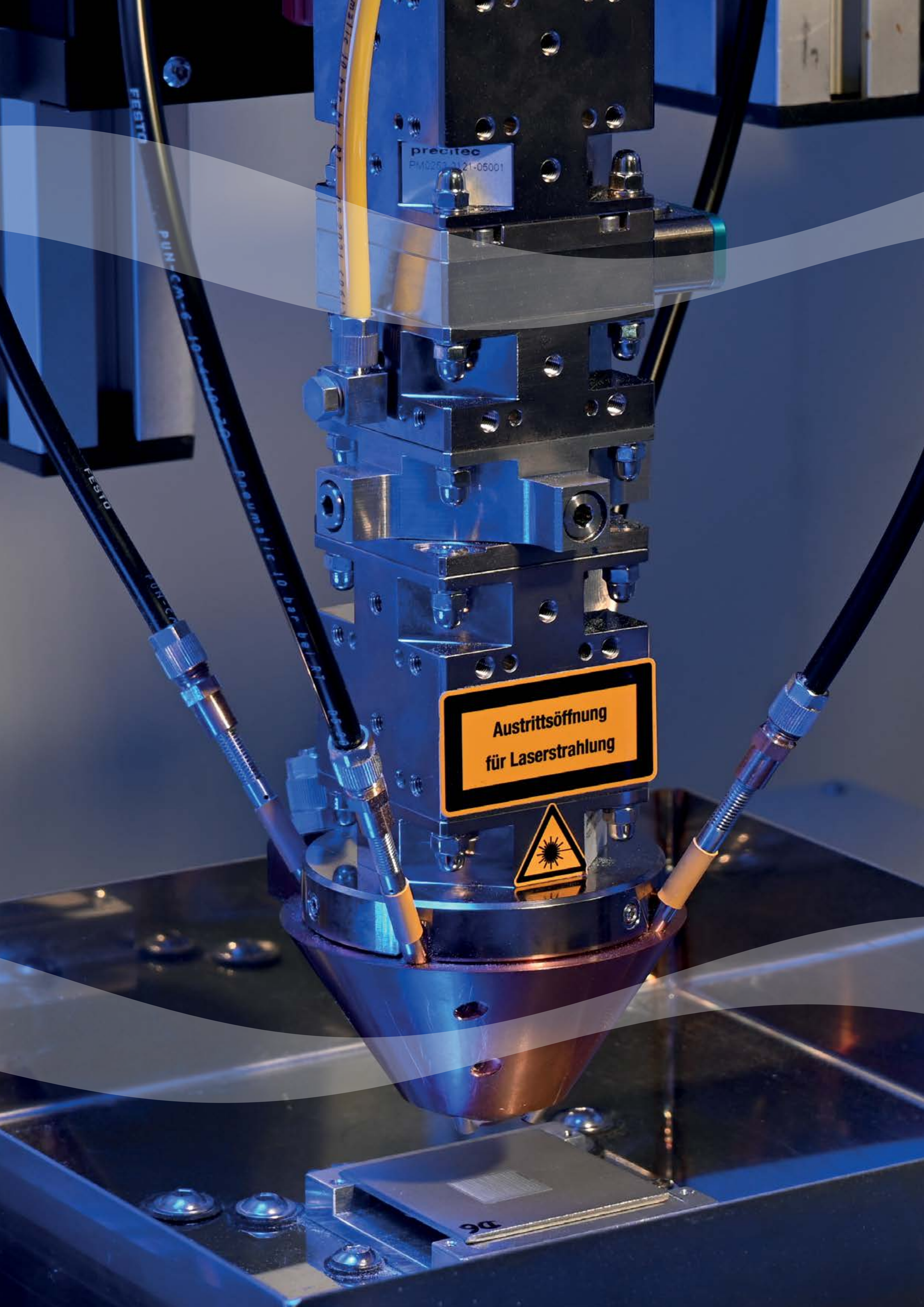
Product design is the formation, formulation, handling, manufacturing and characterization of complex multiphase products across all length scales from molecules to particles and complex materials and devices. The desired **product properties follow the demands** of a variety of applications. These include both classical fields of process technology in the chemical industry as well as new emerging fields of electronics, energy and environmental technologies, life sciences, pharmaceutical applications, fast-moving consumer goods, materials science and engineering, nanotechnology, photonic technologies and additive manufacturing. Unifying principles of product design are widely applicable to many different kinds of products including solid, liquid and even gaseous particles.



The key objective and long-term vision of Collaborative Research Centre 1411 "Design of Particulate Products" is the **targeted design of particulate products** by rigorous optimization based on predictive structure-property and process-structure functions. Particulate products, as considered in CRC 1411, consist in the simplest case of dispersed single particles and in more complex cases of hierarchically organized assemblies of particles in the form of supraparticles, thin films or stationary phases for chromatographic separation.

The CRC targets **scientific breakthroughs in the product engineering of nanoparticles** with optimized optical properties. Their production by continuous synthesis is directly coupled to a property-specific classification by chromatography. These challenges are addressed from **different perspectives** in four strongly interlinked research areas, which are underpinned by the development of joint methodologies in synthesis, classification, characterization as well as modeling, simulation, and optimization.

The **joint venture** of chemical engineering with materials science in concert with the basic sciences opens new prospects for all involved disciplines. Innovative products with new and improved properties must be produced by sustainable process technologies. In a strong move towards digitalization, rigorous mathematical optimization methods based on predictive models for products, structures and processes catalyze **new possibilities for true design of multiphase products**, which is at the core of mesoscale science and technology.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Photonics in Production and Process Technology

Multiple well-established production techniques and analytical methods would not have been developed without the possibilities that emerge from photonics. Almost 20 research groups located in Erlangen have major contributions to this technological progress. This not only includes state-of-the-art laser processing of various material systems, experimental and theoretical lithography or modeling of complex systems, but at the same time also advances in a plethora of metrology approaches comprising interferometry, different kinds of spectroscopy, sensing of fluids and gases, determination of surface and particle properties and much more. This diversity renders Erlangen as a hotspot in next generation production and process technology based on photonics research.

Scientist Spotlight

Erlangen has a long-standing tradition in optics

Andreas Erdmann

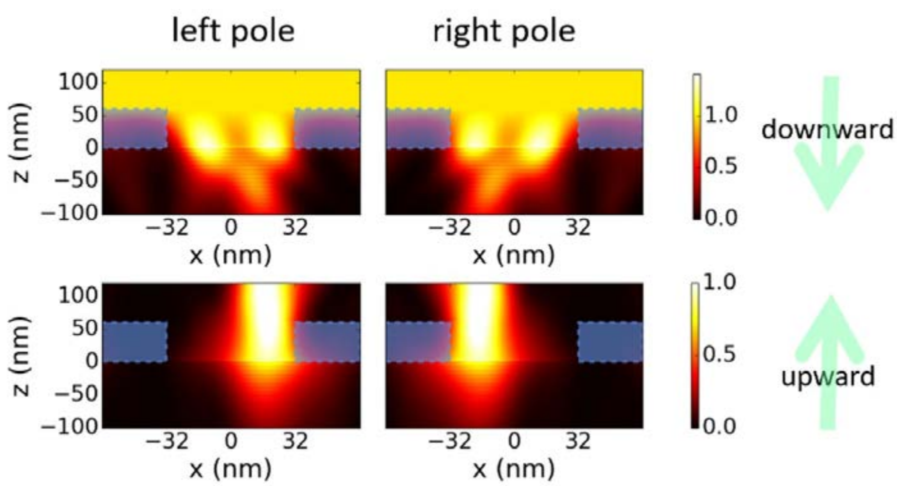
Andreas Erdmann studied physics at the Friedrich-Schiller-Universität Jena, where he received a PhD for his work on "Nonlinear optical phase conjugation in photorefractive $Bi_{12}GeO_{20}$ crystals and applications in optical metrology". From 1990 to 1995 he worked as a post-doc at the University of Osnabrueck where his research was focused on the modeling of optical waveguides and photonic components based on magneto-optical materials. In 1995 he joined the Fraunhofer Institute for Silicon Technology (ISiT), where he started his work on the modeling of optical lithography for semiconductor fabrication. 1999 he moved to Erlangen to lead the research activities of the "Computational Lithography and Optics" at the Fraunhofer Institute for Integrated Systems and Device Technology (IISB).

In 2010, he completed his habilitation on the "Modeling of advanced mask technologies for optical and EUV lithography". Since then he teaches also as Privatdozent at FAU. He chaired and co-chaired SPIE conferences on "Optical Microlithography" and "Optical Design" and the International Fraunhofer Lithography Simulation Workshop. In 2016, he was elected as Fellow of SPIE, the international organisation of optics and photonics.

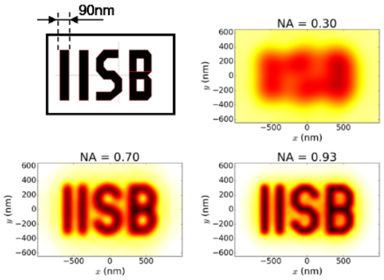
Research Group

Latest Publications

Besides recent publications to e.g. defect detection in lithography masks using deep learning, he published a book on modeling of optical and EUV lithography in 2021.



What are the future questions you are working on and what are the particular challenges?



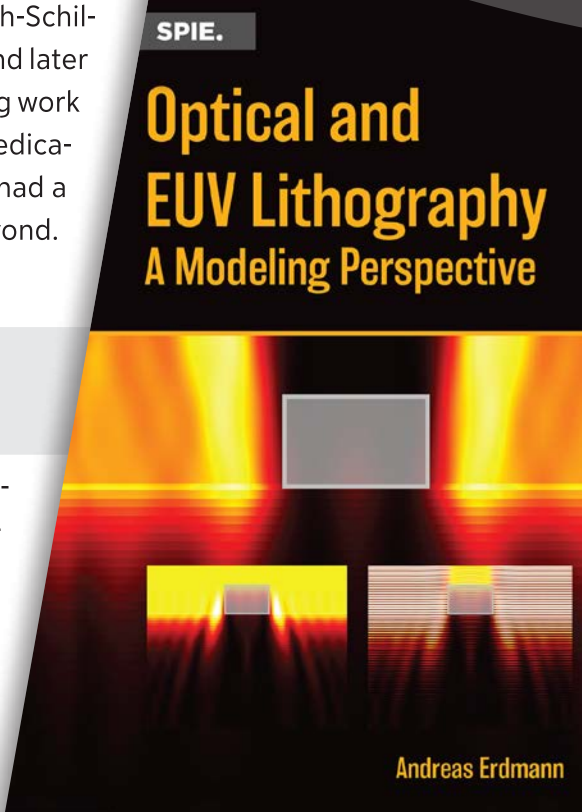
The present focus of the research of our team at Fraunhofer IISB is on the modeling of extreme ultraviolet (EUV) lithography. EUV is the lithography technology for the fabrication of the most advanced microchips. Our group collaborates with ASML, one of the most important tech companies in the world, Zeiss and other partners, to model lithography masks, projection systems and photoresist materials for the next generation of EUV technology. This involves not only an in-depth understanding and modeling of the involved optical and chemical effects, but also the application of deep learning and other machine learning methods to address the extreme computational challenges in this field.

An in-depth understanding as well as accurate and efficient modeling of lithographic techniques become increasingly important for many emerging applications beyond semiconductor technology, especially in the field of design and process technology co-optimization. The close collaboration between designers of semiconductor chips and lithography experts has fundamentally changed both the electronic design of advanced nanoelectronic circuits, and the way how modern semiconductor chips are fabricated. I expect similar developments in other areas like silicon photonics, freeform surfaces for augmented reality virtual reality displays, quantum devices and other applications of nanotechnology.

What do you particularly appreciate about Erlangen as a research location?

The combination of FAU, the Max Planck Institute for the Science of Light, two Fraunhofer Institutes, Siemens and smaller institutes and companies makes Erlangen a unique research location with great opportunities for multidisciplinary collaboration and multicultural exchange with students and researchers from all over the world.

In addition, Erlangen has a long-standing tradition in optics. In 1989, few days after the fall of the Berlin wall, Alfred Lohmann (at this time professor at FAU) and Reinhard Voelkel (one of his PhD students) visited the Friedrich-Schiller-Universität Jena, where I just had finished my PhD. During this visit and later meetings with professor Lohmann, I was very impressed by his pioneering work in optical information processing, his extraordinary teaching skills and dedicated mentorship for many students. Professor Lohmann and his students had a profound impact on various areas of applied optics in Germany and beyond.



What advice can you give to young people who are interested in studying optics-related subjects in Erlangen?

Use the opportunities to learn about modern optics from different perspectives, find your favorite topic and develop a passion for it. A solid theoretical background, practical research experience from (small) projects and the abilities to explain your research plans and results to others are among the most important things when studying optics and photonics.

Scientist Spotlight

Come to FAU and join the group of the best

Marion Merklein

After her study on material science, Marion Merklein received a PhD in mechanical engineering. Her PhD thesis is about laser forming of aluminum alloys and the influence of the laser forming process on the materials' microstructure and mechanical characteristics.

In 2006 she finished her habilitation and since 2008 she is the head (full professor) of the Institute of Manufacturing Technology at Friedrich-Alexander-Universität Erlangen-Nürnberg. Her research covers forming, joining, cutting, additive manufacturing and material characterization.

