Optical Fabrication and Testing (OF&T)

24 June - 28 June 2012, Monterey Plaza Hotel, Monterey, California, United States

Optical Fabrication and Testing will bring together experts working in this field to discuss recent advances and to identify future trends. The meeting will cover all aspects of optics fabrication and testing ranging from micro-optics to large optics, and from high-value one-of-a-kind optics to mass-produced optics. The meeting will emphasize new ideas and concepts in fabrication and testing of micro-optics, the fabrication and testing of aspheric, conformal and freeform optics, fabrication of optics from novel materials, and finishing science.

1. Optical Materials
   - New materials for new applications (plastics, crystals, glasses, lightweight materials, ceramics, carbides, UV optics materials)
   - Material response to fabrication processes
   - Metamaterials
   - Thin films

2. Figuring and Finishing Science
   - Grinding, precision grinding, diamond turning and milling, ultrasound assisted machining, vibration assisted polishing
   - New ideas in traditional (pitch) polishing, MRF, ion beam figuring and polishing, jet polishing, novel finishing processes
   - Glass and plastic molding
   - Abrasives, novel abrasive formulations

3. Optical Testing
   - Testing for sub-surface damage, homogeneity, form, finish, scratch/dig
   - New ideas in interferometry
   - Testing aspheric surfaces with and without null-optics
   - Computer-generated holograms and spatial light modulators for testing
   - Absolute tests for flats, spheres and aspheres
   - New concepts in profilometry: optical and mechanical probes
   - Testing of very large and very small optics
   - White light interferometry, fringe projection metrology, deflectometry
   - Testing in adverse environments: vibration, turbulence, vacuum, space, etc.
   - In-process metrology
   - Testing of freeform surfaces

4. Assembly, Alignment, Contamination Control, Cleaning, Packaging
   - Adhesives and cementing
   - Alignment of optical systems
   - Alignment of systems containing aspheric elements
   - Alignment of multi-element mirrors
   - Mounting, control of deformation and stress birefringence
   - Cleaning optics
   - Clean rooms and contamination control
   - Handling and packing of precision optics

5. Process Engineering
   - Cost effective optics manufacturing processes
   - Cost effective fabrication of aspheric surfaces
   - Automation in optics fabrication
   - Fabrication of large optics
   - Fabrication of micro-optics
   - Experiences from the shop floor

6. Fabrication and Testing of Next Generation Optical Systems
   - Photolithography optics
7. Education and Training in Optics Metrology and Finishing Science

**Chairs**
Stephen Jacobs, Univ. of Rochester, USA
James (Ted) Mooney, ITT Geospatial Systems, USA
Jessica Nelson, Optimax Systems Inc., USA
Jannick Rolland, Univ. of Rochester, USA
Shai Shafrir, Corning, Inc., USA

**Sponsor:** OSA

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**Imaging and Applied Optics Congress**

**24 June 2012 – 28 June 2012, Monterey Plaza Hotel, Monterey, California, USA**

The frontiers in imaging and selected areas in applied optics will be examined at the Optics and Photonics Congress (OPC) to be held in Monterey, California. This congress is composed of six complimentary meetings and is designed to present a comprehensive view of the latest developments in imaging and applied optical sciences. Two of the meetings Imaging Systems and Applications (IS) and Computational Optical Imaging and Sensing (COSI) deal with both latest theoretical advances in imaging sciences as well as the application of imaging techniques and processing methodologies in the development of some of the most advanced imaging system designs. Presentations will further describe the employment of these imaging technologies in scientific, commercial, medical, and military applications. In the applied optics arena, papers describing advanced optical sensing technologies and their application to the solution of numerous environmental, industrial, and testing applications will be presented by recognized leaders in these fields. The Applied Industrial Optics (AIO) meeting continues to attract industrial leaders in the application of cutting edge optical sensors in diverse market sectors including defense, oil & gas, food and beverage and pharmaceuticals to name a few. Advances in optical sensor component technologies and the capabilities demonstrated by these new sensors will be presented in the Optical Sensors (SENSORS) meeting. These advances directly compliments talks presented by speakers in the more applied meeting on Applied Industrial Optics and provide an indication of sensors expected to find use in numerous applied applications. The meeting on Optical Remote Sensing of the Environment (ORS) reports on some of the most advanced sensing techniques used to characterize the environment and the results of studies providing a more complete understanding of the atmosphere. All aspects of optics fabrication and testing ranging from micro-optics to large optical systems will be covered in the meeting on Optical Fabrication and Testing (OF&T). Design concepts and new materials offering novel capabilities as well as fabrication and finishing techniques of aspheric, conformal and freeform optics will be discussed by many of the leaders in this field at this meeting. Together, this Congress represents a form in which the attendees are exposed to the forefront advances in imaging and applied optics and are able to hear discussion of the application of these technologies to important industrial, military and medical problems.

**Featured Speakers**

**Opening General Session, Monday, June 25, 8:00-10:30**

[Image of speaker]

Al Bovik, Univ. of Texas at Austin, USA  
**Image Quality Assessment: How Blind is Blind?**
Assessing a New Imaging Modality

Survey of Applications for Ocean Color and Imagery from EOS-MODIS and early results from NPP-VIIRS

Small Satellites: The Desire for a Mass Producible, Mass Customizable Nanosatellite

Microsoft Kinect - A Look Inside

OSA Corporate Associates: Executive Speaker Series, Wednesday, 27 June, 17:30 - 19:30

This event is made possible in part, through generous support from the OSA Fabrication, Design and Instrumentation Division

- Applied Industrial Optics: Spectroscopy, Imaging, and Metrology (AIO)
- Computational Optical Sensing and Imaging (COSI)
- Imaging Systems and Applications (IS)
- Optical Fabrication and Testing (OF&T)
- Optical Remote Sensing of the Environment (ORS)
- Optical Sensors (SENSORS)

Corporate Sponsor:

Sponsor:
Optical Fabrication and Testing (OF&T)

Program

Conference Program
- **Online Access to Technical Digest Now Available!**
  - Full Technical Attendees now have an alternate way to access the digest papers at the meeting. Access the papers through [Optics InfoBase](#) using the same login email address and password provided during the meeting registration process. Access is currently limited to Advanced Photonics Full Technical Attendees only. If you need assistance with your login information, please use the forgot password utility or "Contact Help" link.
- **Download Pages from the Program Book!**
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  - [Agenda of Sessions/Schedule at a Glance](#) (pdf)
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  - Browse speakers
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  - Use Advanced Search to search the program by author, title, OCIS code and more.
  - Plan and print your personal itinerary before coming to the conference.
    - Add your personal itinerary to your electronic calendar.
    - Email your itinerary to a colleague who might be interested in attending.
- **Invited Speakers**

Special Events

General Session
The Congress will start with a joint General Session on Monday 25 June from 8:00 - 10:30. The speakers are Al Bovik from Univ. of Texas at Austin, Joseph Goodman from Stanford Univ., Henry Helvajian from The Aerospace Corp., and Bruce Guenther from Goddard Earth Science and Technology Center. For more information about each speaker visit the special event page.

Conference Reception
The joint conference reception will be on Monday 25 June from 18:30 - 20:00. The reception will feature light fare and is open to all paid registrants.

Poster Sessions
A joint poster sessions will take place on Tuesday 26, June from 17.30 - 19.00. Posters are an integral part of the technical program and offer a unique networking opportunity, where presenters can discuss their results one-to-one with interested parties. Each author is provided with a 4 ft. x 8 ft. (1.22 m x 2.44 m) board on which to display the summary and results of his or her paper.

OSA Corporate Associates: Executive Speaker Series
Michael Silver, CEO of American Elements
This special evening event on Wednesday, 27 June begins at 17:30 with a networking reception, followed by a brief student award ceremony and then a one-on-one interview with audience questions. Sit down for an entertaining and intimate conversation with Michael Silver, Chief Executive Officer, American Elements as he responds to questions from Dr. Stephen Jacobs, from The University of Rochester, about his observations on the current and future demand of Rare Earth, his career path, and personal perspectives. Mr. Silver was one of the first Americans to establish a direct production and distribution supply chain from the rare earth mines in Inner Mongolia, China to North America and Europe and is credited with making American Elements an early participant in many now billion dollar growth industries including solar energy, fuel cells, optical telecommunications and next generation pharmaceuticals. Presented in collaboration with the OSA Fabrication, Design and Instrumentation Division.
Invited Speakers

**OF&T 1: Optical Materials**
The Role of Ce3+ vs. Ce4+ during the Polishing of Silicon Dioxide and Silicon Nitride Films using Ceria Abrasives, S. V. Babu, Clarkson University, USA

Glass Ductility and Fracture at the 50 to 100 - nm Range, John Lambropoulos, Univ. of Rochester, USA

Engineering Glasses for Next Generation Optics, Kathleen Richardson, Clemson Univ., USA

Synthetic Fused Silica: Improved Properties and New Applications, Ralf Takke, Heraeus Quarzglas, Germany

**OF&T 2: Figuring and Finishing Science**
Aspheric and freeform hybrid glass-polymer optics: the properties, implementation and performance, Valentin Doushkina, N2 Imaging Systems, USA; Doushkina Optics, USA

Abrasive Jet Polishing Approaches to the Manufacture of Micro-optics with Complex Shapes, Oliver Faehnle, Fisba Optik, Switzerland

New Approaches to Magnetorheological Finishing (MRF), Andrew Kulawiec, William Kordonski & Sergei Gorodkin, QED Technologies, USA

Polishing with a vortex: a decade in hydrodynamic radial polishing, Erica Sohn¹,², ¹Instituto de Astronomia, ²Univ. Nacional Autonoma de Mexico, Mexico

Diamond Micromachining of Freeform Infrared Optics, Thomas Suleski & Matthew Davies, Univ. of North Carolina at Charlotte, USA

Aspheric Finishing of Glass and SiC Aspheres, Fleming Tinker, Aperture Optical Sciences, Inc., USA

**OF&T 3: Optical Testing**
Interferometric Measurements of Aspheres with No Axial Symmetry, Piotr Szwaykowski, Engineering Synthesis and Design, USA

Light Scattering & Complex Optical Components: Modelization and Characterization, Myriam Zerrad, Michel Lequime, Prof. Claude Amra, Institut Fresnel, Domaine Universitaire de St. Jerome, France

**OF&T 4: Assembly, Alignment, Contamination Control, Cleaning, Packaging**
New Joining Technologies for Highly Stable and Smart Optical Systems, Ramona Eberhardt, Fraunhofer IOF, Germany

Mass Production of the 100Å° Field of View Active Head Mounted Display, Paul Townley-Smith, Zygo Corp., USA

**OF&T 5: Process Engineering**
Application-oriented Testing of Coatings for Precision Glass Molding Tools, Kyriakos Georgiadis, Fraunhofer IPT, Germany

X-ray Optics for Astronomy, Giovanni Pareschi, INAF-Osservatorio Astronomico di Brera, Italy

Bending Large Glass Plates with Local Heat and Flexible Mold, Tobias Rist, Fraunhofer Inst. for Mechanics of Materials, Germany

Control of Mid-spatial Frequency Errors for Large, Steep Aspherical Surfaces, Dae Wook Kim, Univ. of Arizona Mirror Lab, USA

**OF&T 6: Fabrication and Testing of Next Generation Optical Systems**
Freeforms about to Lift Off - Standardization of Freeform Optics, Sven Kiontke, Asphericon GmbH, Germany
Lab-on-a-chip Applications Enabled by Acousto-opto-fluidics, Xiaole Mao, P & G Mason Business Center, USA
UK Developments Towards Rapid Process Chains for Metre Scale Optics, Paul Shore, Cranfield Univ., Bedford, UK

**OF&T 7: Education and Training in Optics Metrology and Finishing Science**
A Tribute to Norm Brown’s Technical Contributions to the Field of Optical Fabrication and Testing, Jessica Nelson & Robert Wiederhold, Optimax Systems, Inc., USA
OSA continues the tradition of outstanding conferences and focused meetings with the 2012 Optics and Photonics Congress on Imaging and Applied Optics in beautiful Monterey, CA. The Congress has co-located six topical meetings (listed above) for attendees to benefit from exposure to a diverse collection of optical technologies. The Program includes scientific leaders from around the globe in each topical area which should facilitate networking and the cross-pollination of ideas between attendees. We have planned numerous special congress-wide events; the Opening General Session, a Welcome Reception, a Poster Session and an OSA Corporate Associates event with Michael Silver from American Elements.

The Applied Industrial Optics (AIO) meeting was an unprecedented success last year, and promises to be very exciting this year. Scott MeEldowney from Microsoft will join us as a plenary speaker. The remaining four days of the conference cover a wide range of applied optical technologies and a very diverse set of application areas including medical, food, environmental monitoring, and innovative emerging technology with 29 invited speakers. Invited speakers and contributors include industrial, governmental, and academic scientists at the forefront of applied optics from around the globe. Join us for an exciting meeting and volunteer to join the team to help make next year’s meeting even better.

The Computational Optical Sensing and Imaging (COSI) meeting consists of topics that describe theoretical and experimental progress in computational sensing and imaging research. The meeting subject matter spans the areas of fundamental physics, hardware design, and numerical and analytical techniques and has led to significant improvements in the fields of imaging and sensing for medicine, defense, and homeland security, as well as industrial inspection and testing applications. This year, we have prepared an extremely strong program of 12 invited speakers and 34 contributed oral presentations, as well as two joint sessions with the Imaging Systems (IS) topical meeting. We extend a warm welcome to both the longstanding members of the COSI community and those joining us for the first time.

The Imaging Systems and Applications (IS) meeting is an “all-encompassing” conference on imaging that covers topics in imaging system design and components, imaging modalities and systems, and applications of military, industrial, medical and consumer imaging. Its aim is to highlight how different materials, components, and processing combine to determine imaging system performance. Invited speakers from the military, academic, and commercial imaging sectors will address the current status and future of imaging in their organizations. The conference includes 21 invited, 25 contributed oral presentations, and 7 poster presentations that describe recent developments in imaging lens technologies (including gradient index and tunable fluidic lenses), imaging optics (including extended depth of field design and imaging through scattering media), image sensors (including novel SPAD and QD imagers), medical imaging and microscopy (including in vivo brain imaging and compressed sensing microscopy), hyperspectral imaging, military applications, phase space in imaging, computational imaging and digital imaging (including image chain modeling and color imaging for mobile displays).

This year the meeting on Optical Fabrication and Testing (OF&T) consists of 10 sessions organized around topics such as polishing/finishing science, advanced metrology and freeform optics. Twenty-two invited papers from the US and six countries highlight special topics like light scattering from complex optics, engineering of glasses for next generation optics, polishing with a vortex, hybrid glass-polymer optics, aspheres w/o axial symmetry, durable coatings for glass molding tools and x-ray optics for astronomy. Twenty-eight contributed oral presentations and 13 poster papers fill out the three day meeting agenda. During the Opening General Session, Dr. Henry Helvajian will speak about the role of glass-ceramics in micro-satellite construction.
Optical remote sensing of the environment addresses many needs in both civilian and military sectors. The scope of the Optical Remote Sensing of the Environment (ORS) meeting will focus on three general areas: sensors, algorithms and phenomena, and applications. With regard to sensors, the conference will focus especially on hyperspectral and multi-spectral imaging sensors, LiDAR, and multi-sensor imaging (for example, hyperspectral combined with LiDAR or hyperspectral and other non-optical remote sensing modalities such as RADAR). The meeting will include 22 invited and 28 contributed presentations, and 13 poster presentations for you to attend.

The Optical Sensors (SENSORS) meeting consists of six topics which address various sensor types, and include all aspects of optical sensors from the components employed, their configuration through detection schemes and algorithms, and their applications. The conference includes 27 invited, 32 contributed oral presentations, and 8 poster presentations that describe several kinds of micro and nano-engineered sensors, fiber optic and laser-based sensors. Some enabling technologies for advanced sensing are also reported, including the use of pulsed high power lasers, novel materials and imaging methods or new frequency bands, as for example THz radiation. These sensors are used in various applications, namely for quality and process control, chemical and biological applications, metrology, imaging, and remote sensing, to mention a few examples.

