Institute of Applied Physics

Friedrich-Schiller-Universität Jena

2019 Annual Report

Imprint

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EDITORIAL
Ira Winkler, Dr. Frank Schrempel

LAYOUT
Ira Winkler

PHOTOS/GRAFICS
Institute of Applied Physics (IAP), Fraunhofer IOF [W. Oppel], Friedrich Schiller University Jena [J.-P. Kasper], PAF-FSU
p58: aboutpixel.de/Lektüre©marshi

Cover: Prof. Dr. Jens Limpert received the 3rd ERC Grant - making him the first in Germany to do so.

Content

PREFACE / VORWORT

Dear colleagues,

in the past few years, we have successfully established quantum technology as a new research area at our Leistungszentrum Photonik, and are thus involved in major initiatives that are testing the added value of this new technology in a wide range of application fields. Thus, the QuNET project addresses the fundamental right to data sovereignty with goal-oriented research for future networks for quantum communication, first for Germany and later throughout Europe. Together with the Fraunhofer Heinrich Hertz Institute, the Max Planck Society and the German Aerospace Center, we will thus create the basis for a data space with an unattained level of security, thus making an important contribution to a successful research and economic area and a democratic society capable of defending itself.

The fact that we have been involved in this task of trust is the result of our outstanding research work to this point.

In this context, I would like to emphasize again the junior research groups led by Dr. Fabian Steinlechner, Dr. Markus Gräfe, Dr. Falk Eilenberger and Dr. Frank Setzpfandt, whose projects are not only conducting basic research, but also breaking new ground in data encryption and which will also, for example, enable investigations in spectral ranges that have not been possible to date, or realize imaging at very low intensities.

For these future tasks, we will still need very well-trained young researchers. Even if the conditions at our location are very good, we must face international competition. I am therefore very pleased that we have created the Max Plack School of Photonics here as an institution, that has the potential to attract highly qualified talents to Jena.

Since the ceremonial opening by Federal Research Minister Anja Karliczek, ten young scientists have already been welcomed to the Thuringian campus - five of them at our institute itself - who will do their doctorates in the fields of optics and photonics. The joint organization of the "Photonics Days" was also very successful: Particularly noteworthy are the keynote lectures by ZEISS Chairman Prof. Michael Kaschke and Nobel Prize winner Prof. Gérard Mourou, who derived future trends from the development line of laser technology. We were also inspired by many convincing ideas in the elevator pitches, which give us hope that we can inspire young people to be fascinated by photonics also now and in the future.

2019 also launched the Collaborative Research Center SFB 1375 "NOA - Nonlinear Optics down to Atomic scales" at our university, in which fundamental nonlinear processes of light-matter interaction in low-dimensional nanostructures, such as atomically thin layers, nanoparticles and -wires, nanostructured surfaces and molecular assemblies are to be investigated over a period of 12 years in cooperation with other research institutions. NOA will explore quantum phenomena as light-induced tunneling of electrons through metallic nanogaps and field-driven carrier acceleration in plasmonic nanostructures, atomic lattices and 2D-materials. This includes investigating the resulting back-action on the electromagnetic field, causing the generation of higher harmonics and information about the electronic wavefunctions involved in the interaction. So we will expect exciting discoveries in this area too!

I was particularly pleased to be supported for the fourth time by the European Research Council (ERC) with one of the highest endowed EU grants for basic research at the Institute of Applied Physics. To outline the importance of these ERC grants, it should be noted that only "groundbreaking pioneering research" is funded or scientific excellence is the sole selection criterion. Prof. Jens Limpert was one of the first to succeed in obtaining a "Starting Grant" (2009), followed by a "Consolidator Grant" (2014) and now the "Advanced Grant" for the project "SALT" (High-Flux Synchrotron Alternatives Driven by Powerful Long-Wavelength Fiber Lasers). In Germany he is even the only one with such a "series". (Editor's note: In 2014 Andreas Tünnermann's work on laser development was honored with an "Advanced Grant").

This proves that the IAP is doing excellence in the field of laser sources and their applications. It is perceived beyond the borders of Thuringia, and gives reason to hope that we will also draw attention to Jena on the 60th anniversary of laser technology 2020.

Dear colleagues, all the above mentioned achievements and many more success stories are only possible due to your great cooperation, idealism and creativity! I would like to thank you for this and for your commitment to events that bring our joy in our scientific topics to the people, such as the "Tag der Physik", the "Lange Nacht der Wissenschaften", but also for the support of pupils and students. At the same time, I would also like to thank our partners in research, business and politics for their excellent cooperation.

However, with COVID-19, our society is currently facing one of the greatest challenges of recent decades, but I am confident that we will overcome this together and continue to work closely together. My most urgent wish is:
Stay healthy!

With all sincerity,

Andreas Tünnermnann

Prof. Dr. Andreas Tünnermann

Liebe Kolleginnen & Kollegen,

in den vergangenen Jahren haben wir die Quantentechnologie an unserem Leistungszentrum Photonik als neue Forschungsrichtung erfolgreich etabliert, und sind damit an großen Initiativen beteiligt, die die Mehrwerte dieser neuen Technologie in unterschiedlichsten Anwendungsfeldern prüfen. So adressiert das Projekt QuNET das Grundrecht auf Datensouveränität mit zielorientierter Forschung für kommende Netzwerke zur Quantenkommunikation, zunächst für Deutschland und später europaweit. Gemeinsam mit dem Fraunhofer Heinrich-Hertz Institut, der Max-Planck-Gesellschaft und dem Deutschen Zentrum für Luft- und Raumfahrt werden wir damit die Grundlagen für einen Datenraum mit bisher unerreichtem Sicherheitsniveau schaffen, und somit einen wichtigen Beitrag zu einem erfolgreichen Forschungs- und Wirtschaftsraum und einer wehrfähigen demokratischen Gesellschaft leisten. Dass wir in diese vertrauensvolle Aufgabe eingebunden wurden, ist das Ergebnis unserer bisher geleisteten hervorragenden Forschungsarbeit.

In diesem Zusammenhang möchte ich noch einmal die Nachwuchsgruppen um Dr. Fabian Steinlechner, Dr. Markus Gräfe, Dr. Falk Eilenberger und Dr. Frank Setzpfandt hervorheben, die mit ihren Projekten nicht nur Grundlagenforschung betreiben, sondern neue Wege beschreiten, die bedeutend für die Datenverschlüsselung sind - aber beispielsweise auch Untersuchungen in Spektralbereichen ermöglichen werden, die bisher nicht erreicht werden konnten bzw. Bildgebung mit sehr geringen Intensitäten realisieren.

Für diese künftigen Aufgaben brauchen wir weiterhin sehr gut ausgebildeten Nachwuchs. Auch wenn die Voraussetzungen an unserem Standort sehr gut sind, müssen wir uns internationaler Konkurrenz stellen. Daher bin ich sehr froh, dass wir mit der Max Plack School of Photonics hier in Jena eine Institution geschaffen haben, die das Potential hat, hochqualifizierte Talente nach Jena zu locken. Seit der feierlichen Eröffnung durch Bundesforschungsministerin Anja Karliczek konnten bereits zehn Nachwuchswissenschaftlerinnen und Nachwuchswissenschaftler für den Standort gewonnen werden – allein fünf davon an unserem Institut - die in den Bereichen Optik und Photonik promovieren werden. Sehr erfolgreich war auch die gemeinsame Ausrichtung der „Photonics Days“: Besonders hervorzuheben sind die Keynote-Vorträge des ZEISS-Vorstandsvorsitzenden Prof. Michael Kaschke und des Physik-Nobelpreisträgers Prof. Gérard Mourou, der aus der Entwicklungslinie der Lasertechnologie künftige Trends ableitete. Inspiriert wurden wir außerdem von vielen überzeugenden Ideen bei den Elevator-Pitches, die darauf hoffen lassen, dass wir weiterhin junge Menschen für Photonik begeistern können.

2019 startete zudem der Sonderforschungsbereich SFB 1375 "NOA – Nonlinear Optics down to Atomic scales" an unserer Universität, in dem gemeinsam mit anderen Forschungseinrichtungen über 12 Jahre grundlegende nichtlineare Prozesse der Licht-Materie-Wechselwirkung in niedrigdimensionalen Nanostrukturen, wie z.B. atomar dünnen Schichten, Nanopartikeln und -drähten, nanostrukturierten Oberflächen und

molekularen Verbindungen erforscht werden sollen. NOA wird Quantenphänomene, wie lichtinduziertes Tunneln von Elektronen durch metallische Nanolücken und feldgetriebene Trägerbeschleunigung in plasmonischen Nanostrukturen, Atomgittern und 2D-Materialien analysieren. Dazu gehört die Untersuchung der daraus resultierenden Wirkung auf das elektromagnetische Feld, die die Erzeugung höherer Harmonischer und Informationen über die an der Wechselwirkung beteiligten elektronischen Wellenfunktionen generieren. Das heißt also, dass wir auch hier spannende Erkenntnisse erwarten können!

Besonders gefreut hat mich die bereits vierte Unterstützung des European Research Council (ERC) mit einem der höchstdotierten Förderungen der EU für eine grundlagenorientierte Forschung am Institut für Angewandte Physik. Um zu umreißen, welchen Stellenwert diese ERC Grants haben, sei hier erwählt, dass nur „bahnbrechende Pionierforschung“ gefördert bzw. wissenschaftliche Exzellenz das alleinige Auswahlkriterium ist. Prof. Jens Limpert ist es gelungen, als einer der Ersten überhaupt, sowohl einen „Starting Grant“ (2009) gefolgt von einem „Consolidator Grant“ (2014) und nun den „Advanced Grant“ für das Projekt „SALT“ (High-Flux Synchrotron Alternatives Driven by Powerful Long-Wavelength Fiber Lasers) einzuwerben. In Deutschland ist er mit einer solchen „Serie“ sogar der Einzige. (Red. Anmerkung: 2014 wurden die Arbeiten zur Laserentwicklung von Andreas Tünnermann durch einen „Advanced Grant“ gewürdigt.)

Dies belegt, dass am IAP Hervorragendes auf dem Gebiet der Laserquellen und deren Anwendungen geleistet, und dies auch über die Grenzen von Thüringen hinaus wahrgenommen wird und lässt hoffen, dass wir auch zum 60. Jahrestag der Lasertechnologie 2020 auf Jena aufmerksam machen werden.

Liebe Kolleginnen und Kollegen, all die oben genannten Erfolge und noch viele weitere verdanken wir nur Ihrer großartigen Zusammenarbeit, Idealismus und Kreativität! Dafür und für das Engagement bei Veranstaltungen, die mit Spaß unsere Freude an den Forschungsthemen den Menschen nahebringen, wie z.B. zum „Tag der Physik“, „Langen Nacht der Wissenschaften“, aber auch bei Schülerbetreuungen danke ich herzlich. Gleichzeitig gilt mein Dank für die gute Zusammenarbeit auch unseren Partnern aus Forschung, Wirtschaft und Politik.

Jedoch steht unsere Gesellschaft mit COVID-19 derzeit vor einer der größten Herausforderungen der letzten Jahrzehnte, aber ich bin zuversichtlich, dass wir dies gemeinsam meistern werden und weiter eng zusammenstehen. Dabei ist mein dringlichster Wunsch: Bleiben Sie gesund!

Herzlichst,

Prof. Dr. Andreas Tünnermann

The Institute of Applied Physics (IAP) at the Friedrich Schiller University (FSU) Jena 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 partner companies, 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).

But not only excellent research makes the Institute splendid, also outstanding laboratory equipment, an excellent educated staff and a high commitment to the training of students and scientists in cooperation with the Abbe School of Photonics (www.asp.uni-jena.de) belongs to the self-understanding of the IAP.

Structure of the Institute 2019.

Research Facilities / Resources

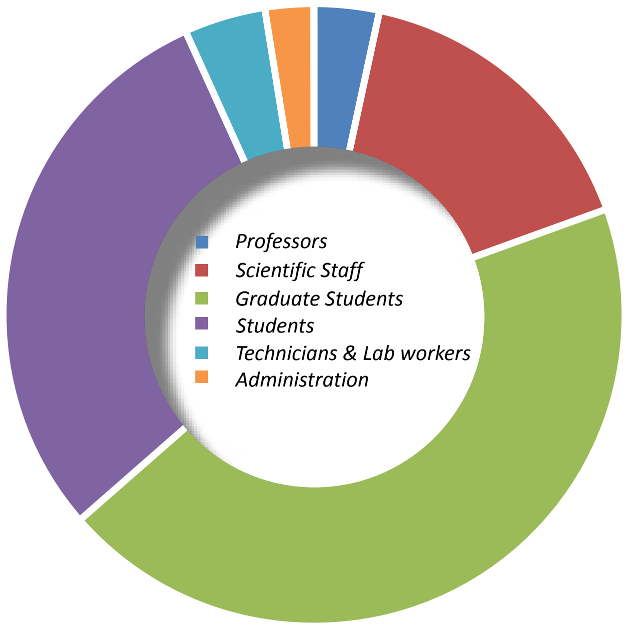
Excellence in research requires high quality equipment for experimental questions and analysis. The state-of-the-art technical infrastructure is driven constantly forward by acquired adaptions for scientific questions, done by an experianced crew.

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

Staff (status 31.12.2019)

8	professors
38	scientists
16	technical & administrative staff members
104	PhD-students
70	students & trainees (over the year)



ABBASIRAD Najmeh
ABBE Sylvia
ACKERMANN Roland
AFSHARNIA Mina
ALBERUCCI Alessandro
ALESHIRE Christopher
ARSLAN Dennis
BADAR Irfan
BALADRON ZORITA Olga
BEER Sebastian
BELADIYA Vivek
BELLOMO Giampiero
BERGNER Klaus
BERLICH René
BERZINS Jonas
BEST Sabine
BIRCKIGT Pascal
BLOTHE Markus
BODEN Justus
BÖRNER Stefan
BÖSEL André
BRADY Aoife
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CAI Danyun
CHAMBONNEAU Maxime
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EILENBERGER Falk
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FASOLD Stefan
FEDERTOVA Anna
FELDE Nadja
FUCHS Hans-Jörg
FÜßEL Daniel
GÄBLER Tobias Bernd
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GÄRTNER Anne
GEBHARDT Martin
GEIB Nils
GEIß Reinhard
GIERSCHKE Philipp
GILI Valerio Flavio
GOEBEL Thorsten
GOUR Jeetendra
GOY Matthias
GRÄF Waltraud
GREBING Christian
GROSS Herbert
HECK Maximilian
HEIST Stefan
HEUERMANN Tobias
HEUSINGER Martin
HILBERT Vinzenz
IMOGORE Thimothy
IWAMA Masaki
JAUREGUI MISAS Cesar
JISHA Chandroth Pannian
JUNGHANNS Marcus
JUNGNICKEL Tom
KABIS Patrick
KAISER Thomas
KÄMMER Helena
KÄSEBIER Thomas
KHOLAIF Sobhy
KIRSCHE Alexander
KLAS Robert
KLEY Ernst-Bernhard
KLUGE Anja
KNOPF Heiko
KRÄMER Ria
KRSTI´C Aleksa
KÜHN Dominik
KUMAR Mohit
KUMAR Pawan
KUNDU Rohan
KUPPDAKKATH Athira
LAMMERS Kim
LAMMERS Tom
LANDMANN Martin
LENSKI Mathias
LI Quingfeng
LIMPERT Jens
LINß Sebastian
LIU Chang
LIU Chang
LÖCHNER Franz
LONDONO Maritza
LU XIANG
LUGANI Jasleen
MARTIN Bodo
MATTHÄUS Gabor
MATZDORF Christian
MERX Sebastian
MÜLLER Amadeus
MÜLLER Michael
MUNSER Anne-Sophie
MUPPARAPU Rajeshkumar
NARANTSATSRALT Bayarjargal
NOLTE Stefan
OLESZKO Mateusz
OTTO Christiane
PAKHOMOV Anton
PALMA VEGA Gonzalo
PAUL Pallabi
PERTSCH Thomas
PFEIFER Kristin
POHLE Lisa
RAN Yang
RICHTER Daniel
ROCKSTROH Sabine
ROCKSTROH Werner
ROTHHARDT Jan
SANTOS SUÁREZ Elkin André
SARAVI Sina
SAUTTER Jürgen
SCHADE Lisa
SCHELLE Detlef
SCHENK Paul
SCHMELZ David
SCHMIDT Holger
SCHREMPEL Frank
SCHULTZE-BERNHARDT Birgitta
SCHUSTER Vittoria
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SERGEEV Natali
SETZPFANDT Frank
SEYFARTH Brian
SHESTAEV Evgeny
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STEINERT Michael
STEINKOPFF Albrecht
STEMPFHUBER Sven
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TANG Ziyao
TISCHNER Katrin
TSCHERNAJEW Maxim
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ULLSPERGER Tobias
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VOIGT Daniel
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WALTHER Markus
WANG Ziyao
WANG Zongzhao
WEICHELT Tina
WEIßFLOG Maximilian
WHITE Jonathon
WIDHOLZ Georg
WIDIASARI Fransiska Ratih
WINKLER Ira
WOHLFEIL Shulin
WORKU Norman Girma
WYROWSKI Frank
YANG Liangxin
YOUNESI Mohammadreza
YÜREKLI Burak
ZAKOTH David
ZEITNER Uwe
ZHANG Site
ZHANG Yueqian
ZHAO Xiaodong
ZHONG Huiying
ZHONG Yi
ZILK Matthias
ZIMMERMANN Tobias
ZOU Chengjun

Guests

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.