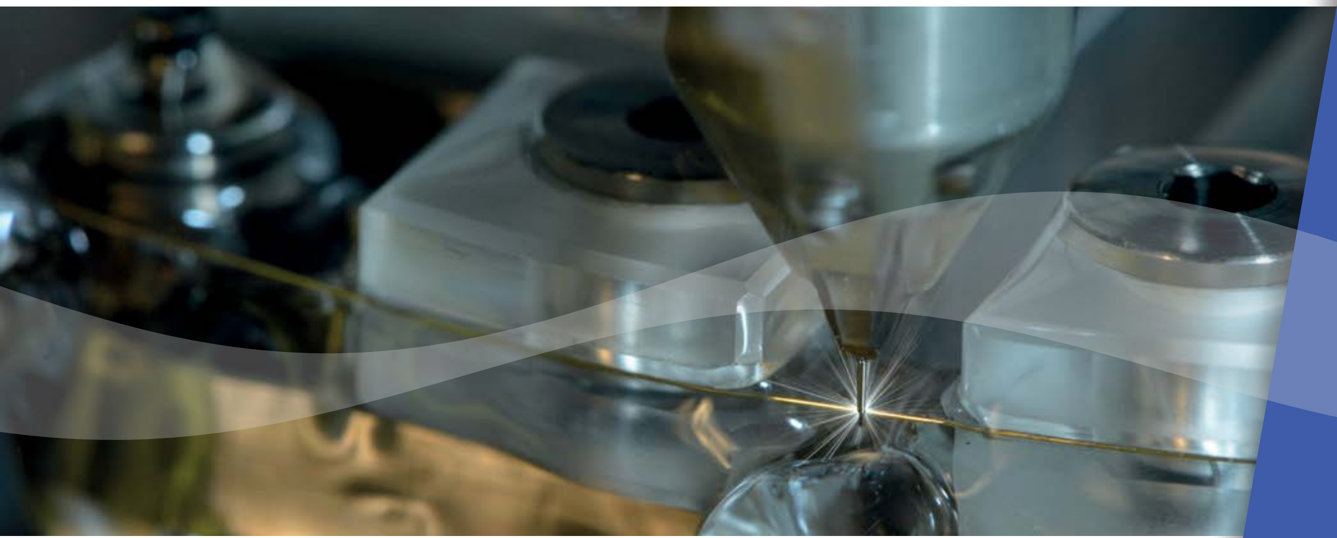
Research Group

Latest Publications

Her recent publications include a review on alloy design and adaptation for additive manufacturing as well as an assessment of the impact of the gear tooth geometry on load and wear within metal-polymer gear pairs.

What are the future questions you are working on and what are the particular challenges?

Future questions are related to sustainability in production engineering as well as more robust processes. The list of challenges in this field is very long, one useful approach to accelerate the necessary transition processes could be to use digitization as additional method.

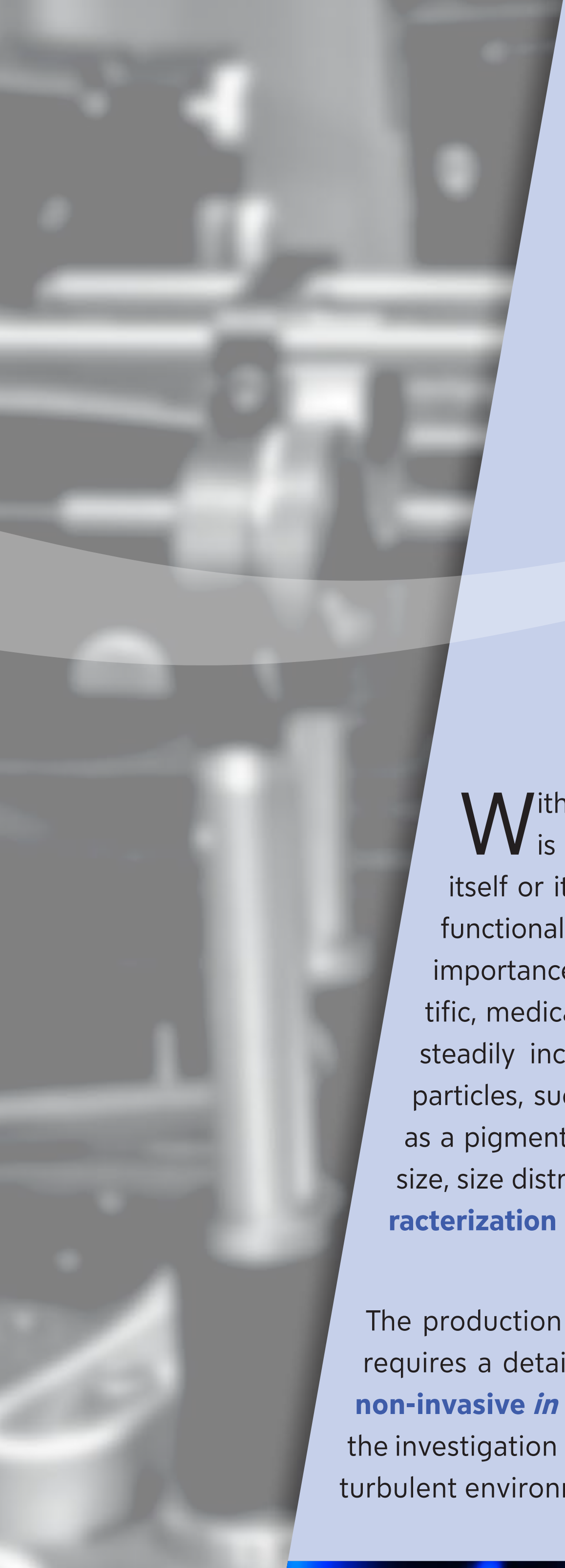


What do you particularly appreciate about Erlangen as a research location?

The metropolitan region of Nuremberg is a good place for research with a huge number of industrial partners.

What advice can you give to young people who are interested in studying optics-related subjects in Erlangen?

Come to FAU and join the group of the best, join SAOT!



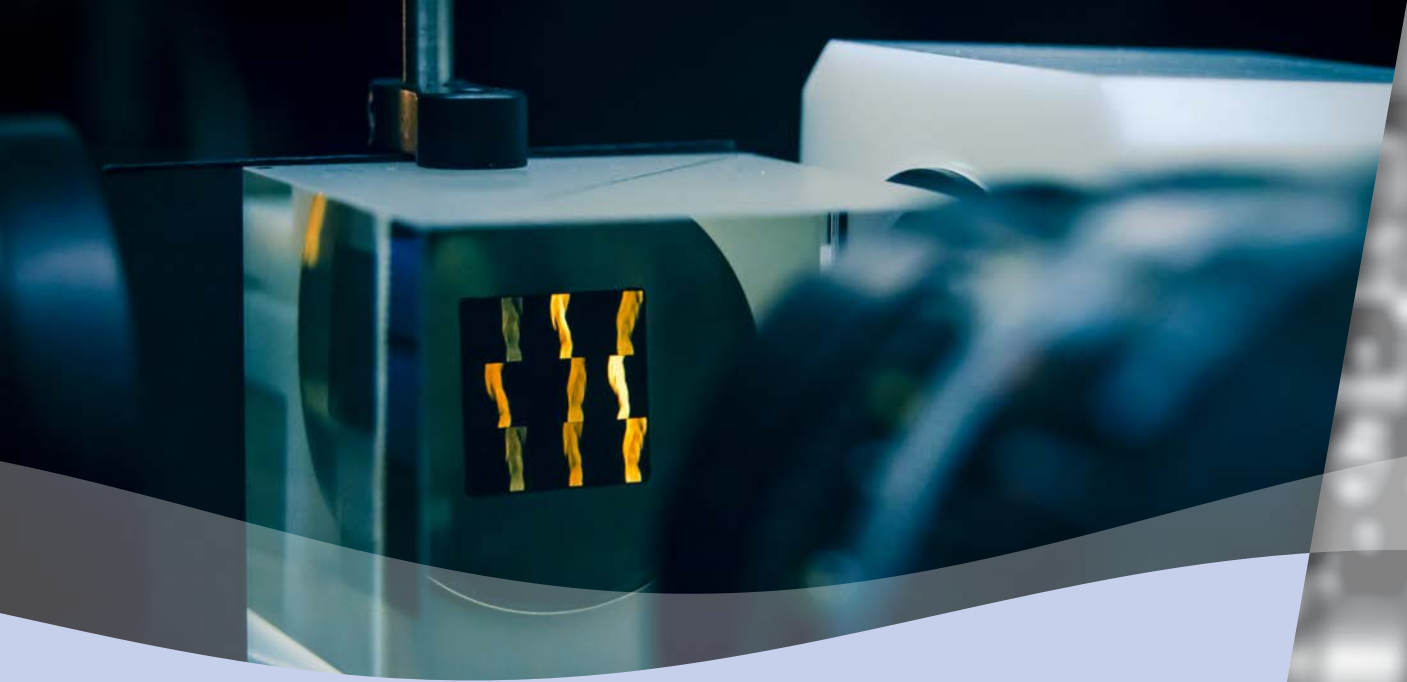
Research Spotlight

Process Metrology

– by Simon Aßmann, Florian Bauer, Franz Huber, and Stefan Will –

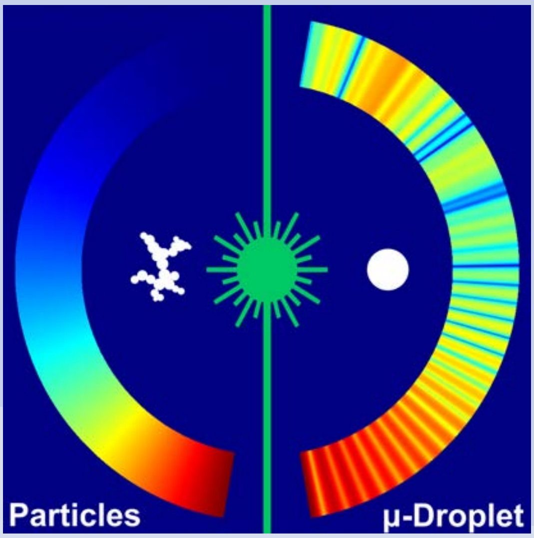
Without knowing core parameters of a process, there is not much guidance for **optimizing the process** itself or its outcome. This also applies to the synthesis of functional nanoparticles. In recent years and decades, the importance and utilization of such nanoparticles in scientific, medical and industrial disciplines and applications has steadily increased. Since the functional properties of the particles, such as the color or the flow behavior when used as a pigment or flow aid, respectively, often depend on their size, size distribution and morphology, a **comprehensive characterization** of the particle properties is of great interest.

The production of particles with tailored properties or a selective modification of them requires a detailed understanding of the underlying particle formation pathways. Here, **non-invasive *in situ* measurement techniques** are of great advantage as they allow for the investigation of particle growth and sintering during their synthesis in typically hot and turbulent environments.



This is where the Institute of Engineering Thermodynamics (LTT) comes into play. One research focus is the development of optical techniques for **contactless particle diagnostics**, in particular for the investigation of gas phase synthesis of particles, such as flame spray pyrolysis, and the formation of pollutants such as soot in combustion processes. While size and morphology of particles are typically accessible with elastic light scattering techniques, in particular **wide-angle light scattering** (WALS), primary particle sizes and particle concentrations are determined with **laser-induced incandescence** (LII), which is also applied tomographically to study particle formation in combustion processes. Additionally, multi-spectral techniques such as UV-VIS absorption spectroscopy or fluorescence techniques are used to characterize optical properties of particles or to study mixing processes during synthesis, respectively.

WALS is applied to obtain information about **droplet evolution and particle formation** simultaneously within spray flame synthesis. With sophisticated evaluation techniques not only droplet and particle size distributions could be resolved, but also the shares of different particle morphologies arising from different formation routes during the process.



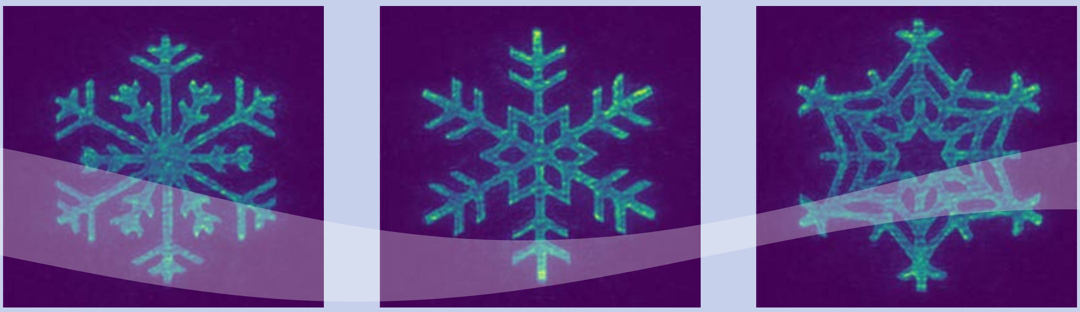
Through the combination of LII, high-speed imaging and tomographic methods **temperatures, reaction and particle formation zones** or **particle parameters in reactive flows** can be investigated in 3D with high temporal resolution.

Laser Beam Shaping

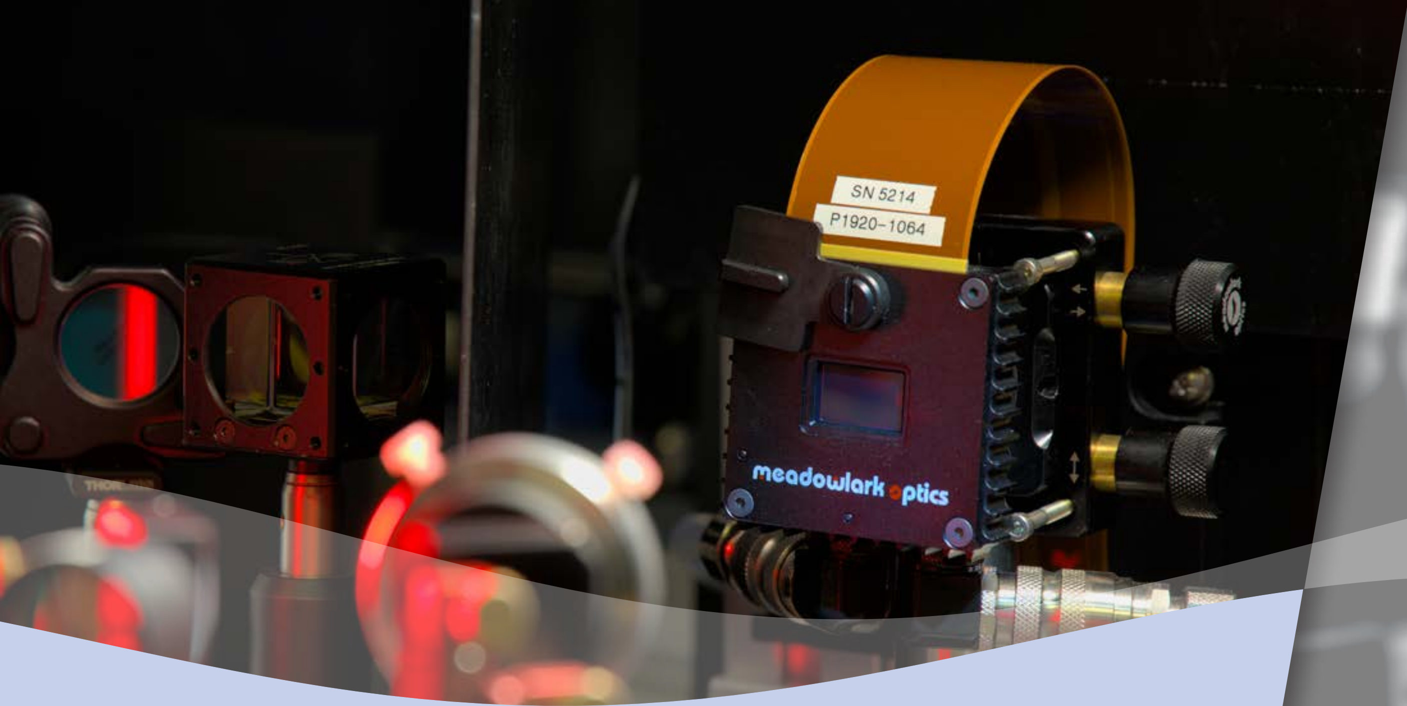
– by Clemens Roider –

The laser is a universal tool in materials processing. Focusing a high-power laser to a single spot allows various applications like **welding and laser-based additive manufacturing**. Heating and consequent melting of the material mainly drives these processes in which the laser beam acts as a heat source. For the processing result, resolidification is critical as defects like cracks can occur but also spatter might be produced during laser interaction due to overheating and turbulences in the melt pool. An important factor for these defects is the heat distribution in the work piece.