**AIO**
Jess Ford, **Wireline R&D Weatherford Intl., USA, General Chair**
Marion O'Farrell, **SINTEF, Norway, General Chair**
Sean Christian, **Optrology, Inc., USA, Program Chair**
Joe Dallas, **Avo Photonics Inc, USA, Program Chair**
Arel Weisberg, **Energy Research Co., USA, Program Chair**

**COSI**
Michael Gehm, **Univ. of Arizona, USA, General Chair**
Gerd Haeusler, **Univ. of Erlangen-Nuremberg, Germany, General Chair**
Andrew Harvey, **Heriot-Watt University, UK, Program Chair**
David Gerwe, **Boeing Company, USA, Program Chair**

**IS**
Peter Catrysse, **Stanford Univ., USA, General Chair**
John T. Sheridan, **Univ. College Dublin, Ireland, General Chair**
Francisco Imai, **Canon USA, Inc., USA, Program Chair**
Dale Linne von Berg, **Naval Research Laboratory, USA, Program Chair**

**OF&T**
Stephen Jacobs, **Univ. of Rochester, USA, General Chair**
James “Ted” Mooney, **ITT Industries, Space System Division, USA, General Chair**
Jessica DeGroote Nelson, **Optimax Systems Inc, USA, General Chair**
Jannick Rolland, **Univ. of Rochester, USA, General Chair**
Shai Shafrir, **Corning Incorporated, USA, General Chair**

**ORS**
Charles Bachmann, **Naval Research Laboratory, USA, General Chair**
Curt Davis, **Oregon State University, USA, General Chair**
Chris Parrish, **NOAA, USA, Program Chair**

**SENSORS**
Ishwar Aggarwal, **Univ. of North Carolina at Charlotte, USA, General Chair**
Mário F.S. Ferreira, **Universidade de Aveiro, Campus de Santiago, Portugal, General Chair**
**Program Committee**

**Applied Industrial Optics: Spectroscopy, Imaging, & Metrology (AIO)**

**General Chairs**
Jess Ford, Wireline Res-D Weatherford Intl., USA
Marion O’Farrell, SINTEF, Norway

**Program Chairs**
Sean Christian, Optrology, Inc., USA
Joe Dallas, Avo Photonics Inc, USA
Arel Weisberg, Energy Research Co., USA

**Committee Members**
Elfed Lewis, Univ. of Limerick, Ireland
Kai Liu, Sichuan Univ., China
Sheng Liu, KLA-Tencor Corp., USA
Hans-Peter Loock, Queen’s Univ., Canada
Prasanna Pavan, Ricoh Innovations, Inc., USA
Sapna Shroff, Ricoh Innovations, USA
Yongchang Wang, KLA-Tencor Corp., USA

**Imaging Systems and Applications (IS)**

**General Chairs**
Peter Catrysse, Stanford Univ., USA
John T. Sheridan, Univ. College Dublin, Ireland

**Program Chairs**
Francisco Imai, Canon USA, Inc., USA
Dale Linne von Berg, Naval Research Laboratory, USA

**Committee Members**
Kenneth Barnard, Air Force Research Laboratory, USA
Gisele Bennett, Georgia Tech, USA
Kathrin Berkner, Ricoh Innovations, USA
David Brady, Duke University, USA
Joyce Farrell, Stanford University, USA
Jim Fienup, Univ. of Rochester USA
Boyd Fowler, Fairchild Imaging, USA
Craig Hoffman, Naval Research Laboratory, USA
Niel Holt, Utah State Univ. - Space Dynamic Lab, USA
Kristina Irsch, Johns Hopkins University, USA
Eddie Jacobs, Univ. of Memphis, USA
Michael Kriss, Consultant, USA
Jun Ke, University of Hong Kong, USA
Ofer Levi, Univ. of Toronto, Canada
Pierre Magnan, Institut Superieur de l’Aeronautique et de l’Espace, France
Joe Mait, Army Research Laboratory, USA
Ricardo Motta, Nvidiia, USA
Mukul Sarkar, Indian Institute of Technology Delhi, India
Guohai Situ, Princeton Univ., USA
Torbjorn Skau, Norwegian Defense Research Establishment (FFI), Norway
Albert Theuwissen, Harvest Imaging, Belgium
Nobukazu Teranishi, Panasonic Corporation, Japan
Edward Watson, Air Force Research Laboratory, USA
Laura Waller, Princeton University, USA
Changhuei Yang, California Inst. of Technology, USA
Zeev Zalevsky, Bar-Ilan Univ., Israel

**Computational Optical Sensing and Imaging (COSI)**

**General Chairs**
Michael Gehm, Univ. of Arizona, USA
Gerd Haesler, Univ. of Erlangen-Nuremberg, Germany

**Program Chairs**
Andrew Harvey, Heriot-Watt University, UK
David Gerwe, Boeing Company, USA

**Committee Members**
George Barbathitis, MIT, USA
Gisele Bennett, Georgia Tech, USA
Marc Christensen, Southern Methodist Univ., USA
Aristide Dogariu, UCF-CREOL, USA
Christy Fernandez-Cull, MIT Lincoln Labs, USA
Michael Fiddy, Univ. of North Carolina-Charlotte, USA
Jason Fleischer, Princeton Univ., USA
Bahram Javidi, Univ. of Connecticut, USA
Keith Knox, Air Force Research Lab., USA
Kenny Kubala, Five Focal, USA
Abhijit Mahalanobis, Lockheed Martin, USA
Joe Mait, Army Research Lab., USA
Mark Neifeld, Univ. of Arizona, USA
Rafael Piestun, Colorado Univ. at Boulder, USA
Chrysanthi Preza, Univ. of Memphis, USA
Tim Schulz, Michigan Tech., USA
Michael Stenner, MITRE Corp, USA
Brian Thelen, Michigan Tech Research Inst., USA
Sam Thurman, Lockheed Martin, USA
David Tyler, Univ. of Arizona, USA

**Optical Fabrication and Testing (OF&T)**

**Chairs**
Stephen Jacobs, Univ. of Rochester, USA
James “Ted” Mooney, ITT Industries, Space System Division, USA
Jessica DeGroote Nelson, Optimax Systems Inc, USA
Jannick Rolland, Univ. of Rochester, USA
Shai Shafrir, Cornning Incorporated, USA

**Committee Members**
Dave Aikens, Savvy Optics Corp., USA
Damon Diehl, Diehl Research Grant Services, USA
Chris Evans, Univ. of North Carolina at Charlotte, USA
Oliver Fanhle, FISBA OPTIK AG, USA
Edward Fess, OptiPro, USA
John Greivenkamp, Univ. of Arizona, USA
Ulf Griesmann, NIST, USA
Joe Howard, NASA Goddard Space Flight Center, USA
Kazu Yoshi Itoh, Osaka University, Japan
Matthew Jenkins, Raytheon Space and Airborne Systems (SAS), USA
Dae Wook Kim, Univ. of Arizona, USA
Thomas Milster, Univ. of Arizona, USA
Brigid Mullany, Univ. of North Carolina at Charlotte, USA
Paul Murphy, QED Technologies Inc, USA
François Piche, L-3 Communications IOS Brashear, USA
Joseph Randi, Penn State Univ., USA
Kathleen Richardson, Clemson Univ., USA
Joe Robichaud, L-3 SSG Tinsley, USA
Markus Schinhaerl, Fachhochschule Deggendorf, Germany
Katie Schwertz, Edmund Optics, USA
Aric Shorey, Corning Inc, USA
Erika Sohn, Instituto de Astronomia UNAM, Mexico
Tayyab Suratwala, Lawrence Livermore National Laboratory, USA
David Vanderpool, SCHOTT N America - Adv Optical Materials, USA
Daniel Waechter, Fraunhofer IPT, Germany
Ray Williamson, Ray Williamson Consulting, USA
Yongbo Wu, Akita Prefectural Univ., Japan
Wei Yao Zou, ASML Engineering, USA

Optical Remote Sensing of the Environment (ORS)

General Chairs
Charles Bachmann, Naval Research Laboratory, USA
Curt Davis, Oregon State University, USA

Program Chair
Chris Parrish, NOAA, USA

Committee Members
Steve Ackleson, Consortium for Ocean Leadership, USA
Francisco Chavez, MBARI, Mexico
Robert Fusina, Naval Research Lab, USA
Roy Hughes, Defence Science Technology Organization, Australia
Fred Kruse, Naval Postgraduate School, USA
Bill Philpot, Cornell Univ., USA
Dar Roberts, Univ. of California at Santa Barbara, USA
Susan Ustin, Univ. of California at Davis, USA
Jan van Aardt, Rochester Ins. of Technology, USA

Optical Sensors (SENSORS)

General Chairs
Ishwar Aggarwal, Univ. of North Carolina at Charlotte, USA
Mário F.S. Ferreira, Universidade de Aveiro, Campus de Santiago, Portugal

Sensors 1: Micro and Nano-Engineered Sensors
Limin Tong, Zhejiang Univ., China, Chair
Bai-Ou Guan, Jinan Univ., China
Misha Sumetsky, OFS Laboratories, USA
Dong Ning Wang, Hong Kong Polytechnic Univ., Hong Kong

Sensors 2: TeraHertz Sensing
Jason Deibel, Wright State Univ., USA, Chair
Enrique Castro Camus, Centro de Investigaciones en Optica AC, Mexico
David Hilton, Univ. of Alabama at Birmingham, USA
Mona Jarrahi, Univ. of Michigan, USA
Sushil Kumar, Lehigh Univ., USA

Sensors 3: Imaging Sensors
Sebastian Schluerke, Univ. Osnabrück, Germany, Chair
Rohit Bhargava, Univ. of Illinois at Urbana-Champaign, USA
Marcus Cicerone, NIST, USA
Benjamin Dietzke, Friedrich-Schiller-Universität Jena, Germany
Costel Flueraru, NRC Inst. for Microstructural Sciences, Canada
Robert Huber, Ludwig-Maximillians-Universität Munchen, Germany
Alex Vitkin, McMaster Univ., Canada
Costel Flueraru, Inst. for Microstructural Sciences, Canada

Sensors 4: Fiber Optical Sensors
Gilberto Brambilla, Univ. of Southampton, USA, Chair
Jaques Albert, Carleton Univ., Canada
John Canning, Sydney Univ., Australia
Alexandre Francois, Univ. of Adelaide, Australia
Wei Jin, Hong Kong Polytechnic Univ., Hong Kong
Jose Miguel Lopez Higuera, Universidad de Cantabria, Spain
Tanya Monro, Univ. of Adelaide, Australia

Sensors 5: Laser Based Sensors
Byoungho Lee, Seoul Natl. Univ., Korea, Chair
Pietro Ferraro, National Inst. for Applied Optics, Italy
Yoshio Hayasaki, Utsunomiya Univ., Japan
Myung K. Kim, Univ. of South Florida, USA
Wolfgang Osten, Institut für Technische Optik, Germany
Gang-Ding Peng, Univ. of New South Wales, Australia

Sensors 6: Optical Chemical and Biological Sensors
Ken Ewing, Naval Research Labs, USA, Chair
Vince Rotello, Program in Molecular and Cell Biology, Univ. of Massachusetts, USA
Robert J. Levis, Temple University, Center for Advanced Photonics Research, USA
George Coyle, DRS Inc., USA
Brandon Shaw, Naval Research Laboratory, USA
Special Events

Opening General Session
Monday, 25 June, 8:00–10:30
The Dolphins, Upper Plaza

Joseph Goodman, Stanford Univ., USA

Joseph W. Goodman received an A.B. Degree from Harvard, an M.S degree and a Ph.D. degree, both from Stanford University. He joined the faculty of the Department of Electrical Engineering at Stanford in 1967, chaired the department from 1989 to 1996, and served as Senior Associate Dean of Engineering until 1999. He retired from Stanford in January of 2001. Dr. Goodman is the author of the books Introduction to Fourier Optics (now in its 3rd edition), Statistical Optics, and Speckle Phenomena in Optics. He has received numerous awards from the IEEE, ASAE, OSA and SPIE, including the highest awards given by the latter two societies.

Al Bovik, Univ. of Texas at Austin, USA

Al Bovik holds the Curry/Cullen Trust Endowed Chair Professorship at The University of Texas at Austin. His recent interests are in the areas of perceptual image and video processing and computational vision. He is the author of The Handbook of Image and Video Processing, Modern Image Quality Assessment, and two recent books, The Essential Guides to Image and Video Processing. Al was named “Imaging Scientist of the Year” by IS&T/SPIE for 2011. He is a Fellow of the IEEE, OSA, and SPIE. Al served on the Board of Governors of the IEEE Signal Processing Society, co-founded and served as Editor-in-Chief of the IEEE journal Transactions on Image Processing, and created and served as the first General Chairman of the IEEE International Conference on Image Processing.

Bruce Guenther, NOAA-JPSS & University of Maryland of Baltimore County, USA

Dr. Bruce Guenther is the NOAA SDR Calibration lead for NPOESS and JPSS Programs since 2007. He was the Chief VIIRS Scientist for the final calibrations and characterizations testing of the NPP VIIRS, and was responsible for the first calibration products published for the EOS Terra MODIS sensor. Guenther’s current research interests are exploiting VIIRS advances in calibration design and accuracy for uses in optical oceanography studies. Guenther received a Ph.D. degree from the University of Pittsburgh in Aeronomy in 1974. He is a University of Maryland, Baltimore County employee serving in a mobility assignment to NOAA.

Henry Helvajian, The Aerospace Corp., USA

Henry Helvajian joined The Aerospace Corporation in 1984. He has worked on gas phase photochemistry and kinetics of activated radical species for chemical laser development and on the photophysical processes of low fluence laser/material interaction phenomenon. In 1992 he began investigations on the applications of microsystems (MEMS) to space systems and in the miniaturization of satellites and satellite subsystems. He has been involved in the design of the first 1 kg mass nanosatellite and in the development of various space microthrusters. Recently, he has been developing a laser processing technique for the fabrication of MEMS in glass/ceramic materials and in the development of the world’s first all glass/ceramic satellite.

AIO Plenary Session
Monday, 25 June 14:00–15:00
Cypress 4

Scott McEldowney, Microsoft, USA

Scott McEldowney is a principal engineer at Microsoft Corporation. He has spent his 3 years at Microsoft working on the development of Natural User Interface technologies based on gesture recognition. Prior to Microsoft, Scott worked for 18 years in the Advanced Optical Technology division of JDSU developing optical components subsystems for consumer electronics, medical instrumentation, and aerospace. Scott holds a MS degree in Mechanical Engineering and PhD in Optical Sciences.

Joint Conference Reception
Monday, 25 June, 18:30–20:00
The Dolphins on the Upper Plaza

The reception will feature light fare and is open to all registrants.

Joint Poster Session
Tuesday, 26 June, 17:30–19:00
The Dolphins on the Upper Plaza

Poster presentations offer an effective way to communicate new research findings and provide an opportunity for lively and detailed discussion between presenters and interested viewers.
Postdeadline Paper Presentations

The program committees of AIO, COSI, ORS, OF&T, and SENSORS accepted postdeadline papers for presentation. The purpose of postdeadline sessions is to give participants the opportunity to hear new and significant materials in rapidly advancing areas. Only those papers judges to be truly excellent and compelling were accepted.

For more information, including a complete schedule of talks, abstracts and papers, see the separate Postdeadline papers booklet.

OSA Corporate Associates: Executive Speaker Series with Michael Silver, American Elements, USA

Wednesday, 27 June, 17:30–19:30
The Dolphins on the Upper Plaza

Sit down for an entertaining and intimate conversation with Michael Silver, Chief Executive Officer, American Elements as he responds to questions from Dr. Stephen Jacobs, from The University of Rochester, about his observations on the current and future demand of Rare Earth, his career path, and personal perspectives. Mr. Silver was one of the first Americans to establish a direct production and distribution supply chain from the rare earth mines in Inner Mongolia, China to North America and Europe and is credited with making American Elements an early participant in many now billion dollar growth industries including solar energy, fuel cells, optical telecommunications and next generation pharmaceuticals.

The program begins with a networking reception, followed by a brief student award ceremony and then a one-on-one interview with audience questions at the end.

Presented in collaboration with the OSA Fabrication, Design and Instrumentation Division.

IS Best Student Paper Award

This year the OSA Imaging Systems and Applications (IS) topical meeting established an award for the best student paper. The decision of the best student paper is made by an award committee that will judge the technical merit of qualifying student submissions that were accepted in the program. The best paper will be recognized during the meeting. This award is sponsored by Canon U.S.A. Inc.

OF&T Best Student Paper Award & Presentation

The OF&T Best Student Paper Award has been established to encourage excellence in research and scientific presentation skills in the student optics community. Awards include a cash prize and a certificate. There will be first- and second-place winners for both oral and poster presentations.

Students participating in the competition are noted within the abstracts section of this program. Please support the next generation of optical engineers and scientists by attending the student presentations and the awards presentation.

Robert S. Hilbert Memorial Student Travel Grant

Established in 2009 in memory of Robert S. Hilbert, President and Chief Executive Officer of Optical Research Associates (ORA), this program recognizes the research excellence of students in the areas of optical engineering, lens design and/or illumination design. Grant has been awarded to two students presenting their work at the Imaging and Applied Optics: OSA Optics and Photonics Congress. The grant is sponsored by ORA, and administered by OSA Foundation.

Anthony Visconti, School of Engineering and Applied Sciences, Univ. of Rochester, USA
IM2C.2, Large Diameter Radial Gradient-Index Lenses Fabricated by Ion Exchange

Matthew Barnum, College of Optical Sciences, Univ. of Arizona, USA
CM2B.5, Experimental Comparison of Computational Approaches to Focus Invariant Optical Systems

Exhibit Hall
The Dolphins on the Upper Plaza

<table>
<thead>
<tr>
<th>Monday, 25 June</th>
<th>18:30–20:00</th>
<th>Welcome Reception</th>
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<tbody>
<tr>
<td>Tuesday, 26 June</td>
<td>10:00–10:30</td>
<td>Exhibit Hall &amp; Coffee Break</td>
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<td></td>
<td>15:00–15:30</td>
<td>Exhibit Hall &amp; Coffee Break</td>
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<tr>
<td></td>
<td>17:30–19:00</td>
<td>Joint Poster Session</td>
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<tr>
<td>Wednesday, 27 June</td>
<td>10:00–10:30</td>
<td>Exhibit Hall &amp; Coffee Break</td>
</tr>
<tr>
<td></td>
<td>15:30–16:00</td>
<td>Exhibit Hall &amp; Coffee Break</td>
</tr>
</tbody>
</table>
Celebrate Applied Optics’ 50th Anniversary with us!

OSA is continuing its yearlong celebration of the 50th anniversary of Applied Optics with you!

As a conference attendee, you’ll receive an Applied Optics anniversary booklet, which features the 50 most cited articles from the journal’s history as well as biographies of the journal’s current and former Editors-in-Chief. You’ll also receive a commemorative gift as a token of our appreciation for your support.

To stay up-to-date with Applied Optics’ anniversary, visit http://ao.osa.org/anniversary.
### Explanation of Session Codes

**Meeting Name**
- A=AIO
- C=COSI
- I=IS
- O=OF&T
- R=ORS
- S=SENSORS

**Day of the Week**
- M=Monday
- Tu=Tuesday
- W=Wednesday
- Th=Thursday

**Series Number**
- 1=First Series of Sessions
- 2=Second Series of Sessions

**Number**
(Presentation order within the session)

**Session Designation**
(alphabetically)

The first letter of the code designates the meeting (For instance, A=AIO, C=COSI, I=IS, O=OF&T, R=ORS, S=SENSORS, J=Joint Session). The second element denotes the day of the week (Monday=M, Tuesday=Tu, Wednesday=W, Thursday=Th). The third element indicates the session series in that day (for instance, 1 would denote the first parallel sessions in that day). Each day begins with the letter A in the fourth element and continues alphabetically through a series of parallel sessions. The lettering then restarts with each new series. The number on the end of the code (separated from the session code with a period) signals the position of the talk within the session (first, second, third, etc.). For example, a presentation coded CTu1A.4 indicates that this paper is part of COSI (C) and is being presented on Tuesday (Tu) in the first series of sessions (1), and is the first parallel session (A) in that series and the fourth paper (4) presented in that session.

Invited papers are noted with **Invited**

Plenaries are noted with **Plenary**

Captured Content Sessions are noted with **Capture**

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### New Features for OSA Topical Meetings

**Online Access to Technical Digest Now Available!**

Full Technical Attendees now have an alternate way to access the digest papers at the meeting. Access the papers through Optics InfoBase (http://www.opticsinfobase.org/conferences.cfm) using the same login email address and password provided during the meeting registration process. Access is limited to Imaging and Applied Optics Congress Full Technical Attendees only.

