### Monday, September 14

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
<th>Speaker(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:00 AM</td>
<td>Registration Open</td>
<td></td>
</tr>
<tr>
<td>8:45 AM</td>
<td>Welcome Remarks</td>
<td>Tom Baer, SPRC</td>
</tr>
<tr>
<td>9:00 AM</td>
<td><strong>Integration Technologies for Dense, Low-Power Optical Transceivers</strong></td>
<td>Jim Harris, Session Chair</td>
</tr>
<tr>
<td>9:00 AM</td>
<td>Narrow linewidth widely tunable lasers using American Institute of Manufacturing (AIM) of Photonics</td>
<td>John Bowers, UCSB</td>
</tr>
<tr>
<td>9:30 AM</td>
<td>Embracing diversity - MEMS-based hybrid optical packaging that brings out the best of each technology</td>
<td>Bardia Pezeshki, Kaiam Inc.</td>
</tr>
<tr>
<td>10:00 AM</td>
<td>A Decade of Data Center Network Architecture and Implementation at Google</td>
<td>Amin Vahdat, Google</td>
</tr>
<tr>
<td>10:30 AM</td>
<td><strong>BREAK</strong></td>
<td></td>
</tr>
<tr>
<td>11:00 AM</td>
<td><strong>Communications &amp; Networking for Data Centers</strong></td>
<td>Joe Kahn, Session Chair</td>
</tr>
<tr>
<td>11:00 AM</td>
<td>Optical Technology Requirements</td>
<td>Hong Liu, Google</td>
</tr>
<tr>
<td>11:30 AM</td>
<td>Hardware Defined Networking within Datacenters</td>
<td>George Papen, UCSD</td>
</tr>
<tr>
<td>12:00 PM</td>
<td>100G Single-Laser Links for Data Centers</td>
<td>Jose Krause Perin, Stanford</td>
</tr>
<tr>
<td>12:30 PM</td>
<td>Poster Intros</td>
<td></td>
</tr>
<tr>
<td>1:00 PM</td>
<td><strong>LUNCH</strong></td>
<td></td>
</tr>
<tr>
<td>2:00 PM</td>
<td><strong>Fiber Sensors</strong></td>
<td>Michel Digonnet, Session Chair</td>
</tr>
<tr>
<td>2:00 PM</td>
<td>Distributed fibre sensing : state-of-the-art and perspectives</td>
<td>Luc Thevenaz, Ecole Polytechnique Federale Lausanne</td>
</tr>
<tr>
<td>2:30 PM</td>
<td>Measuring attostrains with a slow-light fiber Bragg grating</td>
<td>George Skolianos, Stanford</td>
</tr>
<tr>
<td>2:45 PM</td>
<td>Utilizing Fiber Sensor Technology to Miniaturize the Atomic Force Microscope</td>
<td>Antonio Gellineau, KLA Tencor</td>
</tr>
<tr>
<td>3:15 PM</td>
<td>Identification of heart muscle cells using an ultrasensitive fiber hydrophone</td>
<td>Cathy Jan, Stanford</td>
</tr>
<tr>
<td>3:30 PM</td>
<td><strong>BREAK</strong></td>
<td></td>
</tr>
<tr>
<td>4:00 PM</td>
<td><strong>Unconventional Applications of Guided Light</strong></td>
<td>Olav Solgaard, Session Chair</td>
</tr>
<tr>
<td>4:00 PM</td>
<td>In-fiber atom optics using Kagome hollow fiber</td>
<td>Fetah Benabd, XLIM Research Institute</td>
</tr>
<tr>
<td>4:30 PM</td>
<td>Time differentiation deformability cytometry using evanescent fields of waveguides for single cell analysis</td>
<td>Saara Khan, Stanford</td>
</tr>
<tr>
<td>4:45 PM</td>
<td>Ultra-Thin Rigid or Flexible Endoscope using a Multi-Mode Fiber</td>
<td>Ruo Yu Gu, Stanford</td>
</tr>
<tr>
<td>5:15 PM</td>
<td>Double-clad fiber couplers for multimodal sensing</td>
<td>Caroline Boudoux, Ecole Polytechnique Montreal</td>
</tr>
<tr>
<td>5:30 PM</td>
<td><strong>Reception &amp; Dinner</strong></td>
<td>Stanford Faculty Club</td>
</tr>
<tr>
<td></td>
<td><strong>After-dinner presentation by Prof. David Miller</strong></td>
<td></td>
</tr>
</tbody>
</table>
### Tuesday, September 15

8:30 AM  Registration Open

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
<th>Speaker/Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00 AM</td>
<td>Space Optics: Overview of the James Webb Space Telescope and its Optical Systems</td>
<td>Mark Clampin, NASA</td>
</tr>
<tr>
<td>9:45 AM</td>
<td>Imaging extrasolar planets</td>
<td>Bruce Macintosh, Stanford</td>
</tr>
<tr>
<td>10:15 AM</td>
<td>Graphene-GaN ultraviolet photodetector arrays for space applications</td>
<td>Hongyun So, Stanford</td>
</tr>
<tr>
<td>10:30 AM</td>
<td><strong>BREAK</strong></td>
<td></td>
</tr>
<tr>
<td>11:00 AM</td>
<td>Modern Microscopy: Optical mesoscopy with a new giant lens</td>
<td>Gail McConnell, University of Strathclyde</td>
</tr>
<tr>
<td>11:40 AM</td>
<td>Point-spread-function engineering for 3D localization microscopy</td>
<td>Yoav Shechtman, Stanford</td>
</tr>
<tr>
<td>12:05 PM</td>
<td>What direction does point-source stimulated emission go?</td>
<td>Andrew York, Calico Labs</td>
</tr>
<tr>
<td>12:30 PM</td>
<td><strong>LUNCH</strong></td>
<td></td>
</tr>
<tr>
<td>2:00 PM</td>
<td>Quantitative Dynamic Imaging: Evaluating a Biomarker for Pluripotency with Large Scale Time Lapse Imaging</td>
<td>Michael Halter, NIST</td>
</tr>
<tr>
<td>2:30 PM</td>
<td>Time-lapse Quantitative Phase Imaging to Characterize Cell Populations</td>
<td>Christy Amwake, Stanford</td>
</tr>
<tr>
<td>2:45 PM</td>
<td>Large Field of View X-ray Differential Phase Contrast Imaging in Biology/Medicine and Luggage Inspection</td>
<td>Max Yuen, Stanford</td>
</tr>
<tr>
<td>3:15 PM</td>
<td>Image Processing Techniques for Measuring Dynamic Properties of Cells in Culture</td>
<td>Nathan Loewke, Stanford</td>
</tr>
<tr>
<td>3:30 PM</td>
<td><strong>BREAK</strong></td>
<td></td>
</tr>
<tr>
<td>4:00 PM</td>
<td>Quantum Enhanced Microscopy: Biological lasers: for fun and for use</td>
<td>S. H. Andy Yun, Harvard University</td>
</tr>
<tr>
<td>4:30 PM</td>
<td>Quantum Imaging with Undetected Photons</td>
<td>Victoria Borish, Stanford</td>
</tr>
<tr>
<td>4:45 PM</td>
<td>Quantum Super-resolution Imaging in Fluorescence Microscopy</td>
<td>Osip Schwartz, UC Berkeley</td>
</tr>
<tr>
<td>5:15 PM</td>
<td>Multipass Microscopy</td>
<td>Brannon Klopfer, Stanford</td>
</tr>
</tbody>
</table>
Wednesday, September 16

8:30 AM  Registration Open

<table>
<thead>
<tr>
<th>Optics &amp; Quantum Information</th>
<th>Marty Fejer, Session Chair</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00 AM</td>
<td>Quantum Engineering with Light-Mediated Interactions</td>
</tr>
<tr>
<td>9:30 AM</td>
<td>Quantum Optomechanics</td>
</tr>
<tr>
<td>10:00 AM</td>
<td>New Strategies in Nanoplasmonic Engineering</td>
</tr>
</tbody>
</table>

10:30 AM  BREAK

<table>
<thead>
<tr>
<th>Ultrafast and X-Ray Laser Research</th>
<th>Phil Bucksbaum, Session Chair</th>
</tr>
</thead>
<tbody>
<tr>
<td>11:00 AM</td>
<td>X-ray free-electron lasers: status and future developments</td>
</tr>
<tr>
<td>11:30 AM</td>
<td>Ultrafast Molecular Dynamics Probed by Vacuum Ultraviolet Pulses</td>
</tr>
<tr>
<td>11:45 AM</td>
<td>Probing Fullerenes Ionization Dynamics from Within using the LCLS</td>
</tr>
<tr>
<td>12:15 PM</td>
<td>Dynamical Phase Control in Atomic and Nuclear Physics</td>
</tr>
</tbody>
</table>

12:30 PM  LUNCH
Sponsors

SPRC would like to thank our 2015 Symposium Sponsors:

- M Squared
- Newport
- Ophir
- Spiricon Laser Beam Diagnostics
About SPRC

The Stanford Photonics Research Center (SPRC) builds strategic partnerships between the Stanford University photonics research community and corporations and other organizations active in photonics or employing lasers and optical technologies in their research and product development activities. Member companies gain facilitated access to Stanford faculty, students and researchers by participating in SPRC events, supporting and collaborating on specific research projects, mentoring students, and visiting research labs. Member benefits also include priority alerting for Stanford photonics invention disclosures. SPRC promotes member company recruitment of Stanford students, and facilitates research interactions with Stanford PhD students, faculty, and other researchers. In turn, Stanford students establish connections with scientific experts and business leaders in the photonics industry that continue beyond their Stanford experience.

SPRC faculty and student members belong to one or more working groups which are best aligned with their research interests. These working groups cover a wide range of research areas and technologies, including:

- Solar Cell Technologies
- Information Technology
- Telecommunications
- Neuroscience
- Microscopy and Molecular Imaging
- High Power Laser Sources
- Quantum Information Science
- Nanophotonics
- Automotive
- Entrepreneurship

SPRC corporate members interact directly with faculty working groups conducting research in areas most directly related to company interests.

