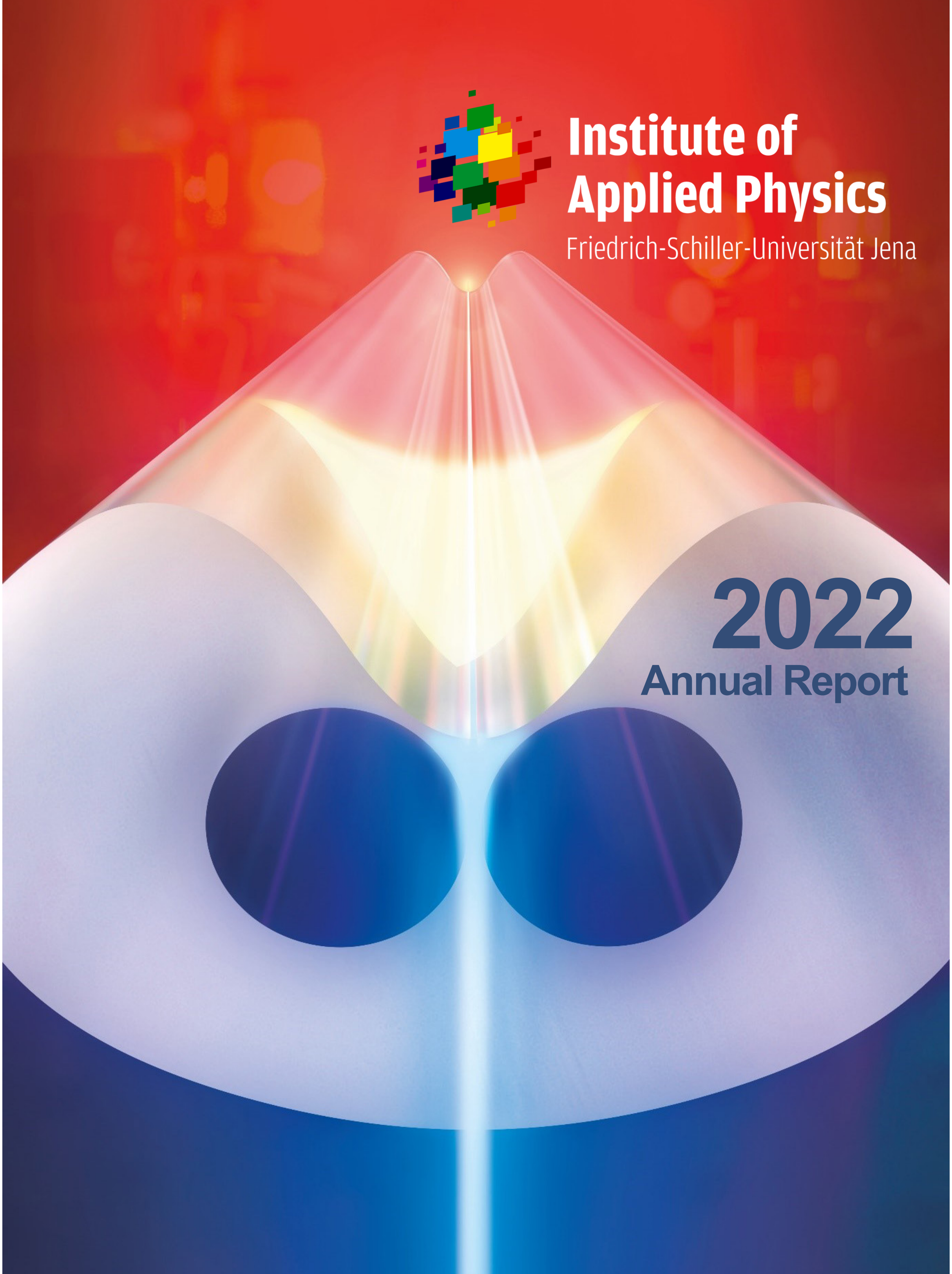
Institute of Applied Physics

Friedrich-Schiller-Universität Jena

2022

Annual Report



Imprint

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EDITORIAL
Ira Winkler

LAYOUT
Ira Winkler

PICTURES/
GRAFICS
Institute of Applied Physics (IAP), Fraunhofer IOF [W. Oppel, C. Süß], Friedrich Schiller University Jena [J.-P. Kasper, J. Meyer], p.36: aboutpixel.de/Lektüre©marshi

Cover: Artists impression of second harmonic generation in an exposed core fiber coated with a triangular TMD-crystal. Used as "hero image" in Nature Photonics November 2022 Issue. (see also p.)

Content

PREFACE / VORWORT

Although 2022 was still strongly influenced by the COVID pandemic and its efforts to control it - but it also brought small steps back to normality: participation in the first national and international conferences to be held in presence again, as well as a personally reconnection in the lecture halls and seminar rooms with students, and in our house in the laboratories and offices. Finally, exciting discussions about challenging ideas could be held together again and outstanding scientific results were achieved. I would like to remind you of some of the highlights here:

Quantum keys were successfully exchanged over conventional optical fibers for the first time on a 75 km distance between Jena and Erfurt. This is a milestone in quantum communication that we achieved together with our partner Fraunhofer IOF and the spin-off "Quantum Optics Jena GmbH". With the successful acquisition of the "PhoQuant" project, we started the construction of a demonstration and test facility for photonic quantum computer chips in order to continue researching the phenomena in the promising field of quantum technologies and to be able to offer solutions issues facing society.

A substantial breakthrough was also achieved in the application of laser-driven EUV sources for high-resolution microscopy. By combining EUV sources with unique characteristics, structured illumination and new numerical methods, sub-20 nm resolution, deep penetration and element contrast could be demonstrated on semiconductor chips for the first time. Further fields of application in biology, medicine and energy research are currently being developed with various partners, including the Fraunhofer Cluster of Excellence CAPS.

For years, we have been contributing to the precise exploration of the universe, for example, with optical gratings and free-form optics developed and produced at our two institutes, which send images from space to Earth via the James Webb telescope, for instance, in order to better understand the origins of the world. With novel aperiodic fiber Bragg gratings (AFBGs), we also hope to raise ground-based astronomy to a new level of precision in the future by filtering out the strong atmospheric hydroxyl (OH) emission lines of the Earth's atmosphere. With such a technique, it is possible to even measure the signals from stars or galaxies, which are several orders of magnitude weaker in the NIR range.

With the engagement and creativity of all our colleagues, as well as the strong cooperation partners and the quality of our results, we were able to convince funding institutions of our visions and acquire future-oriented projects again, so that we can look confidently into a new year and beyond.
I would like to express my grateful thanks to all of you for this,

Sincerely,

Andreas Tünnermnann

Obwohl das Jahr 2022 noch immer stark unter dem Einfluss der COVID-Pandemie und deren Maßnahmen zur Eindämmung stand– brachte es auch kleine Schritte zurück zur Normalität: die Teilnahme an ersten wieder in Präsenz stattfindenden nationalen und internationalen Konferenzen sowie ein Wiedersehen in den Hörsälen und Seminarräumen mit den Studierenden, und in unserem Haus in den Laboren und Büros. Endlich konnten spannende Diskussionen über anspruchsvolle Ideen wieder gemeinsam geführt werden und herausragende wissenschaftliche Ergebnisse wurden erzielt. An einige Highlights möchte ich hier gern erinnern:

Auf einer 75 km langen Strecke zwischen Jena und Erfurt wurden erstmals erfolgreich Quantenschlüssel über konventionelle Glasfasern ausgetauscht. Dies ist ein Meilenstein in der Quantenkommunikation, den wir gemeinsam mit unserem Partner Fraunhofer IOF und dem Spin-Off »Quantum Optics Jena GmbH« erreicht haben. Mit der erfolgreichen Einwerbung des Projektes »PhoQuant« starteten wir in den Aufbau einer Demonstrations- und Testanlage für photonische Quantencomputer-Chips, um weiter auf dem zukunftsträchtigen Feld der Quantentechnologien die Phänomene zu erforschen und für gesellschaftliche Problemstellungen Lösungen bieten zu können.

Ein entscheidender Durchbruch gelang auch in der Anwendung von laser-getriebenen EUV Quellen für die hochauflösende Mikroskopie. Durch Kombination von EUV Quellen mit einzigartigen Kenndaten, strukturierter Beleuchtung und neuen numerischen Methoden konnten erstmals sub-20 nm Auflösung, große Eindringtiefe und Element-Kontrast an Halbleiter-Chips demonstriert werden. Weitere Anwendungsfelder in Biologie, Medizin und Energieforschung werden derzeit mit verschiedenen Partnern erschlossen, unter anderem im Rahmen des Fraunhofer Exzellenzclusters CAPS.

Beiträge zur präzisieren Erforschung des Universums leisten wir seit Jahren z.B. mit den an unseren beiden Instituten entwickelten und produzierten optischen Gittern und Freiformoptiken, die u.a. im James-Webb-Teleskop aus dem All Bilder zur Erde schicken, um die Entstehung der Welt besser zu verstehen. Mit neuartigen aperiodischen Fiber Bragg Gratings (AFBGs) möchten wir in Zukunft auch bodengebundene Astronomie auf ein neues Level der Präzision heben, indem die starken atmosphärischen Hydroxyl (OH)-Emissionslinien der Erdatmosphäre herausgefiltert werden. Mit einer solchen Technik ist es möglich, die im NIR-Bereich um mehrere Größenordnungen schwächeren Signale von Sternen oder Galaxien trotzdem zu messen.

Mit dem Engagement und Ideenreichtum all unserer Kolleginnen und Kollegen, sowie den starken Kooperationspartnern und der Qualität unserer Ergebnisse können wir immer wieder Zuwendungsgeber von unseren Visionen überzeugen und zukunftsweisende Projekte einwerben, sodass wir zuversichtlich in ein neues Jahr und darüber hinausschauen können. Dafür möchte ich mich herzlichst bei allen bedanken,

Ihr Andreas Tünnermann

The Institute of Applied Physics (IAP) has a long-standing tradition and competence in design, fabrication and application of active and passive optical and photonic elements. It is also very well-known for its developments in the area of high power laser technology and nowadys also in quantum optics. Collaborative projects with companies ensure practical relevance and feasibility.

Research Profile

The institute conducts fundamental and applied research in the fields of micro-, nano- and quantum optics, fiber and waveguide optics, ultrafast optics as well as optical engineering.

Our researchers develop novel optical materials, elements and concepts for information and communication technology, life science and medicine, environment and energy as well as process technology including material processing and optical measurement techniques.

Current research topics - investigated by over 150 scientists - concern function, design, fabrication and applications of micro- and nano-optical elements. Those are e.g. plasmonic resonant nanometric structures, polarizers from IR to DUV range, 3D nano-structuring of crystals with ion beam and Atomic Layer Deposition of optical coatings. Also light propagation and non-linear light-matter interaction in e.g. photonic nanomaterials, including metamaterials, photonic crystals, as well as effective media, quantum phenomena and integrated quantum optics, application of photonic nanomaterials and advanced photonic concepts for astronomical instruments are investigated.

Further research fields are the applications of femtosecond laser pulses, such as material processing and spectroscopic analyses, as well as micro- and nano-structuring, medical (laser) application and additive manufacturing usage of ultrashort laser pulses. For further aims, new concepts for solid-state lasers with focus on fiber laser technology are to be developed, such as novel large core diameter fibers, fiber optical amplification of ultra short laser pulses and Mid-IR up to soft x-ray laser sources. With those, absorption spectroscopy with ultrahigh spectral resolution, especially in the (extreme) ultraviolet (XUV) region can be realized.

Classical optical design as well as design of modern optical systems, like freeform optics, illumination systems, laser and delivery systems are considered in our research, as well as aberration theory, quality, performance and tolerancing evaluation of optical systems.

By investigating these fields of research, particularly in close cooperation with the Fraunhofer Institute of Applied Physics and Precision Engineering (IOF) as well as many partners in science and economy, the IAP covers numerous parts of the innovation chain - from interdisciplinary fundamental research to the demonstration of prototypes. This expertise offers remarkable contributions to solve issues in the mentioned before emerging fields.

Excellence in research is confirmed by the structural anchoring of the Competence Centre (ZIK) ultra optics into one of three key research areas of the Abbe Center of Photonics (ACP), four awarded ERC Grants "Powerful and Efficient EUV Coherent Light Sources - PECS" (2009), "Advanced Coherent Ultrafast Laser Pulse Stacking - ACOPS" (2014), "Multi-dimensional interferometric amplification of ultrashort laser pulses - MIMAS" (2015) and "High-flux Synchrotron alternatives driven by powerful long-wavelength fiber lasers - SALT" (2019), the International Research Training Group GRK 2101 (2015) as well as the pilot project "Max Planck School of Photonics" (2017). In recent years, expertise has also been built up in quantum research, and major projects have been successfully conducted, such as QuantIm4Life (2018), QUICK3 (2021) and PhoQuant (2022).