**Recorded Technical Sessions on Demand**

We are delighted to announce that your 2012 Imaging and Applied Optics Congress technical registration includes a valuable new enhancement! A portion of the sessions at this year’s congress are being digitally captured for on-demand viewing. All captured content from listed sessions will be live for viewing within twenty-four hours of being recorded. Just look for the symbol in the Agenda of Sessions and abstracts to easily identify the presentations being captured. Content will be available for 60 days following the Congress. To access it visit OSA’s Media Library (http://www.osa.org/video_library/Technical_Sessions_Symposia.aspx) and selecting Imaging Congress from the list on the left hand side.
### Agenda of Sessions — Sunday, 24 June

<table>
<thead>
<tr>
<th>Time</th>
<th>Sessions</th>
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</thead>
<tbody>
<tr>
<td>15:00–18:00</td>
<td>Registration, Fairway Foyer on Lower Terrace</td>
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### — Monday, 25 June

<table>
<thead>
<tr>
<th>Time</th>
<th>Sessions</th>
</tr>
</thead>
<tbody>
<tr>
<td>07:00–18:00</td>
<td>Registration, Fairway Foyer on Lower Terrace</td>
</tr>
<tr>
<td>08:00–10:30</td>
<td>JM1A • Opening General Session, The Dolphins on the Upper Plaza</td>
</tr>
<tr>
<td>10:30–11:00</td>
<td>Coffee Break, Cypress Foyer on Lower Terrace</td>
</tr>
<tr>
<td>11:00–12:30</td>
<td>AM2A • Emerging Technology (ends at 13:00)</td>
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<tr>
<td></td>
<td>CM2B • Computational High Depth-of-Field Imaging</td>
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<td></td>
<td>IM2C • Imaging Lens Technologies</td>
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<td></td>
<td>OM2D • Optical Materials</td>
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<tr>
<td></td>
<td>RM2E • New Uses of Optical Remote Sensing</td>
</tr>
<tr>
<td></td>
<td>SM2F • Devices and Systems for Laser-based Sensors</td>
</tr>
<tr>
<td>12:30–14:00</td>
<td>Lunch, on your own</td>
</tr>
<tr>
<td>14:00–16:00</td>
<td>AM3A • Wow, You Can Do All This With Optical Systems</td>
</tr>
<tr>
<td></td>
<td>CM3B • Optical Coding and Microscopy</td>
</tr>
<tr>
<td></td>
<td>IM3C • Imaging Optics</td>
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<tr>
<td></td>
<td>OM3D • Polishing</td>
</tr>
<tr>
<td></td>
<td>RM3E • Current and Future Imaging Systems</td>
</tr>
<tr>
<td></td>
<td>SM3F • Digital Holography and Raman Scattering</td>
</tr>
<tr>
<td>16:00–16:30</td>
<td>Coffee Break, Cypress Foyer on Lower Terrace</td>
</tr>
<tr>
<td>16:30–18:30</td>
<td>AM4A • LIBS</td>
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<tr>
<td></td>
<td>CM4B • Compressive &amp; Spectral Imaging</td>
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<td></td>
<td>IM4C • Medical Imaging and Microscopy</td>
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<tr>
<td></td>
<td>OM4D • Figuring and Finishing Science</td>
</tr>
<tr>
<td></td>
<td>SM4F • Fiber Gratings and Displacement Sensors</td>
</tr>
<tr>
<td>18:30–20:00</td>
<td>Joint Conference Reception &amp; Exhibit Hall Opening, The Dolphins on the Upper Plaza</td>
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### Key to Conference Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIO</td>
<td>Applied Industrial Optics: Spectroscopy, Imaging, &amp; Metrology</td>
</tr>
<tr>
<td>COSI</td>
<td>Computational Optical Sensing and Imaging</td>
</tr>
<tr>
<td>IS</td>
<td>Imaging Systems and Applications</td>
</tr>
<tr>
<td>OF&amp;T</td>
<td>Optical Fabrication and Testing</td>
</tr>
<tr>
<td>ORS</td>
<td>Optical Remote Sensing of the Environment</td>
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<tr>
<td>SENSORS</td>
<td>Optical Sensors</td>
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</table>
# Agenda of Sessions — Tuesday, 26 June

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<tr>
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<th>Cypress 1 &amp; 2</th>
<th>Cypress 3</th>
<th>Point Lobos</th>
<th>Big Sur</th>
<th>Carmel</th>
<th>Registration, Fairway Foyer on Lower Terrace</th>
</tr>
</thead>
<tbody>
<tr>
<td>07:00–18:00</td>
<td>AIO</td>
<td>COSI</td>
<td>IS</td>
<td>OF&amp;T</td>
<td>ORS</td>
<td>SENSORS</td>
<td>Registration, Fairway Foyer on Lower Terrace</td>
</tr>
<tr>
<td>08:00–10:00</td>
<td>ATu1A • Industrial Spectroscopy</td>
<td>ITu1C • Military Applications</td>
<td>CTu1B • Aperture Synthesis, Fourier Optics, Coherence</td>
<td>OTu1D • Optical Testing I</td>
<td>RTu1E • Sensor Fusion and Lidar I</td>
<td>STu1F • Temperature and Photonic Crystal Fiber Sensing</td>
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</tr>
<tr>
<td>10:00–10:30</td>
<td>Exhibit Hall &amp; Coffee Break, The Dolphins on the Upper Plaza</td>
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</tr>
<tr>
<td>10:30–12:00</td>
<td>ATu2A • Micro-Optical Systems (ends at 12:30)</td>
<td>ITu2C • Hyperspectral Imaging</td>
<td>CTu2B • Image Restoration</td>
<td>OTu2D • Optical Testing II</td>
<td>RTu2E • Sensor Fusion and Lidar II</td>
<td>STu2F • Gas and Voltage Sensing</td>
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<tr>
<td>12:00–13:30</td>
<td>Lunch, on your own</td>
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<tr>
<td>13:30–15:00</td>
<td>ATu3A • Optical Systems for the Food Industry (13:20 – 15:10)</td>
<td>CTu3B • Compressive Imaging</td>
<td>ITu3C • Phase Space in Imaging</td>
<td>OTu3D • Assembly, Alignment and Control</td>
<td>STu3F • Distributed and Acoustic Sensors</td>
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<tr>
<td>15:00–15:30</td>
<td>Exhibit Hall &amp; Coffee Break, The Dolphins on the Upper Plaza</td>
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</tr>
<tr>
<td>15:30–17:30</td>
<td>ATu4A • Optical Design and Packaging</td>
<td>CTu4B • Computational Imaging</td>
<td>ITu4C • Image Sensors</td>
<td>OTu4D • Nanostructures and Films</td>
<td>STu4F • Micro and Nano-Engineered Sensors</td>
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<tr>
<td>17:30–19:00</td>
<td>JTu5A • Joint Poster Session, The Dolphins on the Upper Plaza</td>
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</table>

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**Key to Conference Abbreviations**

- **AIO**: Applied Industrial Optics: Spectroscopy, Imaging, & Metrology
- **COSI**: Computational Optical Sensing and Imaging
- **IS**: Imaging Systems and Applications
- **OF&T**: Optical Fabrication and Testing
- **ORS**: Optical Remote Sensing of the Environment
- **SENSORS**: Optical Sensors
## Agenda of Sessions — Wednesday, 27 June

<table>
<thead>
<tr>
<th>Cypress 1 &amp; 2</th>
<th>Cypress 3</th>
<th>Cypress 4</th>
<th>Point Lobos</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joint Sessions</td>
<td>AIO &amp; IS</td>
<td>COSI &amp; SENSORS</td>
<td>OF&amp;T</td>
</tr>
<tr>
<td><strong>07:00–18:00</strong></td>
<td>Registration, Fairway Foyer on Lower Terrace</td>
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<td></td>
</tr>
<tr>
<td><strong>08:00–10:00</strong></td>
<td>JW1A • Resolution Limits &amp; Spectral Imaging (IS &amp; COSI)</td>
<td>AW1B • Energy and Applied Optics</td>
<td>SW1C • THz Sensors I</td>
</tr>
<tr>
<td><strong>10:00–10:30</strong></td>
<td>Exhibit Hall &amp; Coffee Break, The Dolphins on the Upper Plaza</td>
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</tr>
<tr>
<td><strong>10:30–12:00</strong></td>
<td>JW2A • Sensing with Optical Fiber (AIO &amp; SENSORS) (ends at 12:15)</td>
<td>IW2B • Digital Imaging</td>
<td>CW2C – COSI Postdeadline Paper Session</td>
</tr>
<tr>
<td><strong>12:00–13:30</strong></td>
<td>Lunch, on your own</td>
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<tr>
<td><strong>13:30–15:30</strong></td>
<td>JW3A • Computational Imaging Sensors (COSI &amp; IS)</td>
<td>AW3B • What’s next in Applied Imaging</td>
<td>SW3C • THz Sensors II</td>
</tr>
<tr>
<td><strong>15:30–16:00</strong></td>
<td>Exhibit Hall &amp; Coffee Break, The Dolphins on the Upper Plaza</td>
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<tr>
<td><strong>16:00–17:30</strong></td>
<td>JW4A • Applied Imaging (AIO &amp; IS) (ends at 18:05)</td>
<td>SW4C • SENSORS Postdeadline Paper Session</td>
<td>OW4D • OF&amp;T Postdeadline Paper Session</td>
</tr>
<tr>
<td><strong>17:30–19:30</strong></td>
<td>OSA Corporate Associates: Executive Speaker Series Michael Silver, CEO of American Elements The Dolphins on the Upper Plaza</td>
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## — Thursday, 28 June

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<tr>
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<th>Cypress 1 &amp; 2</th>
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</thead>
<tbody>
<tr>
<td>AIO</td>
<td>SENSORS</td>
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<tr>
<td><strong>07:00–15:00</strong></td>
<td>Registration, Fairway Foyer on Lower Terrace</td>
</tr>
<tr>
<td><strong>08:00–10:00</strong></td>
<td>AT1A • Spectroscopy, Lasers, and Imaging, Oh My!</td>
</tr>
<tr>
<td><strong>10:00–10:30</strong></td>
<td>Coffee Break, Cypress Foyer on Lower Terrace</td>
</tr>
<tr>
<td><strong>10:30–12:00</strong></td>
<td>AT2A • Pharmacologically and Medically Applied Optics (ends at 12:30)</td>
</tr>
<tr>
<td><strong>12:00–13:30</strong></td>
<td>Lunch, on your own</td>
</tr>
<tr>
<td><strong>13:30–15:00</strong></td>
<td>ST3B • Imaging</td>
</tr>
</tbody>
</table>

## Key to Conference Abbreviations

- **AIO**: Applied Industrial Optics: Spectroscopy, Imaging, & Metrology
- **COSI**: Computational Optical Sensing and Imaging
- **IS**: Imaging Systems and Applications
- **OF&T**: Optical Fabrication and Testing
- **ORS**: Optical Remote Sensing of the Environment
- **SENSORS**: Optical Sensors
08:00–10:30
JM1A • Opening General Session

JM1A.1 • 08:15
Assessing a New Imaging Modality. Joseph Goodman, Stanford Univ., USA. I will consider some of the factors to be considered when assessing the capability and limitations of a new imaging modality, using holography in the 60’s and 70’s as an example.

JM1A.2 • 08:45
Image Quality Assessment: How Blind is Blind?, Al Bovik, Univ. of Texas at Austin, USA. Blind Image Quality Assessment (Blind IQA) is usually synonymous with “no-reference” IQA, viz., without a pristine image available for quality comparison. However, other sources of information are used to design IQA models: human opinion scores, mathematical models of distortion, perceptual models; statistical models of distorted images, and statistical models of images that are not distorted.

JM1A.3 • 09:15
Survey of Applications for Ocean Color and Imagery from EOS-MODIS and Early Results from NPP-VIIRS, Bruce Guenther, NOAA-JPSS & University of Maryland of Baltimore County, USA. Interesting and useful images come from orbiting MODIS and VIIRS instruments, including the ~375-m resolution VIIRS imaging bands and nighttime images from the Day/Night Band. There are five VIIRS imaging bands out to 11450 nm.

JM1A.4 • 09:45
Small Satellites: The Desire for a Mass Producible, Mass Customizable Nanosatellite, Henry Helvajian, The Aerospace Corp., USA. This talk describes the role of small satellites, and work at The Aerospace Corporation to develop an integrated cold gas propulsion system for a 1 kg class nanosatellite vehicle made largely from photostructurable glass ceramics.
Monolithic Waveguide Spectrometer for Mid-Infrared Applications, Eric J. Olson; Spectro Inc., USA. Spectro Inc. has commercialized a ruggedized mid-IR spectrometer platform based on a unique wedge waveguide design that integrates input optics, diffraction grating, and array detector into a monolithic system operating in the 2.5 to 12 micron wavelength range.

AM2A.1 • 11:00

Monolithic Waveguide Spectrometer for Mid-Infrared Applications, Eric J. Olson; Spectro Inc., USA, Presider

AM2A.1 • 11:00

Focus in Multiscale Imaging Systems, David J. Brady; Duke Univ., USA. We consider first order lens design for micro-camera-based focus in multiscale cameras. We compare focal and spectral tomography and we compare dynamic focal scanning with alternative EDoF and focal stacking strategies.

CM2B.1 • 11:00

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Focus in Multiscale Imaging Systems, David J. Brady; Duke Univ., USA. We consider first order lens design for micro-camera-based focus in multiscale cameras. We compare focal and spectral tomography and we compare dynamic focal scanning with alternative EDoF and focal stacking strategies.

CM2B.2 • 11:30

High Resolution Image Reconstruction for Plenoptic Imaging Systems using System Response, Sapna Shroff, Kathrin Berkhout; RIch Innovations, Inc., USA. Plenoptic imaging systems with a micro lens array imaging the pupil at the sensor typically produce low resolution images. We introduce an inverse problem solver using the system response to obtain high resolution image reconstructions.

CM2B.3 • 11:45

Improved Extended Depth-of-Field Microscopy through PSF Engineering and Robust Processing, Shuai Yuan; Univ. of Memphis, USA. Performance investigation of improved extended depth-of-field microscopy achieved with point-spread function engineering to reduce image artifacts due to depth-induced aberrations and processing that is robust to system noise.

CM2B.4 • 12:00

Experimental Verification of Computational Superposition Imaging for Compensating Defocus and Off-axis Aberrated Images, Tomoya Nakamura, Rupicki Horisaki; Univ. of Tokyo, Japan. An aberration compensation method with computational superposition imaging is demonstrated. In this method, aberated images are superposed to equalize the point spread function three-dimensionally and the superposed image is deconvolved with a filter.
Synthetic fused silica, one of the most widely used optical materials, will be discussed. This material is known for its high purity and the absence of defects, which makes it suitable for a variety of applications. Some new applications like ultralow absorption, birefringence and high power laser durability in the UV and IR will be highlighted.

Some new applications of synthetic fused silica and related substrate materials, including SiN4 films, will be discussed. These materials are often used in optical spectroscopy and imaging. The role played by the different cerium oxidation states of cerium (Ce3+ vs. Ce4+) during the chemical mechanical planarization of silica and related substrate materials, including SiN4 films will be discussed.

The role played by the different cerium oxidation states of cerium (Ce3+ vs. Ce4+) during the chemical mechanical planarization of silica and related substrate materials, including SiN4 films will be discussed.
AM2A • Emerging Technology—Continued

AM2A.4 • 12:20 Invited
Dielectric Optical Resonators for Mechanical and Chemical Sensing Using Frequency Combs, Gianluca Gagliardi; CNR-Istituto Nazionale di Ottica, Italy. Strain sensing at the 10-13 level is performed using a fiber Bragg-grating resonator interrogated by an optical-comb stabilized laser. The comb is also used as a coherent radiation source for fiber cavity-enhanced spectroscopy of liquids.

CM2B • Computational High Depth-of-Field Imaging—Continued

CM2B.5 • 12:15 Experimental Comparison of Computational Approaches to Focus Invariant Optical Systems, Joshua I. Brent; Matt Bingham; Nan Ding; Kate Green; Lena Wolfe; College of Optical Sciences, Univ. of Arizona, USA; System & Industrial engineering Department, Univ. of Arizona, USA. Many aerospace sensor platforms have a fixed opto-mechanical layout due to harsh environmental conditions. This design decision results in tight opto-mechanical tolerances. An experimental test bed of computational approaches to alleviate this constraint is presented.

CM2B.1 • 14:00 Invited
Tunable Complex Amplitude Masks for Computer Imaging, Jorge Ojeda-Castaneda; Universidad de Guanajuato, Mexico. We present a method that uses tunable complex amplitude masks, for acquiring and pre-processing pictures, which are suitably post-processed and average into a final image. We visualize the method in terms of the ambiguity function.

CM2B.2 • 14:30 Design of Double-helix Point Spread Functions for 3D Super-resolution Imaging, Giona Grover; Keith DeLuca; Sean Quinn; Jennifer DeLuca; Rafael Piestun; Department of Electrical, Computer and Energy Engineering, Univ. of Colorado at Boulder, USA; Department of Biochemistry and Molecular Biology, Colorado State Univ., USA. The application specific design of double-helix point spread functions enables control of parameters such as the efficiency and depth of field. We demonstrate a design and implementation in single molecule super-resolution microscopy.

CM2B.3 • 14:45 Chromatic depth from defocus: a theoretical and experimental performance study, Pauline Trouvé; Frédéric Champagnat; Guy Le Besnerais; Guillaume Drauz; Jérôme Idier; ONERA-The French Aerospace Lab, France; LUNAM Université, IRCCyN, France. We present a new computational imaging system which combines a chromatic lens and a dedicated processing in order to extract depth. A theoretical performance model of this system is then compared to experimental results.

CM2B.4 • 15:00 Invited
Optical Freeform Surfaces in Integrated Optical Microsystems, Stefan Sinzinger; Technische Optik, Technische Universität Ilmenau, Germany. Freeform surfaces provide degrees of freedom which are essential specifically for the optimization and integration of optical microsystems. We discuss design, optimization as well as fabrication concepts and applications of (micro-)systems involving such non-conventional surfaces.
Optical Sensors has proven its ability to polish complex free-form surfaces. A deterministic polishing tool based on radial expulsion was developed.

Jessica D. Nelson, Robert Wiederhold; 1Optimax Systems Inc, USA. We will pay tribute to Norman J. Brown as we review his technical contributions to the field of optical fabrication and testing over the last decade.

Validation of VIIRS Calibrations for Oceans, Bruce W. Garthner1,2,3; 1IPPS, NOAA-NESSS, USA; 2JET, Univ. of Maryland, Baltimore County, USA. New methods to create VIIRS ocean-color products are reviewed, with recommendations for handling an on-orbit NIR anomaly, exploiting hyperspectral characterization, and correcting for polarization in an operational data-processing environment.

Mineral Mapping using Simulated Short-Wave-Infrared bands planned for DigitalGlobe WorldView-3 Data, Fred A. Kruse1, Sandra Perry1; 1Naval Postgraduate School, USA; 2Perry Remote Sensing LLC, USA. Airborne hyperspectral data were used to simulate imagery from DigitalGlobe’s proposed WorldView-3 (WV-3) satellite. A proposed new band configuration, including eight additional short-wave-infrared channels, demonstrates improved capability for geologic mapping and other applications.

