ABBE CENTER OF PHOTONICS

Status & Perspectives in Science & Education

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

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

ABBE CENTER OF PHOTONICS
Status & Perspectives in Science & Education
FOREWORDS

Light is central to the dreams, activities and evolution of mankind. On the most fundamental level through photosynthesis, sunlight allows for life to exist. In our daily lives, it is the ubiquitous technology of photonics that enables applications such as the World Wide Web, weather and climate monitoring, information transfer at the speed of light, and the fabrication of computer chips to flourish. Without light and, subsequently, photonics we would not be able to create three-dimensional movies, screen our food, drugs, buildings, and precious works of art safely, or produce items and tools with unprecedented precision and subtlety. Without these, we could not explore our surroundings, cities, our planet Earth, and ultimately, the universe.

Thus, it came as no surprise to the global community that the United Nations General Assembly proclaimed 2015 to be the International Year of Light and Light-based Technologies. The main goal of this year-long observance is to raise worldwide awareness of just how essential and fascinating the modern sciences and technologies of light are for mankind. Yet in Jena, Germany’s City of Light, this kind of appreciation has long been – and still is – prevalent in many ways. Due to its unique involvement with, and passion for optics and photonics, the city’s recognition of light and photonics has been deeply embedded in the minds and everyday lives of its inhabitants – probably more than in any other location in the world. Consequently, the Friedrich Schiller University Jena is also committed to this status quo involvement by its choice of the triad Light – Life – Liberty as its long-term motto. In this triad, Light indeed reflects the unique local history of light and photonics research and teaching, as well as the strong connection to and support of the local and regional industries.

Especially during this International Year of Light 2015, it is an honour for me to share the global message of the role that light plays in our daily lives – a message that essentially drives joint research vision and teaching activities of ACP’s principal scientists. I cordially invite you, the reader, to immerse in this booklet’s pages, and find out what light means for the city of Jena, its University, and its scientific community today. If this message has sparked your interest and curiosity, it would be our pleasure to welcome you personally in Jena, the City of Light.

Giving credit where credit is due, Ernst Abbe was thus chosen in 2010 to be the eponym of our Abbe Center of Photonics, at the same time the key institution of the University’s profile line Light. It projects the distinguished position and worldwide recognition of Jena as the City of Light, and the Friedrich Schiller University Jena as being an international focal point for research in the light sciences. Our Center is embedded in a dynamically developing region of technological innovation. At the same time, its location is found in a region with an extremely rich cultural heritage and attractive living surroundings.

Especially during this International Year of Light 2015, it is an honour for me to share the global message of the role that light plays in our daily lives – a message that essentially drives joint research vision and teaching activities of ACP’s principal scientists. I cordially invite you, the reader, to immerse in this booklet’s pages, and find out what light means for the city of Jena, its University, and its scientific community today. If this message has sparked your interest and curiosity, it would be our pleasure to welcome you personally in Jena, the City of Light.

PROF. DR. WALTER ROSSNAGL
PRESIDENT OF THE FRIEDRICH SCHILLER UNIVERSITY JENA

Jena’s deep historical roots in the fields of optics and photonics exhibit a great challenge - but also a strong stimulus - to continue this century-long tradition with a comparable success also in the 21st century. In the past, it was mainly the combination of efforts from various branches, that has nurtured and allowed for many breakthrough achievements. Today more than ever this conviction is commonly shared by the global scientific and economic communities. This is also undoubtedly true for the field of photonics as key enabling technologies driving social change on a global scale. In 2014, both Nobel Prizes in physics and chemistry were awarded to photonics scientists: Akasaki, Amano and Nakamura – for their development of the blue LED light; and Betzig, Helg and Moerner – for their work on super-resolution microscopy and the circumvention of the optical diffraction limit postulated by Ernst Abbe in 1873.

The Abbe Center of Photonics (ACP), part of the Friedrich Schiller University Jena, clearly pursues one of Abbe’s leitmotifs: innovative and ground-breaking science is only possible if many individuals with different backgrounds, expertise and visions work cooperatively to achieve an even higher goal. At ACP, theoreticians and experimentalists, among them physicists, chemists, material scientists, biologists and physicians, have made remarkable headway in establishing the Center as the primary driver of the University’s profile line Light within photonics and photonics-related technologies. Since the center’s founding in 2010, ACP’s members have experienced a remarkable synergetic effect by creating novel ideas together. Jointly we developed our strategic road map called ACP2020 – Agenda for Excellent Photonics, whose implementation is financially supported until 2019 by the Thuringian state government. This roadmap defines ACP’s visions and ambitions concerning Jena’s future academic curriculum in optics and photonics. Our Agenda will be a stimulus of a strong level of commitment for all ACP scientists in the years to come.

ACP’s outstanding developmental growth has brought it to the level of an indispensable global player in photonics. Reverberations of this fact can also be physically seen by our Center’s new expanded building whose shell has been cast in concrete at Jena’s Beutenberg Campus. Around this booklet’s issue date, the newly finished ACP building will be the city’s modern home of multidisciplinary photonics research and innovation.

We are particularly proud that our Center’s excellence is not limited to research. It is our firm belief that the highest standards of academic qualification can be achieved only through a unified approach where research and education are deemed equally important. Our education of young scientists in this way has boosted our integrated Abbe School of Photonics into the Ivy-league of photonics education worldwide. We now receive hundreds of applications from around the world for our Master’s degree program. The consequence internationalization of ACP’s teaching and staff has contributed to its recognition as one of our University’s flagship projects.

With the current 2015 edition of our booklet Status and Perspectives in Science and Education, we wish to again provide you with a summary of our joint efforts during the last several years. The booklet has been updated in lieu of ACP’s most recent developments, particularly concerning breakthrough results in research and our newly appointed faculty. Unlike an annual report, our aim was to attain a balance between manifesting and reflecting on our very dynamic progress – without becoming outdated after only several months.

We truly hope that this booklet will provide you with a clear overview of our activities and plans. Feel warmly welcome to immerse in the lectures all of which excite our unified opinion: Jena is one of the best places in the world for study and research in optics and photonics. In the spirit of our namesake, Ernst Abbe, we would be happy to welcome you soon.

ACP BOARD OF DIRECTORS, NOVEMBER 2015
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Director's Report</td>
<td>8</td>
</tr>
<tr>
<td>Education - Abbe School of Photonics</td>
<td>20</td>
</tr>
<tr>
<td>Key Research Area Ultra Optics</td>
<td>34</td>
</tr>
<tr>
<td>Key Research Area Strong Field Physics</td>
<td>40</td>
</tr>
<tr>
<td>Key Research Area Biophotonics</td>
<td>46</td>
</tr>
<tr>
<td>Principal Scientist Profiles</td>
<td>52</td>
</tr>
<tr>
<td>Editorial</td>
<td>4</td>
</tr>
<tr>
<td>Director's Report</td>
<td>8</td>
</tr>
<tr>
<td>Structure</td>
<td>12</td>
</tr>
<tr>
<td>Funding</td>
<td>16</td>
</tr>
<tr>
<td>Advisory Board</td>
<td>18</td>
</tr>
<tr>
<td>Administration</td>
<td>19</td>
</tr>
<tr>
<td>Education - Abbe School of Photonics</td>
<td>20</td>
</tr>
<tr>
<td>Building Careers in Photonics</td>
<td>22</td>
</tr>
<tr>
<td>Master's Degree Program</td>
<td>24</td>
</tr>
<tr>
<td>Doctoral Program</td>
<td>37</td>
</tr>
<tr>
<td>Junior Scientist Program</td>
<td>30</td>
</tr>
<tr>
<td>Guest Professorship Program</td>
<td>32</td>
</tr>
<tr>
<td>Key Research Area Ultra Optics</td>
<td>34</td>
</tr>
<tr>
<td>Key Research Area Strong Field Physics</td>
<td>40</td>
</tr>
<tr>
<td>Key Research Area Biophotonics</td>
<td>46</td>
</tr>
<tr>
<td>Principal Scientist Profiles</td>
<td>52</td>
</tr>
<tr>
<td>Hartmut Barlett</td>
<td>54</td>
</tr>
<tr>
<td>Michael Bauer</td>
<td>56</td>
</tr>
<tr>
<td>Christoph Biskup</td>
<td>58</td>
</tr>
<tr>
<td>Michael Börsch</td>
<td>60</td>
</tr>
<tr>
<td>Silvana Bonta</td>
<td>62</td>
</tr>
<tr>
<td>Axel Braithage</td>
<td>64</td>
</tr>
<tr>
<td>Detla Bauer</td>
<td>66</td>
</tr>
<tr>
<td>Volker Deckert</td>
<td>68</td>
</tr>
<tr>
<td>Benjamin Dietzke</td>
<td>70</td>
</tr>
<tr>
<td>Stephan Fritzsche</td>
<td>72</td>
</tr>
<tr>
<td>Wolfgang Fritzsche</td>
<td>74</td>
</tr>
<tr>
<td>Torsten Freisch</td>
<td>76</td>
</tr>
<tr>
<td>Holger Gies</td>
<td>78</td>
</tr>
<tr>
<td>Stefanie Gräf</td>
<td>80</td>
</tr>
<tr>
<td>Herbert Gross</td>
<td>82</td>
</tr>
<tr>
<td>Stefan H. Heinemann</td>
<td>84</td>
</tr>
<tr>
<td>Rainer Heintzmann</td>
<td>86</td>
</tr>
<tr>
<td>Mafte C. Kakusa</td>
<td>88</td>
</tr>
<tr>
<td>Ernst-Bernhard Krey</td>
<td>90</td>
</tr>
<tr>
<td>Erika Kothe</td>
<td>92</td>
</tr>
<tr>
<td>Richard Kowarschik</td>
<td>94</td>
</tr>
<tr>
<td>Jens Limpert</td>
<td>96</td>
</tr>
<tr>
<td>Stefan Lorkowski</td>
<td>98</td>
</tr>
<tr>
<td>Stefan Nolte</td>
<td>100</td>
</tr>
<tr>
<td>Gerhard G Paulus</td>
<td>102</td>
</tr>
<tr>
<td>Thomas Pretsch</td>
<td>104</td>
</tr>
<tr>
<td>Ulf Peschel</td>
<td>106</td>
</tr>
<tr>
<td>Adrian H. Pfleger</td>
<td>108</td>
</tr>
<tr>
<td>Jürgen Poppe</td>
<td>110</td>
</tr>
<tr>
<td>Jan Rothhardt</td>
<td>112</td>
</tr>
<tr>
<td>Christian Russel</td>
<td>114</td>
</tr>
<tr>
<td>Felix Schachter</td>
<td>116</td>
</tr>
<tr>
<td>Alexander Schiller</td>
<td>118</td>
</tr>
<tr>
<td>Markus Schmidt</td>
<td>120</td>
</tr>
<tr>
<td>Michael Schmidt</td>
<td>122</td>
</tr>
<tr>
<td>Ulrich S. Schubert</td>
<td>124</td>
</tr>
<tr>
<td>Christian Spielmann</td>
<td>126</td>
</tr>
<tr>
<td>Isabelle Staude</td>
<td>128</td>
</tr>
<tr>
<td>Thomas Stohilker</td>
<td>130</td>
</tr>
<tr>
<td>Alexander Stamen</td>
<td>132</td>
</tr>
<tr>
<td>Adriana Stieghauser</td>
<td>134</td>
</tr>
<tr>
<td>Andreas Tuinemann</td>
<td>136</td>
</tr>
<tr>
<td>Andrey Turukhin</td>
<td>138</td>
</tr>
<tr>
<td>Andreas Wipf</td>
<td>140</td>
</tr>
<tr>
<td>Lothar Wondraczek</td>
<td>142</td>
</tr>
<tr>
<td>Uwe D. Zeitner</td>
<td>144</td>
</tr>
<tr>
<td><strong>IMPRINT</strong></td>
<td><strong>147</strong></td>
</tr>
</tbody>
</table>
DIRECTOR’S REPORT
THE ABBE CENTER OF PHOTONICS
IS THE ACADEMIC CENTER FOR
OPTICS AND PHOTONICS AT THE
FRIEDRICH SCHILLER UNIVERSITY JENA.

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

ACP has the vision of establishing itself by the year 2020 as one of the leading European centers for research and education in optics and photonics, as well as in the development and transfer of optical technologies.
The Abbe Center of Photonics (ACP) is the host of major research and educational activities in optics and photonics at the Friedrich Schiller University Jena. As a cornerstone of the University’s scientific profile, this interfaculty center forms the core of the University’s profile line „Light“ and incorporates major scientific contributions from Jena’s non-university optical research institutes.

Based on more than a century of optics and photonics tradition in Jena, ACP was founded in 2010 by the optical scientists of the Friedrich Schiller University Jena to further shape the University’s scientific profile. ACP’s founding was a milestone in the University’s long term institutional strategy to establish the priority research area Optics, Photonics and Photonic Technologies already in 2005. Besides its academic mission, ACP reflects the strategy of the University by forming a close partnership with Jena’s prosperous optics industry. This fact was also recognized by the German Federal Ministry of Education and Research (BMBF) when it established the Center for Innovation Competence ZIK „ultraoptics“ that same year, remaining a central part of ACP today.

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

ACP membership is open to all members of the Friedrich Schiller University working in the field of optics and photonics. A special type of membership is available for external scientists who are active in ACP’s research fields. ACP membership applications are regularly considered and approved by the board of directors. In November 2015, ACP is comprised of 46 high-profile members who, due to the Center’s interfaculty character, are affiliated with different departments of the University:

- 25 members from the Faculty of Physics and Astronomy
- 12 members from the Faculty of Chemistry and Earth Sciences
- 4 members from the Faculty of Biology and Pharmacy
- 3 members from the Faculty of Medicine

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

ACP is run by a lean but effective management structure. The board of directors is elected by the members every three years to shape the Center’s profile and to initiate common activities. The ACP advisory board, currently formed by six high-profile personalities from academia, industry and politics, supports the directors in questions of strategic importance. Administratively, the Center is run by a chief executive officer, a project accounting clerk, two coordinators of the Master’s degree, doctoral and guest program, and an administrative assistant. The Center’s structure is displayed in the organization chart.

A CROSS-FERTILIZING CENTER FOR OPTICAL SCIENCES

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

AN ATTRACTIVE PERSPECTIVE FOR PHOTONICS EXPERTISE IN ACADEMIA

Hand in hand with the University, ACP offers applicants showing excellent academic achievements the maximum opportunities for an academic career in optics and photonics in Jena. In order to provide this scientific and structural development with a broad foundation, ACP members have managed to actively steer strategic appointments, thereby serving to strengthen the Center’s core identity and the University’s profile line “Light”. Since 2012, a considerable number of strategic professorship appointments have been achieved: Silvana Botti (Condensed Matter Theory), Benjamin Dietzek (Molecular Photonics), Volker Deckert (Nanospectroscopy), Stephan Fritzsche (Relativistic Quantum Dynamics), Stefanie Grafe (Theoretical Chemistry), Herbert Gross (Optical Systems Design), Jens Limpert (Novel Solid-State Laser Concepts), Markus A. Schmidt (Fiber Sensors), Ulf Peschel (Solid State Optics), Thomas Stöhler (Atomics Physics in Extreme Coloumb & Laser Fields), Andrey Turunin (Applied Physical Chemistry), and Lothar Wondraczek (Glass Chemistry).

ORGANIZATION CHART OF THE ABBE CENTER OF PHOTONICS.
EQUAL GENDER OPPORTUNITIES AND FAMILY-FRIENDLINESS

ACP strongly and actively pursues gender mainstreaming and family-friendly working conditions. In addition to ACP internal initiatives, a variety of measures at the federal state, local state, and municipal level are already in place to promote equal gender opportunities. While gender equality is less an issue in the departments of biology and medicine, there is still – despite all efforts – a severe problem in the current staffing of physics and chemistry departments which reflects the acute shortage of women in these disciplines in Germany in general, and optics and photonics in particular. Currently, six out of 46 ACP principal scientists are female, namely Silvana Botti, Dea Braue, Stefanie Graf, Erika Köthe, Isabelle Staude, and Adriana Szeghalmi. As part of our institutional strategy as well as of the ACP qualification strategy, in fact, first successes of academic careers, incorporating this principle in all aspects by supporting women at the earlier stages of their academic careers, have proven to be fruitful. At the beginning of 2015, former ACP member Rachel Grange was appointed as an assistant professor at ETH Zurich. Following this model, also in 2015 ACP opened a new position of a junior researcher group leader which, after a quite competitive appointment procedure, could be staffed with Isabelle Staude. While we will continue to increase our efforts on gender equality, we hope that our already demonstrated success-cases will act as a seed for further appointments of female professors in the future. To further promote equal opportunity and family-friendly conditions, ACP has appointed Isabelle Staude as coordinator and contact person for gender issues. She provides advice and support for equal opportunity or family-related topics within ACP and ASP. On the administrative level, information regarding financial aid earmarked for the promotion of women in academic careers is distributed at all levels. Clearly, the support of young female scientists is a cross-sectional task for both ACP and the University. It creates and secures conditions of equal opportunity for all its members, independent of gender and background.

PUBLICATIONS AND DISTINGUISHMENTS

Publications are the main channels of scientific output, but they also serve to generate public awareness and are thus a primary performance indicator, both for the Center’s scientific excellence and its visibility. Since ACP was officially founded in late 2010, a significant increase in absolute publication numbers has been achieved. This rise is mainly attributed to three factors: First, the recent concentration of the institutional strategy of the Friedrich Schiller University was backed by an enlarged strategic and structural support concept from the University board and the State of Thuringia, creating a global hot spot in optics and photonics. Second, a number of large-scale projects in the optical sciences and adjacent fields led by the ACP principal scientists were put into operation over the past five years. Last but not least, the institutionalization of the profile “Light” by the ACP’s key player, has attracted more researchers of the Friedrich Schiller University to the optical sciences. These additional scientists have fused their complementary expertise into combined research efforts in a synergetic way – this fact is also reflected by the recent rise in publication numbers. But it is not only the mere quantity but also the quality of the publications which is worth noting. By October 2015 and since 2010, more than 65 high-impact publications, marked as ACP research highlights, have been published by ACP principal scientists, and at least 15 of them were issued by the Nature Publishing Group (Nature, Nature Photonics, Nature Materials, etc.).

Among the particularly outstanding achievements are the prices and distinguishments, which the Center’s members have been awarded in recent years. Just to name a few, the Federal German President’s Award for Innovation in Science and Technology was awarded to a team around Stefan Nolte, for their contribution in transferring fundamental research of ultrafast laser processes into an industrial manufacturing tool. Since 2014, the Deutsches Museum in Munich offers a permanent hands-on exhibit on that topic. Moreover, both Jens Limpert and Andreas Tünnermann were awarded one of the highly competitive ERC Consolidator and ERC Advanced Grants, respectively. Only for the second time in its long-standing history since 1957, the Pittsburgh Spectroscopy Award was given to a non-American individual, Jürgen Poppe for his outstanding contributions to the field of applied spectroscopy. Alexander Szameit has been honoured as the first German ever with OSA’s Adolph Lomb Medal in recognition of his noteworthy contributions to optics at an early age and with the Rudolf Kaiser-Preis from the DFG for his outstanding contributions to experimental physics. This list may be well continued, and ACP scientists will strive to do so.
FUNDING

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

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

THE GERMAN RESEARCH FOUNDATION
- Excellence Graduate School GSC 214 Jena School of Microbial Communication (JSMC).
- Collaborative Research Center SFB TRR 18 Relativistic Laser-Plasma-Dynamics.
- Research Training Group RTG 1523 Quantum and Gravitational Fields.
- International Research Training Group IRTG 2101 Guided light, tightly packed.

THE EUROPEAN UNION
- Photonics4life - European Network of Excellence for Biophotonics.
- ICAN - International Coherent Amplification Network - European project for the development on fiber-based particle generators.
- Laserlab Europe - Integrated Initiative of European Laser Infrastructures in the 7th Framework Programme.
- NANOPIX - Europe-Asia-Pacific Exchange Program in Nanophotonics, Erasmus Mundus Staff Mobility project.
- Perspekt-H₂O - Coordination of COST Action CM1202.
- Raman4Clinics - Coordination of COST Action BM1401.

STATE AND FEDERAL FUNDING
- 3D Sensation - Twenty20 research consortium, funded in public-private partnership by the German Federal Ministry of Education and Research (BMBF) and more than 70 other partners.
- ACP2020 - Agenda for Excellent Photonics, funded by the Thuringian Ministry for Economy, Science, and Digital Society (TMWWDG) in the second phase of the ProExcellence program.
- ALASKA - Adapted Glasses for Lasers, Optical Converters and Photonic Applications, funded by the TMWWDG.
- Growth Care Freeform Optics FO₂, funded in public-private partnership by the BMBF.
- InfectoGnostics - Research Campus, funded in public-private partnership by the BMBF, the TMWWDG, and more than 20 companies.
- InfectoOptics - Science Campus, funded by the Leibniz Association.
- PolaX - Precision X-ray spectroscopy and polarimetry, collaborative research initiative funded by the BMBF.
- SITARA - Self-adapting intelligent multi-aperture camera modules, funded in public-private partnership by the BMBF and nine companies.
- XCoherentT - XUV Coherence Tomography, research initiative funded by the BMBF.
- ZIK Ultra optics - Center for Innovation Competence, funded by the BMBF.

In addition to individual grants and fellowships, ACP scientists are also proud to attract an exceptionally high amount of third-party funding for projects aiming to support professional careers within the educational program. Substantial financial support for infrastructure and administration to benefit the Abbe School of Photonics is provided by federal and local state programs (Graduate Research School Photonics, Master Photonics and ProExcellence) and from the Carl Zeiss Foundation (a funding scheme for the strengthening of academic research structures). In addition, ACP gratefully receives financial support for selected doctoral research projects from different types of scholarships from the German Federal Ministry of Education and Research (BMBF), the Thuringian Ministry for Economy, Science, and Digital Society (TMWWDG), the Alexander von Humboldt Foundation, the Carl Zeiss Foundation, the German Academic Exchange Service (DAAD), as well as from our more than 20 industrial partners, among them Bosch, Carl Zeiss AG, Jenoptik AG, Osram, Philips, and Siemens.

The following chart lists the annual budgets which ACP scientists have spent on their optics and photonics projects from 2008 to 2014. As a general trend of the last years, an already considerably high level of funding has been continuously increased, and the €20 million border was broken now for three consecutive years since 2012. Another solid tendency lies in the fact of a growing amount of funding attracted from the German Research Foundation (DFG), while the support of the Federal Ministry of Education and Research (BMBF) is expected to decrease from its climax in 2013. In sum, and over the last four years, ACP’s annual budgets have constituted roughly one quarter of the overall sum of third-party funding which has been granted to all scientists of the entire Friedrich Schiller University. These numbers are proof of the vital and sustainable impact of optics and photonics research and education performed by ACP – a reflection of the University’s impressive research profile as well as on the strong economic and infrastructural backbone of Jena.

ANNUAL BUDGETS OF THIRD-PARTY FUNDING IN OPTICS AND PHOTONICS RESEARCH AND EDUCATIONAL PROJECTS LED BY ACP PRINCIPAL SCIENTISTS. SORTED BY FUNDING SOURCES FROM YEARS 2008 TO 2014. THE NUMBERS FOR 2015 WERE NOT YET AVAILABLE AT THE EDITORIAL DEADLINE OF THIS BOOKLET.
The Abbe Center of Photonics (ACP) reinvigorated its management structure with the establishment of an advisory board, which was commissioned by the University's administration in 2012 and again in 2015. ACP is delighted to welcome seven renowned individuals as board members, all with the highest personal achievements in science, industry, and German society with regard to optics and photonics. The board's primary role is to assist the center with the development of a management strategy and vision for future success and to serve as a medium for strengthening linkages between academia, industry, government and community. Dialogue is warranted through regular assessment meetings of the ACP Advisory Board and the ACP Board of Directors. The board's regular meetings take place in Jena every two years.

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**Advvisory Board**

**Prof. Günther Tränkle, Speaker**
He is the director of the Ferdinand-Braun-Institute and holder of the Chair for Microwave and Optoelectronics at the Technical University Berlin.

**Prof. Monika Ritsch-Marte**
She is a full professor in the Department for Physics and Medical Physics at the Medical University of Innsbruck.

**Prof. Vahid Sandoghdar**
He is the director of the Max-Planck-Institute for the Science of Light in Erlangen and chairholder in the Department of Physics at the University of Erlangen-Nuremberg.

**Dr. Michael Kempe**
He is the Director of Corporate Research and Technology at Carl Zeiss AG, Oberkochen/Jena.

**Prof. Helmut Zacharias**
He is a full professor in the Department of Physics at the University of Münster.

**Mr. Dennys Klein**
He is the head of the division for research support at the Thuringian Ministry for Economy, Science and Digital Society (TMWWDG) in Erfurt.

**Szlávia Mammel** studied German philology in Hungary and at the Friedrich Schiller University before she did her vocational education at the same institution in 2009. With her broad experience serving in different administrative units at the Faculty of Physics and Astronomy of the University, she acts as an indispensable link to the needs and demands of ACP scientists and students, tutors and guest researchers. As administrative assistant, Mrs. Mammel provides administrative support to ACP’s executive board, teaching staff, and undergraduate students. She is always the first address for the Master’s degree students, providing assistance in all issues concerning their educational and career development.

