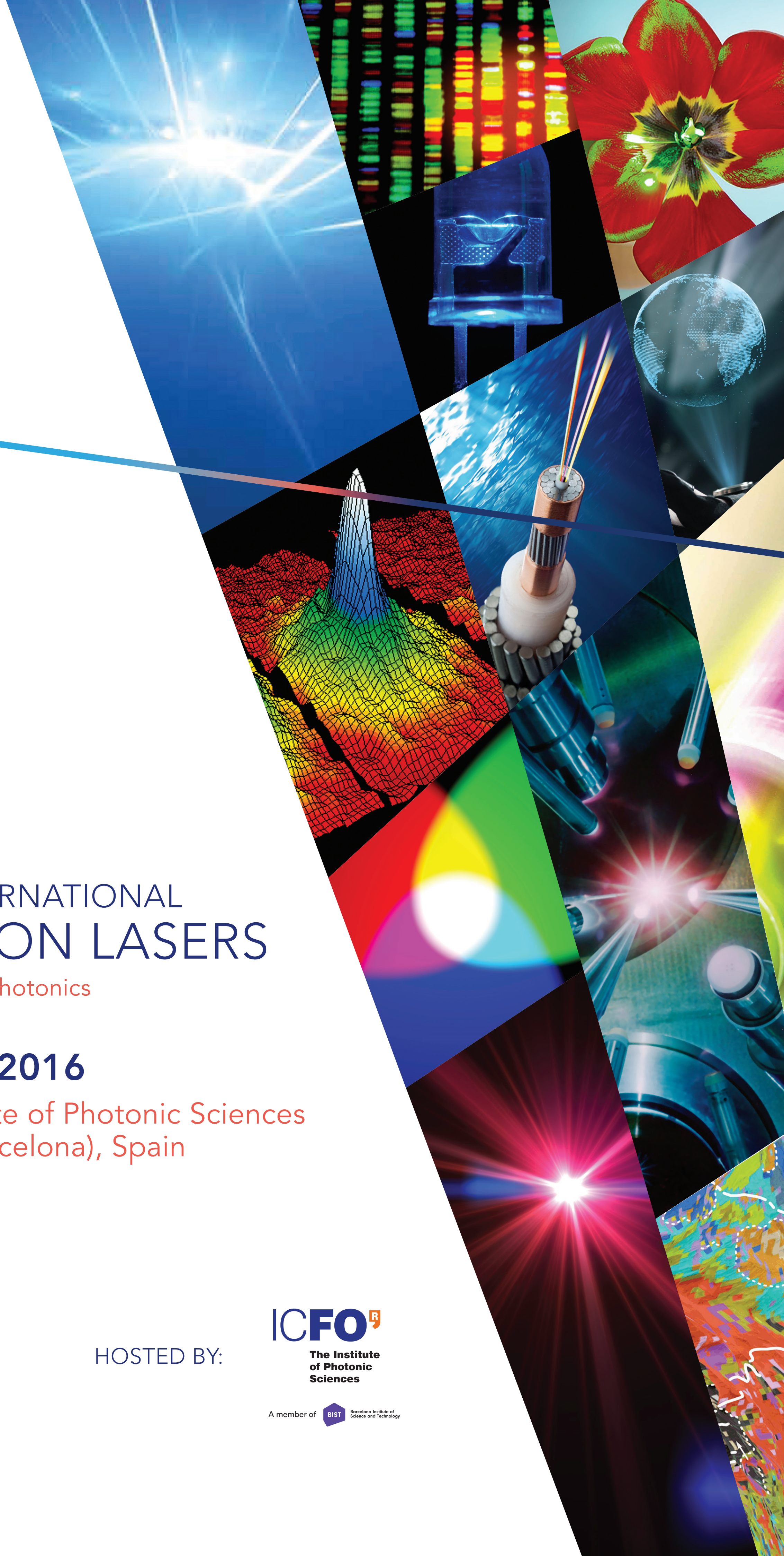
OSA The Optical Society 100 Since 1916



OSA Foundation

SIEGMAN INTERNATIONAL SCHOOL ON LASERS

Co-founded by IPG Photonics

JULY 24–29, 2016

ICFO–The Institute of Photonic Sciences
Castelldefels (Barcelona), Spain

HOSTED BY: ICFO The Institute of Photonic Sciences

A member of BIST Barcelona Institute of Science and Technology

July 2016

Dear Siegman Laser School Participants,

Welcome to the 2016 OSA Foundation Siegman International School on Lasers. The 2016 Siegman School is organized at ICFO – the Institute of Photonic Sciences, in Castelldefels (Barcelona), Spain following its launch at Stanford, USA in 2014 and the 2nd issue in Amberg, Germany in 2015. The school brings together almost 100 graduate students from 35 countries to learn about basics and advances in optics and photonics using lasers, from international leaders both in academy and industry.

We are grateful to the many renowned lecturers who have accepted to teach at the school:

- Lene Vestergaard Hau, Harvard University, Cambridge, USA
- Philip Bucksbaum, Stanford University, USA
- John Collier, Central Laser Facility, Rutherford Appleton, UK
- Eric Van Stryland, CREOL, Univ. Of Central Florida, USA
- Martin Wolf, Fritz Haber Institute. Berlin, Germany
- Jean-Claude Diels, Univ. of New Mexico, Albuquerque, USA
- Scott Diddams, NIST, Boulder, Colorado, USA
- Marcus Motzkus, Univ. Heidelberg, Germany
- Rick Trebino, Georgia Inst. Technology, Atlanta, USA
- Mark Stockman, Georgia State University, Atlanta, USA
- Peter Fendel, Thorlabs, Newton, USA

The lectures will touch upon a wide variety of topics in laser science and applications, ranging for basics to specific highlights, applications and lasers in industry: ultrafast laser spectroscopy, nonlinear optical materials, laser pulse diagnostics, frequency combs, high power laser systems, ultrafast X-ray lasers, quantum control, quantum optics, nanophotonic lasing, and applications in cosmology, chemistry and biology.

The lecturers will be around the whole week, ready to answer any questions. Be alert and actively participate in the special discussion sessions.

ICFO is honoured to host the Siegman School and make the ICFO facilities available to all School participants. Siegman students will have the opportunity to experience ICFO from first hand; to interact with ICFOnians and ICONS, the OSA-student's chapter; and to visit the specialized photonic laboratories and facilities.

The School is complemented by an ample social program. During the week in Barcelona, capital of Catalonia, students will sense the medieval roots, culinary tradition, legendary architecture, creative modernism, mountains, beaches, Mediterranean, sportive drive, international and dynamic mentality, which permeate the Catalan spirit.

Several people and institutions have helped to make this School happen. In particular we thank the OSA Foundation, IPG Photonics, NSF, the staff of ICFO – the Institute of Photonic Sciences, AgencyLB and the Siegman steering and program committees.

We wish you all an inspiring and instructive week at ICFO. With almost 100 students from 35 countries you will surely meet many new colleagues and expand your network of friends all over the world. Rarely you will find such opportunity to learn about laser science and its applications. Quoting our ICFO director; Prof. Dr. Lluis Torner: "Get the most out of it".

Have an enriching week,

The Local Program Committee:
Niek van Hulst (Chairman)**, Jens Biegert, Majid Ebrahim-Zadeh, Rob Sewell, Dolors Mateu, Jordi Roca Solà, Lorena Balsells.**

Agenda

SUNDAY, 24 JULY

	Student Housing Check-In at Pius Font i Quer Residence Hall
17:00 – 20:00	**School Registration** **Welcome Reception at ICFO Picnic Area (Meet at the entrance to ICFO)**

MONDAY, 25 JULY — ICFO AUDITORIUM

8:30	**Registration at ICFO Auditorium**
9:00	**Opening Session Siegman School**
9:30	**Martin Wolf**, Fritz Haber Institute, Berlin, Germany Ultrafast Laser Spectroscopy and Applications to Dynamics at Interfaces and Solids I
10:15	**Discussion**
10:45 – 11:15	**Coffee**
11:15	**Eric Van Stryland**, CREOL, Univ. of Central Florida, USA Characterization and Modeling of Nonlinear Optical Materials for Various Applications I
12:00	**Rick Trebino**, Georgia Inst. Technology, Atlanta, USA Measuring Everything You've Always Wanted to Know About a Light Pulse I
12:45	**Discussion**
13:15 – 14:30	**Lunch**
14:30	**Scott Diddams**, NIST, Boulder, Colorado, USA Laser and Parametric Optical Frequency Combs I
15:15	**Jean-Claude Diels**, Univ. of New Mexico, Albuquerque, USA Frequency combs to detect phase changes of 10-8: Intracavity Phase Interferometry I
16:00	**Discussion**
16:30 – 17:00	**Refreshments**
17:00	**Lene Vestergaard Hau**, Harvard University, Cambridge, USA Quantum Control of Light and Matter
17:45	**Discussion**
18:15	**Poster set-up P01-P26**
19:00	***Canal Olímpic de Catalunya:** **Team building activity: boat building, canoeing, tug of war, kayak** *Swimwear, towel, flip-flop and sun cream are needed for this activity.* **Followed by dinner (Meet at the ICFO Auditorium to walk over)**

Agenda

TUESDAY, 26 JULY — ICFO AUDITORIUM

9:00	**Marcus Motzkus**, Univ. Heidelberg, Germany Multimodal Quantum Control Micro-Spectroscopy I
9:45	**Lene Vestergaard Hau,** Harvard University, Cambridge, USA The Art of Taming Light: What We Can Learn from a Bacterium.
10:30	**Discussion**
11:00 – 11:30	**Coffee**
11:30	**Siegman School Group Photo** (Wear your Siegman School 2016 T-Shirt)
11:40	**Students' Poster Session I (P01-P26)**
13:15 – 14:30	**Lunch**
14:30	**Rick Trebino**, Georgia Inst. Technology, Atlanta, USA Measuring Everything You've Always Wanted to Know About a Light Pulse II
15:15	**Martin Wolf**, Fritz Haber Institute. Berlin, Germany Ultrafast Laser Spectroscopy and Applications to Dynamics at Interfaces and Solids II
16:00	**Discussion**
16:30 – 17:00	**Refreshments**
17:00 – 18:30	**Lab Tour I**
19:00	***ICFO Activity & Castellers – Human castles** **Followed by dinner at "Moments" (Meet at ICFO Auditorium)**

Agenda

WEDNESDAY, 27 JULY — ICFO AUDITORIUM

9:00	**Lasers & Industry** **Peter Fendel**, Thorlabs, Newton, USA Applications of Femtosecond Lasers: from Astro Combs to Deep Brain Imaging
9:45	**Discussion**
10:15 – 10:45	**Coffee**
10:45 – 11:00	**Poster Set-up – P27-P54**
11:00	**Mark Stockman**, Georgia State University, Atlanta, USA Latest Progress in Spasers (Plasmonic Nanolasers) I
11:45	**Eric Van Stryland**, CREOL, Univ. of Central Florida, USA Characterization and Modeling of Nonlinear Optical Materials for Various Applications II
12:30	**Discussion**
13:00	***Siegman excursion by bus: (Leaving from ICFO building)** **Visit to Món Sant Benet** **- Tour of Foundation Alícia, with a culinary demonstration** **- Monastery Tour: Middle Ages and Modernism.** **- Dinner at Món Sant Benet**

THURSDAY, 28 JULY — ICFO AUDITORIUM

9:00	**Jean-Claude Diels**, Univ. of New Mexico, Albuquerque, USA Frequency combs to detect phase changes of 10-8: Intracavity Phase Interferometry II
9:45	**Marcus Motzkus**, Univ. Heidelberg, Germany Multimodal Quantum Control Micro-Spectroscopy II
10:30	**Discussion**
11:00 – 11:30	**Coffee**
11:30	**Students' Poster Session II (P27-P54)**

CONTINUED ON NEXT PAGE

Agenda

THURSDAY, 28 JULY continued — ICFO AUDITORIUM

13:15 – 14:30	**Lunch**
14:30	**John Collier**, Central Laser Facility, Rutherford Appleton, UK High Power Lasers – in all their senses !
15:15	**Philip Bucksbaum**, Stanford University, USA Ultrafast X-ray Lasers: What are they? What are they good for? I
16:00	**Discussion**
16:30 – 17:00	**Refreshments**
17:00 – 18:30	**Lab Tour II**
20:00	***BBQ at Beach Club Kauai, Gava Mar (Meet at ICFO Auditorium)**

FRIDAY, 29 JULY — ICFO AUDITORIUM

9:00	**Philip Bucksbaum**, Stanford University, USA Ultrafast X-ray Lasers: What are they? What are they good for? II
9:45	**Scott Diddams**, NIST, Boulder, Colorado, USA Laser and Parametric Optical Frequency Combs II
10:30	**Discussion**
11:00 – 11:30	**Coffee**
11:30	**Mark Stockman**, Georgia State University, Atlanta, USA Latest Progress in Spasers (Plasmonic Nanolasers) II
12:15	**Discussion**
12:45	**Lunch**
	***Bus to Barcelona (Departing from the ICFO Auditorium)**
15:00	**Guided tour through Barcelona**
17:00	**Closing Ceremony at Antoni Gaudí's La Pedrera** **- Cocktail** **- Poster Award** **- OSA Centennial**

*All Extra Activity information can be found in detail on our program website. Should you have any questions please ask the Siegman School staff.