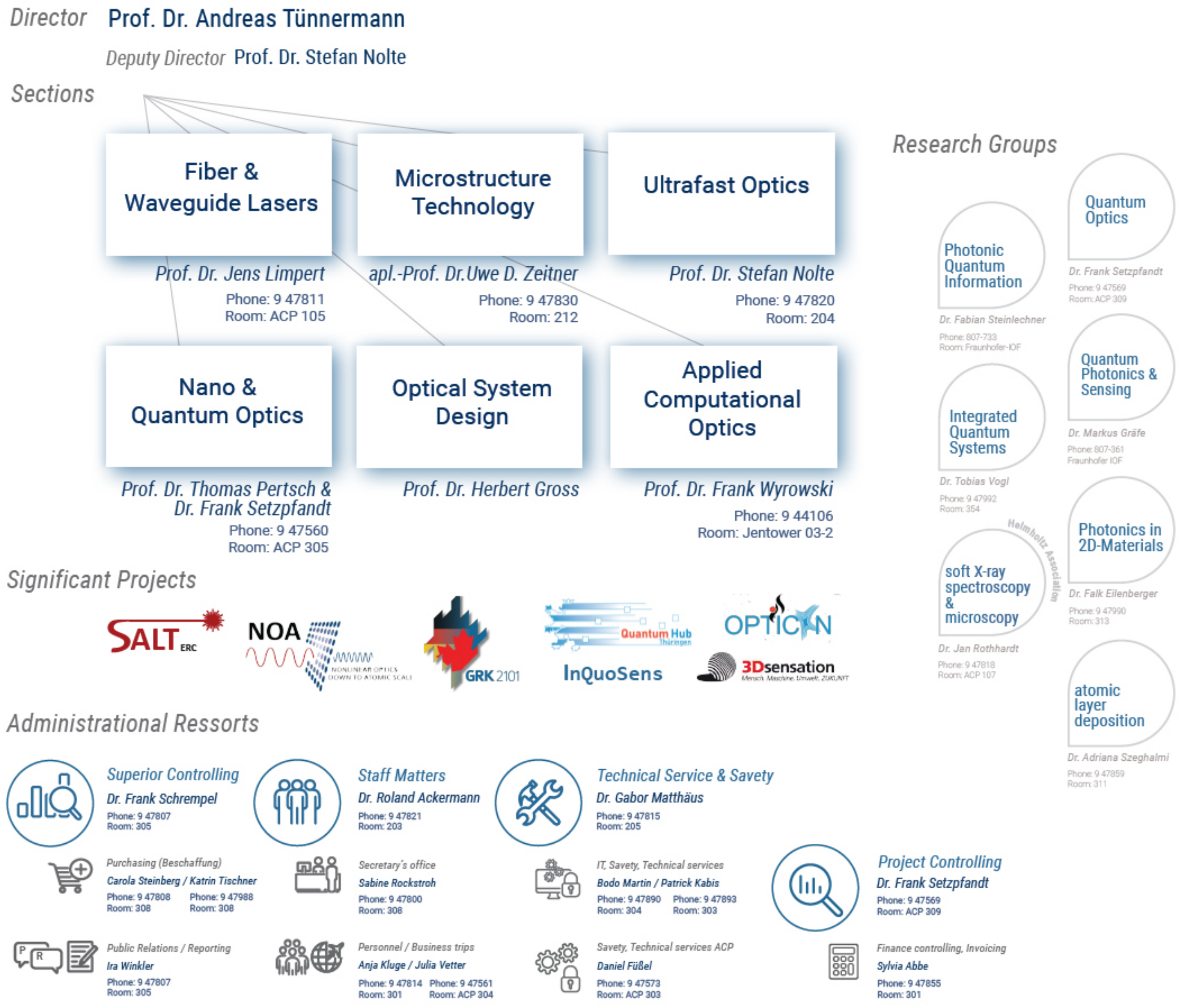
But not only excellent research makes the Institute splendid, also out-standing laboratory equipment, an excellent educated staff and an high commitment to the training of students and scientists in cooperation with the Abbe School of Photonics belongs to the self-understanding of the IAP.

Research Facilities / Resources

Excellence in research requires high quality equipment for experimental questions and analysis. The state-of-the-art technical infrastructure is driven constantly forward by acquired adaptions for scientific questions, done by an experianced crew.

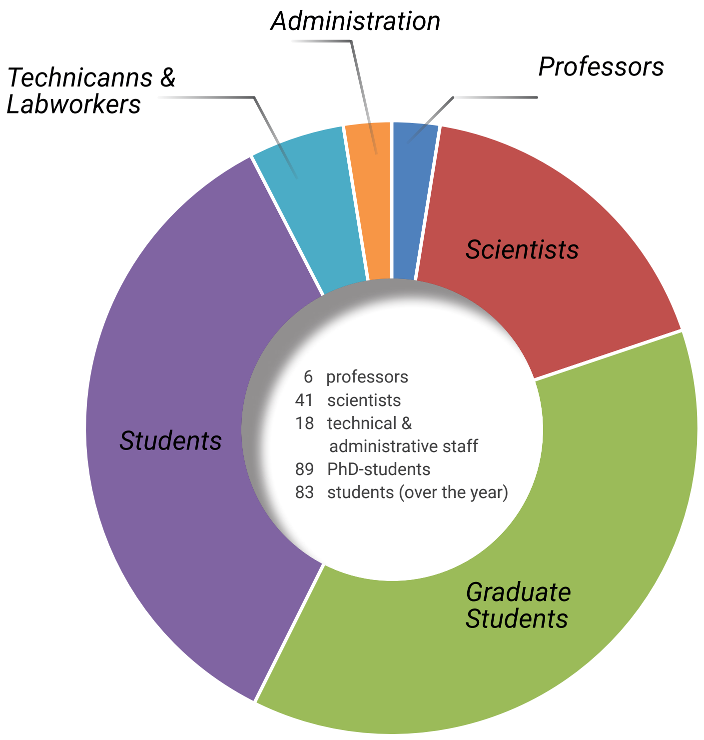
860 m² class 10,000 to 10 clean room area for:

- Electron beam lithography equipped with variable shaped beam and cell projection
- Laser lithography & Photolitography
- Coating technologies (sputtering, electron beam evaporation, ALD)
- Dry etching (RIE, RIBE, ICP)
- Cross beam, scanning electron microscopy, equipped with EDX and EBSD
- Helium ion microscopy
- Scanning nearfield optical microscopy
- Interference optical surface profilometry
- UV-VIS spectrometry & FTIR spectrometry
- Ellipsometry
- Nonlinear optical waveguide characterization
- High repetition rate ultrashort pulse laser systems (25fs to 20ps) including wavelength conversion covering the range from 4nm to 10µm
- High-precision positioning and laser scanning systems
- Laser micro-structuring and additive technology
- Rigorous optical simulation
- Field tracing techniques



Structure of the Institute 2022

Staff in 2022



ABASIFARD Mostafa
ABBE Sylvia
ABDELAAL Mahmoud
ABED Omid
ABTAHI Fatemeh Alsadat
ACKERMANN Roland
AFSHARNIA Mina
AHMADI Najme
ALASGARZADE Namig
ALBERUCCI Alessandro
ALESHIRE Christopher
ALLANDE-CALVET Neus
APELL Jonatan
ARUMUGAM Stree
BAHRI Mehran
BALAJI Vignesh
BEER Sebastian
BENNER Maximilian
BERGNER Alexander
BERMEO ALVARO Domenica
BERRANG Bianca
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BESAGA Vira
BIRCKIGT Pascal
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GOUR Jeetendra
GOZALI Richard
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HEUERMANN Tobias
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JÁUREGUI MISAS César
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JOSHI Prafullakumar
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KAISER Thomas
KARST Maximilian
KÄSEBIER Thomas
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LÖTGERING Lars
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MARTIN Bodo
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PRADUTSCH Sven
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PARAB Tushar
PAUL Pallabi
PAUL Pritom
PENAGOS MOLINA Daniel S.
PERTSCH Thomas
PFALLER Pauline
PFLEGHAR Christian
PILLOT Coltilde
PORWOL Tatjana
PRABHAKARA Nishitha
REDON Melvin

REENTS Johannes
REPP Daniel
RICHTER Daniel
RITTER Sebastian
RIVERA SANCHEZ
ROCKSTROH Sabine
ROMASHKINA Anastasia
ROSARIO RODRIGUES Grucheska
ROTHHARDT Jan
SAFARIARABI Masoud
SANTOS SUÁREZ Elkin André
SARAVI Sina
SARVARZADEH Seyedsaeid
SAUER Gregor
SCHEIBINGER Ramona
SCHELLE Detlef
SCHMELZ David
SCHMIDT Falko
SCHMIDT Holger
SCHÖNBERG Alwin
SCHREMPEL Frank
SEBAK Rana Khaled
SERGEEV Natali
SETZPFANDT Frank
SEVILLA GUITÈRREZ Carlos
SEYFARTH Brian
SHINDE Saniya
SIEFKE Thomas
SIEGMUND Florian
SIEMS Malte
SIGURJOUNSDOTTIR Vilborg
SINELNIK Artem
SOJKA Falko
SOLLAPUR Rudrakant
SPERRHAKE Jan
SRIPATHY Kabilan
STARK Lars Henning
STEFANIDI Dmitrii
STEINBERG Carola
STEINERT Michael

STEINKOPFF Albrecht
STEINLECHNER Fabian
STEMPFHUBER Sven
SZEGHALMI Adriana
TANAKA Katsya
TISCHNER Katrin
TU Yiming
TÜNNERMANN Andreas
ULLSPERGER Tobias
VAVRECKOVÁ Sárka
VEGA PEREZ Andres R.
VETTER Julia
VOGL Tobias
VOIGT Daniel
WALTHER Markus
WANG Changshun
WANG Sici
WANG Ziyao
WEIßFLOG Maximilian
WIEDEMANN Tm
WINKLER Ira M.
WYROWSKI Frank
XU Quian
YANG Ziwei
YILDIZ Benjamin
YOUNESI Mohammadreza
YÜREKLI Burak
ZAKOTH David
ZAND Ashkan
ZEITNER Uwe D.
ZHANG Jiahang
ZHANG Luosha
ZHANG Mingxuan
ZHANG Xiangyun
ZHANG Yueheng
ZHANG Yuzhen
ZHANG Zifei
ZHAO Xiaodong
ZIEBELL Jobst
ZHAO Xiaodong

Guests & Visits

Guests indicate the national and international visibility of research results and enrich the structures of the Institute with new thinking and perspectives - not only in research and teaching, but also open eyes to other cultures and strengthen the network by personal relations.

Due to the pandemic situation in 2020, 2021 and 2022, intensive research visits and personal contacts were unfortunately not possible.

Guests

AHARONOVICH Igor	UTS University of Technology Sydney, Australia
BUTLER Paul	Ludwig-Maximilians-Universität München, Germany
CONLON Lorcan	Australian National University, Canberra, Australia
LÖW Robert	University of Stuttgart, Germany
SOLTWISCH Victor	Physikalisch-Technische Bundesanstalt, Berlin, Germany
SPIEGELBERG Josephine	McGill University, Montreal, Canada
TALBOT Lauris	Centre d'optique, photonique et lasers (COPL), Université Laval, Quebec, Canada

Visits

IMOGORE Timothy	Centre d'optique, photonique et lasers (COPL), Université Laval, Quebec, Canada
KRSTIC Aleksa	Australian National University, Canberra, Australia
SETZPFANDT Frank	Australian National University, Canberra, Australia
WEISSFLOG Maximilian	Australian National University, Canberra, Australia

Cooperations

The IAP has a strong network of partners regionally, nationally, and all over the world. Located in the heart of Jena's optics industry, it is connected to resident international players in the economy as well as research institutions. So, it has a close connection to other departments of the Faculty of Physics and Astronomy at Friedrich Schiller University. Since years the IAP collaborates also with the University of Applied Sciences (EAH) Jena.

Our work is connected deeply to many important research associations of Germany, such as the Max-Planck-Institutions, especially in Erlangen and Garching, as well as the Institutes of the Leibniz and Helmholtz Association - such as the Institute for Astrophysics Potsdam (AIP) and the Leibniz Institute of Photonic Technology (IPHT), the Helmholtz Institute in Hamburg (DESY) and Jena (HIJ) – to name some of them. Firm European cooperation exist with French research institutions, such as the Centre national de la recherche scientifique (CNRS) in Paris and the ELI-ALPS, Extreme Light Infrastructure in Szeged, Hungary.

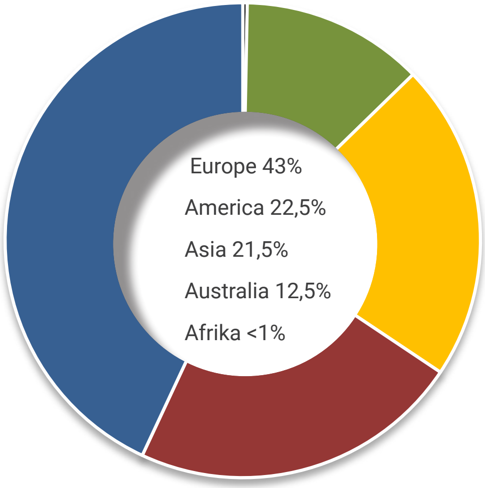
Traditionally, the IAP is linked closely to the Fraunhofer Institute for Applied Optics and Precision Engineering (IOF). Based on this networking between the two Institutes, one major goal is to develop an outstanding application results for micro- and nano-structured optics, whole optical systems, lasers and Quantum optics. Beyond this co-operation, the "Leistungszentrum Photonics" was associated together with other local players, such as Abbe Center of Photonics (ACP), Leibniz Hans Knöll Institute (HKI), Helmholtz Institute Jena and the Leibniz Institute of Photonic Technology. With both of the last mentioned, the "Fasertechnologiezentrum" is being operated to develop and produce novel fibers for worldleading lasers.