Parallel Phase-shifting Digital Holography for Recording 3-D Motion Pictures of Dynamic Phenomena, Yasuhito Awaysagi1, Takahiro Kake1, Takeshi Tahara1, Peng Xia1, Kenzo Niikura1, Shige Urita1, Toshihiro Kubota1, Osamu Matoba3; 1Kyoto Institute of Technology, Japan; 2Kobe Holography Laboratory Corporation, Japan; 3Kobe Univ., Japan. Using parallel phase-shifting digital holography with a high-speed camera, the authors succeeded in phase-shifting interferometry at the rate of 180,000 frames/s. Motion pictures of three-dimensional image of dynamically moving objects were demonstrated.

Polishing with a Vortex: A Decade in Hydrodynamic Radial Polishing, Erika Sohn1,2; 1Instituto de Astronomia UNAM, Mexico; 2Universidad Nacional Autonoma de Mexico, Mexico. We present a review of ten years of polishing with HyDRA, a deterministic polishing tool based on radial expulsion hydrodynamics. This system has reached maturity and has proven its ability to polish complex free-form surfaces.

Polishing with a Vortex: A Decade in Hydrodynamic Radial Polishing, Erika Sohn1,2; 1Instituto de Astronomia UNAM, Mexico; 2Universidad Nacional Autonoma de Mexico, Mexico. We present a review of ten years of polishing with HyDRA, a deterministic polishing tool based on radial expulsion hydrodynamics. This system has reached maturity and has proven its ability to polish complex free-form surfaces.

Adaptive Optics by Digital Holography, Myung K. Kim1; 1Physics, Univ. of South Florida, USA. We present new techniques of adaptive optics by digital holography, with potential applications from ophthalmic to astronomical imaging systems. Wavefront sensors and modulators are replaced with digital holographic sensing and compensation processes.

The Portable Remote Imaging Spectrometer (PRISM) Coastal Ocean Sensor, Pantazis Mounanolou1, Byron E. Van Corp2, Robert O. Green1, Michael Eastwood3, Daniel W. Wilson1, Brandon Richardson1, Heidi Diener1; 1Jet Propulsion Laboratory, USA; 2Marine Sciences, Univ. of Connecticut, USA. We present characterization measurements of PRISM, an airborne pushbroom imaging spectrometer for the coastal ocean with high uniformity, high signal to noise ratio and low polarization sensitivity.

Optical Remote Sensing of the Environment

These concurrent sessions are grouped across two pages. Please review both pages for complete session information.
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**AM3A • Wow, You Can Do All This With Optical Systems—Continued**

**AM3A.2 • 15:00**

**Invited**

**Exploiting High Efficiencies in a Deep LED Water Treatment Device**, Oliver Lawal; Aquionics Inc, USA. Water disinfection employing UV-C LEDs in lieu of mercury based technology has been heralded as a breakthrough poised on the brink of commercialization. Presented are results of an innovative UV LED reactor proving commercial readiness.

**CM3B • Optical Coding and Microscopy—Continued**

**CM3B.4 • 15:00**

**Turbid Stochastic Optical Reconstruction Microscopy (TSTORM)**, Jacob Lapenna; Jason W. Fleischer; Electrical Engineering, Princeton Univ., USA. Stochastic optical reconstruction microscopy (STORM) relies on time resolving overlapping point-spread functions (PSFs) to increase image resolution. Here, we extend STORM from diffraction-limited PSFs to those dominated by scattering.

**CM3B.5 • 15:15**

**DEEP-dome: Towards Long-Working-Distance Aberration-Free Synthetic Aperture Microscopy**, Daniel Feldkamp; Kelvin H. Wagner; EE&CS, Univ. of Colorado at Boulder, USA. A DEEP microscope synthesizes images from dynamic structured-illumination Fourier measurements using a single-element detector, enabling high-resolution imaging with aberrated optics. We describe wide-field 20cm-working-distance DEEP microscopy using a large 0.4 NA diamond-turned reflector.

**CM3B.6 • 15:30**

**3D deconvolution Microscopy using a Microfluidic Tilted Channel**, Nicolas C. Pegard; Jason W. Fleischer; Princeton Univ., USA. We present a 3D microfluidic microscope. Focal stacks are recorded by observing samples flowing through a tilted microfluidic channel and then digitally deconvolved. Experimental results are shown on flowing yeast cells.

**CM3B.7 • 15:45**

**Microfluidic Structured Illumination Microscope**, Chien-Hung Lu; Nicolas C. Pegard; Jason W. Fleischer; Princeton Univ., USA. We apply the principle of structured illumination to microfluidic microscopy. Sample flow across the illumination pattern automatically gives the necessary phase shifts. We experimentally demonstrate the technique by reconstructing a superresolution image of yeast cells.

**IM3C • Imaging Optics—Continued**

**IM3C.4 • 15:15**

**Wave-Plate-Enhanced Retinal Birefringence Scanning for True Foveal Fixation Detection**, Kristina Irzol, Boris Gramatikov; Yi-Kai Wu; David Guyton; School of Medicine, Johns Hopkins Univ., USA. We use spinning and fixed wave plates, optimized using an algorithm and related computer program, based on Müller-Stokes matrix calculus, to enhance foveal fixation detection while minimizing interference from corneal birefringence in retinal birefringence scanning.

**IM3C.5 • 15:30**

**Recent Advances in Imaging Through Scattering Media**, Demetri Psaltis; Boris Gramatikov; Ye Pu; Xin Yang; Ecole Polytechnique Federale de Lausanne, Switzerland. We will describe recent progress in using digital holography and second harmonic nanoparticles to focus light into scattering media. The nanoparticles act as beacons on which light is phase conjugated.

**AM3A.3 • 15:40**

**Optical Fibre Based Scintillation Probe for Radiotherapy Dosimetry**, Sinead O’Keeffe; Denis McCarthy; Peter Woulfe; John Cronin; Elfed Lewis; ‘Optical Fibre Sensors Research Centre, Univ. of Limerick, Ireland; ‘Dept. of Radiotherapy Physics, Galway Clinic, Ireland. A PMMA based plastic optical fibre coated with radiation sensitive inorganic scintillators, which fluoresce when exposed to ionising radiation, is presented for use in applications for monitoring radiation doses a patient receives during radiotherapy.

**IM3C.6 • 15:45**

**Microfluidic Structured Illumination Microscope**, Chien-Hung Lu; Nicolas C. Pegard; Jason W. Fleischer; Princeton Univ., USA. We apply the principle of structured illumination to microfluidic microscopy. Sample flow across the illumination pattern automatically gives the necessary phase shifts. We experimentally demonstrate the technique by reconstructing a superresolution image of yeast cells.

**16:00–16:30 Coffee Break, Cypress Foyer on the Lower Terrace**
OM3D • Polishing—Continued

OM3D.3 • 15:00  
New Approaches to MRF®, Andrew W. Kulawiec, William Kordonski, Sergei Gorodkin; QED Technologies Inc., USA. The discussed advancements in MRF technology offer greater flexibility and productivity in fabrication of modern optics. This is achieved with new efficient structural components, novel system configuration, high performance polishing fluids and improved control algorithms.

OM3D.4 • 15:30  
Abrasive Jet Polishing Approaches to the Manufacture of Micro-optics with Complex Shapes, Oliver W. Fachler; FISBA OPTIK AG, Switzerland. Requirements for polishing of micro-aspheres are discussed identifying abrasive slurry jet techniques as possible solution featuring submillimeter footprints. Their application to the removal of submillimeter structures and the generation of micro-aspheres are presented.

SM3F • Digital Holography and Raman Scattering—Continued

SM3F.3 • 15:00  
In vivo Molecular Labeling of Halogenated Volatile Anesthetics using Adaptively Phase-modulated Femtosecond Pulses, Kazuhiko Misawa; Department of Applied Physics, Tokyo Univ. of Agriculture and Technology, Japan; Interdisciplinary Research Unit in Photon-Nano Science, Tokyo Univ. of Agriculture and Technology, Japan. We determined the low-frequency vibrational modes of one of the most representative volatile anesthetics molecules, sevoflurane, in a live squid giant axon by anti-Stokes Raman scattering microscopy using adaptively phase-modulated femtosecond pulses.

SM3F.4 • 15:30  
Filament-Based Impulsive Remote Raman Spectroscopy for Chemical Detection, Robert J. Levis; Temple Univ., USA. The remote detection of gas phase molecules remains a challenge. Laser filamentation can be used to enhance the cross section for Raman scattering of gas phase molecules and the method will be presented along with applications to signature molecules.

RM3E • Current and Future Imaging Systems—Continued

RM3E.5 • 15:15  
Multi-Slit Optimized Spectrometer: An Innovative Design for Geostationary Hyperspectral Imaging, Tim Valle, Chuck Hardysh, Carsten Davis, Nicholas Tydillane, Michelle Stephens, William Good; Ball Aerospace & Technologies Corp., USA; Oceanic and Atmospheric Sciences, Oregon State Univ., USA. Multi-Slit Optimized Spectrometer is a spatial multiplexing hyperspectral imager designed to reduce mission cost and risk for hyperspectral sensing from geostationary orbit. The multi-slit prism design resulting in 50% telescope aperture reduction will be presented.

RM3E.6 • 15:30  
Wide Field of View Hyperspectral Radiometer for Coastal Imaging from Polar Sun Synchronous Orbit, John Sitko, Jeff Puschell; Raytheon Company, USA. High spatial resolution wide FOV hyperspectral imaging spectroradiometry offers capability for isolating spectral radiance components in complex coastal waters. This paper reports on designs for hyperspectral coastal imagers that measure key data products from sun synchronous orbit.

16:00–16:30  Coffee Break, Cypress Foyer on the Lower Terrace
**AM4A • LIBS**

Arel Weisberg; Energy Research Co, USA, Presider

**AM4A.1 • 16:30**

**Invited**

**Measuring Thermal Properties of Coal with a Commercial Bench Top LIBS System**

Joseph Czapar, Robert De Saro, Carlos Romero, Zheng Yue, Andrew Whitehouse, Arel Weisberg; 1Energy Research Co, USA; 2Energy Research Center, Lehigh Univ, USA; 3Applied Photonics Ltd., UK. Measurements with a bench top commercial LIBS system demonstrate that thermal properties of coal can be measured using LIBS. Knowledge of these properties is crucial for efficient operation of coal fired boilers in power plants and other industries.

**AM4A.2 • 17:10**

**Invited**

Laser Induced Breakdown Spectroscopy (LIBS) for Real Time Analysis of Materials: Challenges and Future

Mohammad Sabahi, National Research Council Canada, Canada. We will give an overview about LIBS applications for on-line measurements such as molten materials, metal ore processing, effluents, slurries, liquids, nuclear industry etc., and we will present some approaches to improve the LIBS sensitivity.

**AM4A.3 • 17:50**

**Invited**

Laser-Induced Breakdown Spectroscopy for the Standoff Detection of Explosive Residues

Jennifer Gottfried, Frank C. De Lucía; 1US Army Research Laboratory, USA. Recent advances in laser-induced breakdown spectroscopy (LIBS) such as double pulse LIBS and advanced chemometric analysis have enabled discrimination between explosive and non-explosive residues on various surfaces at standoff distances.

**AM4A.4 • 17:45**

**Invited**

AFSSI-C: the Adaptive Feature-Specific Spectral Imaging Classifier

Matthew Dunlop, Peter Jansen, Datton R. Golish, Michael E. Gehm; 1HRL Labs, USA. Low cost, low power hyperspectral imaging sensors and real-time, low power processing of hyperspectral data are needed for mobile platforms for agricultural, mineralogical, surveillance and physics applications. In this presentation we will show how two novel technologies - Compressed Sensing (CS) and analog Asynchronous Pulse Processing (APP) - are successfully applied to real time HSI sensing and processing.

**CM4B • Compressive & Spectral Imaging**

David Gerwe; Boeing Company, USA, Presider

**CM4B.1 • 16:30**

**Invited**

Spectroscopy for Intact Particles

Thomas van Dijk, Rahul Bhargava; 1P. Scott Carney; 2Beckman Institute for Advanced Science and Technology, Univ. of Illinois at Urbana-Champaign, USA. Infrared microscopy, the structure and the chemistry of a sample are commingled, distorting the recorded spectra and confounding chemical identification. We provide a physics-based method to recover the material response from spheres.

**CM4B.2 • 17:00**

**Invited**

Chip-Scale Low Power Analog Hardware Implemented Compressed Sensing and Target Detection Algorithms for Hyperspectral Imaging Applications

Matthew Dunlop, Peter Jansen, Datton R. Golish, Michael E. Gehm; 1HRL Labs, USA. A dynamically programmable computational imaging system has been demonstrated. The system operates in the visible and near infrared bands. Principal components and random binary measurements were used with the imaging hardware to demonstrate compressive imaging.

**CM4B.3 • 17:30**

Dynamically Programmable, Dual-Band Computational Imaging System

Brant M. Kayser, Aarti Ashok, Eric M. Segre, Charlie J. Keith, Randy R. Reif; 1Bridger Photonics, Inc, USA; 2College of Optics, Univ. of Arizona, USA. A dynamically programmable computational imaging system has been demonstrated. The system operates in the visible and near infrared bands. Principal components and random binary measurements were used with the imaging hardware to demonstrate compressive imaging.

**CM4B.4 • 17:45**

AFSSI-C: the Adaptive Feature-Specific Spectral Imaging Classifier

Matthew Dunlop, Peter Jansen, Datton R. Golish, Michael E. Gehm; 1HRL Labs, USA. A dynamically programmable computational imaging system has been demonstrated. The system operates in the visible and near infrared bands. Principal components and random binary measurements were used with the imaging hardware to demonstrate compressive imaging.

**IM4C • Medical Imaging and Microscopy**

Joyce Farrell; Stanford Univ., USA, Presider

**IM4C.1 • 16:30**

**Invited**

In vivo Brain Imaging with Miniaturized Optical Systems

M. Skorina, C. Chettiar, C. Cervenka, J. Weingart; 1CNC Program, Stanford Univ., USA. A longstanding challenge in neuroscience is to understand how populations of individual neurons contribute to animal behavior and brain disease. Addressing this challenge has been difficult partly due to lack of brain imaging technology for use in awake behaving animals. We will describe two approaches to studying the brains of awake behaving mice, one of which also allows time-lapse studies of cells in deep brain areas. Using these methodologies we have studied the dynamics of cerebellar Purkinje cells and hippocampal pyramidal neurons and relationships to rodent behavior.
These concurrent sessions are grouped across two pages. Please review both pages for complete session information.

**OM4D • Figuring and Finishing Science**

**Erika Sohn; Instituto de Astronomia UNAM, Mexico, Presider**

**OM4D.1 • 16:30**

Invited Control of Mid-spatial-frequency Errors for Large Steep Aspheric Surfaces, 
*Die Wook Kim, Hubert Martin, James H. Burger*: College of Optical Sciences, Univ. of Arizona, USA; 'Steward Observatory, Univ. of Arizona, USA. Control of mid-spatial-frequency errors on precision optical surfaces is very important for next-generation optical systems. We present results of smoothing experiments and of polishing runs utilizing figuring and smoothing for the 8.4m GMT off-axis segment.

**OM4D.2 • 17:00**

Minimize Mid-Spatial Frequencies on Aspherical Surfaces, 
*Joseph Ellison, Steven Vankerkhove*: Corning, USA. Removal of Mid-Spatial Frequency features on aspherical surfaces is challenging. This paper presents results obtained from novel fabrication and measurement techniques used to reduce MSF errors achieving less than 2nm rms residual error while preserving the aspheric form to better than 3nm PV.

**OM4D.3 • 17:15**

Invited Laser Polishing of Lenses of Fused Silica and BK7, 
*Annika Richmann, Edgar Willenborg, Konrad Wissenbach*: 'Lehrstuhl für Technologie optischer Systeme TOS, Germany.' A novel process for polishing lenses made of fused silica and BK7 with CO2-laser radiation is presented. First results on polishing spherical and aspherical lenses of both materials with an adapted processing strategy are presented.

**OM4D.4 • 17:30**

The Role of the Zetapotential in the Polishing Process of Optical Glasses, 
*Elisabeth Becker, Marcel Aechtsock*: 'Berliner Glas KG, Germany.' This paper shows the significant role of the colloidal chemistry of the polishing suspension in the polishing process. The main properties are the stability of the suspension and the agglomeration state of the polishing grains, which both influence the surface quality of the polished glass.

**OM4D.5 • 17:45**

Invited Evaluating the Effect of Single Frequency Vibrations on Pitch Polishing Outcomes, 
*Mohammad Maimuddin, Brad A. Mullany*: 'Univ. of North Carolina at Charlotte, USA.' To isolate the roles of vibrations in polishing outcomes, specifically designed pitch polishing processes were undertaken using different vibration profiles. The effects of different vibrational approaches are reported.

**SM4F • Fiber Gratings and Displacement Sensors**

**John Canning, Univ. of Sydney, Australia, Presider**

**SM4F.1 • 16:30**

Invited Implementation and Characterization of Polarimetric Heterodyning Fiber Grating Laser Sensors, 
*Rui-Qiu Guan, Long Jin, Hwa-Yaw Tan*: 'Jinan Univ., China, The Hong Kong Polytechnic Univ., China.' In this paper, we briefly review our recent work on polarimetric heterodyning fiber grating laser sensors, including the characterization, implementation, and multiplexing of the polarimetric sensors.

**SM4F.2 • 17:00**

Invited Remote Sensing Networks for Fiber Optic Sensors, 
*Manuel Lopez-Amo, Montserrat Fernandez Valdejo*: 'Ingenieria Electrica y Electronica, Universidad Publica de Navarra, Spain.' This paper presents an overview of optical fiber sensor networks for remote sensing including lasing and non-lasing configurations. The main factors to take into consideration in the design of a fiber optic remote sensor system are gathered.

**SM4F.3 • 17:30**

Study of the Linearity Performances of a Polarization-Based Vibration Sensor, 
*Nicolas Linze, Pierre Tihom, Olivier Verlinden, Patrice Megret, Marc Wuilpart*: 'Electromagnetism and Telecommunication Department, Univ. of Mons, Belgium; 'Department of Theoretical Mechanics, Dynamics and Vibrations, Univ. of Mons, Belgium.' In this paper, the performances of a polarization vibration sensor are theoretically and experimentally analyzed. We show that this sensor can recover the vibration spectrum without distortions up to an acceleration of 300 m/s^2.