AONI Rifat	Australian National University, Canberra, Australia
ASTRAUSKAITE Giedre	University of Glasgow, Scotland
BARREDA Angela	University of Cantabria, Santander, Spain
CHEN Kuan-Chao	Research Center for Applied Sciences, Academia Sinica, Taipeh, Taiwan
CHEN Yen-Hung	National Central University, Zhongli, Taiwan
CHOUDHURY Balamati	CSIR-National Aerospace Laboratories, Bangalore, India
FISHER Bennet	Institut National de la Recherche Scientifique, Varennes, Canada
GAO Jianshu	Technical University Ilmenau, Germany
GAUTHIER Valerie	Université de Sherbrooke, Canada
HADDAD Elissa	Institut National de la Recherche Scientifique, Varennes, Canada
HELLER Lukas	ICFO, The Institute of Photonic Sciences, Barcelona, Spain
KIMBARAS Dziugas	Julius-Maximilians-Universität, Munich, Germany
KIVSHAR Yuri	Australian National University, Canberra, Australia
KOMAR Andrei	Australian National University, Canberra, Australia
KOSHELEV Kirill	Australian National University, Canberra, Australia
KRAUS Ben	University of York, Ukraine
KROYCHUK Maria	Lomonosov Moscow State University, Russia
LEE Ray-Kuang	National Tsing Hua University, Hsinchu, Taiwan
LIEBSCH Mattes	Cellavision, Lund, Sweden
LIN Shih-Yen	Research Center for Applied Sciences, Academia Sinica, Taipeh, Taiwan
LIU Tao	Changchun Institute of Optics, Fine Mechanics and Physics, China
M V Bhavya	CSIR-National Aerospace Laboratories, Bangalore, India
MAIER Stefan	Julius-Maximilians-Universität, Munich, Germany
MINOVICH Alexander	Eureka Aerospace Inc., Pasadena, USA
NESHEV Dragomir	Australian National Univerity, Canberra, Australia
NGO Gia Quyet	Philipps-Universität, Marburg, Germany
OSELLAME Roberto	Politecnico di Milano, Italy
PINSARD Maxime	INRS Montréal, Canada
PORTHUN Steffen	RHK Technology, Troy, USA
QIAO Yang	Changchun University of Science and Technology, China
RASCHKE Markus	JILA, University of Colorado, Boulder, USA
SCHNEIDER Christian	Julius-Maximilians-Universität, Würzburg, Germany
SOAVI Giancarlo	Institute of Solid State Physics, Jena, Germany
SONG Qiang	Telecom Bretagne, IMT- Atantique, Paris, France
SUKHORUKOV Andrey	Australian National University, Canberra, Australia
TALBOT Lauris	Université Laval, Quebec, Canada
TUNIZ Alessandro	University of Sydney, Australia
TZORTZAKIS Stylianos	Texas A&M University at Qatar, Doha, Qatar
von FREYMANN Georg	University of Kaiserslautern, Germany
WENGEROWSKY Sören	Institute for Quantum Optics and Quantum Information, Vienna, Austria
WURDACK Matthias	Australian National University, Canberra, Australia

Research Stays

Going abroad is an important experience for everyone - but in work and research contexts this is a particular challenge. Personal contacts are intensified and immersion in another (working) culture is only possible in this way. This extends the horizon of thinking also for research work at home.

EILENBERGER Falk	Academica Sinica, Taipeh, Taiwan
HILBERT Vincent	GSI Helmholtzzentrum für Schwerionenforschung Darmstadt, Germany
SCHUSTER Vittoria	National Research Council, Ottawa, Canada
	Institut national de la Recherche Scientifique, Varennes, Canada
SETZPFANDT Frank	National Central University, Zhongli, Taiwan
	Universite Paris-Diderot, Paris, France
TÜNNERMANN Andreas	Delegation trip of the Prime Minister of Thuringia to Vietnam & Singapore
	Gigaphoton Inc., Tokyo, Japan

Cooperations

The IAP is cooperating with most of the departments of the Faculty of Physics and Astronomy at Friedrich Schiller University, 2019 in particular with the Institute of Optics and Quantum Electronics and the Otto Schott Institute of Materials Research. Cooperation beyond the faculty exist with the Institute for Geosciences (IGW). But also the collaboration with the University of Applied Sciences (EAH) Jena is grown steadily.

In our work we are connected to many important research centers of Germany, like the Max-Planck-Institute of Quantum Optics (MPQ) and Institute for Gravitational Physics (AEI), as well as the Karlsruhe Institute of Technology (KIT), 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) plus international cooperation, e.g. with the Centre national de la recherche scientifique (CNRS) in Paris and the ELI-ALPS, Extreme Light Infrastructure in Szeged, Hungary.

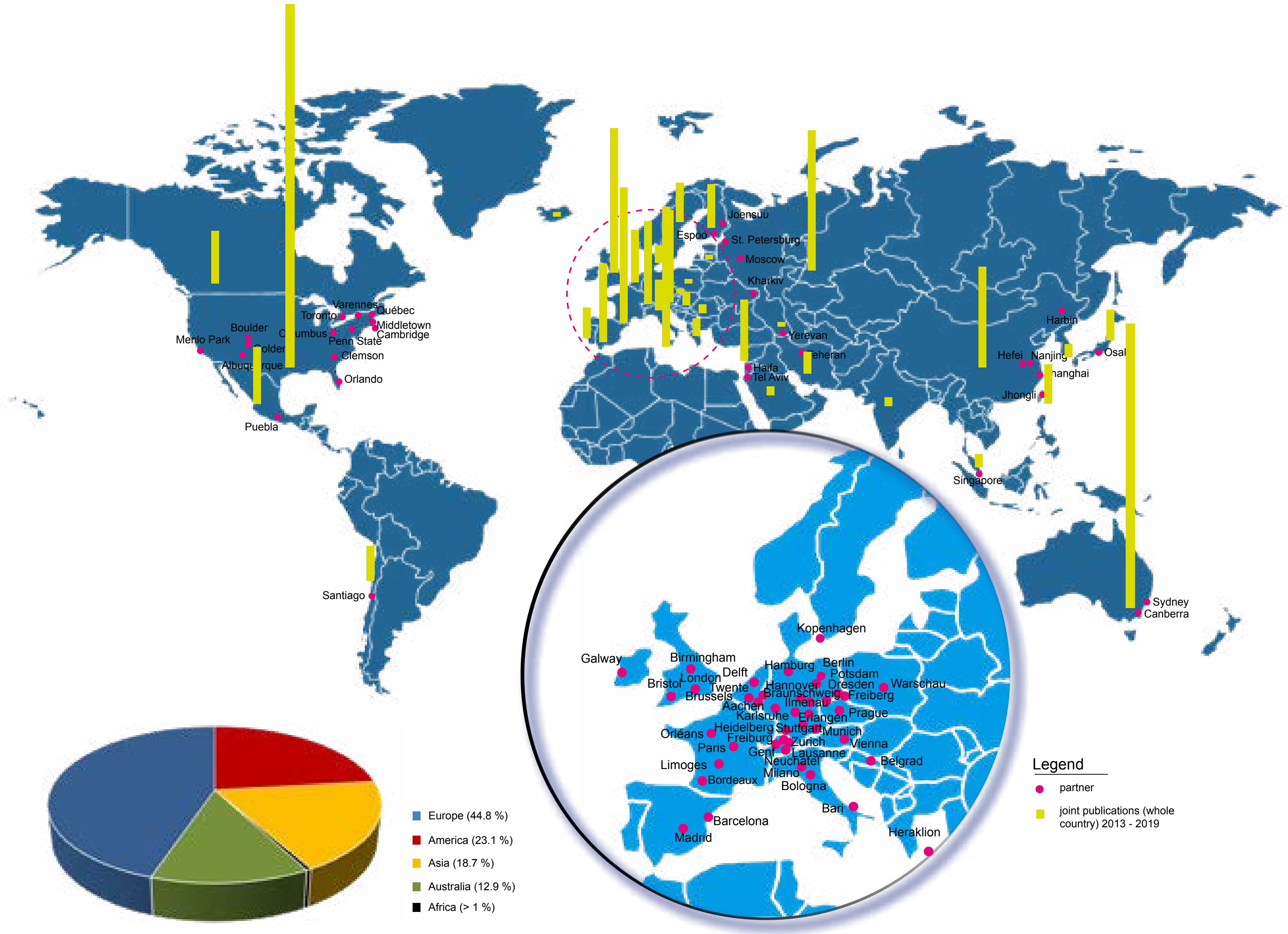
Traditionally, the IAP is linked closely to the Fraunhofer Institute for Applied Optics and Precision Engineering (IOF). Based on this networking between the two Institutes, one major goal is to develop an outstanding international center of excellence for micro- and nano-structured optics, optical systems and laser development and application. 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 (IPHT). 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 nearly all over the world for years: major international collaborations exist with the Centre of Ultrahigh bandwidth Devices for Optical Systems (CUDOS), the Australian National University, as well as the Vrije Universiteit Brussel, Delft University of Technology and universities in China (Nanjing University), Russia (Lomonosov Moscow State University & State University of Information, Mechanics, and Optics (ITMO), St. Petersburg), Serbia (University of Belgrade), Taiwan (National Central University in Jhongli and Academica Sinica in Taipeh), Great Britain (Aston University, Birmingham) and USA (CREOL, University of Central Florida).

In the framework of the German-Canadian International Research Training Group GRK 2101 “Guided light, tightly packed” we are cooperating with the University of Toronto, Université Laval and the Institut National de la Recherche Scientifique (INRS) – the coordination lies in the hands of our partner Abbe School of Photonics here in Jena. Through the Max Planck School of Photonics (MPSP) educational project, we also cooperate with many of the renowned German research institutions mentioned above.

Since 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, Schölly Fiberoptic GmbH, Sick AG and many more.

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



Partners of the IAP and a quantitative figure of common publications in 2013-19.

Cooperations with Joint Research Topics *(Selection)*

AT Technologies
Veldhoven, The Netherlands
Mikhail Loktev

CiS Forschungsinstitut für
Mikrosensorik GmbH
Erfurt, Germany
Andreas Müller

Datalogic
Bolognia, Italy
Federico Canini

Department of Applied Physics
University of Technology Eindhoven
The Netherlends
Erwin Kessels

Department of Electrical and
Computer Engineering
University of Toronto, Canada
Peter Herman

Department of Photonics Engineering
University of Southern Denmark, Odense
Asger Mortensen

Department of Physics and Mathematics
University of Eastern Finland, Joensuu
Jari Turunen

Institut für Energieverfahrenstechnik
und Chemieingenieurwesen
& Institut für Mikrosystemtechnik (IMTEK)
TU Bergakademie, Freiberg, Germany
Stefan Guhl, Alexander Rohrberg

Institut für Geophysik und
Extraterrestrische Physik
TU Braunschweig, Deutschland
Jürgen Blum

Institut für Physik/Nanooptik
Humboldt-Universität zu Berlin
Germany
Oliver Benson

KLA-Tencor
Milpitas, California, USA
Maarten van der Burgt

Laboratoire Ondes et Matière
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Stefanie Kroker

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National Accelerator Laboratory SLAC
Menlo Park, USA
Christian Roedel, Frank Seiboth

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Pablo Benitez

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Göttingen, Germany
Christoph Russmann

Sandia National Laboratories
Albuquerque, New Mexico, USA
Igal Brener

VSL - Dutch Metrology Institute
Delft, The Netherlends
Omar El Gawhary

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, running the International Research Training Group (GRK 2101) "Guided light, tightly packed: novel concepts, components and applications" since 2015 and now the "Max Planck School of Photonics" (MPSP).

Lectures

Elective & Special Courses (Lectures & Seminars)

- Analytical Instrumentation
- Atome und Moleküle II
- Computational Physics
- Computational Photonics
- Design & Correction of Optical Systems
- Fundamentals of Modern Optics
- Grundlagen der Laserphysik
- Imaging and Aberration Theory
- Introduction to Nanooptics
- Introduction to Optical Modeling
- Lasers in Medicine
- Laser Physics
- Lens Design I
- Lens Design II
- Micro/nanotechnology
- Optical Engineering
- Optical Metrology and Sensing
- Physical Optics
- Quantum Communication
- Quantum Imaging and Sensing
- Quantum Optics
- Structure of Matter
- Thin Film Optics
- Ultrafast Optics
- Vakuum- und Dünnschichtphysik

Seminars of the Institute & Devisions

- Applied Computational Optics
- Applied Physics
- Atomic Layer Deposition
- Design of Optical Systems
- Fiber Lasers
- Functional Photonic Nanostructures
- Graduate Seminar
- Microstructure Technologies - Microoptics
- Nano and Quantum Optics
- Ultrafast Optics

As part of the Annual International Summer School GRK2101 on 20th June 2019, Johannes Kretzschmar introduces the participants into the Software "Blender".