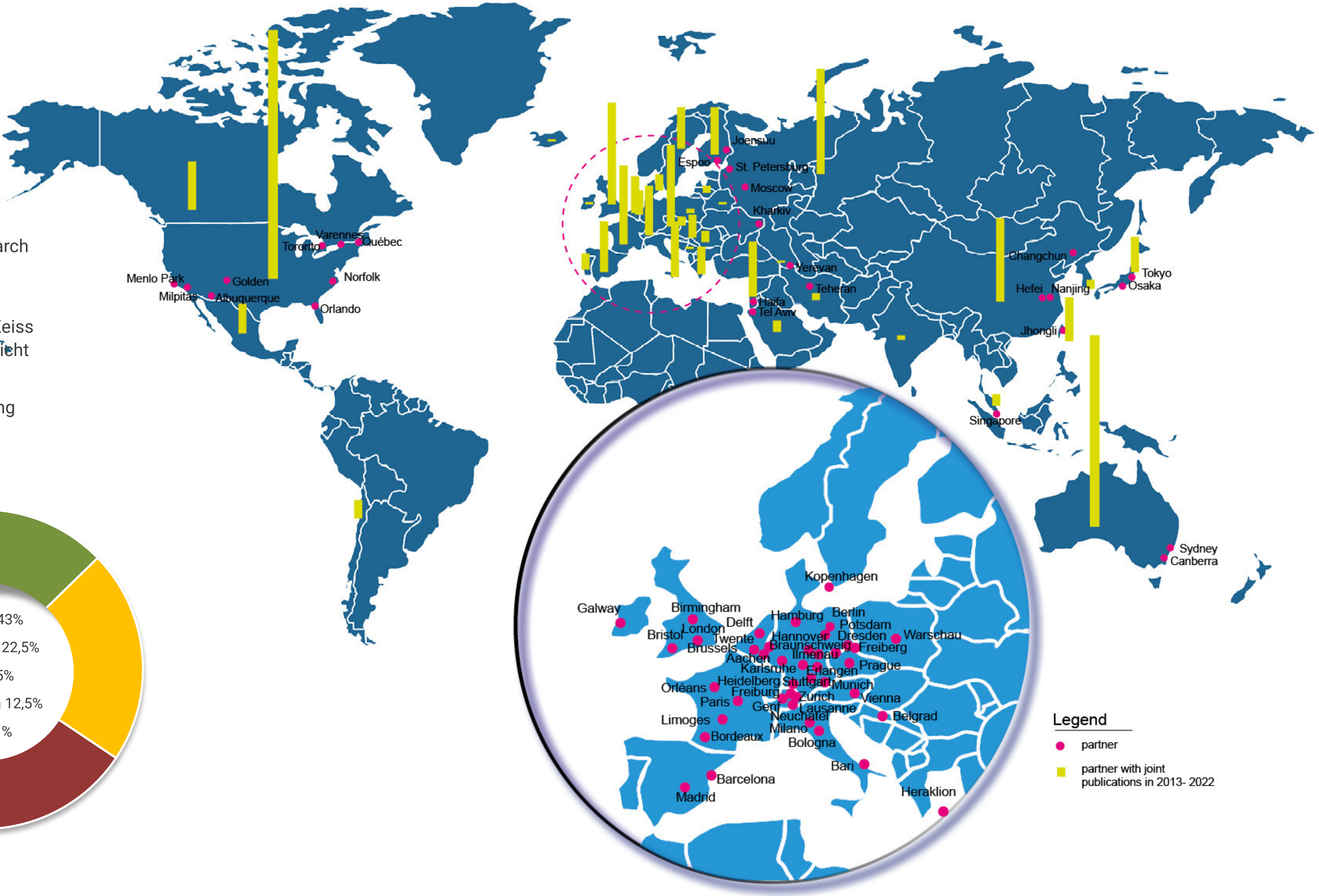
In addition, the IAP maintains close contacts to universities and research facilities worldwide for years: collaborations exist with international universities e.g. in Australia, Belgium, Canada, Great Britain, France, Italy, Rssia, Spain, Switzerland, Taiwan, The Netherlands, Thailand and USA.

Through the Max Planck School of Photonics (MPSP) educational project, we also cooperate with many of the renowned German research institutions mentioned above.

For years, we work also close with regional industry partners - from medium-sized to internationally operating companies; current: Carl Zeiss AG in Jena and Oberkochen, Jenoptik AG, Layertec GmbH, OSRAM Licht AG, Active Fiber Sytems GmbH and many more.

By working together with all our partners, we are constantly expanding our know-how and focus on problem solutions.





TEACHING

EDUCATION

An essential part of the IAP is the training of young scientists on fundamental knowlegde and at the interface of physics, chemistry and material science. Together with our partner in education - the Abbe School of Photonics (ASP) - we offer an education in interdisciplinary international Master´s degree and graduation programs. Since 2017 the "Max Planck School of Photonics" (MPSP) is coordinated in Jena to qualify young scientists in pioneering research fields.

Lectures

- Analytical Instrumentation
- Atome und Moleküle I & II
- Computational Physics I
- Experimental Quantum Technologies
- Fundamentals of Modern Optics
- Grundlagen der Laserphysik
- Imaging and Aberration Theory
- Innovation Methods in Photonics
- Integrated Quantum Photonics
- Introduction to Nanooptics
- Introduction to Optical Modeling
- Laser Physics
- Lasers in Medicine
- Lens Design II
- Mathematical Methods in Physics
- Micro / Nanotechnology
- Quantum Computing
- Quantum Communication
- Quantum Imaging and Sensing
- Quantum Optics
- Structure of Matter
- Thin Film Optics
- Ultrafast Optics
- Vakuum- und Dünnschichtphysik

Practical training / Internships

- Experimental Optics
- Grundpraktikum Biochemie
- Grundpraktikum Pharmazie
- Grundpraktikum Physik
- Grundpraktikum Physik für Humanmediziner
- Kursleiter Grundpraktikum Physik für Chemiker/Lehramt
- Kursleiter Grundpraktikum Physik für Humanmediziner
- Fortgeschrittenenpraktikum Physik

Bachelor Theses

Jakob Bruhnke
Predicting propagation of paraxial waves using physics-informed neural networks

Nicolas Killermann
Auswirkungen hoher Temperaturen auf die optischen und mechanischen Eigenschaften von mittels ALD hergestellten TiO_2-Nanolaminaten

Jonas Margraf
Characterization of a regenerative stretcher for use in CPA Systems

Jan Till Schmieder
Untersuchung des Einflusses thermischer 3D-Messungen auf die Probenunversehrtheit

Sonja Weitzing
Nonlinear frequancy conversion in hybrid Bragg- and Mie-resonant photonic nanostructures

Master Theses

Namig Alasgarzade
Study of the mechanisms governing ultrafast laser waveguide inscription in Silicon and associated properties

Anton Averin
Non -invasive glucose concentration detection based on its specific rotation in human tissues.

Dupish
Towards real-time Quantum Ghost Imaging

Josefine Krause
Coupling of Quantum Emitters in 2D Materials to Laser-Written Waveguides

Luo Meng
Modeling of temperature distribution which is induced by laser light in a cylindrical body

Mohammad Mishuk
Characterization of suspended monolayer 2D Materials for He atom detection

Ahmed Mohamed
*Investigation, implementation and optimization of multi-tone BOFDA Measurements*in the fabrication fo X-ray optics

Daniel Nwatu
Group-delay ripple reduction in femtoseconds inscribed chirped fiber Bragg gratings

Zhen Xing
Design Method of Freeform Off-axis Reflective Imaging System

Doctoral Theses

Najmeh Abbasirad
Automated dual-tip scanning near-field optical microscope for investigation of nanophotonic systems

Dennis Arslan
Positional disorder in Huygens' metasurfaces

Muhammad Irfan Badar
Smooth functions and their use in optical modeling and design

Danyun Cai
Development of Freeform Optical Systems

Martin Gebhardt
Power scaling of few-cycle short-wavelength infrared laser sources for nonlinear frequency conversion

Alina Kim Lammers
Polarization manipulation in femtosecond laser direct written wave-guides in fused silica

Martin Landmann
Schnelle und genaue 3D-Formvermessung mittels Musterprojektion und Stereobildaufnahme im thermischen Infrarot

Amit Vikram Singh
Spatiotemporal evolution of non-diffracting plasmonic pulses

Jan Sperrhake
Semi-analytical modeling of stacked metasurfaces

Habilitations

Jan Rothhardt
High performance nanoscale lensless imaging with table-top high harmonic sources

Frank Setzpfandt
Photon-pair generation in micro- and nanostructured optical systems

RESEARCH

RESEARCH -

Achievements & Results

An intense engagement with all the research topics of the institute ultimately leads to the specialization of separate research groups on key challenges.
In turn, each group contributes with their results to the solution of partial tasks of the other work groups. This constantly self-fertilising approach leads to remarkable results. Measurably honored are such results by success in granting research contracts, the strong interest in cooperation with the IAP and the number of scientists and students who would like to work at IAP scientifically.

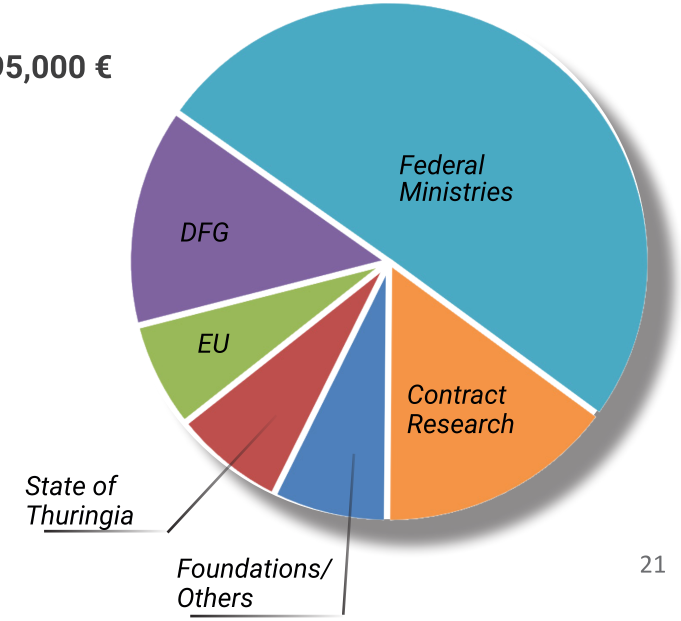
Some highlights of current research topics from our research groups are presented in the following.

Projects

"Applied Physics" is implemented in numerous projects in different application fields that contain fundamental research as well as application aspects. Accordingly, strong partners were explored and cooperation expanded. Thus, the IAP can continuously link the results and transfer those from basic research into innovative and novel demonstrators.

Third-party expenditure

Federal Ministries	5,784,000 €
Contract Research	1,730,000 €
DFG (German Research Society)	1,578,000 €
Foundations / Others	829,000 €
State of Thuringia	809,000 €
European Union	765,000 €
Total:	**11,495,000 €**



Fiber & Waveguide Lasers

Authors:
Wilhelm Eschen, Chang Liu, Michel Krause (IMWS), Jens Limpert and Jan Rothhardt

Nanoscale material-specific EUV imaging

Extreme ultraviolet (EUV) microscopy offers many advantages compared to conventional imaging techniques. Next to a high spatial resolution, due to the short wavelength, EUV radiation enables excellent material contrast, since practically all elements exhibit characteristic absorption edges in the EUV. Additionally, plenty of materials offer transparency windows in the EUV, which allow penetration depths in the micrometer range and thus the investigation of thick samples.

At the same time, lensless imaging techniques that are based on coherent illumination and phase reconstruction algorithms have seen tremendous progress. As a result, imaging in the EUV has been provided with new possibilities. In combination with compact powerful coherent EUV sources, these techniques allow quantitative imaging beyond the capabilities of conventional microscopes.