**Dr. Margrit Glaser** studied Romance languages & literature as well as American literature at the Friedrich Schiller University Jena, receiving her Master’s degree in 1998 and her doctorate degree in 2007. During the next five years, she worked as a postdoctoral fellow, funded by the German Research Foundation (DFG), at the University’s Department of Art History. In 2012, she joined the Bauhaus University Weimar, being responsible for establishing interdisciplinary online courses and coordinating several funding programs which were mainly education-based. In 2015, Dr. Glaser took over the position of ASP’s Master’s degree program coordinator. Her many tasks include coordinating the applicant evaluation and selection procedures, maintaining ASP’s comprehensive data bases, providing advice to students concerning their educational and career development questions, maintaining the programs’ quality assurance, and assisting in the enhancement and continual development of the Master’s degree program.

The Abbe Center of Photonics (ACP) is a comparably small, but highly specialized team. It supports the board of directors regarding all management-related and organizational aspects of the center’s research and educational activities. The administrative staff works closely with ACP’s principal scientists, the University’s institutions, funding agencies and ACP’s industrial partners. Above all, it provides dedicated support to Abbe School of Photonics (ASP) students throughout each stage of their studies.

Dr. Christian Helgert studied physics at the Friedrich Schiller University Jena and at the Università degli Studi di Roma Tor Vergata (Rome, Italy). In 2006 and 2011 respectively, he received his diploma and doctoral degree in physics for his experimental contributions in micro- and nano-optics. His doctoral thesis on photonic metamaterials was distinguished with the University’s Dissertation Award. In 2011, he joined the Nonlinear Physics Centre at the Australian National University in Canberra as a postdoctoral fellow. The opportunity to serve as ACP’s chief executive officer brought Dr. Helgert back to Jena in 2012. He is in charge of all management issues related to the Center’s activities, with a particular focus on the coordination of strategic collaborative projects and acquisition efforts, public representation of the Center, as well as planning the construction of ACP’s new research and teaching building.

Dr. Dorothea Schmidt studied biology at the Friedrich Schiller University, receiving her diploma in natural products chemistry in 1998 and her doctoral degree in biophysical chemistry in 2004. Her work within the interdisciplinary Collaborative Research Center (SFB) 197 was awarded with the Prize for Cooperation from the SFB’s council in 2000. Until 2011, Dr. Schmidt was entrusted with the coordinator position at the “International Leibniz Research School for Microbial and Biomolecular Interactions” at the Leibniz Institute for Natural Product Research and Infection Biology - Hans Knöll Institute under the auspices of the Jena School for Microbial Communication. Dr. Schmidt joined ASP as coordinator of the Doctoral student and guest program in April 2011. She is responsible for all aspects concerning ASP’s doctoral program, guest professors, project management, public relations and marketing strategy.

Dr. Margrit Glaser studied Romance languages & literature as well as American literature at the Friedrich Schiller University Jena, receiving her Master’s degree in 1998 and her doctorate degree in 2007. During the next five years, she worked as a postdoctoral fellow, funded by the German Research Foundation (DFG), at the University’s Department of Art History. In 2012, she joined the Bauhaus University Weimar, being responsible for establishing interdisciplinary online courses and coordinating several funding programs which were mainly education-based. In 2015, Dr. Glaser took over the position of ASP’s Master’s degree program coordinator. Her many tasks include coordinating the applicant evaluation and selection procedures, maintaining ASP’s comprehensive data bases, providing advice to students concerning their educational and career development questions, maintaining the programs’ quality assurance, and assisting in the enhancement and continual development of the Master’s degree program.
BUILDING CAREERS IN PHOTONICS

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

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

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

ASP coordinates and organizes all of ACP’s educational activities. The School was founded in 2008 as an essential part of the ProExcellence Initiative issued by the State of Thuringia. Since then, the local state and the federal governments, Germany’s optics industry and the European Union together have provided more than € 10 million in basic funding necessary to support this process. A key factor of the program is ASP’s close collaborative work with its industrial partners. To sustain these business partners’ exceptionally high degree of economic development in the future, the availability of a substantial number of highly qualified employees will be required. ASP graduates are just such potential candidates, well-prepared for the German photonics industry.

A VISIONARY CAREER TRACK IN OPTICAL SCIENCES

One of the school’s core programs is its Master’s degree program in Photonics (M.Sc. Photonics). This program’s lectures and courses are taught completely in English. The recruitment is based on a global strategy - selecting the best students from around the world. On the Master’s degree level, ASP’s teaching staff is also strongly engaged in specializing its photonics courses for students in the Master’s degree program in physics (M.Sc. Physics) and in medical photonics (M.Sc. Medical Photonics). The latter program is a newly-designed, interdisciplinary course initiated by the University’s Center of Medical Optics and Photonics (CeMOP), which is to start in the autumn of 2016. Moreover, the School has also established a successive, well-coordinated doctoral program comparable to a PhD program in the USA which is directly associated with ACP’s strategic research programs.

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

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

HIGH-LEVEL PHOTONICS TRAINING LABORATORY

Having extensive hands-on experience is one of the most valuable professional attributes by which a true expert in optics and photonics can be distinguished. In 2009, to strengthen laboratory experience already at the beginning of a student’s Master’s degree studies, ASP set up a completely novel photonics training laboratory. It is able to perform high-level experiments using strictly research-grade components and equipment. This lab’s infrastructure was given funding worth more than € 1.5 million through the ProExcellence Initiative OptoTRAIN - Training in Optics of the former Thuringian Ministry of Education, Science and Culture.

The laboratory’s equipment covers continuous-wave and pulsed lasers, interferometry, linear and nonlinear spectroscopy, optical time-domain reflectometry and optical tweeze, to name only a few. The corresponding research techniques were made available with respect to their educational value and designed by ASP’s senior scientists and academic tutors. They are fully operated by students. Currently, the photonics training laboratory is systematically incorporated into the doctoral program to enable candidates to efficiently utilize a broad spectrum of experimental methods when carrying out their research projects. This strong commitment of allowing a maximum of hands-on experience during beginning-stage studies is clearly a distinguishing feature of ASP teaching, as compared to other educational institutions. Moreover, to support our graduate students in their experimental abilities to independently analyze and solve challenges in optics and photonics, they are granted from the beginning of their training full access to ACP laboratories with their respective research equipment.

PURSUING THE PHOTONICS CAREER

ASP prepares its graduate students for a successful start in their professional careers. For example, in cooperation with the Faculty of Physics and Astronomy, ASP organizes an annual job fair, particularly for natural science researchers. Among these are many prospective graduates in photonics. Here, graduate students are brought into direct personal contact with our local industry partners, many of them specialized in applicational fields. This local job fair provides a setting for the efficient matching of career opportunities and expectations. Furthermore, by means of career-mentoring workshops with scientists and representatives from various businesses, students receive valuable orientation and advice. They can thus better ready themselves for a world market full of opportunity.
The Master’s degree programs of the Abbe School of Photonics (ASP) are the key educational activities within the Abbe Center of Photonics. Their purpose is to train students in the optical sciences via a broad array of courses and hands-on seminars. The programs are designed to provide opportunities for students to attain the necessary skills required to fill today’s challenging positions in industry and academia.

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

In addition, ASP’s Master in Science in Photonics program (M.Sc. Photonics) offers an internationally-recognized graduate degree providing multidisciplinary coverage in the fields of optics and photonics. This program incorporates upstream scientific aspects in the engineering field along with relevant and important business courses. Students enrolled in this two-year graduate photonics program – featuring lectures and courses exclusively in the English language – are trained for technical or scientific positions in both industry and academia. While approximately 80% of our graduate students successfully finishing the program continue on the academic track and accept PhD positions at top-ranking universities worldwide, other alumni often find suitable job positions in the optical industry, many being located in Jena and throughout Germany.

Starting in autumn 2016, and under the lead of the University’s Center of Medical Optics and Photonics (CeMOP), a new Master’s degree program in medical photonics will be launched. This degree program (M.Sc. Medical Photonics) is aimed at Bachelor’s degree students of medicine, biology, chemistry and physics. Its curriculum is designed to join these varying disciplines into a group which performs photonics research in the area of applied medicine. The teaching staff will support their interdisciplinary learning endeavors starting at the basic courses – thus helping them to understand the specific language jargon and different ways of thinking.

**B.Sc. in Phys. / Chem. / Eng. / Math.**

### ADJUSTMENT
- 16 ECTS
  - Fundamentals of Modern Optics, Structure of Matter
  - Condensed-Matter Physics

### FUNDAMENTALS
- 22 ECTS
  - Optical Metrology, Sensing, Modeling and Design
  - Laser Physics, Experimental Optics

### SPECIALIZATION
- 24 ECTS
  - Computational Photonics, Micro/Nanotechnology, Nanobiophotonics, Image Processing, Nonlinear Optics, Nanomaterials, Optoelectronics, Photodetectors, Biophotonics, etc.

### INTERNSHIP
- 10 ECTS
  - Practical Training in Photonics Industry

### RESEARCH
- 18 ECTS
  - Optical Training in Advanced Research Labs

### MASTER’S THESIS
- 30 ECTS
  - Research Thesis in University Laboratories, Industry Research Departments, Fraunhofer Institute for Applied Optics and Precision Engineering (IOF), Leibniz Institute of Photonic Technology (IFPT) and Helmholtz Institute Jena (HIJ)

**MSc. in Photonics** 4 semesters & 120 ECTS

**ASP Trainings**
- Short courses, guest lectures, intellectual property science management

**ASP Tutor System**
- Individual student guiding and counseling

**Language Courses**
- German, English

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**STUDYING OPTICAL SCIENCES IN JENA**

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

Since 2009, an annual average of 45 students has been accepted into the M.Sc. Photonics Program. These student numbers, with respect to their countries of origin, are displayed in the world map. Since 2009, a total of individually selected 297 graduate students from 48 countries have been enrolled at ASP. Interestingly, almost 90% of these students are of foreign nationality. This fact alone fulfills one of ASP’s central goals and philosophies - to locally establish an international educational program.

**SYSTEMATIC MENTORING SUPPORT**

Particularly at the start of all programs, graduate students receive dedicated academic and wide-ranging administrative and mentoring support. The ASP mentoring program involves experienced Master’s degree students, doctoral students, and qualified young post-doc scientists. These mentors have the responsibility of coaching and supervising Master’s degree freshmen, helping them get used to their new environment and to other fellow students. The mentors act as contact persons for each individual Master’s degree student with regard to all questions that may arise.
The Abbe School of Photonics (ASP) is strongly committed to the advancement of highly qualified students and their promotion to early-stage researchers. Our doctoral program strongly supports the development of individual science careers in optics and photonics, provides professional and practical course opportunities and contributes to individual soft skills development.

In Jena, the roots for an exceptional scientific community specializing in optics and photonics were laid by the breakthrough work of Ernst Abbe in the late 19th century. Because of this unique historical background and throughout the decades, the numerous doctoral students who have graduated from Friedrich-Schiller University were the inconspicuous but indispensable contributors to the advancement of knowledge in optics and photonics in Jena. Incorporating this rich tradition, the doctoral program of ASP (comparable with a PhD program in the USA) has become firmly institutionalized and sustainably structures the education and interconnection of young academics in optics. Since its start in 2009, ASP’s doctoral program has been denoted by a constantly growing number of doctoral students pursuing research topics in optics and photonics at the University, reflecting the successful acquisition of numerous funding for light sciences research provided by scientists of the Abbe Center of Photonics (ACP) in recent years. In October 2015, 153 doctoral students (among them 51 women) have taken the opportunity to officially register in the ASP doctoral program. While a majority of the students who join the ASP doctoral program have a physics background, also chemists, biologists, and mathemati-
for many of such projects, to strengthen the aspects of doctoral education along with individual research, funded by public organizations as well as industrial partners.

ACP’s principal scientists serve as topical supervisors for ASP doctoral students. The acquisition of new outstanding doctoral students is facilitated by choosing among the most excellent alumni of M.Sc. Physics and M.Sc. Photonics from Jena as well as hundreds of external applications, which we receive each year from students from the entire world. To attract the best candidates to the program, a modern online application system was established. Currently, a share of 32% of ASP doctoral students are of foreign origin, with solid trends for a middle-term increase. Emphasizing its strong engagement in the further internationalization of studies, ASP is dedicated to this important primary aim of the institutional strategy of the Friedrich Schiller University Jena.

that this philosophy translates into a timely advancement in self-reliance and individual responsibility of our students, which is essential for the development of their individual scientific careers at higher levels.

To further promote the ASP doctoral students’ scientific skills, participation in international conferences and presentation of their own contributions is encouraged and enabled, whenever possible. In the early stage of the doctoral phase, ASP students can realize their individual professional and personality-forming experiences on international platforms such as, in particular, scientific conferences. Further opportunities to connect with global science communities are offered locally by ASP guest professors. Besides the topical input which doctoral students obtain by attending the special lectures of the more than 40 guest professors thus far, these distinguished scientists are available for face-to-face discussions here in Jena, to share their perspectives and expertise directly with the doctoral students.

Both opportunities and particular challenges for the doctoral candidates are gained through the interfaculty ASP seminar. At topical sessions in international conference style, which take place at least three times each semester, several doctoral students present their research to a larger audience encompassing doctoral students, ASP supervisors, and interested guests. The talks are completely given in English. This scheme offers an ideal platform for the students to receive concentrated constructive feedback from fellow students and professors, to possibly shift the student’s perspective on their work disclosing formerly disregarded aspects, and to prepare for competitive, demanding on-stage performances as young academics.

Finally in 2011, ASP doctoral students’ own initiative has led to the advent of a fully self-organized but professional conference series on optical concepts called DoDok. It is the purpose of DoDok to bring together young researchers from all disciplines of photonics to create networks, stimulate discussions, exchange methodological skills and share fundamental understanding. As a conference from students and for students, DoDok tries to harness the creative power of young researchers, giving them the chance to present and discuss their ideas in a motivating yet relaxed setting. Meanwhile in its fourth edition, DoDok has become well established and ultimately a permanent part of ACP’s doctoral program. As a cornerstone of ASP’s doctoral students’ networking, it is handed over as an organizational event from one generation to the next. The 4th and latest edition of DoDok took place in October 2015 in Eisenach. On average, more than 60 young researchers and industry professionals attended DoDok every year, the majority of them affiliated with ASP but many of them also from all over Germany and abroad. Moreover, the organizational committee has proven to be able – now four times in a row – to acquire reputable international keynote speakers as well as to attract considerable funding from the photonics industry. In exchange, the industry representatives get the chance to approach their high-potential employees of the future in a very informal atmosphere.

Building Personality Beyond Science

Besides the development of high-standard scientific profiles, the ASP doctoral program supplies a sophisticated combination of scientific exchange and teaching of required skills. In particular transferrable skills, which are essential both for scientific and industrial careers. Combining complementary focus, ASP in close collaboration with the Graduate Academy Jena of the Friedrich Schiller University offers a dense annual seminar schedule covering, among other aspects, transferable skills such as scientific presentations, career prospects, entrepreneurship and patent law, creativity, extramural funding, or gender topics. Additional methodological courses are organized by the ACP principal scientists, like e.g. the largely embraced courses on optical design given by Herbert Gross. Moreover, vivid participation of ASP doctoral students in partner workshops and seminars is actively promoted. Numerous opportunities are available through the regular seminars of the Leibniz Institute of Photonic Technology and the Helmholtz Institute Jena.
The future of optics and photonics will depend on highly skilled scientists. Hence, the Abbe School of Photonics (ASP) provides a full-scale program for young researchers to develop their scientific knowledge and abilities. Furthermore, ASP offers wide career opportunities to first-class young scientists, who will most likely lead the field in the years to come.

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

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

TUTORS

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

JUNIOR RESEARCH GROUP LEADERS

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

- Dr. Torsten Frosch – Junior Group Leader of Spectroscopic Sensors funded by the Thuringian government
- Dr. Jan Rothhardt – Leader of a Helmholtz Young Investigator Group on Soft X-ray spectroscopy and microscopy funded by the Helmholtz Association
- Dr. Isabelle Staude – Junior Group Leader of Functional Nanophotonic Materials funded by the Thuringian government within its ProExcellence initiative
- Dr. Adriana Szeghalmi – DFG-funded Emmy-Noether Junior Group Leader of Atomic Layer Deposition
- PD Dr. Ulve Zeitner – Junior Group Leader of Carbon Optic Technologies funded by the German Federal Ministry of Education and Research in the Centre for Innovation Competence «ultra optics»

JUNIOR PROFESSORS

The flagship program to support young scientists who have already shown great distinction in their academic development is the Junior Professorship. This career track is exclusively for those who can be entrusted with full academic rights to pave their predetermined way into a permanent position in science. ASP attracts exceptional young scientists to a career in Jena, at an early stage. Since 2010, already five Junior Professors in optics and photonics have become tenured and are involved in teaching within ASP, while two others have gained permanent positions at other universities. Junior Professors have the status of principal scientists within ACP. Currently, four young scientists are such Junior Professors, receiving funding from different external sources:

- Jun. Prof. Dr. Delia Brauer – group leader of Structure-Property Relationships in glasses funded by the Carl Zeiss Foundation
- Jun. Prof. Dr. Adrian N. Pfeiffer - group leader of Attosecond Laser Physics funded by the Carl Zeiss Foundation
- Jun. Prof. Dr. Alexander Schiller – group leader of Biomimetic Signal Transduction funded within a Heisenberg scholarship of the DFG
- Jun. Prof. Dr. Alexander Szameit – group leader of Diamond-Carbon-Based Optical Systems funded by the German Federal Ministry of Education and Research in the Centre for Innovation Competence «ultra optics»

Another junior professorship for coherent EUV and x-ray sources, funded by the Carl Zeiss foundation, is currently open and within the appointment process.

A FEMTOSECOND LASER EXPERIMENT IS SUPERVISED BY JUNIOR PROFESSOR DR. ALEXANDER SZAMEIT.

STEERING THE DYNAMICS OF SUGAR MOLECULES IS A SPECIAL DISCIPLINE OF JUNIOR PROFESSOR DR. ALEXANDER SCHILLER.
GUEST PROFESSORSHIP PROGRAM

The Abbe School of Photonics acquires international first-hand teaching experience by inviting internationally renowned experts in optics and photonics to lecture for a period up to three months here in Jena. The program has been established to provide our students with an overview of top-level research and to offer leading researchers the opportunity to share their work through direct contact with ACP members. The successful ASP Guest Professorship Program (including the prestigious Carl Zeiss guest professorship) has become a truly international brand. To date, ACP principal scientists and their students have benefitted from special lectures held by more than 40 distinguished experts from all over the world. Both principal scientists and students have strongly contributed to the educational values of ASP on several levels, a contribution, which is going to be continued. First, many ASP guest professors give regular lectures within the M.Sc. Photonics program. Second, they share their perspective and experience and their cosmopolitan background in science, ASP visiting scholars regularly offer valuable feedback on our curriculum based on their personal perspectives. Some of these impressions are given here.

PROF. MARTIN C. RICHARDSON
UNIVERSITY OF CENTRAL FLORIDA
ORLANDO, FLORIDA, USA

“The M.Sc. Photonics program at the Abbe School of Photonics at the Friedrich Schiller University in Jena is in my opinion the strongest anywhere, and serves best the interests of the surrounding laser and photonics industries. Part of the reason for the program’s success is the strong involvement of the local industries, which provide opportunities for internships and of course employment opportunities for many of its students.”

PROF. JAVIER AIZPURUA
UNIVERSITY OF THE BASQUE COUNTRY
ST. SEBASTIAN, SPAIN

“My stay in Jena at the Abbe School of Photonics (ACP) has been a really enlightening one. It is really encouraging to be immersed in an atmosphere of cooperation and collaboration within optics, being exposed to a multidisciplinary effort that covers aspects of biochemistry, optical signaling, image formation, or chemical physics, at a very high level. It has been a privilege to visit this pole of optics.”

PROF. N. ASGER MORTENSEN
TECHNICAL UNIVERSITY OF DENMARK
LYNGBY, DENMARK

“My stay at the Abbe School of Photonics has been highly rewarding and a truly exciting experience for me. Being invited to spend a sabbatical in the Lichtstadt during the International Year of Light has been a great honour for me! I am leaving Jena with my luggage full of lasting memories and I already anticipate my return for at least shorter visits - hopefully also to see your activities flourish in the new Abbe Center of Photonics building!”

PROF. BENJAMIN EGGLETON
UNIVERSITY OF SYDNEY
AUSTRALIA

“My stay at the Abbe Center of Photonics was very enjoyable and stimulating and a great foundation for future collaboration and partnership. It was wonderful to see the laboratories and facilities in Jena. It is an amazing optics ecosystem and certainly unique.”

PROF. YURI. S. KIVSHAR
AUSTRALIAN NATIONAL UNIVERSITY
CANBERRA, AUSTRALIA

“I visited Jena many times and I believe Jena is a unique town not only as a special place for history of optics in Germany and the world, but also as a home for rapidly developing modern research in photonics that unifies all aspects of research from theory and experiment to technology. I believe the Abbe Center of Photonics has the largest number of enthusiastic young researchers I ever met, who will definitely drive its bright future!”

PROF. FEDERICO CAPASSO
HARVARD SCHOOL OF ENGINEERING & APPLIED SCIENCE
CAMBRIDGE, MASSACHUSETTS, USA

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

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

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

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

NANO OPTICS

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

State-of-the-art nanofabrication technologies allow for the realization of optical structures with sub-wavelength and sub-micron dimensions. These structures can be either tiny photonic components, such as, e.g., waveguide bends, apertures, microdisks, and nanotennas, or they can exhibit periodic arrangements as e.g., diffraction gratings, photonic fibers, artificial crystals and metamaterials. In close collaboration between theory, technology, and experiments, fundamental effects of nanostructures are designed, modeled and characterized with the aim of realizing and using optical systems with new functionality.

Examples of recent research activities of ACP’s scientists targeted the strong coupling of plasmonic nanoantennas to quantum systems, the use of nanostructures to enhance the efficiency of solar cells, the light-induced self-organization of photonic nanostructures, the synthesis of nano-scaled multiphoton light sources, or the generation and control of diffractionless plasmonic beams, just to mention a few.

LASER PHYSICS

Together with the global photonics community, ACP’s principal scientists celebrated the 50th anniversary of the invention of the laser in 2010. Based on the quantum-mechanical effect of stimulated emission, which was postulated by Albert Einstein in 1917, the laser has enabled a number of seminal discoveries in modern science over the last decades. Moreover, a considerable market for laser devices has been developed, which is revolutionizing industrial production and has broad impact on our daily life.
ULTRA OPTICS research area Laser Physics covers activities ranging from the development of lasers able to create extreme intensities (>10²⁰ W/cm²) or ultra-high average powers (above the kW barrier). It includes the control of laser radiation at ultrafast time scales as well as theoretical and experimental studies on light-matter interactions under extreme conditions and in novel structures. The research programs run by ULTRA OPTICS result in the invention and implementation of innovative light sources. These novel sources of light are at the same time highly integrated by the use of novel multifunctional components, as they offer some truly remarkable parameters along with flexible properties tailored to applications’ needs. However, ACP’s research is not limited to light sources – it also comprises the fundamental exploration of light-matter interaction, which can be accessed by them. The final aim is to develop new schemes for spectroscopic measurements, material processing, medical treatment, remote sensing, as well as to study the spatio-temporal dynamics of extreme light states.

PHOTONIC MATERIALS

Similar to a car without a steering wheel, light would be of little use without the appropriate means to control it. With the goal of realizing complex optical systems, ULTRA OPTICS’ expertise comprises a wide range of optical materials, including their processing into sophisticated geometric shapes, thin films, or nanostructures, as well as their combination, tailoring, and integration. Moreover, ULTRA OPTICS runs extensive research programs to set new trends in innovative Photonic Materials. In addition to the currently dominant silicon-based optics, ULTRA OPTICS establishes organic and inorganic carbon-based photonic materials, as well as hybrid photonic nanomaterials. These newly emerging material platforms prospectively enable us to realize entirely novel optical, optoelectronic and mechanical properties. Among them are regimes which are unparalleled by natural materials and accordingly of fundamental interest - but must also be specifically tailored to application needs.

With research on carbon-based optics, such as diamond, carbon nanotubes and graphene, ULTRA OPTICS enters an intensely risky area, which exists at the beginning of its development, but to which a high potential for innovation is attributed. Another class of matter, by which ULTRA OPTICS expects to provide a fundamental perspective shift to the field of optics, is constituted by photonic nanomaterials. Their optical properties are rather determined by sophisticated nanostructures than by the original constituents of which these structures are composed. Hence, photonic nanomaterial’s properties can be widely tailored to cover a wide range by changing the geometrical topographies at the nanoscale level. Consequently, they can access parameter ranges unavailable by existing materials so far. As an example, ACP’s researchers have recently realized optical metamaterials which exceed the optical activity of any other available matter by several orders of magnitude. Technologies to fabricate these materials range from sophisticated and high-resolution lithographic tools to approaches involving lithographically controlled chemical synthesis, which is only possible by the interdisciplinary collaborations between ACP principal scientists.

OPTICAL SYSTEMS

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

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GENERATION OF A VIRTUAL 3D IMAGE BY AN IN-HOUSE DEVELOPED, PRECISE AND EXTREMELY FAST 3D SENSOR TECHNIQUE.