Membership

Membership in the Stanford Photonics Research Center is available to companies interested in establishing mutually-beneficial relationships with the Stanford photonics community. Membership fees directly support research and teaching in photonics at Stanford; in turn, members gain facilitated access to Stanford photonics students, faculty, and current and emerging areas of research at Stanford.

There are four levels of membership in SPRC:

Founding Membership

Founding Members help set the strategic direction of SPRC and may participate on the SPRC Advisory Board. Founding Membership involves a multi-year commitment to membership dues at the Senior Member level (see below) plus a capital donation of $2M. Founding Members receive all benefits of other membership levels.

Senior Membership

In addition to the benefits listed below for all membership levels, Senior Members may participate on the SPRC Advisory Board, may send a scholar/researcher to Stanford for up to six months per year to work with a collaborating Stanford faculty member and research group. Senior members may also support multiple Stanford photonics research groups in accordance with SPRC Advisory Board and University policy. The annual fee for Senior Membership is $150,000.
In addition to the benefits listed below for all membership levels, Standard Membership offers companies the opportunity to send a visiting scholar/researcher to Stanford for up to one month per year to work with a collaborating Stanford faculty member and research group. Regular members may also support a Stanford photonics working group in accordance with SPRC Advisory Board and University policy. The annual fee for Standard Membership is $50,000.

Introductory Membership

The Introductory Membership level is for companies and organizations that wish to join SPRC but do not wish to financially support a specific faculty or research group at the outset. This is a two-year commitment, with the first year fee of $25,000, before a second year at the standard rate.

Basic Benefits for all Members

In addition to the specific benefits stated above for each membership level, all member companies receive the following basic benefits:

- Facilitated access to Stanford photonics research activities and results
- Prompt alerting for Stanford invention disclosures in photonics
- Customized courses delivered via Web or in-person by Stanford photonics faculty
- Discounted Symposium registration fee and complimentary registration to workshops
- Priority notification of, and invitations to, all SPRC events
- Access to photonics students’ resumes for recruitment
- Online access to all SPRC event publications and proceedings
Contact Information

http://photonics.stanford.edu

**Stanford Photonics Research Center**

348 Via Pueblo Mall  
Suite 107  
Stanford, CA 94305

---

**Faculty Co-Directors**

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---

**For Membership information,**  
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(650) 723-4406

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**For general information,**  
please contact:  

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Assistant Director  
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(650) 723-5627
Member Companies

SPRC thanks our member companies for their continued support of photonics research at Stanford University.
The SU²Partnership

www.su2p.com

The Universities of Strathclyde, St. Andrews, Heriot-Watt and Glasgow, together with Stanford University and the California Institute of Technology (Cal Tech), are collaborating in a project supported by Research Councils UK (RCUK), the Scottish Funding Council and Scottish Enterprise.

The partnership is designed to capitalize on leading research in the photonics sector, in fields including life sciences and renewable energy, and the commercial opportunities the research offers. It also aims to bolster existing links between universities and businesses in Scotland and the US.

<table>
<thead>
<tr>
<th>Key Pillars of Activity in the Project</th>
<th>Key research themes will each have a working group</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Development Projects</td>
<td>• Biophotonics (including stem cell imaging and neuroscience photonics)</td>
</tr>
<tr>
<td>• Entrepreneurial Fellowships</td>
<td>• Solar cell devices</td>
</tr>
<tr>
<td>• Researcher Exchanges</td>
<td>• Integrated photonics</td>
</tr>
<tr>
<td>• Investor Network</td>
<td>• Solid-state laser engineering and nonlinear optics</td>
</tr>
<tr>
<td>• Industrial Affiliates</td>
<td>• Photonics sensors (including atom, quantum optic and environmental sensors)</td>
</tr>
</tbody>
</table>

It will also enable businesses in the US and the UK to share ideas and expertise with academics in both countries. The project will give talented young researchers the opportunity to experience working in laboratories in California.

Building on the success of the Stanford Industrial Affiliates scheme and various similar Scottish academic industrial collaborations, there is an opportunity being extended to UK companies to participate and gain real benefits from the SU²P Industrial Affiliates Program.

The program will improve companies’ competitive position by providing a range of activities including facilitated interaction with leading US- and UK-based researchers and entrepreneurs.

For further information please contact:
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Fax +44 (0) 141 552 1575
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SU²P Academic Partners

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Heriot Watt University
University of St Andrews
Stanford University
University of Strathclyde Glasgow
University of Glasgow
SPRC Faculty

Photonics Core Faculty/Senior Researchers

Zhenan Bao  
Associate Professor of Chemical Engineering  
Polymer and organic electronics and photonics

Stacey Bent  
Professor of Chemical Engineering and, by courtesy, of Materials Science & Engineering and of Chemistry  
Nanostructured materials, fuel cells, and inorganic solar cell fabrication

Steven Block  
Professor of Applied Physics and Biological Sciences  
Single-molecule biophysics, laser-based optical traps, biological motors

Mark L. Brongersma  
Professor of Materials Science and Engineering  
Photonic nanoparticles and nanostructures

Manish Butte  
Assistant Professor of Pediatrics  
Immunology, live-cell microscopy, biological atomic force microscopy, single-molecule manipulation

Thomas Clandinin  
Assistant Professor of Neurobiology  
Medical genetics, biology

Bruce Clemens  
Professor of Engineering and of Photon Science  
Thin films, nanostructured materials

Chris Contag  
Professor of Pediatrics  
Pediatrics, neonatology, microscopy

Karl Deisseroth  
Assistant Professor of Bioengineering and of Psychiatry and Behavioral Sciences  
Neurobiology

Michel Digonnet  
Professor (Research) of Applied Physics, Ginzton Lab  
Fiber optics

Jennifer Dionne  
Assistant Professor of Materials Science and Engineering  
Plasmonic and nanocrystalline metamaterials

Abbas El Gamal  
Professor of Electrical Engineering  
Digital imaging and wireless networks

Audrey Ellerbee  
Assistant Professor of Electrical Engineering  
Microscopy, optical coherence tomography, optofluidics, low-cost diagnostics

Shanhui Fan  
Assistant Professor of Electrical Engineering  
Photonic crystals, computational electromagnetics, optical communications

SPRC Co-Directors

Thomas M. Baer  
Executive Director  
Biophotonics, medical diagnostic instrumentation, microscopy, laser source engineering, consumer applications of photonics, entrepreneurship

Martin M. Fejer  
Professor of Applied Physics  
Nonlinear and guided-wave optics, microstructured materials, optical signal processing, tunable and ultrafast sources

Robert L. Byer  
Professor of Applied Physics  
Solid state lasers, adaptive optics, nonlinear optics

David A.B. Miller  
Professor of Electrical Engineering, and, by courtesy, of Applied Physics  
Optoelectronic and nanophotonic physics, devices and systems; optical switching and interconnects; optical sensing

Robert L. Byer  
Professor of Applied Physics  
Solid state lasers, adaptive optics, nonlinear optics

SPRC Faculty
Michael Fayer  
*Professor of Chemistry*  
Dynamics and intermolecular interactions of molecules in liquids, and liquid crystals

Robert Feigelson  
*Professor of Materials Science and Engineering, Emeritus*  
Nonlinear optical materials

Ronald K. Hanson  
*Professor of Mechanical Engineering*  
Laser-based diagnostics and sensors, combustion and gas dynamics applications

James S. Harris  
*Professor of Engineering, Materials Science and, by courtesy, Applied Physics*  
Semiconductor optoelectronic materials, devices and applications, quantum information

Stephen Harris  
*Professor of Electrical Engineering & Applied Physics*  
Fundamentals of photonics and nonlinear optics

Lambertus Hesselink  
*Professor of Electrical Engineering and, by courtesy, of Applied Physics*  
Nanophotonics and ultra-high density optical data storage

Leo Hollberg  
*Professor (Research) of Physics*  
Laser-cooled atoms for tests of fundamental physics and optical atomic clocks

Roger Howe  
*Professor of Electrical Engineering*  
MEMS design, micro/nanomachining processes, self-assembly processes

Joseph M. Kahn  
*Professor of Electrical Engineering*  
Optical fiber communications, free-space optical communications, associated devices and subsystems

Mark Kasevich  
*Professor of Physics and Applied Physics*  
High accuracy navigation and gravimetric sensors based on de Broglie wave interferometry; Future atom optics sensors which exploit the novel coherence properties of Bose-Einstein condensates

Leonid Kazovsky  
*Professor of Electrical Engineering*  
Optical telecommunications and network systems

Thomas W. Kenny  
*Associate Professor of Mechanical Engineering*  
Microsensors based on silicon micromachining

B. (Pierre) T. Khuri-Yakub  
*Professor (Research) of Electrical Engineering*  
Acoustic sensors (temperature, film thickness, resist cure), acoustic materials and devices

Gordon Kino  
*Professor of Electrical Engineering, and, by courtesy, of Applied Physics, Emeritus*  
Optical fiber sensors

Benjamin Lev  
*Assistant Professor of Applied Physics, and, by courtesy, of Physics*  
Condensed matter physics, nanoscience and quantum engineering, lasers and accelerators

Marc Levoy  
*Professor of Computer Science and Electrical Engineering*  
Light field imaging and display, computational imaging and digital photography

Liquin Luo  
*Professor of Biological Sciences and, by courtesy, of Neurobiology*  
Biological science, molecular biology, and neurobiology

W. E. Moerner  
*Professor of Chemistry*  
Single-molecule spectroscopy, biophysics, nanophotonics, single photon sources

Daniel Palanker  
*Assistant Professor (Research) of Ophthalmology*  
Biomedical optics and electronics

Calvin F. Quate  
*Professor (Research) of Electrical Engineering and, by courtesy, Professor (Research) of Applied Physics*  
Imaging and lithography applications of scanning probes.
Alberto Salleo  
Assistant Professor of Materials Science and Engineering  
Laser materials processing, materials and processes for large-area electronics

Krishna Saraswat  
Professor of Electrical Engineering  
Innovative materials, device structures, process technology of silicon devices and integrated circuits

Mark Schnitzer  
Assistant Professor of Applied Physics and Biological Sciences  
Biophotonics.