Speaker Bios & Abstracts

Martin Wolf studied physics at the Freie Universität Berlin and received his PhD there in 1991with Gerhard Ertl for studies on surface photochemistry. After a postdoc period in Austin, Texas, with Mike White, he set up a laboratory for femtosecond surface spectroscopy at the Fritz-Haber-Institute of the Max-Planck Society and was also a visiting scientist at IBM Yorktown Heights with Tony Heinz. In 2000 he was appointed full professor for experimental physics at the Freie Universität Berlin. Since 2008 he has been director of the Physical Chemistry department at the Fritz-Haber-Institute in Berlin.

His research focuses on the dynamics of elementary excitations at surfaces, interfaces and in solids, ultrafast photoinduced dynamics and transient electronic structure in correlated materials, interfacial electron transfer, photochemistry and vibrational spectroscopy at interfaces.

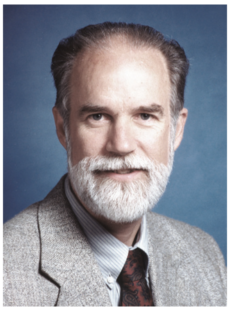
Ultrafast Laser Spectroscopy and Applications to Dynamics at Interfaces and Solids

TIME: MONDAY, 09:30 AND TUESDAY, 15:15

This lecture will provide a brief introduction into ultrafast laser spectroscopy and introduce several spectroscopic techniques aiming to elucidate elementary processes at interfaces and in solids driven by ultrafast optical excitation. The goal of such studies is a mechanistic understanding of the coupling between different degrees of freedom (electrons, spins, lattice) of materials and their role in non-equilibrium processes. One example for coupling between electronic and phonon degrees of freedom are phase transitions in charge-density wave (CDW) materials where at low temperature a periodic lattice distortion leads to an opening of an electronic gap at the Fermi surface. Ultrafast optical excitation can induce non-equilibrium phase transitions as well as electronic and geometrical structure changes in complex materials on femtosecond timescales. Further examples will address displacive excitation of coherent phonons and chemical reactions of adsorbed molecules (surface femtochemistry) induced highly non-equilibrium electron distributions in metals.

All these processes are typically accompanied by pronounced changes of the electronic structure. I will discuss different experimental approaches to probe such tran¬sient electronic structure changes on ultrafast timescales, in particular, (i) time- and angle-resolved photoelectron spectroscopy (trARPES, (ii) time-resolved THz spectroscopy and THz pumping and (iii) time-resolved resonant inelastic x-ray scattering (trRIXS).

Speaker Bios & Abstracts



Eric Van Stryland received his physics PhD working at the Optical Sciences Center, University of Arizona, 1976 and joined the University of North Texas. He joined the start of CREOL in 1987, become director in 1999, and its first Dean in 2004, The College of Optics and Photonics. He is a Fellow and past President of OSA (2006), awarded the R.W. Wood Prize (2012), a Fellow of APS, IEEE and SPIE and past Board member of LIA. He graduated 37 Ph.D.'s published >300 papers primarily in the field of nonlinear optics (e.g. Z-scan, nonlinear Kramers-Kronig, cascaded second-order nonlinearities), and is Pegasus Professor and Trustee Chair at the University of Central Florida in Orlando.

Characterization and Modeling of Nonlinear Optical Materials for Various Applications

TIME: MONDAY 11:15 AND WEDNESDAY 11:45

It is necessary to fully understand the nonlinear optical (NLO) response of materials in order to design useful nonlinear optical devices, e.g. all-optical switches. I will present the basics for understanding nonlinear absorption (NLA) and nonlinear refraction (NLR) from various mechanisms in a variety of materials including semiconductors, solvents, organic dyes and even gases. I will also draw similarities between the light-matter interactions in different materials. I will then describe methods that have been developed to unravel the various NLO responses that can occur simultaneously in materials that have plagued the literature leading to apparent orders of magnitude discrepancies. Among these are Z-scan which can separately determine the sign and magnitude of NLA and NLR, but is a single-beam method that gives no information about the temporal response. Complementary to this are pump-probe techniques for NLA which yield the temporal response. Our new beam-deflection technique gives the temporal response of the NLR. Its high sensitivity (as small as λ/20,000 phase shift) allows measurements of gases. The spectral properties of these various NLO responses is key to their understanding. The nonlinear Kramers-Kronig relations linking the dispersion of nonlinear refraction to the spectrum of nonlinear absorption will also be described in an intuitive manner. This leads us to look at nondegenerate nonlinearities, i.e. where the frequencies used for these 2-photon processes are unequal. For semiconductors we find that by going to extremely nondegenerate photons (energy ratio ~10), the 2-photon absorption is enhanced by 2-3 orders of magnitude. This allows for 2-photon LIDAR imaging and even the possibility of a 2-photon laser.

Speaker Bios & Abstracts

Rick Trebino received his B.A. from Harvard University in 1977 and his Ph.D. degree from Stanford University in 1983. His dissertation research involved the development of a technique for the measurement of ultrafast events in the frequency domain using long-pulse lasers by creating moving gratings. He continued this research during a three-year term as a physical sciences research associate at Stanford. In 1986, he moved to Sandia National Laboratories in Livermore, California. There he developed Frequency-Resolved Optical Gating (FROG), the first technique for the measurement of the intensity and phase of ultrashort laser pulses. In 1998, he became the Georgia Research Alliance-Eminent Scholar Chair of Ultrafast Optical Physics at the Georgia Institute of Technology, where he currently studies ultrafast optics and applications.

Prof. Trebino has received several prizes, including the SPIE's Edgerton Prize, and he was an IEEE Lasers and Electro-Optics Society Distinguished Lecturer. He is a Fellow of the Optical Society of America, the American Physical Society, the American Association for the Advancement of Science, and the Society of Photo-Instrumentation Engineers. His interests include adventure travel, archaeology, and primitive art.

Measuring Everything You've Always Wanted to Know About a Light Pulse

TIME: MONDAY, 12:00 AND TUESDAY 14:30

The vast majority of the greatest scientific discoveries of all time have resulted directly from more powerful techniques for measuring light. Indeed, our most important source of information about our universe is light, and our ability to extract information from it is limited only by our ability to ***measure*** it.

Interestingly, the vast majority of light in our universe remains ***immeasurable***, involving long pulses of relatively broadband light, necessarily involving ultrafast and extremely complex temporal variations in their intensity and phase. So it is im-portant to develop techniques for measuring, ever more completely, light with ever more complex submicron detail in space and ever more complex ultrafast variations in time. The problem is severely complicated by the fact that the timescales involved correspond to the shortest events ever created, and measuring an event in time seems to require a shorter one, which, by definition, doesn't exist!

Nevertheless, we have developed simple, elegant methods for completely meas-uring these events, yielding a light pulse's intensity and phase vs. time and space. One involves making an optical spectrogram of the pulse in a nonlinear optical medi-um and whose mathematics is equivalent to the two-dimensional phase-retrieval problem—a problem that's solvable only because the Fundamental Theorem of Alge-bra fails for polynomials of two variables. And we have recently developed simple methods for measuring the ***complete spatio-temporal electric field*** [E(x,y,z,t)] of an arbitrary light pulse—even for a single pulse.

Speaker Bios & Abstracts

Scott Diddams is a Fellow of the National Institute of Standards and Technology (NIST) where he carries out experimental research in the fields of precision spectroscopy and metrology, nonlinear optics, microwave photonics and ultrafast lasers. He received the Ph.D. degree from the University of New Mexico in 1996. From 1996 through 2000, he did postdoctroral work at JILA, NIST and the University of Colorado. Together with colleagues at JILA, he built the first self-referenced, octave-spanning optical frequency comb and used it to produce carrier-envelope phase stabilized pulses, as well as carry out direct optical to microwave measurements. Since 2000, Diddams has been a staff member at NIST. With his group and colleagues at NIST, he has continued the development of optical frequency combs and pioneered their use in optical clocks, tests of fundamental physics, novel spectroscopy in the visible and mid-infrared, and ultralow noise frequency synthesis. In recent years, special attention has been given to high repetition rate laser-based and microresonator frequency combs, which are being explored for applications in microwave photonics and astronomy. Dr. Diddams is a recipient of the Department of Commerce gold and silver medals for "revolutionizing the way frequency is measured" as well as the Presidential Early Career Award in Science and Engineering (PECASE) for his work on optical frequency combs. He is a Fellow of the Optical Society of America and the American Physical Society, as well as a Professor Adjoint at the University of Colorado.

Laser and Parametric Optical Frequency Combs

TIME: MONDAY, 14:30 AND FRIDAY, 09:45

In the past decade we have witnessed significant advances associated with the frequency stabilization of the comb present in the output of a mode-locked femtosecond laser. While proving itself to be fantastically successful in its role as the "gears" of optical atomic clocks, the optical frequency comb has further evolved into a valuable tool for a wide range of applications, including ultraviolet and infrared spectroscopy, frequency synthesis, optical and microwave waveform generation, astronomical spectrograph calibration, and attosecond pulse generation, to name a few. In this talk, I will trace our progress on some of these applications, and highlight the laser and nonlinear optics advances that have made them possible. In addition, I will offer a perspective on the challenges and opportunities for frequency combs that might lie ahead. Along these lines, I will describe research into a new class of parametric frequency combs that are based on monolithic microresonators. Such microcomb devices are compatible with semiconductor processing and could be further integrated with other photonic and electronic components on a silicon chip. In the future, such technology may bring the precision, flexibility, and measurement power of frequency combs to a wide range of new and emerging applications beyond the confines of the research laboratory.

Speaker Bios & Abstracts

Jean-Claude Diels is presently professor of Physics and ECE at the University of New Mexico, and staff member at the Center for High Technology Materials. His education and experiences include work in Germany, the Netherlands, France, and many U.S. locations (Phillips Research Laboratories in Eindhoven, Netherlands, Max Planck Institute in G¨ottingen, Germany, CEA Saclay, and the University of Bordeaux). He was student of Professor E. L. Hahn at the UC, Berkeley, Research Associate Professor at USC's Center for Laser Studies, and Professor of Physics at the University of North Texas in Denton, Texas.

Professor Diels has been active in the area of coherent interactions and ultrashort laser pulses, leading to the textbook: "Ultrafast Phenomena". He invented the interferometric autocorrelation in 1978 (Proceedings Picosecond Phenomena I, Springer, p. 117), and demonstrated for the first time intracavity pulse compression with prisms in 1983 (Opt. Lett. 8;4). He co-authored with Ladan Arissian the book "Lasers, the power and precision of Light", a layman guide to laser physics celebrating the 50th anniversary of the laser. He was honored with the 2006 Excellence in Engineering Award of OSA for his work on Intracavity Phase Interferometry.

Frequency combs to detect phase changes of 10^{-8}: Intracavity Phase Interferometry

TIME: MONDAY, 15:15 AND THURSDAY, 09:00

The conventional laser gyro is inhomogenously broadened (He-Ne laser to prevent gain competition), single mode, stable cavity, no scattering element to prevent lock-in. These limitations do not exist if a mode-locked laser with two intracavity pulses is used. The measurement — a beat frequency between the two output pulse trains — can be used to detect any physical quantity that produces an optical phase shift (acceleration, displacement, nonlinear index of refraction, electro-optic effect, magnetic field, phonon detection, etc . . .). Intracavity Phase Interferometry is using the laser as an interferometer of near infinite finesse. The noise in the two output combs is correlated, resulting in a sub-Herz beat note bandwidth, even when the individual mode of each frequency comb is several MHz wide. Intracavity scattering elements do not produce a dead band (except if inserted at a crossing point of the two pulses). Because frequency combs have equally spaced teeth, the beat note is a moving fringe pattern with 100% visibility. The theory and implementation of frequency combs applied to intracavity phase interferometry will be reviewed.