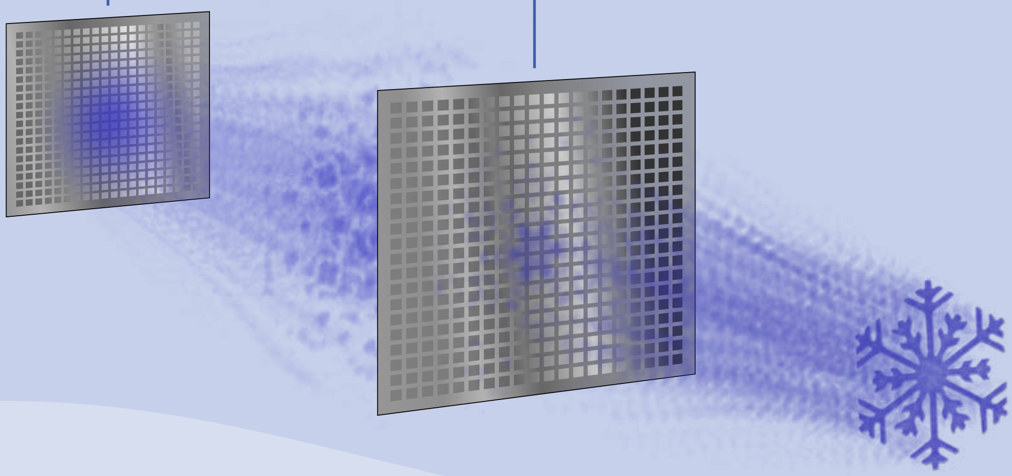
State-of-the-art lasers produce a focus that resembles either a bell (Gaussian) curve or a rectangular (top-hat) shape and therefore the resulting heat profile is predefined. Beam-shaping is a technique for influencing the shape of the focus and therefore **forming the heat profile** in a desired manner. This offers the possibility to mitigate defects and increase the processing window as well as the production efficiency.



To shape laser beams, so-called **diffractive optical elements** can be used, which are glass slides with a surface relief of a few micrometers. By introducing a phase delay, they influence the propagation of light. The Institute of Photonic Technologies (LPT) works on predicting **optimized beam shapes** for specific applications, calculating the appropriate relief, and showing advantages in materials processing. As an example, this technique was successfully used at LPT for welding a crack-prone aluminum-copper alloy, which resulted in a weld seam quality close to a polished surface and an enlarged processing window.



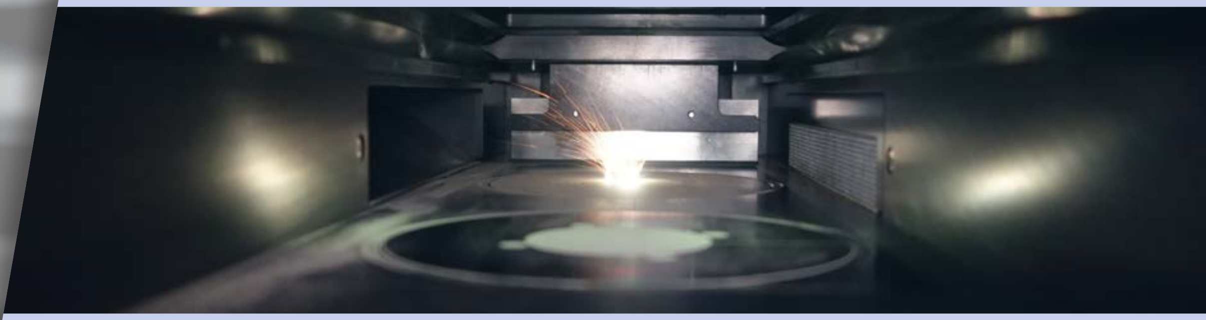
Beam-shaping also offers the possibility of **processing large areas at once**, for example engraving product information without having to move the laser beam. For designing elements for large-area processing, the main challenge is the presence of speckle, which are artefacts due to undesired interference of light. LPT develops setups and algorithms to reduce the influence of speckle during processing. For testing new developments, low average power pulsed lasers are employed which allow using liquid crystal **spatial light modulators** instead of static diffractive optical elements. These modulators work similar to LCD screens and allow quickly displaying different structures without having to manufacture a new glass element each time. By using two sequential modulators, researchers from LPT showed speckle-free large-area beam-shaping.



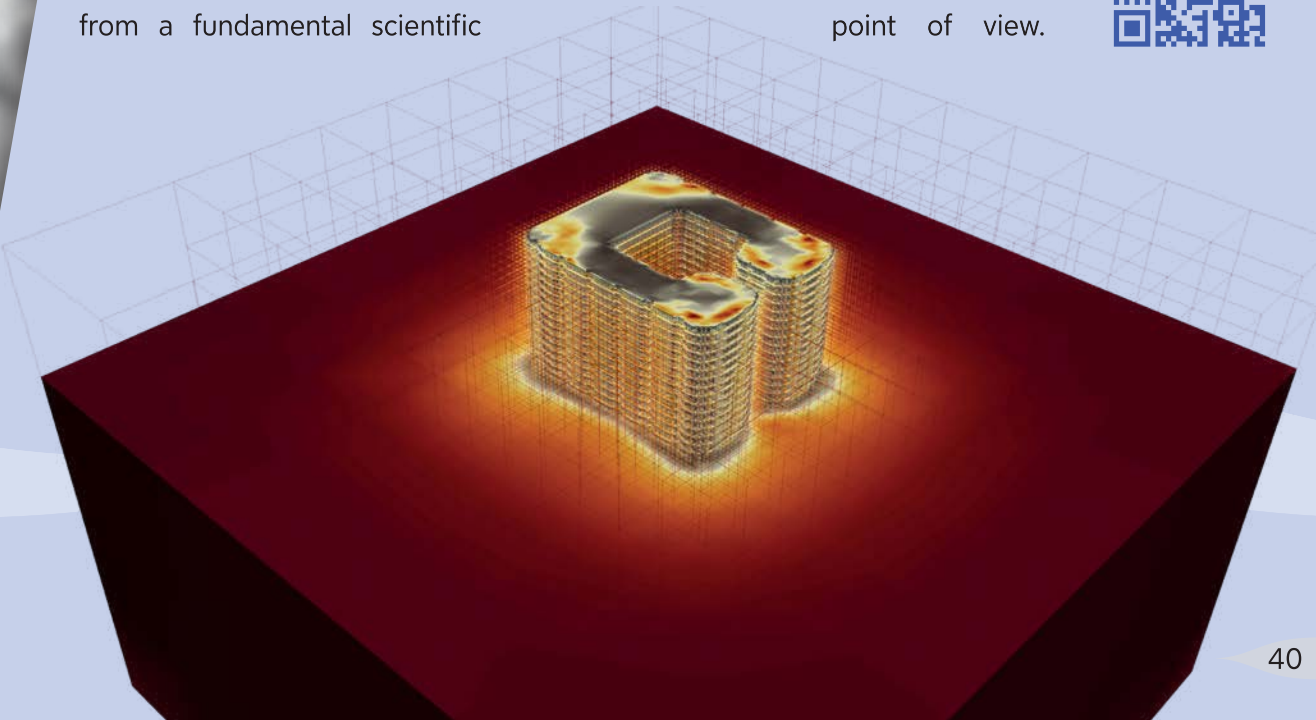
Ongoing research includes the direct manufacturing of beam-shaping elements in bulk glass, which would offer more degrees of freedom compared to a relief. Beyond additive manufacturing, beam shaping also plays an increasing role in other directions of research, for example as a **tool in optical metrology**.

CRC 814 – Additive Manufacturing

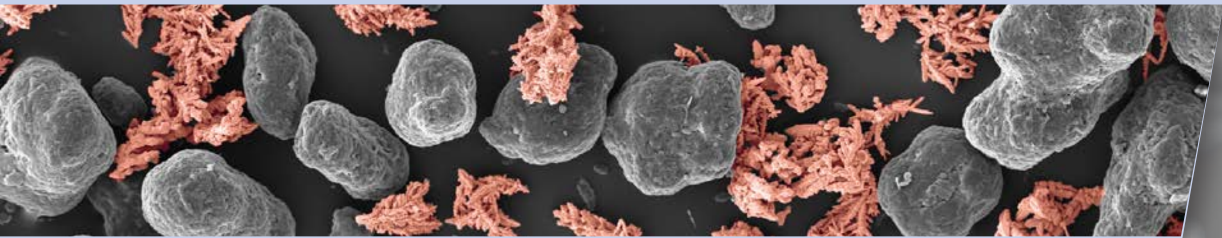
– by Andreas Jaksch –



In recent years, powder- and beam-based additive manufacturing processes have successfully established in the fabrication of **highly individualized, geometrically complex components**. Generating functional components for series production places the highest demands on the robustness of the processes, the feasibility and reproducibility of the component properties, and the degree of automation. These challenges are within the focus of the Collaborative Research Center 814. CRC 814 focuses on additive manufacturing processes that **apply powder layer by layer** and melt it selectively via a laser or electron beam. This beam melting, applied to metals and polymers, is investigated from a fundamental scientific point of view.



The goal of CRC 814 is the production of multifunctional components from one or more materials with both **locally and globally defined reproducible properties**. Before the start of the first funding period in 2011, powder- and beam-based additive manufacturing processes could be assigned to prototype construction or to produce components with a quantity of „one" on a material-specific basis. In order to advance these technologies, a **fundamental understanding of the processes** was created in the first funding period of the CRC 814. Thereby, decisive requirements and influences on the material systems, processes, and components were identified.



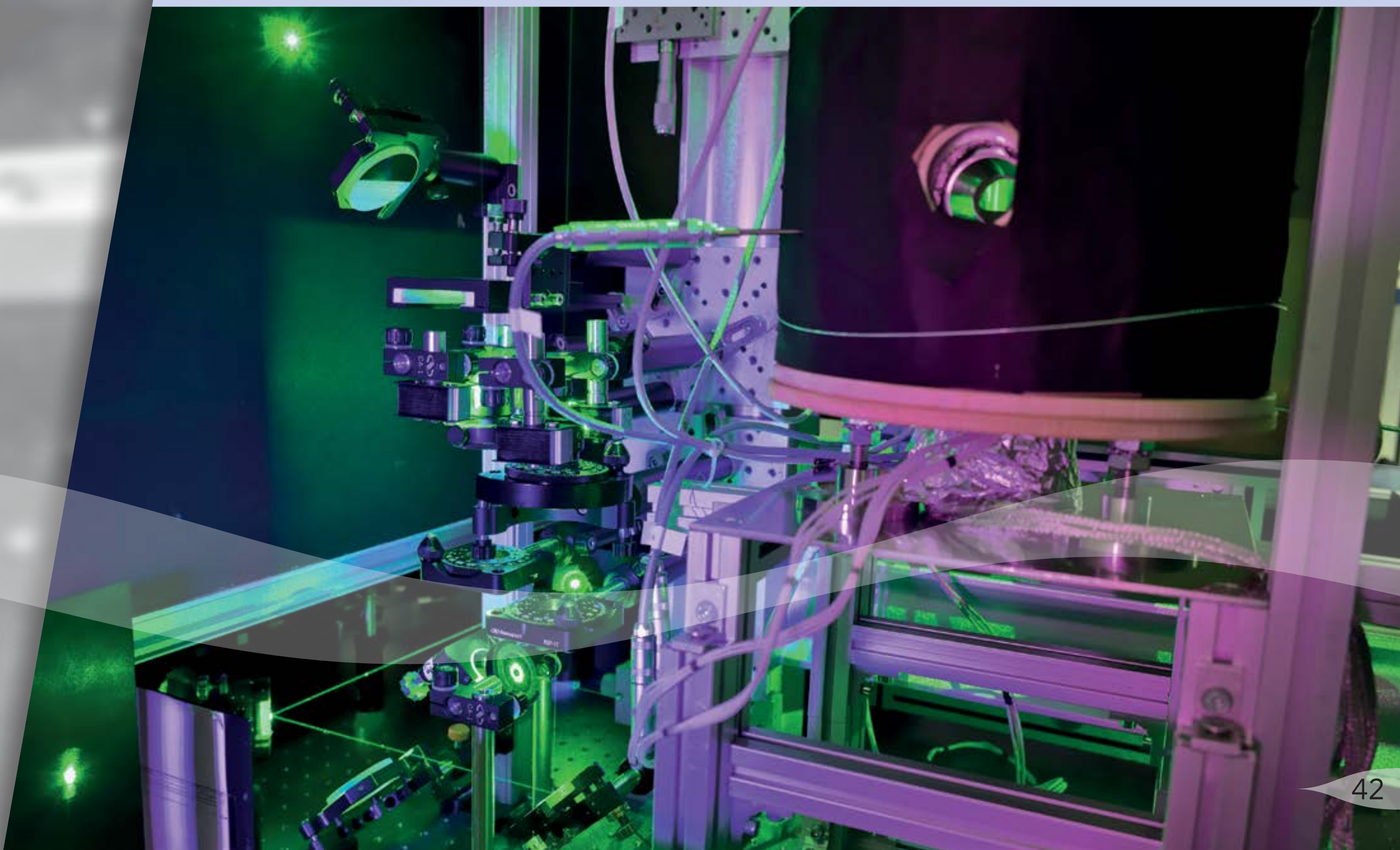
In the second funding period, the CRC 814 scientists worked on the **optimization of the process control**, i.e., the adaptation and expansion of the available material systems to the requirements defined in the first funding period. Further points of focus lied in process control and monitoring in order to identify influences on the reproducibility of component properties, as well as increasing the robustness of the process with respect to disturbance variables. These findings were evaluated in terms of the resulting component properties and used to validate the simulation tools.