TEACHING

Bachelor Theses

Simon Bernet
Überschichtung von 2D-Materialien im Vakuumprozess

Ralf Hühn
Characterization of the optical properties of mono layered MoS_2 in optical resonators

Tom Lippoldt
Untersuchungen zur Laseremission von N_{2+}

Thomas Rölle
Simulation of partially coherent imaging

Master Theses

Makhinia Anatolii
Fully inkjet-printed Organic Light-Emitting Diodes (OLEDs) for microfluidic lab-on-a-chip system

Joao Pedro Berti Ligabo
Design and application of a miniaturized multispectral camera

Huaiyu Chen
Field Tracying Simultioan of Optical Parametric Amplification

Alexandre de Matos Gomez Belsley
Photon-pair generation in lithium niobate waveguide systems

Shih-Te Hung
Physical Optical Modeling of Multi-sphere Scattering Media

Jiacen Jiang
X-ray optical systems

Atefeh Javadzadeh Kalahrodi
3d stiffness mapping of bovine cartilage by using the fast indentation FBG system

Xunyu Li
Physical Optics Modeling of Microstructured Surface

Winglong Li
Modeling and Applications of Microlens Array

Yichen Liu
Holographic Optical Element Inversed Design and Simulations

Kepper Mariia
Assembly and characterization of field-deployable quantum hardware

Pallabi Paul
Atomic Layer Deposition of Optical Coatings on Poly(methylmethacrylate) (PMMA)

Yufei Peng
Wavefront Sensing Based on Coherent Diffractive Imaging

Christopher Spiess
Ultrashort Soliton Generation - Characterization and Modeling

Liudmila Starodubtceva
Fabrication and investigation of a reactively sputtered black coating

TEACHING

Katsuya Tanaka
Chiral Bilayer Dielectric Metasurfaces

Senanayake Udesha Luckshadi
Fully inkjet-printed photodetector device for microfluidic lab-on-a-chip-system

Markus Walther
Methoden zur aktiven optischen Justage pixelierter nanooptischer Filterelemente auf CMOS-Sensoren

Wenxiu Wang
Wave Optical Analysis of Complex Beam Patterns in terms of the Eye Safty

Maximilian Weißflog
Spontaneous parametric down conversion in GaAs nano antennas

Jonathon White
Laser Pulse Optimization for Extreme Ultraviolet Attosecond Pulse Generation

Fransiska Widiasari
Phase retrieval for laser beam characterization

Di Wu
Investigation of New Concept for Lens Design

Linghe Xiong
Multi-Physical Method Applied in Analyzing Thermal Effects of Optical Imaging

Xiaoyan Yu
Determination, Usage, and Design of Bidirectional Scattering Distribution Function (BSDF) in Ray and Physical Optics

Wenjia Zhou
Investigation of Optical Coupling Phenomenon in Silicon Metasurfaces

Doctoral Theses

Klaus Bergner
In-Volumen-Bearbeitung von Glas mit raum-zeitlich geformten ultrakurzen Laserpulsen

Christoph Bösel
Freeform illumination design in optical systems with partial differential equations

André Dathe
Large Scale Tunneling Junctions for Electrically Driven Plasmonics

Nadja Felde
Design, manufacturing, and characterization of robust multifunctional surfaces

Christian Gaida
Power-scaling of ultrafast Thulium-doped fiber laser systems

Martin Heusinger
Untersuchungen zu deterministischen und stochstischen Streulicht in hocheffizienten binären Beugungsgittern

Falk Kemper
Tintenstrahldruck wellenlängenselektiver optischer Detektoren zur Integration in mikrofluidische Lab-on-a-Chip Systeme

Nina Leonhard
Adaptive Optics for Free-Space Communication with Entangled Orbital Angular Momentum Photons

Chang Liu
Design strategy for imaging systems containing freeform surfaces

Gregor Matz
Design, simulation, evaluation and application of miniaturized objectives for in-vivo endomicroscopy

Mateusz Oleszko
Analysis of freeform optical systems based on the decomposition of the total wave aberration into Zernike surface contributions

Daniel Richter
Ultrashort pulse written volume-Bragg-gratings

Carolin Rothhardt
Plasma-aktives Fügen von optischen Komponenten für Hochleistungslaser

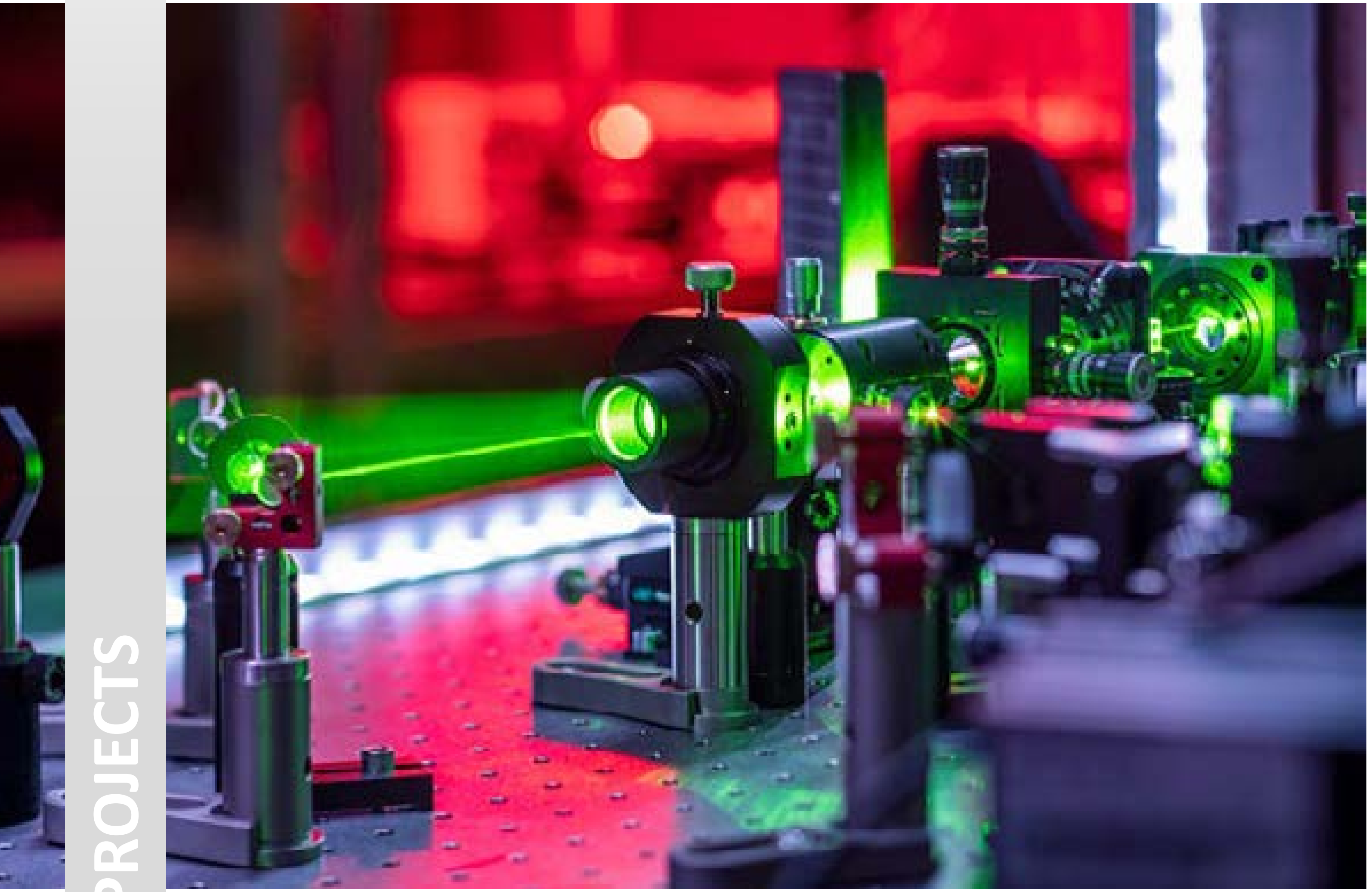
Getnet Kassa Tadesse
Nanoscale Coherent Diffractive Imaging using High-harmonic XUV-Sources

Jannik Trapp
Holographic and Hybrid Spectacle Lenses

Tina Weichelt
Neuartige Methoden diffraktiver Mask Aligner Lithografie zur flexiblen Erzeugung mikrooptischer Strukturen

Yueqian Zhang
Systematic Design of Microscope Objectives

PROJECTS



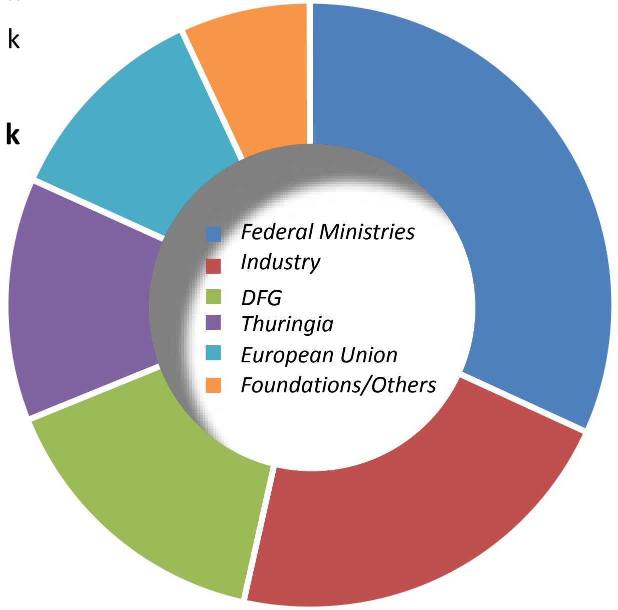
Prototype of a source for entangled photon pairs with different wavelengths.

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.

External funding

European Union	€ 1,277 K
DFG (German Research Society)	€ 1,737 k
Federal Ministries (BMBF, BMWi)	€ 3,607 k
State of Thuringia	€ 1,463 k
Contract Research	€ 2,452 k
Foundations	€ 788 k
Total:	**€ 11,324 k**



European Union

ERC Advanced Grant MIMAS "Multi-dimensional interferometric amplification of ultrashort laser pulses"

ERC Consolidator Grant ACOPS "Advanced coherent ultrafast laser pulse stacking"

ERC Advanced Grant: SALT "High-Flux Synchrotron Alternatives Driven by Powerful Long-Wavelength Fiber Lasers"

Marie Skłodowska-Curie Research and Innovation Staff Exchange (MSCA-RISE): FUNGLASS "Functional Glass" & Innovative Training Networks (ITN-EID): NOLOSS "Lossless management - Optical design for manufacture at different length scales"

European Metrology Programme for Innovation and Research (EMPIR): BECOME "Light-matter interplay for optical metrology beyond the classical spatial resolution limits"

DFG - German Research Foundation

Collaborative Research Center (CRC) SFB 1375 „Nonlinear Optics down to atomic Scales"

International Research Training Group (IRTG) GRK 2101 "Guided light, tightly packed: novel concepts, components and applications"

Priority Programs (PP)

- SPP 1839 „Ausnutzung maßgeschneiderter Unordnung in dielektrischen Nanooberflächen zur Maximierung von deren Informationskapazität"
- SPP 1839 „Kontrolle der Streufeldwechselwirkung in ungeordneten zweidimensionalen Anordnungen von Silizium-Nanopartikeln"
- SPP 1959 „Einfluss des elektrischen Feldes auf die Materialeigenschaften mittels Atomlagenabscheidung hergestellter Oxid-Dünnschichten: Experimentelles und rechnergestütztes Design"
- SPP 2122 „Neue Materialien hoher Steifigkeit für den Leichtbau durch additive Fertigung mit Ultrakurzpulslasern"

BMBF Federal Ministry of Education and Research

Graduate school with integrated master program: Max-Planck-School of Photonics

ZIK UltraOptics: OptiCon „Entwicklung spektroskopischer Methoden für Konversionsprozesse unter Hochdruck-/Hochtemperaturbedingungen"

Verbund-ZIK astrOOptics „Astrooptic components"

Verbund APPA bei FAIR „Anwendung neuer photonischer Methoden zur Präzisionsspektroskopie an gespeicherten, hoch geladenen Ionen"

Verbund Human-Machine-Interaction-Labs: „Teaching-Lab - neue Wege in der Hochtechnologieausbildung im Bereich Photonik"

Innovative university: NUCLEUS Jena - Ein Paradies für Innovationen

Innovative regional growth cores WK+fo+: „Technologieplattform VIS Freiformoptik sowie Design und Strukturierung von Freiformflächen für neuartige Anwendungen"

Program "Zwangzig20" - Project "3Dsensation":

- Dreidimensionale Visualisierungssysteme auf der Basis photonischer Nanomaterialien
- Methoden zur ultraschnellen Detektion und Manipulation von ultrakurzen Lichtpulsen
- Eigenhaptische Manipulation ausgedehnter 3D-Strukturen im Raum; TP1: Erzeugung ausgedehnter 3D-Strukturen im Raum mittels Laser"
- Generation dreidimensionaler visueller Oberflächenerscheinungen mittels mikro- und nanostrukturierter Schichtsysteme
- Hyperspektrale Sensorik auf Basis photonischer Nanomaterialien
- Forschergruppe „Augensichere 3D-Bildgebung im SWIR"
- Forschergruppe „Transformationsoptik für multidimensionale Detektion"
- Forschergruppe „Hochdynamische 3D-Sensorik in erweiterten Spektralbereichen"

State of Thuringia Thuringian Ministry of Economy, Science and Digital Society

Thüringian Innovation Center „Thüringer Innovationszentrum für Quantenoptik und Sensorik"

ProExz-ACP2020 Research group Functional Photonic Nanostructures

TAB-Research Groups

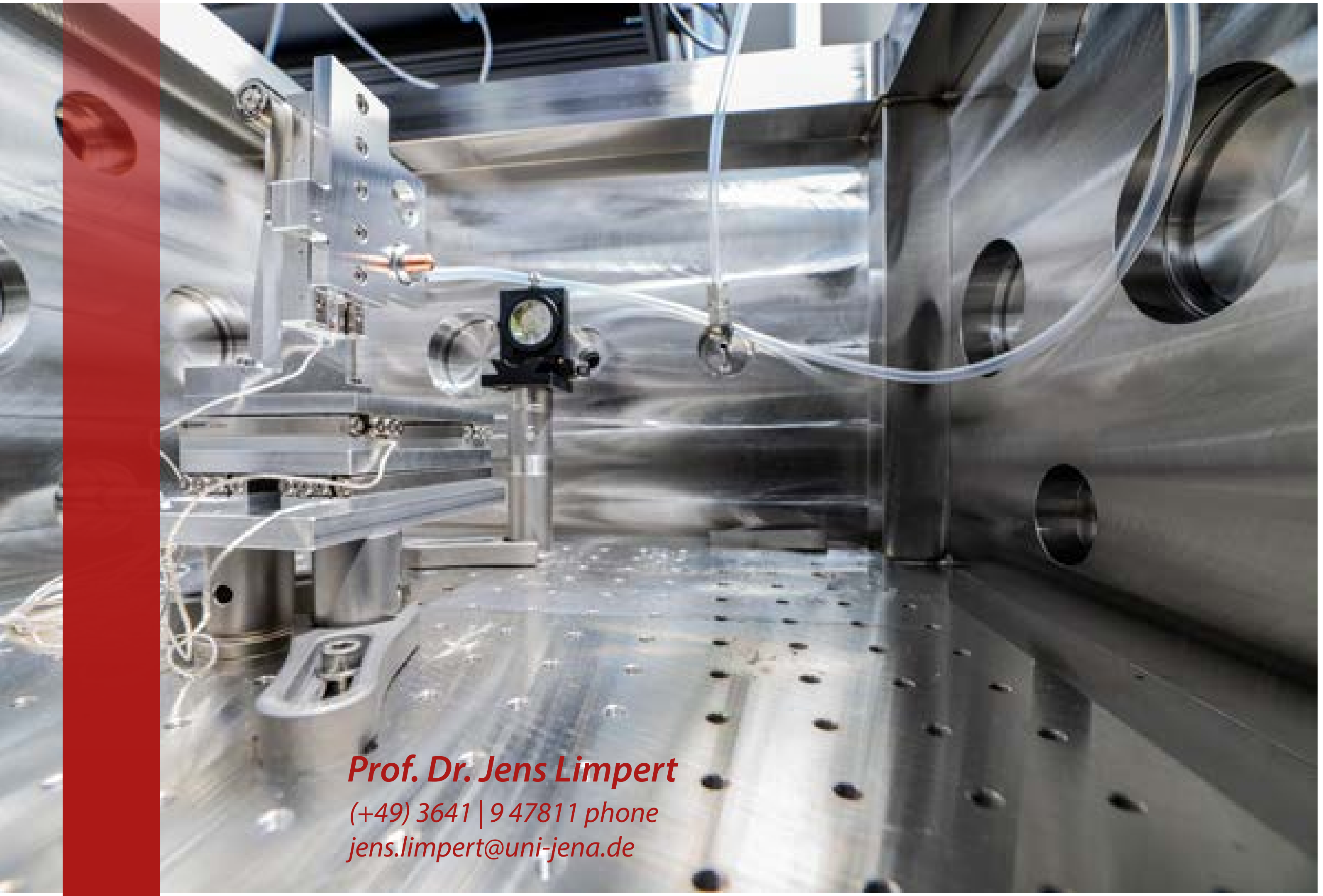
- 2D-Sens
- 3D-Bildaufnahme und -Verarbeitung mit höchstem kontinuierlichem Datendurchsatz
- 3D Erfassung mittels Wärmebildprojektion und Roboterhandling von transparenten komplexen Objekten für die Mensch-Maschine Interaktion und adaptive Fertigung
- Achromatische Diffraktive Optiken auf Nichtplanaren Substratoberflächen
- Erforschung neuartiger Herstellungsverfahren für mikrostrukturierte Fasern
- Hochleistungsoptiken für (kohärente) weiche Röntgenstrahlung
- Quantenoptische Bildgebung mit verschränkten Photonen
- Ultrakurzgepulste Laserstrahlung zur flexiblen Fertigung maßgeschneiderter, optischer Komponenten für die individualisierte Produktion