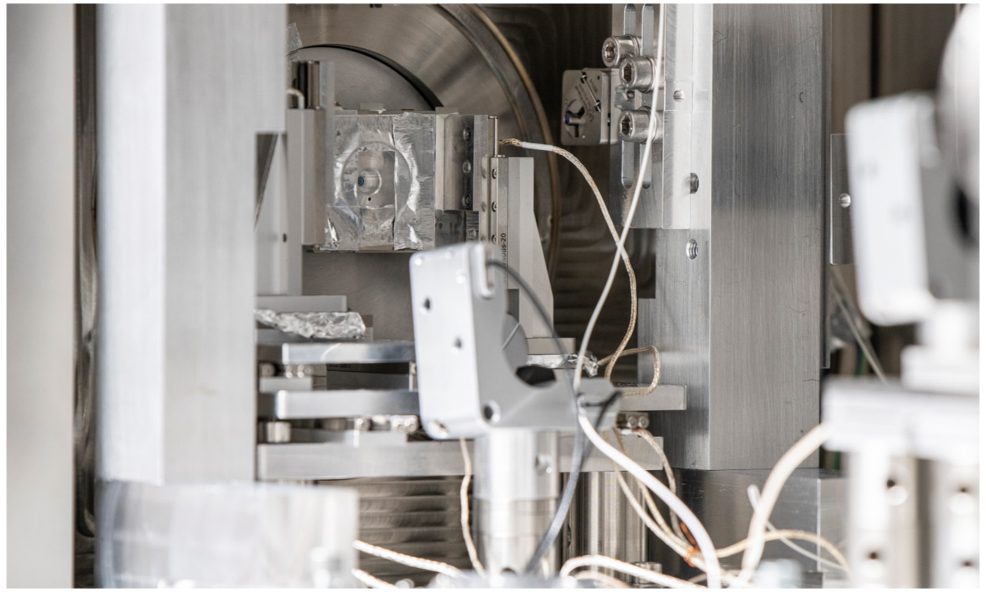


Figure 1:
Lensless EUV microscopy setup

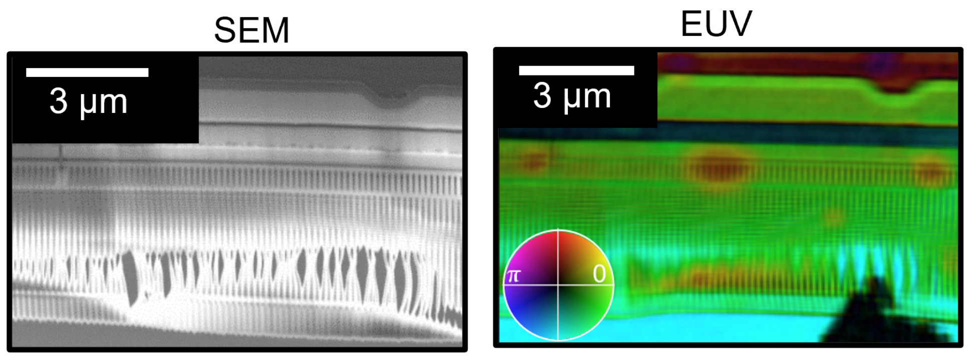


Figure 2:
Complex EUV transmission image of a thin lamella from an integrated circuit and an electron microscope image (SEM) for comparison

Particularly, the recent advances in ultrafast fiber laser technology that have been achieved within the Fraunhofer Cluster of Excellence (CAPS) at the IOF, allow for the generation of secondary radiation in the EUV with unprecedented brilliance on a tabletop /1/. These unique sources are available now in the CAPS application lab at the IOF and open new avenues in table-top imaging.

Taking advantage of these possibilities, a lab-scale lensless EUV microscope was realized operating at 13.5 nm wavelength /2/. By combining an interferometrically stabilized setup, structured illumination, and novel phase-retrieval methods, a record resolution of 16 nm was demonstrated /2/.

The unique capabilities of this instrument have been demonstrated at a real-world semiconductor sample in collaboration with the Fraunhofer IMWS (Fig. 2). In contrast to electron microscope measurements, the recorded EUV images provide higher and quantitative amplitude- and phase- contrast, which additionally allows for the analysis of the material composition. Typical materials such as aluminium and silicon oxide have been successfully identified /2/. The developed EUV microscope and the related analysis methods can be directly applied to a wide range of samples from a broad range of fields.

For example, the identification of sub-cellular features of fungus germlings and bacteria was recently achieved, including the analysis of their nanoscale chemical composition /3/.

/1/ R. Klas, et al.: Megahertz-repetition-rate coherent extreme-ultraviolet light source, PhotoniX 2, 1–8, 2021.

/2/ W. Eschen, et al.: Material-specific high-resolution table-top extresultraviolet microscopy, Light Sci. Appl. 11, 117, 2022.

/3/ C. Liu, et al.: Visualizing the ultra-structure of microorganisms using table-top extreme ultraviolet imaging, 1–24, 2022.

Authors:
Susann Sadlowski, Thomas Flügel-Paul, Tino Benkenstein, Peter Munzert and Uwe Zeitner

The Échelle-Grating for the NIRPS Spectrograph

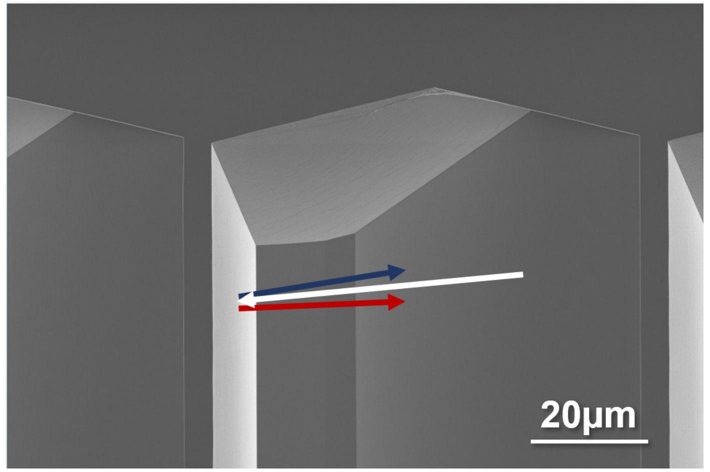


Figure 1:
Scanning-electron-microscope image of the grating facet. The direction of the incident and reflected light are indicated by the arrows.

The NIRPS-Instrument (Near Infra Red Planet Searcher) of the European Southern Observatory (ESO) is dedicated to the search and characterization of exo-planets orbiting low-mass M-type stars using the radial velocity method. Particularly, it aims to find earth-like rocky planets in the habitable zone. For that, it measures the variation of the spectral red-shift of these stars with a high-resolution spectrograph operating in the wavelength range between 97 and 1810nm. The wavelength dispersive core component of the spectrograph is an R4-Échelle-grating used in a high diffraction order. Initially, the instrument was equipped with a mechanically ruled and replicated grating.

Currently, Fraunhofer IOF developed a new technology for the realization of high-quality Échelle-gratings based on anisotropic wet-etching of crystalline Silicon substrates. In specific etching baths, the different crystallographic planes are removed with substantially different etching speeds. Using a well-defined lithographically structured binary etching mask enables the preparation of triangularly shaped grating lines with very smooth surfaces. To adjust the actual tilt of the reflective grating facets, the silicon substrate was cut under a defined angle out of the single crystal raw material. For the realization of the novel NIRPS-grating the etching mask has been realized by electron beam lithography and the etching of the silicon substrate was done in a KOH solution. The resulting grating structure (see Fig. 1) exhibits a high diffraction efficiency above 70% across the whole spectral band and a low wave-front error of <55 nm RMS over the full aperture. The measured PSF of the grating in the Littrow configuration performs very close to those of a plane and unpatterned $\lambda/10$ reference mirror.

The process is long known from the fabrication of micro-mechanical sensor devices and is now being applied by the instituts partner Fraunhofer IOF to the realization of large-area gratings. The new NIRPS grating has a size of 284 mm x 78 mm (see Fig. 2). It was shipped in spring 2022 and has been installed in summer at the 3.6-meter ESO telescope at the La Silla Observatory. During the first measurements, it revealed an improvement of the achieved sensitivity of the NIRPS instrument by approximately a factor of 2 compared to the previously ruled and replicated grating.

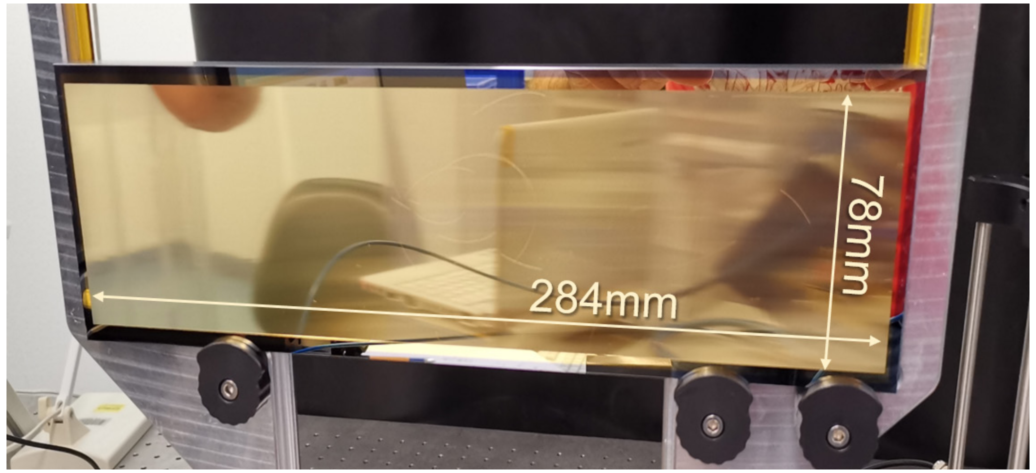


Figure 2:
Photograph of the novel full-size NIRPS Échelle-grating.

Authors:
Ria G. Krämer, Tobias Ullsperger, Daniel Richter and Stefan Nolte

Apodized fiber Bragg gratings by aperture shaping

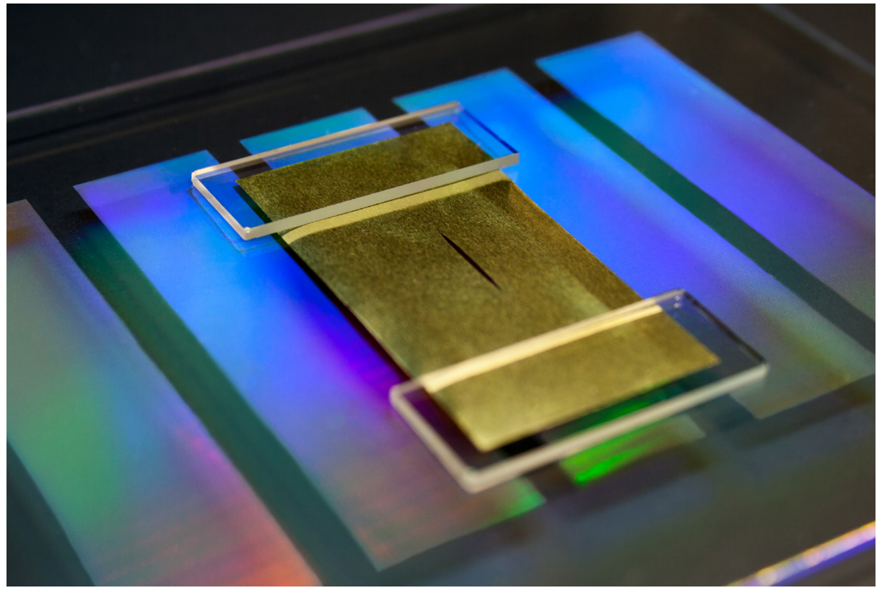


Figure 1:
Shaping aperture placed on phase mask.

Fiber Bragg gratings (FBGs) are vital components for integrated optics in sensing, fiber lasers, and signal processing, e.g. for applications in quantum communications. FBGs consist of a periodic modulation of the refractive index in the fiber core, which acts as a fiber-integrated narrowband reflector. For all application areas, the shape of the spectral response is essential. This is determined by the so-called apodization, the profile of the grating strength over the length of the FBG.

We generate the refractive index modifications in the fiber core by multiphoton absorption of ultrashort laser pulses, which allows to inscribe FBG in different fibers. The so-called phase mask technique ensures the periodicity of the FBG: the phase mask, a diffraction grating, produces a homogeneous interference pattern. This is imprinted into the fiber core by a cylindrical lens that focuses the inscription beam along the fiber axis. Apodization, i.e. the profile of the grating strength along the length of the FBG, is commonly adjusted by varying the refractive index profile along the fiber. Due to the Gaussian intensity profile of the inscription beam, a certain apodization of the generated FBG is automatically predetermined. To adjust this profile, the fiber can be scanned along its axis with different velocities or even pulse energies during the inscription process. Here, however, the variation is limited by the actual beam profile and size of the inscription laser. Alternatively, apodization can be adjusted by varying the overlap of the refractive index modification with the fiber core. This is realized in the writing process by aperture shaping: a customized aperture limits the overlap of the inscription beam with the fiber core, so that a varying cross-section of the refractive index modification along the fiber is created with high reproducibility. These apertures are cut out precisely from 25 µm thick brass foil using an ultrashort pulse laser (Figure /2/ and then placed on the phase mask (Figure /1/). Figure /3/ shows exemplary reflection spectra in which different spectral reflection profiles with respect to shape and bandwidth were realized by means of aperture shaping. The shape of the aperture can be adapted to the respective requirements of the application: from rectangular profiles to (super) Gaussian profiles to e.g. extremely short FBGs of less than 100 µm in length.

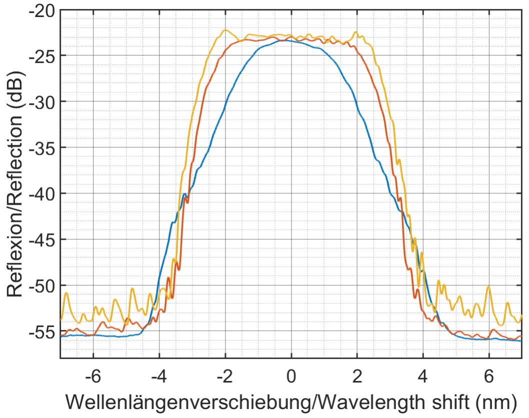


Figure 2:
Microscope image of shaping aperture.