Olav Solgaard  
Associate Professor of Electrical Engineering  
Optical micromechanical devices and applications

Jelena Vuckovic  
Assistant Professor of Electrical Engineering  
Photonic crystal-based optical and quantum optical devices and their integration; solid-state photonic quantum information systems

Brian A. Wandell  
Professor of Psychology, and by courtesy, of Electrical Engineering  
Image system engineering and visual neuroscience

Yoshihisa Yamamoto  
Professor of Electrical Engineering and Applied Physics  
Fundamental optoelectronic physics, structures, and devices, quantum computing, quantum information
SPRC FACILITIES

The New Science & Engineering Quad (SEQ)

The SEQ was designed to provide state-of-the-art facilities for science, engineering, and medicine. We are striving to build a vibrant community and to break down barriers across the disciplines. We offer a range of high quality shared administrative services and support the University's Initiative on Human Health and the Initiative on the Environment and Sustainability. The quad consists of four buildings: The Jerry Yang and Akiko Yamazaki Environment and Energy Building, the Jen-Hsun Huang Engineering Center, the James and Anna Marie Spilker Engineering and Applied Sciences Building, and the Shriram Center for Bioengineering and Chemical Engineering.

SPRC is located in the Spilker building.

James and Anna Marie Spilker Engineering and Applied Sciences Building

The Spilker building features the most advanced equipment available to explore matter at the nanoscale—such as an e-beam lithography tool and an atomic force microscope—much of it located underground to provide the stringent control of vibration, light, and cleanliness that is essential for nanoscale research. The nano center makes these labs available to more than 70 researchers from all over campus, including leaders in the natural and physical sciences, engineering, and medicine, who are exploring nanoscale properties and devices with potential applications as diverse as water purification, energy conservation, drug delivery, and national security. The center is the home of the Ginzton Laboratory and the proposed Institute for Nanoscience and Technology, and its labs will complement the nearby Stanford Nanocharacterization Lab and Stanford Nanofabrication Facility.

SPRC Optical Materials Characterization Facility

With initial DARPA/URI support, the Optical Materials Characterization Facility was established in 1992 as part of Stanford's Center for Nonlinear Optical Materials. This facility contains a variety of coherent sources and characterization tools that make possible the rapid measurement of the properties of optical materials and devices. The Characterization Facility is currently operated with funds derived from the SPRC Affiliates' Program, members of which have access to its facilities for support of research on optical materials and devices.

The measurement capability of the SPRC Optical Materials Characterization Facility is summarized below. Contact Dr. Roger Route through the SPRC office/web page for detailed information about the characterization equipment and for access to the facility.

SPRC characterization capabilities:

1. spatially and temporally resolved spectroscopic absorption measurement,
2. photoconductivity and photovoltaic currents at high optical intensities
3. scatter loss at 633 nm and 1064 nm (TMA Inst.),
4. waveguide refractive index profiles (Metricon),
5. variable angle spectroscopic reflectivity and ellipsometric measurements of thin films, waveguides and multilayers (SOPRA GESP) in the 250 - 1750 nm waveband,
6. spectrophotometric measurements with (Cary 500 and Hitachi U4001) UV-VIS-NIR grating spectrophotometers and (Bio Rad) mid-IR and far-IR Fourier transform spectrophotometers
7. photorefractive gain, diffraction efficiency, and response rates.

Coherent sources in the SPRC Characterization Facility include:
1. Spectra-Physics MOPO 730 Nd:YAG /BBO OPO system, ns pulses 1.84 – 0.21 μm
2. Coherent Mira femtosecond Ti:Sapphire laser system
3. Positive Light Spitfire Ti:S regenerative amplifier, with SHG and THG
4. Spectra-Physics Tsunami femto-second Ti:sapphire laser system,
5. Spectra-Physics OPAL femto-second OPO (1.3 - 2 μm),
6. Coherent Sabre tunable argon lasers

UV and Ultrafast Materials Characterization

The SPRC Optical Materials Characterization Facility has an ultra-fast and UV materials characterization capability with a tunable Coherent Mira/Sabre Ti:Sapphire laser pumping a Positive Light Spitfire/Merlin regenerative amplifier with a frequency doubler/tripler option. Single Guassian mode pulses, either <130 fs or ~1 ps in duration, at a 1 KHz rep. rate are available from 950 to 233 nm, and sum-frequency generation is possible to generate wavelengths shorter than 200 nm. Stretched, flat-top pulses are also available from the harmonic package through the use of a longer set of doubling and tripling crystals. The high spatial and temporal quality output beam was used recently to study UV degradation in nonlinear optical materials such as BBO.

Our ultra-fast capabilities also include a Spectra-Physics OPAL-Tsunami system. Tsunami is a femtosecond, actively mode-locked tunable Ti:sapphire laser producing <130 fs pulses at repetition rate of 80 MHz with average power > 1.5 W. OPAL is a synch-pumped OPO generating <130 fs pulses in a wavelength range covering 1.3 - 2 μm, with average power > 150 mW.

Spectroscopic Measurement of Absorption Loss

The spectroscopic absorption loss apparatus is known as a photothermal common-path interferometer (PCI). It uses the thermo-optic refractive index changes induced by absorbed optical power to monitor the thermalized optical absorption. In its simplest configuration, a pump beam at the wavelength at which the absorption is to be measured is focused coaxially with, but with a smaller waist than, a low-power probe beam. A phase shift is imposed on the central portion of the probe beam by the photothermal index change induced by the local temperature rise resulting from the absorbed pump power. The key feature of the device is a Fourier transforming lens that converts this localized phase shift into an intensity variation. This common path approach is much more robust than conventional methods based on Mach-Zehnder interferometry, and it makes possible near shot-noise limited measurements of the induced phase in a simple, tabletop system. Sensitivities to thermalized optical absorption in the range of 10−6 cm−1 have been demonstrated. A variety of pump lasers have been used, including 1.06 μm and 532 nm Nd:YAG based systems and various Ar-ion laser lines, though the method is applicable with almost any convenient pump laser.
Modifications to the PCI apparatus in the SPRC facility make use of crossed pump and probe beams, illustrated in Fig. 1, which allows spatially localized measurements for studying inhomogeneous bulk absorption, as well as surface and coating absorption effects. Through the use of two simultaneous pump lasers, we have characterized induced absorption effects such as gray tracking in KTP and green-induced IR absorption (GRIIRA) in LiNbO3. The relatively rapid time response, faster than 100 ms, allows observation of transient absorption effects as well.

Direct measurement of photoconductive and photovoltaic current

Characterization of photorefractive transport properties, including photoconductive and photovoltaic currents, at the high intensities characteristic of nonlinear optical devices are difficult by conventional holographic methods. We have developed a transparent contact (liquid electrolyte) cell to measure photocurrents for the characterization of LiTaO3 and LiNbO3. The cell design allows unambiguous measurement with the light beam collinear with the induced current but without the complication of charge accumulation on the surfaces of the samples. Measurements with this apparatus have led to considerable insight into the behavior of stoichiometric lithium niobate and stoichiometric lithium tantalate.

Characterization of materials using spectroscopic ellipsometry

Spectroscopic and multiple angle of incidence ellipsometry is a valuable tool for the determination of the optical constants (n, k) of materials and the characterization of surface and interface morphologies. While optical transmittance and reflectance measurements provide information on bulk sample properties, ellipsometry has great sensitivity to the properties of the reflecting surface and interfaces in the case of multiple layers. When the optical constants of the materials studied are known, the technique can be used to characterize surface and interface roughness. On the other hand, the measurements can also be used to yield the optical constants of materials. The sample morphology must then be characterized by other techniques, since an accurate reduction of ellipsometric data to the physical quantities of interest requires knowledge of the thicknesses of the constituent layers.

A schematic of the experimental set-up is shown above in Fig. 2. The measurement consists in analyzing the change of polarization resulting from reflection off the surface studied. Wavelengths from 0.25-1.7 µm and angles of incidence from 6-90° are accessible using our SOPRA instrument model GESP, which is of rotating polarizer type. The spectra consist of the ellipsometric angles (Ψ, Δ), measured typically at 200 points. Experimental data is fit using a linear regression with the purpose of minimizing an error function consisting of the difference between calculated and measured values of the quantities (Ψ, Δ).
ellipsometric angles are defined in terms of the ratio, where \( r_p, r_s \) are the complex reflection coefficients for light polarized parallel and perpendicular to the plane of incidence. The reflection coefficients are related to the refractive index \( n \) and extinction coefficient \( k \) through Fresnel's equations. The optical constants are related to the microscopic properties of the material studied through the dielectric function which is a direct function of the material band structure. Anticipated imperfections, such as rough interfaces and surfaces are described as layers constituted of mixed materials.

\[
\rho = \frac{r_p}{r_s} = \tan \psi e^{i\Delta}
\]

Fig. 2 Schematic layout of spectroscopic ellipsometer.
SPRC Optical MEMS fabrication

The Stanford research community in photonics has access to the Stanford Nanofabrication Facility (SNF) which is a state-of-the-art, shared-equipment, open-use resource in the heart of Stanford campus (http://snf.stanford.edu/). Most wafers are silicon or silicon-on-insulator (SOI) wafers but processing is also possible using quartz or glass wafers. The standard size is 4” but new machines for 6” wafers are being installed.

The optical MEMS fabrication capabilities of SNF are summarized below. Contact Olav Solgaard through the SPRC office/web page for detailed information about the fabrication equipment and for access to the facility.

SPRC optical MEMS fabrication capabilities:
1. optical lithography
2. thin film deposition by chemical vapor deposition (CVD)
3. oxidation and annealing
4. metallization and sputtering
5. dry etching
6. wet etching

Optical lithography
In addition to automatic and manual coating resist spinners (Headway, Laurell and SVG), the SNF has contact exposure machines (Karlsuss, EV aligner) as well as steppers (Nikon, Ultratech).

Thin film deposition by chemical vapor deposition (CVD)
Low pressure chemical vapor tubes allow deposition of polysilicon, silicon nitride, silicon germanium, low temperature oxide (LTO) either undoped or doped with phosphorus (BPSG).

Oxidation and annealing
Atmospheric horizontal tubes (Tylan) are used for oxidation, doping, and annealing heat treatment.