RESEARCH

Jan Sperrhake explains the results and possible applications to a visitor of the "Long Night of Science" using the prototype "NeoVitalSensor". He and his team received the Edmund Optics Award for this project.

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 itself 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.



Vacuum chamber for Laser development in the laboratory of the Abbe Center of Photonics.

Fiber & Waveguide Lasers

This research group is working on the development of new concepts for solid-state lasers with focus on fiber laser technology.

Scientific focus lies on:

- Fiber optical amplification of ultra-short laser pulses
- Ultra-short pulse oscillators, few-cycle pulse generation and amplification
- Conception of novel large core diameter fibers
- Simulation of non-linear effects and amplification dynamics in active fibers
- Fiber optical frequency conversion
- Mid-IR laser sources
- High Harmonic Generation and applications in imaging and spectroscopy

Authors:
Martin Gebhardt, Christian Gaida, Tobias Heuermann, Cesar Jauregui and Jens Limpert

>1 kW ultrafast laser based on Tm-doped fibers

Power scalable laser sources with output pulse durations in the fs-regime have become indispensable for numerous applications in industry and in fundamental research. While there is a continuous demand for higher average powers to realize higher processing speeds or for increased signal to noise ratios, it has been identified recently that there is a significant application relevance of laser emission wavelengths >1 µm. The benefit of such sources can be found in applications ranging from micro material processing of technologically important solid state materials such as Silicon (transparent >1.2 µm) /1/ to frequency conversion into the THz, far infrared or the soft X-ray regime /2/.

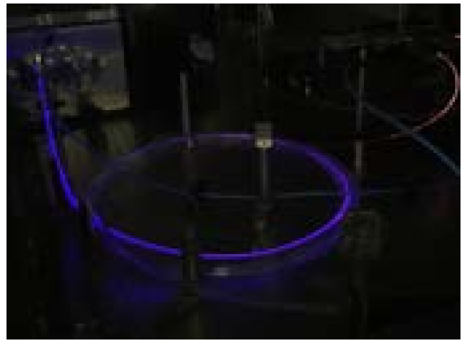


Figure 1:
Main amplifier of the system during operation.

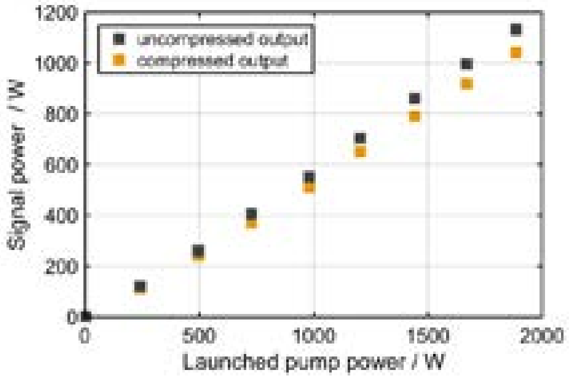


Figure 2:
Output power of the Tm-doped fiber and of the CPA system with respect to launched pump power.

Thulium(Tm)-doped fused silica fibers support a very broadband laser emission and are therefore well suited for the amplification of ultrashort pulses in the wavelength region around 2 µm. Due to the excellent transmission of specialty glasses at this wavelength it is possible to exploit the highly developed fiber technology of Ytterbium(Yb)-based laser systems. However, an important difference to the Yb laser systems is the significantly higher quantum defect of Tm systems (pump wavelength 0.79 µm, signal wavelength 2 µm). At first sight, average power scaling seems to be challenging, especially due to the relatively low efficiency and the high heat load. Fortunately, the unique structure of the energy level diagram in Tm-doped silica allows for energy exchanging interactions between two neighboring Tm ions (so called cross-relaxations /3/). It is possible to achieve two excited active Ions from one pump photon as a result of these interactions. This is enormously beneficial for power scaling, however, it also imposes several challenges to the chemistry composition as well as the experimental conditions.

The amplification characteristics of a thulium-doped photonic crystal fiber have been investigated in a high power experiment /4/. The fiber was employed in the main amplification stage of a CPA system with a spectral bandwidth supporting 260 fs pulse duration. By effectively depleting the upper laser level with a high seed power and by efficient cooling it was possible to reach a total of 1.1 kW signal power at 1.9 kW of launched pump power. This corresponds to an efficiency >60% and is the highest average power ever demonstrated with a Tm-doped fiber laser. The amplified signal pulses were compressed to the fs-regime after the main amplifier stage using a grating based compressor. For this purpose, high efficiency dielectric gratings are highly important. The gratings used in the experiment described herein were favricated in-house at the IOF /5/. Fig. 2 depicts the fiber output power as well as the output power of the CPA system (compressed pulses) with respect to the launched pump power. The operating main amplifier of the system can be seen in Fig. 1 (see page before). It provides an output average power of 1.05 kW and diffraction limited beam quality (M^2<1.1), which are world record parameter for fiber based CPA systems.

/1/ M. Chanal, V. Y. Fedorov, M. Chambonneau,R. Clady, S. Tzortzakis, D. Grojo: Crossing the threshold of ultrafast laser writing in bulk silicon. Nature Communications, 8(1), 773, 2017.

/2/ H. Pires, M. Baudisch, D. Sanchez, M. Hemmer, J. Biegert: Ultrashort pulse generation in the mid-IR. Progress in Quantum Electronics, 43, 1–30, 2015.

/3/ S.D. Jackson, T.A. King: Theoretical Modeling of Tm-Doped Silica Fiber Lasers. Journal of Lightwave Technology, 17(5), 948–956, 1990.

/4/ C. Gaida, M. Gebhardt, T. Heuermann, F. Stutzki, C. Jauregui, J. Limpert: Ultrafast thulium fiber laser system emitting more than 1 kW of average power. Optics Letters, 43(23), 5853–5856, 2018.

/5/ U. D. Zeitner, M. Oliva, F. Fuchs, D. Michaelis, T. Benkenstein, T. Harzendorf, E.-B. Kley: High-performance diffraction gratings made by e-beam lithography, Appl. Phys. A 109, 789, 2012.

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Thomas Siefke at the Oxford Ionfab 300 LC mounting a 100 mm wafer on a sample carrier.

Microstructure Technology & Microoptics

This research group concentrates fundamentally on function and design of micro- and nano-optical elements as well as applications and technology developments for micro structuring.

The following research priorities have been treated:

- Plasmonic resonant nanometric structures
- Resonant reflective monolithic gratings
- Transmissive, reflective and diffractive elements based on effective media
- Metallic and dielectric polarizers from IR to DUV range
- 3D nano-structuring of crystals with ion beam
- Optical and opto-electronic applications of antireflective fused silica and silicon surfaces
- Microoptical light-trapping in optoelectronic devices
- Functional optical layers controlled on the atomic scale
- Diamond based optical components

Authors:
Martin Heusinger, T.homas Käsebier, Thomas Siefke, Ernst-B.ernhard Kley and Uwe Detlef Zeitner

Resonant sub-wavelength structures for highly reflective mirrors

Nowadays, highly reflective surfaces are a key component in many optical devices and especially in optical resonators and cavities reflectivities of up to 99.999% are necessary. So-called resonant grating reflectors offer an alternative to the established dielectric multilayer mirrors while possessing the advantage of a reduced thermal noise. Thus, grating reflectors are considered for application in gravitational wave detectors and high sensitivity monolithic accelerometers.

A grating reflector bases on periodically corrugated slab waveguides. The periodic disturbance within the subwavelength range allows for the excitation of waveguide modes even at normal incidence of light. The modes propagate within the waveguide and are forced by the perturbation to decouple continuously (leaky modes). The out coupled radiation is (constructively) interfering with the directly reflected light, which leads to a reflectance of up to 100 % depending on the accumulated phase difference.

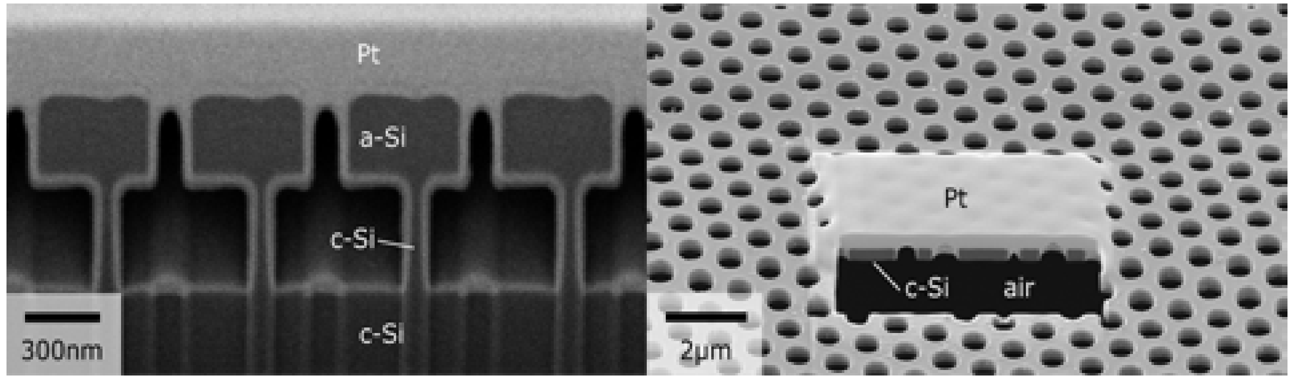

Figure 1:
SEM-image of a T-shaped grating (left) and a crystalline silicon membrane (right), respectively, showing reflectance of more than 99.5%. The Platinum was necessary for cross section preparation.

Based on this principle, a monolithic T-shaped grating geometry can be deduced making use of the effective medium approach. At the Institute of applied Physics (IAP) a process was developed, which allows a very accurate fabrication of such structures. A scanning electron microscope (SEM) image of the cross section profile of a grating is shown in Figure 1. The Corresponding reflectivity measurement within the infrared spectral range is given in Figure 2. The loss in reflectance of about 0.5% is less due to the unavoidable shift of the consecutive exposure layers but to residual absorption of the upper amorphous silicon layer.

Another type of such grating reflectors are crystalline silicon membranes of only 190…300nm thickness, which allow R = 100 % in both directions. A SEM-image of a fabricated membrane is shown in Figure 1 and the corresponding reflectivity measurement is given in Figure 2. An efficiency of R = 99.7 % at a wavelength of 1470 nm was achieved.

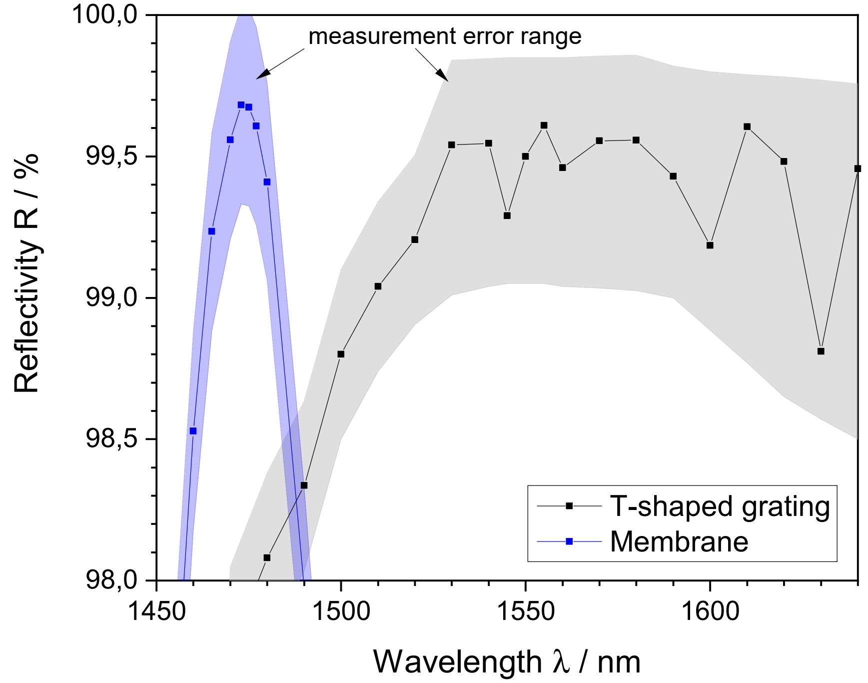

Figure 2:
Reflectivity measurement within the IR spectral range of the gratings reflectors shown in Fig. 1 .

Such membranes would be of interest, for example, in the Breakthrough Starshot Initiative, which seeks to explore the possibility of accelerating a few grams weighing satellite to 0,2 c using a highly reflective light sail and sending it to Proxima Centauri. The membrane shown here would weigh only 3.3g with an area of 16 m².

Authors:
Vivek Beladiya, Margarita Lapteva and Adriana Szeghalmi

HfO_2 and SiO_2 ALD Coatings for Laser Applications

Interest in applying strongly curved lenses to laser systems is increasing. However, many of these lenses cannot be functionalized properly because established coating technologies lead to thickness gradients along the surface of the lens. Atomic layer deposition (ALD) allows uniform and conformal thin films with a precise thickness control on arbitrarily shaped optics to achieve a high optical performance along their surface. Thin ALD functional optical coatings and nanoporous SiO_2 layers have been demonstrated as broadband and wide-angle antireflection coatings or as single-layer antireflection coating with a high laser-induced damage threshold.