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

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The interaction of matter, ranging from atoms to solids, with laser fields stronger than \(1 \text{TW/cm}^2\), has opened new opportunities in atomic, molecular and optical physics. In the early years of nonlinear optics, when strong lasers became available, laser-matter interaction could be successfully described by assuming the laser field as a perturbation, where e.g. low order harmonic generation and parametric processes were manifested. With the development of more powerful lasers, experimentation could reveal new phenomena. To explain these results, new theoretical approaches were necessary. Due to the now accessible strong field regime, the laser field strength becomes comparable to the binding field strength in an atom, thus making the perturbative description obsolete. Consequently, our physical intuition concerning optical phenomena built upon perturbative approaches needs to be re-examined. Furthermore, in order to adequately study such phenomena, more powerful lasers, as well as alternative theoretical methods, are necessary.

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

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

**ULTRAHIGH PEAK POWER LASERS**

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

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

**Nonlinear & Relativistic Laser Physics**

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

**X-ray Optics**

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

**Worldwide Strong Field Physics Collaborations**

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

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KEY RESEARCH AREA
BIOPHOTONICS
KEY RESEARCH AREA
BIOPHOTONICS

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

RECOGNIZING DISEASES AT THE MOLECULAR LEVEL

From a global perspective, BIOPHOTONICS has already provided major innovations for biomedical research and clinical routine. In biomedical research, the recent development of ultrahigh resolution microscopy is providing novel insight into the nanoworld. Now processes in living cells and the development of diseases can be studied in greater detail. Spectroscopic and multimodal imaging methods contribute complementary information on cell function and metabolism. These findings help in developing targeted therapies that treat diseases right at their origin – possibly even before manifest symptoms appear.

BIOPHOTONICS research at the Abbe Center of Photonics explores methods that provide deeper insights into complex biological samples of different size, starting from organs via tissue sections, cells, viruses, down to DNA and RNA.

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

AN OPTICAL SETUP BASED ON AN ULTRASHORT LASER PULSE SOURCE IS DESIGNED TO EVIDENCE MINUTE TRACES OF BIOLOGICAL TISSUE IN REAL TIME.

In combination with the Novel Spectroscopic Techniques, such biosensing technologies are utilized for the highly sensitive and selective detection of biomarkers and pathogens from biological samples, like tissue sections or bodily fluids. The target molecules indicate specific biological states, e.g. diseases like cancer or sepsis. An important task is the provision of suitable labels, i.e. of molecules that specifically couple to the target molecule and thus enable their detection. Especially fluorescence spectroscopy requires these labels, as many biomolecules do not show sufficient autofluorescence, but also Raman spectroscopy can benefit from the use of labels, like e.g. in surface-enhanced Raman spectroscopy (SERS). The applied techniques in BIOPHOTONICS hold great promise to reveal correlations between the metabolic state of cells with the pathophysiological state of tissues.

PROVIDING LIGHT-BASED TOOLS FOR MEDICINE AND THE LIFE SCIENCES

The BIOPHOTONICS research at ACP is based on three complementary fields of technology:

Novel Spectroscopic Techniques, Multimodal Biomedical Imaging & Microscopy, and Chip-based Analytics & Diagnostics. The platform of Novel Spectroscopic Techniques covers, among others, linear and non-linear Raman spectroscopy and fluorescence spectroscopy. By nature, these spectroscopic methods are strongly cross-linked with a second enabling technology field, namely that of Multimodal Biomedical Imaging & Microscopy. Biomedical imaging delivers spatially and temporally resolved information on the distribution of biomolecules in living cells or their environment (molecular imaging). Promising solutions include far-field and wide-field techniques of super-resolution microscopy, Raman and fluorescence microscopy as well as optical coherence tomography. Additionally, questions concerning statistical data and image analysis are in the focus. The field of Chip-based Analytics and Diagnostics includes lab-on-a-chip biosensors based on microfluidic and optofluidic technology, miniaturized spectroscopy, and molecular diagnostics.

IN NUTRITIONAL SCIENCES, BIOCHIPS ARE DEVELOPED TO IDENTIFY THE GENETIC FOOTPRINT OF PARTICULAR BACTERIA.

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

NOVEL SPECTROSCOPIC METHODS

LINEAR & NONLINEAR RAMAN AND FLUORESCENCE SPECTROSCOPY; MARKER SCREENING; LABEL DEVELOPMENT.

CHIP-BASED ANALYTICS & DIAGNOSTICS

MOLECULAR AND CELL-BASED APPROACHES; MICROMANIPULATION & SPECTROSCOPY; INKJET/PRINTING.

MULTIMODAL BIOMEDICAL IMAGING & MICROSCOPING

LINEAR AND NONLINEAR RAMAN MICROSCOPY; FLUORESCENCE MICROSCOPY; FAIR-FIELD AND NEAR-FIELD MICROSCOPY WITH HIGH SPATIAL RESOLUTION; OPTICAL COHERENCE TOMOGRAPHY.

BIOCHIPS ARE AN EMERGING, HIGHLY MULTIDISCIPLINARY RESEARCH AREA EMBRACING INNOVATIVE PHOTONIC TOOLS APPLIED TO THE LIFE SCIENCES AND MEDICINE.
RESEARCH DRIVEN BY USERS’ NEEDS

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

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

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HARTMUT BARTELT

PROFESSOR OF MODERN OPTICS AND DEPARTMENT HEAD FOR FIBER OPTICS, INSTITUTE OF PHOTONIC TECHNOLOGY

He is the research department head for Fiber Optics and the deputy director of the Leibniz Institute of Photonic Technology. Prof. Bartelt also serves as head of the board of the Beutenberg Campus Association. He is a member of the board of the German Society of Applied Optics, the head of the Scientific Council of the Technology and Innovation Park TIP in Jena and member of the board of Trustees of the MFPA in Weimar.

RESEARCH AREAS
Prof. Bartelt is engaged in research on the waveguiding properties of optical fibers including microstructured fibers, photonic crystal fibers, micro- and nanotapers, nonlinear and active fiber properties, fiber Bragg gratings, fiber optical applications including fiber sensor components and fiber light sources. He heads three work groups focusing on:

- fiber optical technology (preparation of preforms and specialty optical fibers)
- active fiber modules (laser fibers and supercontinuum generation)
- passive fiber modules (locally structured fibers, Bragg gratings)

TEACHING FIELDS
Prof. Bartelt gives courses and conducts seminars in the areas of:

- micro-optics
- fiber optics

RESEARCH METHODS
Major scientific equipment for the realization and investigation of optical fibers includes:

- MCVD-technology for preform preparation
- fiber drawing towers
- fiber characterization
- UV- and femtosecond laser pulse Bragg grating inscription
- laser and ion beam structuring, lithography

Recent research results
The Fiber Optics Department has been successful in developing new techniques for the preparation of optical preforms with powder and sinter techniques, and with soft non-linear glasses using melting techniques [1]. Special fiber structures have been developed with large-mode area fiber cores and with air-clad structures. The generation of supercontinuum light has been successfully achieved in all-normal-dispersion fibers [2]. Fiber Bragg gratings are prepared during the drawing process of a fiber, providing the possibility of complex grating arrays. Special inscription techniques have been developed which also enable grating inscription in rare-earth doped fibers, in non-UV-photosensitive fibers and in microstructured fibers [3]. Sensor components include fiber micro-interferometers and gratings in high-temperature stable sapphire fibers.

Supercontinuum generation with all-normal-dispersive fibers

The generation of recompressable octave-spanning supercontinuum pulse generation in all-normal dispersion optical fibers has been achieved. This novel concept overcomes several limitations as seen in conventional supercontinuum generations of optical fibers with a zero dispersion point, such as the soliton generation and noise-sensitive soliton decay. The option of all-normal dispersion properties has become possible due to the availability of micro- and nanostructured optical fibers. Such microstructured fibers (e.g. suspended core fibers) provide the option of using dispersion properties well beyond the materially defined dispersion properties of silica. An almost flat spectrum from the near-infrared to the ultra violet was achieved with a single-pulse characteristic.

MICHAEL BAUER

PROFESSOR OF ANESTHESIOLOGY & CRITICAL CARE, DEPARTMENT OF ANESTHESIOLOGY & CRITICAL CARE THERAPY

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

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

• culture-independent pathogen detection (in cooperation with Prof. Popp)
• in vivo visualization of cellular redox state and function(s), such as dye uptake and excretion
• in vivo and in situ monitoring of heme degradation
• plasmonics to describe the host response

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

• fundamentals of oxygen transport, energy metabolism and redox state
• systems biology of sepsis and organ failure

RESEARCH METHODS
The laboratories led by Prof. Bauer offer a full range of molecular biology techniques with special emphasis on transcriptome/array analysis and in vivo microscopy of solid organs, including:

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

RECENT RESEARCH RESULTS
There is widespread agreement that culture-independent detection of pathogen-associated molecular patterns carries the potential to improve infection diagnostics, even for polymicrobial infections which include fastidious, multi-resistant and difficult-to-culture species. Work has been conducted in ways which aimed at a decrease in time in order to bring about a result which could favourably influence decision-making for antiinfective and immunomodulatory therapy in behalf of critically ill septic patients. Together with the Leibniz Institute of Photonic Technology and the biophotonics group headed by Prof. Popp, we have applied, along with molecular techniques, biophotonic strategies to describe the host response continuum from the uncomplicated infection to sepsis and organ failure.


MICRO-RAMAN SPECTROSCOPY TO STUDY HEPATIC METABOLISM AND EXCRETORY FUNCTION

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

PROFESSOR OF BIOMOLECULAR PHOTONICS, JENA UNIVERSITY HOSPITAL

Prof. Biskup is managing director of the Jena Center of Medical Optics and Photonics (CeMOP) and is a member of the board of directors of the Jena Center for Soft Matter (JCSM). He serves as speaker of the interdisciplinary research focus group Optical Investigation of Physiological and Pathophysiological Membrane Processes. Prof. Biskup is editor-in-chief of the journal Medical Photonics.

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RESEARCH AREAS
One of the aims of the Biomolecular Photonics Group is to establish new photonic techniques and to incorporate them into biological research. The focus is to develop and apply new quantitative multidimensional fluorescence microscopy techniques. Research interests include:
• multidimensional fluorescence lifetime imaging
• optical protein-protein and protein-DNA interaction assays
• structure-function relationships of ion channels
• indicators and nanosensors for ions and biomolecules

TEACHING FIELDS
Prof. Biskup is in charge of the newly established course M.Sc. Medical Photonics which will start in winter term 2016. Moreover, he gives lectures and courses in:
• physiology (for students of Pharmacy, Biochemistry/ Molecular Biology, and Nutritional Science)
• microscopic techniques (for students of Medicine, Molecular Medicine and Medical Photonics)
• image processing

RESEARCH METHODS
The laboratories of the Biomolecular Photonics Group offer a wide range of methods used at the interface of physiology, physics and chemistry:
• standard molecular biology techniques, cell culture
• fluorescence and confocal laser scanning microscopy
• fluorescence spectroscopy
• spectrally resolved fluorescence lifetime measurements based on time-correlated single photon counting and streak camera measurements
• patch-clamp fluorometry

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

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

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


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

Professor of Microscopy Methods, Jena University Hospital

Single-molecule spectroscopy and super-resolution fluorescence imaging of membrane proteins are the topics of our Biophysics Group at the Faculty of Medicine. As a Professor of Microscopy Methods, Michael Börsch has applied single-molecule FRET for nearly 20 years to monitor individual biological nano-machines at work. He is an Adjunct Assistant Professor at SUNY Upstate Medical University (NY, USA) and was a visiting scholar at Stanford University from 2012 to 2014, concentrating on single-molecule research with Prof. W. E. Moerner (who won the Nobel Prize in Chemistry in 2014). Prof. Börsch is a member of SPE and of the Biophysical Society.

Research Methods

My group has been operating a Nikon N-SIM / N-STORM super-resolution microscope as a major piece of equipment since 2013. Additional microscopes exist for wide-field and TIRF-imaging of labeled E. coli and yeast cells. We use custom-built confocal microscopes for in vitro single-molecule FRET measurements in solution, equipped with 3D-piezo scanners. Lasers provide continuous-wave excitation at 488 nm, 514 nm, 532 nm, 594 nm, 658 nm and 785 nm. Picosecond-pulsed lasers exist for 405 nm, 488 nm and 635 nm, and a new super-continuum laser covers the spectrum from 450 nm to 2200 nm. TCSPC electronics count photons simultaneously for up to four avalanche photodiodes. Data-acquisition and analysis software was written by our group and includes calculation of fluorescence lifetimes, auto- and cross-correlation functions, anisotropy and FRET efficiencies at arbitrary time intervals, as well as Hidden Markov Models for analysis of sequential dynamics. One microscope is dedicated for single-molecule FRET, in combination with an Anti-Brownian Electrokinetic trap (ABEL trap) setup.

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

Recent Research Results


Research Areas

Our Single-molecule Microscopy Group investigates conformational dynamics of single cellular nano-motors, pumps and receptors, for example the enzyme FoF1-ATP synthase. We attach two dye molecules specifically to subunits of these machines and measure their distances continuously within the single protein using Förster resonance energy transfer (FRET). The distance changes manifest the sequences of conformations during either catalysis or transport. In the DFG Collaborative Research Center Transregio (SFB/TR) 166 titled „High-end microscopy elucidates membrane receptor function“, we study the dynamics of the G-protein-coupled Neurotensin receptor 1. Recently, we started super-resolution microscopy with structured illumination (SIM) and single-molecule localization (STORM/PALM) for the imaging of single bacterial and yeast proteins. Stimulated emission depletion (STED) microscopy will soon complement our high-resolution microscopy work.

Teaching Fields

My areas of teaching include:

- interdisciplinary lectures on proteins, bio-membranes, single-molecule spectroscopy and super-resolution microscopy,
- directing research labs on single-molecule FRET analysis of proteins,
- practical courses on membrane protein purification, protein-labeling and activity measurements, diffusion- and mobility analysis,
- supervising internships and Master’s theses spanning topics from optics to biophysics.
Professor Silvana Botti joined the Friedrich Schiller University Jena in October of 2014, where she is now head of the Condensed Matter Theory Group at the Institute of Condensed Matter Theory and Solid State Optics (ITCO). Prof. Botti is also a member of the Michael Stifel Center Jena for Data-Driven Simulation Science and of the European Theoretical Spectroscopy Facility. She is an editor of the European Physics Journal B.

RESEARCH AREAS
Professor Botti’s work focuses on many-body approaches to describe electronic excitations in complex materials. One example application is the first-principles simulation (i.e. without experimental parameters) of the response of a material to an external perturbation such as incoming electromagnetic radiation or particles. This field of research is now known as “theoretical spectroscopy.” The Condensed Matter Theory Group works at the forefront of theoretical approaches for excited states. Prof. Botti’s recent research activity is devoted mainly to understanding electronic properties of materials for energy applications, with a main focus on photovoltaics, and, in this regard to the design of new material candidates for energy production, storage, and saving purposes. New materials not yet synthesized are found/proposed using ab initio global structural prediction- and high-throughput calculations. The thermodynamically stable compounds are subsequently pre-characterized in silico using the same techniques employed for already known materials.

TEACHING FIELDS
Professor Botti teaches Master’s degree students in the area of solid state physics, nanophysics and materials science. During her first year in Jena, she taught Solid State Physics II and Electronic Structure Theory. The latter course included a practical tutorial which dealt with learning how to run computer codes for electronic properties.

RESEARCH METHODS
The Botti group develops, implements in numerical codes, and applies first-principles methods for research on electronic excitations. Such methods are based on (time-dependent) density functional theory and many-body perturbation theory. The group possesses a computer cluster consisting of 750 cores.

SEARCHING THE PERIODIC TABLE FOR NOVEL SOLIDS
Together with our collaborators in Halle and Basel, we used the ab initio global structural prediction technique combined with high-throughput calculations to explore the periodic table in search of novel oxide phases. In total, we studied 188 different compositions of the form MXO2, where M can be Cu, Ag, or Au and X an element of the periodic table. The choice of this specific set is motivated by the fact that it includes copper delfasite compounds, the best known p-type transparent conductive oxides. Our calculations identified 81 stable compositions, from which only 16 exist in material databases. We then tested these new phases for their applications as p-type transparent conductors by calculating their electronic band gap and hole-effective masses. Promising candidates were proposed for further experimental investigation.

Density functional theory (often together with some ad hoc corrections) has often been applied when studying excited state properties of materials, despite the fact that the theory was originally designed to determine only ground state properties.

In this context, Prof. Botti’s group has developed new approximations beyond standard density functional theory, using state-of-the-art approaches for excited states to clarify contradictory experimental and theoretical findings. Thanks to the valuable input of experimental collaborations, the obtained results have already succeeded in solving various long-standing issues about the physical laws governing the electronic properties of materials. Such materials can be, for instance, absorbers for thin-film solar cells, nanostructures for optoelectronics or catalysis, amorphous-crystalline phase change materials for data storage, graphite under pressure, p-doped zinc oxide and delfasites for transparent electrodes, materials for hydrogen storage, layered superconductors, topological insulators.

To provide an example of high-result quality, the following figure shows the optical absorption spectra of a copper indium diselenide thin-film which is used as an absorber in the photovoltaic industry. The absorption spectra, calculated using two approximations (labeled RPA and BSE) for different light polarizations, are in excellent agreement with the measured spectra.

[FIGURE FROM KOEBBEL ET. AL., PHYS. REV. B 91, 075134 (2015)]

[FIGURE FROM CERQUEIRA ET. AL., CHEM. MATER. 27, 462 (2015)]
AXEL BRAKHAGE

PROFESSOR OF MICROBIOLOGY AND MOLECULAR BIOLOGY, INSTITUTE OF MICROBIOLOGY

Axel Brakhage is the scientific director of the Leibniz Institute for Natural Product Research and Infection Biology (HKI) and head of the department of Molecular and Applied Microbiology. Since 2004 he has held a Chair of Microbiology and Molecular Biology at the Institute of Microbiology. He serves as the speaker on the Panel of Microbiology, Immunology and Virology of the German Research Foundation (DFG). Additionally, he is the coordinator of the Excellence Graduate School „Jena School for Microbial Communication“ (JSMC) and member of the board of the Center for Innovation Competence Septomics. He is an elected member of the National Academy of Sciences Leopoldina. He has been coordinating several Leibniz, EU and DFG programs and is currently member of several advisory boards.

TEACHING FIELDS
Prof. Brakhage’s teaching is devoted to the early involvement of young scientists in research, as well as to the education of postgraduates. He gives courses in:
- applied microbiology and molecular biology
- molecular biotechnology/ infection biology of lower eucaryotes

RESEARCH METHODS
The laboratory led by Prof. Brakhage offers methods for the characterization of immune effector cells, the molecular biology of fungi, biochemistry and biotechnology:
- 2D-gel electrophoresis and MALDI-TOF/TOF mass spectrometry, proteomics
- fluorescence and confocal laser scanning microscopy
- plasmon resonance spectroscopy
- murine infection models, isolation of compounds, transcriptome analyses

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

HOST IMMUNE EVASION TACTICS OF PATHOGENIC FUNGI
Human pathogenic microorganisms have evolved a multitude of highly different immune evasion strategies for establishing their pathogenic lifestyle inside the host. The pathogen mimics or alters host structures, thereby preventing or at least diminishing the host structure’s immune response. Professional phagocytes are especially the target of manipulation by invading microorganisms. For example, facultative intracellular bacteria are able to prevent degradation after ingestion by phagocytes. By reprogramming the host endocytic pathway, the bacteria inhibit the formation of a hostile phagolysosome and thereby generate a compartment in which the pathogen not only survives but also replicates itself until it is released. However, only little is known about how filamentous fungi avoid intracellular killing by phagocytes. Aspergillus fumigatus represents an important airborne fungal pathogen: it is the primary causative agent of invasive aspergillosis in immunocompromised patients. In lung alveoli, resident alveolar macrophages represent the first line of defense against inhaled conidia. We could show that, depending on dihydroxynaphthalene (DHN)-melanin, the grey green conidial pigment, A. fumigatus prevents acidification of phagolysosomes. By inhibiting the proton pump, the fungus is able to prevent the formation of a hostile phagolysosome and thereby maintain a survival niche inside the host cell. Furthermore, we also discovered that A. fumigatus induces the formation of a hostile phagolysosome that is located on spores [1,2]. His group has been working on eukaryotic transcription factors with emphasis on those regulating the biosynthesis of fungal secondary metabolites, many of them being important drugs [3]. His group was involved in the first activation of silent gene clusters in fungi using genetic engineering, leading to the production of novel compounds. During this work it was shown that fungal silent gene clusters were induced by microbial communication, i.e. triggered by a specific bacterium [4]. Mechanistically, fungal histone modification systems (epigenetics) were reprogrammed, leading to the specific activation of gene clusters [5]. Taken together, this work has opened up the possibilities for further investigation of these thus far untapped reservoirs for drug development purposes. This research also contributes to the understanding of how microorganisms communicate with each other. The group has also been applying methods of functional genome analysis such as proteome and transcriptome analyses.

Recent research results


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Recent research results

Axel Brakhage’s group has been investigating the pathobiology of the human-pathogenic fungus Aspergillus fumigatus for which the first pathogenicity determinant, dihydroxynaphthalene melanin, was discovered. This determinant has major effects on the intracellular processing and apoptosis of human immune effector cells. During this work, it was also discovered that A. fumigatus induces the formation of neutrophil extracellular traps and that, in general, the immune system is silenced by the hydrophobin layer located on spores [1,2]. His group has been working on eukaryotic transcription factors with emphasis on those regulating the biosynthesis of fungal secondary metabolites, many of them being important drugs [3].

His group was involved in the first activation of silent gene clusters in fungi using genetic engineering, leading to the production of novel compounds. During this work it was shown that fungal silent gene clusters were induced by microbial communication, i.e. triggered by a specific bacterium [4]. Mechanistically, fungal histone modification systems (epigenetics) were reprogrammed, leading to the specific activation of gene clusters [5]. Taken together, this work has opened up the possibilities for further investigation of these thus far untapped reservoirs for drug development purposes. This research also contributes to the understanding of how microorganisms communicate with each other. The group has also been applying methods of functional genome analysis such as proteome and transcriptome analyses.

References

**DELIA BRAUER**

**JUNIOR PROFESSOR OF NEW INNOVATIVE MATERIALS FOR PHOTONIC TECHNOLOGIES, OTTO SCHOTT INSTITUTE OF MATERIALS RESEARCH**

Delia Brauer holds a junior professorship position funded by the Carl Zeiss Foundation (2012-2016). She is also a member of the Jena Center for Microbial Communication (JCMC), the Technical Committee 04 (Glasses as Biomaterials) of the International Commission on Glass (ICG) and the Basic Sciences and Technology Committee of the Society of Glass Technology, UK. In 2015, she was awarded the Gottardi Prize from the International Commission on Glass (ICG), which is awarded annually to a young person with outstanding achievements in the field of glass in research and development, teaching, writing, management or commerce.

**RESEARCH AREAS**

Professor Brauer’s research focuses on the materials chemistry of silicate and phosphate glasses, with a particular focus on the interaction between glassy materials and water. She is also interested in how glass composition, structure and properties are connected, particularly in glasses having a highly disrupted structure. Current research areas include:

- Improving the hydrolytic stability of phosphate glasses
- Fluoride-containing glasses and glass-ceramics
- Glass-based cement systems
- Bioactive glasses with improved processing

**TEACHING FIELDS**

Prof. Brauer teaches materials science students at the Bachelor’s and Master’s degree levels. Her courses include:

- Inorganic Chemistry for Materials Scientists
- Glass Structure
- Ceramics in Medicine

**RESEARCH METHODS**

- Glass synthesis using high temperature melt-quench and sol-gel techniques
- Glass thermal properties and crystallisation
- Solid-state nuclear magnetic resonance spectroscopy
- Ion release from glasses and dissolution of glasses

**RECENT RESEARCH RESULTS**

**Glasses as biomaterials**

Some glass compositions have been successfully used as implant materials, e.g. to regenerate bone. The most well-known compositions, commonly referred to as “bioactive glasses” are (phospho)silicate glasses with large contents of modifiers, such as sodium and calcium oxide. They can be used clinically to regenerate bone and to release therapeutic ions. Prof. Brauer’s group investigates how glass structure controls ion release, dissolution and crystallisation, and how a structure-based glass design allows for optimisation of properties. Some recent results have included the characterisation of fluoride-containing bioactive glasses for use in dentinics and the influence of proteins or pH on mineralisation. Because of their predominant amount of modifier contents, these glasses exhibit a pronounced tendency to crystallize, which makes processing (e.g. fibre drawing or sintering) difficult. Other results show how the processing of bioactive glasses can be improved without compromising their bioactivity. Other glasses that react with aqueous solutions and are investigated as biomaterials, are phosphate glasses (see figure 1), or glasses for use in glass ionomer cements [see figure 2].


**Fluoride-containing glasses and glass ceramics**

In recent years, rare earth-doped fluoride crystals within an aluminosilicate glass matrix have gained increasing interest, as they combine the benefits of fluoride crystals (e.g. low phonon energy) with the thermal and chemical stability of aluminosilicate glasses. Most of these glasses, however, have extremely high melting temperatures (around 1600°C), which is a technological disadvantage. Therefore, one current research project focuses on designing rare earth-doped fluorino-aluminosilicate glasses having lower melting temperatures and characterising their crystallisation behaviour.