Metallization and sputtering
Several sputtering machines or evaporators (Gryphon, Innotec, Metallica, SCT) can be used to deposit gold, aluminum or other standard microelectronics metals.

Dry etching
Dry etchers is mostly used to perform anisotropic etching. Many machines (AMT, Drytek, Plasma Quest,…)with an extended library of process recipes gives a wide choice that can be tailored to the specific fabrication process in development.
Two Deep Reactive Ion Etchers (DRIE) are available in SNF. They allow researchers to etch vertically deep into the wafers, which is common when fabricating optical microsystems.

Wet etching
Anistropic etchants such as KOH or TMAH can be used at a wetbench to define optical quality mirror surfaces with anisotropic etching. Cleaning processes before going into a furnace or a lithography step can be performed at these wet benches too.

Characterization tools
The material properties can be tested inside SNF using, among other measurement tools, an ellipsometer, non-contact spectrophotometers or surface profilometers.
2015 Speaker Abstracts & Biographies

in order of presentation
We review recent breakthroughs in silicon photonic technology and components and describe progress in silicon photonic integrated circuits. Heterogeneous silicon photonics has recently demonstrated performance that significantly outperforms native III-V components. As an example, high Q resonators in silicon enable record low phase noise in fixed and tunable lasers. The impact active silicon photonic integrated circuits could have on interconnects, telecommunications, sensors and silicon electronics is reviewed. The goals and plans for the recently announced American Institute of Manufacturing (AIM) of Integrated Photonics will be described.

**John E. Bowers** holds the Fred Kavli Chair in Nanotechnology, and is the Director of the Institute for Energy Efficiency and a Professor in the Departments of Materials and Electrical and Computer Engineering at UCSB. He is a cofounder of Aurrion, Aerius Photonics and Calient Networks. Dr. Bowers is a member of the National Academy of Engineering, a fellow of the IEEE, OSA and the American Physical Society, and a recipient of the OSA Tyndal Award, the OSA Holonyak Prize, and the IEEE LEOS William Streifer Award.
The massive growth in machine-to-machine traffic driven by cloud computing and data center applications creates tremendous demand for high-bandwidth and low-cost optical interconnects. This demand is fundamentally driven by Moore’s law, as electronic switching speeds have far outstripped the scaling in optical interconnects. Though monolithic optical integration, similar to electronic integration, may seem to be the solution, the problems in electronics and optics are quite different in nature. The need for diverse functions and materials in optical systems means that a single integration technology is usually inappropriate. Unfortunately, hybrid integration in optics can also be difficult due to the tight physical alignment requirements of single mode packaging. Because the wavelength of light is small, single mode devices have challenging input and output coupling constraints.

We show how the mechanical problem of hybrid packaging can be solved by using a MEMS-based silicon platform that automatically aligns and couples optical beams. This allows us to build complex integrated optics, using different chips made of different materials for various functions. We use this “mechanical lithography” platform to realize various functions, from multi-wavelength transmitters that provide high-bandwidth at low-cost for datacenters, to simple but powerful tunable lasers, to inexpensive RGB visible sources.

**Dr. Bardia Pezeshki** is the CEO and a founder of Kaiam, a five year old company providing high speed optical interconnects for many of the leading datacenters and enterprise OEMs. Prior to Kaiam, Dr. Pezeshki was the founder and CTO of Santur, which was the leading manufacturer of tunable lasers for metro and long haul systems. These lasers enabled widespread deployment of multi-wavelength DWDM architectures, and supported 80% of world’s internet traffic in the last decade. Prior to his two start-ups, Bardia managed development teams at SDL, Inc, and IBM’s T. J. Watson Research center. He obtained his Ph.D. from Stanford University in Electrical Engineering in 1991, and has about 100 referred publications and about 30 patents.
A Decade of Data Center Network Architecture and Implementation at Google

Amin Vahdat, Google

Data centers power the most demanding interactive, storage, and cloud services in the Internet, all requiring the highest levels of availability. Bandwidth and scale demands are growing exponentially, doubling approximately every year. This makes data center network architecture is a critical and rapidly evolving enabler to new services and programming models in the data center. This talk starts with some background and motivation for some of the problems in data center networking. We conclude by looking at Google’s Data Center network software, hardware, and optical architecture, which must deliver cost-effective networking to tens of thousands of servers, all while maintaining operational simplicity.

Amin Vahdat is a Google Fellow and Technical Lead for networking at Google. He has contributed to Google’s data center, wide area, edge/CDN, and cloud networking infrastructure, with a particular focus on driving vertical integration across large-scale compute, networking, and storage. Vahdat has published more than 150 papers in computer systems, with fundamental contributions to cloud computing, data consistency, energy-efficient computing, data center architecture, and optical networking. In the past, he served as the SAIC Professor of Computer Science and Engineering at UC San Diego and the Director of UCSD’s Center for Networked Systems. Vahdat received his PhD from UC Berkeley in Computer Science, is an ACM Fellow and a past recipient of the NSF CAREER award, the Alfred P. Sloan Fellowship, and the Duke University David and Janet Vaughn Teaching Award.
Optical Technology Requirements
Hong Liu, Google

Google builds world's largest datacenter to support the growing bandwidth and scale demands of modern internet. Hardware and optical interconnects are two key elements for the performance and efficiency of mega scale data centers. In this talk, I will present an overview of interconnect requirements, and discuss the scaling challenges of various optical technologies to meet these requirements.

Hong Liu is a Principal Engineer at Google Technical Infrastructure, where she is involved in the system architecture and interconnect for a large-scale computing platform. Her research interests include interconnection networks, high-speed signaling, and optical access and metro design. Prior to joining Google, Hong was a Member of Technical Staff at Juniper Networks, where she worked on the architecture and design of network core routers and multi-chassis switches. Hong received her Ph.D in electrical engineering from Stanford University.
Hardware Defined Networking within Datacenters

George Papen, UCSD

We discuss the challenges of using optical switching at microsecond time scales in large-scale datacenters addressing both the physical requirements of the optical switch and aspects of the design of the control plane, which must coordinate the optical switching with end hosts.

George Papen is a professor of electrical engineering at the University of California at San Diego.

His current research interest is in the design optical networks for data center network applications.
100 G Single-Laser Links for Data Centers

Jose Krause Perin, Stanford University

100 G single-laser links are a stepping-stone in scaling up data center transmission rates and represent a shift from the traditional on/off keying in optical communications to other modulation formats such as pulse-amplitude modulation (PAM), carrierless amplitude-and-phase (CAP), and orthogonal frequency-division multiplexing (OFDM). In this talk, I will present the main challenges and opportunities of these different modulation formats in enabling 100 G interconnects and beyond, as well as alternatives to increase the power margin of such systems.

Jose Krause Perin received the B.S. degree in 2013 from Universidade Federal do Espirito Santo, (Vitoria, Brazil) and the M.S. degree in electrical engineering in 2015 from Stanford University. He is currently working toward the Ph.D. degree in electrical engineering at Stanford University.
Optical fibres offer the possibility to realize distributed sensing, which means that each point along the fibre can separately and selectively sense quantities such as temperature, strain, acoustics, and pressure, in total similarity to a real organic nerve. The fibre can therefore distinctively inform on the position of the stimulus and on its magnitude. This unique feature makes the optical fibre actually play two essential roles: linear sensing element transducing the quantity value into an optical modulation and transmission line to convey this optical information to the processing unit at the fibre end.

Distributed optical fibre sensors have today demonstrated their capability to measure quantities such as deformation and temperature over tens of km with an excellent accuracy, essentially thanks to the extreme transparency of the glass fibres. Using the most advanced nonlinear interactions, up to 1,000,000 distinct sensing points can be resolved along a single optical fibre, meaning that a quantity can be selectively measured each 10 cm over some 100 km, or each millimetre over 1 km. This makes the proposed concept of a fibre optic sensing nerve possible, either by monitoring a large distance, area or an entire facility remotely controlled from a safe place, or by densely innerving a tool or a structure to make it as selectively sensitive as the human skin.

We shall review the physical principles underlying the different distributed fibre sensing configurations, essentially based on the 3 natural scatterings present in silica fibres: Rayleigh, Raman and Brillouin scatterings. This will be illustrated by examples of real sensing and by some exemplary implementations. Focus will be placed on the fundamentals and the concepts, rather than on the technical solutions.

**Luc Thévenaz** received the M.Sc. degree and the Ph.D. degree in physics from the University of Geneva, Switzerland. In 1988 he joined the Swiss Federal Institute of Technology of Lausanne (EPFL) where he currently leads a research group involved in photonics, namely fibre optics and optical sensing. Research topics include fibre sensors, slow & fast light, nonlinear fibre optics and laser spectroscopy in gases. He achieved with his collaborators the first experimental demonstration of optically-controlled slow & fast light in optical fibres, realized at ambient temperature and operating at any wavelength since based on stimulated Brillouin scattering. He also contributed to the development of Brillouin distributed fibre sensing by proposing innovative concepts pushing beyond barriers. He recently developed a simple technique to generate perfect Nyquist pulse to boost the data rate in already installed optical links.

During his career he stayed at Stanford University, at the Korea Advanced Institute of Science and Technology (KAIST), at Tel Aviv University and at the University of Sydney. In 2000 he co-founded the company Omnisens that is developing and commercializing advanced photonic instrumentation based on distributed fibre sensing. He is Fellow of the Optical Society of America, Senior Member of the IEEE and Editor in 3 major scientific journals.
Measuring attostrains with a slow-light fiber Bragg grating

George Skolianos, Stanford University

Strain sensors have many applications in structural health monitoring, in civil engineering, security and in the higher end strain sensors are needed for sensing gravitational waves with ultra small strain resolution in the order of $10^{-21}\, \varepsilon/\sqrt{\text{Hz}}$. Thus there is need of strain sensors capable to measure ultra small strains, strain below the pε level in science and real life applications like in structural health monitoring. In this talk we are presenting an ultra-sensitive strain sensor based in a slow-light FBG capable to measure strains as low as 200 attostrains. This kind of sensors enable us to measure the thermal phase noise in a short FBG.