With the recent success of LIGO in detecting a gravitational wave, there has been a surge of interest in amplifying the response of intracavity phase interferometry by socalled "slow light" or "fast light". We demonstrate large changes in response sensitivity of intracavity phase interferometry, related to dispersion, but not to pulse velocity. We find thus the label "fast" or "slow" light to be a misnomer. Inserting a Fabry-Perot etalon in a mode-locked laser, we show that the group velocity of the intracavity pulses can be modified, but there is no corresponding change in intracavity phase interferometry beat note response. The intracavity etalon produces a nested frequency comb, of which the mode spacing (inverse of pulse velocity) can be varied. The very counter-intuitive properties of this nested comb will be explained. The uncoated etalon acquires the finesse of the laser cavity, resulting in a resonant dispersion that modifies the beat note response.

Speaker Bios & Abstracts

Lene Vestergaard Hau is the Mallinckrodt Professor of Physics and of Applied Physics at Harvard University, and received her Ph.D. from the University of Aarhus, Denmark. Her Ph.D. work was in theoretical condensed matter physics, and she has worked in the fields of experimental and theoretical optical, atomic, and condensed matter physics. Her research has included studies of ultra-cold atoms and superfluid Bose-Einstein condensates, channeling of high-energy electrons and positrons in single crystals with experiments at CERN, Brookhaven, and Lawrence Livermore National Laboratory. She is a MacArthur Fellow, and was elected to the American Academy of Arts and Sciences, the Royal Swedish Academy of Sciences, and the Royal Danish Academy of Sciences and Letters. She is a recipient of numerous awards, including the Ledlie Prize, Harvard University's highest faculty award, as well as the Ole Roemer Medal, and the Richtmyer Memorial Lecture Award. In 2010, she was appointed National Security Science and Technology Faculty Fellow by the Secretary of Defense, and was named "World Dane", thus becoming one of only three Danes to have been elected for this honor. In 2012 she was named "Thomson Reuters Citation Laureate" by Thomson Reuters.

TIME: MONDAY, 17:00 AND TUESDAY, 09:45

Lecture I:

Quantum Control of Light and Matter

In the lecture, I will describe how quantum mechanics can be used to manipulate light to the extreme. Light pulses are slowed to bicycle speed, 25 km/hour, in Bose-condensed clouds of ultra-cold atoms. This is 50 million times lower than the light speed in vacuum. In the process, a light pulse spatially compresses by the same large factor, from 1 km to only 0.02 mm, and the pulse can then be completely stopped and later restarted. From here, we will take matters further: stop and extinguish a light pulse in one part of space and revive it in a completely different location. In the process, the light pulse is converted to a perfect matter copy that can be stored – put on the shelf – sculpted, and then turned back to light. The storage time can be many seconds, and during this time, light could – under normal circumstances – travel back and forth to the Moon several times over. The observations represent novel paradigms for powerful information processing, and for control and interconversion of light and matter.

Lecture II:

The Art of Taming Light: What We Can Learn from a Bacterium

In this lecture, I will describe a new research direction at the interface of the fields of light-matter interactions, nanoscience, and molecular and synthetic biology. The research will involve fundamental studies of light-driven photosynthetic proteins coupled to engineered, inorganic nano-scale structures, and encompasses both natural and gene-engineered proteins. This could have applications, for example, for the development of new schemes for biofuel production. In the lecture, I will introduce the fascinating process of photosynthesis in natural systems, gene manipulation and why it is needed, as well as the special properties of nanoscale systems.

Speaker Bios & Abstracts

Marcus Motzkus is Professor of Physical Chemistry at the Ruprecht-Karls Universität Heidelberg. His research interests are ultrafast multidimensional time resolved spectroscopy on biological molecules and new materials, nonlinear optical microspectroscopy and coherent control. He received his PhD in Physics from the Ludwig-Maximilians Universität (LMU) in Munich in 1994 and worked as a postdoc in the group of Ahmed H. Zewail at the California Institute of Technology. Between 1996 and 2002 he did his Habilitation work on "Coherent control of ultrafast quantum phenomena" at the Max Planck Institute for Quantum Optics, Garching, and LMU. In 2002 he was invited guest professor at the University of Franche-Comte in Besancon and lecturer at the LMU. In 2003 he became professor for physical chemistry at the Philipps Universität Marburg before taking charge of his current position in Heidelberg in 2009.

Multimodal Quantum Control Micro-Spectroscopy

TIME: TUESDAY, 09:00 AND THURSDAY, 09:45

Nonlinear spectroscopic methods, such as coherent Raman microscopy, have seen tremendous development over the recent years resulting in many different applications in both the physical and life sciences. One of the main reasons is the ever increasing availability of high power, femtosecond laser systems producing tunable pulses of various spectral energies (visible, infrared and ultraviolet) and pulse durations (<10 fs achievable). The utilization of such broadband (100's nm) and transform limited laser pulses with modern pulse shapers, can permit the generation of specifically tailored excitation fields, whereby the different nonlinear responses can be coherently controlled. For example, such shaped pulses can be used for the selective population of specific vibrational modes or the direct manipulation of the motion of molecular systems.

In my lecture I will present the experimental realization of combining ultrashort, sub 10 fs laser pulses with pulse shapers, and show in detail the successful implementation of different Raman schemes and other coherently controlled nonlinear processes for chemical analytics. Achievable applications include the switching between narrowband, single-resonance nonlinear Raman and broadband, multiplex coherent anti-Stokes Raman spectroscopy with relative ease. Other advantages include the elimination of unwanted two-photon fluorescence or even the direct acquisition of linear Raman spectra. Finally, with the integration of several pulse-shaping techniques, the concept can offer a simple route for multimodal microscopy, both in the steady state and transient regimes.

Speaker Bios & Abstracts

Dr. Peter Fendel is the Head of the Laser Division and New Technology Scout at Thorlabs Inc. He received his Diploma Degree in Physics from the University of Essen, Germany studying low temperature plasmas by laser spectroscopy. After an internship at the Air Force Research Laboratory in Dayton, Ohio he started his PhD work under Ted Hänsch at the Max Planck Institute for Quantum Optics (MPQ) in Munich. Main areas of interest during his time at MPQ were experimental verifications of Bound State Quantum Electrodynamics and frequency comb spectroscopy. After his PhD work was completed Dr. Fendel joined Franz Kärtner at the Massachusetts Institute of Technology (MIT) in Boston in 2006. Among other projects he developed high repetition rate, octave spanning femtosecond (fs) laser to be used in the search for exoplanets. Simultaneously he introduced this technology into Menlo Systems while setting up their US operation. In 2009 Professors Kärtner and Fujimoto both MIT, Alex Cable, Founder and CEO of Thorlabs and Dr. Fendel founded idesta Quantum Electronics to further commercialize IP around fs lasers and fs timing distribution developed at MIT. After spending almost 1.5 years at Coherent Inc. in Santa Clara, CA to oversee the ultrafast oscillator development, he joined Thorlabs in his current role in 2013.

Applications of Femtosecond Lasers: from Astro Combs to Deep Brain Imaging

TIME: WEDNESDAY, 09:00

In this talk I will present a brief overview about a few different application examples of femtosecond lasers in fundamental and applied science. The first part of the talk will focus on the use of femtosecond lasers for frequency combs and precision spectroscopy. The invention of the frequency comb by Hall and Hänsch in 1999 marks the beginning of a revolution in precision spectroscopy providing a universal tool to bridge the gap from the radiofrequency time standard to optical frequencies. Besides their use in frequency metrology, frequency combs enable a series of astrophysical experiments like the search for planets outside of our solar system so called exoplanets. For these experiments frequency combs are linked to high resolution Echelle spectrometers on telescopes around the world to provide a dense and long term stable calibration matrix.

But femtosecond lasers had not only a great impact in the physical sciences but they also drove a major development in the life sciences mainly in non-linear microscopy. Denk and Webb pioneered two photon absorption laser scanning microcopy allowing for an unprecedented insight into neuroscience and cellular biology. Two photon imaging, for example, allows the study of neural activity deep inside the brain tissue possibly providing an understanding of diseases such as the Alzheimer's disease. Only femtosecond lasers are able to deliver the necessary peak power to achieve measureable fluorescence rates while at the same time keeping the heating of the sample and photo-toxicity low. Today, two photon imaging is the single largest commercial market for femtosecond lasers and hence will be the topic of the second part of my presentation.

Speaker Bios & Abstracts

Mark I. Stockman received his PhD and DSc degrees from institutes of the Russian Academy of Sciences. He is a Professor of Physics and the Director of the Center for Nanooptics (CeNO) at Georgia State University, Atlanta, GA, USA. He is a Fellow of the American Physical Society, Optical Society of America, and SPIE – The International Society for Optoelectronic Engineering. He has served as a Distinguished Visiting Professor at Ecole Normale Supérieure de Cachan (France) and as a Visiting Professor at Ecole Supérieure de Physique and de Chimie Industrielle (Paris, France), and also as a Guest Professor at University of Stuttgart (Germany), Max Plank Institute for Quantum Optics (Garching, Germany), and Ludwig Maximilian University (Munich, Germany). A major direction of his research is theoretical nanoplasmonics and strong-field ultrafast optics. He is a co-inventor of spaser (nanoplasmonic laser). He is an author of over 200 major research papers and has presented numerous plenary, keynote, and invited talks at major international conferences. He gave lectures and taught courses on nanoplasmonics and ultrafast optics at many major international meetings, schools, and scientific institutions in US, Canada, Europe, Asia, and Australia.

Latest Progress in Spasers (Plasmonic Nanolasers)

TIME: WEDNESDAY, 11:00 AND FRIDAY, 11:30

Nanoplasmonics deals with collective electron excitations at the surfaces of metal nanostructures, called surface plasmons. The surface plasmons localize and nano-concentrate optical energy creating highly enhanced local fields. Nanoplasmonics has numerous applications in science, technology, biomedicine, environmental monitoring, and defense.

There is an all-important need in active devices capable of generating and amplifying coherent optical fields on the nanoscale analogous to lasers and amplifiers of the conventional optics or transistors of microelectronics. Such an active device is the spaser (surface plasmon amplification by stimulated emission of radiation), also called plasmonic nanolaser. We will focus on the newest ideas and review the latest experimental progress in spasers, which presently cover a wide optical spectrum from near-IR to near-UV.

We will present two new theoretical ideas in the field of spasers: spaser with electric pumping via quantum wire and quantum-cascade graphene spaser. We will consider an example of the latest progress in spasers and some applications of spasers. Among them is a recent breakthrough in ultrasensitive detection of explosives using the spaser. Another recent breakthrough to be presented is an application of the spaser as an ultrabright nanolabel and an efficient theranostic agent in biomedicine (cancer diagnostics and treatment).

Speaker Bios & Abstracts

John Collier is the Director of the UK's Central Laser Facility (CLF), based at the Rutherford Appleton Laboratory at Harwell, Oxfordshire and part of the UK Science and Technology Facilities Council (STFC). A laser scientist by training, Prof Collier initially joined the CLF as a research scientist from CERN (where he was a Research Fellow), a position from which he has grown to become the Director of the CLF about 6 years ago. Prof Collier has played a central role in building the CLF into one of the world's leading research centres for multi-disciplinary science and innovation using lasers, and establishing the CLF at the heart of major international programmes. Today, he leads a staff of around 150 scientists, engineers and technicians in this endeavour, in activities that span the scientific spectrum, working with the majority of UK universities, all five UK scientific Research Councils, the European Commission, industry, charities, other agencies of the state such as the Ministry of Defence, the National Health Service, the Home Office and a wide range international partners. He has published over 90 peer reviewed articles and sits on numerous international advisory and review bodies in Europe and the USA. He is a Director of one of CLF's spinouts *Scitech Precision Ltd.* and was recently elected a Fellow of the Learned Society of Wales.

High Power Lasers – in all their senses!