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**SOFTWARE**

- Phosphorus NMR on aqueous solutions after early stages of dissolution (Döhler et al., J. Mater. Chem. B 3, 1125 (2015)).

**CHARACTERISATION OF PHOSPHATE GLASS DISSOLUTION BY SOLUTION NMR**

The high refractive indices and low dispersion of phosphate glasses make them interesting for optical uses, but their poor durability in the presence of water limits their usefulness. On the other hand, their ability to react with water may be applied for biomedical applications. So far, there are still many unanswered questions as to their dissolution mechanism – and a thorough understanding of how phosphate glasses dissolve is key for developing chemically stable glasses or glasses with a controlled solubility. Recent preliminary studies in Prof. Brauer’s group combined the use of solid-state $^{31}$P NMR on the glasses before dissolution with solution $^{31}$P NMR on aqueous solutions after immersion of the glasses. Results showed that, in contrast to existing literature, glasses do show congruent dissolution of phosphate chains but they also include P-O-P hydrolysis at early stages of dissolution (Döhler et al., J. Mater. Chem. B 3, 1125 (2015)).

**FIGURE 1** Left-hand side: Phase separation in an untreated aluminosilicate glass. Two subfigures on the right-hand side: Barium gadolinium fluoride crystals after heat treatment of an aluminosilicate glass.

**FIGURE 2** Left-hand side: $^{31}$P NMR spectra showing changes in the relative concentration of structural (Q) groups in solution during phosphate glass dissolution. Right-hand side: Connectivity between phosphate groups after dissolution [X-AXIS OF BOTH SUBFIGURES: CHEMICAL SHIFT (PPM)].
PROFESSOR OF NANOSCALE STRUCTURAL INVESTIGATIONS OF BIOLOGICAL AND BIOMEDICAL SYSTEMS, INSTITUTE OF PHYSICAL CHEMISTRY

Professor Deckert holds a joint position at the Institute of Physical Chemistry and the Leibniz Institute of Photonic Technology where he heads the Nanoscopy Department. His main research field deals with investigations of structures within the nanometer range. In 2012, he was appointed as a Fellow of the Society of Applied Spectroscopy for his achievements in high-resolution spectroscopy.

RESEARCH AREAS

Dr. Deckert uses the specific properties of nanoscale metallic structures to investigate structural properties of molecules at the highest possible spatial resolution.

Research interests include:

- near-field optics
- electromagnetic and chemical interactions on the nanometer scale
- Raman spectroscopy
- structural investigation of proteins and protein aggregations
- membrane-protein interaction
- single-site catalysis

TEACHING FIELDS

Prof. Deckert is involved in the teaching of general physical chemistry and gives courses on scanning probe microscopy.

RESEARCH METHODS

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

- tip-enhanced Raman scattering (TERS) microscopy
- force distance spectroscopy
- fabrication of thin layers (evaporation/sputtering/ALD)
- cell culture laboratory
- AFM-coupled transient absorption spectroscopy

RECENT RESEARCH RESULTS

Based on spectroscopic results related to single DNA strands, the group was able to attain a contrast of amino acids to within a few nanometers using tip-enhanced Raman scattering (TERS). By moving a plasmonic nanoparticle in a step-like fashion with a step size of a mere 0.5 nm over fibril polymorphs and protofibrils, the increase and decrease of specific amino acids, and even more importantly, the relative abundance of α-helix and β-sheet secondary structure on the actual surface was detected. This is in contrast to normal spectroscopy where the whole system provides only an average response. In this case, not only single amino acid propensities but also the secondary structure of specific surface locations on the protein fibrils could be identified, and structural variations along a single fibril were evaluated. Consequently, this provides a method of following protein aggregation for instance in Alzheimer’s disease, Diabetes mellitus or other prion-related diseases [1, 2].

Another field of interest has been the investigation of chemical reactivity on a nanometer scale. In particular, plasmon-mediated reactions and their specific reaction mechanisms have been investigated. A quite unexpected and to date unknown reaction was the plasmon-mediated protonation of a pyridine analogue under ambient conditions. Temperature dependent experiments under controlled atmosphere conditions revealed a clear dependency on plasmonic conditions rather than on laser power and temperature related effects. Similarly, the reaction mechanism of the plasmon induced dimerization of nitrothiophenol was investigated under low concentration conditions. For the first time, reaction dynamics on a single molecule level was demonstrated by using a step-like concentration change [3, 4].

Finally, the group is involved in further investigations regarding the implementation of extremely high lateral resolution. The investigation of signal fluctuations of homogeneous monolayers with tip-enhanced Raman scattering (TERS) and surface enhanced Raman scattering (SERS) has indicated that the sample volume addressed by TERS is so small that averaging effects that lead to a band broadening are significantly less pronounced. The findings are in line with previous sub-nm resolution experiments on protein crystals [5].

REFERENCES


NANOSCALE REACTIVITY AND DETECTION CAPABILITIES

p-Nitrothiophenol, when immobilized on an atomically flat and still optically transparent gold crystal, forms a uniform and stable monolayer. This can be verified by TERS using red excitation (633 nm) that at powers below 1 mW of this wavelength, even in the presence of silver particles, cannot induce a chemical reaction. Irradiation at 532 nm in the presence of a silver nanoparticle, however, induces a photocatalytic reaction, namely a reduction to a diazo compound. This can again be verified using a probe of 633 nm excitation. As different experiments have demonstrated, an extremely high lateral resolution of the method, the technique can be used to investigate reactions even on a single molecule level.
BENJAMIN DIETZEK

PROFESSOR OF PHYSICAL CHEMISTRY, INSTITUTE OF PHYSICAL CHEMISTRY AND INSTITUTE OF PHOTONIC TECHNOLOGY

Benjamin Dietzek is professor of Physical Chemistry and head of the research department Functional Interfaces at the Leibniz Institute of Photonic Technology. He is a member of the executive board of the Abbe School of Photonics. He chairs the COST Action CM1202 Perspective: H₂O – Supramolecular Photocatalytic Water Splitting. His research was awarded with the Thuringer Forschungspreis for Angewandte Forschung in 2013.

RESEARCH AREAS

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

- electron transfer reactions in molecules in solution and in moleculeBulk interfaces
- photoinduced processes in molecular sensors
- photochemistry underlying molecular photocatalytic water splitting
- developing experimental tools to characterize structural and electronic intermediates in (photo)catalytic cycles and the impact of local environment on the photophysics of molecules

TEACHING FIELDS

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

- Physical Chemistry
- Molecular Spectroscopy

RESEARCH METHODS

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

- ultrafast time-resolved pump-probe spectroscopy
- time-resolved luminescence spectroscopy
- resonance-Raman spectroelectrochemistry
- time-resolved characterization of molecular chirality
- ultrafast pump-probe microscopy

RECENT RESEARCH RESULTS

The group has been working on understanding the molecular mechanisms of self-healing reactions [1]. To this end, particularly (resonance) Raman spectroscopy [2] has been employed to study molecular intermediates during heat-driven self-repair of polymer coatings, in which the reversible interactions required for self-repair of the materials function are provided by coordination bonds between polypyridines and metal ions [3, 4]. In addition, it was shown that two-dimensional correlation analysis of Raman data recorded in situ during temperature treatment of a polymer film can be used to sensitively detect the structural changes in the material associated with reversible bond formation [5].

ELECTRONIC INTERMEDIATES DURING SUPRAMOLECULAR PHOTOCATALYTIC WATER SPLITTING

Recent research was devoted to studying the electronic intermediates in heterodinuclear transition-metal complexes, which serve as homogeneous photocatalysts for the production of molecular hydrogen as an environmentally clean fuel. The work performed in collaboration with the Institute for Inorganic Chemistry I at Ulm University combined ultrafast time-resolved optical pump-probe spectroscopy, with resonance Raman spectroscopy, electrospectrochemistry and in situ X-ray absorption near-edge structure spectroscopy to elucidate the impact of structural variations on the mechanism of charge transfer and of proton reduction. We identified molecular vibrational mode efficiently coupling various excited electronic states and thereby facilitating electron transfer from the photoactive, i.e., light-absorption center of the molecule, to the catalytically active metal center. [Chem. Eur. J. 21, 7668 (2015)]. The identification of such reactive vibrational modes is extremely rare and presents an important step in the mechanistic understanding of the electron transfer pathway. In situ XANES spectroscopy under catalytic conditions has aided the identification of the catalytically active species and has shown that the Pd version of the molecular photocatalysts forms Pd-colloids under catalytic conditions, which is the present the active species. However, exchange of the Pt-ion by Pd leads to a stable molecular photocatalyst [Angew. Chem. Int. Ed. 54, 5044, 2015] the catalytic efficiency of which can be tuned by exchanging the co-ligand structure at the Pt center [Angew. Chem. Int. Ed. 54, 6627, 2015]. Notably, the first ultrafast photoinduced electron transfer (two subsequent light-induced electron transfer processes are required to accumulate a sufficient number of redox equivalents on the catalytically active metal center for hydrogen formation) are only minimally affected by the structural changes of the structural framework of the molecular catalyst. Further insight into the mechanism [Chem. Commun. 50, 5227, 2014] revealed a strong dispersion in the intermolecular charge transfer characteristics upon electrochemical reduction of the molecular bridge connecting the photoactive center of the complex with the catalytically active center.
PRINCIPAL SCIENTIST PROFILES

STEPHAN FRITZSCHE

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

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

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RESEARCH AREAS
Prof. Fritzschke’s research interests deal with the structure and dynamics of finite quantum systems for applications in atomic, optical and nuclear physics. Current research topics are:
- time-dependent multi-photon ionization dynamics in intense FEL radiation
- auto-ionization and Auger cascades of atomic and molecular systems
- light-matter interactions and light scattering in strong Coulomb fields
- the structure and spectroscopy of heavy and radio-active isotopes
- particle beams carrying quantized orbital angular momentum
- parity and time-reversal violating interactions in atoms and ions

TEACHING FIELDS
Prof. Fritzschke’s teaching has as its focus the behavior of correlated quantum systems and includes courses in:
- atomic structure and collision theory
- light-matter interactions in strong and short pulses
- computational quantum physics

RESEARCH METHODS
Various concepts and theoretical techniques are applied by Prof. Fritzschke’s group for studying the structure and light-matter coupling of finite quantum systems, including
- relativistic atomic & many-body theory
- numerical simulation techniques and code development
- time-independent and time-dependent density matrix theory
- computer-algebraic techniques
- concepts and protocols from quantum information theory and quantum state estimation

RECENT RESEARCH RESULTS
In recent years, the atomic density matrix theory has been successfully applied to model the excitation, ionization and recombination dynamics of neutrals and multiple-charged ions, and with applications in nuclear, atomic and plasma physics as well as x-ray science. Emphasis has been especially placed on angular and polarization correlations of emitted photons and electrons in order to explore the relativistic light-matter coupling, both in strong Coulomb and intense light fields. It was shown, for example, that magnetic interactions in the coupling of the radiation field often lead to strong modifications in the emission and scattering of photons by atoms and highly-charged ions [1, 2]. Moreover, many of these photon-atom interactions are enhanced by auto-ionizing resonances due to the excitation of inner-shell electrons [3, 4].

Apart from interaction of atoms with plane-wave photons and electrons, recent interest was placed upon the role of the orbital angular momentum in atomic processes. Today, twisted beams of electrons can be generated quite readily with a kinetic energy of up to a few hundred keV and with topological charges of, say, m = 100. Their unique features make such beams ideal tools for studying the magnetic structure of materials or for improving the resolution in spectroscopy. Indeed, such twisted electrons offer a new and intriguing degree of freedom for different processes, including the radiative recombination [5] or the inverse Compton scattering of laser light on high-energetic twisted electrons [6]. For the latter, we have shown theoretically how tailor-made x-ray beam profiles with a well-defined spatial structure can be generated by suitably chosen states of twisted electrons.


STRUCTURED X-RAY BEAMS FROM TWISTED ELECTRONS BY INVERSE COMPTON SCATTERING

Inverse Compton scattering of laser light on a beam of twisted electrons help generate x-rays with tailor-made spatial intensity distributions. (a) The light from an optical laser is focused by a parabolic mirror and collides head-on (under 180°) with electrons from a twisted beam (blue cone). The photons are mainly backscattered, frequency up-shifted to X-ray energies, and recorded on a CCD screen down-stream of the beam of electrons. Plane-wave laser light is assumed to have an extent in the focal plane much larger than the waist of the electron beam. (b) Definition of coordinates and angles that are used to characterize the propagation of electrons and photons in the Compton scattering (figure from Phys. Rev. A 90, 012118 (2014)).
WOLFGANG FRITZSCHEN

HEAD OF DEPARTMENT OF NANOBIPHOTONICS

PD Dr. Wolfgang Fritzsche is the Head of Department of Nanobiophotonics at the Leibniz Institute of Photonic Technology (IPHT).

RESEARCH AREAS

- molecular plasmonics
- LSPR (localized surface plasmon resonance)-based bioanalytics
- DNA nano- and single metal nanoparticle characterization and manipulation
- micro-nano integration

TEACHING FIELDS

Dr. Fritzsche is involved in teaching Physical Chemistry as well as Instrumental Analytics for pharmacists.

RESEARCH METHODS

- scanning force microscopy
- spectroscopy and fluorimetry
- (imaging) microspectroscopy of (single) plasmonic nanostructures
- synthesis and characterization of nanoparticles (microfluidic and batch, TEM and SEM, DLS and NTA)
- micro-nano integration
- molecular techniques: self-assembly monolayers, biofunctionalization and conjugation of nanoparticles and nanostructures
- nanobiomanipulation (laser-irradiation of plasmonic antennas for manipulation of biomolecules)
- hybrid nanostructures
- sensors: SPR and LSPR (DNA analytics)

RECENT RESEARCH RESULTS

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


FINE-TUNING PLASMONIC RESONANCES

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

**RESEARCH GROUP LEADER OF FIBER SPECTROSCOPIC SENSING**

Dr. Torsten Frosch is the head of the Fiber Spectroscopic Sensing Group at the Leibniz Institute of Photonic Technology and the Institute for Physical Chemistry at the Friedrich Schiller University Jena. He is a member of the DFG Collaborative Research Center (CRC) 1076 AquaDiva, the Jena Center for Microbial Communication and the International Max Planck Research School for Global Biogeochemical Cycles in Jena. He was awarded the PhD thesis price in chemistry from the Friedrich Schiller University and the STIFT award. He has been working as a postdoctoral fellow at the Center of Biospectroscopy at Monash University (Melbourne) and Imperial College (London).

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**RESEARCH AREAS**

Torsten Frosch’s research interests address the development of highly sensitive and miniaturized Raman spectroscopic sensing techniques for interdisciplinary research in the areas of environmental, pharmaceutical and biomedical analysis. Research thrusts include:

- novel hollow-core fibers for low-loss light guidance in the visible and ultraviolet spectral range
- development of cavity enhanced and fiber enhanced Raman spectroscopy (CERS and FERS)
- ultrasensitive FERS analysis of pharmaceutical drugs and biomolecules
- CERS multi-gas sensing for environmental monitoring and investigation of biogeochemical processes
- chemical imaging of biological cells and pharmaceuticals
- Raman difference spectroscopy for investigation of drug-target interactions

**TEACHING FIELDS**

Dr. Frosch is actively involved in teaching physical chemistry courses for chemistry and pharmacy students. He contributes to the education and support of doctoral candidates with lectures in analytical methods at the International Max Planck Research School for Global Biogeochemical Cycles. His teaching is devoted to the early involvement of students and young scientists in state-of-the-art research.

**RESEARCH METHODS**

The laboratories led by Torsten Frosch, and the infrastructure at the Leibniz Institute of Photonic Technology, offer a wide range of spectroscopic methods, different lasers and Raman spectrometers as well as a fiber drawing tower facility for the development of novel hollow fibers. Several miniaturized and home-built Raman sensors are developed for interdisciplinary research and are applied for onsite analysis.

**RECENT RESEARCH RESULTS**

Our recent research is concerned with the development of highly sensitive and chemically selective Raman spectroscopic sensing techniques and their interdisciplinary application.

A special focus is on the design of novel optical hollow-core fibers for low-loss light guidance in the visible and ultraviolet spectral range and their application for ultrasensitive analysis of pharmaceutical drugs [1] and biogenic gas compositions [2, 3]. Fiber enhanced Raman spectroscopy (FERS) provides unique capabilities for chemo- and bioanalysis, such as applicability in hydro/or biological environment as well as label-free, non-destructive, and simultaneous analysis and quantification of several analytes. FERS has been developed as a new point-of-care analytical technique for personalized treatment of intensive care patient in close cooperation with the Center for Sepsis Control and Care (CSCC) and the University hospital. FERS is also applied for the analysis of breath for gaseous and volatile biomarkers for non-invasive early stage disease diagnosis [3].

Another research focus of our group is Raman spectroscopic sensing of biogenic gases for the investigation of environmental processes and biogeochemical cycles with strong cooperative links to the Collaborative Research Center (CRC) AquaDiva and the International Max Planck Research School for Global Biogeochemical Cycles (IMPRS BGC) [4-7]. By analyzing the exchange of a suite of biogenic gases rapidly and in line with help of cavity-enhanced Raman spectroscopy (CERS), we were able to characterize climate sensitive microorganisms and ecosystems [4, 5]. CERS has a high potential for the assessment of denitrification processes and can contribute substantially to our understanding of nitrogen cycling in both natural and agricultural systems [6].

**Figure 1:** Fiber enhanced Raman spectroscopic analysis of breath for disease markers [3].

**Figure 2:** Raman spectroscopic quantification of environmental gases and climate sensitive ecosystems [4].

**Figure 3:** Double antiresonant hollow-core fibers for low-loss light guiding in the deep ultraviolet.

Our recently developed double antiresonant hollow-core fibers provide low-loss light guidance with Gaussian-type mode quality in transmission windows spanning from the near infrared to the deep ultraviolet [8, 9]. These novel fibers with large central hollow cores, matched with the cladding air holes, are extremely promising for our interdisciplinary research in UV-Raman fiber spectroscopy and other applications in biophotonics. The fiber design relies on only four to six large cladding air holes and a central core surrounded by very thin silica strands and thus provides high potential for wider application of this simplified hollow fiber structure.

**Figure 3: Double antiresonant hollow-core fibers for low-loss light guiding in the deep ultraviolet.**

**REFERENCES**

HOLGER GIES

PROFESSOR OF QUANTUM THEORY, INSTITUTE OF THEORETICAL PHYSICS

Prof. Gies is a principal investigator of the collaborative research center SFB TR 18 on laser plasma dynamics and of the research training group GRK 1523 on quantum and gravitational fields, both funded by the German Research Foundation (DFG). He serves as a member of the extended directorate of the Helmholtz Institute Jena and on the board of the Helmholtz Research School of Advanced Photon Science.

RESEARCH AREAS

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

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

QUANTUM OPTICS

Recent algorithmic developments make it now possible to study the quantum-modified propagation properties of light within such a geometry.

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

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

RECENT RESEARCH RESULTS

Dealing with quantum processes in realistic inhomogeneous fields requires a thorough understanding of quantum fluctuations in general field profiles. The quantum theory group is strongly involved in method development for the efficient determination and prediction of salient signatures of the quantum world in upcoming strong-field experiments. For instance, the group has developed the worldline Monte Carlo technique which currently is the only theoretical tool in practice which is capable of determining quantum properties of light in general strong-field backgrounds.

A main topic deals with the spontaneous vacuum decay in high-intensity laser fields in terms of particle pair production. This generic non-equilibrium process requires new quantum-field theory techniques to describe possible observables as a function of real Minkowskian time. Using and developing non-equilibrium methods for quantum-field theory, the group has recently predicted unequivocal signatures of the effective mass of electrons in a strong field vacuum environment. After a decades-old debate about the observability of the effective mass, this work has given an operative meaning to this concept with a clear relation to experimental observables [1].

Furthermore, the group explores the potential of upcoming high-intensity laser facilities as discovery machines of fluctuation induced vacuum nonlinearities. The group has recently proposed new experimental detection schemes [2], one of which makes use of the inherent quantum property of over-the-bareer scattering. This potential signature of quantum reflection of photons off a high-intensity region is a prototypical example of a new kind of all-optical phenomena at the high-intensity frontier that has the potential to explore this new regime of physics for the first time [3].

STEFPANIE GRÄFE

PROFESSOR OF THEORETICAL CHEMISTRY, INSTITUTE FOR PHYSICAL CHEMISTRY

Prof. Gräfe has joined the Friedrich Schiller University Jena in 2013 and is the head of the Theoretical Chemistry Group at the Institute for Physical Chemistry. Based on her research in strong field molecular physics, she has also close collaboration within the Faculty of Physics and Astronomy.

RESEARCH AREAS
Prof. Gräfe’s research covers a wide range of topics in quantum chemistry and molecular dynamics with strong emphasis on the theoretical description and modeling of processes involving the interaction of weak and intense ultrashort laser pulses with atomic, molecular and other quantum systems. Time-resolved spectroscopy
• time-resolved spectroscopy
• femtosecond chemistry and attosecond physics
• photophysics of electron transfer systems
• electronic and spectroscopic properties of molecular systems
• quantum chemistry
• strong-field atomic and molecular physics

TEACHING FIELDS
Prof. Gräfe is teaching basic and advanced topics of physical and theoretical chemistry for both undergraduate and graduate students. She aims at introducing students to modern research areas and supporting their education towards young researchers. Current topics include:
• quantum mechanics and molecular dynamics
• theoretical and quantum chemistry
• light-matter interaction
• symmetry and chemistry

RESEARCH METHODS
The research group lead by Prof. Gräfe applies state-of-the-art quantum chemical methods and develops numerical schemes to describe various aspects of light-matter interaction:
• ab-initio quantum chemistry
• numerical solution of the time-dependent Schrödinger equation
• non-adiabatic (quantum) dynamics
• time-dependent density functional theory (TD-DFT)

RECENT RESEARCH RESULTS
Our research activities have been focused on the theoretical description and simulation of ultrafast internal, ionization and fragmentation dynamics of atomic and molecular systems in intense and ultrashort laser fields. We closely collaborate with world-leading experimental groups in this research area.

In collaboration with the experimentally working group of Andrius Baltuška and Markus Kitzler (Vienna) we have probed the influence of the Coulomb field on strong-field-driven continuum electron wavepackets. Key is the use of sculpted-ω–ω two-color pulses for which the relative phase can be tuned. This allows us to control the temporal structure of the wavepacket emission and propagation with sub-cycle precision. In turn, the relative importance of the laser field and Coulomb field can be controlled. With the same technique, we have extracted the phase of the atomic bound state wavefunction undergoing strong-field ionization using sculpted two-color laser fields. Based on an interferometric technique, the sub-cycle dynamics of the function was retrieved with an accuracy of 10 attoseconds [1, 2]. The sensitivity of this technique has the potential to become a useful tool for monitoring ultrafast dynamical and structural information of complex multi-electron systems.

When the Born–Oppenheimer approximation is valid, electrons adiabatically follow the nuclear motion in molecules. For strong nonadiabatic coupling between electronic states, one encounters a diabatic motion where the electrons remain local and do not adapt to molecular geometry changes. Together with Volker Engel (Würzburg) we have shown that these limiting cases are reflected differently in the asymmetry of time-resolved photoelectron momentum distributions. Whereas for adiabatic dynamics, the asymmetry directly maps the time-dependent average nuclear moment, in the diabatic case, the asymmetry is determined by a nonclassical interference effect arising from the mixing of wave function components in different electronic states, which is present at times nonadiabatic transitions take place [3].

We have analyzed atomic ionization by strong and ultrashort laser pulses with frequencies in the midinfrared spectral region which have revealed novel features such as the low-energy structures (LES). The atomic photoionization spectrum generated by such laser pulses displays both strong quantum interference effects and classical focusing effects [4]. The positions and the forward-backward asymmetry of the LES peaks depend on the wavelength, pulse duration, and carrier-envelope phase. The latter may open up the opportunity to monitor the carrier-envelope phase in the low-energy continuum.


FRAGMENTATION DYNAMICS OF POLYATOMIC MOLECULES

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

**PROFESSOR OF THEORY OF OPTICAL SYSTEMS, INSTITUTE OF APPLIED PHYSICS**

Herbert Gross is the head of the research group Theory of Optical Systems at the Institute of Applied Physics. He is a member of EOS and SPIE.

**RESEARCH AREAS**

Prof. Gross’s research deals with optical systems, their design, modelling, simulation and performance evaluation. In particular, his research interests include:

- the design of optical systems, methods and modern approaches
- modelling of coherent and partial coherent light propagation
- computational methods for illumination
- optimization methods of optical systems, initial trials and structure of systems
- performance evaluation of non-symmetrical and free form surface optical systems
- phase retrieval for metrology, system testing
- phase imaging, microscopy, image formation with enhanced contrast and resolution
- calculation of scattering of light in tissue, link to conventional calculation of systems

**TEACHING FIELDS**

Prof. Gross’s teaching activities aim to provide young developing scientists the practical knowledge to design and simulate optical systems. He gives courses in:

- technical optics, design and correction of systems
- aberration theory and microscopy
- lens design with Zemax

Due to the practical approach of his teaching, he also holds seminars and courses for professionals in the field of optical design.