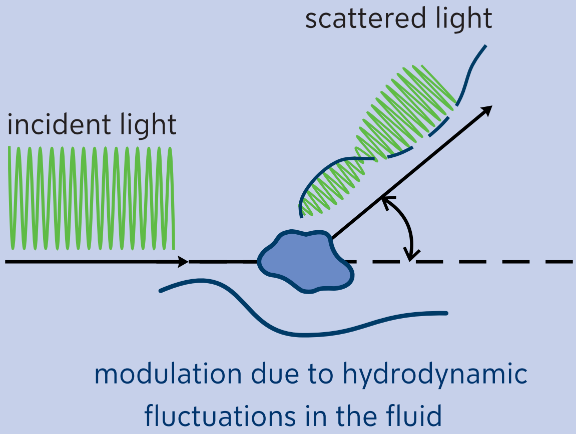
Today, **30 scientists work on 15 interdisciplinary subprojects** on powder, material, process, and part properties. Furthermore, in three transfer projects, results achieved in the CRC 814 are tested in industrial conditions.

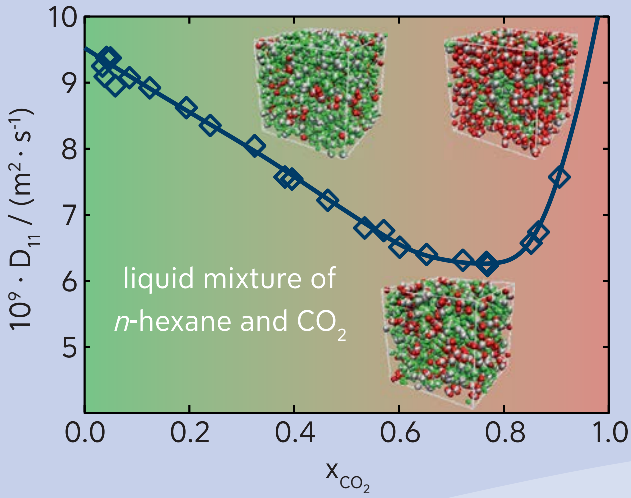
Thermophysical Property Research

– by Tobias Klein, Thomas Koller, Johannes Knorr, Michael Rausch, and Andreas Paul Fröba –

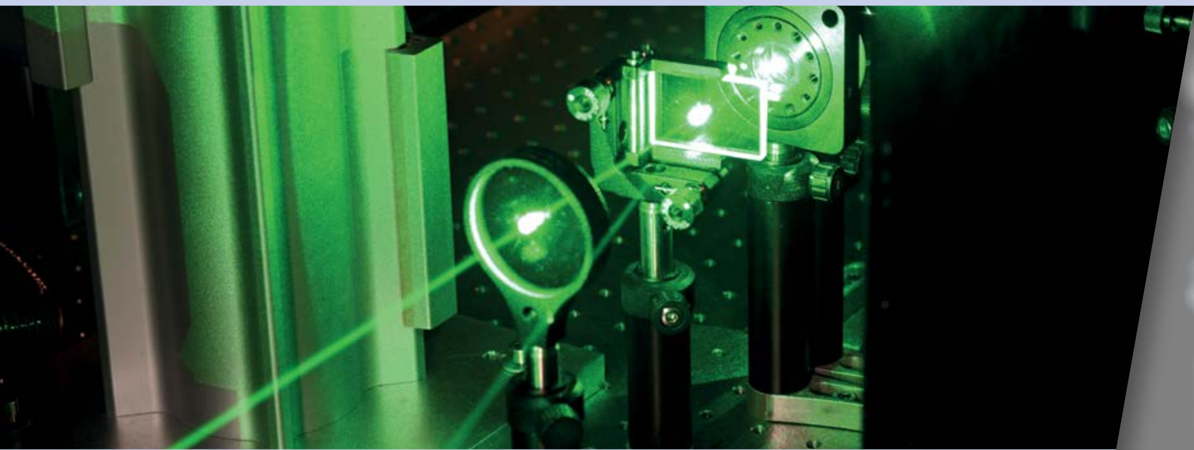
Accurate knowledge of thermophysical properties of working fluids in chemical and energy engineering is necessary for the proper design or optimization of apparatuses and processes. This aspect is linked to the subject area Thermophysical Property Research dealt within the research activities of the Institute of Advanced Optical Technologies – Thermophysical Properties (AOT-TP). Closely associated with its name, AOT-TP is active in the development and optimization of several – mainly optical – methods for the accurate **determination of thermophysical properties** over a wide range of thermodynamic states including harsh conditions.



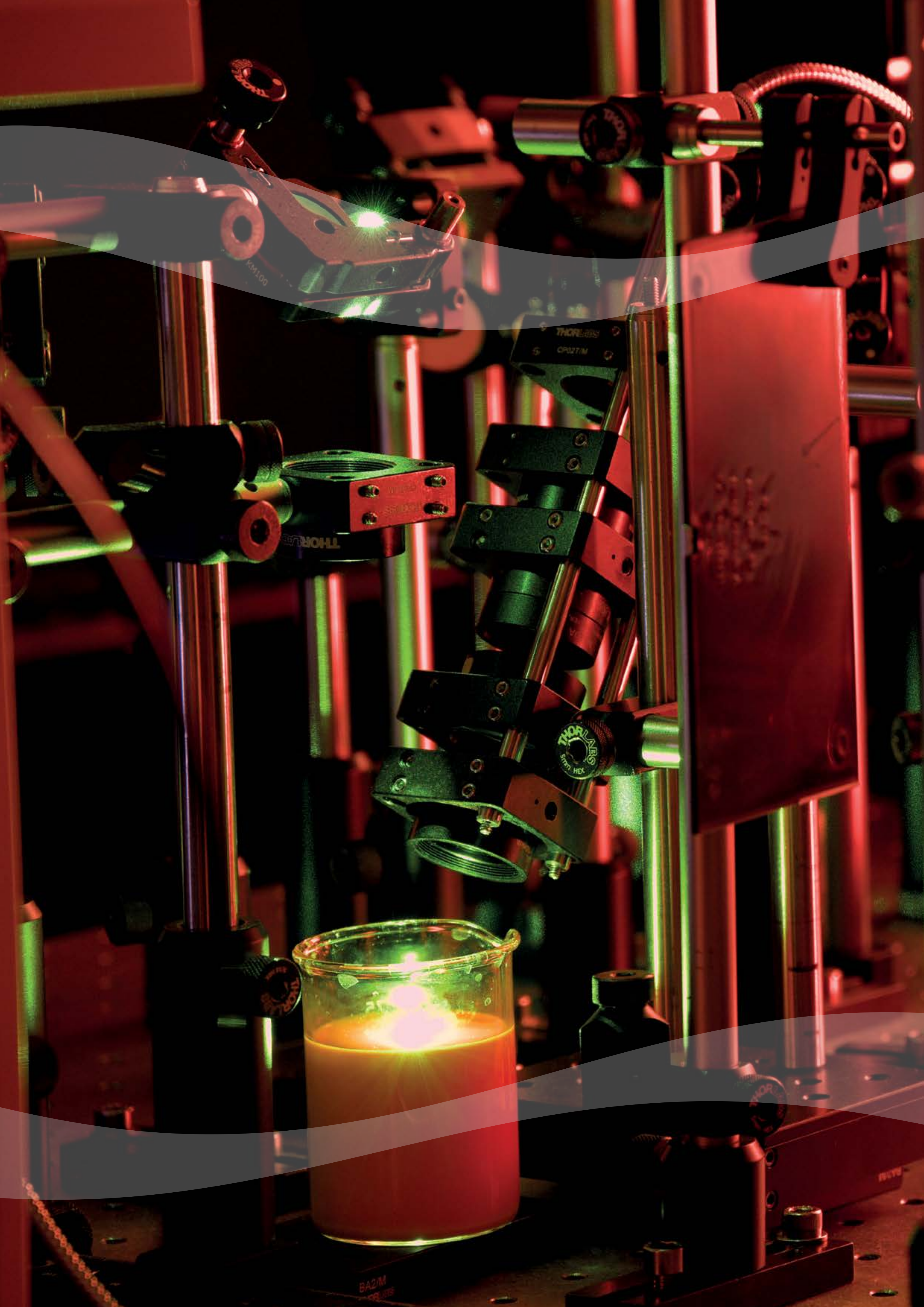




In addition to **dynamic light scattering** (DLS), which is continuously advanced for its application to the bulk of fluids and to interfaces, also called **surface light scattering** (SLS), further techniques are currently being established at the institute. They include, e.g., the **shadowgraph method** for the simultaneous determination of several transport properties in fluid mixtures as well as **laser-induced gratings** (LIG) applied to the bulk of fluids and interfaces. Furthermore, **Raman spectroscopy** is used for the determination and characterization of sample composition and structure.



Current activities regarding the theoretical determination of transport and equilibrium properties focus on **molecular dynamics (MD) simulations**. Here, available molecular models, known as force fields, are used, modified, and tested regarding their transferability within specific substance families. MD simulations help to identify and quantify **structure-property relationships** which can serve for the development of prediction methods for specific properties of various fluid classes. Within thermophysical property research by using optical techniques and MD simulations, recent objects of investigation cover, e.g., liquid organic hydrogen carriers (LOHCs), polymer melts, electrolyte systems, alkanes, ionic liquids, and particulate systems in form of microemulsions and nanofluids.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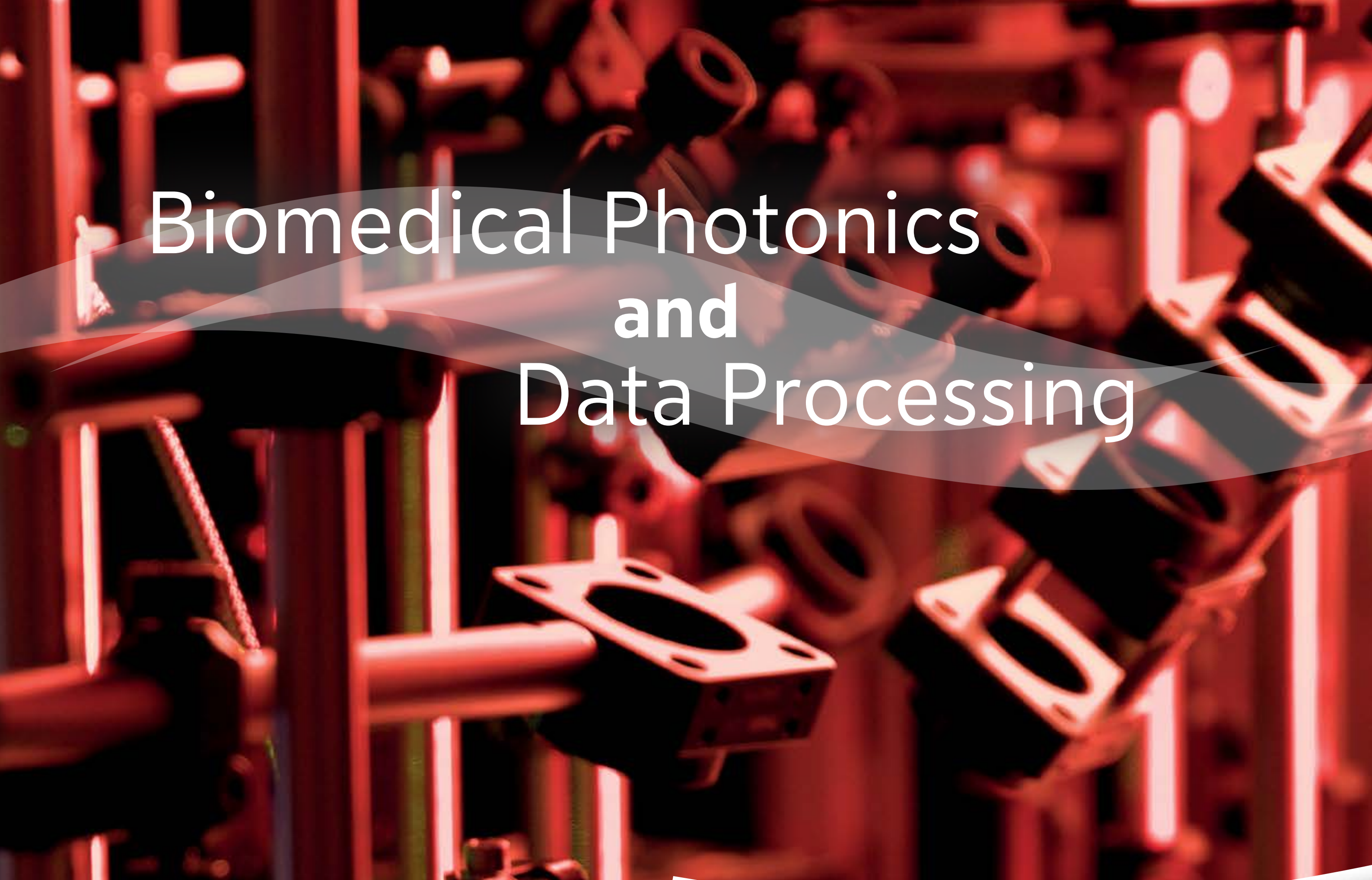


Biomedical Photonics and Data Processing

Visualizing and influencing biological structures and processes using photonic technologies is a both challenging and promising field of research. It spans from fluorescence spectroscopy of human tissue and in-vivo endo-microscopy to opto-biomechatronics and optogenetics. Further, artificial intelligence and deep learning algorithms play an increasing role in data processing, pattern recognition and classification in medical imaging, e.g. in MRT diagnostics. Future healthcare and medical applications based on photonic technologies developed by more than 30 research groups in Erlangen accelerate and improve diagnoses and therapies on many kinds of diseases.