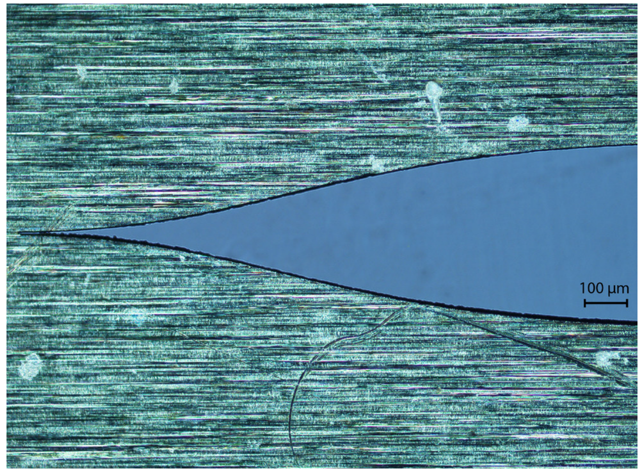


Figure 3:
Reflection spectrum for aperture shaped FBG.

/1/ R. G. Krämer, et al.: Tailored Apodization of Femtosecond Written Fiber Bragg Gratings by Aperture Shaping, Optica Advanced Photonics Congress 2022, Technical Digest Series (Optica Publishing Group, 2022), paper BTu1A.5.

Authors:
Maxime Chambonneau, Markus Blothe and Stefan Nolte

Through-silicon ultrashort pulse laser processing

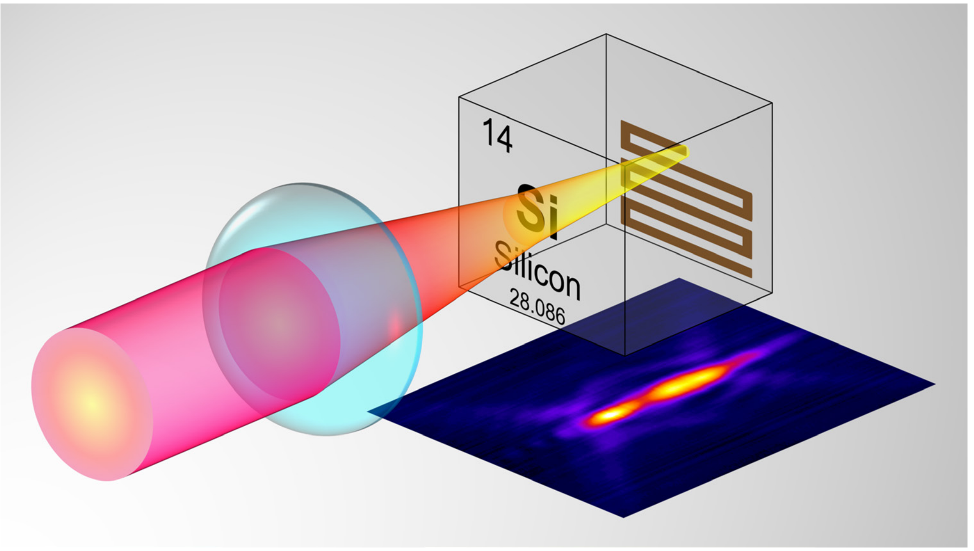


Figure 1:
Investigation of nonlinear propagation of ultrashort laser pulses in silicon for back surface processing applications.

The permanent joining of dissimilar materials is an essential work step for the manufacture of countless products. Various processes such as clamping, gluing, soldering or welding are available for this purpose. However, often, one would like to avoid the usage of additives such as adhesives or solder, e.g. if the connections are exposed to extreme environmental conditions. In this case, for example, chemical reactions, aging or outgassing must be avoided.

The ideal solution would often be direct welding without additives. However, extreme challenges are faced, especially when brittle materials are used. As welding requires high process temperatures, the induced thermal stresses usually lead to irreversible damage.

Laser welding using ultrashort laser pulses (USP) offers an alternative solution. Here, the laser radiation is focused into the area of the contact surface (Fig. 1). Due to the short interaction times (t<10-11 s) and reduced radiation energies of a few microjoules, the thermal loads are significantly lower than those of conventional laser welding processes. Consequently, strain can be reduced, and durable joints can be produced.

We were able to successfully weld different types of glass (borosilicate glass, quartz glass, Zerodur) onto metals such as copper, aluminum or molybdenum using this novel process. (Fig. 2a, /1/). The weld seams produced exhibit tensile strengths above 10 MPa, and significantly higher strengths can be expected when further optimization steps are taken into account in the future. Using long-wave laser radiation in the IR range, it was even possible for the first time to weld semiconductors such as silicon onto metals using this method (Fig. 2b, /2,3/).

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/2/ M. Chambonneau, et al.: Taming ultrafast laser filaments for optimized semiconductor-metal welding, Laser & Photonics Reviews, 15, 2000433, 2021.

/3/ M. Chambonneau, et al.: Ultrafast laser welding of silicon, arXiv:2211.03518, 2022.

/4/ M. Blothe et al.: Nanostructured back surface amorphization of silicon with picosecond laser pulses, Applied Physics Letters 121, 101602, 2022.

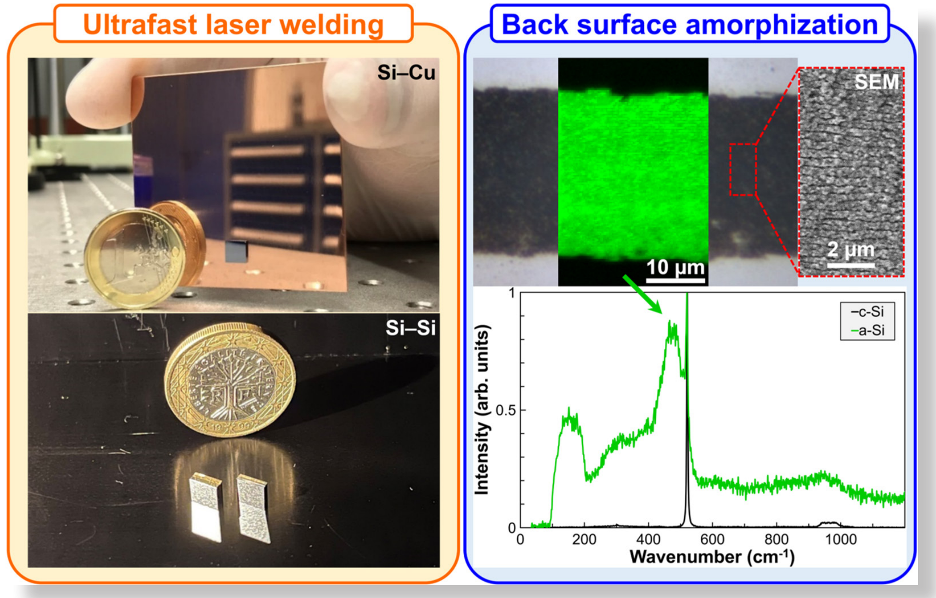

Figure 2:
Through-silicon ultrashort pulse laser processing applications.

Authors:
Valerio Flavio Gilli, Thomas Pertsch and Frank Setzpfandt

Scanning Quantum Microscopy

Quantum correlations are ubiquitously present in quantum mechanical systems, and have both puzzled and intrigued physicists since the formulation of the Einstein-Podolsky-Rosen paradox and the Bell inequalities. Nowadays, researchers are trying to exploit them in a number of emerging quantum technologies, for example quantum imaging, in which increased signal-to-noise ratios are expected due to the statistics of non-classical light. In our work, we exploit quantum correlations of near-infrared photon-pairs generated through spontaneous parametric down-conversion (SPDC) in a lithium niobate waveguide to perform quantum microscopy. SPDC, mediated by second-order nonlinear materials, allows one photon to decay into a pair of photons exhibiting time, frequency, momentum, and spatial correlations. Our quantum microscope is conceptualized in Fig. 1: one photon, the signal, is directly sent to detection, and heralds the detection of the second photon, the idler. The idler photon is injected into a scanning microscope, operating with two fast galvo-galvo mirrors, gets scanned across the sample surface, gets reflected back, and is sent to detection. Temporal correlations are evaluated with a

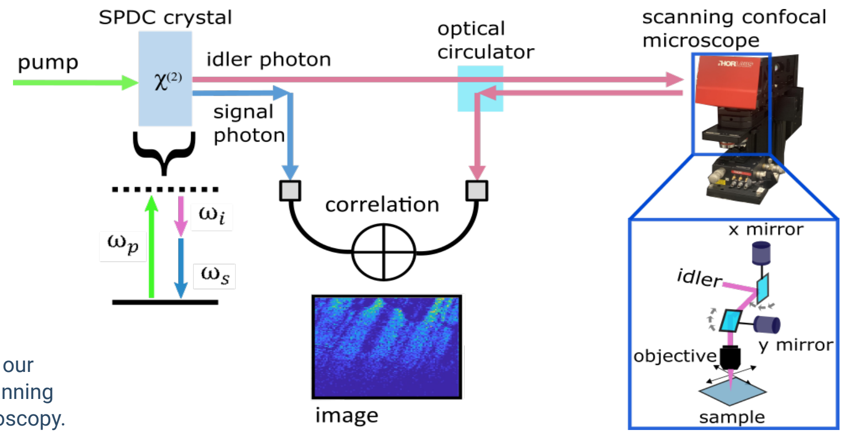

Figure 1:
Schematics of our system for scanning quantum microscopy.

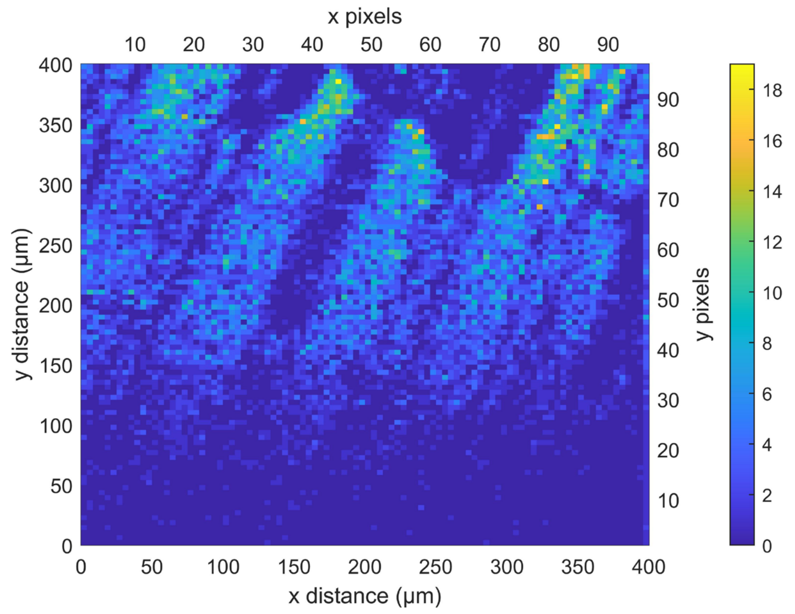

Figure 2:
Quantum image of onion epithelial cells .

time-to-digital converter, which also receives a line-scan triggering signal from the microscope, in order to assign correlation counts to spatial pixels and finally reconstruct an image of the sample. With our approach, we were able to investigate biological samples such as onion cells (see Fig. 2), at an infrared wavelength of 1670 nm. This spectral region is beyond the sensitive region of InGaAs infrared cameras, and its investigation has been unlocked by the development of superconducting nanowire single-photon detectors. Importantly, the spatial resolution of our quantum microscope is limited only by diffraction, rather than by the SPDC source as in wide-field quantum imaging. Our results represent a first step towards more complex quantum-enhanced microscopy schemes such as hyperspectral and 3D imaging. Finally, the very recent development of nanowire detectors working at wavelengths up to 10 µm can potentially lead to the extension of quantum imaging and sensing application towards the molecular fingerprint region.

/1/ V. F. Gili, et.al.: Experimental realization of scanning quantum microscop, Appl. Phys. Lett. 121, 104002, 2022.

Authors:
Christopher Spiess and Fabian Steinlechner

Clock synchronization with single photons

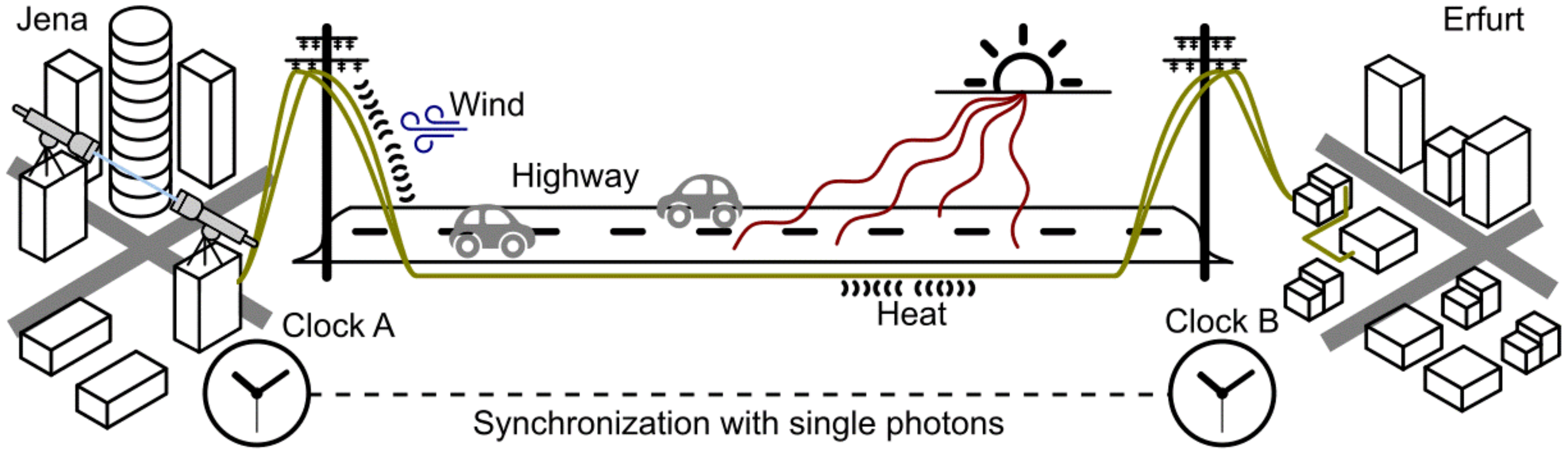

Figure 1: Synchronization of clocks with single photons in different application scenari-os. We show robust synchronization for long-distance fiber or turbulent free-space links

The synchronization of remote clocks is a key function in communication networks. To this end, the network time protocol is widely used for the synchronization of computers in communication networks, with typical stability of the order of 10-7. This can be further enhanced to the order of 10-19 using optical timing transfer technologies, in particular optical frequency combs. Such levels of stability are crucial in emerging quantum optical communication networks and require external additional hardware, such as rubidium clocks, synchronization lasers, or the global navigation satellite system for a long time.