**RESEARCH METHODS**

In Prof. Gross’s research group, realistic lens design and simulation techniques are performed with the help of several commercial software packages and using their own tools:

- Matlab for physical optical simulation development
- Zemax for classical lens design
- various special tools such as FRED or VirtualLab

**CURRENT AND RECENT RESEARCH RESULTS**

The research group Theory of Optical Systems has been established at the Institute of Applied Physics in April 2012 under Prof. Gross’s leadership. The professorship was founded by the Ernst Abbe Foundation, STIFT Thuringia and several companies. The staffing of the research group is now complete, and the group has approached a size of approx. 20 Master’s degree and doctoral students as well as postdocs. Having close cooperative ties with the Fraunhofer Institute for Applied Optics and Precision Engineering and with the optics industry is a declared goal of this group. Several special topics of optical design as well as system simulation are the current subjects of projects with these companies. Funded projects include larger activities and research on free form surface systems, the modelling of partial coherent imaging, high energy beam guiding systems and the efficient modelling of illumination. Furthermore there are several collaborations with partners of other University research groups or institutes on the subject of lens design.

**HANDBOOK OF OPTICAL SYSTEMS**

One of Dr. Gross’s important activities during the past few years has been the publishing of the Handbook of Optical Systems. He is the editor and main author of this series of books. Currently, five of six planned volumes are available. In this handbook for practical lens design work, the whole subject of optical system design from basic technical optics, physical optical image modelling, the design and correction of systems, as well as performance evaluation and metrology of components and systems is treated [H. Gross (Ed.), “Handbook of Optical Systems,” Wiley-VCH, Vol. 1–5].
EINEMANN

STEFAN H.

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

- the fundamentals of biophysics
- molecular medicine and pharmacology
- biomembranes and cellular sensors
- biophotonics

A GATEABLE NON-PHOTONIC ROS SENSOR
Reactive oxygen species (ROS) and their intermediates play crucial roles in physiological processes. While excessive ROS damages cells, low levels of ROS represent physiological signals important for vital functions. Despite their physiological importance, many fundamental questions remain unanswered.

In our lab, we developed a ratiometric sensor of intracellular oxidative modifications that occur near the plasma membrane with a sensitivity similar to existing fluorescence-based sensors. roNaV, does not need excitation light for sensing, and thus, can be used to detect phototoxic cellular modifications. The ROS dynamic range of roNaV, is easily manipulated by means of the endogenous channel inactivation mechanism. Moreover, roNaV was used to assess ROS lifetime in individual mammalian cells [4].

TEACHING FIELDS
Dr. Heinemann teaches students at various levels of proficiency – Bachelor’s degree students in biology and biochemistry, Master’s degree students in molecular life science and molecular medicine, biochemistry and photonics. He gives courses in:

- voltage-gated ion channels
- cell signaling via redox processes and heme
- neurotoxins and pain signaling
- photonic manipulation of living cells
- the biophysics of ion transport

Our research also focuses on voltage-gated Na+ channels important for the initiation of action potentials in excitable cells. Of particular interest are Na+ channels that take part in the transmission of pain signals. We showed that a single-point mutation in human Na+, 1.9 channels gives rise to a loss of pain perception phenotype owing to an altered gating of these channels causing hyperactivity at resting voltages [3]. By conducting systematic studies, we currently investigate how Na+, 1.9 channel mutations affect the electrical signaling in dorsal root ganglia cells to modulate the nociceptive system.

Further research areas are related to the photonic modulation of living cells. Based on voltage-gated Na+ channels, we have developed gated and ratiometric molecular sensor systems for photo toxicity (see figure) [4]. Such tools will be important for evaluating and controlling the impact of photonic manipulations in living systems. Furthermore, we are studying the photo-electric coupling at cellular plasma membranes as an alternative to optogenetic cellular manipulations. In collaboration with the Leibniz Institute of Photonic Technology, we devise novel approaches for local light generation with molecular targeting of up-converting nanoparticles.

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

- high-resolution fluorescence microscopy using linear and nonlinear structured illumination
- fast optical sectioning via polarization illumination coded structured illumination
- resolution enhancement in scanning microscopy via an image inversion interferometer
- pointillistic single molecule imaging modes in crowded situations
- high-resolution light wedge microscopy
- light sheet based Raman microscopy
- image processing in microscopy

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

- biophotonics
- image processing in microscopy
- light microscopy

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

- fast structured illumination microscopy
- pointillistic microscopy (dSTORM)
- confocal microscopy
- optical coherence tomography
- light wedge microscopy
- light sheet based Raman microscopy

RECENT RESEARCH RESULTS
The Nanobiophotonics group has a long tradition working on aspects of structured illumination. In structured illumination the fluorescent biological sample is illuminated with a very fine pattern of lines. This leads to a Moiré effect in the sample, translating information beyond Abbe's resolution limit into coarse fringes, which can be resolved in the microscope. With the help of a computer, the original sample information can be calculated from a number of such measurements under different pattern positions and orientations. Recently, advances in data reconstruction aspects with unknown or aberrated illumination have been made [1], and the speed was increased [2].

A high resolution image can also be obtained with the help of a modified detection scheme in confocal microscopy. In this case light emitted from the fluorescent sample after a focused laser excitation passes through a special interferometer (UZ-Interferometer) which causes the amplitude image to interfere with a version of itself rotated by 180 degrees with respect to the optical axis. This leads to a substantially improved resolution [3].

Another line of research concentrates on pointillistic imaging modes [4]. In the dSTORM method molecules are forced into a dark, non-emitting state from which they return to an emitting state only rarely. Thus the raw data consists of a sparse distribution in which the emitting molecules are well separated. Localizing these molecules with an algorithm can then pin down their position with a precision of better than 30 nm. From many hundred thousands of these positions an image can be assembled in a pointillistic manner. This typically requires the acquisition of several 10,000 images for one reconstruction. Recent developments in pointillistic imaging (see figure below) allowed for overlapping emitters to be analyzed in a probabilistic way (Bayesian analysis of blinking and bleaching) [5]. This drastically reduced the required number of images to typically 600, allowing for high-resolution movies of living cells to be made.


POINTILLISTIC IMAGING FOR LIVING CELLS
In 2005, the term “pointillism” was coined for a method imaging a fluorescent sample by isolating single molecules or quantum dots using their blinking statistics [4] and then assembling an image in a pointillistic fashion by drawing a dot in every localization position. Successively, this was further simplified (PALM, STORM, PALM, dSTORM) by ensuring that only a few molecules are visible at a given time (Ernst Betzig, Nobel price for Chemistry in 2014). This has the disadvantage of requiring many (typically >10000) raw images for a single reconstruction. Recently, it was shown [5] that even life cell movies are possible at a final image frame every six seconds if the overlap of the molecules in the raw data is tolerated and accounted for in the analysis. The data is analyzed with the help of a Bayesian model using a hidden Markov model to reflect the switching behavior of the individual molecules. A single frame looks similar to the grey values shown in (a). Many possible realizations, see red dots in (a), are averaged, yielding the probabilistic image (here podosomes in a lung cell), as shown in (b).
Malte C. Kaluza

Professor of Experimental Physics/Relativistic Laser Physics, Institute of Optics and Quantum Electronics

Prof. Kaluza is a member of the extended board of directors of the Helmholtz Institute Jena and the coordinator of the Euronan Program of the Faculty of Physics and Astronomy of the FSU Jena. Dr. Kaluza is the head of the High-Intensity Laser Physics Group at the Center for Innovation Competence «ultra optics».

Recent Research Results

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

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

Furthermore, new approaches for the generation and amplification of high-power laser pulses have been studied by the Relativistic Laser Physics Group. These include the development and characterization of new laser materials, especially Yb3+-doped CaF2, which is well suited for diode-pumping as used in the operation of the POLARIS laser which is currently the most powerful, diode-pumped system worldwide [3]. To enhance the performance of such laser systems, novel cryogenic cooling techniques are being developed with the aim of increasing the repetition rate of laser pulses.


Research Areas

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

- the development of laser systems with peak powers from TW to PW
- laser-based particle acceleration
- realization of secondary light pulses with ultra-short duration
- high-resolution probing of transient states of matter with optical pulses and particle beams
- the development of novel materials for laser operation

Teaching Fields

Prof. Kaluza’s teaching is devoted to young scientist education from their first year onward to the doctorate level using state-of-the-art research. He gives courses in:

- standard courses on experimental physics
- high-intensity, relativistic optics
- plasma physics

Research Methods

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

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

Direct Observation of the Injection Dynamics of a Laser Wake-Field Accelerator Using Few-Femtosecond Shadowgraphy

Ultra-short probing techniques developed by the Relativistic Laser Physics Group have led to the first monitoring of the evolution of the laser-generated plasma wave, driven by a high-intensity laser pulse. The periodic density modulation, propagating through the plasma at a velocity close to the speed of light, is visible as the grey-scale intensity modulation as seen in the time-resolved snap shots shown in the image. By observing the propagation of the plasma wave through the plasma and its evolution, new insight into the acceleration dynamics could be gained. In particular, we could show for the first time that the injection and acceleration of electrons by this plasma wave is preceded by dynamic changes of the plasma wave’s shape. These details – crucial for a comprehensive understanding of the acceleration physics – are important for a further optimization of the laser-electron accelerator towards possible applications. Image taken from [1].

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RESEARCH AREAS

His field of research is concerned with micro- and nanostructured optics with an emphasis on their fabrication, characterization and application. The current main activities deal with diffractive elements based on effective media, resonant waveguide gratings for low thermal noise and special filter applications, metal wire grid polarizers for the UV and DUV range, 2D- and 3D plasmonic elements and chiral metamaterials. Further research interests include:

- technologies for optical metamaterials and photonic crystals
- technologies for plasmonics and near field optics
- the application of optical nanostructures for efficiency enhancement of solar cells
- the interaction of light with microstructured and nanostructured matter

RESEARCH METHODS

Dr. Kley’s research group ideas for micro- or nanooptical elements range from rigorous design and modeling up to fabrication and characterization. His laboratories contain a comprehensive collection of state-of-the-art micro- and nanolithography equipment specializing in particular on optical applications. The central equipment that characterizes the group’s potential is a powerful electron beam writer SB350-CS (Vistec) as well as coherent etching facilities for substrate diameters of up to 300 mm. Other equipment includes:

- e-beam lithography, photolithography, imprint and etching techniques
- helium ion and scanning electron microscopes, focused ion beam
- surface profilometry, interferometry, high-resolution DUV-microscopy
- optical setups for diffraction efficiency measurements

The intense collaboration with many other groups, especially with the nanoptics group led by Prof. Pertsch, further broadens the spectrum of scientific activities.

RECENT RESEARCH RESULTS

Spectral and polarization filters are well known and have long been established. Due to the new lighting concepts catalyzed by the global demand for energy supply and by certain technical system needs, directional selective filters are now of growing interest. Therefore, based on a high-index contrast resonant waveguide grating, we have developed a novel type of filter. We designed an efficient out-coupling mechanism by confining the propagation length of the light inside the waveguide down to just one grating period. Thus, it was possible to arrange the resonant behavior of the angular spectrum by tailoring the grating period in an asymmetric fashion. The geometry of the grating period is a simple binary silicon sub-wavelength grating having three different grating ridges. Due to the high index of the silicon grating working in air on a fused silica substrate, the grating also functions as a waveguide [1].

A technological field of activity is the realization of optical nanostructures for real applications. Such examples are metamaterials [2] or polarizers [3]. The main problem to be solved is: to find a fabrication method that suits an involved design which does not negatively affect the material properties and is able to fabricate the pattern in both an effective and uniform way. A fabrication technique based on high-speed electron beam writing, a double patterning technology and a novel planarization technology have recently been developed. The picture shows a 75 nm period tungsten wire grid polarizer recently developed for the DUV spectral range for wavelengths between 193 nm and 350 nm.

ERIKA KOTHE

PROFESSOR OF MICROBIAL COMMUNICATION, INSTITUTE OF MICROBIOLOGY

Professor Kothe is, among other affiliations, co-coordinator of the Excellence Graduate School, ‘Jena School for Microbial Communication’ and speaker for the Research Training Group, ‘Alteration and Element Mobility at Microbe-Mineral Interfaces’, both funded by the German Research Foundation (DFG). In addition, she is coordinator of the profile line ‘Life’ of Friedrich Schiller University and president of the German University Association for Advanced Graduate Training.

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

- mating type genes and sexual development in the white rot fungus *Schizophyllum commune*
- mutually beneficial symbiotic interactions of basidiomycetes in ectomycorrhizae
- heavy-metal resistance in fungi and streptomycetes
- applications to improve bioremediation

TEACHING FIELDS
Professor Kothe teaches at the basic and advanced levels, including the coordination of the M.Sc. program Master’s degree in Microbiology and she is involved in the Bachelor’s and Master’s degree programs in Biogeo-sciences. Additionally, she is involved in many graduate teaching programs. Subjects taught are:

- basic and advanced microbiology
- bio-geo-interactions
- high level microbial interactions, cell biology and development

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

- fluorescence video-imaging
- high resolution microscopy
- gene technology
- the characterization of mutations
- the characterization of native consortia

RECENT RESEARCH RESULTS

Heavy metal pollution is widespread, causing serious ecological problems in many parts of the world, especially in developing countries where a budget for remediation technology is not affordable. Therefore, screening for microbes with high accumulation capacities and studying their stable resistance characteristics is advisable to define the cost-effectiveness of remediation strategies. The metal-resistome [4] of streptomycetes isolated from metal-contaminated environments, is studied. Community analyses are used to study specific activities of microbes in the environment [5].

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

CONTROL OF DEVELOPMENT IN MUSHROOMS

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RICHARD KOWARSCHIK

PROFESSOR OF EXPERIMENTAL PHYSICS/ COHERENT OPTICS, INSTITUTE OF APPLIED OPTICS

Prof. Kowarschik is the director of the Institute of Applied Optics (IAO) at the Friedrich-Schiller-University Jena. Prof. Kowarschik serves as a member of the DFG scientific advisory board 308 Optics, Quantum Optics and Physics of Atoms, Molecules and Plasmas and of the DFG Review Panel Medical Technology.

RESEARCH AREAS

The research interests of Prof. Kowarschik cover optical metrology, optical information storage and processing, including:

- coherent optical measurement techniques
- holography and holographic interferometry
- 3D shape measurement with structured light
- wavefront sensing and adaptive optics in physiological optics and ophthalmology
- diffractive optical elements
- real-time storage materials (photorefractive crystals and polymers)
- wave mixing processes, phase conjugation, spatial solitons

TEACHING FIELDS

Prof. Kowarschik’s teaching is devoted both to undergraduate courses in the fields of physics and optics as well as special lectures in the field of modern optics. He gives courses in:

- fundamentals of modern optics
- physical optics
- optical metrology and sensing
- coherent optics
- holography, optical information processing and storage

RESEARCH METHODS

The laboratories led by Prof. Kowarschik offer various methods in the field of optical measurement techniques which include:

- interferometers (VIS to IR)
- adaptive optical setups
- microscope facility
- digital holography
- 3D shape measurement with structured light
- optical storage materials (such as photorefractive crystals and polymers)

RECENT RESEARCH RESULTS

For high-speed optical 3D shape measurements, our group has developed new stereo photogrammetric methods based on statistical patterns that illuminate the object undergoing testing. The correspondence problem can be solved by the temporal correlation of the statistical patterns. Both incoherent and coherent statistical patterns have been tested [1, 2]. Both for the high-speed translation of incoherent statistical patterns and the ultra-fast switching of speckle patterns with and without acousto-optical deflectors we have determined the physical limits of such systems underpinned by numerical simulations. The partnership with the Fraunhofer Institute for Applied Optics and Precision Engineering Jena (IOF), several companies and academic institutions in the field of 3D-measurement was intensified within the strategic alliance 3Dimension. The development of fast 3D-sensors at IAO and IOF were honored with the Thuringian research award 2013 for Prof. Kowarschik and the IOF-colleagues Dr. Notni und Dr. Kühlmeister.

The research in digital holography using high resolution CCD-chips was continued. The Moiré-effect was applied to increase the angular size of objects to be recorded and to increase the resolution of objects in image field holography. Work in the field of a holographic version of an image inverting interferometer has been continued as well characterizing the setup and exploring characteristics of the technique [3].

Several simulations have been done to demonstrate the imaging properties of different microscopic techniques in combination with an image inverting interferometer [4]. The work on measuring the complex coherence function using an image inverting interferometer has been continued. E.g. in theory an infinite depth-of-field can be gained by this method. The theoretical predictions have been compared to measurements. Additionally, the technique yields a suppression of different aberrations as well as an increased lateral resolution [5].

Works on the “adaptive optical real-time phoropter” have been continued in 2014 in cooperation with the hospital ophthalmology at the Johann-Wolfgang-Goethe University Frankfurt (Main). Preparations have been done to extend the system into a binocular setup.


WIDEFIELD MICROSCOPY WITH INFINITE DEPTH OF FIELD AND ENHANCED LATERAL RESOLUTION

The imaging properties of different microscopic techniques can be clearly improved by using an image inverting interferometer. So, measuring the complex coherence function with such an interferometer in a microscopic setup allows an extreme extension of the depth of field. We could experimentally demonstrate this effect [3]. The figure shows the cross section of an imaged LED demonstrating the extended depth-of-field of the image inversion technique (b, f, h) compared to a conventional incoherent image (a, c, e).
The Fiber and Waveguide Laser Group has demonstrated a significant performance scaling of fiber-based laser systems in recent years. Based on a fundamental knowledge of waveguide optics and laser physics, novel fiber designs such as the rod-type large-pitch photonic crystal fiber have been invented. This fiber design is based on a novel mechanism, the delocalization of higher order transverse modes, and allows for single-mode extraction from a core size of ytterbium-doped fibers as large as 135 μm, 135 times larger than the guided wavelengths. This record mode area has enabled an enormous performance increase in ultrafast fiber laser systems. Gigawatt peak power, in combination with several 100 W of average power, constitutes unique laser parameters [1, 2].

To extract performance which is beyond the capabilities of a single aperture emission, the approaches of spatially separated amplification, following by the coherent addition of amplified femtosecond pulses, are pursued. These concepts are based on the idea of distributing the load or challenges, respectively, to more than just one amplifier channel. In this regard, an amplifying interferometer is constructed. Besides producing a careful numerical analysis, the group has been able to extract parameters beyond the capabilities of a single channel emission [3], demonstrating a new and promising scaling concept for ultrafast lasers. Based on this work, fiber based laser systems are now considered potential drivers for laser wake-field particle accelerators.

The strong-field process of high harmonic generation (HHG) is the foundation for isolated attosecond pulses (IAP), representing the fastest controllable events ever induced. This coherent extreme ultraviolet radiation has become an indispensable tool to resolve ultrafast motion in atoms and molecules. Despite numerous spectacular developments in attoscience, small data acquisition rates imposed by low (max. 3 kHz) repetition rate fiber lasers-pumped optical parametric amplifiers (OPAs) including new phase-matching strategies, tailored signal broadening in nonlinear fibers and new concepts for CEP stabilization. Finally, the group has been able to demonstrate the most powerful few-cycle laser system in the world, delivering sub-2 cycle optical pulses with an average power as high as 22 W at a 1 MHz repetition rate [3]. This laser will enable numerous possibilities in femto- and atto-science.

Besides performance scaling fundamental effect in amplifying fibers are investigated. Among them thermally induced modal instabilities. This new affect is a serious issue for high average power fiber laser system. Over the recent years the group has contributed to the understanding of that effect and proposed most efficient mitigation strategies [4].

Transferring the performance of high-repetition rate fiber lasers to the few-cycle pulse duration regime would enable a number of scientific applications. We have successfully developed fiber laser pumped few-cycle optical parametric amplifiers (OPAs) including new phase-matching strategies, tailored signal broadening in nonlinear fibers and new concepts for CEP stabilization. Finally, the group has been able to demonstrate the most powerful few-cycle laser system in the world, delivering sub-2 cycle optical pulses with an average power as high as 22 W at a 1 MHz repetition rate [3]. This laser will enable numerous possibilities in femto- and atto-science.


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Besides performance scaling fundamental effect in amplifying fibers are investigated. Among them thermally induced modal instabilities. This new affect is a serious issue for high average power fiber laser system. Over the recent years the group has contributed to the understanding of that effect and proposed most efficient mitigation strategies [4].

Transferring the performance of high-repetition rate fiber lasers to the few-cycle pulse duration regime would enable a number of scientific applications. We have successfully developed fiber laser pumped few-cycle optical parametric amplifiers (OPAs) including new phase-matching strategies, tailored signal broadening in nonlinear fibers and new concepts for CEP stabilization. Finally, the group has been able to demonstrate the most powerful few-cycle laser system in the world, delivering sub-2 cycle optical pulses with an average power as high as 22 W at a 1 MHz repetition rate [3]. This laser will enable numerous possibilities in femto- and atto-science.
STEFAN LORKOWSKI

PROFESSOR OF NUTRITIONAL BIOCHEMISTRY AND PHYSIOLOGY AT THE INSTITUTE OF NUTRITION

Prof. Lorkowski is the head of the Department of Nutritional Biochemistry and Physiology at the Institute of Nutrition. He is Fellow of the Royal Society of Chemistry and of the Royal Society of Biology. He serves as a member of the scientific executive committee of the German Nutrition Society. Prof. Lorkowski is a member of the scientific advisory board of the DACH Society for the Prevention of Cardiovascular Disease and of the executive board of the German Atherosclerosis Society. He is also coordinator of the Competence Cluster for Nutrition and Cardiovascular Health (nutriCARD).

RESEARCH AREAS
In his research Prof. Lorkowski investigates the function and plasticity of human monocytes and macrophages, which are the phagocytic cells of the immune system, in physiological processes and in pathophysiological conditions. Research interests include:

- cellular lipid transport and metabolism
- targeted delivery into human cells
- the regulation of cellular metabolism and function by nutrients and metabolites
- molecular mechanisms of atherosclerosis

TEACHING FIELDS
Prof. Lorkowski’s teaching is aimed at the theoretical and practical training of undergraduate and graduate students, as well as young scientists, with state-of-the-art knowledge. He gives courses on:

- the fundamentals of biochemistry and nutritional biochemistry
- principles of cellular transport processes
- molecular basics of age-related diseases
- state-of-the-art techniques of life science research

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

- confocal laser-scanning fluorescence microscopy
- Raman microscopy
- isolation and culture of human cells
- targeted delivery of cargos into human cells
- cell and animal models of atherosclerosis
- expression profiling and flow cytometry
- fatty acids and analytics

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

RECEN RESEARCH RESULTS
Prof. Lorkowski and his research group have contributed to the unraveling of molecular mechanisms of lipid droplet formation in macrophages [1, 2]. The storage of neutral lipids such as triglycerides and cholesterol esters in cytosolic lipid droplets is a complex process. In contrast to previous assumptions, studies by Lorkowski’s group and others indicate that the lipid droplets of eukaryotic cells are not in a dynamic state of continuous or long-term storage of lipids. Lipid droplets, for example in macrophages, are in a dynamic state of continuous and tightly regulated esterification and hydrolysis.

In addition, the group developed several state-of-the-art techniques in order to achieve a deeper insight into the spatio-temporal dynamics of lipid droplet formation and into the molecular constituent parts of the lipid droplet protein machinery [3-5]. In particular, the group developed a simple and rapid approach for efficiently transfecting macrophages with different types of cargo for in-depth functional studies. Transfection of macrophages is usually accompanied by a progressive loss of cell viability and functionality. By contrast, the technique developed by Lorkowski’s group maintains cell viability and functionality, thus allowing efficient genetic modification of these hard-to-transfect cells.

Furthermore, this research group has contributed to the characterization of the complex picture of macrophage plasticity by adding a new dimension to macrophage heterogeneity. Macrophages derived from blood monocytes perform many tasks related to tissue injury and repair. The main effect of macrophages on the extracellular matrix is generally considered to be destructive in nature, because macrophages secrete metalloproteases that degrade and destabilize the surrounding extracellular matrix. Macrophages ingest foreign material as part of the remodeling process that occurs in wound healing and other pathological remodeling conditions. By contrast, the group discovered that macrophages may promote tissue integrity and contribute to the extracellular matrix and hence to tissue stabilization both indirectly, by inducing other cells to proliferate and release matrix components, and directly by secreting components of the extracellular matrix such as fibronectin and different types of collagen [6].

RESEARCH AREAS
The research topic of Prof. Nolte is ultrashort laser pulses with the main focus on ultrashort pulse micromachining and material modification for industrial and medical applications, areas where he has been actively engaged in since the field’s inception in the mid-1990s. Current research interests include:

- Linear and nonlinear interaction of light and matter
- Micro- and nanostructuring by ultrashort laser pulses
- Ultrashort pulse laser welding
- 3D-volume structuring of glasses and crystals
- Fiber Bragg gratings, volume Bragg gratings
- Linear and nonlinear optics in discrete systems
- Medical applications of ultrashort laser pulses in ophthalmology
- THz technology

TEACHING FIELDS
Stefan Nolte is teaching courses ranging from fundamental aspects of physics to state-of-the-art research. He is also responsible for the ASP optics training laboratory, including labwork internships. He gives courses in:

- Atomic and molecular physics (also for teachers)
- Laser physics and ultrashort pulse optics

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

- High repetition rate ultrashort pulse laser systems (25 fs to 20 ps) including wavelength conversion covering the range from 300 nm to 10 µm
- High-resolution positioning and laser scanning systems
- Equipment for sample preparation and characterization (optical microscopes, electron microscope, Raman microscope, etc.)
- Characterization of spectral and spatial properties of micro- and nanostructured samples
- Characterization of nonlinear spatio-temporal dynamics

RECENT RESEARCH RESULTS
The Ultrafast Optics Group has extensive capabilities to precisely structure virtually any material on a micrometer scale. This includes the defined modification of the material properties within the volume of transparent materials, which is e.g. used to realize complex coupled waveguide array structures of various three-dimensional geometries. Its potential is exploited for tailoring the flow of light in artificially structured glass, done in collaboration with the Junior Research Group Diamond/-Carbon-based Optical Systems led by Jun. Prof. Szameit. It is here that investigations cover e.g. analogies to solid state physics and quantum effects, up to optical quantum computing [1].