Scientist Spotlight

Always have applications in mind

Oliver Friedrich

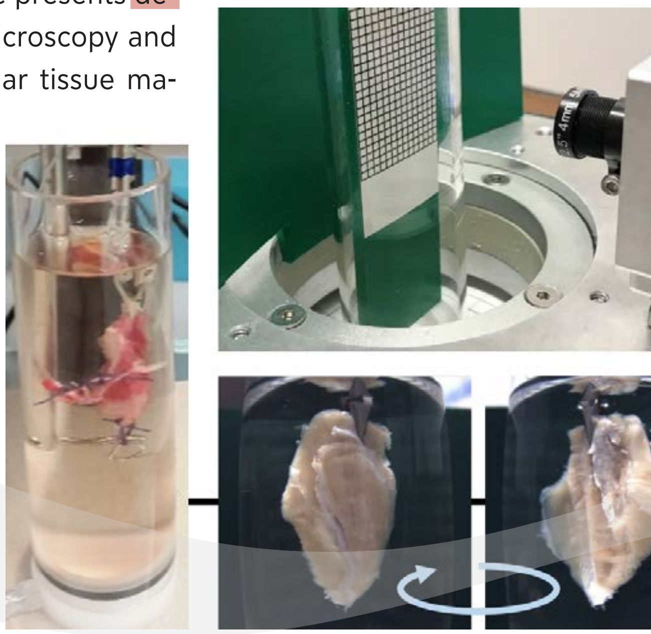
Research Group

Oliver Friedrich had a quite diverse education, studying Medicine and Physics at University of Heidelberg, then specializing as Physiologist and Biophysicist before finally ending up at FAU as Biotechnologist with a strong focus on label-free optical technologies development and applications. In between, he spent a year in Brisbane at the University of Queensland and has been going back and forth between Germany and Australia ever since. In Erlangen, he directs the Institute of Medical Biotechnology.

The central research topic is to conceive, design, engineer and apply new technical solutions for Biomedical Research and Life Sciences in the fields of label-free biophotonics, cell biomechanics and biomechatronics, bioreactor technologies, and combinations thereof, like the new field called 'Opto-Biomechatronics'.

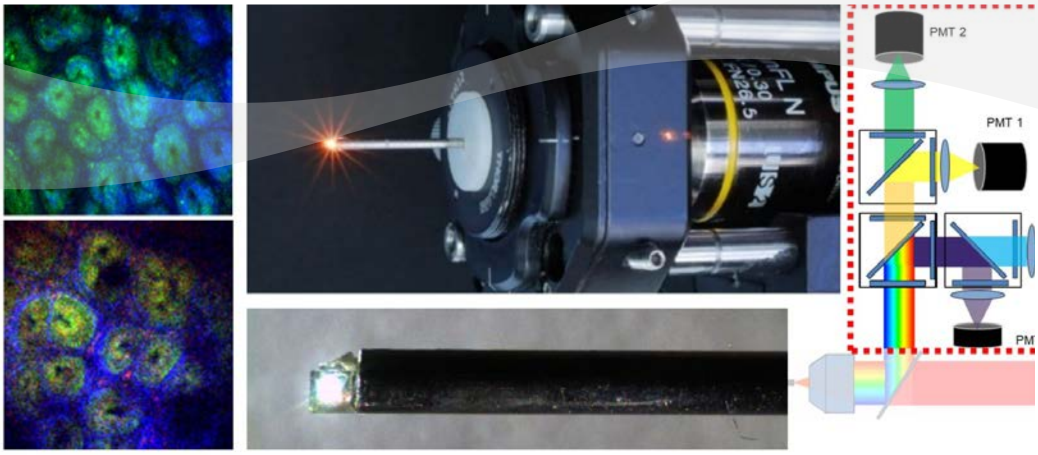
Latest Publications

In his latest publications related to optics, he presents detection of tissue necrosis via multiphoton microscopy and imaging of collagen structures of extracellular tissue matrix and muscle motor-protein architecture using two-photon excited autofluorescence and second harmonic generation in optically cleared tissue with penetration depths of several hundreds of microns. This paper lays the foundation to know what to look for to detect muscle damage with cellular resolution. One day needle endomicroscopy with two-photon imaging becomes available in an even more miniaturized form suitable to perform needle imaging in muscle.



What are the future questions you are working on and what are the particular challenges?

We are currently working on an automated system for organ and tissue decellularization and regeneration that includes actuator systems for mechanical conditioning and optical sensor technologies to receive feedback about the tissue quality based on imaging modalities and tissue architecture. Challenges here are of course to combine the opto-biomechatronics hardware and software environment but also find biological cues and 'recipes' to mature bioartificial constructs into functional bio-tissue. That would be a major advancement in Tissue Engineering where optical technologies make an important contribution. Also, we are continuing to use our multiphoton microscopy/endomicroscopy technologies to combine with AI modalities in the field of digital pathology. We have very fruitful collaborations here with the Medical Clinics in Erlangen (i.e. the Department of Medicine I).



What do you particularly appreciate about Erlangen as a research location?

The multi-disciplinarity; when I look back on my time in Heidelberg, what I was missing there most, was an engineering or technology aspect, at the time. Here, at FAU, the complete spectrum of a 'full university' provides the opportunity to directly connect between specialists in the MINT areas. It is easy to find new collaborators here and try out even unconventional approaches. I enjoy brainstorming with partners from the clinics and biology; they always have very applied needs where we start to think about technological solutions.

What advice can you give to young people who are interested in studying optics-related subjects in Erlangen?

I am very application-driven; therefore, my advice would be to always have applications in mind for your specific optics-topic, e.g. 'where would I want to go from there in the field of Medicine, Physics or Engineering with what applications in mind?' It is easy to get entangled in the fundamentals; having an application goal can help to sort one's mind and act as a bridge to applied problem-solving.

Scientist Spotlight

"Look into other disciplines"

Maximilian Waldner

Maximilian Waldner is a clinician scientist with a specialization in gastroenterology. Since the beginning of his scientific career at the Ludwig-Maximilians-Universität München, he has been interested in applications of optical imaging techniques for the evaluation of inflammatory diseases and cancer.

Following his clinical and scientific training in Mainz and Erlangen, he started his own research group as Professor for Functional Imaging in Medicine in Erlangen. His group is interested in exploring new optical techniques to enable the label-free characterization of immune responses in intestinal inflammation and cancer.

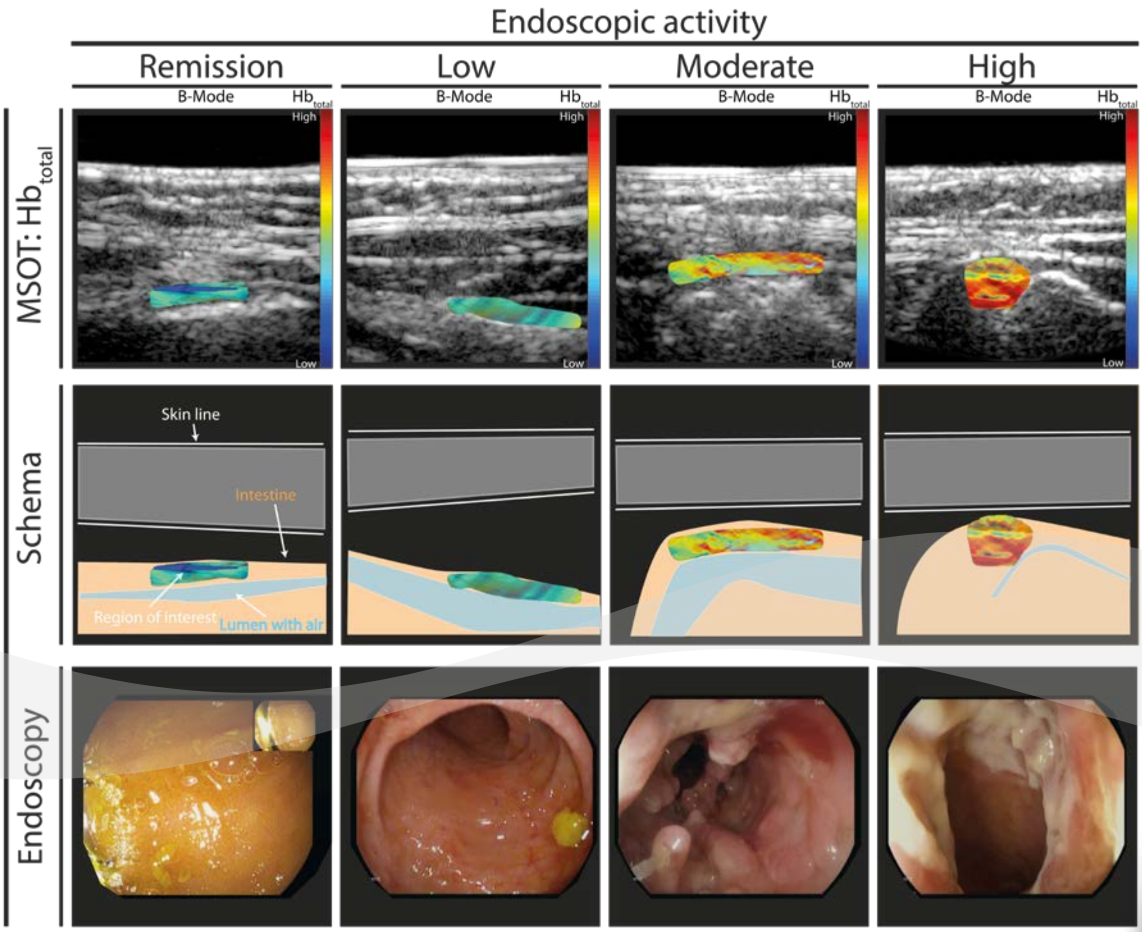
Research Group

His latest publications related to optical technologies cover multispectral optoacoustic tomography on Duchenne muscular dystrophy and inflammatory bowel disease patients. These papers were among the first to show new clinical applications of optoacoustic imaging.

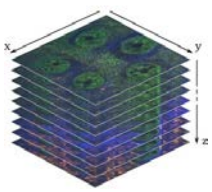
Latest Publications

What are the future questions you are working on and what are the particular challenges?

We are currently working on various spectroscopic approaches to aid the diagnosis, characterization and therapeutic management of inflammatory diseases within the gastrointestinal tract. Challenges include the adaption of existing technologies to the specific scientific question and the interpretation of acquired data. To successfully work on these topics, interdisciplinary research teams are mandatory.



What do you particularly appreciate about Erlangen as a research location?



Erlangen offers a unique environment for translational research on new optical technologies and advanced data analysis methods. This includes SAOT, the Max Planck Institute for the Science of Light, the newly founded Max-Planck-Zentrum für Physik und Medizin as well as the Department for Artificial Intelligence in Biomedical Engineering (AIBE) at the Faculty of Engeneering.

What advice can you give to young people who are interested in studying optics-related subjects in Erlangen?

Take advantage of the possibilities offered by the wide range of applications for optical technologies Erlangen offers. Look into other disciplines like biomedicine or data analysis.

Scientist Spotlight

"Just come here and experience it yourself!"

Andreas Maier

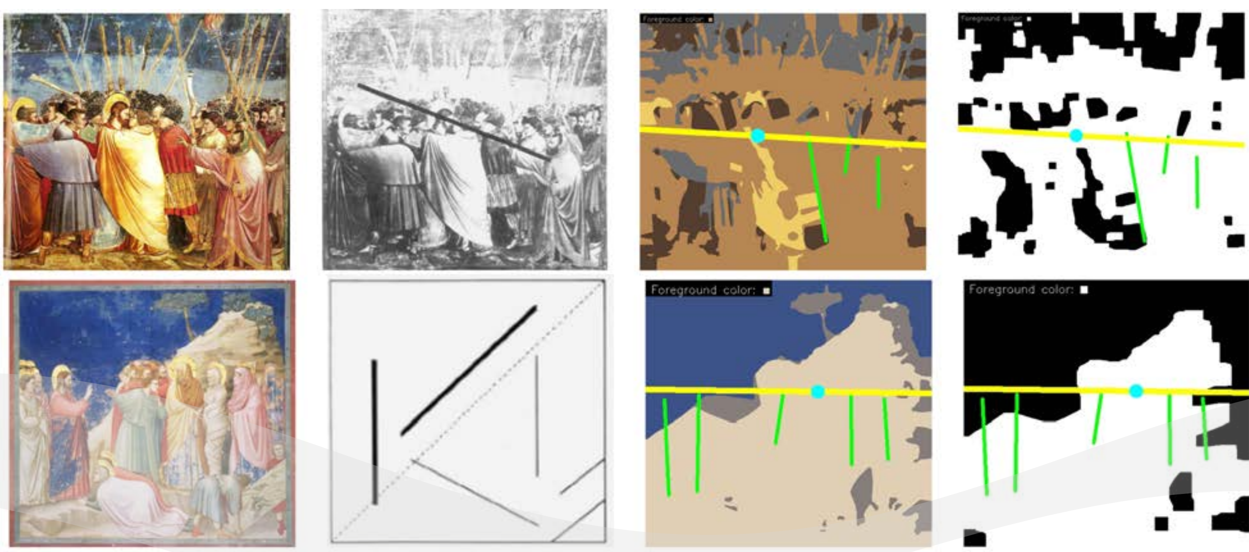
Andreas Maier is a professor of computer science working in the fields of pattern recognition and machine learning. After graduation in 2009 he started working as post-doctoral fellow at the Radiological Sciences Laboratory at the Stanford University. Subsequently he became innovation project manager at Siemens Healthcare before he returned to FAU in 2012.