TIME: THURSDAY, 14:30

High Peak Power lasers have become ubiquitous over the last several decades, and now internationally there are many systems installed on a commercial basis that are capable of achieving PW level performance at relatively low cost. Additionally, several systems to achieve 10PW or more are under construction as part of international consortia, and the coupling of high peak power lasers to other facilities is increasingly occurring.

Equally, over the last few decades the cost reductions and performance increase of diode laser technology has advanced to the point that it has now become a very attractive and generic means of driving laser systems. High average power lasers based on diode pumped technology has found widespread uptake in the industrial sector - multi kW CW powers are routine and a wide variety of low energy pulsed systems have been reported – many are commercially available.

However the development of systems where both these approaches are combined has been very limited, which is essential if the transformative potential for the application of the effects induced by high peak power lasers is to be realised in a "real world" sense.

So in this talk I will review some of the basic concepts of high peak power and high average power lasers, discuss the state-of-the-art, including efforts to combine both approaches and finally highlight some downstream real word applications of a combined approach.

Speaker Bios & Abstracts

Philip H. Bucksbaum is the Marguerite Blake Wilbur Professor in Natural Science at Stanford University. He is a member of the Physics, Applied Physics, and Photon Science Departments. He directs the Stanford PULSE Institute at the SLAC National Accelerator Laboratory, devoted to research utilizing ultrafast lasers and the LCLS at SLAC. His own research interests are in the areas of quantum control of atoms and molecules, with particular emphasis on attosecond time scales, strong laser fields, and short wavelength radiation. Bucksbaum holds degrees from Harvard College (A.B. 1975 magna cum laude in Physics) and the University of California at Berkeley (M.A. 1978 in Physics; Ph.D. 1980 in Physics). He has been elected to the National Academy of Sciences and the American Academy of Arts and Sciences, and also has been elected a Fellow of the American Physical Society and the Optical Society. He served as President of the Optical Society in 2014. Prior to joining the Stanford faculty he was on the faculty of the University of Michigan and the staff of Bell Laboratories.

Ultrafast X-ray Lasers: What are they? What are they good for?

TIME: THURSDAY, 15:15 AND FRIDAY, 09:00

The Stanford Linac Coherent Light Source (LCLS) is the world's first hard x-ray free electron laser, in operation since 2009. It produces millijoules of 10-100 femtosecond kilovolt x-rays, which can be focused to intensities as high as 10^{18} W/cm^2. This is a billion times brighter than any previous x-ray source. How does an ultrafast x-ray free electron laser work? And what kinds of research can be done with it?

I will provide an introduction to the physics of x-ray FELs, and the physics of intense x-ray matter interactions. Then I will describe some of the current research in this field.

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Session 1 poster setup will be Monday 18:15 (P01-P26) and removed Wednesday Morning.
Session 2 poster setup Wednesday 10:45 (P27-P54) and removed Friday morning.

P01 ■ SHUNGO ARAKI

Tunable optical vortex parametric oscillator

Optical vortices, carrying a doughnut-shaped intensity profile and an orbital angular momentum, have been widely investigated in various applications, including super-resolution microscopes, materials processing and so on.

I report on a widely tunable mid-infrared vortex laser based on an optical vortex pumped KTiOPO4 optical parametric oscillator (KTP-OPO) in combination with a difference-frequency generator. The KTP-OPO with a linear cavity configuration produced a vortex signal (with a topological charge of 1) and a Gaussian idler outputs within the wavelength range of 1780~2630 nm. Also, we successfully generated a tunable 6.0~17 μm optical vortex output from ZnGeP2 or AgGaSe2 difference frequency generator pumped by in the above-mentioned signal and idler outputs.

P02 ■ JAMES GAYNOR

Fourier Transform Two-Dimensional Electronic-Vibrational Spectroscopy Using a Broadband Mid-Infrared Probe

The development of coherent Fourier transform two-dimensional Electronic-Vibrational (2D EV) spectroscopy with acousto-optic pulse-shaper-generated near-UV pump pulses and an octave-spanning broadband mid-infrared probe pulse is presented. A 2D EV spectrum of a silicon wafer demonstrates the full experimental capability of this experiment, and a 2D EV spectrum of dissolved hexacyanoferrate establishes the viability of our 2D EV experiment for studying condensed phase molecular ensembles. The latest 2D EV data and current experimental developments in-progress will be discussed.

P03 ■ KAVITA SHARMA

Non-linear behavior of ring-down time in cavity ring-down spectroscopy with tapered fibers

Cavity ring-down technique (CRDT) in an all-fiber configuration is studied in two different modes of operation. The noise and detection limits of the conventional and amplified CRD techniques are compared. It is found that though conventional CRDT has the lowest noise levels, the ring-down time is very small. Amplified CRDT provides an improvement in ring-down time, albeit at higher noise levels.

The evanescent field in tapered fibers is used to detect the refractive index of sugar solutions. The effect of ambient refractive index on loss and ring-down time is studied in conventional and amplified CRDT with tapered fibers. Simulation and experimental results indicate that ring-down time varies as rational function of ambient refractive index.

P04 ■ YITZI CALM

From Airy to Abbe: Design Criteria for Highly Nonparaxial Flat Lenses

A new class of 2D metamaterials (metasurfaces), called planar optical elements (POEs), are characterized as having a microscopic thickness ($\lesssim \lambda$), macroscopic transverse dimension ($\gtrsim 100\lambda$), and being composed of an array of nanosctructured light scatterers. For imaging purposes, the lens-type POE is referred to as a "flat lens", and in this paper, we pay attention to the general design criteria one should consider when constructing a flat lens.

Recent advances in optical microscopy have enabled imaging with spatial resolution beyond the diffraction limit. We numerically integrate the scalar Kirchhoff diffraction integrals, and examine the features of a nonparaxial point spread function. In performing a parametric study, we propose new functional forms for the resolution limits derived from the focusing of scalar spherical waves. Our results serve as a qualitative guideline for flat lens design, and could materially impact the design of high intensity focused ultrasound systems.

P05 ■ CATALINA RAMÍREZ GUERRA

Laser-pump mode-matching enhancement by astigmatism compensation in a femtosecond oscillator

A program based on genetic algorithms to compensate astigmatism applicable to any resonator was developed, which was achieved by optimizing the mode-coupling,

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pump and laser emission beams within the gain medium. Astigmatism in the beams is generated by the rotation angle -relative to the propagation direction of the pump beam- of different elements in the cavity and it can be compensated by rotating the pump focusing lens and the pump concave mirror. The program uses the ABCD propagation matrix method of gaussian beams and satisfies the stability condition for any resonator. In this work the program was applied to a concentric cavity Ti:sapphire laser. The program is composed on a series of functions. The main function executes a genetic algorithm to find the rotation angle of the focusing lens under two convergence conditions: minimizing the cross sectional coupling area between the pump and fluorescence beams and matching their volumes in the gain medium. Side functions perform different tasks dedicated to the beam propagation parameters calculation, in the tangential and sagittal planes. Theoretical and experimental results are presented varying the mode-coupling condition according to the angle of the pump beam focusing lens.

P06 ■ ANDREW HUZORTEY

Range Independent Background Subtraction Algorithm Using Second derivative Method for Raman Peak Recovery

We report a novel computational technique that recovers Raman peaks embedded in highly fluorescent contaminated spectra. Our technique uses a Second derivative method to identify the most intense Raman peak after which a modified Savisty Golay algorithm is used to iteratively filter and recover the hidden Raman peaks. This technique is an improvement on existing background removal algorithms in both performance and user objectivity.

P07 ■ YUTA SASAKI

Deep ultraviolet vortex generation by employing a periodically bonded β-BaB2O4 device

An optical vortex exhibits an orbital angular momentum and an annular intensity profile owing to its helical wavefront, and it can be applied to several applications such as super resolution microscopes and materials processing. Such applications require the wavelength-versatility of the optical vortex.

Frequency conversion processes such as second harmonic generation and sum-frequency generation based on second-order nonlinearity have been demonstrated, however, the spatial form of the frequency converted output was degraded owing to the walk-off effects of the nonlinear crystals.

I report on the first demonstration of a deep ultraviolet vortex output without a spatial separation of phase singularities by frequency-doubling a green vortex laser with a periodically-bonded β-BaB2O4 device. Maximum output energy was measured to be 1.3 mJ, corresponding to a conversion efficiency of 15.1%.

P08 ■ LORIS MARINI

Breakdown Flash at Telecom Wavelengths in Direct Bandgap Single-Photon Avalanche Photodiodes

Breakdown flashes in single-photon avalanche diodes can adversely affect low-level photon experiments. We present the first measurement of this phenomenon at telecom wavelengths which is essential to the design and implement of preventive measures.

P09 ■ FELIPE CEZAR SALGADO

Spectral analysis of gas absorption lines using optical time-domain reflectometry

Detection of gas is a major concern for the industry especially to spot leakages of natural gas in pipelines by oil companies. The main component of the natural gas is methane, which can cause explosions besides the environmental problems. Several approaches using optical fibers to detect gas leakages and its concentration have been proposed, e.g., direct absorption and wavelength modulation spectroscopy (WMS). This work proposes a new experimental setup to perform a spectroscopy analysis of the gas using only an Optical Time-Domain Reflectometer.

The proposed sensing system is composed by an Optical Time-Domain Reflectometer (OTDR), which modulates a booster optical amplifier operating around 16455 nm fed by a continuous-wave signal from a tunable distributed feedback laser. A conversion system named transponder OTDR is used to modulate the semiconductor optical amplifier with the OTDR pulses. The transponder OTDR has a photodetector and a set

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of electronics that converts the optical pulse emitted by the OTDR device into electrical pulses to modulate the BOA. The optical cell used on this experiment is filled with pure methane at 50 torr of pressure and has an optical path equal to 5.5 centimeters. This optical cell is placed 4 km away from the pulsed light source by a single spool of optical fiber. After the optical cell, another spool of 8 km optical fiber is connected.

The obtained attenuation spectrum of the pure methane gas at 50 torr of pressure coincides with the HITRAN online database for the same gas conditions. Moreover, a 3D map of the optical link with its attenuations at each scanned wavelength is created by combining all OTDR traces.

P10 ■ CRISTIAN ANDRES TRIANA INFANTE

Spectrally encoded fiber Bragg grating sensors using Optical Code Division Multiplexing

Encoded ber Bragg grating (FBG) sensors are proposed in order to provide full distinction between sensors operating at the same wavelength range. We used Optical Orthogonal Codes (OOC) to define the spectral shape of the FBG sensors, providing them with a unique spectral signature. As a result we demonstrated the detection and tracking of the proposed sensors which allows efective measurement of the Bragg wavelength even under overlapping conditions.

P11 ■ MOHIT CHOUBE

Aluminum based Plasmonics in Visible Frequencies of the Electromagnetic Spectrum

Ever since the beginning, Gold and Silver have been used in the plasmonics based devices in the visible frequency range. Very recently, it has been shown that Copper can also be used in this range. Aluminium shows surface plasmon resonance in Deep- UV. We are working to device a versatile method to use Aluminium and Aluminium based systems in visible frequency range. Successful results of our research will be a great contribution towards the scientific community and will significantly reduce the prices of biosensors, photonic integrated circuits and solar cells benefiting the society and the plasmonics industry, since Aluminium is a cheap, abundant and non-toxic metal.

P12 ■ DIPENKUMAR BAROT

Optical Metrology, Imaging and Sensing based on Femtosecond Optical Frequency Comb

Femtosecond-laser optical frequency combs (OFC) are versatile tools with a lot of unique features. The objective of this research is to leverage some of the key advantages of OFC over conventional lasers, such as high frequency stability and frequency tunability, to achieve novel applications in a number of fields, including optical metrology, optical imaging and optical sensing.
We have developed an OFC-based optical sampling scheme called Optical Sampling by Cavity Tuning (OSCAT), and we have demonstrated time domain applications such as ranging, optical imaging and 3D profilometry. In ranging, target vibration as small as 15 μm peak to peak and as fast as 50 Hz along line-of-sight has been successfully detected at an equivalent free-space distance of more than 2 km. In optical imaging, optical coherence tomography (OCT) has been demonstrated on a wide range of targets with an emphasis on probing multi-phase systems. Three-dimensional surface profilometry has also been realized with a depth resolution greater than 50 μm.

In the frequency domain, we have successfully locked two diode lasers to two different comb modes of an OFC. The slow frequency drift of each diode laser has been removed due to the long-term stability of the OFC. This setup will be used to study ultrahigh sensitivity fiber-optic sensing in the infrasonic region as well as multi-wavelength interferometry.