In addition, we use the nonlinear interaction process to realize highly periodic structures. To this end, we are using the interference pattern behind a phase mask in order to imprint a periodic refractive index modification inside the volume of transparent materials. This way we are able to inscribe efficient Bragg gratings into various fibers. Due to the nonlinear interaction process, there is no need for photosensitivity, enabling e.g. the direct inscription into active fibers. In addition, it is possible to position the modifications anywhere in the fiber irrespective of the fiber core. This allows to tailor mode coupling, e.g. to enhance or depress coupling to cladding modes or between different core modes [2]. When this technique is extended to bulk material, volume Bragg gratings can be generated. We recently managed to inscribe such highly efficient gratings into various glasses enabling a monolithic integration, e.g. in fast axis collimators (FAC) for laser diode stabilization, or the combination of different beams [3].

When ultrashort pulse lasers with repetition rates above 1 MHz are used, successive pulses lead to heat accumulation and local melting around the focal volume. We make use of this process to achieve highly-stable localized welds between different transparent substrates by scanning the laser focus along the interface of the two samples. Breakdown strengths of almost the bulk material’s value were demonstrated [4]. Potential applications can be found e.g. in the fields of opto- and microelectronics and in micro-optics.

In addition, ultrashort pulse structuring has also great potential for biomedical applications, e.g. in ophthalmology. Here, we have exploited the precise and localized energy deposition in the crystalline lens for investigating recent research on birefringent phase elements. By tuning the processing parameters we can precisely control the structural properties and, thus, the birefringence. This enables to realize specific waveplates in order to generate e.g. optical vortices or for advanced microscopy techniques based on structured illumination.

Dr. Gerhard G. Paulus is currently the dean of the Faculty of Physics and Astronomy. He is a member of the board of directors of the Helmholtz Institute Jena and serves on several scientific advisory committees at major laser facilities all over Europe.

**Professor of Nonlinear Optics, Institute of Optics and Quantum Electronics**

Dr. Paulus’s research group has developed a novel method for measuring the absolute (carrier envelope) phase of few-cycle laser pulses. As a result, it has become possible to measure this phase with unprecedented precision for each and every pulse at multi-kHz repetition rates. The method has revolutionized a number of experiments by rendering phase stabilization obsolete, and its success and use is spreading quickly to other labs.

In the group’s own lab, experiments on intense laser interaction with a fast ion-beam are performed. Particularly, emphasis is put on the investigation of fundamentally important systems such as He+ or H+. One highlight has been the control of the localization of the single electron of H+ by precisely shaped single optical cycles. An important achievement has been the ionization of, e.g., Ne+ to Ne++ with nearly relativistic intensity and full characterization of the ion momentum. In both cases, new insight into the attosecond dynamics of ionization and dissociation has been obtained.

Another project has generated intense XUV attosecond pulse trains via relativistic laser surface interaction. For the first time, the efficiency of the process has been measured with a calibrated XUV spectrometer. Novel effects in the attosecond dynamics of frequency conversion and relativistic frequency mixing processes were discovered.

In yet another project, the extinction ratio of x-ray polarimeters was improved by several orders of magnitude to the level of $10^{10}$ at Angstrom wavelengths. The exquisite sensitivity has allowed optical activity of sucrose to be detected on the arc-second level at these wavelengths. In this way, the minute effects of the chiral molecular structure on core electrons can be quantified.


**Recent Research Results**

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

- attosecond pulse generation via relativistic laser surface interaction
- precision measurement of the absolute phase of few-cycle pulses
- phase-dependent ionization and dissociation of fundamentally important atomic and molecular systems
- relativistic ionization dynamics
- strong-field QED
- x-ray polarimetry with an extinction ratio of $10^{10}$

**Research Areas**

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

- attosecond pulse generation via relativistic laser surface interaction
- precision measurement of the absolute phase of few-cycle pulses
- phase-dependent ionization and dissociation of fundamentally important atomic and molecular systems
- relativistic ionization dynamics
- strong-field QED
- x-ray polarimetry with an extinction ratio of $10^{10}$

**Teaching Fields**

- introductory physics
- fundamentals of modern optics
- nonlinear optics
- strong-field and attosecond laser physics
- x-ray physics and free-electron lasers
- renewable energies

**Research Methods**

- photoelectron spectroscopy
- momentum spectroscopy
- XUV spectroscopy
- polarimetry
- vortex laser beams

**Ion Beam Experiments**

Ion beams provide unique experimental opportunities in strong-field and attosecond laser physics. One reason is the existence of fundamentally important molecules such as H2+. We have used tailored few-cycle pulses to control the electron localization during photo-dissociation. In many respects, this can be regarded as the most fundamental chemical reaction. Multi-photon, multi-electron ionization of atomic ions is another interesting problem, particularly with respect to correlated quantum dynamics. The figure displays the momentum distribution of Ne+ ions after double ionization. The outer half-moon-like structures correspond to events where both photoelectrons are emitted in the same direction, whereas they leave in opposing directions for the inner half-moons.
THOMAS PERTSCH

PROFESSOR OF
APPLIED PHYSICS/ NANOOPHTICS,
INSTITUTE OF APPLIED PHYSICS

Prof. Pertsch is a member of the board of directors of the Abbe Center of Photonics and the spokesman of the Abbe School of Photonics. He currently serves as vice dean of the Faculty of Physics and Astronomy and as speaker of the German Research Excellence Initiative on Photonic Nanomaterials. He is the head of the Nanooptics Group of the Center for Innovation Competence «ultra optics» at the Institute of Applied Physics.

RESEARCH AREAS

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

• the interaction of light with microstructured and nanostructured matter
• optical metamaterials, photonic crystals, plasmonics, near field optics, and high-Q nonlinear optical micro-resonators
• nonlinear spatio-temporal dynamics, quantum phenomena, and all-optical signal processing
• application of advanced photonic concepts for astronomical instruments
• exploitation of optical nanostructures for efficiency enhancement of solar cells

TEACHING FIELDS

Prof. Pertsch's teaching is devoted to the early involvement of young scientists in state-of-the-art research. He gives courses in:

• fundamentals of modern optics
• computational physics and photonics
• introductory and theoretical nanooptics

RESEARCH METHODS

The labs led by Prof. Pertsch offer a range of methods for the experimental characterization and numerical modelling of photonic nanostructures, including:

• multi-tip scanning nearfield optical microscopy
• phase-resolved micro-spectroscopy in the UV-VIS-IR
• time-resolved single photon microscopy
• photoemission electron microscopy (PEEM)
• characterization of ultrafast nonlinear spatio-temporal dynamics up to the few-cycle regime
• high-performance computing for rigorous numerical modelling of photonic nanostructures

RECENT RESEARCH RESULTS

The Nanooptics Group demonstrated a nonlinear optical chip that generates photons with reconfigurable nonclassical spatial correlations. In a collaboration with scientists from Australia and Germany they employed a quadratic nonlinear waveguide array, where photon pairs are generated through spontaneous parametric down-conversion and simultaneously spread through quantum walks between the waveguides. Because of the quantum interference of these cascaded quantum walks, the emerging photons can become entangled over multiple waveguide positions, confirming the high fidelity of on-chip quantum interference [1].

In collaboration with scientists from Finland, Australia, Poland, and Russia the Nanooptics Group performed research on the impact of order and disorder, which is of fundamental importance to perceive and to appreciate the functionality of modern photonic metasurfaces. Metasurfaces with disordered and amorphous inner arrangements promise to mitigate problems that arise for their counterparts with strictly periodic lattices of elementary unit cells such as, e.g., spatial dispersion, and allows the use of fabrication techniques that are suitable for large scale and cheap fabrication of metasurfaces.

NANO-TIP BASED EXCITATION OF RADIALY POLARIZED CONICAL SURFACE PLASMON POLARITONS

The excitation of radially polarized conical Surface Plasmon Polariotons (SPP) was demonstrated in a fully metal-coated conically tapered M-profile fiber which works as a “plasmonic tip” for the Scanning Nearfield Optical Microscope (SNOM). The radially polarized waveguide mode of the fiber resonantly excites the radially polarized SPP on the metal surface which consequently experiences superfocusing at the apex with longitudinal fields. Furthermore the reverse process was demonstrated for nearfield detection. Unlike the sharp aperture-less scattering SNOM tips that detects only the longitudinal field component or aperture SNOM tips that detect the transversal components, the plasmonic tip detects both longitudinal and transversal field in collection mode and backward-scattering mode, respectively. Due to its ability of background-free near-field detection, ease of operation, and high conversion efficiency from far-field to near-field, plasmonic tips are currently integrated into advanced SNOM devices. [B. Tugchin et al., ACS Photonics 2, 1468 (2015)]
PRINCIPAL SCIENTIST PROFILES  Ulf Peschel

ULF PESCHEL

PROFESSOR OF THEORETICAL PHYSICS AND SOLID STATE OPTICS

In October 2014, Ulf Peschel became a chairholder at the Institute of Solid State Theory and Optics (WS), where he is currently the institute’s director. Prof. Peschel is a Senior Fellow of the Optical Society of America.

RESEARCH AREAS

Ulf Peschel has been working in the field of optics for more than 20 years, both theoretically and experimentally, with a focus on integrated optics, nanophotonics, nonlinear dynamics, and electromagnetic modeling. He currently investigates optical fiber systems, where discreteness is realized in the temporal domain, and where gain and loss can be applied in a balanced manner obeying parity-time (PT) symmetry. He is currently working on the efficient implementation of codes simulating light-matter interaction in semiconductor nanostructures based on finite-difference time domain (FDTD) codes coupled with semiconductor Maxwell-Bloch equations [8].

RESEARCH METHODS

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

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

TEACHING FIELDS

Prof. Peschel is currently giving lectures on the theoretical concepts of modern optics, including the linear and nonlinear aspects of light-matter interaction.

RECENT RESEARCH RESULTS

Some of Peschel’s current research activities focus on the time evolution of optical pulses in fiber systems. Together with his group “Nonlinear Optics and Nanophotonics (NONA)”, and for the first time, he realized a discrete system in the time domain and investigated time discrete temporal solitons [1]. He currently studies optical systems with balanced gain and loss, which may allow for the formation of fractal patterns [2], and if they obey parity-time (PT) symmetry, also for sudden-phase transitions and unidirectional invisibility [3]. Recently, the group observed the first PT-symmetric optical solitons [4]. Prof. Peschel’s research in the field of nanophotonics focuses on metamaterials, photonic crystals and plasmonic structures. Together with his co-workers, he developed new methods to characterize highly focused beams [5], and explored the optical response of dielectric-plasmonic crystals [6]. For the first time, his group realized the excitation of sub-wavelength plasmonic gap-waveguides and of plasmonic nano-circuitries via nanoantennas [7]. Modelling activities focus on the efficient implementation of codes simulating light-matter interaction in semiconductor nanostructures based on finite-difference time domain (FDTD) codes coupled with semiconductor Maxwell-Bloch equations [8].

OPTICAL DIAMETRIC DRIVES

Newton’s third law demands that, for every action, there is an equal and opposite reaction. If for some reason, one of the masses of two mutually attracting particles is negative as $m = -m$, both bodies will indefinitely accelerate in the same direction while keeping a constant distance among themselves (see Figure a).

Quite recently, we have reported the first experimental demonstration of this intriguing effect for pulses propagating in a nonlinear optical mesh lattice. Pulses circulating in two coupled fiber loops of different lengths (see Figure b) experience a band structure with two bands of opposite curvature or group velocity dispersion (see Figure c). Similar to two particles with opposite masses, pulses from different bands accelerate in the same direction due to the action of nonlinear cross-phase modulation (see Figure d). As a result, a bound state experiencing perpetual acceleration is established, provided that the power in both field distributions is appropriately chosen [Wimmer et al. Nature Phys. 9, 780 (2013); Batz and Peschel, Phys. Rev. Lett. 110, 193901(2013)].
ADRIAN N. PFEIFFER

JUNIOR PROFESSOR OF ATTOSECOND LASER PHYSICS, INSTITUTE OF OPTICS AND QUANTUM ELECTRONICS

Prof. Pfeiffer holds a Carl Zeiss endowed Junior Professorship at the Institute of Optics and Quantum Electronics of the Friedrich Schiller University Jena.

RESEARCH AREAS
In his research Prof. Pfeiffer targets the measurement and control of quantum dynamics on the attosecond time scale. Research interests include:
- quantum optics with attosecond pulses in strong fields
- strong field induced multiple ionization
- coherent valence electron motion in strong fields
- attosecond pulse generation
- optical spectroscopy of attosecond dynamics
- high-harmonic spectroscopy

TEACHING FIELDS
Prof. Pfeiffer's teaching encompasses introductory lectures in experimental physics for Bachelor's degree students and advanced courses in modern optics for Master's degree students. He gives courses on:
- experimental physics (classical mechanics and thermodynamics)
- experimental physics (electrodynamics and optics)
- attosecond laser physics

RESEARCH METHODS
The experimental methods target the characterization and manipulation of atoms and molecules on the attosecond time scale. Examples include:
- XUV spectroscopy
- momentum imaging
- pump-probe spectroscopy

RECENT RESEARCH RESULTS
The interest of the research group focuses on new directions in attosecond science, such as fast processes in bulk dielectrics. Attosecond metrology of condensed matter and signal processing are very exciting new directions in attosecond science, because there is the potential to produce great discoveries of both fundamental importance and great technological relevance. Most methods of attosecond science (especially those based on photoelectron detection) are not applicable to bulk solids. Therefore, new methods need to be developed.

A new method was developed which delivers time-resolved information about strong-field processes that occur in dielectric solids during one laser cycle [1]. The method is based on the well-known retardation of a probe pulse in the presence of a strong pump pulse. The retardation of a probe pulse in a strong-field pumped, bulk dielectric is measured with sub-cycle resolution in the pump-probe delay. A close-to-collinear alignment of pump and probe beams facilitates the detection of sub-cycle dynamics.

After the interaction in the bulk sample, the probe and the reference pulses are focused head-on into a custom cuvette containing a fluorescent solution (Fluorescein). The fluorescence is imaged with a microscope objective onto a CCD camera. Through two-photon fluorescence, the temporal overlap of the probe and the reference pulses is mapped to the spatial domain: the spatial location of the maximum fluorescence shifts in space upon temporal retardation of the probe pulse (see figure).


ATTOCLOCK MEASUREMENTS OF IONIZATION TIMES
One of Prof. Pfeiffer’s important activities during the past few years has been the measurement of ionization times with the attoclock method [Pfeiffer et al., Chem. Phys. 414, 84 (2013)]. The attoclock makes use of intense few-cycle laser pulses with close-to-circular polarization. After ionization, the electrons are accelerated in the remainder of the laser pulse. The angle of electron emission is synchronized to the rotating electric field vector and hence gives time information in fractions of the laser period time. Reading the angle of electron emission is similar to reading the hands of an analog clock, but with a precision of a few tens of attoseconds. Precise measurements of the ionization dynamics in single and double ionization have been made and the influence of multielectron effects has been revealed.
Raman spectroscopy for biomedical diagnostics

Innovative spectroscopy and imaging approaches for:
- Fundamentals of physical chemistry
- Optical coherence tomography
- Second harmonic generation (SHG) microscopy
- Multi-photon excited fluorescence microscopy
- UV/Vis absorption spectroscopy
- Steady state fluorescence spectroscopy
- Optical coherence tomography

Recent Research Results

The Biophotonics Group has made significant progress towards the application of Raman spectroscopy as point-of-care test for a fast classification and identification of single microorganisms. Such a fast and reliable identification of microorganisms without the need of time-consuming pre-cultivation steps is extremely important in medicine for a quick diagnosis of infectious diseases or in food, pharmaceutical, chemical, water and waste industry [1-6]. The application of Raman spectroscopy as point-of-care test requires chip-based sampling methods offering the opportunity to handle small sample volumes and to apply sample preparation steps. Here, the Biophotonics Group introduced innovative chip-based bacterial isolation strategies out of complex sample matrices (e.g. body liquids, food, water) [7].

Another focus of the Biophotonics Group is the Raman spectroscopic detection of cell and tissue pathologies [8]. Here, the medical focus lies on the determination of the tumor type and grade and a better delineation of tumor margins. It could be shown that the combination of Raman approaches with other spectroscopic technologies is very beneficial for addressing the aforementioned unmet medical needs. The group introduced a combined Raman /FLIM (Fluorescence lifetime imaging microscopy) fiber optical probe for in-vivo tissue screening [9]. Here, FLIM allows for a fast tissue area pre-segmentation and location of the points for Raman spectra acquisition. Furthermore it has been demonstrated how the combination of CARS (coherent anti-Stokes Raman scattering), SHG (second harmonic generation) and two-photon excited autofluorescence (TPEF) enables the characterization of the morphochemistry of frozen section biopsy specimens. To extend the applicability of this multimodal CARS/TPEF/SHG imaging approach for in-vivo tissue screening suitable optical fiber based probes for an endoscopic access of certain body regions requires further development. The Biophotonics Group has presented a novel CARS imaging fiber probe integrated into a compact fiber, consisting of 10,000 coherent light guiding elements, preserving the spatial relationship between the entrance and the output of the fiber [10]. Therefore the scanning procedure can be shifted from the distal to the proximal end of the fiber probe and no moving parts or driving current are required to realize in vivo CARS endoscopy.

Clinical Microbial Raman Analysis from Sepsis Pathogens Recovered from Body Liquids

Sepsis is a major reason of death worldwide. The successful treatment of sepsis relies on timely identification of the pathogen and its antibiotic resistance pattern to select the appropriate antibiotic treatment as early as possible. We could demonstrate the unique potential of Raman spectroscopy to bypass time-consuming cultivation procedures enabling an identification of sepsis pathogens directly out of body liquids (urine, sputum, ascites) in less than three hours. This has been achieved by developing an automated Raman setup for use in clinics (BioParticle Explorer) together with innovative pathogen isolation strategies (e.g. a dielectrophoresis Raman chip). Not only the identification has been realized, but also the characterization of bacteria-drug interaction as a first step towards antibiotic susceptibility testing. Changes in the bacterial Raman spectra due to antibiotic treatment can be identified already after 30 minutes of treatment.
Dr. Rothhardt is head of the Soft X-ray Spectroscopy and Microscopy Group at the Helmholtz-Institute Jena and a member of the extended board of directors of the Helmholtz Institute Jena.
CHRISTIAN RÜSSEL

PROFESSOR OF GLASS CHEMISTRY, OTTO-SCHOTT-INSTITUT

Prof. Rüssel is a full professor at the Otto Schott Institute for more than 20 years. He is Chairman of the Committee Physics and Chemistry of Glasses of the German Society of Glass Technology and a board member of the German Society of Glass Technology. In 2014, he obtained the title Dr. h. c. from the University of Chemical Technology and Metallurgy in Sofia and the Marin-Drinov-Medal of the Bulgarian Academy of Science.

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RESEARCH AREAS
His research is focused on various technical glass types and glass-ceramics, their preparation, structure and properties, and liquid state. Other areas are:
• technical glasses: high-modulus fibre glasses and glasses with adapted rheology
• crystallization of glass, preparation of glass-ceramics: fundamentals of nucleation and crystal growth, nano glass ceramics and interface controlled crystallization, oriented crystallization and glass-ceramics with special mechanical and optical properties
• optical materials: optical glasses with nanocrystalline inclusions, optical fibres and fiber amplifiers, luminescence glasses and active laser glasses
• polycrystalline zinc sulphide as an infrared material
• new zero thermal expansion materials

TEACHING FIELDS
• glass, glass technology
• ceramics and other inorganic non-metallic materials
• recycling
• materials characterization

RESEARCH METHODS
• glass melting in high quality, glass crystallization
• characterization of melts at high temperatures: rheology, UV-VIS-NIR spectroscopy,
• scanning electron microscopy and transmission electron microscopy, electron backscatter diffraction, laser scanning microscopy
• spectroscopy (UV-vis-NIR, FTIR, fluorescence) and x-ray diffraction
• characterization of mechanical and electrical properties

RECENT RESEARCH RESULTS
Luminescent Glasses and Laser Glasses

The most recent project in the field of luminescent materials is entitled ‘Angepasste LASer-und Konvertergläser für photonische Anwendungen – ALASKA’ (engl. Adapted Laser Glasses and Optical Converters for Photonic Applications). The project is done in close cooperation with the Institute of Optics and Quantum Physics (Prof. Paulus, Prof. Kaluza and Dr. Hein). The objective of the project is to combine the good thermo-mechanical properties of various types of glass with advantageous luminescence properties as high luminescence efficiency and long luminescence lifetimes. The main focus is on high-power laser applications, but such glasses can also be used for all other applications that need light conversion.

Polycrystalline ZnS
Polycrystalline ZnS is prepared by a physical vapour deposition process from metallic zinc and H2S. This work is conducted with Vitron GmbH, Jena. These materials are studied using x-ray diffraction and electron backscatter diffraction [1]. The latter is carried out inside a scanning electron microscope and enables to determine the crystalline phase in a spot of few nm and also the orientation of the crystals. The produced material is highly textured and heavily twinned. The crystallographic [1 1 1]-direction is oriented parallel to the growth direction.

Optical materials with nano crystalline inclusions
If a crystalline phase is precipitated from a multicomponent glass, the viscosity around the formed crystal will either decrease or increase. If the latter is the case, a highly viscous layer around the growing crystals is formed which hinders further crystal growth [3]. This offers a possibility to generate glass-ceramics with tiny crystals and narrow size distribution. The present work is focused on systems from which alkaline earth or rare earth fluorides can be crystallized. New photo-thermal refractive (PRT) glasses, irradiated by UV light and then thermally treated, are an application of prior importance. In the irradiated regions, nanocrystalline CdF2 is precipitated and the refractive index is smaller than in non-irradiated regions. These new PRT glasses can be used for the preparation of holograms and they exhibit 10 times larger differences in the refractive index than conventional PRT glasses. Other applications arise from new glasses with nanocrystalline precipitations of K2ZnF7 or ZnF2. For the first time, transition metal fluorides were crystallized from glasses [4]. By contrast to other rare earth or alkaline earth fluorides, they are suitable as a host for other transition metals. Nickel doped KZnF3 was crystallized showing a broad fluorescence in the wavelength range from 1200 to 2400 nm.

HIGH-ENERGETIC COLOR CONVERSION IN YTTRIUM ALUMINUM GARNET
For the first time, Ce3+ doped yttrium aluminium garnet was crystallized from a silicate glass using the surface crystallization. The YAG layer exhibits intense green luminescence when irradiated with UV light. When illuminated with blue light from LEDs, the transmitting light is converted to white light. The material shows a much higher temperature stability than conventional materials consisting of phosphors embedded in polymers. This enables much higher energy densities.

FELIX SCHACHER

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

Since 2010, Prof. Schacher’s research group at the Friedrich Schiller University Jena operates at the interface of organic, physical, and macromolecular chemistry. He has received the Hermann-Schneid-Fellowship of the German Chemical Society (GDCh) in 2013 and is also a member of the Jena Center for Soft Matter (JCSM) and the Fachgruppe Makromolekulare Chemie of the German Chemical Society (GDCh).

RESEARCH AREAS

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

- controlled/living polymerization techniques
- stimuli-responsive block copolymer membranes
- hierarchy and compartmentalization in block copolymer materials
- design and manipulation of interfaces, in particular within organic/inorganic hybrid materials
- morphological investigations using a combination of imaging and scattering techniques

TEACHING AREAS

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

- the fundamentals of polymer chemistry
- the synthesis and characterization of block copolymers
- self-assembly and supramolecular chemistry
- polymers in materials science

RESEARCH METHODS

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

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

RECENT RESEARCH RESULTS

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

In another study, we use thiol-terminated, polyether-based amphiphilic block copolymers with a hydrophilic poly(ethylene oxide) (PEO) segment and a second crosslinkable block of either poly(furfuryl glycidyl ether) (PFGE) or poly(ally glycidyl ether) (PAGE) as ligands for Au nanoparticles. In both cases, direct reduction of (PFGE) or poly(ally glycidyl ether) (PAGE) as ligands leads to Au NPs with a block copolymer shell which can be crosslinked using either Diels–Alder reactions for the PFGE segment or hydrosilylation chemistry targeting the PAGE segment. In this way, shell-crosslinked Au-NPs with enhanced stability against ligand exchange reactions in the presence of competitive ligands like alkyll thiols could be prepared [2].