**SM4F.4 • 17:45**

Dynamic monitoring of an elevated water reservoir with a biaxial optical accelerometer, 
*Paulo Antunes, Hugo Rodrigues, Jose Mafra, Humberto Varum, Paulo S. Andre*: 'Instituto de Telecomunicacoes, Portugal; 'Univ. of Aveiro, Portugal.' The dynamic monitoring of a water reservoir employing a biaxial optical accelerometer, is described. The structure natural frequencies were measured with an error of 0.08 %, when compared with the values attained from seismograph.
These concurrent sessions are grouped across two pages. Please review both pages for complete session information.

**AM4A • LIBS—Continued**

**CM4B • Compressive & Spectral Imaging—Continued**

**CM4B.5 • 18:00**
Spectrally Selective Compressive Imaging by Matrix System Analysis, Henry Arguello\(^1,2\), Gonzalo Arce\(^1\); \(^1\)Univ. of Delaware, USA; \(^2\)Computer Science, Universidad Industrial de Santander, Colombia. A new CASSI formulation is presented which allows the design of spectrally selective measurements. Given a desired spectral sensing profile, the model permits the calculation of the required structure of the code apertures.

**CM4B.6 • 18:15**
Coded-Aperture Compressive Spectral Image Classification, Ana Ramirez\(^1\), Gonzalo Arce\(^2\), Brian Sadler\(^2\); \(^1\)Dept. of Electrical and Computer Engineering, Univ. of Delaware, USA; \(^2\)Army Research Laboratory, USA. A classification method of compressed hyperspectral images acquired by using a Coded Aperture Snapshot Spectral Imaging (CASSI) system is proposed. A sparse vector that represents the HSI image in a multidimensional representation of the scene is used to determine the class label of the test pixel.

**IM4C • Medical Imaging and Microscopy—Continued**

**IM4C.5 • 18:00**
**Invited**
Compressive Fluorescence Microscopy for Biological and Hyperspectral Imaging, Maxime Dahan\(^1\); \(^1\)Ecole Normale Superieure, France. We present a novel approach to fluorescence bioimaging based on the theory of compressed sensing and demonstrate its potential on sparse fluorescent samples as well as hyperspectral images.

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**18:30–20:00 Joint Conference Reception & Exhibit Hall Opening, The Dolphins on the Upper Plaza**

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**NOTES**
OM4D • Figuring and Finishing Science—Continued

OM4D.6 • 18:00 Invited
Aspheric Finishing of Glass and SiC Optics, Flemming Tinker1, Kai Xin1; 1Aperture Optical Sciences, Inc, USA. Aperture Optical Sciences Inc. was founded in 2010 to develop and produce advanced aspheric optics in silicon carbide and other materials. This paper explores Zeeko robotic polishing as an effective technology for aspheric finishing.

SM4F • Fiber Gratings and Displacement Sensors—Continued

SM4F.5 • 18:00
Investigation of the Directional Response of Fiber Bragg Grating-Based Acoustic Emission Sensor, Harish V. Achar1, Rajkumar Ramakrishnan1, Krishnan Balasubramanian2, Balaji Srinivasan1; 1Electrical Engineering, Indian Institute of Technology, Madras, India; 2Mechanical Engineering, Indian Institute of Technology Madras, India. We investigate the directional response of fiber Bragg gratings to acoustic emissions using a home built dynamic interrogator capable of sensing acoustic emissions from few kHz to 1 MHz.

SM4F.6 • 18:15
Size Effect in Fiber Optic Displacement Sensors, Garry Berkovic1, Shlomo Zilberman1, Ehud Shafir1; 1Soreq Nuclear Research Center, Israel. We explain anomalous results obtained when small core optical fibers probe the distance to some scattering surfaces, such as machined metal surfaces. Large intensity variations occur when different sections of surface are probed at constant distance.

18:30–20:00 Joint Conference Reception & Exhibit Hall Opening, The Dolphins on the Upper Plaza

NOTES
**CTu1A • Industrial Spectroscopy**

08:00–10:00

**ATu1A • Industrial Spectroscopy**

Elfed Lewis; Univ. of Limerick, Ireland, Presider

**ATu1A.1 • 08:00**

*Direct Real-Time Determination of Compositional Profiles in Structured Materials Using Laser Ablation Instruments: LIBS and LA-ICP-MS, Alexander A. Bolshakov1, Jong H. Yu2, Jianhua J. Gonzalez3, Chi-Hui Liu4, Richard E. Rousse5; 1Applied Spectra Inc, USA. Laser ablation offers rapid micro-analysis with spatial resolution ~10nm in depth, ~3μm lateral. Structured materials are mapped, depth-profiled for elemental and isotopic composition using LIBS or LA-ICP-MS without dissolving samples. Molecular structure can be inferred by chemometric processing.*

**ATu1A.2 • 08:40**

*Advances in Laser Assisted Microwave Plasma Spectroscopy (LAMPS), Philip C. Efthimion1; 1Envimetics, USA. LAMPS, Laser Assisted Microwave Spectroscopy, is a plasma spectroscopic technique that has higher sensitivity to LIBS using little or no laser energy. The higher sensitivity is due to microwave energy extending the duration of the micro plasma for analyzing material. The sensitivity is enhanced a factor of 10 at wavelengths < 300 nm and 40 - 200 for wavelengths > 300 nm. The lower laser energy results in no surface damage. The technique can be used to determine the composition of materials and detect biological and explosive agents. Recently, the device has been miniaturized to develop a portable hand held instrument.*

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**CTu1B • Aperture Synthesis, Fourier Optics, Coherence**

08:00–10:00

**CTu1B.1 • 08:00**

*Imaging Geostationary Satellites with a Common-Mount Optical Interferometry, Anders Jorgensen1, David MacFarlane2, Henrik R. Schmidt3, J. T. Armstrong4, Robert B. Hindley5, Ellyn K. Raines6, Sergio R. Restaino7; 1New Mexico Institute of Mining and Technology, USA; 2Seabrook Engineering, USA; 3Computational Physics, Inc, USA; 4Naval Research Laboratory, USA. We present design and preliminary performance analysis of an optical interferometer which is capable of imaging geostationary-satellites. It consists of a large number of simple telescopes on a single mount fiber-feeding a beam combiner.*

**CTu1B.2 • 08:30**

*Form the state-of-the-art in interferometric imaging visible in near infrared astronomy and how the lessons learned from this field can be applied to imaging of structure in deep-space satellites.*

**CTu1B.3 • 09:00**

*Experimental measurement of 4D Ambiguity functions of 2D signals, Gautha Sita1, Laura Haller2, Jason W. Fleischer3; 1Princeton Univ., USA. We present a windowed-Fourier-transform-based technique for measuring the 4D Wigner distribution function and Ambiguity function of 2D signals. Experimental results agree very well with numerical simulation.*

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**CTu1C • Military Applications**

08:00–10:00

**CTu1C.1 • 08:00**

*Pixel Scaling in Infrared Plane Arrays, Peter B. Catrysse1, Torbjorn Skau1; 1L. Ginzton Laboratory, Stanford Univ., USA; 2Norwegian Defence Research Establishment (FFI), Norway. We discuss challenges that arise in infrared focal plane arrays when pixel size scales down to approach the wavelength. We also explore opportunities that emerge for controlling light with subwavelength optics in very small pixels.*

**CTu1C.2 • 08:30**

*Generating 3D Reflectance Images of the Shallow Water Seafloor from Airborne Lidar Data, Grady Tuell1, Joong Y. Park2, Viktor Kogelés2, Vinod Ramnath2; 1Georgia Tech Research Institute, USA; 2Optech Inc., USA. Bathymetric lidar waveforms may be inverted to estimate seafloor reflectance, and rasterized to generate 3D reflectance images. These images compare favorably to diver measurements, and may be used for seafloor classification and target detection.*

**CTu1C.3 • 08:45**

*Formation of Wide-FOV Active Image Mosaics, Samuel T. Thurman1, Andrew Bratcher1; 1Lockheed Martin Coherent Technologies, USA. The field-of-view (FOV) for active imaging systems typically is matched to the illumination-beam width. We describe a registration algorithm that forms wide-FOV image mosaics by taking the illumination-beam profile into account.*
Optical Fabrication and Testing

Optical Remote Sensing of the Environment

Optical Sensors

These concurrent sessions are grouped across two pages. Please review both pages for complete session information.

08:00–10:00

OTu1D • Optical Testing I

Ulf Griesmann; NIST, USA, Presider

OTu1D.1 • 08:00

Invited

Light Scattering & Complex Optical Components: Mod-
elization and Characterization, Myriam Zerrad1,2, Michel

Lepquime3,4, Claude Anna5,6,7; Institut Fresnel, France; 6CNRS,

France; 7Aix Marseille Université, France; 4École Centrale

Marseille, France. Limitation and quantification of scattering

losses are new challenges to enhance optical components

performances. Last numerical and metrological platforms

involved at Institut Fresnel and dedicated to light scattering

characterization and modelization will be presented.

OTu1D.2 • 08:30

Invited

Light scattering-based Measurement of Relevant Surface

Roughness, Sven Schröder1, Marcus Trost1, Luisa Coriand1,

Angela Dapprich2,3, Fraunhofer IOSB, Germany. Light scatter-
ing measurements are used to determine surface PSD func-

tions and application-specific roughness values in different re-
elvant spatial frequency ranges. A new method is presented

to cover area and investigations of the high-spatial frequency

roughness.

OTu1D.3 • 08:45

Apparent wave front aberration in the «Cat’s Eye» con-
figuration at high apertures, Hans-Martin Heuck1, Jakob

Weiser1, Joachim Heil1, Andreas Dorbach1; 1Optic Systems

Automation, Leica Microsystems CMS GmbH, Germany. With-
in the “Cat’s Eye” configuration the reflected phase depends on

the incident angle on the return mirror, particular for high NA

lenses. This phase-error is derived from Fresnel’s law and

compared with interferometric measurements.

OTu1D.4 • 09:00

Lateral resolution and instrument transfer function as
criteria for selecting surface metrology instruments, Xavier

Colomea De Lega1, Peter de Graaf1; Zygo Corporation, USA. We

review definitions of optical resolution and how they relate to

the Instrument Transfer Function of surface profiling

interferometers. The corresponding optical cutoff provides a

selection criterion for a given metrology application (PSD,

waviness).

08:00–10:00

RTu1E • Sensor Fusion and Lidar I

Christopher Parrish; NOAA, NGS, Remote

Sensing Div, USA, Presider

RTu1E.1 • 08:00

A Multi-Sensor Approach to Coastal Characterization,

Charles M. Bachmann1, Andrei Abelev1, William Plaut2,1,

C. Reid Nichols1,2, Geoffrey Smith1, Dan Korwan1, Joan

Gardner1, Mark Stetser1, Joseph A. Musser2, Robert A. Fossa1,2,

Michael Vermillion1,2, Christopher E. Parrish1, Yong-Kyoung

Lee4, Jun Sun3; 4US Naval Research Laboratory, USA; 5Univ.

of Miami, USA; 1US Department of Energy, USA; 2United

States Geological Survey, USA; 3Civil and Environmental

Engineering, Univ. of Houston, USA. An airborne LiDAR

system that integrates design characteristics of terrestrial

and bathymetric sensors to enable high-resolution mapping

of land and shallow bathymetry simultaneously is discussed.
We also present early test results and outline future work.

RTu1E.2 • 08:15

First Results From a High-Resolution Full Waveform

Airborne Bathymetric LiDAR System, Craig Glennie1, Wil-

liam L. Carter1, Ramesh L. Shrestha1; 1Civil and Environmental

Engineering, Univ. of Houston, USA.

RTu1E.3 • 08:45

Calibration of a Frequency Agile, Mixed Vapor-Aerosol

LiDAR, David Stoker1, Eunice Li1, Jan van der Laan1, Rusel

Warren1, Richard Vanderheuck2; SRI International, USA; 1EBRC,

USA; 2Ex-Stat, USA. We model LiDAR backscattering from

outdoor mixed vapor-aerosol (MVA) detonation tests and

show that we are able to correctly separate MVA components

into silica and TEP (tri-ethyl phosphate) using a novel aerosol

partitioning algorithm.

RTu1E.4 • 09:00

Withdrawn

08:00–10:00

STu1F • Temperature and Photonic Crystal Fiber Sensing

John Canning; Univ. of Sydney, Australia, Presider

STu1F.1 • 08:00

Withdrawn

STu1F.2 • 08:30

A Compact Temperature Sensor Based on Micrometric

Optical Fiber Coupler Tip, Ming Ding1, Pengfei Wang1,2,

Gilberto Brambilla3; 3Optoelectronics Research Centre, Univ.

of Southampton, UK; 1Photonics Research Centre, Dublin Institute

of Technology, Ireland. A compact temperature sensor based

on a coupler tip with micrometric size is demonstrated. This

sensor can measure a temperatures as high as 1283 oC with

an average sensitivity of -12 pm/oC.

STu1F.3 • 08:45

Double Cladding Fiber Interferometer Suitable for Mea-

suring Thermo-Optic Coefficient of Liquid, Young Ho Kim1,

Seoung Jun Park1, Chanki Lee1, Se-Jong Baik1, Byoung Ha Lee2;

1School of Information and Communications, Gwangju Institute

of Science and Technology, Republic of Korea; 2Department

of Physics /SJ Photonics Co., Ltd. Industry foundation of Chonnam

National Univ., Republic of Korea. A double cladding fiber

interferometer for obtaining the thermo-optic coefficient (TOC)

of liquid was demonstrated by simultaneously measuring the

refractive index and temperature. The TOC of water at 1550

nm was about -1.465 x 10^-4 RIU/degree.

STu1F.4 • 09:00

Temperature Monitoring of Bend Insensitive Fibers After

the Fuse Effect Propagation, Maria Domingues1,2, Ana Ro-

cha2, Paula S. Andre2,3, Ana Frias2, Maria Andre2,3; Instituto de

Telecomunicacoes, Portugal; 2Physics, Univ. of Aveiro, Portugal;

3CICECO, Univ. of Aveiro, Portugal. In this work we study

the thermal behavior of bend insensitive fibers after the fuse

effect. The region where the fuse effect has stopped reveals a

high burning risk for optical power above 1.0 W.
fabrication processes in industrial dispersions, where other optical techniques fail due to multiple light scattering. Fabrication of nanoemulsions as well as nano- and microparticles is discussed.

\[\text{... continued...}\]
Cypress 4
Applied Industrial Optics: Spectroscopy, Imaging, & Metrology

Cypress 3
Computational Optical Sensing and Imaging

Cypress 1 & 2
Imaging Systems and Applications

These concurrent sessions are grouped across two pages. Please review both pages for complete session information.

ATu2A • Micro-Optical Systems—Continued

CTu2B • Image Restoration—Continued

ITu2C • Hyperspectral Imaging—Continued

ATu2A.3 • 11:50 Invited
Novel Diffractive Gas Sensors, Ib-Rune Johansen1, Matthieu Lacolle1, Thor Bakke1, Håkon Sagberg2; 1Microsystems and Nanotechnology, SINTEF ICT, Norway; 2GasSecure, Norway. The functions of lenses, beam-splitters and band pass filters are integrated into a single surface hologram. Three different types of low cost micro-system spectrometers for gas detection have been developed, tested and industrialized.

CTu2B.3 • 11:30
Platform Motion Blur Image Restoration System, Stephen J. Olovair1, Michal Sorel2, Nima Nikzad1, Joseph Ford1; 1Univ. of California San Diego, USA; 2Heriot-Watt University, UK. We present a computational imaging system that incorporates an optical position sensing detector array, a conventional camera and a method to reconstruct images degraded by spatially variant platform motion blur.

ITu2C.3 • 11:15
Optimizing the Information Rate from Spectral Imagers in the Design Tradeoff between Resolution and Coregistration, Torbjørn Sand1; Norwegian Defence Research Establishment (FFI), Norway. Spatial coregistration errors limit the accuracy of multispectral and hyperspectral imaging. A new metric for these errors enables a quantitative tradeoff against resolution in spectral imager design. The performance optimization is expressed in information-theoretic terms.

ATu2A.4 • 11:50
Phase-Diverse Phase Retrieval of Undersampled Systems via Super-Resolution Pre-Processing, Eric A. Shields1; Sandia National Laboratories, USA. Super-resolution techniques are applied to undersampled imagery for application with phase diversity algorithms. Experimental results are shown for phase-diverse phase retrieval, but the algorithm is extendable to imaging as well.

CTu2B.4 • 11:45
Fabry-Perot Fourier-Transform Hyperspectral Imaging for High Efficiency Fluorescence Microscopy, Marco Pisani1; 1INRiM, Italy. A fluorescence microscope making use of a novel hyperspectral technology allows fast and simple multilabeled analysis without the need of selective band pass filters. Preliminary results obtained with q-dots fluorescent particles will be shown.

CTu28.A • 11:30–11:45
Platform Motion Blur Image Restoration System, Stephen J. Olovair1, Michal Sorel2, Nima Nikzad1, Joseph Ford1; 1Univ. of California San Diego, USA; 2Heriot-Watt University, UK. We present a computational imaging system that incorporates an optical position sensing detector array, a conventional camera and a method to reconstruct images degraded by spatially variant platform motion blur.

CTu28.B • 11:45–12:00
Phase-Diverse Phase Retrieval of Undersampled Systems via Super-Resolution Pre-Processing, Eric A. Shields1; Sandia National Laboratories, USA. Super-resolution techniques are applied to undersampled imagery for application with phase diversity algorithms. Experimental results are shown for phase-diverse phase retrieval, but the algorithm is extendable to imaging as well.

12:00–13:30 Lunch, on your own
OTu2D • Optical Testing II—Continued

OTu2D.3 • 11:15 OFAT Student Paper Contest Participant
Application of a Multiple Cavity Fabry-Perot Interferometer for Measuring the Thermal Expansion and Temperature Dependence of Refractive Index in New Gradient-Index Materials, Peter McCarthy, James Corsetti, Duncan T. Moore, Greg R. Schmidt; ‘The Institute of Optics, Univ. of Rochester, USA. A multiple cavity Fabry-Perot interferometer is used to measure thermal properties as a function of position. Homogeneous samples of ALON and PMMA, which have recently been used to create new gradient-index materials, are measured.

OTu2D.4 • 11:30
In-situ Testing of High Resolution Optical Systems via Localized Wavefront Curvature Sensing, Ryan Miyakawa1, Christopher N. Anderson1, Patrick P. Naulleau1; ‘Lawrence Berkeley National Laboratory, USA. We present a new form of optical testing based on measuring localized wavefront curvature. In this method a system of pseudo-sine gratings reveal the partial second derivatives of the wavefront at specific locations, and the wavefront aberrations are reconstructed using a least squares approach.

OTu2D.5 • 11:45
Objective Measurement of Scratch and Dig, Dave Aikens1,2; 1Savvy Optics Corp., USA; 2OEOSC, USA. Description of the meaning of scratch and dig specifications, and the methods available for validating optical components to a surface quality level. Particular attention is paid to objective measurement methods currently available, such as scatterometry.