P13 ■ MITCHELL COX

Scalar and Vector Vortex Modes through Turbulence

Free-space optical communication with spatial modes of light has become topical due to the possibility of dramatically increasing communication bandwidth. Modes carrying Orbital Angular Momentum (OAM) provide a basis for both modulation and Mode Division Multiplexing (MDM) due to their orthogonal nature, and while both scalar and vector vortex modes have been used as transmission bases, it has been suggested that the latter is more robust in atmospheric turbulence. We demonstrate theoretically and experimentally that the crosstalk due to turbulence is the same in the scalar

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and vector basis sets of Laguerre-Gaussian modes. This work brings new insights about the behaviour of vector and scalar modes in turbulence, but more importantly it demonstrates that when considering optimal modes for MDM, the choice should not necessarily be based on their vectorial nature.

P14 ■ CHRISTINE HOLZAMMER

Investigation of the Inhibition Effect of Thermodynamic and Kinetic Hydrate Inhibitors by Raman Spectroscopy

Gas hydrates are solid ice-like structures that consist of a framework formed by hydrogen bonded water molecules and usually one gas molecules incorporated inside of it. The undesired formation of gas hydrates can cause blockage in oil and gas pipelines. Especially in off-shore drilling the formation is of particular concern as low temperatures and high pressure enhance gas hydrate formation. Thus, a wide range of different inhibitors has been developed in order to prevent gas hydrates from forming. In general inhibitors can be classified in two groups : Thermodynamic and kinetic hydrate inhibitors. Thermodynamic inhibitors shift the equilibrium to lower temperatures and higher pressures, whereas kinetic inhibitors do not prevent hydrate nuclei from forming, but hinder them from further growth and agglomeration. We developed two methods to characterize their respective inhibition effect on carbon dioxide containing water using the water stretching vibration gained from Raman Spectroscopy. Thermodynamic inhibitors increase the competition for water molecules and thereby disturb hydrogen bonds between water molecules. Therefore we analyze the development of hydrogen bonds in the liquid water-rich phase: Using a van't Hoff plot, it is possible to calculate the change in entropy and enthalpy of formation of hydrogen bonds. For kinetic inhibitors we are able to quantify the amount of hydrate in the still flowable hydrate-water-CO2 mixture. With these two methods thermodynamic and kinetic inhibitors can be compared regarding their suitability in flow assurance.

P15 ■ DRAKE ANTHONY

Developments for Preparing and Measuring 129Xe and 15N Hyperpolarization via Spin-Exchange Optical Pumping

Hyperpolarization is a technique used in NMR and MRI related disciplines that provides strong signal enhancement and therefore allows sample detection in low magnetic field environments. In particular, Spin-Exchange Optical Pumping (SEOP) is a hyperpolarization method that generates gases with high spin polarization that has recently shown use in novel MRI methods. In this study, circularly polarized laser light matching the Rb D1 absorption line was used to optically pump a glass cell containing Rb and Cs vapor in a Xe atmosphere. Electron spin polarization for the gaseous Rb and Cs were found to be 48.3% and 48.7%, respectively, suggesting successful cross polarization of the alkali metal species. Nuclear spin polarization of 129Xe in the cell was found to be 29.1%, signifying efficient spin polarization transfer from the alkali metal species to Xe nuclei. In the future, hybrid SEOP may find use in clinical hyperpolarizers for efficient generation of NMR/MRI active gases.

P16 ■ SVYATOSLAV KHARITONOV

Isolator-free unidirectional thulium-doped fiber laser

I report the first demonstration of a unidirectional, isolator-free 2-μm thulium-doped fiber (TDF) laser, relying on the properties of the theta cavity (ring resonator with S-shaped feedback). The core pumped theta cavity TDF laser provides sub-Watt output power with a slope efficiency of 25%, a 2 dB flat tuning range of 1900–2050 nm, and a linewidth of 0.2 nm, and achieves the extinction ratio of 18–25 dB (depending on the feedback value) between the favored and suppressed lasing directions. It is shown that these characteristics are competitive with, if not superior to, those of conventional ring cavities. The simulation results of the linear and Kerr-nonlinear theta cavities are also presented, explaining certain unexpected features of the laser behavior and establishing the importance of the doped fiber nonlinearity on the spectral shaping of the emitted signal.

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P17 ■ TOBIAS KLIMA

Raman-spectroscopy in multiphase flows at supercritical conditions

In diesel combustion processes a multicomponent fluid is injected into supercritical air at pressures up to 10 MPa and temperatures up to 800 K.

For modeling and optimization of the process, knowledge about the phase transition and mixture behavior of the liquid/gas/supercritical system is important, and up to date still controversially debated.

Raman-spectroscopy allows for direct measurement of composition and phase, yet suffers from an extremely low scattering cross section.

By application of modern long-pulse laser systems this issue can be overcome and new information about the injection process can be gained

The thermodynamical background of the phase transition from liquid to gas or supercritical mixture, i.e. the mixing and heating rates as well as phase equilibria at high pressures and temperatures are investigated in a microcapillary setup, also employing Raman-spectroscopy with a sophisticated triggering mechanism for phase-sensitive measurements.

P18 ■ HAMPUS WIKMARK

An interferometer setup for attosecond pump-probe experiments on aligned molecules

In High-order Harmonic Generation (HHG), an intense laser field is used to create subfemtosecond pulses with high photon energies. At the Lund Laser Centre Intense XUV beamline, we produce an attosecond pulse train, which can be focused to an intensity high enough for nonlinear light-matter interaction. To take advantage of the time resolution provided, the most common approach is pump-probe experiments, enabling investigations of the structure and dynamics of molecules. For a better insight into these properties, it is beneficial to also align the molecule.

A design is presented for an interferometer setup, which will enable pump-probe experiments on molecules aligned by an infrared field. In order to reconcile the time scales of ultrafast dynamics and molecular alignment, the setup consists of two interferometers. The presented design may also be combined with an XUV split-and-delay unit in order to enable IR-XUV-XUV experiments on aligned molecules.

P19 ■ RICCARDO PENNETTA

Adiabatic silica nanospike with ultra-narrow mechanical linewidth

In optomechanics, high mechanical Q-factors are usually preferred since a long phonon lifetime is crucial for increasing the coupling of the mechanical motion to the electromagnetic field. For clamped resonators, however, it is usually challenging to reach high Q-factors because of leakage of acoustic energy into the supporting structure. For this reason more complex structures such as suspended micro-resonators [1] or phononic crystals [2] need to be employed. Here we demonstrate that a properly designed free-standing silica microspike can, because of efficient reduction of clamping losses in the fiber taper, provide high Q-factors for the fundamental flexural resonance mode at low gas pressures. At the same time, this high Q-factor mechanical resonator maintains adiabatic guidance of the fundamental optical mode, offering an ideal tool for optomechanical measurements. We have already reported one application of this probe, as a novel adiabatic device for launching light into hollow core photonic crystal fibres [3]. In addition, the microspike also offers an elegant means of studying non-trivial phenomena related to thermal dissipation and molecular dynamics in the free molecular regime.

P20 ■ OMAR CALDERÓN-LOSADA

Control of the spatial correlations of pairs of photons by tuning the focusing of the pump laser

In this work we study the effects of changing the focusing of the pump laser on the spatial correlations of pairs of photons generated by spontaneous parametric down-conversion (SPDC) type II in a non-collinear configuration. Essentially, we present a theoretical model to describe the degree of correlation (DOC) in the transverse momentum domain for these pairs of photons and experimentally show how this DOC depends on the parameters that describe the crystal and the waist of the laser beam used as pump. Interestingly, we also found that the DOC behavior changes if one scans different directions of the biphoton transverse plane.

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P21 ■ MEDYA FOUAD NAMIQ NAMIQ

Refractive Index Determination of Hydrofluoric Acid using In-situ Monitoring of Etched Fibre Bragg Gratings

In this work, based on simple technique of measuring the differential relative shifts of the Bragg resonances between the fundamental mode LP01 and the higher-order modes; LP11, LP02, LP21, LP12, LP31 in an etched FBG, we determine the refractive index of a buffered HF (BHF) acid solution with concentration (20:1) to be ~ 1.360± 0.005 at 1.55μm, and use that to demonstrate precise control the fibre etch diameter during the etching process. The refractive index is calibrated against known indices of liquids and solvents, including water, methanol, acetone, IPA and ethylene glycol. The experimental results were compared with simulations and exhibited excellent agreement.

P22 ■ MITZI ODÓÑEZ PÉREZ

Construction and design of a femtosecond Erbium Doped Fiber Amplifier (fs-EDFA) for THz generation applications

In this work, we present the design and construction of a femtosecond Erbium Doped Fiber Amplifier (fs-EDFA). We determine the optimal condition using a model for EDFA´s and ring lasers based on optical dispersion and self-phase modulation parameters. We consider a model of a self- mode-locked fiber ring laser for which the evolution of a propagating pulse in a birefringent optical fiber is periodically perturbed by the rotation of the owing to the presence of a passive polarizer. The oscillator system produces a nonlinear polarization rotation with polarization selectivity, which gets inside the erbium doped fiber which can act as a saturable absorber. The output pulses characteristics are; repetition rates of 61 MHz. generates pulses of about 82 fs with a spectrum bandwidth > 100 nm and corresponding peak power up to 6.8KW which can be increased with a single amplification stage. The fs-EDFA will be coupled with a photoconductive antenna for THz generation.

P23 ■ SIVASHAKTHI A

Wideband, high resolution instantaneous frequency measurement using stimulated Brillouin scattering

Instantaneous frequency measurement (IFM) is the technique of detecting an unknown RF or microwave frequency. A wideband (25 GHz) and high resolution (50 MHz-determined by the step size of pump tuning) microwave photonic instantaneous frequency measurement is proposed and demonstrated using stimulated Brillouin scattering in single mode fiber. The Brillouin shift is wavelength dependent and this property is exploited to obtain an amplitude comparison function (ACF). The pump is obtained by modulating (carrier suppressed single side-band modulator) a narrow linewidth laser using an unknown RF. A probe is placed at a fixed frequency (Brillouin shift) from the pump. When the pump is tuned, the Brillouin shift changes from resonance and the gain seen by the probe reduces. If the pump changes by 40 GHz, the Brillouin shift changes by only 2 MHz thereby enabling wide-bandwidth measurement. By scanning the instantaneous frequency, the ACF can be obtained. It is also possible to obtain the ACF by tuning the probe to 2 MHz around its initial frequency while keeping the pump frequency fixed.

P24 ■ JOÃO MAIA

Fabrication of optofluidic devices by femtosecond laser direct writing

Lab-on-chip systems integrate microfluidic channels to transport, mix, make react and analyze small volumes of samples. These devices are usually manufactured by soft lithography, however femtosecond laser direct writing adds new advantadges such as three-dimensional fabrication and on-chip optical detection. Therefore, this fabrication technique allows the implementation of monolithic optofluidic devices.

In this technique, the interaction between laser irradiation and a glass sample alters the material properties around the focal volume by increasing the refractive index and etching selectivity in hydrofluoric acid. The first effect allows fabrication of low-loss waveguides, Bragg grating waveguides and directional couplers, among others, which are demonstrated in this work. Irradiation of the sample also promotes an anisotropic etching reaction thus allowing fabrication of channels inside the glass with variable geometry while maintaing smooth sidewalls and uniform aspect ratio. By placing the microfluidic channels next to optical layers (Bragg gratings or interferometers) we can analyze the fluid properties either by evanescent coupling or by crossing the waveguide with the channel; results are presented.

P25 ■ ANJALI PS

Demonstration of filterless and tunable-thulium doped fiber laser with emission in the 2 µm region

Laser systems based on thulium doped silica fibers have the key attractiveness due to its operation in the eye safe region, where the optical absorption by aqueous portion in the eye prevents retinal damage. Research works in this field have got much attention in the past few years because of the availability of thulium doped in silica fibers. These fibers have a very broad emission in the wavelength range 1.7 to 2.1 µm and it has versatile applications in the area of medicine, material processing, sensing and communication.