George Skolianos is a Ph.D. candidate in Electrical Engineering at Stanford University. He received his Diploma in Electrical and Computer Engineering from Aristotle University of Thessaloniki, Thessaloniki, Greece, in 2010, the M.S. in Electrical Engineering from Stanford University, Stanford, California, in 2012. His research interests involve applications of FBGs and optical sensors.
Utilizing Fiber Sensor Technology to Miniaturize the Atomic Force Microscope

Antonio Gellineau, KLA-Tencor / Stanford University

Atomic Force Microscopes (AFMs) are known for their high spatial resolution images and are widely used as the gold standard in research and the semiconductor industry. Quantitative Atomic Force Microscopy is a technique which quickly measures the interaction force between the probe and sample, extracting the mechanical properties of the sample. This technique offers the benefits of nanoindentation while maintaining the speed of tapping mode imaging. This talk will present an AFM miniaturized to the facet of an optical fiber. This fiber sensor provides increased force resolution and opens new applications for AFMs. I will further show results from probes built at Stanford University and beneficial modifications they enable in the AFM system.

Dr. Antonio Gellineau received his doctorate in Electrical Engineering at Stanford University where he studied photonic crystals, fiber sensors and AFMs in the Solgaard Laboratory. During this time he received the CPN Fellowship for his work in probe design for biological investigation. He is currently a research scientist at KLA-Tencor—a leader in metrology and inspection for the semiconductor industry. At KLA-Tencor, he continues research on probing the nanoscale with next generation technologies.
A new generation of Fabry-Perot fiber hydrophones with improved fluidics to dramatically increase the sensitivity to pressure and the response at low frequencies has been designed, assembled, and characterized. The interferometer consists of a sub-micron photonic crystal diaphragm for near-unity reflectivity placed at the tip of a single-mode fiber coated with a reflective dielectric stack. The sensor head is assembled on a monolithic silica ferrule using silicate bonding for greater mechanical stability and ease of fabrication. To minimize squeezed-film damping in the Fabry-Perot cavity, the sensor head is filled with water connected to the surrounding environment through holes in the protective housing for increased sensitivity. The response extends below 100 Hz, with a measured average sensitivity over the flat-band (100 Hz to 2.5 kHz) of \( \sim 0.23 \text{ Pa}^{-1} \) and a record average minimum detectable pressure \( \sim 90 \, \mu\text{Pa}/\sqrt{\text{Hz}} \). The fiber hydrophone is used to measure the pressure emitted by a heart muscle cell during its action potential and identify the cell type.

**Catherine Jan** is a graduate student in Electrical Engineering at Stanford University. She holds a B.S. degree in Electrical Engineering from Yale University. She works in the Microphotonics Lab under Professor Olav Solgaard, and her research interests include the fabrication and characterization of photonic crystal fiber tip sensors and their uses in biological applications.
In-fiber atom optics using Kagome hollow fiber

Fetah Benabid

We review the recent progress on kagome hollow-core photonic crystal fibers (HC-PCF). An emphasis will be given to the new developed inhibited-coupling guiding hypocycloid core Kagome HC-PCF, and which led to new state-of-the-art in HC-PCF. Using this type of hollow fibers, we review the different results obtained in thermal rubidium filled HC-PCF and the first in-fiber wall-collision free cold strontium lattice.

Fetah Benabid is a CNRS director of research and honorary professor at the universities of Bath (UK) and Western Australia (Australia). He is the group leader of Gas-Phase Photonic and Microwave Materials (GPPMM) at the CNRS UMR Xlim, Limoges, France. Fetah Benabid has pioneered the development of hollow-core photonic crystal fibres (HC-PCF) and their incorporation into scientific and technological applications. He is the inventor of Kagome HC-PCF and an all-fibre gas cells, coined photonic microcell (PMC). He is the inceptor of new optical guidance mechanism called inhibited coupling optical guidance that led to low loss optical fiber with negative curvature core-contour, and the “photonic tight-binding model” to explain the formation of photonic bandgap in photonic crystal fibres. Fetah Benabid research interests covers guided photonics, gas-phase based nonlinear and coherent optics.
Blood tests are among the most important tools in medical diagnostics. Traditionally, blood has been examined by microscopy, flow cytometry, or chemical reactions that detect altered cell populations, pathogens, and drugs but only at relatively high concentrations. However, a new paradigm based on high resolution imaging is emerging, in which blood cells are queried on a cell by cell basis with high sensitivity and specificity. We are proposing to advance this emerging technology by combining optical traps, microfluidics, and to apply our technology to a significant global public health problem, the detection of malaria parasites. Our immediate goal is to detect the malaria parasite at the trophozoite stage, and then detect the malaria parasite at all developmental stages.

Saara Khan is a PhD student in Electrical Engineering at Stanford University. Her research focus lies in optical sensing and particle manipulation in collaboration with the Stanford Biomedical Optics Group and Stanford Microphotonics Laboratory. Saara was awarded a Stanford Graduate Fellowship and an NSF Graduate Research Fellowship to pursue her doctoral studies. Saara was named an Accel Innovation Scholar for 2015-2016 and was awarded the Stanford Center for Systems Biology Seed Grant to pursue further work on her waveguide technology. She received her M.S. from Stanford University and her B.S. from University of Maryland, College Park in Electrical Engineering.
Ultra-Thin Rigid or Flexible Endoscope using a Multi-Mode Fiber

Ruo Yu Gu, Stanford University

Multi-mode fiber (MMF) endoscopes are medical endoscopes that use only a single MMF to optically transmit an image, by taking advantage of the multiple spatial modes of a MMF waveguide. They thus have the potential to be thinner, more flexible and have higher resolution than existing endoscopes in a way that closely matches the theory. However, the modes of a MMF are coupled to each other, which causes distortion in the image as it propagates and complicates the imaging process. I will describe some existing and proposed procedures to compensate for this effect, both when imaging through a rigid MMF endoscope, in which the mode coupling coefficients are static, and when imaging through a flexible MMF endoscope, in which the mode coupling coefficients change continually as the MMF bends.

Ruo Yu Gu is a PhD candidate at Stanford University in the optical communications research group of Professor Joseph M. Kahn. His research interests are in optical communications, multi-mode optical fibers, and imaging.
Endoscopy has changed modern medicine by allowing physicians explore inner organs with minimal trauma. Single fiber endoscopes offer the potential to further increase patient comfort and increase access to remote organs through miniaturization. Current research focusses on sub-milimeter endoscopy using dedicated optical fibers for imaging large volumes of tissue. One such fiber - a double clad fiber - allows many imaging modalities to be performed simultaneously for greater diagnostic sensitivity and specificity. In this presentation, I will present our latest research in fiber optics for miniature endoscopy and discuss potential avenues, including theragnostics: the capability to treat a lesion as you discover it.

Double-clad fibers are increasingly used in biomedical imaging and multimodal sensing as they combine the benefits of single-mode (coherent illumination and detection) and multimode (massive incoherent detection) fibers. To improve mechanical stability and decrease the coupling losses of the current free-space beam-splitter approach, all-fiber DCF couplers (DCFCs) were developed. Previously reported DCFCs allow for quasi-lossless transmission of coherent single-mode signal (illumination and collection) and >40% transmission of multimodal signal (collection). These DCFCs have theoretical multimodal collection efficiency limited to 50%. In this presentation, I will describe double-clad fiber couplers capable of transmitting 90% of single mode core signal, while extracting >80% of the multimode signal from the inner cladding. These all-fiber couplers are robust, achromatic, quasi-lossless and insensitive to environmental conditions.

Caroline Boudoux, PhD, obtained her PhD in 2007 from the Harvard-MIT Division of Health Sciences and Technology in biophotonics. She then studied coherent control applied to nonlinear microscopy at École Polytechnique (France) before joining the Engineering Physics department of École Polytechnique Montréal in 2007 as an assistant professor. She is now an associate professor and a faculty member of the Biomedical Engineering Institute. She is currently a Fulbright visiting scholar at Stanford University.

Her research focuses on biomedical optics, particularly the translation of optical diagnostics technologies for clinical applications in the fields of laryngology, head and neck surgery and orthopaedics. With her students and collaborators she develops wavelength swept lasers, optical fiber components and custom miniature lenses for confocal endomicroscopy, optical coherence tomography and fluorescent miniature endoscopy. Recently, she co-founded Castor Optics to commercialize a line of double-clad fiber couplers for biomedical sensing.
Overview of the James Webb Space Telescope and its Optical systems

Mark Clampin

The James Webb Space Telescope (JWST) is a large aperture, infrared telescope planned for launch in 2018. JWST is a facility observatory that will address a broad range of science goals covering four major themes: First light and Re-Ionization, the Assembly of Galaxies, the Birth of Stars and Protoplanetary Systems, and Planetary Systems and the Origins of Life. With a 6.5 meter diameter, primary mirror it will be the largest space telescope ever flown. It is the first cryogenic telescope to incorporate passive cooling, achieved by means of a large sunshade, to reach its ~40 K operating temperature. JWST has a complement of four science instruments that offer a range of imaging and spectroscopic capabilities. I will present an overview of the observatory design, highlight recent progress towards integration, testing, and science operations. I will also discuss JWST’s launch and commissioning timeline.

Dr. Clampin is currently the James Webb Space Telescope (JWST) Observatory Project Scientist at GSFC. Previously, Dr. Clampin was ACS Group manager at the Space Telescope Science Institute (STScI), where he supported three Hubble Space Telescope (HST) Servicing Missions. Dr. Clampin is a Co-Investigator with the Advanced camera for Surveys (ACS) science team and served as the Detector Scientist, and a Co-Investigator on the Transiting Exoplanet Survey Satellite. His research focuses on the formation and evolution of planetary systems.
Although more than a thousand extrasolar planets are now known, almost all have been detected indirectly - through the Doppler shift or photometric dimming they induce on their parent star. Directly imaging - spatially resolving the planet from its parent star is potentially scientifically rewarding, allowing studies of the planet’s atmospheric composition with spectroscopy, but also extremely challenging. The angular separation of an Earthlike planet orbiting a nearby star would typically be less than a micro radian at a planet to star brightness ratio of 10 billion to one, and hence completely lost in the diffraction of any plausible telescope. I will discuss the techniques for imaging extrasolar planets, ranging from advanced image processing, to next-generation adaptive optics instruments such as the Gemini Planet Imager, to future possible space telescopes using either active optics and diffraction control, or ultimately a pair of spacecraft - a star shade and a telescope - separated by hundreds to tens of thousands of km.