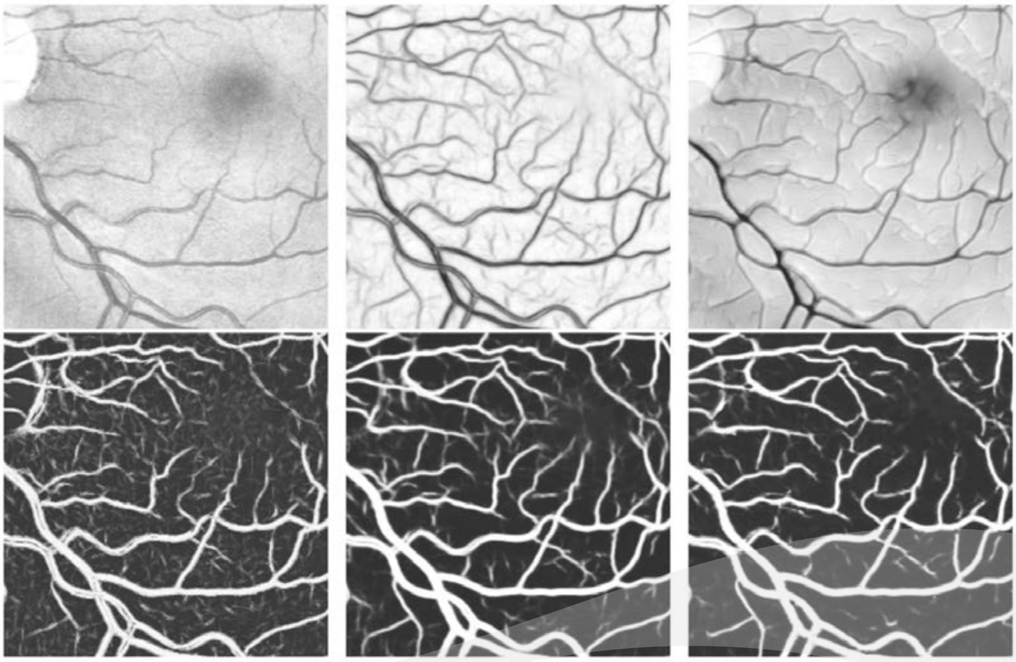
Since 2015 he is head of the Pattern Recognition Lab and mainly works close to the signal from speech recognition to image and abstract data processing.

Research Group

Latest Publications

His latest publications include deep learning techniques for image reconstruction in computed tomography (CT) as well as for grading of fracture severity or melanoma characterization.





What are the future questions you are working on and what are the particular challenges?

We have a couple of topics that will be very relevant for the future from medical image analysis over computer vision to AI-guided dialogue systems. One topic that might be very important in the future is animal sound recognition which may lead to a better understanding of our nature in the future. Also, we are interested in the actual processing inside the brain to learn more about its complex processing to gain further insights on phenomena such as consciousness.

What do you particularly appreciate about Erlangen as a research location?

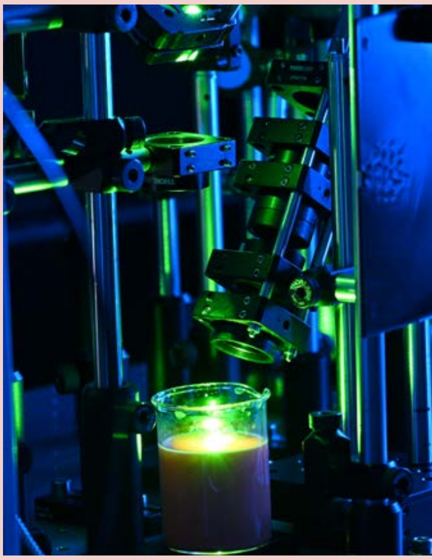
Erlangen is a great place to live and work. It features an international English-speaking atmosphere and is home to a great academic and industrial institutions.

What advice can you give to young people who are interested in studying optics-related subjects in Erlangen?

Just come here and experience it yourself!

Clinical Photonics Lab

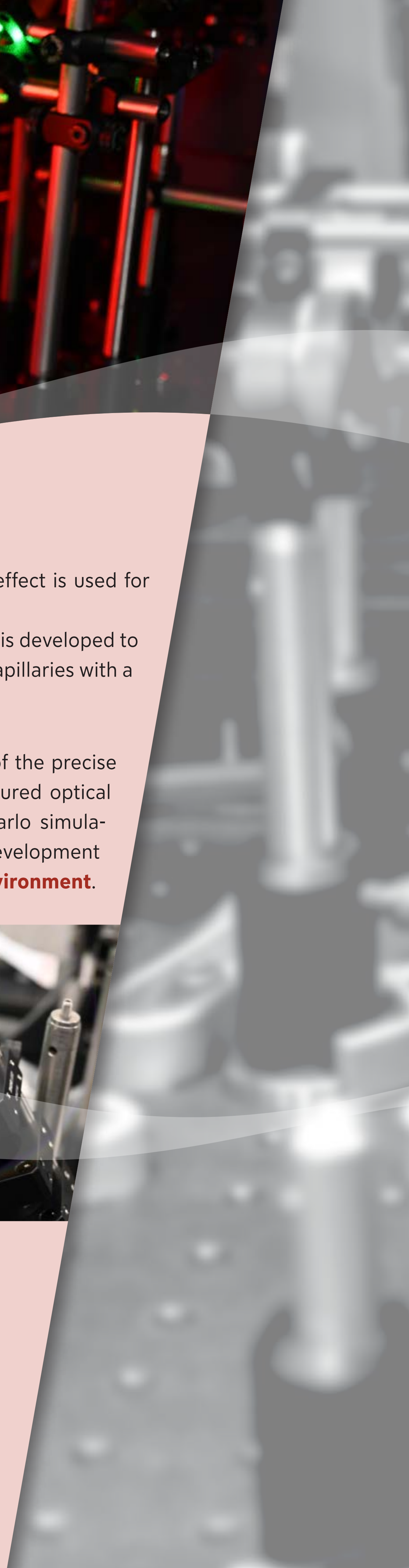
– by Martin Hohmann –



The main objective of the Clinical Photonics Lab (CPL) is to explore **optical technologies in biology and medicine** with a focus on diagnostics. In general, there are two main approaches for diagnostics: First, the **measurement of a physical parameter** (e.g. the absorption coefficient at a certain position or the diameter of a capillary) can be associated with a specific disease. Second, there is the possibility of an **automatic detection** of the target disease using a black-box approach like **machine learning** (ML). While the first approach often requires the development of new methodologies, the second one can be used with both known as well as new methods.

Most methods in CPL build on both the measurement of physical parameters and ML:

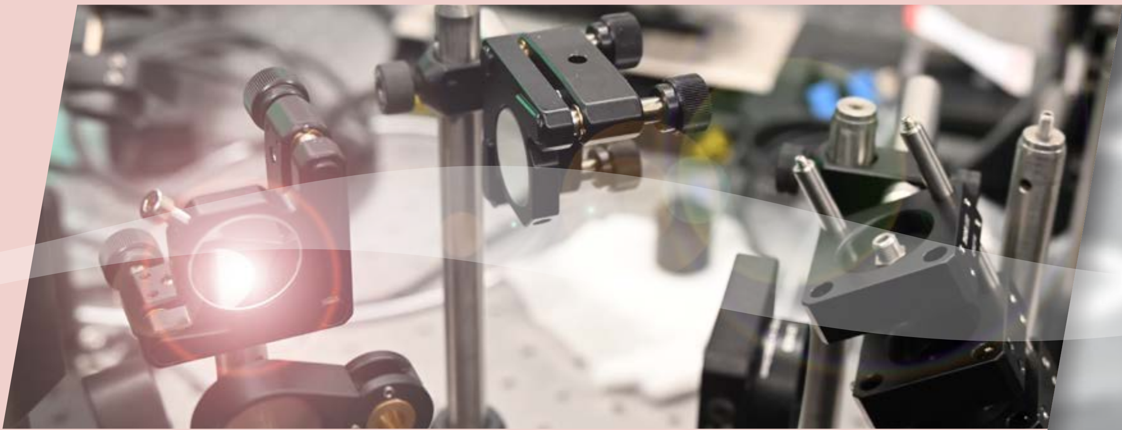
- **Hyperspectral imaging** is used with ML to find carcinoma in the gastrointestinal tract and it is applied to reconstruct depth information of inclusions in tissue.
- **Laser-induced breakdown spectroscopy** (LIBS) is combined with ML to find carcinoma and to differentiate among tissue types. At the same time, the underlying differences in the elemental composition are investigated.
- Also **random lasing** is used with ML to differentiate tissue types. Moreover, it is applied to directly measure the scattering coefficient of tissue.



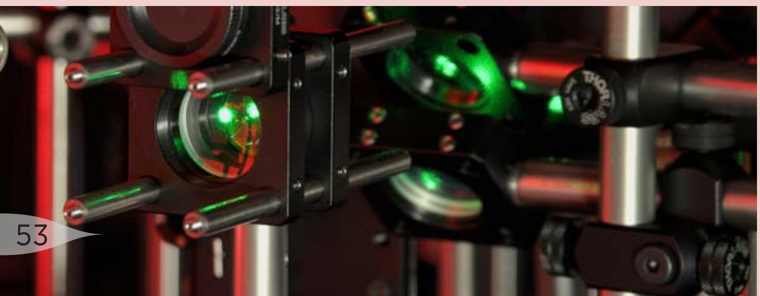
Additionally, new methods are researched:

- By a speckle pattern, the surface vibrations can be measured. This effect is used for speckle based **remote photo-acoustics**.
- **Shifted position-diffuse reflectance imaging** as new variant of DRS is developed to enable the measurement of vasoconstriction/-dilation of superficial capillaries with a diameter of a few micrometres.

As the research of the presented methods requires the knowledge of the precise optical properties, measurements of them are conducted. Self-measured optical properties as well as those from literature are applied for Monte-Carlo simulations of tissue and the manufacturing of phantoms. This enables the development and validation of the aforementioned methods in a **controlled environment**.



The heads of the lab are Maximilian Waldner from the University Hospital Erlangen and Michael Schmidt from the Institute of Photonic Technologies (LPT).

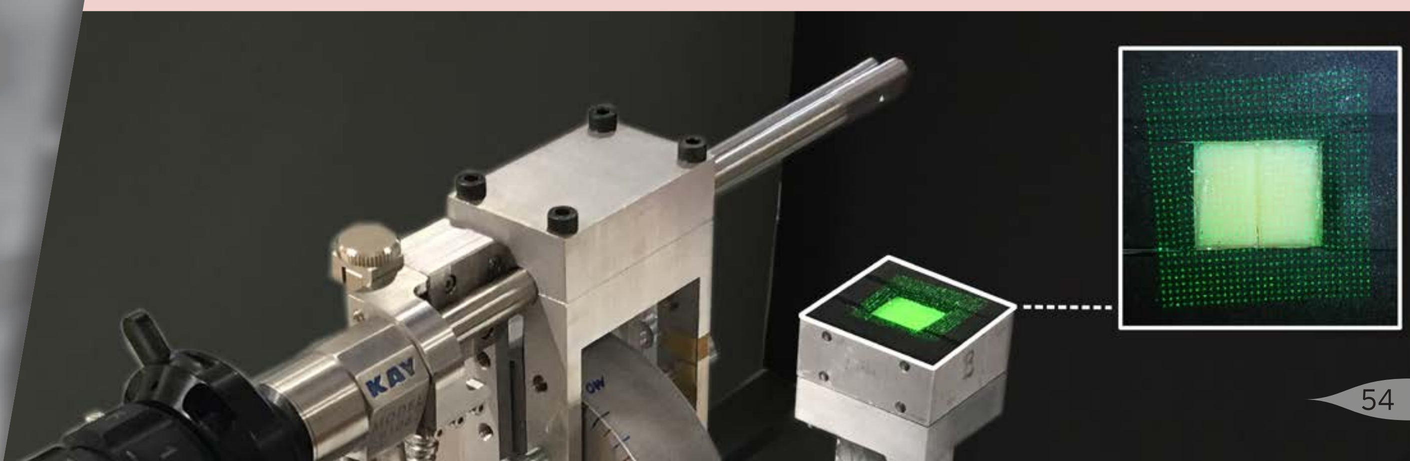


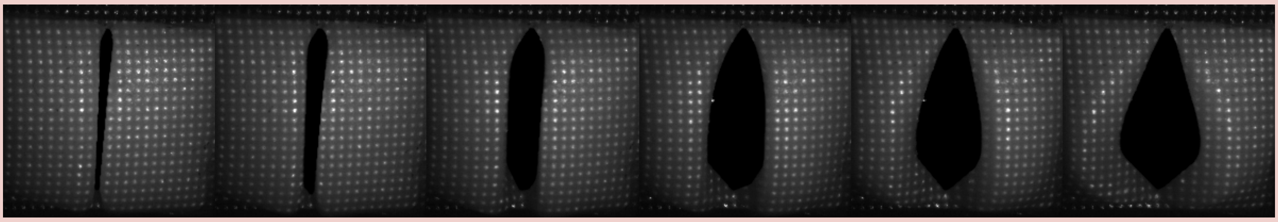
Three-Dimensional Laryngoscopy

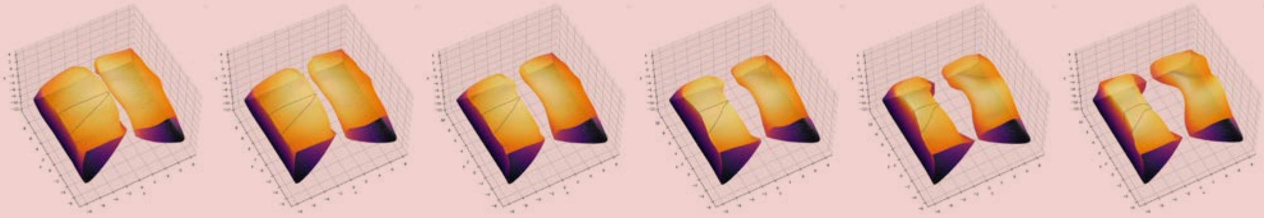
– by Jann-Ole Henningson –

Human interaction is fundamentally based on the ability to communicate. A lasting impairment of our oral expression is necessarily accompanied by severe social and economic limitations, increasing the significance of **diagnosing laryngeal and voice-related disorders**. Conventionally, human vocal folds have been examined using standard video endoscopy that only regards the 2D lateral and longitudinal deformation of vocal folds. However, recent research has found that vocal folds during phonation also have a significant vertical deformation. This third dimension therefore needs to be taken into account as well.