RTu2E • Sensor Fusion and Lidar II—Continued

RTu2E.4 • 11:15 Invited
Combining Lidar Data and Hyperspectral Imagery for Coastal Engineering and Environmental Characterization, Joseph Harwood2, Christopher L. Macon2; ‘USA Army Corps of Engineers - SAM, USA, ‘Joint Airborne Lidar Bathymetry Technical Center of Expertise, USA. This paper discusses advanced lidar and hyperspectral data fusion techniques that enable the extraction of subaqueous bottom characterizations and their relationships to provide quantitative end user products.

RTu2E.5 • 11:45
In-situ Testing of High Resolution Optical Systems via Localized Wavefront Curvature Sensing, Ryan Miyakawa1, Christopher N. Anderson1, Patrick P. Naulleau1; ‘Lawrence Berkeley National Laboratory, USA. We present a new form of optical testing based on measuring localized wavefront curvature. In this method a system of pseudo-sine gratings reveal the partial second derivatives of the wavefront at specific locations, and the wavefront aberrations are reconstructed using a least squares approach.

STu2F • Gas and Voltage Sensing—Continued

STu2F.3 • 11:15
Fibre Microfabrication and Characterization for Gas Sensing, Eoin Sheridan1, Mohammad Amanzadeh1, Saied M. Aminossadati1, Mehmet S. Kizil2, Warwick P. Bowen1; ‘School of Mathematics and Physics, The Univ. of Queensland, Australia; ‘School of Mechanical and Mining Engineering, The Univ. of Queensland, Australia. Microchannels drilled in standard and hollow core optical fibres are studied using a novel probing technique that gives information about hole depth and interaction with fibre core. Application to gas sensing considered.

STu2F.4 • 11:30
Utilizing Optical Measurements to Characterize Metal Oxide Thin Films for Gas Sensing in Advanced Coal-Based Power Systems, Thomas D. Brown1, Paul Ohodnicki1; ‘US Department of Energy, National Energy Technology Laboratory PO Box 10940, USA. Results utilizing optical measurement techniques associated with hydrogen gas sensing of metal oxide-based films will be presented, and future work plans that fully leverage unique expertise and facilities available at NETL will be discussed.

STu2F.5 • 11:45
Optical High Voltage Sensor with Oil- and Gas-free Insulation, Sergio V. Marchese1, Stephan Wildermuth1, Olivier Steiger1, Joris Pasca1, Klaus Bohnert1, Giron Erikson1, Jan Czyzewski1; ‘Corporate Research, ABB Switzerland Ltd., Switzerland; ‘Corporate Research, ABB Sweden Ltd., Sweden; ‘Micafil, ABB Switzerland Ltd., Switzerland. We present an electro-optic high voltage sensor with novel oil- and gas-free insulation based on capacitive electric field steering. The sensor’s accuracy is within ±0.2% in a temperature range from -40 °C to +80 °C.
Imaging Systems and Applications

Tuesday, 26 June

13:30–15:00
Atu3A • Optical Systems for the Food Industry
Marion O’Farrell; SINTEF Norway, Presider

Atu3A.1 • 13:20
Invited
Automatic Sorting of Meat Cuts using NIR Interactance Imaging, Vadgar Segman1, Ingrid Måldal2, Martin Kerm7, Fredrik Bjørke3, Jens T. Thiele2; 1YoFood Division, Nofima AS, Norway; 2Tomas Sorting Solutions, Norway; 3SINTEF ICT T. Thielemann3, Jon Tschudi3, Jens P. Wold1; 1Food Division, Nofima Imaging and Applied Optics: OSA Optics & Photonics Congress • 24–28 June 2012

Atu3A.2 • 14:10
Invited
Low Cost Real-Time Sorting of In-Shell Pistachio Nuts from Kernels, Ron Hal1, Eric S. Jackson1; 1Agricultural Research Service, USDA, USA. A simple, low cost optical system for separating in-shell pistachio nuts and kernels is reported. Testing indicates 95% accuracy in removing kernels from the in-shell stream with no false positive results.

Atu3A.3 • 14:50
Invited
Dairy & Optics - Blurring the Boundaries, Chris Pandzian; 1Daisy Brand, USA. For decades, the food and especially the dairy industry has steered processes largely in manual control. In recent years, however, the emergence of affordable and reliable optics technologies has made a wide array of instrumentation available for automating operations and vastly improving product consistency.

13:30–15:00
Ctu3B • Comprehensive Imaging
Sudhakar Prasad; Univ. of New Mexico, USA, Presider

Ctu3B.1 • 13:30
Invited
Statistical Performance Bounds for Coded-Aperture Compressive Spectral-Polarimetric Imaging, Sudhakar Prasad1, Robert J. Plummer2, Qing Zhang1, David J. Brady1; 1Univ. of New Mexico, USA; 2Wike Forest Univ., USA, ‘Buke Univ., USA. We apply statistical information and Bayesian estimation theories to calculate certain fundamental bounds on the reconstruction of segment boundaries, material type, and surface texture of sparse objects from their coded-aperture, compressive spectral-polarimetric image data.

Ctu3B.2 • 14:00
Advances in the Design, Calibration and Use of a Static Coded Aperture Compressive Tracking and Imaging System, Phillip Poon1, Esteban Vera2, Michael E. Gehm3,4; 3College of Optical Sciences, Univ. of Arizona, USA; 4Department of Electrical and Computer Engineering, Univ. of Arizona, USA. We present our latest results in static compressive tracking and imaging. We have developed a design methodology using the compressed sensing concept of mutual coherence. We also elucidate a modified calibration scheme that boosts compressive imaging capabilities.

Ctu3B.3 • 14:15
Information Optimal Static Measurement Design for Compressive Imaging, Amit Ashok2, Mark Allen Neff3, James Huang2; 1Univ. of Arizona, USA. We present an information-theoretic framework for measurement basis design in compressive imaging. Simulation results show that the reconstruction error obtained with information-optimal projections is nearly an order of magnitude lower than that for random projections.

Ctu3B.4 • 14:30
Compressive Reflectance Field Acquisition using Confocal Imaging with Variable Coded Apertures, Ryosuke Hirose1, Tsuake Tanaka2, 1Osaka Univ., Japan. We propose a scheme for acquiring an eight-dimensional reflectance field based on compressive sensing. The reflectance field is modulated and observed multiple times with variable coded apertures. The proposed scheme was verified in numerical experiments.

Ctu3B.5 • 14:45
HoloCam: Low-power wide-field incoherent target detector, Sri Rama Prasanna Parvati1, Jonathan Hall1, Sergey Chemishkian1, 1Thayer School of Engineering, Dartmouth College, USA. The combination of a computer generated target hologram and a large-area detector leverages optical correlation with a novel single-pixel spot blur classifier to achieve low-power high-speed target detection with a wide-field-of-view in room light.

13:30–15:00
Thu3C • Phase Space in Imaging
John Sheridan; Univ. College Dublin Ireland, Presider

Thu3C.1 • 13:30
Invited
A Phase Space Tour of Optical Imaging, Markus E. Testorf; 1Prayer School of Engineering, Dartmouth College, USA. The phase-space instrument function is used to analyze optical systems. The Wigner distribution function and the ambiguity function of a lenslet array are constructed to interpret imaging systems as forms of phase-space tomography.

Thu3C.2 • 14:00
New Challenges for Sampling Theory for Linear Canonical Transforms in Optics, John J. Healy1; 1National Univ. of Ireland, Maynooth, Ireland. The linear canonical transforms are a popular model for the paraxial propagation of scalar wave fields through first order optical systems. We examine some new sampling problems arising at the boundaries of existing knowledge.

Thu3C.3 • 14:15
Invited
Generalized Wigner Functions in Classical Optics, Miguel A. Alonso1; 1The Institute of Optics, Univ. of Rochester, USA. We give a prescription for defining generalized Wigner functions that extend the property of conservation along paths to a wider range of problems, including nonparaxial field propagation and pulse propagation within general transparent dispersive media.

15:00–15:30
Exhibit Hall & Coffee Break, The Dolphins on the Upper Plaza

15:30–16:30
CTu3B.1 • 13:30
Invited
Statistical Performance Bounds for Coded-Aperture Compressive Spectral-Polarimetric Imaging, Sudhakar Prasad1, Robert J. Plummer2, Qing Zhang1, David J. Brady1; 1Univ. of New Mexico, USA; 2Wike Forest Univ., USA, ‘Buke Univ., USA. We apply statistical information and Bayesian estimation theories to calculate certain fundamental bounds on the reconstruction of segment boundaries, material type, and surface texture of sparse objects from their coded-aperture, compressive spectral-polarimetric image data.

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Exhibit Hall & Coffee Break, The Dolphins on the Upper Plaza
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13:30–15:00
OTu3D • Assembly, Alignment and Control
Weiyao Zou, ASML Optics LLC, USA, Presider

OTu3D.1 • 13:30 Invited
New Joining Technologies for High Stable and Smart Optical Systems, Ramona Eberhardt1, Gerhard Kalkowski2, Andreas Tümermann2, Erik Becker1, Steffen Böhme1; ‘Precision Engineering, Fraunhofer IOF, Germany. The presentation gives an overview about joining technologies for next generation optics. New concepts for polymer-free, precise and cost efficient manufacturing and assembly processes of modern optical sub-systems are illustrated.

OTu3D.2 • 14:00 Invited
Lab-on-a-chip Applications Enabled by Acousto-optofluidics, Xiaole Mao1,2, Tony Jun Huang1; The Pennsylvania State Univ., USA; P & G Mason Business Center, USA. In this work we discuss novel lab-on-a-chip applications such as liquid lens and on-chip cell detection and manipulation that are enabled by combining the principles of acoustics, optics, and microfluidics.

OTu3D.3 • 14:30 Invited
Mass Production of 100° Field of View Helmet Mounted Display, Paul Townley-Smith1; Zygo Corporation, USA. Production of a stereoscopic, see-through, wide field of view head mounted display presents many design, assembly and test challenges. Presented here are the strategies employed to overcome these challenges to enable mass production.

13:30–14:45
STu3F • Distributed and Acoustic Sensors
Gilberto Brambilla, Univ. of Southampton, USA, Presider

STu3F.1 • 13:30 Invited
Miniature Fiber Acoustic Sensors and Sensor Array Using Photonic-Crystal Membranes, Michel J. Digonnet1, Omar Alkaya1, Gordon Kino1, Olav Seliguard1; Stanford Univ., USA. We report a low-profile acoustic fiber sensor array incorporating ten miniature fiber Fabry-Perot acoustic sensors utilizing a reflective photonic-crystal diaphragm with exhibit high sensitivity, broad bandwidth, high thermal stability, and nearly identical operating wavelengths.

STu3F.2 • 14:00 Invited
Fiber Optic Distributed Sensing with Active Self-heating, Tong Chen1, Kevin P. Chui1, Qiongqiong Wang1, Botao Zhang1, Rongzhang Chen1; Electrical and Computer Engineering, Univ. of Pittsburgh, USA. We report distributed sensing with active control using self-heated optical fibers. The heat loss profile along the fiber is spatially interrogated with Rayleigh backscattering to perform gas flow, liquid level and hydrogen gas leakage measurements.

STu3F.3 • 14:30 Invited
Carrier Suppressed Modulation for Brillouin Gain Spectrum Analysis, Vemula Venkat Achuth1, Ramalakshmi Agasthi1, Deepa Venkatesh1, Balaji Srinivasan1; Electrical Engineering, Indian Institute of Technology Madras, India. We characterize the temperature dependent gain spectrum of Stimulated Brillouin scattering in an optical fiber by using a probe signal generated through carrier suppressed modulation. Probe amplification with pulsed pump is analyzed using these results.

15:00–15:30 Exhibit Hall & Coffee Break, The Dolphins on the Upper Plaza
Challenges and resolution approaches to harsh environment optical packaging will be discussed.

Renny A. Fields, David Hinkley; The Aerospace Corporation, USA.

Use of Cubesats, Rapid Low Cost Electro-Optic Prototyping for Space Through cutting edge COTS components and multiple missions to achieve mission assurance. Examples will be presented.

Donald B. Conkey, Antonio M. Caravaca-Aguirre, Rafael Piestun; University of Colorado, USA.

High-speed Focusing of Light through Dynamic Turbid Media, Focusing through Dynamic Disordered Media using a MEMS Spatial Light Modulator, Thomas Bifano, Christopher Stockbridge, Yang Liu, John Moore; Samuel Hoffman, Kimani Toussaint, Richard Pacament; Boston Univ., USA; University of Illinois, USA; Parvian Consulting, USA. Experiments demonstrating controlled optical propagation through a dynamic, highly scattering medium are described. The phase of a coherent beam is controlled both spatially and temporally using a reflective, 1020-segment MEMS spatial light modulator.

Jingshan Zhong, Justin Tudef; From Defocused Intensity Images, Low-complexity Noise-Resilient Recovery of Phase and Amplitude of an Object given a Single Pixel Measurement over a Range of Angles. We demonstrate an approach using nonlinear optimization, giving an example in two dimensions using Lambertian reflectance.

Computational Lightcurve Imaging, Keith J. Dillon, Yehia El Khoury; Computational Optical Sensing and Imaging, Univ. of California San Diego, USA. We consider lightcurve inversion, the reconstruction of an object given a single pixel measurement over a range of angles. We demonstrate an approach using nonlinear optimization, giving an example in two dimensions using Lambertian reflectance.

Ji-Seok Han, Jeong Wook, Hye Sung; University of Science and Technology, South Korea. We present a CMOS image sensor dedicated to lightning detection and imaging. The detector has been designed for the lightning detector pre-development phase of the European Space Agency Meteosat Third Generation Imager satellite.

Rafael Pietsun; University of Colorado, USA.

This talk will use a medical device as an example to discuss optical design considerations of polarization and fluorescence imaging systems.

Positive and Negative Results of Non-Adaptive Projective Visual Signal Sampling, Analysis of Linear Non-Adaptive Projective Visual Signal Sampling, Kshitij Marwah, Ashok Varasanghavan, Ramesh Rao; Media Lab, Massachusetts Institute of Technology, USA; Electrical Engineering, Rice Univ., USA. We present a first empirical analysis on the best sampling strategy, progressive or random for sensing unknown visual signals of which we can have no more than m linear, non-adaptive measurements.

Yang Lu, John Moore; Samuel Hoffman, Kimani Toussaint; Richard Pacament; Boston Univ., USA; University of Illinois, USA; Parvian Consulting, USA. Experiments demonstrating controlled optical propagation through a dynamic, highly scattering medium are described. The phase of a coherent beam is controlled both spatially and temporally using a reflective, 1020-segment MEMS spatial light modulator.

Edward H. Sargent; University of Washington, USA.

Quantum Dot Image Sensors, Quantum Dot Image Sensors, Edward H. Sargent; University of Toronto, Canada. Colloidal quantum dots are semiconductors synthesized in, and applied from, the solution phase. They enable wide tuning of their sharp spectral response via the quantum size effect. We will present advances in colloidal quantum dot light sensing materials and devices and their application in imaging.

Edward H. Sargent; University of Toronto, Canada.
These concurrent sessions are grouped across two pages. Please review both pages for complete session information.

**Point Lobos**

**Optical Fabrication and Testing**

**Carmel**

**Optical Sensors**

15:30–17:30

**OTu4D • Nanostructures and Films**

*Stephen Jacobs, Univ. of Rochester, USA, Presider*

**OTu4D.1 • 15:30**  
**Invited**

Glass Ductility and Fracture at the 50 to 100 - nm Scale, John C. Lambropoulos1, Karan Mehrotra2, Heather P. Howard1, Stephen Jacobs1; 1Department of Mechanical Engineering, Univ. of Rochester, USA; 2Laboratory for Laser Energetics, Univ. of Rochester, USA. We discuss the ductile-brittle transition in optical glass either as ductility occurring at a sufficiently low indenting load (or depth of cut) or nanoindentation of patterned surfaces with features in the range 50-250 nm.

**OTu4D.2 • 16:00**  
**Invited**

Optical Design with Gradient-Index Elements Constrained to Real Material Properties, Peter McCarthy1, Duncan T. Moore2; 1The Institute of Optics, Univ. of Rochester, USA; 2School of Laser Technology and Photonics, Institute of Science, Suranaree Univ. of Technology, Thailand. An approach for designing and optimizing optical systems with gradient-index elements constrained to real material properties is detailed. Any two-component GRIN system can be modeled with these tools, providing a way to explore new design spaces.

**OTu4D.3 • 16:15**  
**Invited**

Nondestructive Metrology of Layered Polymeric GRIN Materials Using Optical Coherence Tomography, Jianing Yao1, Panomsak Meeom1, Jannick P. Rolland1; 1The Institute of Optics, Univ. of Rochester, USA; 2School of Laser Technology and Photonics, Institute of Science, Suranaree Univ. of Technology, Thailand. Based on swept-source OCT technology, we investigated the unique capability of OCT for nondestructive three-dimensional characterization of the sub-surface textures and layer thickness profiles of layered polymeric GRIN samples in micrometer scale.

**OTu4D.4 • 16:30**  
**Withdrawn**

**OTu4D.5 • 16:45**  
**Invited**

Improved Modeling of Grid Structures on Optics: Transmission, Sheet Resistance and Diffraction Effects, Matthew W. Pieniat1, Ian B. Murray2, Doug Hibbard2; 1Exotic Electro-Optics, USA. Metallic grid layers are used for EMI-shielding and heating on aerospace windows and domes. The authors demonstrate the capability to accurately model the optical transmission, EMI attenuation and diffraction effects of such sub-mm-scale grid structures.

15:30–17:30

**STu4F • Micro and Nano-Engineered Sensors**

*Limin Tong, Zhejiang Univ. China, Presider*

**STu4F.1 • 15:30**  
**Invited**

Micro-engineered Optical Fiber Sensors Fabricated by Femtosecond Laser Micromachining, Dong Ning Wang1; 1Hong Kong Polytechnic Univ., Hong Kong. Micro-structures in optical fiber created by femtosecond laser micromachining can function as the sensing elements. Different types of micro-structures can be combined together in single optical fiber to perform multiple parameter measurement without ambiguity.

**STu4F.2 • 16:00**  
**Invited**

Waveguiding Polymer Single-Nanofibers for Optical Sensing, Fuxing Gu1; 1Optical Engineering, Zhejiang Univ., China. We report highly versatile nanosensors using polymer single nanofibers (PSNFs). Based on optical response of waveguiding PSNFs to specimens, gas and strain sensing are demonstrated with fast response and high-sensitivity.