In this poster, we present a tunable fiber ring laser where the gain medium is thulium doped silica fiber. Among the different possible pumping mechanisms, pumping at 790 nm is very effective because of the "two for one" cross relaxation mechanism associated with it. Diode lasers at these wavelengths are readily available and we pump our thulium-doped system with the same. The gain medium used is double clad fiber, which permits the system to be pumped with high brightness pump diodes. With 2 m of gain medium and using a 50/50 coupler in the ring cavity, we achieved lasing at 2020 nm with a slope efficiency of 32.2 %. A laser system can be tuned by changing the intra cavity loss or reflectivity of the cavity. We used a 90/10 coupler to give 90 % feedback to the cavity and the lasing wavelength shifted to 2047 nm. The same coupler is then used to give 10 % feed back to the cavity, with which we got the lasing at 1992 nm. We further model the laser system using appropriate rate equations and considering cross relaxation mechanisms. In the poster, we also present the simulations results and a comparison of the same with the experimental results.

P26 ■ NESTOR JR. BAREZA

Subluminal Speed of twisted light in free space

Light is long known to be invariantly emanating at the speed limit c in free space. The constant c has been a fundamental constant governing modern physics especially in the foundation of Einstein's special relativity and in derivation by Maxwell of electromagnetic wave formulation. This has been a basic assumption in various astronomical observations and light applications. However, physical light beams naturally have transverse structures that alter the wavevector to include non-axial components k_t. The speed of light during propagation relies on its group velocity v_g. The presence of k_t makes the v_g of physical light to be less than the speed limit c. Thus, physical light propagates with subluminal speed even in free space. This has already been demonstrated to photons in both Bessel and Gaussian beams. In these beams, the delay is due to presence of radial wavevector k_r component. The motivation of the study is to observe the effect of azimuthal wavevector k_a to v_g reduction. The presence of k_a induces orbital angular momentum (OAM) to light. OAM-carrying light has helical wavefront such that the energy flow follow a helical path - twisted light. The twisted light travels an added distance, causing time delay in the propagation. OAM of light is reported here to significantly contribute to v_g delay. In this study, the v_g of Laguerre-Gauss (LG) beam, a common OAM-carrying beam, is calculated in the paraxial regime. The delay for LG beam is due to an added path that originated from both k_r and k_a. The v_g of LG beam in paraxial regime is calculated to be inversely proportional to beam's divergence, orbital order l and radial order p. This implies that LG beam has subluminal speed and dispersion during propagation even in free space. It is also remarked here that the delay is directly related to the order of the beam, 2p+|l|. LG beams of different orders will disperse even in free space, and that beams of higher orders travel relatively slower than beams of lower orders. This free-space speed variance is an added effect to the dispersion due to field confinement. Degenerate modes of LG beams with same orders but different (l, p) combinations are found to propagate with the same speed. These findings suggest necessary corrections in LG beam's practical uses, especially in its far-travel-range applications such as data transmission in free space and data treatment from astronomical sources. The study also consequently implies that even in vacuum, aside from the fact that light travels less than c, we can control its speed by endowing it with certain OAM value. This study is significantly important both in revisiting the fundamental nature of light propagation and in extensive applications of light with orbital angular momentum.

P27 ■ TSZ KWAN LAI

Time-stretch imaging flow cytometry on Phytoplankton

Optical time-stretch imaging can capture single-cell images with high sensitivity (i.e. high resolution) and throughput (>MHz line scan rate), leading to a profound impact in biomedical (e.g. rare cancer cell detection) research fields. The potential in marine research, however, has not been fully explored. Phytoplankton, as the building blocks of aquatic ecosystem and remarkable indicators of aquatic system quality, is currently investigated solely by manual inspection. Contrarily, optical time-stretch imaging could classify a multitude of population of phytoplankton with single-cell profiling within hours. We report an automated multi-class classification of phytoplankton by implementing support vector machine learning based on the extracted features of high-resolution time-stretch images, classifying more than 10 species of phytoplankton with cross-validated accuracy of >90% . We assert this can provide an efficient and effective aquatic continuous monitoring tool with single-cell analysis capability.

P28 ■ INBARASAN MUNIRAJ

Low Photon Count 3D Imaging: Integral Imaging, Holography, and Ptychography

Over the past two decades, the rising availability of inexpensive, accurate digital cameras facilitated the study of digital holography. We note that conventional approaches works well on high-level illumination scenes or on the irradiance objects. In practice, low-light level imaging are likelihood. Such the image sequences are, in general, binary in nature that tells us either the presence or the absence of light particles. Nevertheless, it has a potential applications in broader spectrum. We investigated the applications of low light imaging and examined it on conventional approaches.

1) We presented a method of securing multispectral 3D photon-counted integral imaging using classical Hartley Transform based encryption by employing optical interferometry.
2) Recently, we developed low photons based in-line digital hologram for the application of quadratic phase cryptography.
3) We are developing a Ptychography based imaging model using modified phase retrieval algorithms.

P29 ■ WENBIN HE

High-harmonic Mode-locked Fiber Laser Based on Optoacoustic Interactions in PCF

Photonics crystal fibers (PCF) with μm-solid-core and large air-filling ratio provides a platform for enhanced optoacoustic interaction with acoustic resonance in GHz range and it can be utilized to achieve stable GHz high-harmonic passive mode-locking in fiber laser, which is conventionally regarded as an unstable and undesired behavior. By inserting a short piece of such PCF in the mode-locked cavity, a self-organized transition could occur and a steady state with a long-range pulse-to-pulse interaction can be reached, in which the pulse train coherently drives an acoustic wave in PCF through electrostriction and the acoustic wave, as an back action, phase-modulates the pulse, and together with cavity dispersion, forms a trapping potential for each pulse's position, leading to equal pulse spacings and highly suppressed timing-jitter. Based on this technique, we first demonstrated a stable GHz mode-locked soliton all-fiber ring-laser. The laser features high robustness with an invariant harmonic order (> 100) regardless of the wideband wavelength tuning, power scaling and cavity length tuning. We recently introduced the stretched-pulse laser scheme to this high-harmonic mode-locked laser, with modifications of intracavity self-consistency scheme to adapt the low pulse energy. We achieved GHz, sub-100 fs pulse generation with high stability, low noise and simple configuration. Moreover, since the pulse train can interact with the acoustic wave in PCF so strongly that a certain degree of intracavity pulse drop-off would not affect the laser stability. This can be regarded as an optomechanically bound states. We have successfully controlled such states, i.e., the pulse drop-off pattern, via an external addressing pulse

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train, and stored such pattern, with bit information assignment, for hundreds of hours, leading to potential application in all-optical bit-storage.

P30 ■ VICENTIU IANCU

XUV attosecond pulses implemented for high resolution imagery

Post-compression of high energy pulses was performed by ionization low pressure He, in a guided geometry. A TW CPA based Ti:Sapphire laser chain delivering high-peak pulses of 150 mJ and 35 fs pulse duration (FWHM) around 800 nm at a repetition rate of 10 Hz, was utilized for high harmonic generation in a loose focusing geometry in Ar and Kr. The XUV beam was characterized both spatially and spectrally on a single shot basis. The influence of the iris diameter and the gas-filled cell pressure on the XUV flux were also investigated. Under optimum conditions, a 1.6·10^8 photons/pulse was determined.

P31 ■ RAFAEL SIBILO

Multifunctional surfaces for optical devices

Previous experimental en theoretical work has shown that functionalized surfaces that simultaneously exhibit hydrophobic and oleophilic properties are more efficient in deactivating enveloped viruses compared to non-functionalized ones.(1) Based on these findings current work is focussing on understanding and elucidating the molecular and biophysical mechanisms through which bacteria interact with surfaces. The aim is to work towards developing antimicrobial, durable and optically transparent surfaces that could find applications in settings with a high occurrence of micro-organisms such as in hospitals and public multi-users electronic devices where transmission and spreading of micro-organisms could be reduced by these functionalized surfaces. These surfaces could be chemically treated and/or nanostructured. In addition to a computational approach, real-time fluorescence microscopy will be one of the important characterization tools to study bacteria interacting with the functionalized surfaces.

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P32 ■ WILFRID INNOCENT NDEBEKA

Investigation of charge transfer in silicon/ silicon dioxide interface of silicon membranes

Silicon (Si) based materials have been of technological importance throughout the years and today Si continues to be a leading material in microelectronics and photonics industries. The interface between Si and its oxide, namely silicon/silicon dioxide (Si/SiO2), has been one of the most studied systems in the realms of material and condensed matter physics. The optical properties, both linear and nonlinear, of the interface region are of interest. Some of the nonlinear optical phenomena may occur simultaneously and it can be difficult to discriminate between for instance coherent two-photon absorption (TPA) and free carrier absorption (FCA). The electric field induced second harmonic (EFISH) generation process is used as a valuable technique to investigate the mechanisms of charge transfer, trap generation and population at the interfaces through nonlinear absorption. The second harmonic (SH) response is dependent on the interfacial electric field formed by both electrons and holes being pumped across the interface. In this work, Si membranes are irradiated with a femtosecond (fs) laser light at an angle of 45o. A geometry of the experimental setup was chosen to enable simultaneous measurements of the fundamental and SH signals in transmission and in reflection. Results obtained show that, while laser beam in reflection from a Si membrane displays a nearly perfect linear dependence on the incident laser power, both laser beam and SH signals in transmission show an increase with increased power, then reach a maximum, and continue to decrease considerably as the incident power is increased. The experimental setup is presented and the results obtained will be discussed.

P33 ■ AMY TONG

Multilayer Thulium-Doped Tantalum Pentoxide Ring and Racetrack Laser Technology

Tantalum pentoxide (Ta2O5) is a high-permittivity silicon process compatible dielectric material ideal for optical waveguide devices. Its high index contrast allows efficient and compact devices to be achieved. Full integration of circuit functions will require an on-chip laser as one of the key building blocks, and ring or racetrack resonators coupled to conventional dielectric or silicon waveguides are under investigation. Through doping the ring with rare-earth ion such as thulium, gain can be achieved resulting in lasing. Thulium doping would enable operating wavelengths ranging from 1.9 to 2.1 µm, compatible with silicon photonics and suitable for extended wavelength telecommunications. The design of a multilayer thulium-doped tantalum pentoxide ring or racetrack resonator laser, compatible with silicon photonics, is discussed.

P34 ■ SAMUEL FELIPE SERNA-OTALVARO

Bi-directional top hat D-scan: a third order nonlinear waveguide characterization method

The effective Kerr and two photon absorption (TPA) nonlinear parameters of a silicon strip waveguide are characterized by means of a single beam nondestructive technique. First, irrespective of the injection and collection losses (in and out) of the guide, we demonstrate the measurement of the nonlinear third order figure of merit $FOM_{TPA} = \gamma/(2\pi\gamma_{TPA})$, with $\gamma = k_0 S^2 n_2/A_{NL}$ and $\gamma_{TPA} = S^2 \beta_{TPA}/A_{NL}$ the effective Kerr and TPA parameters that depend on n_2 and β_{TPA}, the nonlinear refractive index and the TPA coefficient, and the nonlinear effective area of the guided mode A_{NL}. The expressions take into account the nonlinear enhancement due to localization effects and quantified as the ratio between the group index and the bulk material index $S = n_g^{wg}/n_0$. By measuring the bi-directional nonlinear transmission, the coupling coefficient values of each facet and the γ_{TPA} parameter are evaluated experimentally. We describe in further detail the experimental set-up and procedure which uses spectrally quasi-rectangular pulses, being the analogous in the temporal domain of the top-hat Z-scan, and is applicable to other waveguide geometries, materials or hybrid cases.

P35 ■ ASMITA SINGH

Investigating the excited electronic states of carotenoids in the main plant light-harvesting complex (LHCII) via femtosecond pump-probe spectroscopy

The natural photosynthetic apparatus of plants contains complex membrane-bound pigment-protein networks. In the main plant light-harvesting complex, LHCII, the chlorophyll (Chl) and carotenoid (Car) pigments capture solar photons and transfer the excitation energy on ultrafast timescales to a reaction center where a charge separation is induced. Plants are self-protected against over-illumination by the process of non-photochemical quenching (NPQ). We studied the excited-state dynamics of LHCII Cars in spinach leaves upon intensity-dependent, selective Car excitation at 489 and 506 nm, using femtosecond transient absorption pump-probe spectroscopy. Global Analysis was applied to obtain the transfer rates and decay lifetimes of various transiently induced photoproducts. The dependence of the kinetics on the pump wavelength and intensity, and possible link to the Cars' involvement with NPQ will be discussed.