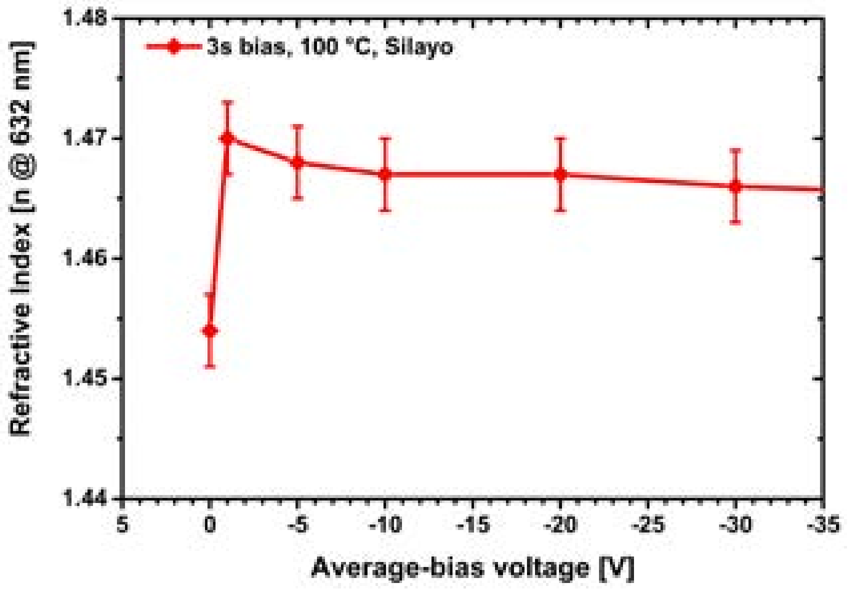

Figure 1:
Refractive index of SiO_2 ALD thin films as a function of the bias voltage.

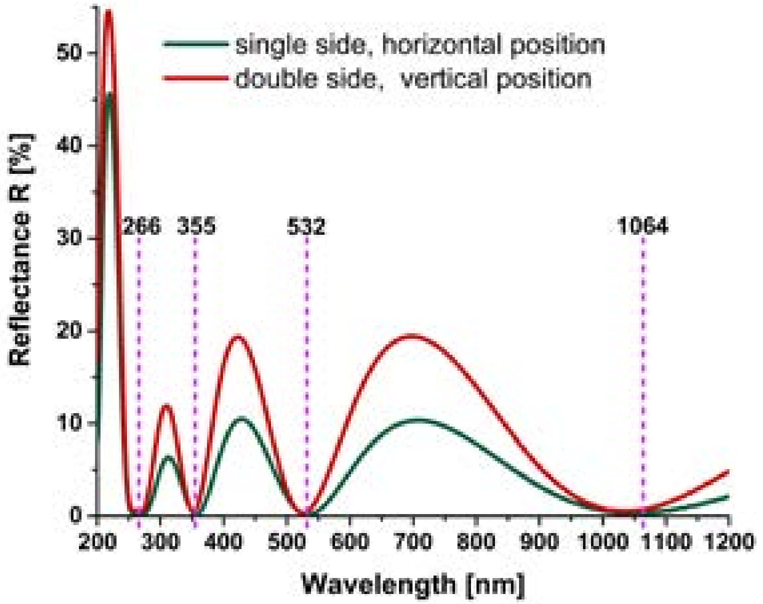

Figure 2:
Reflectance from one side and from both sides of a fused silica substrate with an antireflection multilayer system.

/1/ K. Pfeiffer, L. Ghazaryan, U. Schulz, A. Szeghalmi: ACS Appl. Mater. Interfaces, 11 21887-21894 (2019). Cover Art

/2/ L. Ghazaryan, Y. Sekman, S. Schröder, C. Mühlig, I. Stevanovic, R. Botha, M. Aghaee, M. Creatore, A. Tünnermann, A. Szeghalmi: Adv. Eng. Mater. 1801229 1-10, 2019.

/3/ V. Beladiya, et.a.: Effect of an electric field during the deposition of silicon dioxide thin films by plasma enhanced atomic layer deposition: an experimental and computational study, Nanoscale, 12(3), 2089-2102, 2020.

At *Leistungszentrum Photonik*, a large-scale plasma-enhanced ALD (PEALD) tool for the deposition of oxides and nitrides on substrates with a diameter of up to 330 mm and a height up to 130 mm has been installed. Thin films of SiO_2, Al_2O_3, TiO_2, and HfO_2 can be grown with very good uniformity at low deposition temperature. Additionally, the optical and mechanical properties of the coatings can be tailored by applying a bias voltage. Figure 1 shows the refractive index of SiO_2 thin films as a function of the applied bias voltage /3/. Coatings with superior quality are obtained already at very low bias voltage.

A multilayer interference coating is demonstrated for antireflection coatings of fused silica substrates at 1064, 532, 355, and 266 nm wavelength for laser applications.


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Large mode area fiber with long period modifications.

Ultrafast Optics

The group Ultrafast Optics works on applications of femtosecond laser pulses, such as materials processing and micro/nano structuring of optical materials.

The scientific topics are:

- Linear and nonlinear laser-matter interaction: A fundamental understanding of the interaction between ultra-short laser pulse solids forms the basis for the work of our group. For this purpose, propagation and absorption effects as well as subsequent relaxation processes are analyzed in detail.
- Micro-and nanostructuring with ultrashort laser pulses: Ultrashort laser pulses allow high-precision structuring on the micro- to nanometer scale. Our investigations range from ablation to the defined manipulation of material properties.
- Additive manufacturing using ultrashort laser pulses: We investigate the use of ultrashort pulses for processing advanced materials like supersaturated metal alloys or materials with extreme properties like extraordinary high melting points or increased thermal conductivity, which are not accessible with conventional systems.
- Volume modifications in glasses: The nonlinear absorption inside transparent materials allows the modification of the propagation properties of light. Application examples include fiber and volume bragg gratings, waveguide systems, and artificially birefringent structures.
- Spectroscopic methods for gas analysis: Non-linear spectroscopy methods are developed for the analysis of gases under extreme conditions.

Authors:
Thorsten A. Goebel, Ria G. Krämer, Maximilian Heck and Stefan Nolte

Selective Spectral Filtering through Complex Gratings in Fibers

Fiber Bragg gratings (FBG) consist of a periodic refractive index modulation within the core of a glass fiber that acts like a wavelength-selective mirror. Because the reflected spectral section is missing in transmission, FBGs are suitable as fiber-integrated spectral filters. Their bandwidths can range from 0.1 nm up to several 10 nm. The filter strength can be flexibly adjusted and thus allows light to be filtered out over several orders of magnitude of intensity (more than 30 dB). To realize the refractive index modulations, the fiber cores are usually irradiated with laser light. Ultra-short laser pulses make it possible to structure a wide variety of core materials (e.g. silica glass, photosensitive, or rare-earth-doped glasses) /1/.

Typically, an FBG has a single grating period, so that exactly one wavelength can be spectrally filtered. However, in astronomy, for example, there is a need to suppress a large number of wavelengths as spectroscopy with terrestrial telescopes is limited by narrow-band emission lines of molecules from the upper atmosphere. Due to the large number of lines to be suppressed, a simple series of different FBGs would result in very long filter structures that are susceptible to temperature and strain. In addition, broadband losses are critical. An alternative is complex grating structures, where the FBG no longer has only one but several resonances /2/. This enables compact filter elements that can filter out multiple wavelengths while simultaneously only having a minimal influence on the light outside these ranges. This allows the overall length of the filter and thus unwanted losses to be significantly reduced. In an initial design, we suppressed 10 wavelengths for demonstration purposes, limiting the grating length to only 5 cm.

The spectral transmission measurement is shown in Figure 1. The wavelengths addressed, which are represented by dotted lines, could be reached with an accuracy of 0.034 nm (corresponding to a deviation of 0.0023%). In addition to astrophotonics, this offers a wide range of applications in spectroscopy, sensor technology, and communication.

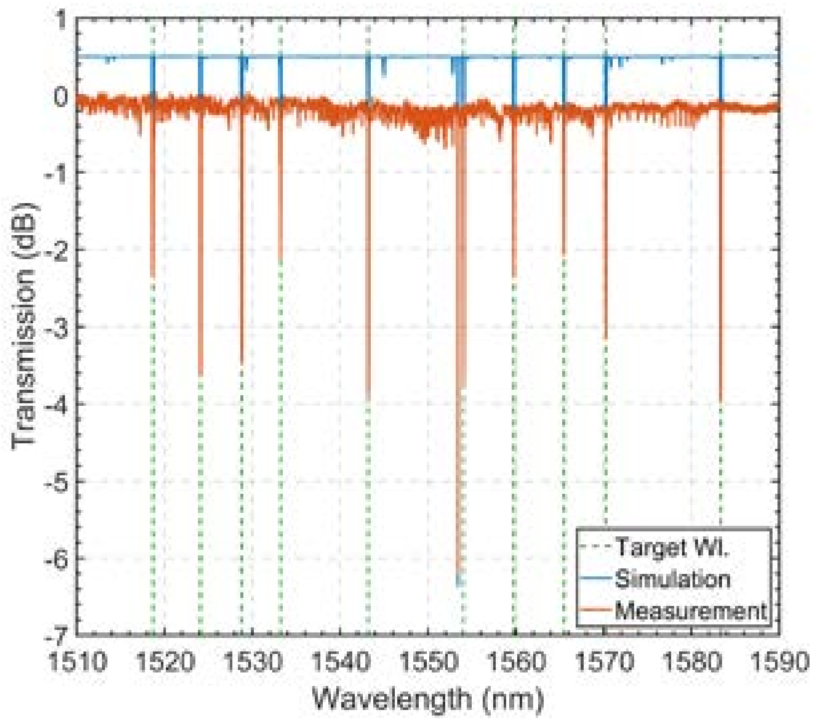

Figure 1:
Transmission spectrum of a complex FBG /2/.

/1/ J.U. Thomas, C. Voigtländer, R.G. Becker, D. Richter, A. Tünnermann, S. Nolte: Femtosecond pulse written fiber gratings: A new avenue to integrated fiber technology, Laser Photonics Rev. 6(6), 709–723, 2012.

/2/ T.A. Goebel, G. Bharathan, M. Ams, M. Heck, R.G. Krämer, C. Matzdorf, D. Richter, M.P. Siems, A. Fuerbach, S. Nolte: Realization of aperiodic fiber Bragg gratings with ultrashort laser pulses and the line-by-line technique, Opt. Lett. 43(15), 3794–3797, 2018.

Our PhD Students Ziyao Wang, Timothy Imogore, Najmeh Abbasirad and Katsuya Tanaka discuss their ideas.

Nano & Quantum Optics

The research group Nano & Quantum Optics deals with ultrafast light-matter interactions and optical quantum phenomena in microstructured and nanostructured matter, as e.g. photonic nanomaterials, meta-materials, photonic crystals, and effective media.

The scientific emphasis lies on:

- nonlinear spatio-temporal dynamics, integrated quantum optics, plasmonics, near field optics, high-Q nonlinear optical microresonators, opto-optical processes in integrated optics, all-optical signal processing
- Multi-tip scanning optical nearfield microscopy (SNOM), photoemission electron microscopy (PEEM)
- Application of photonic nanomaterials for multi-functional diffractive optical elements
- Application of optical nanostructures for efficiency enhance-ment of photovoltaic elements
- Application of advanced photonic concepts for astronomical instruments

Authors:
Isabelle Staude, Frank Setzpfandt and Thomas Pertsch

Functional and active metasurfaces

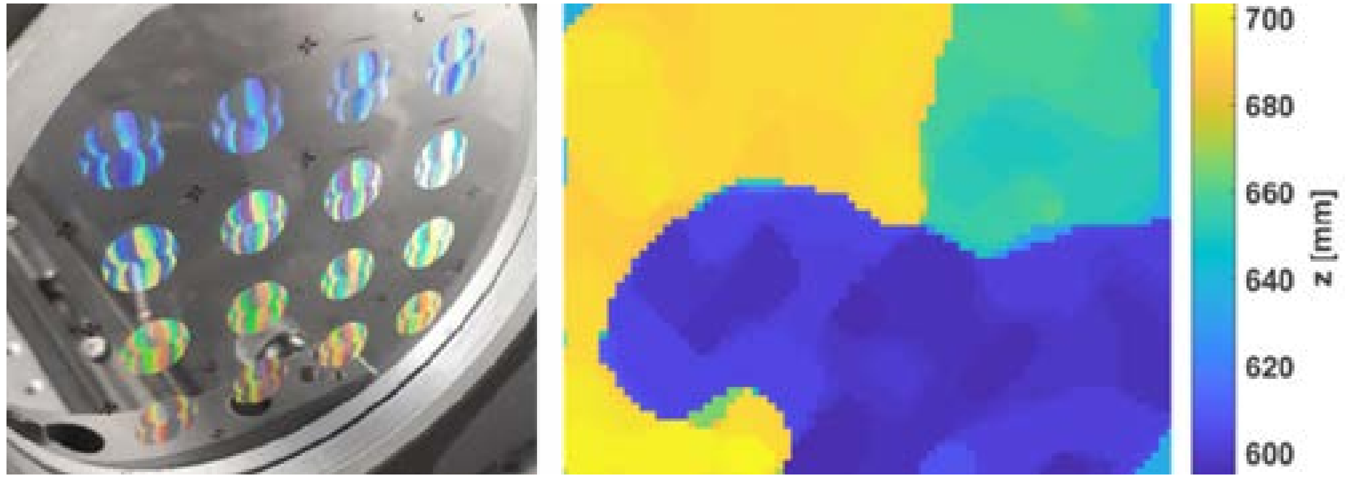

Figure 1:
Metasurface based phase masks for three-dimensional imaging (left), and a corresponding obtained depth image of an example scene (right).

Mie scattering describes elastic scattering of light by small particles having diameters on the order of the wavelength. This mechanism of light scattering is responsible for the characteristic white colour of e.g. milk or fog. What is less well-known is that tailored Mie-resonances of dielectric designer nanoparticles allow for a selective and efficient manipulation of light fields at the nanoscale. Importantly, by arranging millions of Mie-resonant dielectric nanoparticles in a plane, functional metasurfaces with nanoscale thickness can be constructed. Such metasurfaces cannot only replace certain conventional optical components, but they can also provide completely new photonic functionalities. For example, during the last year we were able to demonstrate the deployment of such dielectric metasurfaces for three-dimensional imaging for the first time /1/. To this end, we designed and experimentally realized a metasurface composed of silicon nanocylinders, which imprints a specific phase profile onto an incident light field that generates a helical intensity distribution behind the metasurface. By placing this metasurface between the camera and the scene to be imaged, depth information of the scene can be reconstructed from the camera image using suitable algorithms (s. Fig. 1). However, metasurfaces offer even further reaching opportunities beyond their use as passive optical components like lenses or phase masks. In particular, by the direct integration of nanoscale emitters into the metasurface architecture they can act as sources of complex light fields, and by their hybridization with responsive materials they can enable the realization of actively tunable optical components. Last year we could e.g. show that light emission from molecular monolayers of the semiconductor material molybdenum disulfide can be carfully manipulated in its emission characteristics /2/ (s. Fig. 2a). Moreover, we demonstrated a new metasurface based display concept by integrating silicon metasurfaces into a nematic liquid crystal cell /3/ (s. Fig. 2b). By application of an external voltage between the metasurface substrate and the upper cell window the liquid crystal molecules can be rotated from their predominantly horizontal into a predominantly vertical orientation. Thereby, the anisotropy axis of the liquid crystal's refractive index is also rotated, leading to a change in the resonance condition of the metasurface. This way, we were able to dynamically tune the transmission of the metasurface for red light in selected spatial areas.