Bruce Macintosh has been a professor of Physics at Stanford and a member of the Kavli Institute for Particle Astrophysics and Comology since 2014. Prior to coming to Stanford he was a staff physicist at the Lawrence Livermore National Laboratory. He is an expert in adaptive optics and the studies of extrasolar planets. He was a member of the team that discovered the first directly imaged exoplanet system in 2008, and is the Principal Investigator for the Gemini Planet Imager. He has also worked on adaptive optics for x-ray and biomedical applications.
Harsh environment capable and highly reliable photodetectors are needed for sun sensors whose numerous space applications include satellite/rover orientation, navigation, and tracking. Sun sensors use photodetectors to detect the direction of the sun and estimate the position of the sun with respect to the sensor, operating much like a sun dial. Current silicon-based sun sensors have a minimum size constraint due to the complex packaging required to protect the sensor from high levels of radiation and other harms of the space environment. A gallium nitride (GaN)-based sun sensor will nearly eliminate this packaging requirement because GaN exhibits a direct bandgap, thermal/chemical stability, and radiation hardness. A more sensitive photodetector is obtained by using graphene (a transparent monolayer of carbon atoms) electrodes. The performance of graphene-enhanced GaN photodetectors during gamma irradiation as well as a microscale sun sensor concept will be discussed.

**Dr. Hongyun So** received the B.S. from Hanyang University, Korea in 2009, M.S. from KAIST, Korea in 2011, and Ph.D. degrees from the University of California at Berkeley in 2014, all in mechanical engineering. He joined Stanford University in 2015 and is currently a Postdoctoral Research Fellow in the Aeronautics and Astronautics Department. His research interests are in design, modeling, and fabrication of microscale sensors and actuators as well as mechanical issues in micro/nanosystems including heat transfer and fluid mechanics.
Optical mesoscopy with a new giant lens

Gail McConnell, University of Strathclyde

Optical lenses reached the limit of resolution set by the wavelength of light more than a century ago. However, no attempt was made to achieve the maximum resolution in the case of low-magnification lenses, probably because the visual image would then have contained detail too fine to be perceived by the human eye. Currently available lenses of less than 10x magnification are of simple construction and their numerical apertures (which determine their resolving power) are 0.2 or less, as compared with 1.3 or more in high-power lenses. They are perfectly adequate for the eye or a standard camera, but in the 1980s, confocal microscopy and improvements in camera resolution revealed a need for better low-power lenses: many researchers found that thin confocal optical sections could not be obtained at 4x magnification.

We have developed a novel lens system called the Mesolens, which achieves an N.A. of nearly 0.5 at a magnification of only 4x. When compared with a standard 4x objective, its lateral resolution is 2.5 to 5 times better and its depth resolution (which is vital for confocal or multi-photon microscopy) is 10x better. This lens provides, for the first time, good optical sectioning of specimens as large as entire 11-day mouse embryos (5mm long) with subcellular detail in every developing organ. The lens is difficult to make because of the need for a higher degree of aberration control than in any standard camera lens and it is too large (optical train 50cm x 7 cm) to fit on any standard microscope as well as having too great an aperture size for standard confocal apparatus.

Through the Next Generation Optical Microscopy Initiative, the UK government has made funds available for a facility in Strathclyde for the development and application of Mesolenses in biomedical science, including super-widefield, confocal, multi-photon and light-sheet imaging modes. Progress in the creation of the facility, recent data and some future work will be presented.

Gail McConnell is Chair of Biophotonics at the Strathclyde Institute of Pharmacy and Biomedical Sciences at the University of Strathclyde. Following a first degree in Laser Physics and Optoelectronics (1998) and PhD in Physics from the University of Strathclyde (2002), she obtained a Personal Research Fellowship from the Royal Society of Edinburgh (2003) and a Research Councils UK Academic Fellowship (2005), securing a readership in 2008. Since 2004, Gail has secured over £8M of research funding from a range of sources including EPSRC, MRC, BBSRC, EU Framework Programme and industry. The work in Gail’s group involves the design, development and application of linear and nonlinear optical instrumentation for biomedical imaging, from the nanoscale to the whole organism. She is a Fellow of the Institute of Physics, Fellow of the Royal Microscopical Society, and is current Chair of the Instrument Science and Technology Group of the Institute of Physics.
Super-resolution microscopy has revolutionized the field of cellular imaging in recent years. Related methods relying on sequential localization of point emitters enable spatial tracking at ~10-40nm resolution, using visible light. Moreover, tracking and imaging in three dimensions is made possible by various techniques, prominent among them being point-spread-function (PSF) engineering – namely, encoding the axial (z) position of a point source in the shape that it creates in the image plane. In this talk I will describe how our search for the optimal PSF for 3D localization, using tools borrowed from information theory, led to the development of novel PSFs with extraordinary capabilities in terms of depth of field and spectral sensitivity.

Dr. Yoav Shechtman is a postdoc researcher in the lab of W.E. Moerner at Stanford University. His research focuses on developing novel microscopy methods for super resolution and localization microscopy, and on applying them answer to biological questions. Other research interests include finding sparse solutions to inverse problems in optics, and compressed sensing. Yoav holds a BSc in Electrical Engineering and in Physics, and a PhD in Physics all from the Technion, Israel’s Institute of Technology. In 2011 he was awarded the Irwin and Joan Jacobs Excellence Scholarship for graduate studies and research, and in 2012 he was awarded the Gutwirth Excellence Scholarship for graduate studies. In 2013 he received the Hershel Rich Innovation Award.
What direction does point-source stimulated emission go?

Andrew York, Calico Labs

Excite an isolated fluorescent molecule, and use a collimated beam of light to stimulate this molecule to emit. What direction will the stimulated emission travel? Stimulated emission is often described as indistinguishable from the stimulating beam, suggesting the emission from our isolated molecule is also collimated, detectable only as a change in the total intensity of the stimulating beam. However, waves cannot travel in a well-defined direction while simultaneously originating from a well-defined position, suggesting stimulated emission will diverge and travel in many directions. This apparent paradox was addressed and solved long ago [1, 2], but has never been examined in the context of imaging fluorescent molecules.

I'll show preliminary measurements which suggest that stimulated emission has a coherent point-spread function (PSF) similar to the PSF for elastic (Rayleigh) scattering, differing only in magnitude and phase. I'll also describe how existing techniques for imaging via coherent scattering can be adapted to image stimulated emission from fluorescent molecules, with the added advantage that excitation and stimulation can be separately controlled, combining the high signal levels of transmitted light microscopy with the specificity of fluorescence microscopy.


Andrew York is a Scientist at Calico Labs. His research focuses on using math, physics, engineering, and coding to make biological imaging faster, gentler, higher resolution, and more useful. His recent interests include structured-illumination microscopy, light-sheet microscopy, stimulated emission, two-photon microscopy, fluorescent probe development, localization microscopy, and terahertz imaging.
Characteristics of cells that can provide predictive information about the fate of those cells are critical for advancing cell therapy manufacturing. We use live imaging of cell populations to track the relationship between cellular characteristics at a specific time and the fate of those cells in the future to determine what characteristics are meaningful for evaluating preparations and predicting future response of cells. Results of a study using a model fibroblast system engineered express GFP under the control of the tenascin-C promoter will be described. Fluctuations in GFP expression were measured by live cell imaging and used as inputs to a stochastic model for gene expression. We found that the dynamic data acquired over ~3 days could predict changes in expression in the population that occurred over several months.

We are applying similar methodologies to study pluripotent stem cell preparations. This required collecting images from large numbers of human embryonic stem cell colonies, which can be a millimeter in diameter, and developing software tools for the large-scale analysis and visualization of time-lapse microscopy. I will describe the application of this software to quantify variations in nominally-identical preparations and between colonies, correlation of colony characteristics with Oct4 expression, and identification of rare events.

Dr. Michael Halter is a Research Scientist at the National Institute for Standards and Technology (NIST), a measurement standards laboratory within the U.S. Department of Commerce. He works in the Cell Systems Science group developing advanced methods to quantify biological cells. Part of his research is to advance cellular measurement technology, especially microscopic imaging of live pluripotent stem cells. He has developed methods to quality control fluorescence microscope performance to facilitate reproducible imaging. Another aspect of his research focuses on mathematical modeling of dynamical processes of cells to develop predictive models. He is also a Scholar of the International Society for Advancement of Cytometry (ISAC) where he serves on the committee to promote cytometry education. Michael has been at NIST since 2006, when he was awarded a prestigious NIST/NRC Postdoctoral Fellowship, and in 2008, became a staff scientist. Prior to working at NIST, Michael received his Ph.D. in Bioengineering from the University of Washington at Seattle.
Time-lapse Quantitative Phase Imaging to Characterize Cell Populations

Christy Amwake, Stanford University

Biological systems such as differentiated stem cell populations and beating cardiomyocytes cannot be completely characterized through traditional static imaging techniques. Continuous time-lapse imaging and quantitative analysis of cells gives otherwise unattainable insight into phenotyping and understanding biological processes. In this talk, I will discuss the characteristics and advantages of quantitative phase imaging, which provides optical thickness data unattainable with traditional microscopy methods, for dynamic live cell analysis and will give examples of how it can be used.

Christine Amwake is a 5th year Ph.D. student in the Electrical Engineering Department at Stanford University. Her research focuses on novel optical and analysis techniques applied to dynamic biological processes. She specializes in Quantitative Phase Microscopy, which she has applied to dynamic characterization of stem cells, stem-cell derived cardiomyocytes, and smooth muscle cells. At Stanford, Christine served as President of the Women in Electrical Engineering group 2014-2015 and is the incoming Graduate Coordinator for the Society of Women Engineers 2015-2016. Prior to joining Stanford, Christine worked as an Antenna Design Engineer for Northrop Grumman Information Systems in San Diego, CA and also worked as a Communications Systems Engineer for Boeing Satellite Development Center in El Segundo, CA.
Large Field of View X-ray Differential Phase Contrast Imaging in Biology/Medicine and Luggage Inspection

Max Yuen, Stanford University

Conventional X-ray Imaging provides excellent contrast when materials of interest have very different attenuation constants, but many applications require the imaging and discrimination of materials with very similar or very low attenuation constants. Differential Phase Contrast (DPC) X-ray Imaging based on the Talbot-Lau interferometer introduces new contrast modes for distinguishing materials based on the measurement of small angle refraction of the x-ray beam due to phase shifts introduced by the real part of the index of refraction, and on the measurement of visibility changes due to small angle scattering, also known as Dark Field (DF) Imaging. The additional information gained from DPC and DF greatly improves the discrimination of materials. In our lab, we extended the X-ray DPC technique by Panoramic Extended Field of View to image objects much larger than the 64mm field of view limited by the grating active area. Potential applications to bio-imaging and luggage inspection will be discussed.