P36 ■ JULIANA RICHTER

Near Infrared Laser Spectrometer

The near-infrared spectrometer is modeled from a Czerny-Turner design. Light is coupled into the system using a fiber optic and data collection is conducted using an Arduino through USB cable. The design is free of lenses to limit system error due to dispersion and absorption. A linear grating is mounted on a rotation stage to spread and select frequencies for analysis. Light from the 1st diffraction order is incident on a collimating mirror. The portion of the beam under analysis is selected using a pinhole in front of the detector.

P37 ■ MARIIA BOROVKOVA

Measurement of Water Concentration in Biological Samples by Terahertz Time Domain Spectroscopy

The noninvasive measurement of water concentration in biological samples using terahertz waves is a promising tool in bio and medical applications. Due to the strong water attenuation of THz radiation, a device based on the terahertz time-domain-spectroscopy (THz TDS) would be a noninvasive, sensitive and precise sensor of water concentration. Methods for water level measurement in leaves using THz radiation in transmission mode have been reported. In order to examine thicker biological objects, the reflection geometry should be applied. The project is devoted to the development and testing the methods for non-invasive measurement of water status in biological samples by THz TDS both in transmission and reflection modes. A series of experiments using different biological samples demonstrated good correlation of water concentrations values calculated by THZ TDS methods and the data measured gravimetrically.

P38 ■ ANDREW MALOUF

Optimisation of 3.5 μm dual-wavelength pumped fiber lasers

The performance of mid-infrared Er3+-doped fiber lasers has improved dramatically in the last few years. We present a numerical model that provides valuable insight into the dynamics of a dual-wavelength pumped (DWP) Er3+-doped fiber laser. This system operates at the 3.5 μm as well as the more commonly known 2.8 μm transition in erbium.

A numerical model is essential to test our understanding of the laser system and to provide valuable insight into the interactions that occur at the atomic and photonic level that ultimately determine laser performance. The significance of competing processes may be analyzed to determine optimum fiber specifications and system design. A successful model is, therefore, a much needed tool for optimizing the performance of DWP fiber lasers.

Laser dynamics of DWP Er3+-doped fiber laser systems are presented. These include the evolution of atomic populations and laser intracavity power in the time domain, steady state atomic populations as functions of second pump power, and competing rates of transitions that affect laser performance. Comparisons between simulated and experimentally measured laser output powers are presented for three different systems published in literature showing good agreement. Finally, we demonstrate an example of an optimization technique by optimizing the length of the fiber for maximum laser output power. We can also optimize parameters such as core radius, doping concentration, and output coupler reflectivity for customized fiber design.

P39 ■ HUZIFA ELNOUR

Ultrafast pump-probe spectroscopic investigations of the energy transfer dynamics in the main light- harvesting complex of plants and diatoms

The photosynthetic light-harvesting apparatus of plants and diatoms switches between a highly efficient light capturing state and a state where the absorbed energy is thermally dissipated, depending on the incident light intensity, through a process known as non-photochemical quenching (NPQ). The rapidly reversible component of NPQ is known as qE. The light-harvesting complexes (LHCs) of these organisms contain protein-bound chlorophylls (Chls) and carotenoids (Cars) that capture and transfer excitation energy. Depending on the pigments' orientation, electronic excitation may be shared amongst tightly packed pigments within LHCs, resulting in coherent superpositions of electronic excitations, called exciton states. Energy is passed on an ultrafast timescale amongst exciton states to a molecular reaction centre, where a pair of Chls become excited and the process of charge separation is initiated. We used ultrafast pump-probe spectroscopy to investigate the qE- related excited-state dynamics of wild-type and mutant LHCII from Arabidopsis thaliana and spinach leaves, as well as FCPb extracted from Cyclotella meneghiniana diatoms. Measuring the LHCII-NPQ2 mutant, which consists of LHCII depleted with the Car neoxanthin, at different pump wavelengths (488 nm, 510 nm, and 520 nm) for selective Car excitation, we have found that both neoxanthin and zeaxanthin play an integral role in the mechanisms underlying qE. We will also discuss the transient dynamics resolved from intensity-dependent, selective Car excitation. For FCPb we examined the excitation energy transfer dynamics upon excitation of Chl a at 680 nm and studied the role of singlet- singlet annihilation using different pump intensities. In particular, qE-related excited-state dynamics were investigated using FCPb complexes in three different environments, viz., in solution (sFCPb), aggregated (qFCPb), and incorporated in proteoliposomes (plFCPb). We observed long-lived Chl absorption near 710 nm for qFCPb and plFCbP, which may be explained by more significant energy trapping.

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P40 ■ SIDIKI ZONGO

Biosynthesis, Characterization and Nonlinear absorption Optical absorption of Cu(OH)2-Nanoparticles/nanorods-like

The present work reports the characterization and nonlinear optical properties of Copper hydroxide nanorods-like ($Cu(OH)_2$-NRs) and nanoparticles (NPs). $Cu(OH)_2$-NRs and CuO-NPs were biosynthesized from copper sulphate using saffron extract in propanol and methanol, respectively. X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), High Resolution-Transmission electron microscopy (HR-TEM) and Scanning electron microscopy (SEM) were initially used to characterize the synthesized nanorods-like/nanoparticles. The morphological analysis showed the formation of uniform nanorods decorated spherical nanoparticles in propanol-dye extract and typical spherical NPs ranging from 10 to 27 nm in the methanol-dye extract. The structure and crystalline nature was confirmed by the nanopowder X-ray diffraction patterns. The nonlinear optical study using a femtosecond laser revealed two-photon absorption behavior, interesting for possible optical limiting devices application.

P41 ■ RA'ED MALALLAH

Investigating non-linear distortion in the photopolymer materials

There are lot of applications of photopolymer materials for example hologram data storage and self-written waveguide (SWWs). Recently, we presented a model to calculate the absorption and polymerization efficiencies using the 3D Nonlocal Photopolymerization Driven Diffusion (NPDD) model. We note that in nonlinear materials, significant light beam absorption occurs (that leads to strong beam attenuation) due to the presence of concentric dye and the physical thickness of the recording layer. This also produces spatial and temporal nonlinear behaviours of the photophysical and photochemical material. We also investigated the applications of self-trapping and self-written waveguide during photopolymarization process. We validated our proposed predictions both theoretically as well as experimentally.

P42 ■ VASILIY VOROPAEV

Ultrashort-pulse fiber lasers for frequency metrology

Ultrashort-pulse lasers become an important tool in the emerging field of optical frequency metrology and are enabling unprecedented measurement capabilities and new applications in a wide range of fields, including precision spectroscopy, atomic clocks, ultracold gases, and molecular fingerprinting.

Two erbium-doped all-fiber ring lasers hybridly mode-locked with Boron Nitride-doped Single-Walled Carbon Nanotubes in the co-action with a nonlinear polarization evolution have been investigated. The main difference of this lasers is the intracavity dispersion value. In one of this lasers, generation of solitons and stretched pulses have been obtained. In other laser, similariton (self-similar pulses) have been generated. These lasers are highly promising for further development of the stabilized combs. For further comb stabilization, pump modulation of commercial fiber mode-locked laser has been studied.

P43 ■ TORREY HAYDEN

Large Amplitude Wavelength Modulation Spectroscopy for Sensitive Measurements of Broad Absorbers

We demonstrate the first wavelength modulation spectroscopy of gases at >30 atm. Wavelength Modulation Spectroscopy (WMS) is a technique in which one rapidly tunes the wavelength of a laser across an absorption feature of a species of interest, generating absorption-induced harmonic signals at high frequencies above system noise levels. Coupling this technique with a far tuning MEMs laser enables sensitive measurement of species with broadband absorption features,such as high-pressure gases and large molecules, for the first time.

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P44 ■ ABHISHEK ANCHAL

Frequency-shift free Optical Phase Conjugation in nonlinear fiber

We have developed a method of frequency- and polarization shift-free OPC using counter-propagating dual pumped FWM in fiber. The two counter-propagating pumps create a Bragg grating inside the fiber, which diffracts the forward propagating signal and generates a backward propagating idler wave whose phase is conjugate of signal phase. By placing the pump frequencies symmetrically about signal frequency, we ensure that the idler has the same frequency as that of the signal. Since the signal and idler waves appear at opposite ends, the idler is easily filtered out from the rest of the spectrum. Ideal phase conjugation is achieved at an optimum length of fiber for a given pump power. A detailed study of effect of critical design parameters such as nonlinear length, pump power, and detuning between pump and signal on conjugate efficiency and phase-offset has been carried out.

We examined the performance of OPC as MSSI element for mitigation of nonlinear effects in standard single mode transmission fiber. By numerical simulations, we demonstrate near complete non-linearity mitigation of 40 Gbps DQPSK modulated data transmitted over 1000 km standard single mode fiber using our proposed OPC.

P45 ■ LOÏC LAVENU

Nonlinear compression of fiber laser in Kagomé fiber

We present the generation of sub-50 fs and 50 µJ pulses from a high energy, 300 fs, 1030 nm Yb-doped fiber amplifier using nonlinear compression in a 1 m-long air-filled hypocycloid-core Kagome fiber. The properties of this fiber allow an increase of the self-focusing threshold by maintaining the light outside of the glass structure. They also permit the generation of sub-10 fs pulses owing to the large guidance spectral bandwidth of hundreds of nanometers. A compression factor of 10 is demonstrated, with a fiber transmission of up to 70%. We also investigate the use of hollow-core capillaries for energy scaling of these nonlinear compression setups. These architectures provide excellent solutions for efficient high harmonic generation with high repetition rate sources.

P46 ■ ANDRE LUIZ MARQUES MUNIZ

Ultra-broadband Photonics-based RF Front-End Towards 5G Networks

We propose the concept and report the development of an ultra-broadband photonics-based RF front-end, as well as its experimental digital performance analysis up to 38 GHz. The proposed RF front-end applies optical frequency multiplication based on external modulation technique and the optical nonlinear effect four-wave mixing for enabling a combination of photonic-assisted RF upconversion and amplification, without requiring any hardware modifications. We present, for the first time in literature, ultra-broadband operation and frequency tunability from DC to 38 GHz by simultaneously performing RF conversion and amplification in the optical domain. Experimental results of a successfully implementation in a real wireless-optical network demonstrate the RF frontend applicability in the three potential frequency bands for 5G networks, namely: 6.0, 28 and 38 GHz. Furthermore, a detailed digital performance investigation using different modulation formats is presented based on diverse RF and optical parameters, including signal-to-noise ratio, RF gain and error vector magnitude. Low phase noise, spectral purity and distortion absence are also observed for all frequency bands.

P47 ■ RAMIRO CONTRERAS MARTINEZ

Spectral interferometry technique for determining the mínimum resolution of a Czerny-Turner spectrometer.

We propose the design of a new technique for measuring the spectral resolution of a Czerny-Turner Spectrometer based on spectral interferometry of ultrashort laser pulses. It is well known that ultrashort pulse measurement like SPIDER and TADPOLE techniques requires a precise and well characterized spectrum, especially in fringe resolution. We developed a new technique, in which by measuring the nominal fringe spacing of a interferogram one can characterize the minimum spectral resolution in a Czerny-Turne. This technique was tested in a commercial Czerny-Turner spectrometer. The results demonstrate a consistent spectral resolution between what was reported by the manufacturer. The actual calibration technique was applied in a homemade broad-

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band astigmatism-free Czerny-Turner spectrometer. Theory and experimental results are presented.

P48 ■ KÉVIN GENEVRIER

Polarization and crystal-orientation dependency of thermal effects in cryogenically cooled Yb:CaF2

We studied the polarization and crystal-cut dependency on thermal effects in cryogenically cooled laser bulk crystal Yb:CaF2 under high power pumping. We were interesting in observing any anisotropy or rupture of symmetry versus polarization and versus different crystal cuts. We then monitored the polarization patterns and thermal wavefront distortions for two crystal cuts [110] and [111]. Beside a similar experimental setup for both crystals, we saw strong different behaviors versus polarization between them. As expected for CaF2, the [111] cut is very close to the optimal cut which reduces thermal, but the classical "Malte cross" was only observed for the [110] cut. Moreover we observed a strong astigmatic thermal lens depending on the polarization for the [110] cut whereas [111] cut did not demonstrated any anisotropy. These ruptures of symmetry are important in the purpose of developing high power amplifiers with Yb:CaF2 since they diverge from the ideal isotropy of fluorite.