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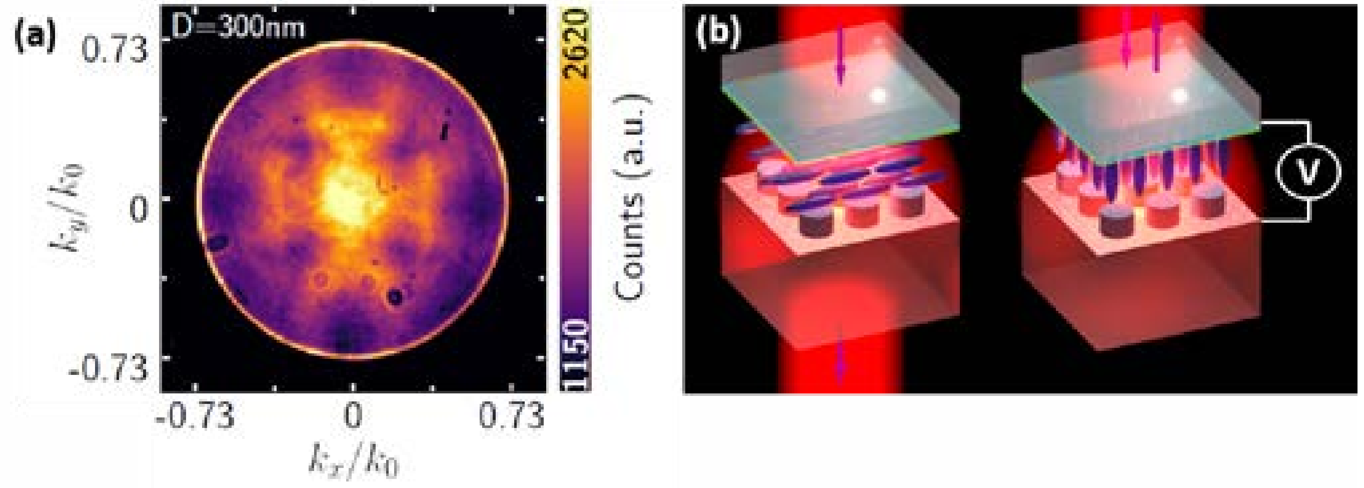

Figure 2:
The spatial spectrum of emission of a monolayer of molybdenum disulfide coupled to a silicon metasurface clearly shows a directional emission pattern. (b) Integration of silicon metasurfaces in nematic liquid crystal cells allows for dynamic tuning of the metasurface transmission by an external voltage.

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Figure:
Swarm intelligence is used in social and now also in many branches of science to solve complex problems and also to minimize computing times. [Wikimedia: Balaram Mahalder].

Optical System Design

In classical optics design, especially the following topics will be addressed:

- Design of modern optical system
- Aberration theory
- Quality evaluation of optical systems
- Measurement of the performance of optical systems
- Design of laser and delivery systems
- Design and evaluation of freeform optical systems for imaging and illumination
- Optimization methods in optical design
- Tolerancing of optical systems

In somewhat more general physical issues relating to optical systems, in particular the following topics of interest are:

- Simulation of diffraction effects
- Microscopic image formation
- Calculation algorithms of wave propagation
- Straylight and scattering in optical systems
- Modelling of illuminations systems
- Partial coherent imaging and beam propagation
- Point spread function engineering and Fourier optics.

The professorship Theory of Optical Systems aims to support optical companies in their development and training. Amongst others, this could be reached in the project “Freeform Optics Plus (fo+)”, which combines research on the brand new technology field of freeforms in optics but also in education and training.

Authors:
Ziyao Tang and Herbert Gross

Ant colony optimization in lens design

Real optical design tasks are usually too complex for analytical solutions and needs therefore numerical approaches for optimization. As the most widely used optimization algorithm in optical design, damped least square (DLS) method is advantageous due to its fast convergence and deterministic optimization path. However, the result is strongly dependent on the initial system and problematic when it is stuck in a local minimum in the searching space. Therefore, a biology intelligence based algorithm - ant colony optimization (ACO) - is implemented and tested for optical design tasks. Nowadays, there are several different ideas about continuous ACO algorithm categorized by different pheromone models, which indirectly determine the ants' movements. Based on the implementations and case studies, two of the ACO ideas, namely mACOR and API, are proved to work well for optical design.

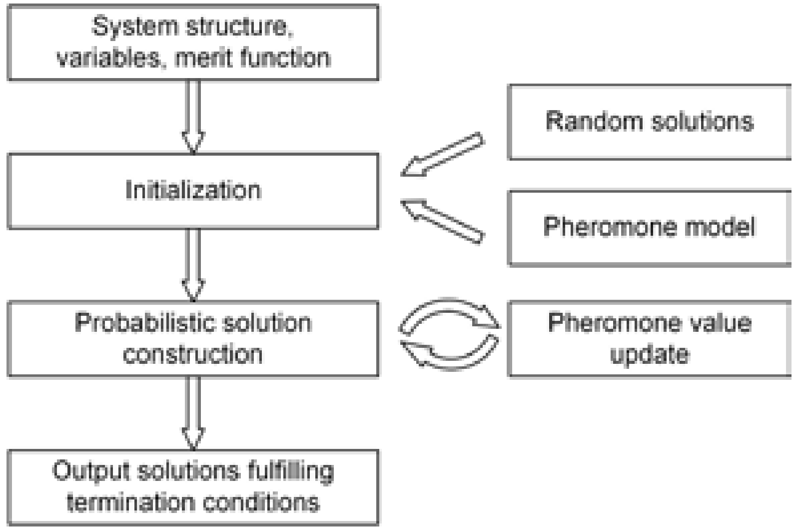
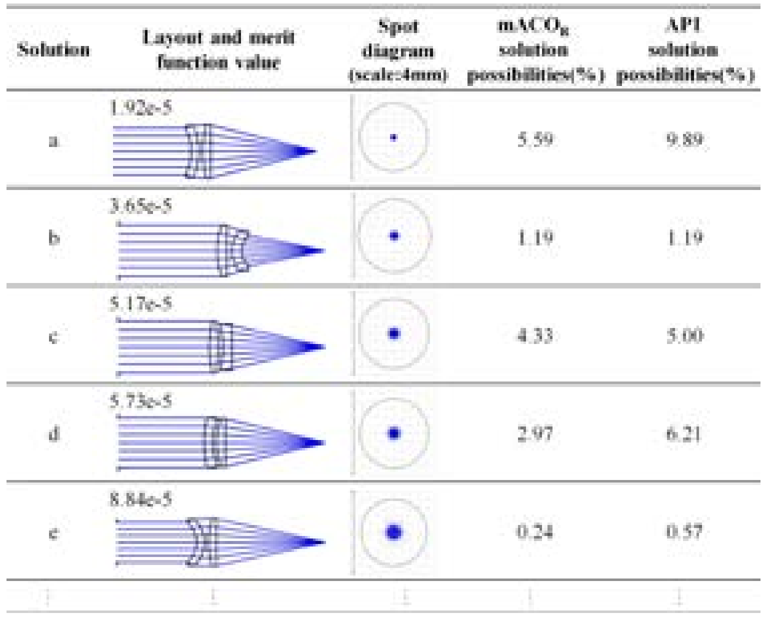


Figure 1:
General working principle of ACO ideas.



Solution	Layout and merit function value	Spot diagram (scale:4mm)	$mACO_R$ solution possibilities(%)	API solution possibilities(%)
a	1.92e-5		5.59	9.89
b	3.65e-5		1.19	1.19
c	5.17e-5		4.33	5.00
d	5.73e-5		2.97	6.21
e	8.84e-5		0.24	0.57
⋮	⋮	⋮	⋮	⋮

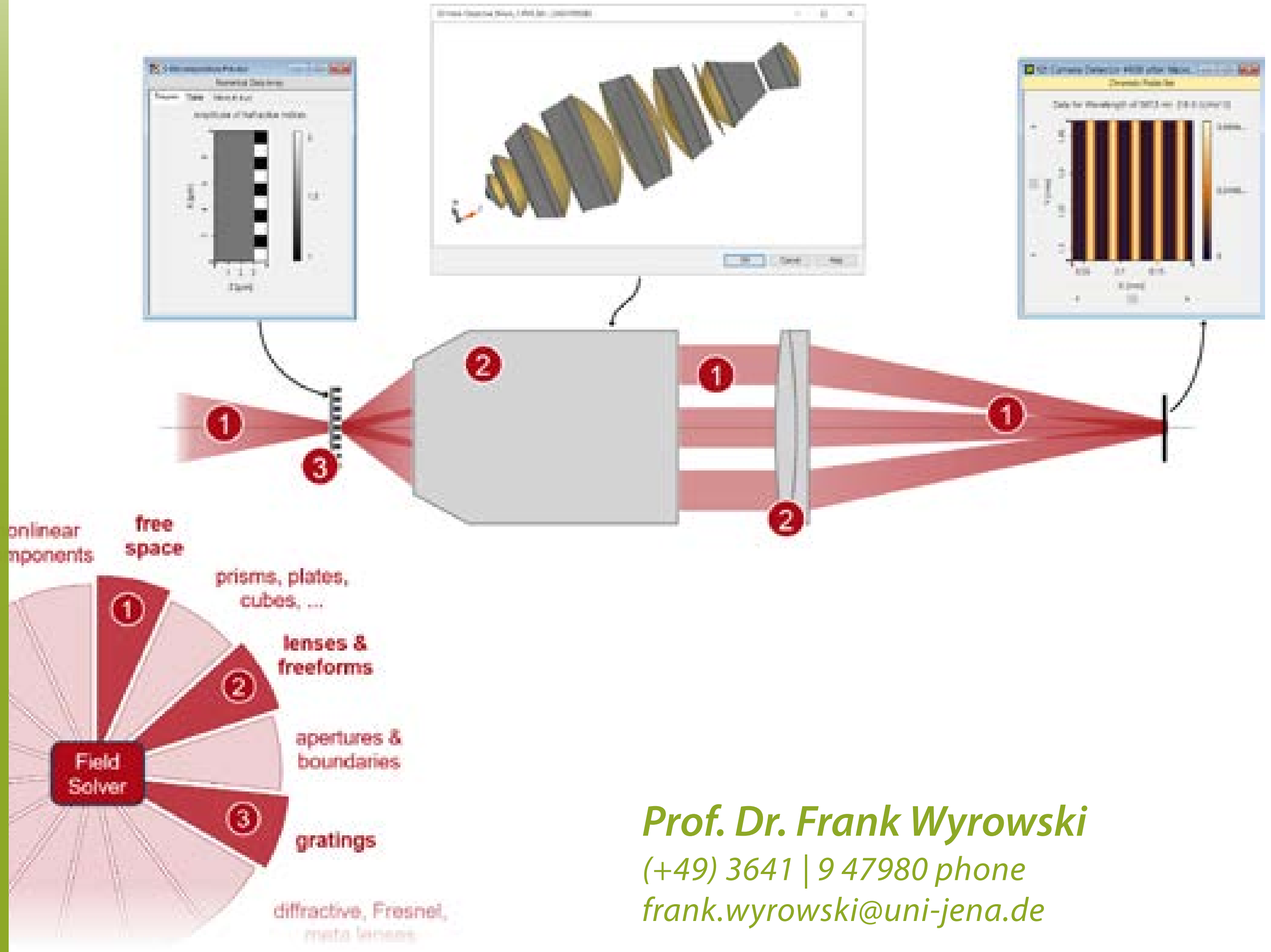
Figure 2:
Solutions found by different algorithms.

The algorithms are implemented in MATLAB and the optical design tool OpticStudio is utilized for performance assessment. The general optimization process is illustrated in Fig.1. The initialization includes both the randomly generated solutions and a given pheromone model. All the variables of a new solution are generated simultaneously within the allowed variable intervals, according to the pheromone value. All the newly generated solutions also help updating the pheromone map. This loop keeps going until the output solution fulfills the termination criteria.

As a test for the basic optimization function, a simple optical system composed of two lenses was considered. With a certain number of repetitions of the optimization procedure, both algorithms find various local minima. Part of the different solutions, as well as the solution appearance probabilities, are listed in Fig.2. The spot diagrams are indicating the quality of the found solutions.

Both of the ACO ideas are also feasible for discrete glass optimization, for which mACOR can find better solutions than DLS global optimization results.

Compared with conventional DLS method, ACO method is not influenced by the initial system. The execution time mostly depends on the variable number, algorithm parameters and data exchanging efficiency. Similar to real optical design procedure, structural change and aberration analysis can be tackled during the optimization, when more physical knowledge or practical experience are taken into consideration. For example this means, the algorithms determines the necessary number of lenses automatically. Therefore, it provides a hint that there is much space to improve the efficiency of the algorithm.



General concept of field tracing.

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Applied Computational Optics

In the Applied Computational Optics Group, we seek to tackle various modeling and design tasks ranging from lens to micro- and nano-optical components. We put our focus on simulating all different types of optical components through a physical optics perspective to achieve a unified approach for optical system modeling. Optical systems, now more than ever before, are heterogeneous: many different elements, with varied working principles, are combined and must function together. But if we are to simulate such systems, we cannot restrict ourselves to employing a single solver across the board. We must show flexibility: different solvers for different elements must be connected. The technique for connecting field solvers is referred to as field tracing.

In 2019, research and development topics include:

- Fast physical optics modeling of lens systems including diffractive and meta lenses
- Modeling of light guides for augmented (AR) and mixed reality (MR)
- Systematic optical design for light shaping
- Pointwise Fourier transform and algorithms
- Kogelnik theory for volume gratings and its limitations
- Propagation of fields through graded-index media
- Microstructure surface modeling and connection to BSDF
- Modeling of nonlinear effects

Authors:
Olga Baladron Zorita and Frank Wyrowski

Isolation of the Gouy phase shift in a full physical-optics formulation of the propagation problem

Any convergent beam accumulates a π phase shift as it propagates from −∞ to +∞ which cannot be explained by the optical path length (OPL) traversed by each of the rays describing the beam. From the theory of complex numbers it is straight-forward to conclude that the π phase shift can also be understood as an overall minus sign which differentiates the convergent and divergent sides of a focused beam /1/. This effect was first identified – theoretically and experimentally – by the scientist Louis Georges Gouy /2, 3/, after whom it has been named.

The Gouy effect has awakened continued, albeit niche, interest since its discovery at the end of the nineteenth century, despite the fact that, as a constant phase, it is rather inconspicuous in most optical systems (that is not to say that it is completely without application, though: it has been employed, for instance, as the basis for measurement systems /4/).

This fascination resides in the fact that the problem of a focused beam propagating from its inverse far-field zone, through its focus, on to the far-field zone seems almost perfectly described by a geometrical-optics model of the situation, except for a trifling constant phase term.

The ability of the geometrical model to provide such a satisfactory outcome for this configuration can however mask the fact that its application rests on a violated assumption: namely, that the rays used to describe the beam can be defined throughout the entire propagation step, so that we can follow them along the straight line delineated by Fermat's principle. But in the focal zone, where diffraction takes over, the ray skeleton cannot be easily defined. The Gouy phase can then be understood as the one remnant at the target plane of this no-longer evident diffraction effect, the thankfully practically insignificant consequence of a treatment which rests on a false premise.