**STu4F.3 • 16:30**  
**Invited**

Gas Detection with Micro and Nano-engineered Optical Fibers, Wei Jie1, Lifeng Qi2, Hoi Lut Ho1, Yingkun Cao1; 1Department of Electrical Engineering, Hong Kong Polytechnic Univ., Hong Kong. The prospects for realization of all-fiber gas sensors with hollow-core photonic bandgap fibers and tapered micro/nano optical fibers are investigated. Issues such as high background level and slow response time are discussed.
Transport of intensity imaging with TV regularization and nonlinear diffusion denoising, Lei Tian1, Jonathan Petruccelli1, George Barbastathis1,2; 1MIT, USA; 2Singapore-MIT Alliance for Research and Technology (SMART) Centre, Singapore. We quantify the effect of noise on phase retrieved using transport of intensity equation, and demonstrate the application of total variation regularization and non-linear diffusion techniques for improving the accuracy of the retrieved phase.

Three-Dimensional Kaleidoscopic Imaging, Ivo Ihrke1,2, Ilya Reshetouski1, Alkhazur Manakov1, Hans-Peter Seidel2; 1MMCI, Universität des Saarlandes, Germany; 2Computer Graphics, MPI Informatik, Germany. Planar mirror systems are capable of generating many virtual views, yet their practical use for multi-view imaging has been hindered by limiting configurations that enable view decomposition. In this work we lift those restrictions.

An ebCMOS camera system for Extreme Low Light Imaging, Remi Barbier2,1, Thomas Cajgfinger2, Agnes Dominjon1, Quang Tuyen Doan1; 1IN2P3 CNRS, France; 2IPNL, Univ. of Lyon, Univ Lyon 1, France. This paper is devoted to a Single-Photon Imaging system based on an electro-bombarded CMOS. A new Multiple-Target Tracking method is developed. The results on a Shack-Hartmann array for adaptive optics are presented as a proof of concept.
OTu4D • Nanostructures and Films—Continued

OTu4D.6 • 17:00 OFAT Student Paper Contest Participant
Monolithic, Low-index Guided-mode Resonance Filters: Fabrication and Simulation, Aaron Pung¹, Menelaos Poutous¹, Raymond Rump², Zachary Roth³, Eric Johnson¹; ¹Clemson Univ., USA; ²The Univ. of Texas at El Paso, USA; ³The Univ. of North Carolina at Charlotte, USA. This study presents a technique to fabricate monolithic, low-index guided-mode resonance filters by means of conventional photolithography. Linear and hexagonal grating geometries achieved narrowband resonance while demonstrating control over polarization dependence.

OTu4D.7 • 17:15
Multi-dielectric Structured Components for Giant Optical Field Enhancement: an Optimization Process, Cesaire Ndialaye¹, Myriam Zerrad¹, Fabien Lemarchand¹, Michel Leguime², Claude Amra²; ¹Institut Fresnel, France; ²Institut Fresnel, CNRS, France; ³Institut Fresnel, Universite Aix Marseille, France; ⁴Institut Fresnel, Ecole Centrale Marseille, France. Multiedielectric coatings are designed to reach total absorption and maximum field amplification at resonances. The design method is analytic, numerical results are given. Comparison with plasmons is detailed. Scattering behavior is investigated for amplification measurement.

Stu4F • Micro and Nano-Engineered Sensors—Continued

Stu4F.4 • 17:00
Self-Assembled Silica Microwire: A New Platform For Optical Sensing, Masood Naqshbandi¹, John Canning¹, Maxwell J. Crossley¹; ¹The Univ. of Sydney, Australia. We report a novel method of fabricating photonic silica microwires using room temperature self-assembly of silica nanoparticles. Rectangular slab microwires up to 7cm in length and 5-90μm in width have been made.

Stu4F.5 • 17:15
Cavity Optomechanical Magnetometer, Eoin Sheridan¹, Stefan Forstner¹, Joachim Knittel¹, Halina Rubinsztein-Dunlop¹, Warwick P. Bowen¹; ¹School of Mathematics and Physics, The Univ. of Queensland, Australia. We demonstrate a cavity optomechanical magnetometer where the magnetic-field induced expansion of a magnetostrictive material is transduced onto a highly-compliant optical microresonator. The resulting motion is read out optically with nanoTesla per root Hertz sensitivity.
Joint Poster Session

17:30–19:00

**JTu5A.1**
Collaborative work within Optical Engineering: Ethnography and curriculum development, Donna M. Lanoix1, Angela M. Ferrara1, Matthew A. Davies1, Chris J. Evans2, Thomas J. Suleski2; *Univ. of North Carolina at Charlotte, USA*. Ethnographic research is used to reveal the nature of collaborative optical engineering work between team members of different backgrounds. Observations in an academic environment are combined data derived from interviews with industry professionals.

**JTu5A.2**
**UFF Belt Characterization**, Philip Katz1, Timothy Lynch1, Alexander Magill1, Jakob Maag-Tanchack1, Jonathan D. Ellis12; **Department of Mechanical Engineering, Univ. of Rochester, USA**; **Institute of Optics, Univ. of Rochester, USA**. Research was conducted on the belts used in Optipho’s UltraForm Finishing (UFF) system to better understand the fundamental mechanics of wear and material removal rates during belt polishing.

**JTu5A.3**
Nano-Structured Optics for Surface Metrology Research at the National Institute of Standards and Technology, Uli Griesmann1, Quandou Wang1, Johannes Soons1; **NIST**, USA. Metrology holograms are critical for interferometric testing of precision aspheric and free-form surfaces with low uncertainty. We describe a new facility for fabrication and research of metrology holograms at NIST.

**JTu5A.4**
Step-height measurement by low-coherence interferometry based on wavelet transform, Takamasa Suzuki1, Satoishi Ai1, Osami Sasaki2, Samuel Choi; **Graduate School of Science and Technology, Niigata Univ., Japan**; **Faculty of Engineering, Niigata Univ., Japan**. This study proposes low-coherence interferometry based on wavelet transform. This method can simultaneously detect the peak position and frequency of a signal. The use of this method for step-height measurement is demonstrated.

**JTu5A.5**
Withdrawn

**JTu5A.6**
Optical Testing Applied to a 6.5-Meter Mirror, Rafael Izazaga1, Fermin S. Granados-Agudis1, Ma. Elizabeth Perez-Carrasco1, Enrequired Carrasco-Licea1; **Instituto Nacional de Astrofisica, Optica y Electronica, INAOE, Mexico**. We present an optical testing method for the fabrication of a hyperbolic mirror of 6.5-m diameter using a small aperture interferometer. A comic that best fits an off-axis conic section of the mirror is analyzed in order to implement an optical testing method by using sub-apertures.

**JTu5A.7**
Model For Frictional Forces to Reproduce the Dragging Forces in the Polishing Process, Jorge Gonzalez-Garcia1, Alberto Cordero-Davila1, Rafael Izazaga1; **Instituto de Fisica y Matematicas, Universidad Tecnologica de la Mixteca UTM, Mexico**; **Facultad de Ciencias Fisico Matematicas, Benemérita Universidad Autonoma de Puebla Buap, Mexico**; **Posgrado de Optica, Instituto Nacional de Astrofisica, Optica y Electronica, INAOE, Mexico**. Dragging forces exerted on a fixed Table top for several relative velocities of the tool center and polisher densities were measured. Therefore a model for frictional forces that reproduces the dragging forces results is described.

**JTu5A.8**
**OSA Student Paper Contest Participant**
Modernizing and Unification of Optical and Mechanical Constructions of Micro-objects, Alexey Frolov1, Sryatsoval M. Latyev1, Alexey G. Tabachkov2, Dmitiry N. Frolov3, Olga A. Vino-gradova1; **NRU ITMO, Russian Federation**; **Labor-Microscopes, Russian Federation**. Microobjective is one of the main and most principal functional units of the microscope. A variety of methods and techniques work for the microscope determines demand for a wide range of lenses with different characteristics.

**JTu5A.9**
Precision Glass Molding of Lenses by using the Nanotech Molding Process - A Practical Summary, Michael Fuch1, Rolf Rascher1, Alois Kaisberger1, Christian Wistl1; **Univ. of applied science Deggendorf, Germany**. Practical review of precision glass molding in usage of the nanotech gpm process for aspheres with form accuracy lower than 1 micron.

**JTu5A.10**
Quality assessment of precision optical surfaces through light scattering techniques, Sven Schroder1, Alexander von Finck1, Tobias Herfurth1, Angela Duppa1; **Fraunhofer IOE, Germany**. Scattering methods are extremely capable for the characterization of optical surfaces. This will be demonstrated for different applications ranging from anisotropic diamond-turned surfaces to polished surfaces exhibiting defects.

**JTu5A.11**
**OSAT Student Paper Contest Participant**
Birefringence Dispersion Measured by Low-coherence Spectral Interferometry Using a Spectrophotometer, Zhizhao Han1, Lei Chen1, Zhu Xue1; **School of Electronic and Optical Engineering, Nanjing Univ. of Science and Technology, China**; **Department of Chemistry & Biochemistry, Univ. of Missouri-St. Louis, USA**; **Center for Nanoscience, Univ. of Missouri-St. Louis, USA**. Transmittance spectral interferograms were obtained to understand the birefringence dispersion of quartz crystal with fast axis orientation unknown. The interferograms have uniform background and modulation and were taken with 0.5 nm spectral resolution.

**JTu5A.12**
**OSAT Student Paper Contest Participant**
Physical, Structural, and Optical Changes in Infrared Glasses as Prepared by Precision Glass Molding (PGM), Bens Gleason1, Peter Wach1, J. David Musgraves1, Kathleen A. Richardson1; **COMSET - Clemson Univ., USA**. The physical, structural, and optical properties of Schott IGS were quantified and compared prior to and following precision glass molding.

**JTu5A.13**
Applying Ronchi test to evaluate local and global surface errors without both approximations and integration, Alberto Cordero-Davila1, Juan A Rosauro Kanitum-Mondiel1, Jorge Gonzalez-Garcia1; **Instituto de Fisica y Matematicas, Universidad Tecnologica de la Mixteca UTM, Mexico**; **Facultad de Ciencias Fisico Matematicas, Benemérita Universidad Autonoma de Puebla BUAP, Mexico**. A new method to evaluate local and global errors on freeform surfaces is reported. The experimental bimorphgram image is reproduced by simulating bimorphgrams images. We do not use fringe interference orders neither any integration methods.

**JTu5A.14**
**LANDSAFE** Precision Flight Instrumentation System, Pri Mamipudi1, Elizabeth Dakin1, Daniel Dakin1; **Optical Air Data Systems, USA**. Helicopter hover and landing in dust, fog, rain, and high winds is an integral part of military & commercial flight operations. This paper presents capabilities and flight-test results of a standalone Ladar Precision Flight Instrumentation System.

**JTu5A.15**
 Intracavity Terrace赫上 Optical Parameter Oscillator for Stand-off Spectroscopy Applications, Nils Hempler1, Keith Ruxton1, Gordon Robertson1; **Centre for Spectroscopy Applications, NISTy, USA**. The Dolphins on the Upper Plaza

**JTu5A.16**
Withdrawn

**JTu5A.17**
Polarization Sensitivity Allows Novel Sensing Opportunities in Terahertz Time-Domain Spectroscopy, Enrique Castro Camus1; **Centro de Investigaciones en Optica AC, Mexico**. The introduction of novel polarization-sensitive photoconductive sensors has considerably broadened the information that can be obtained in single-scan time-domain spectroscopy measurements.

**JTu5A.18**
Morphological Analysis of Bovine Sperm Head in Quantitative Evaluation of the Physical, Structural, and Optical Changes in Infrared Glasses as Prepared by Precision Glass Molding (PGM), Bens Gleason1, Peter Wach1, J. David Musgraves1, Kathleen A. Richardson1; **COMSET - Clemson Univ., USA**; **Instituto de Fisica y Matematicas, Universidad Tecnologica de la Mixteca UTM, Mexico**; **Facultad de Ciencias Fisico Matematicas, Benemérita Universidad Autonoma de Puebla BUAP, Mexico**. A practical review of precision glass molding in usage of the nanotech gpm process for aspheres with form accuracy lower than 1 micron.

**JTu5A.19**
Measurement and Analysis for Biological Tissue from a Ring-scanning-based NIR Optical Imaging System, Min-Cheng Pan1, Liang-Yu Chen1, Hao-Ming Yu1, Hung-Chih Chiang1, Jang-Jhong Cao1, Min-Chun Pan1, Shen-Hsiin Sun1, Chia-Cheng Chou1, Ya-Fen Hung1; **Department of Electronic Engineering, Tung-Nan Univ., Taiwan**; **Department of Mechanical Engineering, National Central Univ., Taiwan**; **Tao-Yuan General Hospital National Central Univ., Taiwan**; **Department of Surgery, Landseed Hospital, Taiwan**. System verification and the reconstructed optical property images of breast-like phantoms and biological tissue are presented using a ring-scanning-based imaging system of frequency-domain near infrared diffuse optical tomography with a high degree of spatial flexibility.

**JTu5A.20**
Radial Slope Measurement of Transparent Samples, David Ignacio Serrano-Garcia1, Noel-Iván Toto-Arellano1, Gustavo Rodriguez-Zurita1, Facultad de Ciencias Fisico-Matematicas, Benemerita Universidad Autonoma de Puebla, Mexico; **Instituto de Investigaciones en Optica, A.C., Mexico**. An method to measure the radial slope of transparent samples is presented. We have implemented a Mach-Zehnder Radial Shear interferometer. The experimental results are presented, as well as the experimental evidence for the generation of spirals.

**JTu5A.21**
Design and Comparison for a Ring-scanning-based NIR Optical Imaging System, Jiao-Ming Yu1, Liang-Yu Chen1, Min-Chun Pan1, Hung-Chih Chiang1, Min-Cheng Pan1, Shen-Hsiin Sun1, Chia-Cheng Chou1, Ya-Fen Hung1; **Department of Mechanical Engineering, National Central Univ., Taiwan**; **Department of Electronic Engineering, Tung-Nan Univ., Taiwan**; **Tao-Yuan General Hospital, Taiwan**; **Department of Surgery, Landseed Hospital, Taiwan**. Comparison is made among several different imaging configurations in order to evaluate how the source-and-detector arrangement affects the resulting image. Results show that the ZIS design is the optimal design for the scanning mechanism.

**JTu5A.22**
Simulator in Augmented Reality Environment for Natural Interaction for Assembling Electrical Equipment, Nelson Sosa Macmahon1, Electronic, OSA INAOE, Mexico.

**JTu5A.23**
An Estimation Theoretic Framework for Structured Illumination Microscopy, David Stoker1, Erik Mallin1; **SRI International, USA**. We consider an estimation theory for a structured illumination microscopy (SIM). Simulation results suggest that SIM can be made less susceptible to noise and illumination modulation error.
**The Dolphins on the Upper Plaza**

**Joint Poster Session**

**JTu5A • Joint Poster Session—Continued**

- **JTu5A.24**
  - **Ringing Reduction for Radially Restored Images**, Yupeng Zhang, Toshiyuki Ueda; Graduate school of information, production and systems, Waseda Univ., Japan. This paper demonstrates a ringing reduction method for radially restored images, whose blurred versions are produced by a spherical single lens imaging system (SSLIS) embedded in an experimental camera module.

- **JTu5A.25**
  - **Quasi-optical Terahertz Devices**, Benedikt Scherger, Martin Koch; Philipp University Marburg, Germany. We present a collection of new low-cost quasi-optical terahertz (THz) devices. Including wave plates made from ordinary copy paper, lenses made from micro powders and liquid filled lenses with variable focus length.

- **JTu5A.26**
  - **Parallel Shot Noise Reduction of Phase Reconstruction in Digital Holographic Microscopy**, Bryan Hennelly; Department of Computer Science, NUIM, Ireland. Digital Holographic Microscopy enables capture of quantitative phase images. With low exposure time the phase is significantly affected with a noise preventing efficient unwrapping. We demonstrate an algorithm to reduce this noise in the phase image.

- **JTu5A.27**
  - **A High Magnification Light Field Telescope for Extended Depth-of-Field Biometric Imaging**, David Stoker, Jonathan Wedd; Of-Field Biometric Imaging, A High Magnification Light-Field Telescope for Extended Depth-JTu5A.27. We demonstrate an algorithm to reduce this noise in the phase image.

- **JTu5A.28**
  - **Parallel Shot Noise Reduction of Phase Reconstruction in Digital Holographic Microscopy**, Bryan Hennelly; Department of Computer Science, NUIM, Ireland. Digital Holographic Microscopy enables capture of quantitative phase images. With low exposure time the phase is significantly affected with a noise preventing efficient unwrapping. We demonstrate an algorithm to reduce this noise in the phase image.

- **JTu5A.29**
  - **Improving Layered 3D Displays with a Lens**, Stefan Muenzel, Jason W. Fleischer; Princeton Univ., USA. We enhance layered 3D displays using a lens placed in front of or in between attenuation layers, which improves resolution or field-of-view of the display. In addition, we significantly reduce memory requirements for layer calculations.

- **JTu5A.30**
  - **3-Point LPG with High Temperature Sensitivity**, Paulo Lopes; Physics, Universidade de AVEIRO, Portugal. We report the fabrication of 3-point only Long Period Gratings (LPG) with a CO2 Laser. Using a high precision translational system, short LPG are obtained, while keeping good sensing parameters: 30dB peak loss and sensitivity of 109 pm/°C.

- **JTu5A.31**
  - **Improving Layered 3D Displays with a Lens**, Stefan Muenzel, Jason W. Fleischer; Princeton Univ., USA. We enhance layered 3D displays using a lens placed in front of or in between attenuation layers, which improves resolution or field-of-view of the display. In addition, we significantly reduce memory requirements for layer calculations.

- **JTu5A.32**
  - **3-Point LPG with High Temperature Sensitivity**, Paulo Lopes; Physics, Universidade de AVEIRO, Portugal. We report the fabrication of 3-point only Long Period Gratings (LPG) with a CO2 Laser. Using a high precision translational system, short LPG are obtained, while keeping good sensing parameters: 30dB peak loss and sensitivity of 109 pm/°C.

- **JTu5A.33**
  - **Improving Layered 3D Displays with a Lens**, Stefan Muenzel, Jason W. Fleischer; Princeton Univ., USA. We enhance layered 3D displays using a lens placed in front of or in between attenuation layers, which improves resolution or field-of-view of the display. In addition, we significantly reduce memory requirements for layer calculations.