Dr. Max Yuen is currently an Academic Research Associate at the E. L. Ginzton Laboratories at Stanford University since March 2015. He received his PhD in Applied Physics in March 2014 under the mentorship of Prof. Lambertus Hesselink and subsequently completed a postdoctoral appointment in the same group until March of 2015. Before coming to Stanford University, he completed his BS in Applied Physics at Caltech in 2001. He was involved in a variety of projects, such as fabrication of c-shaped apertures in metal thin films, fluorescence fluctuation correlation spectroscopy using nano-apertures, near-field trapping with nano-apertures, and recently differential phase contrast x-ray imaging and tomographic reconstruction. He co-authored more than a dozen papers in peer-reviewed journals and is a named co-inventor on four patents.
Image Processing Techniques for Measuring Dynamic Properties of Cells in Culture

Nathan Loewke, Stanford University

Our team has developed a unique set of optical and image processing tools for the non-invasive interrogation of cell culture time-lapses. In particular, we present automated methods of texture analysis for use with cell colonies and densely-packed monolayers, orientation and directed flow modeling for a variety of population densities, and single tracking with cell segmentation for lower density populations. All of these techniques have been developed for use with our Quantitative Phase Microscopy incubated setup, which allows for label-free, temporally-stable imaging of cell cultures with signals proportional to optical thickness.

Nathan Loewke is a Ph.D. candidate in the Electrical Engineering department at Stanford University. His current scientific research is focused on the development of biomedical-, optical-, and software-based tools for studying the dynamic phenotypes of cells and early disease models. He received a B.S. degree in Mechanical Engineering from UCLA in 2011 and a M.S. degree in Electrical Engineering from Stanford University in 2015. His primary and secondary research advisors are Professor Olav Solgaard (Electrical Engineering) and Professor Christopher Contag (Pediatrics, Microbiology, and Immunology), respectively. He is also a member of the Stem Cell Instrumentation Group (SCIG) at Stanford, working with Dr. Thomas Baer and Dr. Bertha Chen.
Lasers made of biological materials open new avenues for generating coherent light within living matters. I present recent progress in this new class of light sources and demonstrate how tiny biological lasers are useful.

Dr. Yun received his Ph.D. degree in physics from KAIST, Korea, in 1997. His thesis research in fiber optics has led to a $68m-funded startup company founded in San Jose, CA, in 1999. In 2003, Dr. Yun joined the Wellman Center for Photomedicine at Massachusetts General Hospital and Harvard Medical School, where he is currently an Associate Professor. He is also an faculty member of the Harvard-MIT Health Sciences and Technology. Dr. Yun has published over 140 journal manuscripts and holds over 50 patents.
We present a novel imaging system that relies upon quantum interference to image an object using light that never interacted with it. Our experiment creates pairs of photons in two separate down-conversion crystals and overlaps the paths of the photons to make it impossible to distinguish the source. This allows us to discard the light that interacts with the object and to only detect the photons that never interacted with the object. We demonstrate absorption imaging, phase imaging, and spectroscopy with this setup. This allows us to probe delicate samples at a wavelength different from the one of the detected photons.

Victoria Borish is just beginning her second year as a PhD student in the Applied Physics department at Stanford. She received her B.A. from Williams College in 2012 with a double degree in physics and mathematics. There she wrote a senior thesis investigating one model of real-vector-space quantum theory. She then worked for a year and a half in Anton Zeilinger’s lab in Vienna where she was introduced to experimental quantum optics and did the work she is talking about here. She began at Stanford in the fall of 2014, where she rotated with various research groups and is currently working with Monika Schleier-Smith on a cold atoms experiment.
Quantum super-resolution in fluorescence microscopy

Osip Schwartz, UC Berkeley

Overcoming the diffraction limit using non-classical properties of light has been the goal of intense research in the recent years. We demonstrate a quantum super-resolution imaging method taking advantage of the non-classical light naturally produced in fluorescence microscopy due to photon antibunching, the tendency of fluorophores to emit photons one by one rather than at random. Although antibunching is a distinctively quantum phenomenon, it is observed in most common fluorescent markers even at room temperature. The non-classical far-field intensity correlations induced by antibunching carry high spatial frequency information on the spatial distribution of the fluorophores. Using a photon counting digital camera, we detect antibunching-induced second and third order intensity correlations and perform sub-diffraction limited quantum imaging in a regular wide-field fluorescence microscope.

Dr. Osip Schwartz earned his Ph.D. at Weizmann Institute of Science, Israel, where he worked with Prof. Dan Oron on optical properties of nanoparticles and optical microscopy. Dr. Schwartz has received several awards for this work, including the prestigious Adams Fellowship of Israel Academy of Arts and Sciences and the Gad Reshef Prize of the Feinberg Graduate School. After receiving his PhD, he has conducted experiments in atomic physics and worked on problems in computational electrodynamics. Dr. Schwartz is currently a postdoc with Prof. Holger Mueller at UC Berkeley.
Multipass Microscopy

Brannon Klopfer, Stanford University

Imaging of biological samples (cells, proteins, organic molecules) often requires low levels of illumination to avoid damage. In this regime, images are typically impaired by shot noise, the statistical fluctuation of the number of detected photons. This so-called standard quantum limit is not a fundamental limit; if adequately correlated probe particles are used to illuminate the sample, image quality can be significantly increased. This can be achieved if the photons interact with the sample multiple times. I will describe our preliminary work developing an optical multipass microscope with the ultimate goal of demonstrating sub-shot-noise measurements as well as contrast enhancement.

**Brannon Klopfer** is a graduate student in Professor Mark Kasevich’s group. His research focuses on ultrafast electron optics and noninvasive imaging. He graduated from Stanford as an undergrad in 2009 with a degree in physics and a minor in computer science. After several years working at an online education startup, he returned to Stanford to join the Applied Physics doctoral program. In 2012, he was awarded the Herb and Jane Dwight Stanford Graduate Fellowship.
Quantum Engineering with Light-Mediated Interactions

Monika Schleier-Smith

A hallmark of quantum information is that it can be non-local: it need not be stored in individual bits or particles but can be woven into the correlations (entanglement) among distant entities. Our ability to fully exploit this feature is hampered by the fact that most interactions in nature are local. I will describe an experimental approach to engineering non-local interactions among laser-cooled atoms strongly coupled to light in an optical resonator. The unique properties of these photon-mediated interactions—including the ease of switching their sign to effectively reverse the flow of time—open new directions in quantum metrology and in many-body quantum simulation.

Monika Schleier-Smith is an assistant professor in the Physics Department at Stanford University. She received her Ph.D. from the Massachusetts Institute of Technology in 2011, following undergraduate studies at Harvard University in Chemistry, Physics, and Mathematics. Prior to coming to Stanford in 2013, she was a postdoctoral fellow at the Ludwig-Maximilians-University of Munich and the Max Planck Institute of Quantum Optics. Her honors and awards include the Hertz Foundation Thesis Prize, the Hellman Faculty Scholar Award, and an Alfred P. Sloan Foundation Fellowship.
Quantum Optomechanics

Amir Safavi-Naeini, Stanford University

Abstract unavailable

Amir Safavi-Naeini received his Ph.D. in Applied Physics at the California Institute of Technology in June 2013, working in the group of Oskar Painter. He came to Stanford in September 2014 after a post-doc at ETH Zurich in the group of Andreas Wallraff.
The marriage of nanophotonics with soft materials offers new design strategies and system architectures to active and passive nano-optical devices. In this talk, I will show that top-down approaches involving the self-assembly of metal-dielectric spheres are the basis for nanophotonic structures. By tailoring the number and position of spheres in close-packed clusters, plasmon modes exhibiting strong magnetic and Fano-like resonances emerge. Large scale cluster assembly can be facilitated by DNA and template-based assembly schemes, which bring us one step closer to chemically-assembled metamaterials. I will also discuss a new chemical synthesis technique that can realize ultra-smooth single crystalline gold nanospheres, which have applications in “precision plasmonics” experiments. Finally, I will present a new class of hybrid materials that combines plasmonic nanostructures with mechanically soft elastomeric substrates, thereby serving as a route to new mechano-actuated nanophotonic materials.

Jonathan Fan received his BSE degree in Electrical Engineering from Princeton University in 2004 with highest honors and his PhD in Applied Physics from Harvard University in 2010 under the supervision of Professor Federico Capasso. He was an NSF Graduate Fellow, and his dissertation focused on nano-plasmonic materials and optics. Afterwards, he was a Beckman Institute Postdoctoral Fellow at the University of Illinois in Urbana-Champaign, where he researched epidermal-based stretchable electronics systems under the supervision of Professor John Rogers. At Stanford, Jonathan is building a research program around topics in nano-optics, materials science, and stretchable devices. He was an invitee to the 2014 NAE Frontiers Symposium and is the 2015 recipient of the AFOSR Young Investigator Award.
X-ray Free-electron Lasers: Present Status and Future Developments

C. Pellegrini, Department of Physics and Astronomy, University of California at Los Angeles and SLAC National Accelerator Laboratory

The first X-ray Free-electron Laser (X-ray FEL), LCLS at SLAC, started lasing in 2009. From that time this novel type of X-ray source has seen a growing interest from the scientific community motivated by its capability of generating tunable coherent radiation in the wavelength region of a few nanometer to about one angstrom, with pulse duration of a few hundreds X-ray Free-electron Lasers to a few femtoseconds and peak power from about 1 to 100 GW. Their brightness exceeds that of all other X-rays sources by over a billion times. X-ray FELs allow the exploration of the structure and dynamical processes of matter at the space and time scale, angstrom-femtosecond, characteristic of atomic and molecular processes. We review the present status of X-ray FELs, in the US, Asia and Europe and their future development.