Further, we use amphiphilic diblock terpolymers for the preparation of free-standing integral asymmetric membranes via nonsolvent induced phase separation (NIPS) processes. The diblock terpolymers consist of a hydrophobic poly(styrene-co-isoprene) block and a hydrophilic segment of poly(N,N-dimethylaminoethyl methacrylate). The materials are synthesized either via nitroxide mediated polymerization or living anionic polymerization. The NIPS process is used for the fabrication of porous diblock terpolymer membranes where the membrane morphology can be influenced by several parameters such as the applied solvent mixture, open time, or relative humidity. The resulting anisotropic membranes exhibit pH- and temperature-dependent water flux and pore sizes. UV-induced crosslinking of the isoprene part of the membrane matrix can be used to enhance membrane stability against solvents or to simply improve handling [3].

ALEXANDER SCHILLER

JUNIOR PROFESSOR AT THE INSTITUTE FOR INORGANIC AND ANALYTICAL CHEMISTRY

Professor Schiller holds a junior professorship position and is currently supported by a Heisenberg grant from the German Research Foundation (DFG). He is involved in the DFG research unit FOR 1738 Heme and Heme Degrading Products (HHEP). He is also a member of the Center of Medical Optics and Photonics and a member of the Jena Center for Soft Matter. Prof. Schiller is an associate editor of the journal Reviews in Inorganic Chemistry.

RESEARCH AREAS

Prof. Schiller’s research focuses on biomimetic signal transduction incorporating methods from the areas of materials- and bio-inorganic photochemistry and supramolecular analytical chemistry. Research thrusts include:

• supramolecular inorganic chemistry
• inorganic analytical chemistry
• research skill development for scientists (www.schillermertens.de)

RESEARCH METHODS

Prof. Schiller’s laboratories can perform advanced synthesis of small molecules and polymer materials. His research also includes chemometrics and basic programming techniques. The following analytical methods and equipment are available and utilized in these laboratories:

• fluorescence and UV-Vis spectroscopy using a Varioskan plate reader (Thermo Fisher) and a Specord S 600 (Analytik Jena)
• electrochemical detection of nitric oxide (NO) and carbon monoxide (CO)

TEACHING FIELDS

Prof. Schiller’s teaching activities involve inorganic chemistry courses for Bachelor’s and Master’s degree students, as well as student teachers. He holds lectures and gives courses in:

• molecular logic and computing using sensors and molecular probes for bioanalytes in water
• materials- and bio-inorganic photochemistry and supramolecular inorganic chemistry
• photo-inducible nitric oxide (NO) and carbon monoxide (CO)
• inorganic analytical chemistry
• molecular logic and computing using sensors and molecular probes for bioanalytes in water
• research skill development for scientists

RECENT RESEARCH RESULTS

The Schiller group developed the concept of embedding water-insoluble, photoactive nitrosyl- and carbonyl metal complexes into nanoparticles and fibrous polymer non-wovens [1-4]. For this process, nitric oxide (NO) and carbon monoxide (CO) are released into the surrounding medium via light stimulation of the nanoparticles. As a result, for example, manganese carbonyl complexes in electrospun poly(L-lactide-co-D,L-lactide) fibers revealed nanoporous morphologies. Irradiation with blue light triggered a CO release from the non-wovens, thereby eradicating biofilms with methicillin-resistant Staphylococcus aureus. These non-wovens are currently being investigated as potential antibacterial wound compressions. Finally, a remote-controlled CO release has also been attained with optical fibers.

FURTHERMORE, the Schiller group uses a two-component sensing concept based on anionic fluorescent dyes as reporters, and boronic acid-appended bipyrindinium salts as receptors. Analyte targets are sugars, nucleotides and anions in water. [5] In addition, real-time label-free fluorescent enzyme assays have been developed for sucrose phosphorylase, phosphoglucomutase and β-glucosidase [6]. The assays are suitable for high-throughput screening of novel carbohydrate enzymes for industrial applications.

SUGAR COMPUTER

A method to integrate an (in principle) unlimited number of molecular logic gates to construct complex circuits has been developed by the Schiller group. Logic circuits such as half- or fulladders can be reinterpreted by using the functional completeness of the implication function (IMP) and the trivial FALSE operation (see figure, part a). The molecular gate IMP is represented by a fluorescent boronic acid sugar probe [Elstner et al., J. Am. Chem. Soc., 134, 8098 (2012)]. An external wiring algorithm translates the fluorescent output from one gate into a chemical input appearing on microtiter plates for the next gate (see figure, parts b,c). This process was demonstrated on a four-bit full adder and by playing tic-tac-toe [Elstner et al., Angew. Chem. Int. Ed., 53, 7339 (2014) and Elstner et al., J. Chem. Inf. Model., 55, 1547 (2015)].
MARKUS A. SCHMIDT

PROFESSOR OF FIBER OPTICS AT THE LEIBNIZ INSTITUTE OF PHOTONIC TECHNOLOGY

Markus Schmidt is full professor at the Friedrich Schiller University Jena since 2012 and leads the research group Fiber Sensors at the Leibniz Institute of Photonic Technology. His main research directions are photonics, plasmonics, nonlinear optics, optofluidics and biophotonics, material science and liquid dynamics.

RESEARCH AREAS
Prof. Schmidt currently focusses his research on nano-photonic optical fibers by placing nano- and microstructured elements into and onto fibers and using these hybrid multimaterial devices in various areas of optics, mainly in biophotonics. Current research interests include:

- propagation of light in novel fiber structures (e.g. hollow core and metamaterial fibers)
- optical metamaterials and metasurfaces
- plasmonics and near field-optics
- nonlinear light generation
- special materials in fibers (e.g. metals, chalcogenide or liquids)
- biosensing (e.g. in-fiber confocal nanoopect detection or fiber-based Paul traps)

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

- Photonic Materials – Basics and Applications
- Active Photonic Devices

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

- broadband mid-IR ultrashort pulse lasers
- fiber-drawing tower and lithography technology
- pressure-assisted melt infiltration
- scanning optical near-field microscopy
- various spectrometers, transmission setup, lasers and other light sources

RECENT RESEARCH RESULTS
Markus Schmidt has focused his research on the development of hybrid optical fibers which include nano- and microstructured elements either inside the fibers or on the end faces (conceptually shown in the figure). These fibers have found application in various areas of science such as nanoscale plasmonics, cylindrical polarization, nonlinear optics, biosensing, ultrashort pulse transportation, various spectrometers, transmission setup, lasers and other light sources.

By creating metallic nanowires in optical fibers, Schmidt and coworkers were able to excite spiraling planar surface plasmon modes in fibers [1, 2]. It was recently found that these modes are strongly influenced by geometric momenta, which only exists in the cylindrical geometry, which distinguishes them from simple planar plasmons [3]. These unusual and previously unknown excitations found application in several scientific areas and have been used to observe ultra-long range hybrid plasmonic modes [4], plasmonic supermodes [5] or plasmonic molecules [6]. Metallized fibers have also been used for in vivo electro-chemical glucose detection, for octave-wide azimuthal mode polarization and for fiber-based near field microscopy [7].

Moreover, hybrid fiber waveguides have been implemented by placing chalcogenide glasses [8, 9] or nonlinear liquids into the nanoholes of silica fibers, combining materials which cannot be drawn together in a drawing tower. Such hybrid waveguides have been used for effective photonic band gap guiding, nanoopect detection (e.g., viruses) and for octave-spanning supercontinuum generation in the mid-IR (a spectral regime not accessible with standard silica fibers) [10, 11]. Other research topics include fiber-based biosensing using nanostructured devices (e.g., light cage or integrated Paul traps) or the development of novel hollow core fibers [12].

SUPERMODES IN PLASMONIC FIBERS

Regular arrays of gold nanowires have been implemented by placing metallic wires of a hexagonal arrangement into Photonic Crystal Fibers (PCFs) [1]. Depending on the wire spacing, we could create an ultra-strong coupled plasmonic system with a modal coupling even larger than the attenuation of the individual plasmon. We observe the excitation of superplasmonic modes consisting of more than one hundred individual quadrupole spiral plasmons, all operating close to their modal cut-offs. The electromagnetic field patterns and the local orientation of the electric field vector, i.e. the nanoscopic polarization, have been measured with a spatial resolution better than 60 nm by using a new scanning near-field calibration technique [5]. A particular interesting feature of these modes is the emergence of two geometric momenta, which strongly influence the propagation properties of the plasmons and only exist in the curved geometry [3].

MICHAEL SCHMITT

ADJUNCT PROFESSOR OF PHYSICAL CHEMISTRY AT THE INSTITUTE OF PHYSICAL CHEMISTRY

Adjunct Professor Michael Schmitt is a research associate at the Institute of Physical Chemistry. He serves as Assistant Editor of the Journal of Biophotonics.

RESEARCH AREAS

Professor Schmitt’s research interests are focused on linear and nonlinear laser microspectroscopy for:
• biomedial tissue diagnosis (spectral histopathology)
• characterization of the interaction between low molecular molecules and biological target molecules
• derivation of structure-property and structure dynamical relationships of biomolecules and innovative materials

TEACHING FIELDS

Prof. Schmitt teaches classes in fundamental physical chemistry (for Bachelor’s and Master’s degree students in chemistry) and spectroscopy and imaging for Master’s degree students in chemistry and chemical biology.

RESEARCH METHODS

The laboratories led by Prof. Schmitt offer possibilities for linear and nonlinear laser spectroscopy by utilizing the following equipment:
• resonance Raman spectroscopy
• non-linear multimodal imaging, combining:
  - coherent anti-Stokes Raman (CARS) microscopy
  - stimulated Raman scattering (SRS) microscopy
  - second harmonic generation (SHG) imaging
  - multi-photon excited autofluorescence imaging

RECENT RESEARCH RESULTS

Multimodal nonlinear microscopy has matured during the past decades to become one of the key imaging modalities in the life sciences and biomedicine. This is due to the following unique capabilities:
• label-free visualization of tissue structure and chemical composition, high-depth penetration, intrinsic 3D sectioning, diffraction-limited resolution and low phototoxicity. In close cooperation with the University Hospital Jena, the Leibniz Institute of Photonic Technology and the Institute of Applied Physics, we research a multimodal imaging approach combining two-photon-excited fluorescence (TPEF), second harmonic generation (SHG) and coherent anti-Stokes Raman scattering (CARS) within the CH-stretch region. We could demonstrate the diagnostic potential of this label-free TPEF/CARS/SHG multimodal imaging approach compared to conventional histopathological images related to cancer and atherosclerosis [1-3]. To facilitate handling and interpretation of the image data, characteristic properties can be automatically extracted via advanced image processing algorithms.

Furthermore, we explored innovative technological concepts of image acquisition and sample illumination in order to further adapt the aforementioned multimodal imaging approach to adapt to clinical needs. In this context, we realized a fiber-based dual-focus time-demultiplexed SHG imaging approach, doubling the image acquisition time [4]. Here, SHG detection is performed sequentially, generating two individual images in one scan. During other research work, we investigated novel CARS illumination geometries via Bessel beam excitation [5, 6]. Bessel beam CARS can be used for axial profiling of multi-layered structures and for the enhancement of lateral resolution by a factor of up to 1.33. Finally, a widefield CARS vibrational phase imaging scheme allowing for non-resonant CARS background suppression has been recently introduced [7].

HIGH SPECTRAL RESOLUTION COHERENT ANTI-STOKES RAMAN SCATTERING IMAGING FOR CLINICAL DISEASE DIAGNOSTICS

In order to discern several biomolecules from each other, CARS microscopy needs to be performed at multiple spectral positions. This so-called multispectral CARS imaging allows for a precise investigation of tissue composition within the highly-congested C-H-stretching spectral region. This kind of imaging offers access to the discrimination of proteins from lipids by viewing their different ratios of methylene-to-methyl functional groups, respectively imaging tissue samples at two vibrational resonances characteristic of methylene and methyl groups, and analyzing the multispectral CARS images using a novel image analysis approach based on co-localization allows not only for a visualization of protein and lipid distribution, but also a correlation of spectrally distinct pixels with morphologic structures. This signifies the analysis of multi-contrast images with respect to the molecular origin of SHG and TPEF signals.

ULRICH S. SCHUBERT

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

Prof. Schubert is director of the Jena Center for Soft Matter (UCSM) and spokesman of the priority research area Innovative Materials and Technologies at the Friedrich Schiller University Jena. He received many awards including the Heisenberg-Fellowship of the DFG, the VICI Award of the Netherland Organization for Scientific Research, the Jan Pieter Lemstra Innovation Award of the Dutch Polymer Institute, the International BPG Award/Belgium and the ACS Division POLY Fellow Award/USA. Prof. Schubert is the head of the Laboratory of Organic and Macromolecular Chemistry.

Research Areas

Professor Schubert’s research areas cover the fields of polymers for lifesciences, polymers and energy as well as smart and stimuli-responsive polymers. His research thrusts include:

- metallo-supramolecular polymers
- polymer batteries
- tailor-made functional polymers and nanoparticles
- responsive materials
- organic solar cells and polymer LEDs
- high-throughput experimentation
- inkjet-printing and nanolithography
- optical metamaterials

Teaching Fields

Prof. Schubert’s teaching includes undergraduate courses as well as graduate courses involving state-of-the-art research. He gives courses in:

- organic chemistry
- macromolecular chemistry
- polymers and energy
- nanotechnology and nanostructured polymers

Recent Research Results

A core area of the Schubert group is the prototype fabrication of functional, micro- and nanostructured surfaces. Utilized experimental approaches cover e.g. inkjet printing technologies (for structure formation in the micrometer dimension range) and high-resolution chemical lithography. The latter approach utilizes self-assembled monolayers of initially chemically inert molecular precursors which can be chemically oxidized by a tip-mediated electrochemical oxidation reaction via the local application of bias voltage pulses. Due to the small tip dimensions of the scanning force microscope probe, oxidized areas can be as small as 10 nm or reach up to several hundred nanometers in line width. The exceptional advantage of this lithography technique is the possibility to generate a chemical contrast between the chemically inert n-octadecyl trichlorosilane (OTS) starting monolayer and the oxidized areas, featuring reactive polar groups such as, carboxylic acids. Thus, chemical reaction protocols can be applied to further build up nanostructures within the oxidized structures. This kind of addressability is hardly available in conventional nanolithographic fabrication schemes, since classical semiconductor nanofabrication relies mainly on topographical features and SOI technologies. With different nanofabrication steps such as the site-selective growth of polymer brushes by controlled living polymerization techniques, the fabrication of metallized structures, or the site-selective placement of metal nanoparticles, significant progress could be demonstrated by introducing a hierarchical, controlled formation of gap structures, thereby essentially taking advantage of all features of the developed electro-oxidative lithography approach. A highly controllable fabrication scheme was introduced to easily fabricate nanometric gap structures [1]. Its purpose was also to introduce efficient metalization routines in order to obtain electrodes, and, finally, to introduce a tailor-made bonding scheme within the gap structure for the subsequent application of self-assembly processes which would immobilize an individual nanoparticle precisely within the gap. Recent studies succeeded to transfer the lithography process to transparent ITO substrates [2].

Additional research topics addressed by Schubert’s group involve the synthesis of nanomaterials which include assemblies of metal nanoparticles or self-assembled copolymer particles in solution. Therefore, classical reaction schemes as well as new microwave synthesis approaches are the main thrusts of our developmental research. These have been successfully applied for the fast, easy and very inexpensive fabrication of carbon nanotubes, various carbon nanofibers, CNT functionalized glass fibers and corrector micropatterns [3] as well as nickel cermet sheets [4]. Additionally, microwave synthesis can be utilized for the synthesis of metal nanoparticles, this approach is currently being investigated for its ability to provide plasmonic nanostructures. Besides the previously introduced electro-oxidation lithographic approach, the integration of individual plasmonic nanoparticles within phase-separated polymer films, as well as the controlled assembly of particle aggregates of a defined size and shape are addressed, utilizing, among other approaches, microwave-synthesis techniques. The Schubert group’s research is based on a highly interdisciplinary background of its group members which consists of chemists, physicists, biologists and material scientists.


SequENTIAL Hierarchical Fabrication of NanoMetic Gap Structures

A conceivable way of establishing the hierarchical fabrication of complex architectures using electrooxidative nanolithography has been developed which relies on a multi-step oxidative and functionalization approach. Due to the highly controllable oxidation on OTS monolayers, selective oxidation at different levels of a multilayer structure can be achieved. This process includes the fabrication of a bilayer line consisting of a double layer of OTS molecules. The additional oxidation across this line results in the formation of an interrupted line where the bilayer is crossed. The functionalization of the newly created line introduces the possibility of fabricating a gap structure; the width of the gap is determined by the line thickness of the double-layer line. Creating a new binding site applying a longer voltage pulse within the gap creates a new binding site which can be used to selectively bind an individual nanoparticle. This process allows for full control of individual nanoobjects’ self assembly and of their reliable integration into nanoscopic circuits.
CHRISTIAN SPIELMANN

PROFESSOR OF QUANTUM ELECTRONICS AT THE INSTITUTE OF OPTICS AND QUANTUM ELECTRONICS

Prof. Spielmann is member of the board of directors of the Abbe Center of Photonics and of the executive board of the Abbe School of Photonics. Further, he is the speaker of the Graduate School for Advanced Photon Science at the Helmholtz Institute Jena. Besides his duties at the University, he serves as elected deputy speaker of the scientific advisory board of the Leibniz Institute of Photonics Jena, member of the board of trustees of the Fraunhofer Institute for Applied Optics and Precision Engineering Jena, and was co-founder of Femtolasers GmbH, one of the premiere manufacturers of ultra-fast laser systems. Prof. Spielmann served as executive director of the Abbe Center of Photonics until June 2013.

RESEARCH AREAS

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

- generation and amplification of ultrafast optical pulses and application in medicine
- nonlinear optics in structured materials
- generation of spatially and temporally coherent XUV radiation
- laser plasma physics for realizing x-ray sources and Raman amplifiers
- application of XUV radiation for functional imaging of nanoscale materials

TEACHING FIELDS

Besides lecturing in the field of optics, Prof. Spielmann is responsible for the Abbe School of Photonics’ doctoral seminar and the guest professor program. His lecture center on:

- atomic and molecular physics
- fundamentals of modern photonics
- XUV and x-ray optics
- modern methods of spectroscopy

RESEARCH METHODS

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

- spatial and temporal shaping of ultrashort pulses
- nonlinear optics for coherent XUV generation
- laser-based XUV and x-ray spectroscopy
- time-resolved photoelectron spectroscopy
- design and characterization of supersonic gas jets for laser plasma experiments
- setup for high resolution XUV imaging in reflection and transmission geometry

RECENT RESEARCH RESULTS

It is the dream of physicists, biologists, and chemists to follow atomic motions during chemical reactions or structural reorientation in real time. Although e.g. for chemical reactions could take place over a period of several days or months, the primary process, such as the breaking and formation of a chemical bond, take place on a femtosecond timescale. To observe the dynamics of these initial processes, experimental methods have been developed which include ultrafast optical spectroscopy and time-resolved x-ray spectroscopy. The major objective of the research in Prof. Spielmann’s group is to depict ultrafast processes in real time and in real space, i.e. realizing an ultrafast x-ray microscope. To reach this goal, it is first necessary to steer and control atomic motion with tailored light fields, and follow the subsequent changes with high resolution imaging or spectroscopy.

Owing to the enormous progress made in ultrashort pulse laser technology, producing bright short wavelength radiation via high harmonic generation (HHG) is an interesting approach for making “laser-like x-ray radiation” available to small university laboratories. The state-of-the-art laser-driven HHG sources also offer significant absolute values: high-energy photons emitted in few femtosecond to attosecond pulses, time scales that cannot be accessed by any other source and the x-ray pulses are perfectly synchronized to form a visible laser pulse. In recent years, his research group succeeded in demonstrating HHG radiation up to the keV range whereby the efficiency has been increased by the introduction of several quasi-phase matching schemes. Additionally, they recently presented the first experimental realization of a new x-ray laser schema based on parametric amplification of high-order harmonic radiation [1]. This kind of spatially and temporally coherent XUV light sources meet also the requirements for high resolution lensless imaging. In a recent collaboration with the groups of ACP principal scientists Limpert and Tünnermann, we were able to demonstrate a spatial resolution less than the illuminating XUV wavelength with a decent exposure [2]. Moreover we also succeeded in the first real-world application of these novel imaging techniques and were able to classify breast cancer cells without staining or any other complicated preparation technique [3].

Over the last few years, another promising approach towards a compact x-ray source has been investigated: the use of betatron radiation, emitted during laser-plasma interaction. When a high-intensity femtosecond laser pulse interacts with gas, electrons are accelerated and subsequently forced into transverse oscillation. From this relativistic electron motion (betatron radiation), we obtain a collimated beam of broadband x-ray radiation covering the range up to 20 keV. Our recently demonstrated betatron source paves the way for time-resolved XAS in the keV range [4]. Additionally, by engineering the target and the laser parameter, we have increased the photon flux, allowing a single shot measurement of an x-ray absorption spectrum, which substantially simplifies the measurements.

CANCER CELL CLASSIFICATION BY XUV COHERENT DIFFRACTION IMAGING

In cancer treatment it is highly desirable to classify individual cancer cells in real-time. The standard method is PCR which is costly and time-consuming. Here we present a different approach to rapidly classify cell types: We measure the diffraction pattern of coherent extreme ultraviolet (XUV) laser generated radiation that is scattered off a single cell. We demonstrate that these patterns can be used to distinguish different breast cancer cell types. Moreover, the outer shape of the object can be retrieved from the diffraction pattern with sub-micron resolution. For a proof-of-principle experiment MC77 and SKBR3 breast cancer cells were pipetted on gold-coated silica slides. The output of a laser driven XUV light source is focused onto a single unstained and unlabeled cancer cell, and the resulting diffraction pattern is measured in reflection geometry [5]. Using a more powerful laser even the classification of circulating tumor cells at a high throughput seems possible. This lab-sized equipment might allow fast classification of any kind of cells, bacteria or even viruses in the near future.

ISABELLE STAUDE

JUNIOR GROUP LEADER AT THE INSTITUTE OF APPLIED PHYSICS

Dr. Isabelle Staude joined the Abbe Center of Photonics in July of 2015 to establish a junior research group, dealing with functional photonic nanostructures. Prior to this she coordinated the experimental activities related to optical nanoantennas at the Nonlinear Physics Centre, Australian National University, where she also served the nanoplasmics stream found at the Australian Centre of Excellence CUDOS as Deputy Project Leader. She received her Ph.D. degree from the Karlsruhe Institute of Technology, Germany.

RESEARCH AREAS

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

• nanophotonics, -plasmonics, and -antennas
• high-index dielectric nanoparticles
• hybrid quantum systems and quantum emitters
• nanofabrication technology
• subwavelength optics
• metamaterials and photonic crystals

RESEARCH METHODS

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

• electron-beam lithography based nanofabrication
• linear and nonlinear optical spectroscopy
• time-resolved photoluminescence spectroscopy
• back focal plane imaging
• assembly of hybrid nanostructures via dry transfer
• assembly of hybrid quantum systems by selective surface functionalization

TEACHING FIELDS

In the 2015 fall semester, Dr. Staude teaches the graduate course on Nano Optics. During her course lectures, she is committed to sharing not only her knowledge, but also her fascination for optics at the nanoscale.

RECENT RESEARCH RESULTS

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

Recently we have focused on nanoparticles composed of highly transparent, high-refractive-index dielectrics. Such nanoparticles support localized electric and magnetic Mie-type resonances (see image), thereby providing a low-loss alternative to plasmonic nanostructures [1]. Most prominently, highly efficient functional nanosurfaces [2], e.g., for resonant wavefront shaping using liquid crystals [6]. Furthermore, we have studied the use of Mie-resonant all-dielectric nanoparticles as high-emission efficiency nanoantennas for spontaneous emission control [1, 7].

ALL-DIELECTRIC HUYGENS’ NANOSURFACES

Resonant optical nanostructures tailored to impose a spatially variant phase shift onto an incident wavefront have recently developed as a breakthrough concept for advanced wavefront engineering. However reflection and/or absorption losses, as well as low polarization-conversion efficiencies, pose a fundamental obstacle for achieving the high transmission efficiencies required for practical applications. We showed that all-dielectric nanostructures with high efficiency and full phase coverage in transmission can be realized at NR frequencies using arrays of silicon nanodisks with crossed electric- and magnetic dipole resonances. If these resonances are brought into spectral overlap, the nanodisks emulate the behavior of the forward-propagating elementary wavelets known from Huygens’ principle. All-dielectric Huygens’ nano-surfaces offer unique opportunities for flat optical devices including beam-steering, beam-shaping and focusing, as well as holography and dispersion control.