P49 ■ SIMAS SOBUTAS

Control of thermal effects in high harmonics generator of solid-state femtosecond laser

While generating high peak intensity ultrashort pulses in the ultraviolet (UV) spectral range linear and nonlinear (two-photon – TPA) absorptions could become significant in transmitting optical components (lenses, beamsplitters, etc.). TPA also occurs in nonlinear crystals such as beta barium borate (beta-BaB2O4, BBO), which are used in conversion of radiation frequency, resulting in decrease of conversion efficiency to UV spectral range radiation. The crystal absorbs some of generated UV radiation where it transforms into heat – causing an increase of crystal temperature and a change of phase matching angle.

The thermal effects prolong the warm-up time of the high harmonics generator (UV radiation). In order to reduce the influence of these effects, it is important to compensate the change of phase matching angle of nonlinear crystal. The crystal tilt angle is alternated using the motorized rotation stage which trajectory is based on the time-dependent function.

To explore and discuss the thermal effects on phase matching angle a system generating high average power femtosecond laser pulses of UV spectral range was designed. A sum of two exponential functions was used to define the temperature change of the crystal when cooling. This allowed the calculations of the crystal cooling constants. The same pair of exponential functions, using cooling constants, was applied to the motorized control of nonlinear crystal angle. The result is the finding of the optimal motion trajectory which in turn compensates the influence of thermal effects and reduces the warm-up time of high harmonics generator. The method demonstrates a significant reduction in the warm-up time of the fourth (257.5 nm) and the fifth (206 nm) harmonics from 25 s to 5 s and from 30 s to 7 s respectively without experiencing any power loss. The findings show that this method can be applied to the high harmonics generator of solid-state femtosecond laser. This laser system could be used in applications, such as ophthalmic surgery, where the speed of the laser-assisted microfabrication of materials is of very high importance.

Though the findings are promising, the method remains open for further development and improvement.

P50 ■ TAO CAO

Measuring Carrier-Envelope Offset Frequency with Resonant Dispersive Waves

The carrier-envelope phase (CEP) stabilized pulse train generated by mode-locked lasers has a broad spectrum, where millions or about a million of comb-like spectral peaks at fixed frequencies space equally at the interval of the repetition rate [,]. Spectra like this are called optical frequency combs, which have had a significant impact on high-precision optical frequency metrology, optical clocks, low-phase-noise microwave generations and many other fields.

To obtain a CEP stabilized pulse train, it is necessary to stabilize the carrier-envelope offset (CEO) frequency, which derives from the difference between the group velocity and the phase velocity of the oscillating pulses

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in the cavity. Usually, the so-called f-to-2f technique is used to measure the CEO frequency and to realize the feedback control. Typically, in this technique, a higher-frequency component of an octave-spanning super-continuum is used to beat with the second harmonic induced by the corresponding lower-frequency component, and the radio-frequency beating signal indicates the CEO frequency [1-]. Obviously, this method has low energy efficiency, because the medium-frequency component, containing the majority of the supercontinuum's energy, is not wanted in this method. Besides, the spectral envelop of supercontinuum combs is sensitive to the power and the duration of pump pulses. Once the f-to-2f setup is determined, changing the output power or the chirp of the mode-locked laser will lead to changes of the supercontinuum spectral envelope, and thus degrade the beating signal. That is to say, the output laser properties and the f-to-2f measurement can't be optimized simultaneously.

In this work, we try to solve these problems with resonant dispersive waves (RDWs), also named as Cherenkov radiation emitted by optical solitons. When an ultrashort pulse propagates in a fiber with specific nonlinearity and dispersion characteristics, it evolves into a fundamental soliton, or breaks up into several fundamental solitons due to perturbations of the high-order dispersion. During the formation of the fundamental solitons, excess energy is shed to the phase-matched linear dispersive waves, namely RDWs, besides of intra-pulse Raman scatterings [,]. These processes can be described by the well-known generalized nonlinear Schrödinger equation (GNSE).

In our method, the output pulse train is frequency doubled by an LBO crystal. The remaining fundamental light is coupled into a Kagome photonic crystal fiber to generate RDWs, and the RDWs are used to beat with the second harmonic generated by the LBO crystal to obtain the CEO frequency [ ]. Apparently, the better the RDWs spectrum overlaps with the second harmonic spectrum, the higher the energy efficiency will be. This means the wavelength, the bandwidth and the intensity of the RDWs should be matched with the second harmonic.

There are several methods to reach a better matching. First, the wavelength of the RDWs can be tuned to the appropriate value by coupling the fundamental light into the appropriate PCF microstructure [ ]. Second, the bandwidth and the intensity of the second harmonic can be optimized by optimizing the phase-matching angle and the phase-matching bandwidth of the LBO crystal. Third, the efficiency of the RDWs generation can be improved by a better coupling efficiency. In our experiment, we obtain the beating signal with a fine signal-to-noise ratio even though the RDWs spectrum is not matched with the second harmonic spectrum strictly [6]. This result confirms the feasibility for RDWs to be used for f-to-2f measuring, and it implies a much higher energy efficiency can be achieved by a better matching between the RDWs spectrum and the second harmonic spectrum.

Another important advantage of RDWs is the frequency stabilities against to changes of the pump power and the pulse duration, which means the beating signal won't be degraded even though the output power and the pulse duration are changed in the f-to-2f measurement based on RDWs. To understand the good frequency stabilities of RDWs, it is necessary to notice that the frequencies of RDWs are solely determined by the phase-matching conditions, which are insensitive to changes of the pump power and the pulse duration. In fact, our experimental results have shown that the frequencies of the RDWs stayed almost unchanged even though the single-shot pump energy changed from 0.79 nJ to 1.84 nJ with the pump pulse duration fixed, or the pump pulse duration changed from 20 fs (negatively chirped) to 153 fs (positively chirped) with the pump power fixed, which confirms the good frequency stabilities of RDWs.

P51 ■ DANIEL MORRIS

Research and development of thulium-doped fibre lasers

Two free-space coupled thulium-doped fibre lasers (TDFL) were developed and characterised: a CW laser and a Q-switched polarised laser. The CW laser was pumped by a single, 793 nm laser diode. The maximum power achieved by the laser was 66 W corresponding to a slope efficiency of 54 % with respect to the launched pump power. The free running output wavelength was determined to be 2017 nm. The measured M2 value for the un-spliced Tm-doped fibre was <1.05. After the addition of spliced passive fibres to the doped fibre, the

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beam quality degraded to < 1.85 due to introduction of cladding modes at the splice joints. We found the continuous wave (CW) output had a slight (< 10%) modulation. The frequency of the modulation corresponded to the round trip cavity time of the TDFL. The pulsed output of the Q-switched laser had peak powers of ~1 kW at pulse repetition frequencies (PRF's) ranging from 25 -85 kHz. These peak powers corresponded to pulse length of ~208 ns. We achieved a maximum average power of 30 W when bidirectionally pumping the doped fibre with ~69 W of pump power at a PRF of 100 kHz. The slope efficiency corresponding to the maximum output power was ~49 %.

P52 ■ MICHAEL GARDNER

Towards Early Retinal Detection of Alzheimer's Disease Using Scattering-Angle Resolved Optical Coherence Tomography

An Alzheimer's disease (AD) patient, prior to her death, will experience dramatic memory loss and the progressive demise of other cognitive and physical facilities. Recent studies show an AD development pathway involving early synaptic failure and abnormal mitochondrial dynamics in the central nervous system - before the onset of the conventional clinical symptoms and histopathological hallmarks of AD. The eye, as a "window into the brain," is an ideal location to monitor morphological changes associated with failed synapses. A new scattering-angle resolved optical coherence tomography (SAR-OCT) design for murine retinal imaging will be used to monitor changes in the retinas of transgenic mice that will develop AD symptoms over the course of one year. With this effort, new biomarkers will be uncovered for early detection of AD, enabling future researchers to monitor the efficacy of prospective AD drugs and ultimately extend the lives of AD patients with the option of earlier treatment.

P53 ■ CARLOS ALBERTO QUINTERO

Analysis of the Effects of Periodic Forcing in the Spike Rate and Spike Correlation's in Semiconductor Lasers with Optical Feedback

We study the dynamics of semiconductor lasers with optical feedback and direct current modulation, operating in the regime of low frequency fluctuations (LFFs). In the LFF regime the laser intensity displays abrupt spikes: the intensity drops to zero and then gradually recovers. We focus on the inter-spike-intervals (ISIs) and use a method of symbolic time-series analysis, which is based on computing the probabilities of symbolic patterns. We show that the variation of the probabilities of the symbols with the modulation frequency and with the intrinsic spike rate of the laser allows to identify different regimes of noisy locking. Simulations of the Lang-Kobayashi model are in good qualitative agreement with experimental observations.

P54 ■ JAISMEEN KAUR

Leaky Optical Fiber based Refractive Index Sensor

A theoretical analysis of a large-mode-area (LMA), effectively single mode fiber design for refractive index sensing is presented here. This sensing mechanism requires very small amount of analyte and is also capable of continuous measurements. Effective Index of the design depends upon the analyte which forms the outermost layer. Thus, the leakage loss and transmittance of the fiber show a variation with the refractive index of the analyte. This characteristic of the fiber has been exploited to design a refractive index sensor. To achieve an effectively single mode LMA configuration, the parameters have been chosen such that only the LP01 mode survives and the higher modes have extremely high leakage loss such that they do not interact with the analyte layer. The structure has been analysed using the transfer matrix method. Effect of design parameters on sensitivity of the proposed sensor has also been investigated. Results show that a highly sensitive leaky optical fiber based sensor can be designed using this structure.

*Reflects abstracts received by 11 July 2016.

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ICFO The institute of Photonic Sciences

ICFO is a young research institution that aims to advance the very limits of knowledge in Photonics, namely the science and technology of harnessing Light. Light, especially laser light, is one of the major enabling technologies currently available to humankind. The ICFO research thrusts target the global forefront of photonics, and aim to tackle important challenges faced by society at large. ICFO focuses on current and future problems in Health, Energy, Information, Safety, Security and caring for the Environment.

The most valued assets at ICFO are the MSc and PhD students and the post-doctoral researchers. They are bright, ambitious young women and men, with a talent for discovery and strong moral values, who aim to achieve difficult but important goals. Central to the ICFO mission is the training of the next generation of scientists and technicians through courses, seminars, access to cutting-edge experimental infrastructures, and mentoring by researchers that are among the best in the world in their field. This training aims to equip talented students with unique capabilities that help them become future leaders, either in the academic or in the industrial world.

The 2016 Siegman School on Lasers is a splendid example of training at ICFO. A broad palette of Laser Science topics presented by leading world renowned scientists, both academic and industrial, brought to you in a setting of intimate learning and discussion.

The OSA Foundation

In keeping with its mission to promote the generation, application, archiving and worldwide dissemination of knowledge in optics and photonics, The Optical Society (OSA) established the OSA Foundation in 2002 to carry out a wide range of charitable activities.

The OSA Foundation is a non-profit organization that relies on the generous financial support of donors to help graduate students and early career professionals as they become active members of research, engineering and corporate communities around the globe. Foundation-sponsored travel grants, prizes, scholarships, fellowships and programs are just some of the ways donor contributions directly benefit these innovators and leaders of tomorrow. Enabled by engaged contributors like you, the Foundation also works to secure OSA Awards and Honors Program endowments.

As has been the case since the OSA Foundation's earliest days, every donation is matched 100% by The Optical Society's contributions to the OSA Foundation's General Fund. OSA's commitment to the Foundation and its matching program allows every gift to make twice the impact!

About

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The Optical Society's (OSA) mission is to promote the generation, application and archiving of knowledge in optics and photonics and to disseminate this knowledge worldwide. The purposes of the Society are scientific, technical and educational. OSA's commitment to excellence and long-term learning is the driving force behind all its initiatives.

Since 1916, OSA has been the world's leading champion for optics and photonics, uniting and educating scientists, engineers, educators, technicians and business leaders worldwide to foster and promote technical and professional development. Through publications, events and services, Optical Society is helping to advance the science of light by addressing the ongoing need for shared knowledge and innovation.

OSA was founded exactly 100 years ago as The Optical Society of America and has evolved into a global enterprise serving a worldwide constituency. In recognition of its global reach and focus, since 2008 the Society has been known as OSA - The Optical Society.

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