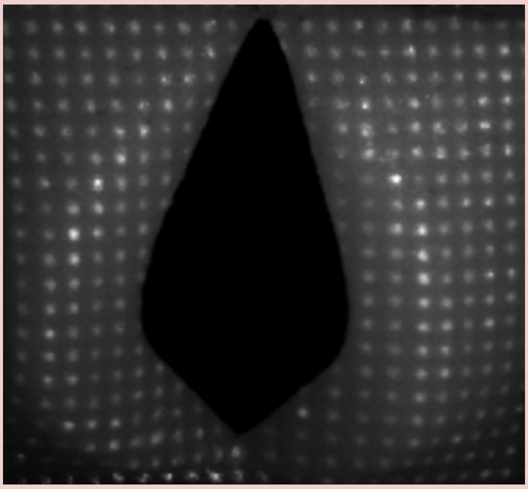
In a collaboration with the Division of Phoniatrics and Pediatric Audiology at the Department of Otorhinolaryngology of the University Hospital Erlangen, the Institute of Photonic Technologies (LPT) and the Chair of Visual Computing of the Friedrich-Alexander-Universität Erlangen-Nürnberg develop novel **endoscopic structured light systems and specialized algorithms** that reconstruct the three-dimensional deformation of oscillating vocal folds in real-time. In all of Europe, Erlangen is the only place where such a system already exists.

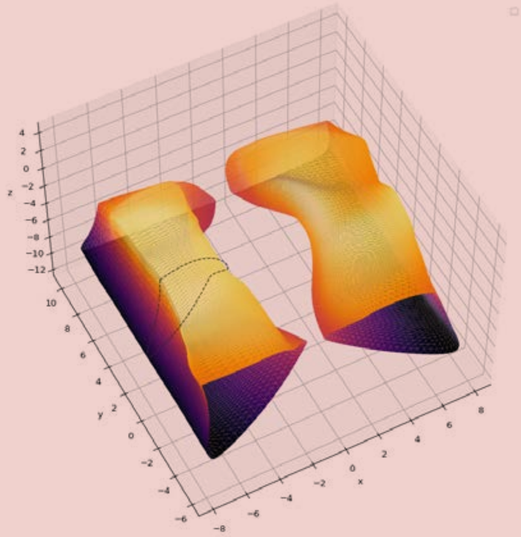






The system consists of an **endoscope with a built-in laser projection unit**, projecting a symmetric laser grid into the laryngeal area and onto the vocal folds. As vibrating vocal folds require a high temporal resolution, the system records videos with up to 4000 Hz using a high-speed video camera. It estimates the laser points position inside the image, determines which laser beam the point corresponds to, and then uses stereo triangulation techniques to compute the 3D position on the vocal fold. In a next step, a novel parametric vocal fold model is fitted into the estimated surface points to obtain a **dynamic 3D surface model of the vocal folds**, which is then the basis for medical diagnosis.





Looking forward, this work may take a big step towards integrating **3D video endoscopy** into the clinical routine as well as improving the ability to diagnose voice related disorders.

Publication Spotlights

The backbone of photonics research in Erlangen is formed by several hundred **doctoral candidates and junior scientists**. With their everyday work in the labs and offices, they greatly contribute to the scientific achievements of the research groups.

To increase the visibility of these young scientists, and to provide an insight into their research to the general public, **SAOT spotlights** their latest **scientific results and publications**. On this page you find a small snippet of an **online exhibition**, which introduces their work, gives impressions of their labs and provides links to detailled information on the respective topic. This online exhibition is **constantly updated**.

Online Exhibition

Marc-Oliver Pleinert

Validating Quantum Theory

Yakun He

Single-Component Organic Solar Cells

Florian Kordon

Deep Learning for Knee Surgeries

Karen Schwarzkopf

In-Situ Imaging of Additive Manufacturing

Max Köppel & Jasper Podschus

Remote Temperature Sensing

Moritz Späth

Improving Vessel Diagnostics

Florian Bauer

In-Situ Spectroscopy of Soot Formation

Stefan Richter

Locating Quantum Emitters

Publication Spotlights on LinkedIn

Graduate Programs **and** Schools

Erlangen Graduate School in Advanced Optical Technologies

In 2006, the Erlangen Graduate School in Advanced Optical Technologies (**SAOT**) was established at Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU) within the **excellence initiative** by the German federal and state governments to promote science and research at German universities.

Homepage

Since its foundation, SAOT has been the **central hub** for activities in the field of **"Optics and Optical Technologies"** at FAU and associated institutions by providing an **interdisciplinary research and education program** of excellence within a broad international network of distinguished experts to promote innovation and leadership. The multi-faceted activities cover the areas of optical metrology, optical material processing, optics in medicine, optics in communication and information technology, optical materials and systems, and computational optics. Furthermore, SAOT increases the **scientific outreach to the general public** and coordinates joint applications on research funding in the fields of photonics and optical technologies.

For young scientists, SAOT provides an interdisciplinary, structured **education and research training program** towards a doctoral degree (PhD) within a highly attractive research environment. This means that, in addition to their own research, candidates participate in a structured training program that includes **academies, workshop, seminars, and key qualification events**. Personal progress, which includes active participation in international conferences and publication of own research results, is monitored in a credit point system. To date, **more than 150 candidates** have completed the SAOT program.

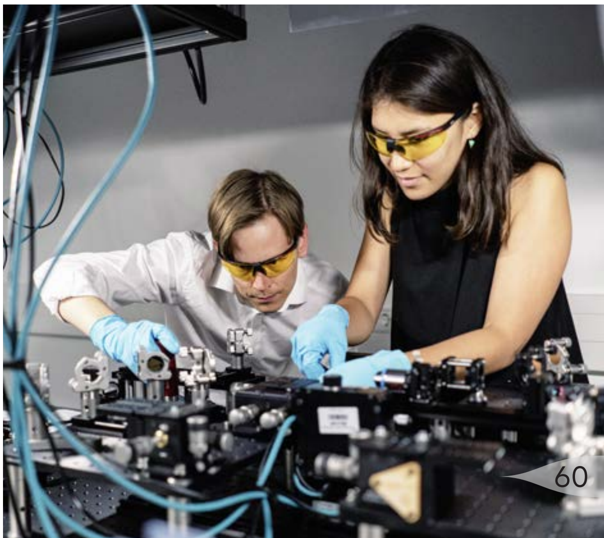
Max Planck School of Photonics

Cutting-edge research in optics and photonics has long since ceased to take place in the ivory tower of a single laboratory, but happens in comprehensive research networks. So what could be more obvious than to also train young scientists as a network and make the knowledge of the best researchers in Germany available to them? This is the idea of the Max Planck School of Photonics (**MPSP**), an **international graduate school** established in 2018 and funded by the German Federal Ministry of Education and Research (BMBF), the Max Planck Society and the Fraunhofer Society.

Homepage

The school offers the most talented young scientists in the field of photonics a unique and **integrative MSc and PhD program** in a network of 16 universities and non-university research institutions. The PhD candidates first obtain a **Master's degree** in photonics at one of **three teaching universities** – the FAU in Erlangen, the FSU in Jena or the KIT in Karlsruhe – before moving to one of the **partner research institutions** throughout Germany for their **doctorate** – e.g. the Max Planck Institute for the Science of Light in Erlangen. During the entire time, they can network with each other and with more than 40 supervising senior-researchers, called "Fellows", at virtual events or in-person **Spring and Autumn Schools**. Joint virtual courses on the „Virtual Campus" and individual transferable-skills trainings prepare the PhD candidates for a successful career in academia or industry and complete the doctoral program.

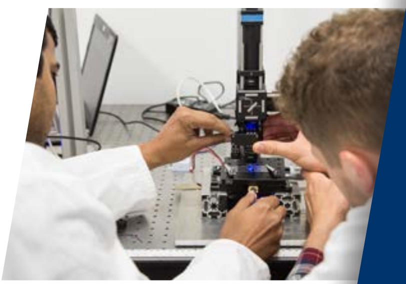
This new, network-oriented graduate program stimulates new research collaborations and makes **perfect use of synergies** between the partner institutions. Thereby, it brings young international talents to Germany and further expands Germany's role as a leading optics and photonics nation. **Erlangen plays a key role** in this network with currently two partner institutions, eleven MPSP Fellows and 15 enrolled PhD candidates.



Master Program in Advanced Optical Technologies

The Master's degree program in Advanced Optical Technologies (**MAOT**) provides extensive training in **all essential fields of modern optical technologies**. Just like SAOT, it covers:

- Optical Metrology
- Optical Materials and Systems
- Optics in Communication and Information Technology
- Computational Optics
- Optics in Medicine
- Optical Material Processing
- Physics of Light



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Students are taught the fundamentals of optics and lasers, and receive an introduction to all topics, from which they choose two as major subjects. MAOT is **highly interdisciplinary**; lectures are given by experts from the fields of physics, medicine, computer science and engineering. The program is **open to students from all disciplines of engineering as well as physics**. Students can compile their own study plan from a wide range of courses that can be combined flexibly. They can choose to focus on one major in detail or study several majors to gain broader knowledge.

Graduates proceed with a PhD in Erlangen or at another university. Moreover, they can also decide to apply for a position in industry instead. A significant proportion of the people who work in the optical industry have a university education, meaning there are many opportunities for highly qualified Master's graduates. MAOT is an **international program** with courses in English and students from many different countries. While studying, MAOT students develop their language and intercultural skills. The program is **part of the Elite Network of Bavaria**. MAOT collaborates closely with SAOT, the Max Planck Institute for the Science of Light (MPL), the Fraunhofer Institutes and the Bavarian Laser Center (blz).

bLz Bayerisches Laserzentrum

HI ERN
Helmholtz Institute
Erlangen-Nürnberg
part of
Forschungszentrum Jülich

OICE

Fraunhofer
IIS

Fraunhofer
IISB

MAX PLANCK INSTITUTE
FOR THE SCIENCE OF LIGHT

Participating Institutions

Fraunhofer
IISB

Fraunhofer Institute for Integrated Systems and Device Technology

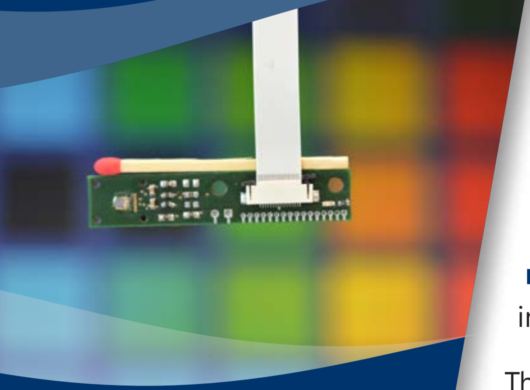
Intelligent Power Electronic Systems and Technologies - according to this motto, the Fraunhofer Institute for Integrated Systems and Device Technology **IISB**, founded in 1985, conducts **applied research and development** for the direct benefit of industry and society. With scientific expertise and comprehensive systems know-how, IISB supports customers and partners worldwide in **transferring current research results into competitive products**, for example for electric vehicles, aviation, production, and energy supply.

The institute consolidates its activities in the two major business areas of **Power Electronic Systems** and **Semiconductors**. In doing so, it comprehensively covers the entire value chain from basic materials to semiconductor device, process, and module technologies to complete electronics and energy systems. As a unique European competence center for the semiconductor material **silicon carbide (SiC)**, IISB is a pioneer in the development of highly efficient power electronics, even for the most extreme requirements. With its solutions, IISB repeatedly sets benchmarks in energy efficiency and performance. By integrating intelligent data-based functionalities, **new use cases** are continuously emerging.

The IISB employs about 300 people. Its headquarters are in Erlangen, with an additional branch lab at the Fraunhofer Technology Center High Performance Materials (THM) in Freiberg. The institute closely collaborates with Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU) and is a founding member of the **Energie Campus Nürnberg** (EnCN) as well as the **Leistungszentrum Elektroniksysteme** (LZE). In joint projects and associations, IISB collaborates with numerous national and international partners.

Homepage

Fraunhofer Institute for Integrated Circuits



Homepage

The Fraunhofer Institute for Integrated Circuits **IIS**, headquartered in Erlangen, Germany, conducts world-class research on **microelectronic and IT system solutions and services**. In the field of **optical sensor technology**, application-specific optical sensors and sensor systems, especially image sensors as well as low-cost spectral sensor technology are developed.

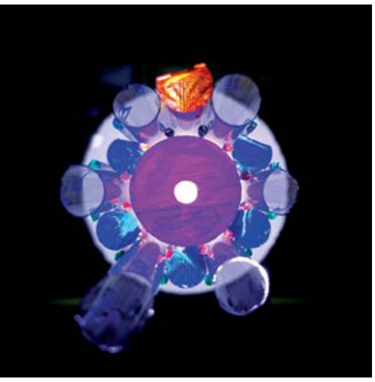
The competencies include, on the one hand, simulating the optical properties of metallic nanostructures and, on the other, IC design for photodiodes and for analog and digital signal processing. The **nanoSPECTRAL** technology makes it possible to manufacture **optical filters** for the wavelength range of visible light and near infrared (400 nm to 900 nm) at very low cost. This is done by structuring the metal layers using a CMOS semiconductor process. As a result, production costs can be kept constant regardless of the number of spectral channels to be implemented.

Current research efforts are looking into how to apply the technology in smart farming. Thanks to spectral detection of weeds, herbicides need only be applied locally at the desired location. Furthermore, the technology is also suitable for mobile consumer products in the field of cosmetics and food products as well as for environmental analytics and smart lighting.

Research at Fraunhofer IIS revolves around two guiding topics: In the area of **audio and media technologies**, the institute has been shaping the digitalization of media for more than 30 years (like MP3 and AAC). In the context of **cognitive sensor technologies**, the institute researches technologies that add a cognitive component to the function of the conventional "smart" sensor.