Recent approaches use the single-photon timing information itself for synchronization without adding hardware or dedicated synchronization strings in the quantum communication channel [1,2]. The arrival-time information of every single photon provides a reference signal for synchronization. In the context of the BMBF-funded QuNET initiative, we have developed efficient postprocessing algorithms that show unprecedented synchronization performance. In particular, we show how remarkable timing stabilities of 186 (238) ps in a 30 (100)-second integration time can be achieved while using only simple quartz oscillators as a local time reference. Notably, these have several orders of magnitude worse stability than atomic references from the literature [3]. Remarkably, these results are close to the performance with ultra-stable clocks that show timing stabilities of 38.1 (88) ps in a 30 (100)-second integration time [4,5].

This method for software-based synchronization in postprocessing can be implemented straightforwardly in state-of-the-art QKD systems. It is easy to integrate on channels with strongly varying (or low) link transmissions, e.g., free-space/satellite communication or long-distance fiber channels. On the hardware side, well-established rubidium clocks or GPS references become redundant. It paves the way towards quantum networks with improved synchronization performance, as well as entirely new applications such as secure time transfer.

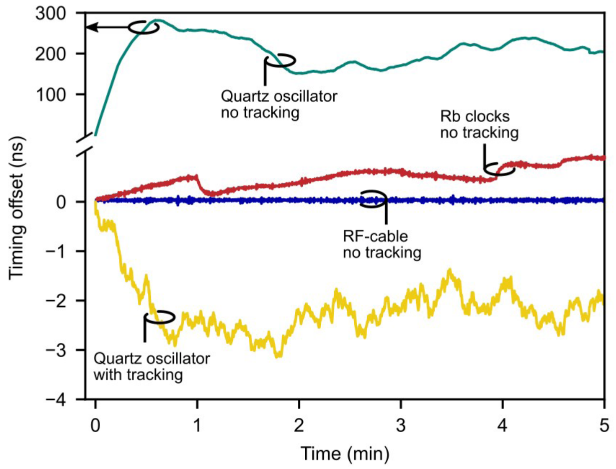

Figure 2: The variation of the timing offset is indicator of the stability of the system. The performance increases drastically by applying frequency-tracking algorithms between the clocks to be synchronized. We can reach stabilities close to highly stable rubidium oscillators (Rb).

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/2/ E. Fitzke, PRX Quantum 3, 020341, 2022.

/3/ C. Spiess et al., arXiv:2108.13466, 2021.

/4/ R. Quan, Optics express 30 (7), 10269–10279, 2022.

/5/ J. Lee, Optics Express 30 (11), 18530, 2022.

Authors:
Quyet Ngo, Antony George, Markus Schmidt, Heike Heidepriem-Ebendorff and Falk Eilenberger

Second Harmonic from Optical Fibers Coated with 2D-Materials

Optical fibers one of the most versatile platforms for nonlinear integrated photonics, because of their long interaction lengths and the ability to tailor dispersion to the requirements of applications. However, they are strictly bound to third order nonlinearities, because they are made from amorphous materials. Hence, they cannot create second harmonic, nor can they be used for fiber-based OPOs or entangled photon sources.

In/1/ we have shown that we can functionalize optical fibers with atom-scale nonlinear materials to overcome this limitation. The functionalizing media in question are semiconducting transition-metal dichalcogenides (TMDs), have a very strong second order nonlinearity, if they are used as monolayers, i.e. as two-dimensional crystals with a thickness of less than one nanometer.

TMDs, of which we use MoS_2 and WS_2, are so-called van-der-Waals-Materials, which interact only weakly with their substrate and hence can be grown as monocrystals on almost any substrate, including non-planar, amorphous fibers and integrated silicon waveguides. The growth process is based on a scalable chemical-vapor-deposition method, developed at the Friedrich-Schiller-University. The fibers itself are microstructured exposed-core fibers, i.e. they have a guided mode at the surface with a substantial evanescent field, that can interact with the TMD monolayer crystals.
They have been developed in a collaboration with the Leibniz Institute of Photonics Technologies and the University of Adelaide.

We have shown that we can interact with the TMDs of the functionalized fibers in guided wave experiments, demonstrating exciton physics, gas sensing, and nonlinear optics. The arguably most successful demonstration has been a fiber-integrated light source for second harmonic light. In this proof of principle experiment we have demonstrated TMD-functionalized fibers used as a platform for integrated nonlinear optics. After a thorough analysis of the nonlinear dynamics, we find that this system may lead to fiber-based nonlinear elements with interaction efficiencies, that rival that if $LiNbO_3$-waveguide, if technical issues with the fibers and the growth of 2D-materials can be addressed.

Figure 1:
See Cover: Artists impression of second harmonic generation in an exposed core fiber coated with a tri-angular TMD-crystal. Used as "hero image" in Nature Photonics November 2022 Issue.

To this end, Fraunhofer IOF implements various schemes for achieving HDE sources. From theory to experiment we are leveraging Fraunhofer IOF applied optics and photonics manufacturing capabilities to harness such correlations to attain HDE photon pairs in time-, frequency, and space.

/1/ G. Q. Ngo, et al. Nature Photonics 16 (11), 769-776, 2022.

Within the Attract project, we have developed approaches to harness the carrier frequency of photons to encode vast amounts of quantum information. Figure 1 depicts a microring resonator that was used to generate quantum frequency combs with massive entanglement dimensionality. We are currently working with photon pairs of 100x100 frequency modes, which corresponds to a possible information capacity of more than 6 qubits per photon. Similarly, we have developed phase-stabilization techniques for unbalanced interferometers which enable the analysis of quantum states encoded in discrete time-bin superposition states.

Within the BMBF-Funded Quantum Photonics Labs (QPL), we are developing new techniques to control and manipulate the complex wavefront of photons. Employing "Multi-Plane Light Conversion" (Figure 2) we have realized a spatial mode sorter for up to 7 Hermite-Gauss modes that uses custom phase elements developed in collaboration with the nano and micro-optics department at IOF.
A current project employing entanglement in space is QSource, which aims to develop a bright and stable modular HDE source in orbital angular momentum with scalable dimensionality.

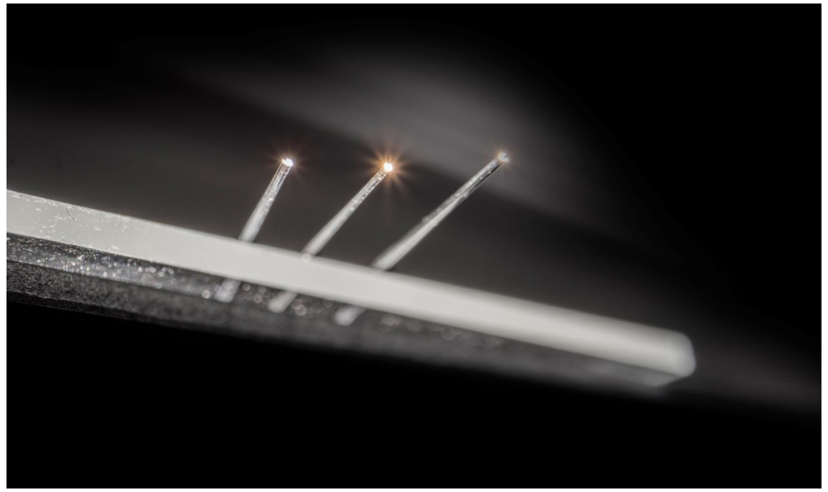

Figure 2:
Image of an assortment of Exposed Core fibers in an SHG experiment.

PUBLICATIONS

Aim of applied research is the implementation of the results and thus to make contributions to overcome certain problems of the future. For this reason, the research actually not only ends in itself, but their results must be discussed and adjusted with further findings. In the end again, new ideas and scientific approaches can be developed.

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Conferences

Invited

A. Klenke, A. Steinkopff, C. Aleshire, C. Jauregui, S. Kuhn, J. Nold, C. Hupel, S. Hein, S. Schulze, N. Haarlammert, T. Schreiber, A. Tünnermann, J. Limpert, High power multicore fibers – current status and future perspectives, ICUIL, Seogwipo, Korea.

A. Tünnermann, Power Scaling of Solid state lasers, Europhoton 2022, Hannover, Germany.

M. Eichhorn, A. Tünnermann, Lasertechnologie - Strategische Schlüsseltechnologie für Deutschland , Konferenz "Angewandte Forschung für Verteidigung und Sicherheit in Deutschland: Zukunftstechnologie für die Bundeswehr", , Bonn, Germany.

C. Aleshire, A. Steinkopff, A. Klenke, C. Jauregui, S. Böhme, T. Koch, S. Kuhn, J. Nold, N. Haarlammert, T. Schreiber, J. Limpert, Tapered multicore fibers for energy-scalable fiber laser systems, EOS Annual Meeting (EOSAM 2022), Porto, Portugal.

F. Eilenberger, Albert Einstein, die Simpsons und die gar nicht so spukhafte Fernwirkung, Lange Nacht der Wissenschaften, Jena, Germany.

F. Setzpfandt, Lithium Niobate Metasurfaces for Parametric Frequency Conversion, European Conference on Optical Communication (ECOC), Basel, Switzerland.

H. P. Kohl, L. Schade, G. Matthäus, T. Ullsperger, B. Yürekli, B. Seyfarth, S. Nolte, Additive manufacturing of geometrically complex pure copper parts, Photonics West 2022, online, .

M. Chambonneau, Domesticating micro-filamentation in silicon for ultrafast laser welding applications, International Conference on Laser Filamentation (COFIL) 2022, Chania, Greece.

S. Nolte, N. Alasgarzade, A. Alberucci, M. Blothe, C. P. Jisha, G. Matthäus, M. Chambonneau, Ultrashort Pulse Written Waveguides in Silicon, Optica Advanced Photonics Congress - BGPP, Maastricht, The Netherlands.

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Talks & Posters

A. Kirsche, R. Klas, M. Gebhardt, L. Eisenbach, W. Eschen, J. Buldt, H. Stark, J. Rothhardt, J. Limpert, Continuously tunable high photon flux high harmonic source at 50–70 eV, HILAS, Budapest, Hungary.

A. Klenke, A. Steinkopff, C. Aleshire, C. Jauregui, S. Kuhn, J. Nold, C. Hupel, S. Hein, S. Schulze, N. Haarlammert, T. Schreiber, A. Tünnermann, J. Limpert, 500 W average power, multicore fiber-based femtosecond CPA system, SPIE Photonics West, San Francisco, USA.

A. Krstić, F. Setzpfandt, T. Pertsch, S. Saravi, A General Formalism for Describing High-gain Photon-pair Generation in Dispersive and Absorbing Nanostructured Systems, Quantum 2.0 Conference and Exhibition, Boston, Massachussetts, USA.

A. Krstić, F. Setzpfandt, T. Pertsch, S. Saravi, High-gain Spontaneous Parametric Down-conversion in Dispersive and Absorbing Nanostructured Systems, Advanced Photonics Congress, Maastricht, Netherlands.

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A. Steinkopff, C. Aleshire, A. Klenke, C. Jauregui, J. Nold, S. Kuhn, N. Haarlammert, T. Schreiber, J. Limpert, Investigation of optical core-to-core crosstalk in multicore fibers, Advanced Photonics Congress, Maastricht, The Netherlands.

A. Szeghalmi, Plasma-Enhanced Atomic Layer Deposition Coatings for High-Power Laser Optics. Virtual Meeting, Photonics spectra Conference, online.

A. Szeghalmi, Atomic Layer Deposition for Functional Coatings, BuildMoNa, Leipzig, Germany.

A. Szeghalmi, Tailoring material properties of PEALD coatings by bias, ALD for Industry, Dresden, Germany.

B. Fehér, V. Hanus, Z. Pápa, J. Budai, P. Paul, A. Szeghalmi, P. Dombi, Laser-Induced Ultrafast Currents in Dielectrics Enhanced by Iridium Nanoparticles, High Intensity Lasers and High Field Phenomena, Budapest, Hungary.