Following a strictly mathematical derivation of the full electromagnetic description of the same situation, and having at our disposal the mathematical tool we have chosen to call "homeomorphic Fourier transform" /5/, we arrive at a conclusion /6/ which is applicable to any focused beam (including aberrant waves and beams with orbital angular momentum) propagating from one side of the focus to the other, and which reveals a "physical-optics" anatomy of the result: all the different terms which we know must appear are there, and can be isolated: the OPL accumulation, the map from the input to the target plane (both of which coincide with the ray-tracing prediction), but also, in addition, all the extra phenomena that only physical optics can account for, like the handling of the amplitude values (transported according to the aforementioned map and weighted to ensure energy conservation), and the Gouy phase.

The latter turns out to be, in our formulation, the sign of a measure closely related with the curvature of the wavefront, which becomes negative as the wavefront morphs from concavity to convexity as the beam transforms from convergent to divergent.

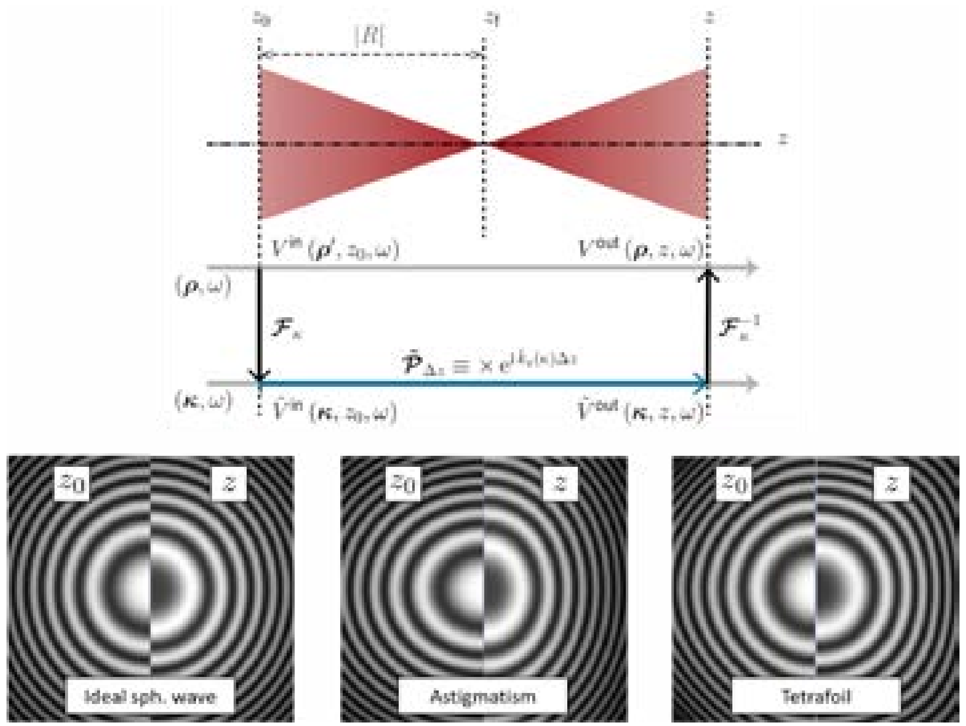

Figure 1:
The figure shows (from top to bottom and left to right) a schematic representation of a focused beam propagating from one side of its focus to the other, below which there is a graphic description of the algorithmic steps used to propagate said beam; finally, at the bottom, the simulation results of interfering three different convergent beams (an ideal spherical wave, one with astigmatism, and one with tetrafoil) with a collimated beam at the input and target plane, in order to reveal the Gouy phase shift. Only half of the detected intensity is shown for either plane, and both are then counterposed against each other, so that the changes from brightness to darkness (evidence of the Gouy phase) and the deformation in the patterns (due to the presence of aberrations) are made explicit.

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Authors:
Zongzhao Wang and Frank Wyrowski

Fast Physical Optics Modeling Benefits from Advanced Fourier transform Techniques

Physical optics modeling requires frequent shifting from the spatial domain into the spatial-frequency domain and vice versa. This is achieved by performing a Fourier transform of the electromagnetic field components. Therefore, the Fast Fourier Transform (FFT) algorithm makes up the backbone of fast physical optics modeling. Its numerical effort, approximately linear on the sample number of the function to be transformed, already constitutes a vast computational improvement over the original Discrete Fourier Transform. However, in optics, we often encounter field components presenting strong wavefront phases: per the Nyquist-Shannon sampling theorem, this translates into the need to resolve the complex amplitude with its phase wrapped to 2-pi intervals and leads to a considerable sample number. So much so that finding a workaround that allows us to evade these stringent sampling requirements is then fundamental for the practical feasibility of the Fourier transform in optics.

We propose two kinds of techniques to perform the Fourier transform of field components which possess a strong wavefront phase. The first one is a rigorous approach that eschews the sampling of second-order polynomial phase terms, handling them analytically instead: it is for this reason that we refer to this method as the “semi-analytical Fourier transform”. The second one is an approximated algorithm whose fundamental basis is the method of stationary phase. When the condition of the approximation is fulfilled, the Fourier transform operation exhibits a behavior that can be described as a bijective mapping of the amplitude distribution, so that the second kind of technique is named “homeomorphic Fourier transform”.

To investigate the performance of different Fourier transform techniques, we configure a simple optical setup: an ideal spherical wave illuminates a house-shaped mask, in which the distance from the point source to the aperture is variable, i.e., we investigate different values of the numerical aperture (NA). Then, we perform different Fourier transform techniques onto the field behind the mask and compare their accuracy and their sampling effort. The simulation results and analysis of the numerical effort are respectively presented in Fig. 2 and Fig. 3.

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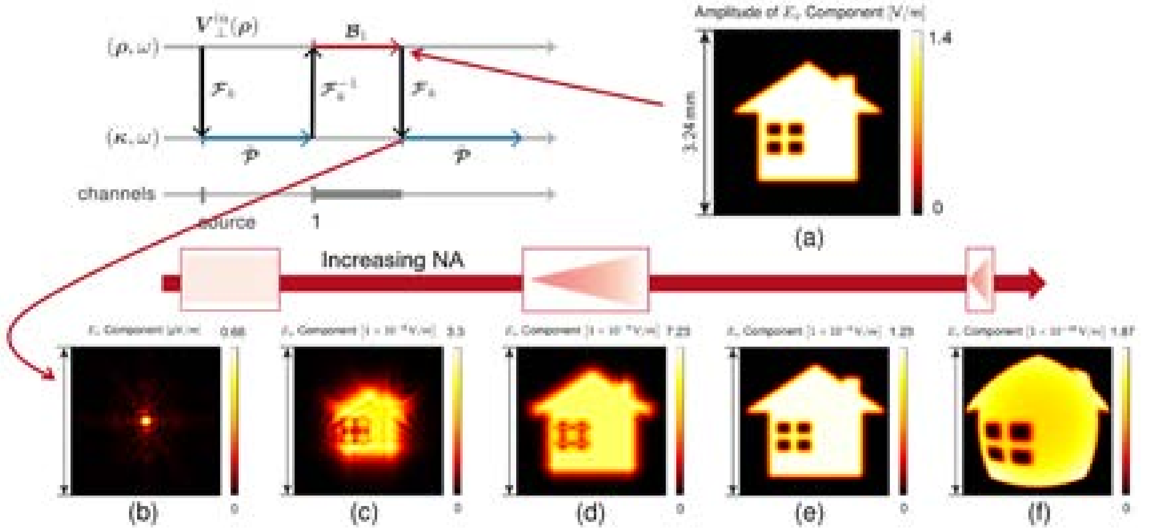

Figure 2:
Fourier transform of a field with house-shaped amplitude and different values of the spherical-phase radius. Panel (a) shows the amplitude distribution of the Ex component in the spatial domain. Panels (b) to (f) present the result of the Fourier-transform operation for different values of the spherical-phase radius: R = +infinity, 200 mm, 50 mm, 10 mm, and 1 mm.

We can conclude that the proposed techniques significantly benefit the computation of the Fourier transform for different kinds of situations. It can be summed up in three brief rules: weak wavefront phase, FFT; strong quadratic phase, SFT; strong wavefront phase, HFT.

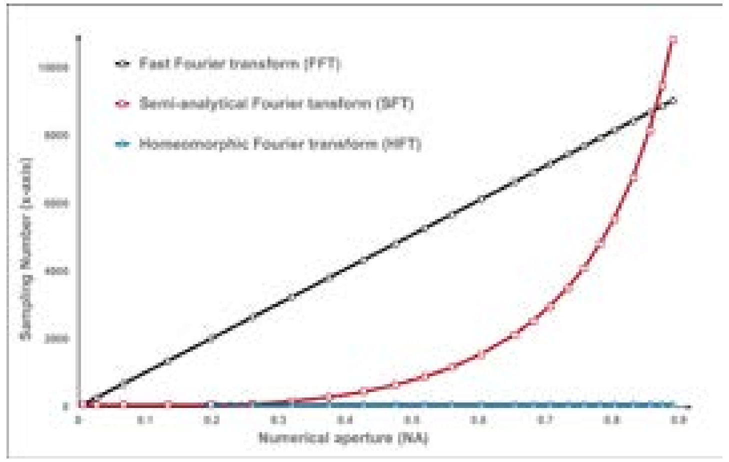

Figure 3:
Comparison of the numerical effort of the semi-analytical, homeomorphic and Fast Fourier transforms (SFT, HFT and FFT for short) for the case of a house-shaped field with a spherical phase, for different values of the numerical aperture (NA) of said spherical phase.

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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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F. Setzpfandt, Bildgebung und Spektroskopie mit Photonenpaaren, 474. JENAer Optikkolloquium, Jena, Germany.

F. Setzpfandt, Photonenpaarerzeugung durch spontane Frequenzkonversion in komplexen Wellenleitersystemen, Physikalisches Kolloquium, Jena, Germany.

F. Eilenberger, F. Steinlechner, M. Gräfe, O. de Vries, F. Setzpfandt, T. Pertsch, U.D.Zeitner, E. Beckert, R. Ursin, A. Tünnermann, Photonische Prozessketten als Enabler für Quantenkommunikation, OptecNet Meeting, Jena, Germany.

H. Gross, Simulation methods for optical systems, Universität Freiburg, Freiburg, Germany.

H. Gross, Optische Systeme mit Freiformflächen, Universität Heidelberg, Heidelberg, Germany.

H. Gross, Optical systems with freeform surfaces, Universität Rostock, Rostock, Germany.

H. Knopf, A. Kuppadakkath, F. Rickelt, U. Schulz, N. Lundt, F. Löchner, T. Bucher, R. Mupparapu, A. George, C. Schneider, I. Staude, F. Setzpfandt, S.-Y. Lim, T. Pertsch, A. Turchanin, F. Schwierz, F. Eilenberger, Halbleitende 2D-Materialen: neue Werkstoffe für optische Schichten, Quantenlichtquellen und Fluoreszenzmikroskopie, Thüringer Werkstofftag, Ilmenau, Germany.

H. Knopf, A. Kuppadakkath, F. Rickelt, U. Schulz, N. Lundt, F. Löchner, T. Bucher, R. Mupparapu, A. George, C. Schneider, I. Staude, F. Setzpfandt, S.-Y. Lim, T. Pertsch, A. Turchanin, F. Schwierz, F. Eilenberger, E. Sedov, M. Waldherr, M. Klaas, S. Tongay, S. Klembt, A. Kavokin, S. Höfling, C. Schneider, Zweidimensionale Halbleiter atomarer Dicke: neue Freiheitsgrade für aktive und passive optische Schichtsysteme, 6. Kolloquium „Dünne Schichten in der Optik“, Thüringer Grenz- und Oberflächentage, Zeulenroda, Germany.

K. Pfeiffer, L. Ghazaryan, P. Paul, A. Szeghalmi , Entspiegelungen mittels ALD, 6. Kolloquium „Dünne Schichten in der Optik“, Thüringer Grenz- und Oberflächentage, Zeulenroda, Germany.

P. Schenk, A. Szeghalmi, Iridium-Alumina Nanolaminates for Epsilon Near-Zero Coatings in the DUV Spectral Range, Nano- and Ultrafast Surface Sciences, NUSS Workshop, Garching, Germany.

P. Schenk, A. Szeghalmi, Konforme Innenbeschichtung von Kapillaren mit Iridium mittels Atomlagen-abscheidung, 6. Kolloquium „Dünne Schichten in der Optik“, Thüringer Grenz- und Oberflächentage, Zeulenroda, Germany.

R. Geiss, J. Hengster, T. Kaiser, G. Leuchs, A. Tünnermann, Max Planck School of Photonics: research-oriented photonics education in a network of excellence throughout Germany, Education and Training in Optics and Photonics, Quebec, Canada.

S. Nolte, Ultrakurzpulslaser – Universelles Werkzeug von der Mikromaterialbearbeitung bis zur Augenheilkunde, Otto-Lummer-Kolloquium, Gera, Germany.

U. Schulz, K. Pfeiffer, F. Rickelt, A. Szeghalmi, N. Kaiser, ALD/PVD – Kombination für eine effektive Entspiegelung von 3D-Oberflächen, 6. Kolloquium „Dünne Schichten in der Optik“, Thüringer Grenz- und Oberflächentage, Zeulenroda, Germany.

U.D. Zeitner, Mikro- und Nanostrukturen für Hoch-leistungsoptiken, 476. Jenaer Optikkolloquium, Jena, Germany.

V. Beladiya, M. Becker, M. Sierka, A. Szeghalmi, Manipulating material properties of atomic layer deposited oxide thin films by electric field: experimental and computational design, 4th Convention SPP 1959, Weimar, Germany.

Granted Patents

A. Klenke, E. Seise, J. Limpert, A. Tünnermann
Optische Verstärkeranordnung
EP 2612405B1

C. Jauregui Misas, A. Tünnermann, J. Limpert, C. Gaida
Optical Waveguide
US 10,281,647B2

C. Stihler, C. Jauregui Misas, J. Limpert, H.-J. Otto, A. Tünnermann
Active stabilization of mode instabilities in optical waveguides
US 10,490,969B2

H. Gross, M. Zhong
Device for contactless optical distance measurement
CN 105992929B

H. Gross, M. Zhong
Vorrichtung zur berührungslosen optischen Abstandsmessung
DE 102013113265B4

H.-J. Otto, C. Jauregui Misas, J. Limpert, A. Tünnermann
Optical Waveguide as Amplifier Fibre for High-Performance Operation (Low gain active optical fibers for high average power operation)
US 10,340,655B2

M. Gräfe, M. Gilaberte-Basset, F. Eilenberger, F. Setzpfand
Optische Anordndung für floureszenzmikroskopische Anwendungen
DE 102018215831B1

M. Gräfe, M. Gilaberte-Basset, F. Eilenberger, F. Setzpfand
Optische Anordndung für floureszenzmikroskopische Anwendungen
DE 102018215833B1

M. Schürmann, S. Schwinde, N. Kaiser
Optical Element Comprising a Reflective Coating (Optisches Element mit einer reflektierenden Beschichtung)
US 10,429,549B2

S. Heist, P. Kühmstedt, G. Notni
Verfahren und Vorrichtung zum berührungslosen Vermessen von Oberflächenkonturen
US 10,302,421 B2

U. Schulz, A. Szeghalmi, L. Ghazaryan, E.-B. Kley
Verfahren zur Herstellung einer niedrigbrechenden Schicht und Schichtsysteme zur Entspiegelung
DE 102016100907B4

U. Schulz, A. Szeghalmi, L. Ghazaryan, E.-B. Kley
Verfahren zur Herstellung einer porösen Brechzahlgradientenschicht
DE 102016100914B4

Participants of the jDPG Meeting at their Lab-tour. Here, Dr. Vinzenz Hilbert explains our research.