MAX PLANCK INSTITUTE
FOR THE SCIENCE OF LIGHT

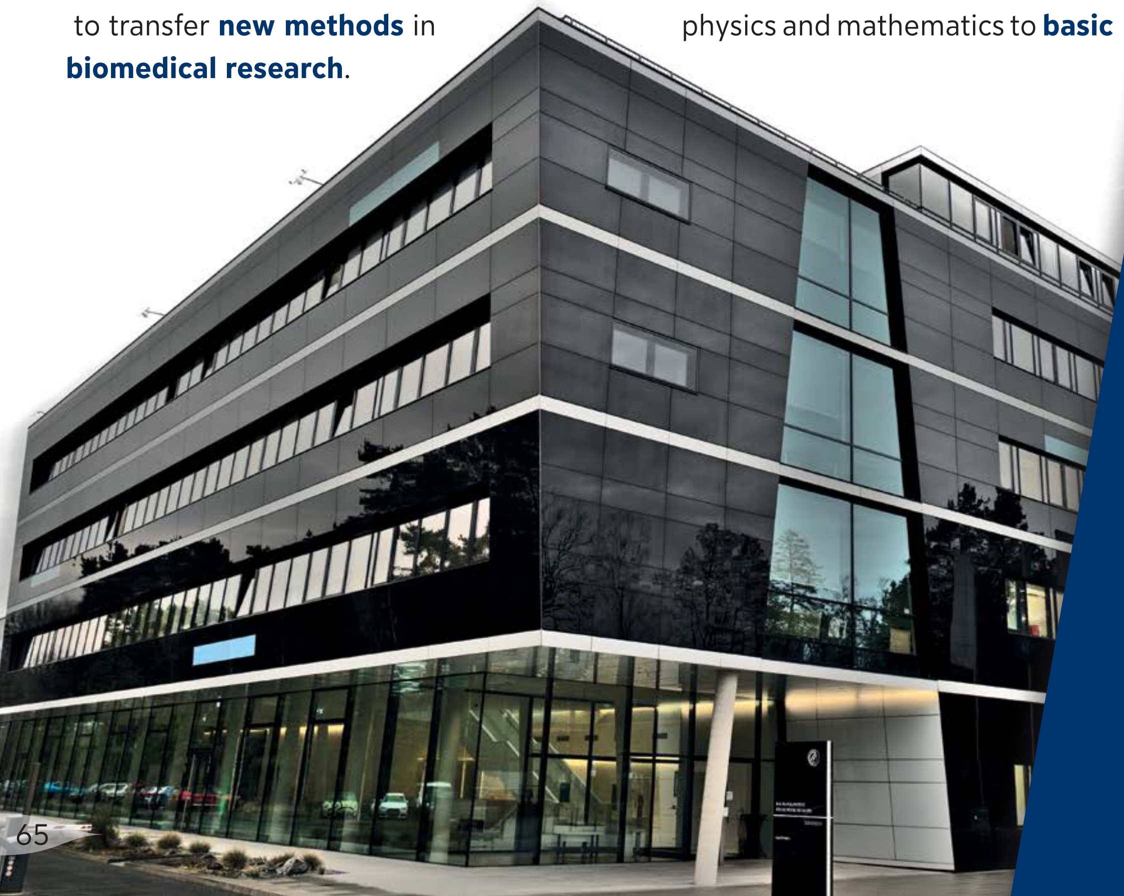
Max Planck Institute for the Science of Light



The Max Planck Institute for the Science of Light (**MPL**), established in 2009, is based on the long tradition of research in the field of optics in Erlangen. It focuses on **basic research** into all aspects of the **interaction between light and matter**, from modern optics to photonics, quantum effects and their real-world applications. The institute aims to extend the realm of the possible in the science and technology of light.

MPL's fields of activity include **modern optics and optical materials**, **nano-optics**, **quantum information processing**, **optical sensors**, **non-linear optics** and **biological optomechanics**. The scientists at MPL want to explore light and its interaction with matter in all respects: in space and time, in polarization and its quantum properties. MPL is one of the more than 80 institutes that make up the **Max Planck Society**, whose mission is to conduct basic research in the service of the general public in the natural sciences, life sciences, social sciences and the humanities. Currently, MPL consists of **three divisions**, several independent research groups and three technology development and service groups.

In addition, the **Max-Planck-Zentrum für Physik und Medizin** (**MPZPM**) is under construction, a joint project of MPL, Friedrich-Alexander-Universität Erlangen-Nürnberg and University Hospital Erlangen. The new center aims to transfer **new methods** in physics and mathematics to **basic biomedical research**.



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Helmholtz Institute Erlangen-Nürnberg for Renewable Energy

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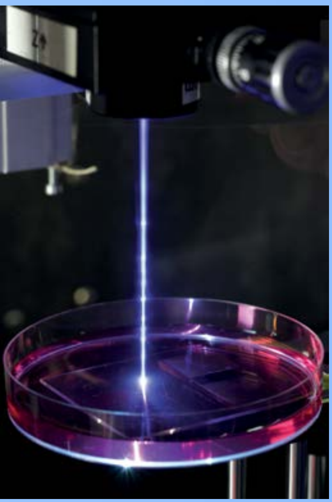
ZAE Bayern operates the „**Solar Factory of the Future**" (SFF) on the Energy Campus Nuremberg (EnCN), in close cooperation with FAU's Institute of Materials for Electronics and Energy Technology (i-MEET) and the Helmholtz Institute Erlangen-Nuremberg (HI ERN). The SFF develops printing processes for manufacturing **third-generation solar technologies**, namely **organic and perovskite-based photovoltaics** (PV). Both technologies have in common that they can be manufactured from solutions using printing and coating processes, in combination with laser patterning. When using flexible substrates, e.g. PET films, the corresponding PV modules can be **produced with extremely high throughput** in roll-to-roll (R2R) processes.

SFF's core competence is the upscaling of manufacturing processes for organic opto-electronics. This includes the high-throughput evaluation of new materials and their integration into the production process, as well as the development of new and the optimization of existing processes for coating and laser patterning. The goal here is to **improve the efficiency**, **lifetime** and **aesthetics of printed PV modules** while reducing costs. Important achievements of the SFF along this path include the development of transparent electrodes based on silver nanowires and the production of an organic solar module with a **world record efficiency** of 11.7%.

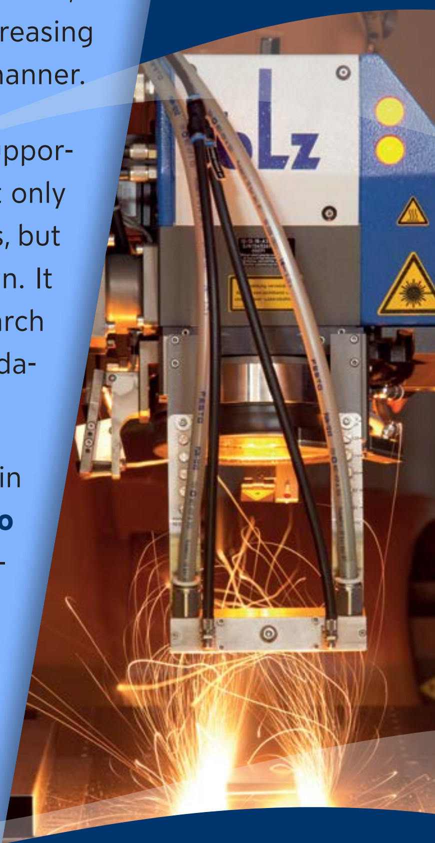
At the SFF, **various manufacturing processes** are available. On the one hand, PV modules are produced by combining full-area coating and laser patterning. On the other hand, a R2R inkjet printing process has been developed for the production of organic photovoltaic (OPV) modules of discretionary shape.

Due to their unique properties, such as flexibility, light weight, and semitransparency, the solar modules produced by these processes can be integrated into **various applications** for which silicon solar modules are not suitable. Examples are **semitransparent OPV glass roofs** as shading elements for building facades and flexible modules with a **high power-to-weight ratio** as an energy source for electric motors for zeppelins.

Bayerisches Laserzentrum



Competence on laser and photonics - If you want to use and control the "tool laser", you need more than standard engineering skills. When using a laser, **complex physical and chemical effects** as well as aspects concerning **materials science** come together and have to be understood to achieve the desired result. In addition, it is also important in laser technology to implement the increasing trend towards **digitization in production** in a suitable manner.



Since 1993, the Bayerisches Laserzentrum (blz) has been supporting its partners as an **independent service provider** – not only in realizing technical and economically appropriate solutions, but also in bringing new scientific achievements into production. It is one of the well-established centers for applied laser research in Germany, that considers itself as an **application-oriented interface** between fundamental research and industrial application.

The blz is developing **applied laser technologies** and supports companies in opening up new fields of application for photonic technologies, **from analyses to implementation**. The work focuses on the processing of metals and plastics, automotive and electronic production, additive manufacturing as well as precision processing with short pulse laser systems. By performing numerous research and development projects, extensive knowledge in the field of laser system technology is gained. This knowledge is used for the configuration and design of **customized processes and optical systems**.

Furthermore, the Bayerisches Laserzentrum is an approved **testing laboratory** for laser safety products. It not only conducts customized laser safety consultations but the laser safety experts also carry out basic and advanced training courses for laser safety officers. A broad range of **training programmes and seminars** on current topics in the field of applied laser technology is completing blz's service portfolio.

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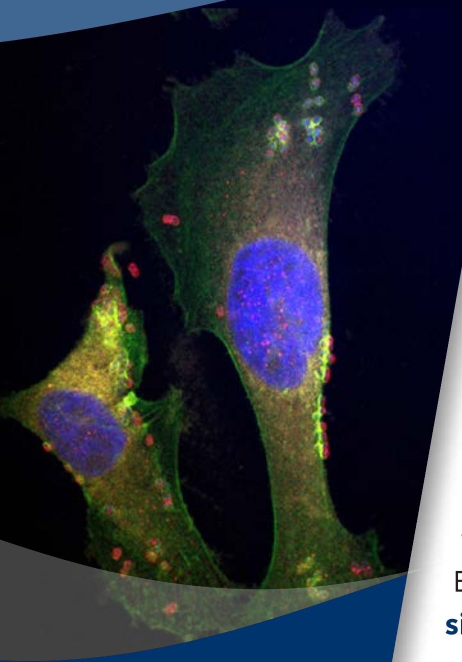
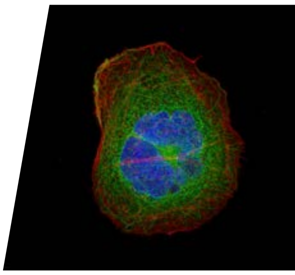
Optical Imaging Center Erlangen



Optical Imaging Centre Erlangen (OICE) is a scientific central institute (Competence Center) of FAU, open to FAU and external researchers.

The center's mission is to provide and coordinate access to **high-end light microscopes** within its Core Facility Unit (CFU) and to promote the research and development of new systems and techniques within its Exploratory Research Unit (ERU). Currently CFU maintains 9 imaging systems and provides access to more than 10 imaging technologies within FAU. On average, more than 170 individual researchers out of 68 research groups are currently supported in one year, generating > 16.000 usage hours in house. Most researchers come from the Faculty of Medicine, the Faculty of Sciences and from Universitätsklinikum Erlangen. In addition to its optical expertise, OICE offers **post image processing**, **image analysis** and the development of **software for data visualization**.

At ERU, currently **two main projects** are supported. Making iSCAT, a **single molecule technology** derived from the Sandoghdar group at MPL available for CFU users and further a collaboration on **quantum correlation imaging** with the von Zanthier group at the physics department.



The Education and Training Unit (ETU) provides more than 45 **seminars and practical courses** a year, starting from basic imaging courses and diving into specialized technologies such as multi-photon intra-vital imaging.

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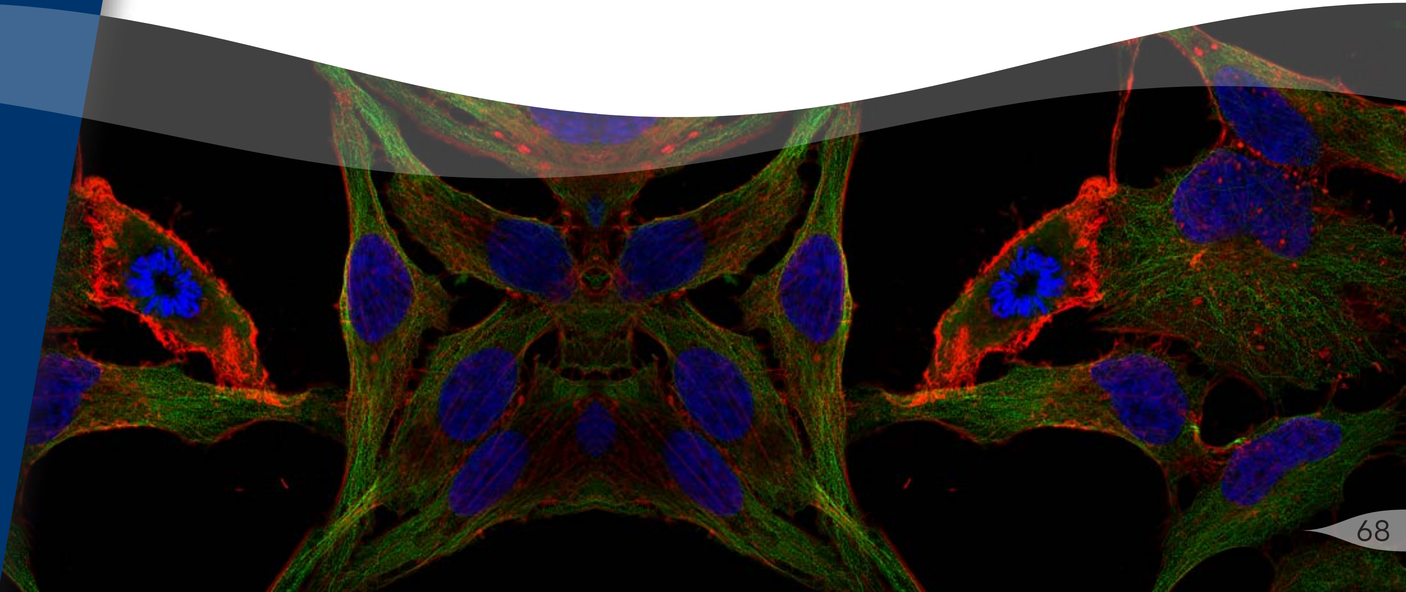
OICE has close ties with the Max Planck Institute for the Science of Light and the Fraunhofer Institute IIS and has vivid connections to the Cluster of Excellence Engineering of Advanced Materials and the Erlangen Graduate School in Advanced Optical Technologies (SAOT).




CA-1
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City Map
of
Erlangen
MPZPM
FAU
Schwabach
Schlossgarten
blz
SAOT
MAOT
Regnitz
A73
MPL
Exerzierplatz
MPSP
B4
OICE
IISB
HI ERN
Erlangen
A3
A73
Fürth
Nürnberg
Brucker Lache
IIS
A73
B4
A3

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