B. Laudert, J. P. B. Ligabô, K. Elyas, A. Tarapkin, K. Höflich, F. Eilenberger, Towards the Integration of hBN based Single Photon Emitters with Freely Suspended Si3N4 Planar Resonant Structures, TMOS Conference 2022: Meta Together, Murray Bridge, Australia.

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C. Cholsuk, S. Suwanna, F. Eilenberger, T. Vogl, Manipulating ground-state properties of hBN quantum emitters, DPG Spring Meeting, Erlangan, Germany.

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M. Lenski, T. Heuermann, M. Gebhardt, Z. Wang, C. Gaida, C. Jauregui, J. Limpert, Highly efficient, high-power thulium-doped fibre amplifier via in-band pumping at 1.7 µm, 10th EPS-QEOD Europhoton Conference, Hannover, Germany.

M. P. Siems, D. Richter, T. A. Goebel, R. G. Krämer, S. Nolte, Realization of Chirped Volume Bragg Gratings in Fused Silica by Femtosecond Phase Mask Inscription, Optica Advanced Photonics Congress - BGPP, Mastricht, The Netherlands.

M. Walther, T. Siefke, K. Gerold, U. Zeitner, Switchable optics based on guided mode resonance in lithographically patterned vanadium dioxide, EOS Annual Meeting (EOSAM 2022), Porto, Portugal.

P. Gierschke, C. Grebing, M. Abdelaal, M. Lenski, J. Buldt, Z. Wang, T. Heuermann, M. Müller, M. Gebhardt, J. Rothhardt, J. Limpert, High Average Power Nonlinear Pulse Compression in a Gas-filled Multipass Cell at 2 µm wavelength, 10th EPS-QEOD Europhoton Conference, Hannover, Germany.

P. Paul, P. Schmitt, W. Li, Z. Wang, N. Daryakar, C. David, K. Hanemann, S. Beer, R. Rafi, M.F. Kling, A. Tünnermann, A Szeghalmi, Linear and nonlinear optical properties of Iridium nanoparticles grown by atomic layer deposition (ALD), International Conference of Quantum, Nonlinear and Nanophotonics ICQNN 2022, Jena, Germany.

P. Paul, P. Schmitt, Z. Wang, W. Li, M. F. Kling, A. Tünnermann, A. Szeghalmi, Structural and optical properties of atomically engineered Ir/Al2O3 nanocomposites, SPIE Photonics Europe, Strasbourg, France.

R. Ackermann, A. Stöcker, T. Gabler, T. Koch, J. Mißbach-Güntner, C. Rußmann, S. Nolte, Ultrabroadband two-beam CARS using a dual output OPCPA at high NA, 20th European Conference on Non-linear Optical Spectroscopy, Kiruna, Sweden.

R. Klas, A. Kirsche, M. Gebhardt, J. Buldt, H. Stark, S. Hädrich, J. Rothhardt, J. Limpert, Ultrafast HHG source delivering 13 mW of average power, HILAS, Budapest, Hungary.

R. Klas, A. Kirsche, V. Hilbert, P. Gierschke, L. Eisenbach, A. Borovik, S. Trotsenko, S. Schippers, Z. Andelkovic, U. Spillmann, R. Mihalcea, L. Mihai, A. Stancalie, M. Lestinsky, F. Herfurth, G. Weber, A. Bräuning-Demian, T. Stöhlker, J. Limpert, J. Rothhardt, XUV photoionization at CRYRING, Annual Meeting of the ErUM-FSP APPA, online, Germany.

R.G. Krämer, C.P. Schmittner, T.A. Goebel, M.P.Siems, T.Ullsperger, T.O. Imogore, D. Richter, S. Nolte, Tailored Apodization of femtosecond written fiber Bragg gratings by aperture shaping, Optica Advanced Photonics Congress - BGPP, Mastricht, The Netherlands.

S. Beer, J. Gour, A. Alberucci, C. David, S. Nolte, U. Zeitner, SHG under doubly resonant lattice plasmon excitation, Near Field Optics Conference (NFO16), Victoria, Canada.

S. Beer, J. Gour, A. Alberucci, C. David, U. Zeitner, S. Nolte, Investigation of surface lattice resonance enhancement on SHG in plasmonic metasurfaces, Frontiers in Optics 2022, Rochester, USA.

S. Ritter, J. Kretzschmar, F. Sojka, T. Kaiser, R. Geiss, T. Vogl, F. Eilenberger, Open Source Experiments in Quantum Photonics: An Affordable Approach, EDULEARN22, Palma, Spain.

S. V. Arumugam, C. P. Jisha, A. Alberucci, S. Nolte, Properties of Waveguides Based Upon the Pancharatnam-Berry Phase, Frontiers in Optics 2022, Rochester, USA.

Sebastian Linß, U. D. Zeitner, Wave-Optical Design of Wide-Angle Computer-Generated Holograms, 27th Microoptics Conference (MOC2022), Jena, Germany.

T. A. Goebel, C. P. Schmittner, Z. Lin, R. G. Krämer, M. P. Siems, T. O. Imogore, D. l Richter, S. Nolte, Phase-Shifted Fiber Bragg Gratings via Localized Femtosecond Photo-Treatment, Optica Advanced Photonics Congress - BGPP, Mastricht, The Netherlands.

T. Flügel-Paul, M. Heusinger, K. Gerold, A. Szeghalmi, U. Zeitner, Optical methods for measuring the feature size of optical diffraction gratings with nano-meter accuracy and implementation of suitable feedback control loops, EOS Annual Meeting (EOSAM 2022), Porto, Portugal.

T. Siefke, M. Walther, C. Stock, U. Zeitner, Fabrication influences on a miniaturised stokes polarimeter consisting of stacked nano-optical wire grid polarizer and retarders, EOS Annual Meeting (EOSAM 2022), Porto, Portugal.

V. Hanus, B. Feher, Z. Papa, J. Budai, P. Paul, A. Szeghalmi, On-chip carrier-envelope phase scanner, SPIE Photonics Europe, Strasbourg, France.

V. Hanus, B. Fehér, Z. Pápa, J. Budai, P. Paul, A. Szeghalmi, P. Dombi, On-Chip Carrier-Envelope Phase Scanner, CLEO 2022, San Jose, USA.

X. Zhao, A. Boden, S. Nolte, R. Ackermann, Spectral broadening of IR filamentation in air for coherent anti-Stokes Raman scattering, International Conference on Ultrafast Phenomena, Montreal, Canada.

X. Zhao, A. Boden, S. Nolte, R. Ackermann, Spectral broadening in IR-filamentation induced by 1 ps pulses for coherent anti-Stokes Raman scattering, 20th European Conference on Nonlinear Optical Spectroscopy, Kiruna, Sweden.

X. Zhao, T. Lippoldt, T. Gabler, S. Nolte, R. Ackermann, Thermometry by picosecond optical parametric amplifier for Coherent Anti-Stokes Raman Scattering, 20th European Conference on Non-linear Optical Spectroscopy, Kiruna, Sweden.

Y. Tu, C. Jauregui, S. E. Kholaif, J. Limpert, Realtime modal decomposition of fiber laser beams using a spatial mode multiplexer, SPIE Photonics West, San Francisco, USA.

Z. Wang, T. Heuermann, M. Gebhardt, M. Lenski, P. Gierschke, R. Klas, C. Jauregui, J. Limpert, 100W, 1 mJ, few-cycle pulses at 2 µm wavelength, 10th EPS-QEOD Europhoton Conference, Hannover, Germany.

Colloquia

A. Kuppadakkath, A. Barreda, L. Ghazaryan, T. Bucher, K. Koshelev, Y. Kivshar, D. Choi, T. Pertsch, I. Staude, F. Eilenberger, Temperature tunability of BIC resonance, Workshop-Structured Light and its Applications, Jena, Germany.

A. Kuppadakkath, E. Najafidehaghani, Z. Gan, A. Tuniz , G. Ngo, H. Knopf, F. Löchner, F. Abtahi, T. Bucher, S. Shradha, T. Käsebier, S. Palomba, P. Paul, T. Ullsperger, S. Schröder, A. Szeghalmi, T. Pertsch, I. Staude, U. Zeitner, A. George, A. Turchanin, F. Eilenberger ,Direct growth of monolayer MoS_2 on nanostructured silicon waveguides, Workshop-Integration of novel materials into silicon photonics, Aachen, Germany.

A.Tünnermann, Abbe Center of Photonics Jena – principal investigators and research topics, Integrated Quantum Science Technology Day, online, Germany.

A.Tünnermann, Laudatio für Prof. Ursula Keller, Überreichung des Schweizer Wissenschaftspreises Marcel Benoit, Bern, Switzerland.

D. Repp, A. Barreda-Gomez, F. Vitale, I. Staude, C. Ronning, T. Pertsch, Numerical parameter study of Purcell factor enhancement and lasing threshold for semiconductor nanowires coupled to planar metals, Nanowire week, Charmonix, France.

F. Abtahi, P. Paul, A. Szeghalmi, F. Eilenberger, Surface Second Harmonic Generation in Dielectric Nanofilms, ICFO Summer School 2022 (ICFO International school on the frontiers of light), Barcelona, Spain.

F. Eilenberger, Quantenalgorithmen -eine viel zu kurze Einführung-, FhG HiWi Days, Jena, Germany.

F. Eilenberger, Quantum Computing: Seen through the Eyes of a Photonics Guy, MPSP Winter School, Jena, Germany.

F. Eilenberger, Quantum Computing: Seen through the Eyes of a Photonics Guy, MPSP Spring School, Jena, Germany.

F. Eilenberger, Quantenalgorithmen-eine viel zu kurze Einführung-, FSU Girls Day, Jena, Germany.

F. Eilenberger, Quantum Computing: an Introduction, Photonics Manager, Jena, Germany.

F. Eilenberger, Integration of 2D-materials in optical systems: towards nonlinear waveguides, integrated quantum light sources, and polariton physics, MPSP Autumn School, Jena, Germany.

F. Eilenberger, Quantum Algorithmus: an Introduction, FH Regensburg, Regensburg, Germany.

F. Eilenberger, Integration of 2D-materials in optical systems: towards nonlinear waveguides, integrated quantum light sources, and polariton physics, KIT, Karlsruhe, Germany.

F. Eilenberger, Hybrid Nanomaterial Photonics: Harnessing the Quantum Properties of Two-Dimensional Materials, Technische Universität Braunschweig, Braunschweig, Germany.

F. Eilenberger, Quantum on the Nanoscale: Integration of Monolayer Materials for Quantum Light and Sensing Applications, Friedrich-Schiller-Universität, Jena, Germany.

F. Eilenberger, Integration of two-dimensional materials in optical systems: towards nonlinear waveguides, integrated quantum light sources, and polariton physics, Carl von Ossietzky Universität, Oldenburg, Germany.

F. Eilenberger, Integration of two-dimensional materials in optical systems: towards nonlinear waveguides, integrated quantum light sources, and polariton physics, Friedrich-Schiller-Universität, Jena, Germany.

F. Schmidt, J. P. B. Ligabo, A. Kumar, M. Plidschun, M.-H. Khosravi, M. Schmidt, T. Vogl, F. Eilenberger, A monolithic nanophotonic system based on single-photon emitters, Integrated Photonics Workshop, London, UK.

K. Gerold, P.Paul, V. Beladiya, D. Kästner, A. Szeghalmi, Konforme Entspiegelung komplex-geformter Optiken mittels ALD,15. Auswärtsseminar der Arbeitsgruppe Optische Technologien Leupold-Institut für Angewandte Naturwissenschaften (LIAN) der Westsächsischen Hochschule Zwickau und des Fraunhofer-Anwendungszentrums (AZOM), Nesselwang, Germany.

S. Linß, D. Michaelis, U. D. Zeitner, Wave-optical simulation of macroscopic dielectric metasurfaces,Workshop on Structured light and its applications, online, Germany.

S. Nolte, Structured light for ultrashort pulse materials processing, Workshop on Structured Light and its Applications, Jena, Germany.