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.

Beside this, more and more it is a concern to involve the public in the work we do. We want to attract people for our topics to show them the significance of research for daily life but also win interest of young persons and so to encourage young scientific talents.

Key moments in our institute life 2019

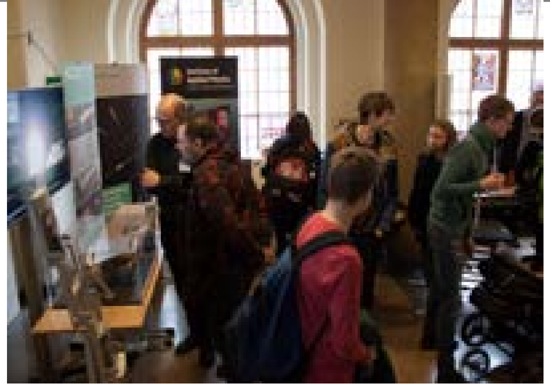
Also in 2019, we were lucky to take part at the "Tag der Physik" (08.03.) which takes place annually at the faculty. Always together with the Fraunhofer IOF and Lichtwerkstatt, we informed a lot of pupils about the interesting and multifarious themes of physics. In May (09.05.) the faculty organized the yearly job fair and the IAP contribute their offers to remind talented students on their chance of a researcher career with excellent conditions. The “Tag des Lichts” (14.06.) is the event for the IAP and Fraunhofer IOF Alumni to meet again and celebrate together with current colleagues in the evening. But before, there are exciting lectures from both institutes as well as contributions from two alumni. Traditional too, is the participation in the induction day for students (01.10.), which is organized jointly with the student council.

In 2019, very special was the visit of representatives of the Financial Department of the university, we could explain some of our work, which promoted and strengthened the understanding and exchange of administrative procedures on both sides. From September 17 to 19th, the Photonics Days Jena focused on young scientists. Together with the Photonics Graduate School Max Planck School of Photonics, participants were offered a multi-faceted program. In addition to the elevator pitches by the Leistungszentrum Photonik, highlights included the presentation of the Applied Photonics Award for Young Scientists and lectures by ZEISS CEO Michael Kaschke and Nobel Prize winner Gérard Mourou. For the second time we could welcome inquisitive people of the jDPG (27.10.). They were warmly welcomed by T. Kaiser and R. Geiss, who gave lectures on special questions of optics. During laboratory tours of the AG Limpert many questions could be discussed. On 22.10. it was time again: the 7th "Lange Nacht der Wissenschaften" entertained thousands of residents of Jena with fascinating insights into current research topics of the city. At the Leistungszentrum Photonik alone, nearly 1000 visitors came to listen to exciting lectures and to try out opport-unities for all ages to participate.

Dr. H.-J. Fuchs and W. Gräfe retired. We will miss their special commitment to the IAP.
Jun. Prof. B. Schulze-Bernhard left us in April after two years a Junior-professorship of the Carl Zeiss Foundation to continue her research work at the Graz University of Technology.

We heard with great sadness about the tragic accident of our much esteemed colleague Jürgen Sauter, PhD student of the research group Nano & Quantum Optics, and the sudden death of Prof. Peter Pertsch, who was deputy director in the years of our institute's beginnings.

Events in 2019: 1 and 2) At "Tag der Physik" we inform older pupils about how interesting physics is. 3 and 4) At the Alumni-Networking day: Dr. J. Petschulat and Dr. F. Steinlechner gave latest information about research at ZEISS and Leistungszentrum Photonik. 5) This year, Dr. D. Richter introduced the institute to the new students. 6) A. Kirsche at the Institute Council election. 7) D. Schelle hands over the joint gift of the colleagues to Dr. H.-J. Fuchs (right). 8 and 9) Fun for actors and audience at the "Lange Nacht der Wissenschaften". 10) G. Mourou gave a deep impression about laser research in past and an outlook to its future. 11) The members of Dezernat 2 were very surprised about our research and regarded the visit as helpful for their work. 12) For many years, W. Gräfe was a great support for the laboratory work.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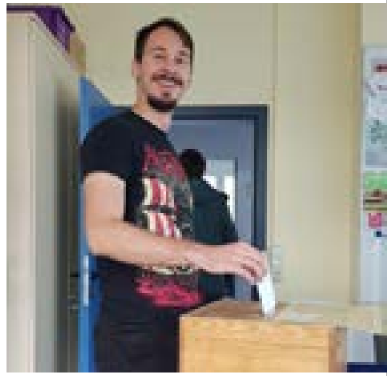
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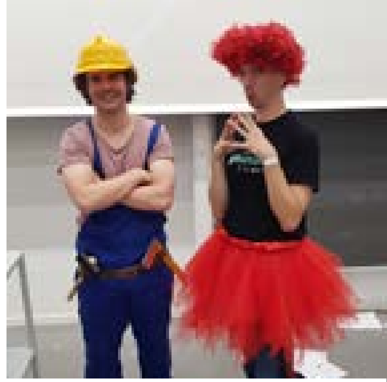
7, 10 ↘


8, 11↘


9, 12↘

Awards

Alessandro Alberucci
Outstanding Reviewer
The Optical Society (OSA)

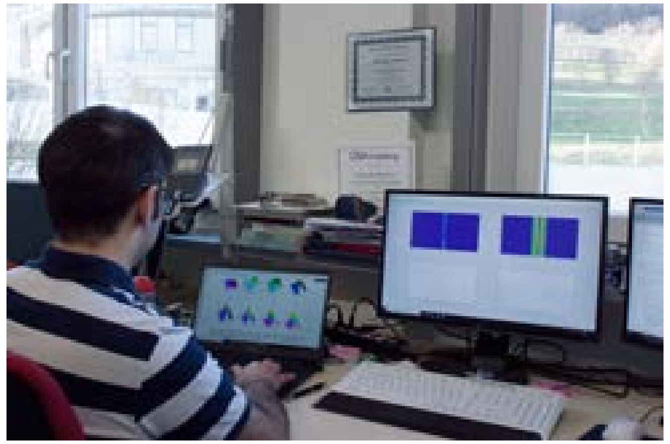
Alessandro Alberucci
Outstanding Reviewer
American Physical Society (APS)

Wilhelm Eschen
ZEISS Ph.D. Award in Modern Optics
ZEISS Group
“Table-top Coherent Diffractive Imaging using a High-Harmonic Source”

Wilhelm Eschen
Poster Award: Source Workshop on EUV-Lithography
EUV Litho, Inc., Austin/USA
“Towards High-Resolution Imaging at 13.5 nm using a Fiber Laser Driven High-order Harmonic Source”

Maximilian Heck
3rd place "Best Paper Award - SPIE Frontiers in Ultrafast Optics"
SPIE. Photonics West
“Next generation of tailored mode selective transmission gratings for fiber integrated devices”

Stefan Heist
SPIE »Rising Researcher Award«
SPIE DCS 2019
(Defense + Commercial Sensing)
„Forschungsarbeit in den Bereichen der optischen Messtechnik, dreidimensionalen Formmessung und schnellen Musterprojektion“



Until January 2019, A. Alberucci reviewed 75 times for five different APS journals.

C. Jauregui-Misas was honored for his research and teachting with a Heisenberg Scholarship.

Prof. Stefan Nolte was awarded as SPIE Senior Member.

Lukas Heller
Fakultätspreis (Physikalisch-Astronomische Fakultät)
Rohde & Schwarz GmbH & Co. KG, Munich
“Cavity enhanced cold atom quantum memories for temporally multiplexed quantum repeater nodes”

Tobias Heuermann
3rd Place: Best sudent paper "Fiber Lasers XV: Technology, Systems, and Applications"
SPIE. Photonics West
“High-Power ultrafast Tm-doped fiber lasers for the generation of mid-infrared radiation in the molecular fingerprint region”

César Jáuregui-Misas
Heisenbergstipendium
Deutsche Physikalische Gesellschaft (DPG)

Heiko Knopf
Nanoscale Advances Poster Prize
Royal Society of Chemestry,
Fudan University Shanghai
“Nanophotonics of 2D Materials”

Left to right: M. Heck, E. Beckert (IOF), T. Heuermann, H. Stark, M. Müller after their success at the Photonics West.

Kristin Pfeiffer, Ulrike Schulz, Andreas Tünnermann and Adriana Szeghalmi
Best Paper Awards 2018, 2nd Place
Journal: Coatings
“Antireflection coatings for strongly curved glass lenses by Atomic Layer Deposition”

Jens Limpert
European Research Council Advanced Grant
“High-Flux Synchrotron Alternatives Driven by Powerful Long-Wavelength Fiber Lasers-SALT“

Michael Müller
2nd Place: Best Student Paper "Fiber Lasers XV: Technology, Systems, and Applications"
SPIE. Photonics West
“3.5 kW coherently combined ultrafast fiber laser”

Stefan Nolte
SPIE Senior Member

Sina Saravi
Research Support "IMPULSE2019"
Friedrich Schiller University Jena
“Experimental realization of atom-mediated pair-generation processes”

Sina Saravi
Best PhD Thesis
Dr.-Ing. Siegfried Werth Foundation
“Photon -pair generation in photonic crystal waveguides”

Paul Schenk
3rd Place: »Elevator Pitches«
Leistungszentrum Photonik
„Funktionalisierung von Brochosomen für optische Anwendungen“

Jan Sperrhake
2nd Place: »Elevator Pitches«
Leistungszentrum Photonik
„Kontaktlose medizinische Sensorik für Neugeborene - Aufbruch in die Diagnostik der Zukunft“

Henning Stark
1st Place: Best sudent paper
"Fiber Lasers XV: Technology, Systems, and Applications"
SPIE. Photonics West
“High-power electro-optically controlled divided-pulse amplification”

Yi Zhong
PhD Award of the
Friedrich Schiller University Jena
Gesellschaft der Freunde und Förderer der Friedrich-Schiller-Universität
“Optical design methods of non-rotational symmetric optical systems with freeform surfaces”

Dr. Falk Eilenberger gave the laudation for Dr. Klaus Bergner.

M. Nisser (UniKlinikum) and J. Sperrhake test in their NeoVitalSensor project contactless sensors that can measure vital parameters such as heart rate, blood oxygen concentration and respiratory volume by combining high-resolution 3D measurement technology and nano-optical filters.

ACTIVITIES

Organizing Activities

Falk Eilenberger

Fellow of the Max-Planck-School of Photonics

Coordinator of the Graduate Research College "3D-Technologien in der Mensch-Maschine-Interaktion"

Herbert Gross

Member of the program committee conference „European Optical Society Annual Meeting"

Referee as an expert for the Dutch Research Council NOW

Stefan Heist

Member of the International Society for Optics and Photonics SPIE

Member of the Conference Committee for SPIE DCS

Member of Deutsche Gesellschaft für angewandte Optik (DGaO)

Jens Limpert

Member of Deutsche Physikalische Gesellschaft (DPG)

Member of the Optical Society of America (OSA)

Stefan Nolte

Vice Dean Faculty of Physics and Astronomy

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

Member of the executive board of the Abbe School of Photonics

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

Scientific Coordinator for International Graduate Research School GRK 2101 (DFG)

Member of jury "Jugend forscht"

Member of several scientific committees (e.g. Phot. West, BGPP, LANE, Lasertagung Jena)

Fellow of the Optical Society of America (OSA)

Senior Member of the International Society for Optics and Photonics SPIE

Member of Deutsche Physikalische Gesellschaft (DPG)

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 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

Coordinator of the study program "Master of Science in Photonics"

Fellow of the Optical Society of America (OSA)

Referee for several international journals

Fellow of the Max Planck School of Photonics

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

Brigitte Schultze-Bernhardt

Member of the Optical Society of America (OSA)

Member of Deutsche Physikalische Gesellschaft (DPG)

Member of Österreichische Physikalische Gesellschaft (ÖPG)

Alumna of the Alexander-von-Humboldt Foundation

Jan Rothhardt

Member of the extended directory board of the Helmholtz Institute Jena

Member of the Program committee for CLEO Europe conference

Member Optical Society of America (OSA)

Frank Setzpfandt

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

Isabelle Staude

Session Chair, e.g. at the 13th International Congress on Artificial Materials for Novel Wave Phenomena, Rome 2019 and CLEO US 2019, San Jose.

Associate Editor for Optics Express

Member of the Junge Akademie

Member of Deutsche Physikalische Gesellschaft (DPG)

Coordinator of the research association “Nano-Film” within the funding program “Photonik Plus” of the German Federal Ministry for Education and Research (BMBF)

Member of the Management Board of the Collaborative Research Center (SFB) “Nonlinear Optics Down to Atomic Scales (NOA)

Adriana Szeghalmi

Member of Deutsche Physikalische Gesellschaft (DPG)

Senior Member of the Optical Society of America (OSA)

Andreas Tünnermann

Council member of the Faculty

Council member of the TU Bergakademie Freiberg

Chairman of the Technical Council Fraunhofer-Gesellschaft

Board of Trustees MPA, Heidelberg

Board of Trustees MPQ, Garching

Board of Directors Helmholtz Institute, Jena

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

Research Training Group GRK2101 "Guided light, tightly packed: novel concepts, components and applications"

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

Spokesman of the Fraunhofer Innovation Cluster “Leistungszentrum Photonik”

Spokesman of the Fraunhofer Innovation Cluster “Leitprojekt Quilt”

Co-spokesman of the Fraunhofer cluster of excellence “Advanced photon source”

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

Spokesman of the BMBF program Zwanzig20 “3Dsensation”

Spokesman 3Dsensation Graduiertenforschungskolleg

Spokesman of the Fraunhofer graduate college "Fraunhofer Graduate Research School Photonics"

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

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

Member of the 1st scientific level of the BMBF research cluster “infectooptics”

Member of program committee "Qantensysteme", BMBF

Board of Trustees Leibinger Stiftung

Supervisory board member Jenoptik AG

Supervisory board member ARRI AG

Member of Technical Council committee Docter Optics

Chairman "AG Naturwissenschaften", Wissenschaftliche Gesellschaft Lasertechnik e .V.

Member of acatech "Deutsche Akademie der Technikwissenschaften"

Stakeholder Photonics 21-Platform

Member of the Executive Board OptoNet e.V.

Co-Editor Applied Physics B

Editorial Advisory Board Lasers&Photonics Review

Fellow of OSA – Optical Society of America

Fellow of SPIE International Society of Optics and Photonics

Frank Wyrowski

Visiting Professor at the Chinese Academy of Science, China

Visiting Professor at the Institute of Technology (HIT), China

Conference Co-Chair: SPIE Workshop on Light Shaping

Conference Co-Chair: SPIE Meeting on Computational Optics

Conference Co-Chair: EOS Topical Meeting on Diffractive Optics

Member of the Technical Program Committee SPIE Conference on Optics and Photonics for Information Processing

Member of the Technical Program Committee SPIE Conference on Digital Optics for Immersive Displays

Member of the Technical Program Committee OSA Conference on Digital Holography and 3D Imaging

President of the LightTrans GmbH

President of Wyrowski Photonics GmbH

Uwe D. Zeitner

Member of the Program Committee for Micro-optics Conference, MOC2018 and SPIE Advanced Lithography: Optical Microlithography XXXI

LOCATION

Institute of Applied Physics
Albert-Einstein-Straße 6 & 15
Campus Beutenberg
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