Professor Claudio Pellegrini is a Distinguished Professor Emeritus, Distinguished Research Professor in the Department of Physics and Astronomy of the University of California at Los Angeles, and a Consultant Professor in Photon Science at the SLAC National Accelerator Laboratory. His current work is focused on particle and photon beams physics and technology and the application to coherent electromagnetic radiation sources and high-energy particle accelerator. He is recognized for his pioneering work for the development of X-ray free-electron lasers and, before that, to electron-positron colliders. He is a Fellow of the American Physical Society and served as Chair of the Division of Physics of Beams. He has received the Free-electron Laser Prize, the American Physical Society R. R. Wilson Prize and the Enrico Fermi Presidential Award.
I will present time-resolved measurements of the relaxation dynamics, in a small molecular system, following ultraviolet (UV) photo excitation. We probe these excitations through photoionization and velocity map imaging (VMI) spectroscopy. Vacuum and extreme ultraviolet (VUV/XUV) pump and probe pulses are created by exploiting strong-field high harmonic generation (HHG) from our state-of-the-art 30 mJ, 1 kHz laser system. Three dimensional photoelectron and photo-ion momentum images recorded with our VMI spectrometer reveal non-Born Oppenheimer dynamics in the vicinity of a conical intersection, and allow us track the state of the system as a function of time.

Dr. James Cryan is an associate staff scientist at SLAC National Accelerator Laboratory. His current scientific research is focused on photo-induced dynamics of atoms and molecules. He is particularly interested in the dynamics of excited states in these systems, and how energy transfer takes place inside a molecule. The relevant timescales for these interactions is typically in the range of attoseconds to picoseconds. These dynamics include photo-triggered chemistry such as non Born-Oppenheimer molecular dynamics and quantum phenomena in strong-field driven systems. His current work at SLAC seeks to understand coherent electronic phenomena that evolve on attosecond timescales. As a postdoctoral scholar at Lawrence Berkeley National Laboratory, James conducted time-resolved experiments of excited state dynamics in small molecular systems. His talk will cover many of these results. In 2012 James won the William E. and Diane M. Spicer Young Investigator Award for his thesis work on the interactions of ultrafast x-ray pulses with aligned molecular ensembles.
The new class of x-ray lasers, the intense-femtosecond Free Electron Lasers (FELs), has opened up new opportunities to study AMO physics with atomic spatial resolution and femtosecond temporal resolution. The understanding of physical and chemical changes at an atomic spatial scale and on the time scale of atomic motion is crucial not only for AMO physics but also for a broad range of other scientific fields. We will report on the photoionization and fragmentation dynamics of gas phase fullerenes using intense femtosecond x-ray pulses from the Linac Coherent Light Source (LCLS) FEL.

**Dr. Nora Berrah** is a Professor and Head of the Physics Department at the University of Connecticut. Her research experience and interests are in Atomic and Molecular Physics. Her team investigates the interaction of atoms, molecules, clusters and their ions with weak and strong electromagnetic fields produced by lasers and synchrotron facilities. Recent research interests are in the areas of non-linear physics, quantum control of atoms, molecules, and clusters with emphasis on short wavelength radiation, ultrafast time scales and strong laser fields. This research involves the use of intense femtosecond table-top lasers and free electron lasers (FEL) in the vuv and x-ray regimes to probe physical and chemical processes that happen on ultrafast time scales. She is a Fellow of the American Physical Society and the recipient of the APS 2014 Davisson-Germer award.
2015 Poster Abstracts
A plasma photonic crystal (PPC) is an array of plasma structures that interacts with electromagnetic (EM) waves in ways not possible with natural materials. PPCs can be used for generating a band gap, which forms when an EM wave travels through a PPC with spacing on the order of the wavelength of the wave and plasma frequency (wp) on the order of the frequency of the wave. Until recently, research on PPCs has been limited to wp less than 30 GHz, which is equivalent to a plasma density of n less than $10^{13}$ cm$^{-3}$. Over the last year, PPCs of n greater than $10^{15}$ cm$^{-3}$ have been generated at Stanford through the use of high-power lasers. The PPCs are generated by expanding the laser beam from a Q-switched Nd:YAG laser through a Galilean beam expander and subsequently focusing the beam through an optical micro-lens array. The intense photoionization of air that occurs at the focus of the individual lenses leads to the formation of a 2D array of very dense plasma spots. Finite-difference time-domain (FDTD) simulations and experimental results are presented that confirm the formation of band-gaps centered at a wavelength of the same order as the periodicity of the plasmas in the PPC.
Large-scale, dense arrays of plasmonic nanodisks on low modulus, highly stretchable elastomeric substrates are demonstrated as a tunable optical system with the ability to reversibly shift optical resonances over a range of nearly 600 nm. At extreme levels of mechanical deformation, with strains greater than 40 and up to 107 percent, nonlinear buckling processes transform initially planar arrays into three-dimensional configurations. Analytical and finite element models are used to capture the physics of these buckling processes and the distinct modes that occur. We use finite-difference time-domain simulations to explore the optical properties of the system and the quantitative effects of these deformations on the plasmonic responses. The resulting mechanically tunable optical system has potential relevance to soft optical sensors that could be integrated with the human body or other deformable systems.
We present a microscopic technique that allows for phase and absorption imaging beyond shot noise.
3D Super-resolution Imaging with Engineered PSF

Maurice Lee
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Advisor: W. E. Moerner

We engineer the point spread function (PSF) of a fluorescence microscope in order to obtain 3D spatial information from single molecules. The new PSFs (e.g., the double helix, the saddle point, and the corkscrew) change their shapes or positions as the single-molecule emitter moves along the optical (Z) axis--thus conveying rich information about the Z position of the molecule. Here, we use an array of nanoholes filled with fluorescent molecules and the corkscrew PSF to calibrate a computational model of our microscope, mapping the 3D object space of molecules within a sample to the 2D image space on our camera. This mapping function accounts for any field-dependent aberrations that would otherwise cause errors in the position measurements of single molecules.
Vitrification is an increasingly popular method of embryo cryopreservation that is used in assisted reproductive technology, however its long-term effects on embryo development are still poorly understood. We demonstrate an application of full-field optical coherence tomography (FF-OCT) to visualize the effects of vitrification on cell mitochondria distribution in live single-cell (2 pronuclear) mouse embryos without harmful labels. Using FF-OCT, we observed that vitrification causes a significant increase in the aggregation of structures within the embryo cytoplasm, consistent with reports in literature based on fluorescence techniques. We quantify the degree of aggregation with an objective metric, the cytoplasmic aggregation (CA) score, and observe a high degree of correlation between the CA scores of FF-OCT images of embryos and of fluorescence images of their mitochondria.
Optical Coherence Tomography (OCT) uses low-coherence interferometry to provide micron resolution images of scattering from structures millimeters deep in tissue. Here we demonstrate the use of exogenous imaging agents with OCT to provide a promising platform for studying functional biology of tissues in vivo. In this study, we developed and applied highly-scattering large gold nanorods (LGNRs) and custom spectral detection algorithms for contrast-enhanced OCT. We used this approach for noninvasive 3D imaging of blood vessels deep in solid tumors in living mice. Additionally, we demonstrated multiplexed imaging of spectrally-distinct LGNRs that enabled observations of functional drainage in lymphatic networks. This method, which we call MOZART, provides a platform for molecular imaging and characterization of tissue noninvasively at cellular resolution.
We demonstrate dynamic tuning of metafilm absorber by using the electro-optical effect in the transparent conducting oxide (TCO) sandwiched by two metal structures. Upon electrical bias, TCO either forms the depletion layer and the accumulation layer, in which the optical property is strongly changed. Around the plasma frequency of the TCO where an electric permittivity approaches zero, the electric field amplitude in the TCO is substantially increased, giving rise to effective modulation.
A Review of the Factors for the Outcome Following Laser Vaporization of the Difficult Urethral Strictures; Unexpected long term Durability and Normalization of The Urethra

Inder Perkash

68 males and one female 26 to 72 years old, 1 to 5 cm long urethral stricture for 2 to 56 years. 51 spinal injured, 13 able bodies with 5 post radical TUR incalcitrant strictures. Circumferential Laser vaporization of fibrous tissue was done using Nd:YAG or HO:YAG 15-22.5 W. Vaporization was done in a Contact mode with no charring. Followed: 2 to 9 years (mean 7.1)= 83% durable results. *17% repeated with easy revaporization and durable results as well. 9/13 patients on random cystoscopy showed restitution of normal urethra. It could be considered a minimal invasive procedure with durable results instead of repeated dilatation with resultant repeated bactreamia, or stents which are difficult to remove. It can eliminate the use of open urethroplasty.
Multi-emitter cavity quantum electrodynamics

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Advisor: Jelena Vuckovic

Silicon Carbide is an emerging wide band gap photonics material featuring room temperature color centers and second order optical nonlinearity for applications in optical switching, quantum computing, infrared to visible wavelength interfaces, and sensing. We present results on silicon carbide microresonators, hybrid structures consisting of silicon carbide and color center rich diamond, and modeled performance of devices containing multiple emitters coupled to a resonator.
Immersion graded refractive index optics enable passive optical concentrators, although they also present challenges in design, fabrication, and integration. Simple and scalable fabrication techniques were implemented and the performance of prototypes was measured. We present two tileable designs and demonstrate passive concentration of 3 Suns.
Degenerate OPO's are an efficient and straightforward way of transferring power from one wavelength to another while maintaining phase locking. We present our work on power scaling of our 1um to 2um systems.
Radiative cooling of Solar absorber

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We experimentally demonstrate a thermo-photonic approach to passive, radiative cooling of a silicon solar absorber, that radiates the heat to the cold outer space, through atmosphere’s infrared transparency window. By placing a silica photonic crystal atop, we lower the temperature of the substrate by as much as 13˚C, while preserving or even slightly enhancing solar absorption.