Granted Patents

M. Blothe, M. Chambonneau, S. Nolte, M. Kumkar
Verfahren zum Zerteilen eines transparenten Werkstücks

DE 102021100675.9

C. Jauregui Misas, A. Tünnermann, J. Limpert, C. Gaida
Lichtwellenleiter

EP 15785059.5

H. v. Lukowicz, J. Hartung, M. Beier, S. Risse
Halterung zur Fixierung und Referenzierung von mit einer Messvorrichtung an mehreren, nicht in einer gemeinsamen Ebene angeordneten Oberflächen in einer Einspannung zu vermessenden Bauteilen

DE 102018209017B4

S. Nolte, R. Steinkopf, A. Szameit, H. Gross, C. Vetter, M. Ornigotti
Arrangement for Producing a Bessel Beam

US11,372,254B2

S. Nolte, K. Bergner
Laserbearbeitung eines transparenten Werkstücks

EP 3676045B1

J. Popp, M. Schmitt, T. Meyer, S. Nolte, R. Ackermann, J. Limpert
Laser mikroscope with ablation function

US 16/303,558

C. Schenk, S. Risse
Verfahren zur Verbesserung der Positioniergenauigkeit von mittels Gaslagerelementen geführten Tischen und Verwendung von Luftlagerelementen mit Dichtsystemen für in Umgebungsatmosphäre geführten Tischsystemen

DE 102009019773B4

F. Setzpfand, F. Eilenberger, M. Gräfe, T. Pertsch
Optical assembly for the hyperspectral illumnination and evaluation of an abject

US 11,371,932B2

F. Setzpfand, F. Eilenberger, M. Gräfe, T. Pertsch
Optische Anordnung zur hyperspektralen Beleuchtung und Auswertung eines Objektes

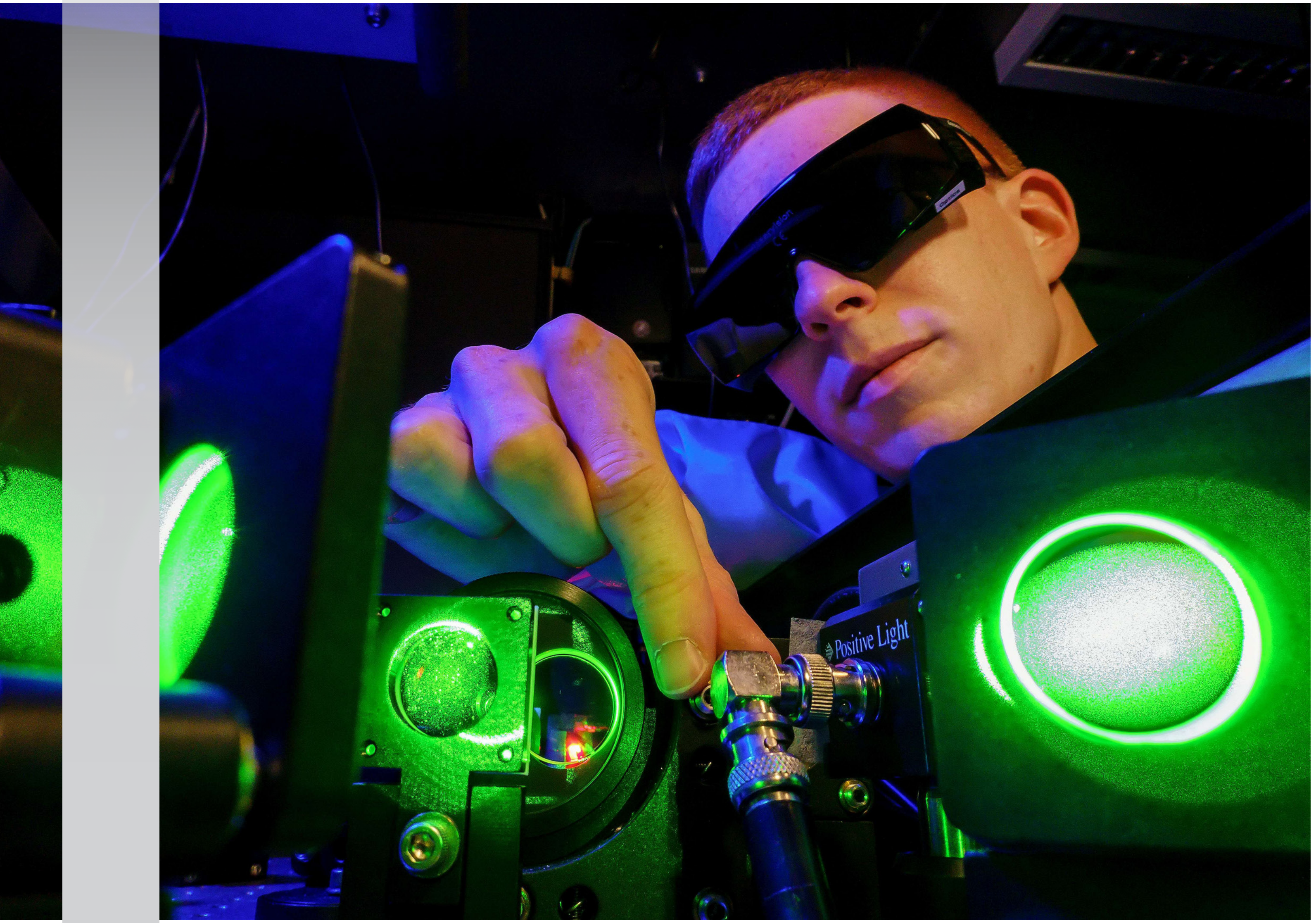
EP 19734763.6

A. Tünnermann, C. Stihler, C. Jáuregui Misas, J. Limpert
Avoiding mode instability in an optical amplifier fiber

US 11,381,054B2

A. Tünnermann, A. Klenke, J. Limpert, H.-J. Otto
Optische Anordnung mit Strahlaufteilung, Optical Array Comprising a Beam Splitter

EP 15707047.5



Thorsten Goebel adjusts experimental equipment on an optical setup.

ACTIVITIES

A key feature of the IAP is the active and engaged exchange of its employees within the scientific community. This commitment can be measured in both the participation at conferences and at cooperation in projects with other institutions. Such community projects are the fruits of compulsory networking and strengthen the reputation of the institute within the research society and industrial associations. Appreciation of these efforts are also the call-ups of particular scientists in committees and editorial positions of academically approved journals.

Awards

Mostafa Abasifard
Best Poster Award: Quantum 2022 Summer School on Quantum Optical Technologies,
Università degli Studi di Bari Aldo Moro & INFN Sezione di Bari
Towards quantum key distribution with true single-photon sources at room

Jisha Chandroth Pannian
Senior Member
Optical Society (OSA)

Martin Gebhardt
Friedrich-Hund-Dissertation Award for Applied Research,
Faculty of Physics and Astronomy, University of Jena
Power scaling of few-cycle short-wavelength infrared laser sources for nonlinear frequency conversion

Lilit Ghazaryan
Best Paper Award,
27th Microoptics Conference (MOC2022)
Single Crystal Diamond Membranes for Optical Quantum Devices

Magdalena Hilbert
Applied Photonics Award: Best Bachelor Thesis,
Photonic Days Jena, Fraunhofer-Gesellschaft
Gas Sensing with 2D Materials on Exposed-Core Fibers

Ria Krämer
Best Students Award,
Bragg Gratings, Photosensitivity and Poling in optical materials and waveguides (BGPP),
Optical Society (OSA)
Tailored Apodization of femtosecond written fiber Bragg gratings by aperture shaping

Kim Alina Lammers
Friedrich-Hund-Dissertation Award for Basic Research,
Faculty of Physics and Astronomy, University of Jena
Polarization manipulation in femtosecond laser direct written waveguides in fused

Yiming Tu
2nd Place Best Student Award,
SPIE Photonics West
Real-time modal decomposition of fiber laser beams using a spatial mode multiplexer

Andreas Tünnermann
Medal of Honour,
Fraunhofer Gesellschaft

Maximilian Weißflog
2nd Place Poster Session, Colloquium on the Physics and Applications of Metasurfaces
Entangled Photon-Pair Generation in Dielectric Nanoresonators

Daniel Werdehausen
Post-Graduate Applied Photonics Award:
Jury award for scientific excellence,
Photonic Days Jena, Fraunhofer-Gesellschaft
Nanocomposites as Next- generation Optical Materials: Fundamental Properties and Potential

Sabine Best, Johannes Kretzschmar, David Zakoth
Teaching Award,
Friedrich Schiller University Jena
Innovation Methods in Photonics course

ACTIVITIES

Organizing Activities

Falk Eilenberger

Fellow of the Max-Planck-School of Photonics

Referee for Optica, Annalen der Physik, Opt. Comm.

Jens Limpert

Member of Deutsche Physikalische Gesellschaft (DPG)

Member of the Optical Society of America (OSA)

Referee for several scientific journals

Stefan Nolte

Deputy Director of the Institute for Applied Optics and Precision Engineering IOF

Fellow of the Max Planck School of Photonics

Member of the Abbe School of Photonics

Chair of the Faculty´s Budget Commission and member of the Budget Board of the Senate

Member of jury "Jugend forscht"

Member of several scientific committees (e.g. Phot. West, CLEO, ICALEO, LANE, Lasers in Manufacturing LiM, Lasertagung Jena)

Fellow of the Optical Society of America (OSA)

Fellow of the International Society for Optics and Photonics SPIE

Member of Deutsche Physikalische Gesellschaft (DPG)

Referee for Nature Photonics, Nature Communications, Optics Letters, Optics Express, J Phys B, Appl. Phys B, Applied Optics, European Physical Journal D and funding organizations

Thomas Pertsch

Member of the board of directors of the Abbe Center of Photonics at the Friedrich Schiller University Jena

Spokesman of the Abbe School of Photonics at the Friedrich Schiller University Jena

Member of the advisory board of London Institute for Advanced Light Technologies of King's College London, Imperial College London and University College London

Member of the board of trustees of the Center of Excellence in Photonics ("Leistungszentrum Photonik") of the Fraunhofer Society

Member of the board of directors of the Thuringian Innovation Center for Quantum Optics and Sensing

Associate Investigator of the ARC Centre of Excellence for Transformative Meta-Optical Systems

Associate Investigator of the Cluster of Excellence Balance of the Microverse

Fellow of the Max Planck School of Photonics

Fellow of the Optical Society of America (OSA, Optica)

Referee for several international journals

Member of the Undergrad Committee of the Faculty of Physics and Astronomy at the Friedrich Schiller University Jena

Study program director for "Master of Science in Photonics" at the Friedrich Schiller University Jena – also responsible for accreditation

Advisor of the Student Chapter Jena of the Optical Society of America

Jan Rothhardt

Member of the extended directory board of the Helmholtz Institute Jena

Member of the Program committee for EOSAM conference 2021

Member Optical Society of America (OSA)

Referee for Nature Photonics, Nature Communications, Optics Letters, Optics Express, J Phys B, Appl. Phys B, Applied Optics, European Physical Journal D

Frank Setzpfandt

Journal-Referee for: Laser & Photonics Reviews, Optics Express, Optica

Project Referee for: Deutsche Forschungsgemeinschaft (DFG)

Managing Director of the „Thüringer Innovationszentrums für Quantenoptik und Sensorik"

ACTIVITIES

Markus Gräfe

Journal-Referee for: Nature Photonics, Optics Letters, APL Photonics, Physical Review Letters, Physical Review A, Optics Communication, Advanced Photonics Research, Laser & Photonics Reviews, Journal of Microscopy

Member of Deutsche Physikalische Gesellschaft (DPG)

Member of the ACP

Fabian Steinlechner

Referee for Physical Review Letters, Nature Physics, Optica, and other international journals

Reviewer for DFG

Speaker of the Quanten Hub Thüringen Qi1 – Quantenkommunikation

Speaker of the EU-Canada Project “HyperSpace”, Horizon Europe

Adriana Szeghalmi

Member of Deutsche Physikalische Gesellschaft (DPG)

Senior Member of the Optical Society of America (OSA)

Reviewer for several scientific journals

Andreas Tünnermann

Member of the BMBF Research Cluster “infectooptics”

Spokesman of the BMBF Center for Innovation Competence ZIK “ultra optics”

Spokesman of the BMBF Program Zwanzig20 “3Dsensation” & BMBF Program QuNET

Spokesman of DFG Research Training Group GRK2101

Council member of the excellence cluster “Balance of the microverse”

Director Fraunhofer IOF

Chairman of the Technical Council Fraunhofer-Gesellschaft

Co-Spokesman of the Fraunhofer Cluster of Excellence “Advanced photon source”

Spokesman of the Thuringian Innovation Center of “Quantum optics and sensors”

Board of Directors Helmholtz Institute, Jena

Board of Trustees MPA, Heidelberg

Spokesman of the “Max-Planck-School of Photonics”

Surveyor BMBF, DFG, EU, AIF, MF, VF Projektträger Euronorm (BMWI)

Alexander von Humboldt Stiftung - Selection Committee Alexander-von-Humboldt Professur

Jury member STIFT - Thüringer Innovationspreis

Stakeholder Photonics 21-Platform

Member of Program Committee Quantum Technology 514

Member of the Strategic Advisory Board for the Quantum Technologies Flagship (SAB), EU

Member of the Expert Council "Quantumcomputing" of the Federal Gouvernment

Council Member of the TU Bergakademie Freiberg

Council Member of the Faculty PAF at FSU

Member of the Excecutive Board of the Abbe Center of Photonics at the Friedrich Schiller University Jena

Spokesman of the Fraunhofer Innovation Cluster “Leistungszentrum Photonik” & Fraunhofer Graduate College "Fraunhofer Graduate Research School Photonics"

Member Wissenschaftliche Gesellschaft Lasertechnik e .V. - Chairman "AG Naturwissenschaften"

Member of acatech "Deutsche Akademie der Technikwissenschaften"

Fellow Opical Sociaty of America (OSA) & SPIE

Member of Deutsche Physikalische Gesellschaft (DPG)

Spokesman Thuringian Quantum Hub

Member of „Rat für technischen Souveränität RAT4TS“, BMBF

Representative of „Fraunhofer-Gesellschaft im QVLS | Quantum Valley Lower Saxony“ and Munich Quantum Valley

Tobias Vogl

Member of Deutsche Physikalische Gesellschaft (DPG)

Speaker of Research Network QUICK3, DLG and BMWK

Referee for international journals

Frank Wyrowski

Fellow of the Max-Planck-School of Photonics

Referee for Optica, Annalen der Physik, Opt. Comm.

Uwe D. Zeitner

Conference Co-Chair of the 27th Microoptics Conference MOC2022

Member of the Program Committee for the Microoptics Conference MOC2023

Referee of several scientific journals

LOCATION

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