THOMAS STÖHLKER

RESEARCH AREAS
Prof. Stöhlker’s research interests are focused on electron dynamics in strong and even extreme fields, with particular emphasis of the effects of quantum electrodynamics (QED):
- experiments on bound-state QED and the atomic structure of few-electron ions at high-Z
- radiative processes in collisions of relativistic particles
- collision dynamics involving heavy ions
- light matter interaction in the strong-field regime
- application of advanced x-ray and electron-detector and spectrometer concepts

TEACHING FIELDS
Prof. Stöhlker’s teaching is focused on the physics of simple atomic systems, including the atomic structure, atomic collisions, and fundamental aspects such as QED and parity violation. He gives courses and seminars in:
- key experiments in modern atomic physics
- the interaction of high-energy radiation with matter

RESEARCH METHODS
Prof. Stöhlker runs sophisticated setups for photon, x-ray, electron, and ion spectroscopy which are used for the studies at storage rings, traps and synchrotrons, including:
- energy, time and spatially resolving detectors for x-ray imaging and polarimetry of hard x-rays
- x-ray spectrometers of transmission and reflection type
- micro calorimeters
- dense-cluster targets for H, He, Ne, Ar, Xe

RECENT RESEARCH RESULTS

ne- and two-electron ions provide an ideal testing ground for fundamental atomic structure theories, for the investigation of QED (self energy and vacuum polarization) as well as relativistic and correlation effects. Via spectroscopy of the x-ray transitions of the heaviest ions at the storage ring ESR in Darmstadt, the ground-state Lamb shift in hydrogen-like uranium was determined with an accuracy of 1% [1], providing the most stringent test of bound-state QED for one-electron systems in the strong field regime (~10^14 W/cm). Moreover, for He-like heavy ions, the simplest multi-electron systems, the specific two-electron contributions to the ground state ionization potential, as well as important spectroscopic information about the first excited state have been obtained [2]. Besides using x-ray spectroscopy and time-resolved x-ray imaging in polarization studies for the hard x-ray or y-ray regime, the application of Compton scattering is a further challenging topic, addressed in experiments by means of novel 2D strip or pixel detectors. These experiments focus on the study of photonic transitions of electrons in the strong-field domain (characteristic radiation, electron bremsstrahlung and recombination radiation) where spin effects are important and provide detailed information about the quantum dynamics in the strong-field domain [3, 4].

ALEXANDER SZAMEIT

JUNIOR PROFESSOR OF DIAMOND-/CARBON-BASED OPTICAL SYSTEMS AT THE INSTITUTE OF APPLIED PHYSICS

He is the head of the Junior Research Group Diamond-/Carbon-based Optical Systems at the Center for Innovation Competence »ultra-optics«. Prof. Szameit’s work was awarded several times, including, for example, with the thesis prize of the German Physical Society and the WLT Award of the German Society for Laser Technology.

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RESEARCH AREAS
Prof. Szameit’s research targets a variety of unconventional classical and quantum-optical phenomena on the micro- and nanoscales. Research thrusts include:
- photonicics in periodic structures
- optical quantum computing on a chip
- optics with complex fluids
- topological photonics
- complex free-space optics

RESEARCH METHODS
The laboratories led by Prof. Szameit offer a wide range of methods for the experimental characterization of photonic micro- and nanostructures:
- ultrashort laser systems (femto- and picosecond regime)
- fluorescence microscopy
- beam shaping devices
- time-resolved single photon microscopy
- characterization of nonlinear spatio-temporal dynamics

TEACHING FIELDS
Prof. Szameit’s teaching is devoted to the early involvement of young developing scientists in state-of-the-art research. He gives courses in:
- optical diffraction theory
- photonicics in waveguide arrays
- atomic and molecular physics
- fundamentals of microscopy

RECENT RESEARCH RESULTS
The diamond-optics group has recently demonstrated experimentally and theoretically that, by properly structuring a dielectric lattice, it is possible to realize a photonic topological insulator [1]. The discovery of topological insulators relying on spin-orbit coupling in condensed matter systems has created much interest in various fields, including in photonics. In two-dimensional electronic systems, topological insulators are insulating materials in the bulk, but conduct electric current on their edges such that the current is completely immune to scattering. However, demonstrating such effects in optics poses a major challenge because photons are bosons, which fundamentally do not exhibit fermionic spin-orbit interactions (i.e., Kramer’s theorem). Moreover, at optical frequencies the magneto-optic response is extremely weak, such that no quantum Hall effect can take place. Hence, a photonic topological insulator would have to rely on some other property. In our realized structure, light propagates through waveguides that are arranged in a honeycomb geometry, and topological protection is achieved in the transverse plane along the edges of the structure, around corners and defects without any scattering. We foresee applications of photonic topological insulators in advanced optical quantum computing, robust transport of photons and highly compact optical isolators.

Moreover, the diamond-optics group demonstrated an entangled so-called W-state with as much as 16 entangled channels [2], which doubled the previous world record of 8 entangled channels achieved in an arrangement of ultra-cold atoms. W-states are multipartite quantum states that are in generalized form a coherent superposition of N qubit states exhibiting equal probability amplitudes. The entanglement carried by these quantum entities has the remarkable property of being intrinsically robust to decoherence in one of the qubits. Hence, these states promise to be an exceptional tool in various advanced fields of research, such as secure quantum communication, quantum teleportation, and generating genuine quantum random numbers.


OPTICAL SIMULATION OF CHARGE CONSERVATION VIOLATION AND MAJORANA DYNAMICS

Ettore Majorana discovered in 1937 that Lorentz invariance permits not only the Dirac equation for describing the dynamics of relativistic particles, but also a similar equation, which bears his name today. However, this equation contains a continuous conversion of the particle into its charge conjugate counterpart, implying that the Majorana particle must be its own antiparticle, which is clearly unphysical except for neutral particles. Yet, such charge non-conserving processes could be relevant in theories beyond the Standard Model and their simulation in analogue physical systems has been proposed.

Recently, the diamond-optics group presented the experimental implementation of an analogue physical simulator, which permits the observation of the non-physical Majorana dynamics in the laboratory. To this end, coherent light propagation in a specifically designed waveguide lattice interferometer is employed. This approach makes use of the fact that the unphysical Majorana equation can be decomposed into two Dirac equations with masses of opposite sign, which are simulated in two parallel waveguide lattices. After a predefined evolution length the two lattices are recombined and the evolution of the Majorana wave function can be inferred from measurable intensities of the output light. Input state preparation, evolution and read-out are all realized within one compact optical chip (see Figure). The free-particle evolution as well as the unphysical operation of charge conjugation was simulated, such that a strong impact of the charge conjugation on the dynamics of the simulated particle could be observed. These results represent the first implementation of a simulator for an unphysical phenomenon. These findings are anticipated to open the field of simulation of exotic particles beyond the Standard Model and to substantially widen the scope of future investigations with respect to yet unknown benefits from unphysical operations in other fields such as quantum information processing.
ADRIANA SZEGHALMI

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

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

RESEARCH AREAS

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

- low and high refractive indices
- porous materials
- advanced nanostructuring technologies
- interference coatings
- functional coatings for diffractive optical elements
- space & laser technology, spectrometry, UV-VIS, DUV, EUV, BEUV, x-ray optics
- understanding chemical reactions during nucleation and film growth

TEACHING FIELDS

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

RESEARCH METHODS

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

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

RECENT RESEARCH RESULTS

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

High and low refractive index dielectrics are essential for refractive and diffractive optics. High optical quality and excellent reproducibility have been achieved for SiO2, Al2O3, HfO2, Ta2O5, and TiO2 coatings. The deposition of titanium dioxide (TiO2) using/via ALD was thoroughly investigated [1] and the optical properties are depicted in Figure 1.

Encapsulated gratings show higher efficiency levels than do binary gratings. An improved encapsulation process was developed based on atomic layer deposition and microstructuring. A detailed description of the process is published in [2]. Figure 2 shows a cross-sectioned FIB-SEM image of an encapsulated grating designed for TM-polarized light at wavelengths of 1000…1064 nm. The first SiO2 layer on top of the grating is realized via/using ALD deposition to ensure a high degree of chemical bonding to the substrate. Fortunately, no boundary is visible between the grating top and the encapsulation layer. The Ta2O5 and SiO2 layers serve as antireflection coatings made via PVD. The system is in accordance with the ISO9211-4:2007-03 norm pertaining to the adhesive strength of the layers. The grating efficiency is 97.5% at 1030 nm. The encapsulated grating has a much higher efficiency (up to 8%) than conventional binary gratings in the given spectral range.


![Figure 1: Dispersion of TiO2 layers deposited via plasma enhanced atomic layer deposition (PEALD), and (b) thermal atomic layer deposition (thermal ALD) at different deposition conditions. The plasma-enhanced atomic layer deposition of TiO2 was performed at different oxygen gas flow rates, plasma powers and deposition temperatures. Thermal depositions were carried out at deposition temperatures of 150 °C, 150 °C, and 200 °C. Refractive indexes are based on the cosh-Greensitz model, chosen for its suitability to the obtained ellipsometric data.](image)

![Figure 2: A FIB-CUT SEM cross-section image of an encapsulated grating. The three layer system on the grating is only 700 nm thick for use as an antireflection coating.](image)

EMBEDDED GRATING

Another approach to enhance the diffraction efficiency of transmission gratings is by embedding silica gratings into a high refractive index material. During this study, the TiO2/Al2O3 nanolaminate has been applied to functionalize a binary-fused silica grating for highly efficient transmittance gratings between 1000...1060 nm wavelengths which are designed for TM or TE-polarized light. Figure 3 depicts a FIB-cut SEM cross-section image of an embedded grating designed for TM-polarized light. The nanolaminate’s fine structure can be viewed in the cross-section image, and proves that a pinhole-free embedding is possible via ALD. This is essential due to the fact that even tiny air pockets will drastically reduce the grating’s efficiency. The transmission efficiency at the 1st diffraction order is 95% at the 1030 nm wavelength, being confirmed using RCWA simulations with the real grating parameter. The grating’s period of 343 nm is nearly half of the incident wavelength for very high dispersion of fs pulses using the chirped pulse amplification method (CPA).
ANDREAS TÜNNERMANN

PROFESSOR OF APPLIED PHYSICS,
INSTITUTE OF APPLIED PHYSICS

Prof. Tünnermann is the director of the Institute of Applied Physics, the Fraunhofer Institute for Applied Optics and Precision Engineering and the Helmholtz Institute in Jena. He is a member of the board of directors of the Abbe Center of Photonics and currently its executive director. Andreas Tünnermann has been distinguished with many prizes and awards, among them the Gottfried Wilhelm Leibniz, the Schott-award of the Zeiss Foundation, the Leibinger-Innovation award of Trumpf Laser, and the Thuringian Order of Merit. In 2015 he was awarded with a prestigious European Research Council (ERC) Advanced Grant for boosting novel concepts of nanostructure technology and amplification of ultrashort laser pulses. In addition, the employees of the Fraunhofer Institute for Applied Optics and Precision Engineering conduct application-oriented research in the field of optical technology for industry and as part of publicly funded joint projects. The various work groups headed by Andreas Tünnermann represent the entire process chain from system design to the production of prototypes for optical, opto-mechanical and opto-electronic systems. Close cooperation with the Institute for Applied Physics is of strategic importance in scientific projects as well as in training young scientists. In recent years, solutions incorporating light for markets such as energy, environment, communication, information, security, medical and automotive technologies have been addressed.

TEACHING FIELDS
Prof. Tünnermann teaches students in the courses B.Sc. Physics, M.Sc. Physics and M.Sc. Photonics. He offers lectures in:
- fundamental experimental physics
- atomic and molecular physics
- laser physics and ultra-short physics

RESEARCH AREAS
Andreas Tünnermann is leading one of the most creative research groups in modern optics and photonics worldwide. His main research interests include scientific and technological aspects associated with the tailoring of light. Research topics are the design and manufacturing of novel photonic devices and their application for light generation, amplification, steering and switching, including:
- functional optical surfaces and coatings
- micro- and nanooptics
- optical fibers, waveguides, and fiber lasers
- imaging and projection systems

RESEARCH METHODS
The laboratories of the Institute of Applied Physics and of the Fraunhofer Institute Jena offer world-unique facilities, including the following to name only a few:
- 860 m² class 10,000 to 10 clean room area
- electron beam lithography (Vistec SB350) and related nanostructure technology
- ultra-precise diamond tools for 3D pattern generation

NEXT GENERATION EARTH OBSERVATION OPTICS
Optical instruments for multispectral imaging and remote sensing of the earth atmosphere from outer space are the key to the spatially resolved determination of chemical constituents from the soil or air layers. The dispersion-free optical imaging over a wide spectral range in telescopes and spectrometers is based on mirror optics. Their optical performance strongly depends on the mirror quality and their precise alignment within the beam path. Recent research has focused on the development of diffraction-limited optical systems for the IR and the VS based on aspheres and freeform mirrors. Ultra-precision machining of aluminum alloy based mirrors and subsequent finalizing steps allowed for the fabrication of high-performance mirrors. An efficient optical alignment was achieved using diamond-machined interfaces. The diffraction-limited imaging quality of the efficiently mounted optics is the enabling technology for high-resolution spaceborne telescopes and spectrometers.

RECENT RESEARCH RESULTS
The Institute of Applied Physics headed by Prof. Tünnermann carries out fundamental and applied research in the fields of micro- and nanooptics, fiber and waveguide optics and ultrafast optics. It develops novel optical materials, elements and concepts for information and communication technology as well as process technology including material processing and optical measurement techniques.

Current research topics - dealt with by over 120 scientists - concern function, design and fabrication of micro- and nano-optical elements. Those are e.g. resonant grating structures, metallic and dielectric polarizers, opto-optical switching processes in integrated optics and effective media. Also light propagation and nonlinear light-matter interaction in micro- and nanostructures, optical meta-materials and photonic crystals are examined. Andreas Tünnermann is the German spokesperson for the International Research Training Group RTG 2101 of the German Research Foundation (DFG) with Canadian partners.

Further research fields are application of femtosecond laser pulses, e.g. for material processing and micro- and nanostructuring, development of new concepts for solid state lasers such as fiber lasers, fiber-optic pulse shaping and amplification of ultrashort laser pulses.
ANDREY TURCHANIN

PROFESSOR OF PHYSICAL CHEMISTRY, FACULTY FOR CHEMISTRY AND EARTH SCIENCES

Professor Turchanin received his Ph.D. in Solid State Physics (1999) from the National University of Science and Technology, Moscow. In 2000, he was awarded an Alexander von Humboldt Research Fellowship for studies of wetting phenomena at the Faculty of Chemistry and Biosciences at the Technical University of Karlsruhe, Germany. In October of 2004 he joined the University of Bielefeld and completed his habilitation on "Novel phenomena and materials in two-dimensional (2D) inorganic and organic systems" in 2010. In 2012, Prof. Turchanin was awarded a Heisenberg Fellowship from the German Research Foundation (DFG), and in 2013 the Bernhard-Hell-Preis from the University of Regensburg for his research achievements in the field of emerging 2D materials. Since December 2014, Prof. Turchanin is leading the group of Applied Physical Chemistry and Molecular Nanotechnology at the Institute of Physical Chemistry of the Friedrich Schiller University Jena.

RESEARCH AREAS

Professor Turchanin's research interests focus on novel two-dimensional (2D) materials, their hybrids, and van der Waals heterostructures. Topics include:

- self-assembled monolayers
- electron irradiation induced chemical reactions
- carbon nanomembranes with atomic thickness
- graphene and related 2D materials (e.g. MoS2)
- carbon electronics for sensing and energy storage
- biofunctional surfaces and interfaces
- nanolithography, ultramicroscopy and nanofiltration

TEACHING FIELDS

Prof. Turchanin gives courses in:

- basics of physical chemistry
- molecular nanotechnology and nanobiotechnology
- nanospectroscopic and microscopic methods
- nanolithography and microfabrication

RESEARCH METHODS

Based on equipment available in the Turchanin laboratory, and in collaboration with other research groups, the Turchanin group employs the following techniques and methods:

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

RECENT RESEARCH RESULTS

Andrey Turchanin’s research activities concentrate on 2D carbon materials (graphene, carbon nanomembranes, organic monolayers) and their hybrids with other low-dimensional materials for novel applications in nanoelectronics, nanosensor, energy-saving and nanobiotechnology. This interdisciplinary work embraces (i) growth of these materials with tailored physical and chemical properties [1-3], (ii) their nanolithography and microfabrication [4], (iii) their implementation in novel functional nanostructures for both fundamental studies and applied research [5, 6].

A novel route to ultrathin, freestanding 2D carbon materials has been developed (see Figure). Such an approach enables both the generation of 2D materials with adjustable properties as well as their scalable production, paving the way for a variety of applications in nanoscience and nanotechnology.


ATOMALLY THIN INORGANIC AND ORGANIC MEMBRANES

Atomically thin sheets offer many properties that are not provided by conventional materials. These sheets open new prospects for fundamental and applied research in such areas as quantum mechanics, photonics, flexible electronics, nanosensor, nanobiotechnology, catalysis, ultrafiltration and ultramicroscopy, to name only a few. The included figure represents two freestanding gratings made of 1nm-thick bipyphenyl-based carbon nanomembrane (CNM) (left) and of 0.4nm-thick single-layer graphene (right). Imaging was performed via scanning electron microscopy and helium ion microscopy, respectively. The CNM and graphene gratings were recently utilized as ultrathin-matter wave interferometers to study the basics of quantum mechanics – wave-particle duality – by studying the interference phenomena of massive organic molecules at these extreme dimensions [6].
Professor Wipf is director of the Institute for Theoretical Physics and speaker of the Jena-based research training group GRK 1523 Quantum- and Gravitational Fields. He is an organizer of the annual Saalburg summer school Foundations and Methods in Theoretical Physics in Wolfsdorf/Thuringia. Prof. Wipf is a member of the honorary advisory board of Annalen der Physik.

In his research Prof. Wipf investigates systems with many or infinitely many degrees of freedom under extreme conditions – in very strong electromagnetic and gravitational fields, at high temperatures and at high densities. He aims to gain understanding in and calculation of physical effects like Hawking radiation in strong gravitational fields, dispersive and absorptive vacuum effects in quantized electrodynamics, phase transitions in the early universe and the phase diagram of strongly coupled gauge theories, and in particular of quantum chromodynamics. Research thrusts include:

- the interaction of matter with photons and gauge particles
- vacuum polarization effects and particle production in strong fields
- phases and phase transitions at high temperatures and ultra-high densities
- quantum field theories with supersymmetry

In his research Prof. Wipf uses a wide range of modern and powerful theoretical methods and equipment to investigate strongly correlated physical systems and systems under extreme conditions. These include:

- high-performance simulations at local clusters and computer centers
- Monte-Carlo renormalization group methods
- functional renormalization group equations
- properties of supersymmetric systems

We study and calculate the potential energy between heavy, charged particles in gauge theories. Our work is based on an improved and efficient, local, multilevel Lüscher-Weisz algorithm with an exponential error reduction to accurately measure expectation values of non-local loop variables. We show that, at intermediate distances, the force between the heavy particles is constant due to a flux tube which develops between the two particles. Actually, we demonstrate that the strength of the force depends linearly on the Casimir invariant. When the distance between the particles is increased, the flux tube breaks and the energy stored in the flux is converted into newly produced particles. The produced light particles shield the two heavy particles such that at larger separations, the inter-particle force falls off with the distance. The results from the quantum field theory group in Jena are the most accurate ones obtained thus far. With the improved exponential error reduction method developed in Jena, it was possible to calculate signals decreasing by more than fifty orders of magnitude.

Furthermore, the research group is studying phases and phase transitions in cold and dense gauge systems. During this process, it has constructed a new type of order parameter similar to the magnetization in ferromagnets to detect new phases. The new analytical and numerical results have led the research group to conjecture a new state of cold dense matter for which a previously unseen Fermi-Einstein condensation has now been realized. The transitions between different well-understood sectors are keys to the solution of the celebrated Silver-Blaze problem in theoretical particle physics when applied to ultra-dense matter [2].

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

**RESEARCH AREAS**
Prof. Wondraczek’s research activities span all areas of experimental glass science with particular focus on the exploration and development of new glass and glass ceramic compositions and surface modification techniques. His main thrusts are the optical and mechanical properties of multi-component oxide, oxynitride and oxyhalide materials. He is exploring structure-property relations with the ultimate objective of providing tools for materials design. Such tools are, e.g., potentials and spatial relations between constituents, the atomistic level [1, 2], the generic design of specific short- and mid-range topology, packing density, molecular interactions occurring at surfaces and their consequences on meso- and macro-scale processes. These tools are aimed at targeting material applications in the fields of optics and photonics, as well as in energy technologies, architecture and for the automotive industry. Specifically, we are exploring and developing strategies with the goal of attaining glassy materials with superior mechanical resistance [1], optical fiber glasses and magneto-optical glasses [2, 4] and glasses for light conversion purposes [5]. At present, optical amplification for broadband telecommunication and new fiber lasers, solar spectral conversion for improved harvesting of sunlight and inorganic materials for transient optical storage via spectral hole burning techniques represent the thrusts of the group’s activities in optics.

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

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

**TEACHING FIELDS**
Prof. Wondraczek teaches interdisciplinary materials science where he connects materials engineering, physics and chemistry. He gives courses in:

- solid state kinetics and thermodynamics
- composite and nanocomposite materials
- glasses and optical materials

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

**ULTRABROAD LUMINESCENCE FROM Ni2+-DOPED GLASS CERAMICS**
Nanocrystalline Ba-Al titanate precipitates from supercooled TiO2-BaO-Al2O3 melts via catalyzed volume nucleation in the presence of Ni2+, forming a Ba13Ti2O19 hollandite-type lattice. Ni2+ species are incorporated into the crystalline environment in octahedral coordination. Hollandite formation is accompanied by precipitation of tetrahedrally distorted BaTiO3, as a secondary crystal phase, where crystal species and habitus can be clearly distinguished by dark-field transmission electron microscopy. The resulting photoluminescence due to spin-allowed relaxation of 3T2g(3F) to 3A2g(3F) in Ni2+ occurs from three distinct emission centers. Photoluminescence spans the spectral range of 1.0 to 1.6 μm. Besides red and IR laser excitation, NIR photoemission can be excited with conventional near UV light sources, i.e. in the spectral range of 350-420 nm. Decay kinetics as well as the position and shape of the emission band can be adjusted by dopant concentration and synthesis conditions [5].

**REFERENCES**
UWE D. ZEITNER

DOCENT AT THE INSTITUTE OF APPLIED PHYSICS AND THE FRAUNHOFER INSTITUTE FOR APPLIED OPTICS AND PRECISION ENGINEERING

Dr. Zeitner is the head of the research group Advanced Fabrication Technologies for Micro- and Nano-Optics at the Center for Innovation Competence »ultra optics«. Simultaneously, Dr. Zeitner is the head of the Center for Advanced Micro- and Nano-Optics (CMN-Optics) at the Fraunhofer Institute for Applied Optics and Precision Engineering, Jena.

RESEARCH AREAS
Dr. Zeitner’s research is focused on novel fabrication technologies for optical microstructures with a strong emphasis on the exploitation of their application potential. Research fields include:
- high-resolution lithographic fabrication technologies
- diffraction-based lithography
- gratings for high end applications
- high-precision computer-generated-holograms (CGHs)
- broadband refractive and diffractive optics
- mode shaping of semiconductor lasers by intracavity diffractive structures

TEACHING FIELDS
Dr. Zeitner gives lectures in:
- optical modeling and design
- micro- and nanostructure technology for optics

RESEARCH METHODS
The laboratories led by Dr. Zeitner offer a wide range of methods for the fabrication and characterization of optical micro- and nanostructures. Methods and facilities include:
- electron beam lithography on large areas
- optical and grayscale lithography
- various reactive ion etching (RIE) facilities
- scanning electron microscopy (SEM) and focused ion-beam (FIB)
- tactile and optical profilometry
- optical characterization lab

RECENT RESEARCH RESULTS
H is research group has demonstrated the use of diffractive photo-masks in mask-aligned lithography for the realization of high-resolution microstructures with feature dimensions well below 500 nm [1]. They proposed different exposure strategies for periodic and non-periodic structures, developed proper design methods for the diffractive photo-masks and considerably improved the mask-aligned exposure tools. The increase in achievable resolution is in the range of a factor between 2 and 10, depending on the particular structure [2].

Parallel to the activities in the field of novel photolithography methods, the group is working to improve the photo-mask fabrication technology via special exposure regimes in the field of electron beam lithography. Together with the company Vistec, a new cell-projection writing principle has been incorporated into the work group’s electron beam writer. It allows for an extremely time-efficient exposure of complex high-resolution patterns [3]. This is not only a mandatory step for the fabrication of diffractive photo-masks, but also enables both the realization of optical metamaterials and, alternatively, effective refractive index structures on large areas.

An additional thrust of the CMN-Optics Group is the development of novel grating concepts for spectroscopic- and laser applications [4]. High diffraction efficiencies near the 100% limit at large bandwidths and, at the same time, low wave-front errors and stray light levels are the main challenges for these devices. Such gratings are required e.g. for the stretching or compression of ultra-short laser pulses or in high-performance spectroscopy methods for space missions such as GAIA, Sentinel-4 (see figure), or CarbonSat.

EFFECTIVE MEDIUM BLAZED GRATING FOR SPACE MISSION
A novel type of grating has been successfully developed for the radial-velocity spectrometer of ESA’s GAIA satellite. It is based on an effective refractive index structure made of subwavelength features with variable local fill factor fabricated using electron beam lithography techniques and reactive ion etching. The grating structure is not resolved by the wavelength in the operational spectral band, but the light experiences the structures as an effective refractive index structure. The local fill-factor variation is optimized to achieve a high, polarization-independent diffraction efficiency. The special grating approach was the key factor in fulfilling the extremely stringent requirements for diffraction efficiency, wave-front quality, and stray light performance. It was the first real-world application of an effective medium grating on areas with an extent larger than 200 mm.