- **JTu5A.34**
  - **Spectral Models of Non-optical Water Quality Parameters of Urban Lakes: A case Study in Guangzhou, China**, Xiaohui Chen, Shuisen Chen, Yongxian Su, Dan Li, Weiqi Chen, Liusheng Han; Guangzhou Institute of Geography, China; Graduate School of Chinese Academy of Sciences, China; Department of Geography, Oklahoma State University, USA; College of Earth, Ocean and Atmosphere Sciences, Oregon State University, USA. Derivative indices may be successfully applied to estimate concentrations of optical water constituents from remotely sensed data. Reflectance, spectral derivative and spectral ratio technologies are used to evaluate the potentiality of developing spectral models for the prediction of three water quality parameters. Results indicate that derivative spectra and spectral ratio are more effective in simulating pH, NH4-N concentrations and DO than original reflectance. Multiple bands combination models of first-derivative spectra and second-derivative spectra can greatly improve NH4-N simulation accuracies. Comparison with derivative spectra, spectral ratio models are much simpler methods to derive pH, NH4-N and DO while not losing of the simulation accuracies.
08:00–10:00 JW1A • Resolution Limits & Spectral Imaging (IS & COSI)
Kathrin Berkner; Ricoh Innovations, Inc., USA & Michael Gehm; Univ. of Arizona, USA, Presiders

JW1A.1 • 08:00 Invited
Overcoming the Classical Limits Imposed by Diffraction and Multiple-scattering via Computational Optical Imaging, Rafael Piestun; 1Univ. of Colorado, USA. Imaging beyond the resolution limit with subwavelength resolution as well as imaging through strongly scattering media have been recently accomplished overcoming classical limitations. These techniques share the need for wavefront engineering/modulation and matched algorithms.

JW1A.2 • 08:30
Some Topics in Quantum Imaging, Mikhail I. Kolobov1,2; 1Mathematics, Stanford Univ., USA; 2Laboratoire PHLAM, Université Lille 1, France. This talk will give an overview of quantum imaging which investigates ultimate performance limits in optical imaging imposed by the quantum nature of the light. I will discuss several topics of quantum imaging such as noiseless image amplification, quantum limits of super-resolution, etc.

JW1A.3 • 08:45
System Model and Performance Evaluation of Spectrally Coded Plenoptic Camera, Lingfei Meng1, Kathrin Berkner2; 1Ricoh Innovations, Inc., USA, 2Univ. of Arizona, USA. We introduce an end-to-end imaging system model for a spectrally coded plenoptic camera. The model includes a system-dependent spectral demultiplexing algorithm and is used to evaluate spectral quality and classification performance of a spectrally coded plenoptic camera.

JW1A.4 • 09:00 Invited
Field Distribution Techniques for Multi-Dimensional Snapshot Imaging, Tomasz Tkaczyk1; 1Rice Univ., USA. Imaging techniques e.g. field slicing and mapping, pinhole or lens field arrays to rapidly acquire multi-dimensional data are discussed. They allow recording and display of spectral, polarization or 3D spatial information in a snapshot mode.

JW1A.5 • 09:30
Random-access Spectral Imaging, Patrick Kelleher1, Andrew R. Harvey2; 1School of Physics and Astronomy, Univ. of Glasgow, UK. Real-time high resolution spectral imaging is prevented by various bottlenecks in data acquisition and processing. Discussed here is a prototype instrument based on a random-access approach to data collection that circumvents these limitations.

JW1A.6 • 09:45
Low-cost multi-spectral imaging camera array, James Downing1, Andrew A. Murray1, Andrew R. Harvey2; 1Imaging, STMicroelectronics, UK; 2Physics and Astronomy, Glasgow Univ., UK. Snap-shot multi-spectral imagers remain prohibitively expensive for many applications. A 5x5 array of miniature, low-cost camera modules record discrete spectral bands from which, with aid of calibration, a co-registered spectral data-cube may be reconstructed.

08:00–10:00 AW1B • Energy and Applied Optics
Sean Christian; Weatherford International Ltd, USA, Presider

AW1B.1 • 08:00 Invited
A Real-time Gas Cloud Imaging Camera for Fugitive Emission Detection and Monitoring, Robert T. Kester1; 1Rebellion Photonics, Inc., USA. Rebellion Photonics has developed a new snapshot spectral imaging technology for continuous monitoring of fugitive gas emissions. Its advantages include elimination of motion artifacts due to gas plume movement, high sensitivity, and low maintenance.

AW1B.2 • 08:40 Invited
Rapid Determination of Hydrocarbon Reservoir Quality Properties at the Wellsite by Energy Dispersive X-ray Fluorescence Spectroscopy (ED-XRF), Christopher Smith1; 1Weatherford International Ltd, USA. Elemental analysis of reservoir cuttings can be obtained by ED-XRF in near real-time during oil and gas drilling. Elemental data can be used in stochastic models to predict lithology, mineralogy and brittleness of the reservoir formations.

AW1B.3 • 09:20 Invited
Wireless Infrared Gas Sensor, Håkon Sagberg1, Britta Fismen1, Knut Sandven1, Pål Nordbrynh1, Niels Aakvaag1, Lars Borgen1, Jon Tschudi2, Kari Anne Bakke2, Ib-Rune Johansen2; 1GasSecure, Norway; 2SINTEF, Norway. Infrared hydrocarbon gas detectors are essential for safety, but the requirement for cabled power complicates installation. A new low-power optical design based on a micro-opto-electromechanical system gives reliable battery operation over several years.

10:00–10:30 Exhibit Hall & Coffee Break, The Dolphins on the Upper Plaza
These concurrent sessions are grouped across two pages. Please review both pages for complete session information.
These concurrent sessions are grouped across two pages. Please review both pages for complete session information.

**Cypress 1 & 2**

**Joint AIO & SENSORS**

**Imaging Systems and Applications**

**Wednesday, 27 June**

10:30–12:15
**JW2A • Sensing with Optical Fiber (AIO & SENSORS)**  
**Hans-Peter Loock; Queen's Univ., Canada, Presider**

**JW2A.1 • 10:30**  
Fiber-coupled Fluorescence and Absorption Spectroscopy for Oil and Fuel Characterization, Hengameh Omrani1,2; Alexander Dudelzak1; Hans-Peter Loock1; 1Chemistry, Queen's Univ., Canada; 2GasTOPS Ltd., Canada. We combined two fiber-optic techniques to permit real-time monitoring of machinery fluids. Excitation emission matrix spectroscopy and fiber-loop cavity ring-down absorption spectroscopy were used to characterize jet fuel and aero-turbine lubrication oil.

**JW2A.2 • 10:50**  
Optical Fibre Chemical Sensors for Process and Environmental Monitoring, Antoine Proulx1; Serge Caron1, Claude Paré1, Sébastien Dubuis1, Noëwren Le Bouché1, Patrick Paradis1, Charla Meneghini1, Pierre Galerneau1; 1INO, Canada. Ion-selective optodes offer potential for in-line monitoring of various processes. Fibre sensors were developed for H+, Ca2+, K+, Na+, NH4+ and NO3-. Applications in hydroponic culture optimization, soil characterization and anaerobic digester process control were demonstrated.

12:00–13:30  
**Lunch, on your own**

**Cypress 3**

**Imaging Systems and Applications**

10:30–12:00
**IW2B • Digital Imaging**  
**Francisco Imai; Canon USA, Inc., USA, Presider**

**IW2B.1 • 10:30**  
Invited  
Image Chain Modeling and Applications, Robert D. Fiete1; 1ITT Exelis Geospatial Systems, USA. Modeling the imaging chain of digital cameras is necessary to relate the camera design parameters to the resulting image quality. Applications include designing cameras to meet image quality requirements as well as identifying fake images.

**IW2B.2 • 11:00**  
Pixel Count Wars Revisited, Michael A. Krisa1; 1MAK Consultants, USA. This paper explores why larger pixels and sensors are key to the future of DSCs. It also looks at how aliasing artifacts are created as a function of the relationship between the optical spread function of the lens, the pixel size and the presence of a color filter array.

**IW2B.3 • 11:15**  
Invited  
A Critical Review of the Slanted-edge Method for Color SFR Measurement, Prasanna V. Rangarajan1, Indrulal Sinharoy1, Marc F. Christensen1, Predrag Milojkovic2; 1Southern Methodist Univ., USA; 2US Army Research Laboratory, USA. Critical examination of the slanted-edge method for color SFR measurement reveals inaccuracies in the estimated SFR, due to the use of demosaicing. The proposed method resolves these inaccuracies by eliminating the need for demosaicing during SFR measurement.

**IW2B.4 • 11:30**  
Color Imaging for Mobile Displays, Ricardo J. Metta1; 1NVIDIA Corporation, USA. We will discuss how changes in technology and viewing conditions require new thinking about color encoding and image processing for mobile displays.
10:30–12:00
OW2D • Freeform Optics
Matthew Jenkins; Raytheon Company, USA, Presider

10:30–12:00
CW2C • COSI Postdeadline Paper Session

OW2D.1 • 10:30 Invited
Freeforms about to Lift Off - Standardization of Freeform Optics, Sven Kiontke1; Asphericon, Germany. With growing demands in optics the complexity of optical surfaces is increasing. Together with the world wide optical marked we depend on understanding technically definitions and descriptions internationally. Standardization for freeforms is a important tool and it helps to remain competitive.

OW2D.2 • 11:00 OF&T Student Paper Contest Participant
Interferometric Null Configurations for Measuring φ - polynomial Surfaces, Kyle Fuerschbach1, Kevin F. Thompson1, Jannick P. Rolland1; The Institute of Optics, Univ. of Rochester, USA; Synopsys Inc., USA. Interferometric null configurations are presented for measuring the form error of two nonsymmetric, Zernike polynomial based optical surfaces designed for use in an off-axis, reflective imaging system.

OW2D.3 • 11:15 Withdrawn.

OW2D.4 • 11:30 Invited
Diamond Machining of Freeform Infrared Optics, Thomas J. Suleski1, Matthew A. Davies2, Brian S. Dutterer2; Physics and Optical Science, Univ. of North Carolina at Charlotte, USA; Mechanical Engineering and Engineering Science, Univ. of North Carolina at Charlotte, USA. We discuss the application of diamond machining to the fabrication of freeform infrared optical components and structures. Fabrication approaches, challenges, and experimental results are presented for several novel optical designs.

12:00–13:30 Lunch, on your own
13:30–15:30  
**JW3A • Computational Imaging Sensors (COSI & IS)**  
David Brady; Duke Univ., USA & Gisele Bennett; Georgia Tech, USA, Presiders  

**JW3A.1 • 13:30 Invited**  
Validation and Clinical Deployment of a Spatial Frequency Domain Imaging (SFDI) System for Wide-field, Quantitative Subsurface Analysis of Tissue Health, David J. Cuccia1; ‘Modulated Imaging Inc., USA. We present instrument validation and clinical results using a novel spatial frequency domain imaging system, which utilizes structured light projection and wide-field camera detection for quantifying subsurface, spatially-resolved tissue scattering and absorption properties and chromophores.

**JW3A.2 • 14:00 Invited**  
Combining Digital Holographic Microscopy with Optical Manipulation: A New Tool in Biomicrofluidics, Pietro Ferraro1, L. Miccio1, P. Memmolo1, M. Patruno1, F. Merola1; ‘Istituto Nazionale di Ottica Applicata, Italy. Here we show a completely new concept of a compact holographic microscope can ensure the multi-functionality by accomplishing be the same configuration, trapping, manipulation, quantitative phase-contrast maps and accurate 3D tracking in microfluidic environment.

**JW3A.3 • 14:30 Invited**  
Scaling Properties of Well-Tiled PFCAs, Patrick Gill1, Alyosha C. Mobare1; ‘Univ. of Toronto, Canada; 2Cornell Univ., USA. Planar Fourier Capture Arrays (PFCAs) are imaging devices made from unmodified CMOS Angle-Sensitive Pixels (ASPs). PFCAs require no external imaging optics to photograph distant objects. Here, we explore PFCAs miniaturization in two analyses. First, we show an efficient method of tiling Fourier space with ASPs. Second, we show that the area of an optimally-tiled PFCA scales as the square of the effective number of pixels.

**JW3A.4 • 15:00**  
Challenges in Gigapixel Multiscale Image Formation, Dathon R. Golish1, Esteban Vera1, Kevin Kelly2, Qian Gong1, Peter Iansiti1, John Hughes1, David S. Kittle3, David J. Brady3, Michael E. Gehm1,2; ‘Department of Electrical and Computer Engineering, Univ. of Arizona, USA; ‘College of Optical Sciences, Univ. of Arizona, USA; ‘Department of Electrical and Computer Engineering, Duke Univ., USA. We present new results from the image formation team on the AWARE Wide-Field project. We will report on new strategies prompted by new challenges encountered in experiments with two prototype AWARE Wide-Field systems.

**JW3A.5 • 15:15**  
CoDAC: Compressive Depth Acquisition using a Single Time-resolved Sensor, Ahmed Kirmani1, Andrea Colaco1, Franco N. C. Wong1, Vivek K. Goyal1; ‘EE, MIT, USA. We present a method for compressive acquisition of scene depth with high spatial and range resolution using a single, omnidirectional, time-resolved photodetector and no scanning components by applying novel signal processing to time-of-flight imaging.

**JW3A.5 • 15:30**  
Challenges in Gigapixel Multiscale Image Formation, Dathon R. Golish1, Esteban Vera1, Kevin Kelly2, Qian Gong1, Peter Iansiti1, John Hughes1, David S. Kittle3, David J. Brady3, Michael E. Gehm1,2; ‘Department of Electrical and Computer Engineering, Univ. of Arizona, USA; ‘College of Optical Sciences, Univ. of Arizona, USA; ‘Department of Electrical and Computer Engineering, Duke Univ., USA. We present new results from the image formation team on the AWARE Wide-Field project. We will report on new strategies prompted by new challenges encountered in experiments with two prototype AWARE Wide-Field systems.

**AW3B • What’s next in Applied Imaging**  
Sapna Shroff; Ricoh Innovations, Inc., USA, Presider  

**AW3B.1 • 13:30 Invited**  
Structured Light Optical Super-Resolution: Encoding for Limited Optical Bandwidth, Marc P. Christensen1, Prasanna V. Rangarajan1, Indrumi Sinharoy1, Predrag Milojkovic2; ‘Department of Electrical Engineering, Southern Methodist Univ., USA; ‘Army Research Laboratory, USA. Structured illumination finds widespread use in microscopy and optical profilometry. A marriage of the principle underlying these methods promises novel solutions to the resolution problem that plagues consumer cameras.

**AW3B.2 • 14:10 Invited**  
Use of Hyperspectral Imaging for Pharmaceutical Formulation Development, Gabor Kemeny1, Gina Stuessy1; ‘Middleton Research, USA. Push-broom hyperspectral imaging based in-situ pharmaceutical blend monitor was developed to aid solid formulation development. Aggregates of the API or excipients are identified using chemometrics and can be monitored with 30 um spatial resolution.

15:30–16:00  
**Exhibit Hall & Coffee Break, The Dolphins on the Upper Plaza**
Terahertz Excitation of Three-level Λ-Type Exciton-Polariton Modes in Quantum-Well Microcavities

Daniel Marks, David J. Brady; 1Army AMRDEC WSD, USA; 2Duke Univ., USA.

Ethan Minot, Yun-Shik Lee; 1Oregon State Univ., USA; 2AIXTRON Ltd., UK; 3Physics and Applied Physics, Univ. of Massachusetts, USA.

THz responses from closely packed, vertically grown CNTs. Non-negligible conductivity in a direction normal to the CNT axis indicates carrier transport between adjacent CNTs.

Terahertz Ellipsometry of Vertically Grown Carbon Nanotubes, Michael J. Paul, Nicholas Khabat, Joseph L. Tomason, Tal Sharf, Nalin Ragupathi, Kenneth Tez, Viktor Podolsky, Ethan Minot, Yun-Shik Lee; 1Oregon State Univ., USA; 2AIXTRON Ltd., UK; 3Physics and Applied Physics, Univ. of Massachusetts, USA. THz ellipsometry with broadband THz pulses reveals anisotropic THz responses from closely packed, vertically grown CNTs. Non-negligible conductivity in a direction normal to the CNT axis indicates carrier transport between adjacent CNTs.

Coherent Terahertz Holographic and Tomographic Imaging, Henry O. Everitt, Martin Hohenbeek, Daniel Marks, David J. Brady; 1Army AMRDEC WSD, USA; 2Duke Univ., USA. This talk will survey the application of digital holographic and tomographic techniques to highly coherent, single frequency terahertz sources and extremely sensitive heterodyne receivers for high resolution three dimensional reconstructions of extended, visibly opaque objects.

Light-weighting, Polishing, Bonding and Testing for the SEOSAT/Ingenio Telescope Mirrors, Emmanuel Hugot, Johan Floriot, Nicolas Roussellet, Marc Ferrat, Marie Laslandes, Sébastien Vivès, Anais Bernard, Gérard Lemaitre; 1CNRS/CEA, 2Centre d’Études et de Recherche en Optique et Spectrométrie, 3Laboratoire d’Astrophysique de Marseille, France. LAM is manufacturing a 1.45m diameter off axis segment for the ELT primary mirror. The optimised stress polishing process will allow reaching less than 0.5μm RMS of surface error, prior to finishing.
16:00–18:05
JW4A • Applied Imaging (AIO & IS)
Sri Rama Prasanna Pavani; Ricoh Innovations, Inc., USA; Laura Waller; Princeton Univ., USA, Presider

JW4A.1 • 16:00 Invited
Lensfree On-Chip Microscopy and Tomography Toward Telemedicine Applications, Aydogan Ozcan1,2; 1Electrical Engineering Department, UCLA, USA; 2Bioengineering Department, UCLA, USA. We review our recent progress on lensfree holographic on-chip microscopy and tomography techniques that are aimed at telemedicine applications.

JW4A.2 • 16:40 Invited
CMOS Angle Sensitive Pixels for 3-D Imaging, Alyosha C. Molnar1, Albert Wang1, Patrick Gill1; 1Cornell Univ., USA. Angle Sensitive Pixels (ASPs) are micro-scale diffractive structures sensitive to the angular distribution of incident light. Arrays of ASPs built in standard CMOS, are able to image 3-D structures with or without a lens.

JW4A.3 • 17:20
Deviations in Long Exposure Laser Speckle Contrast Imaging: Accounting for Static Scatterers, Yaaseen Atchia1,2, Hart Levy1,2, Ofer Levi1,2; 1Electrical Engineering, Univ. of Toronto, Canada; 2Biomedical and Biomaterials Engineering, Univ. of Toronto, Canada. The long exposure speckle imaging model exhibits discrepancies in high velocity vessels. It is shown that static scatterers affect higher velocities more, and multi-exposure imaging may be implemented to account for these deviations.

JW4A.4 • 17:35 Invited
Fast, Automatic, Photo-realistic, 3D Modeling of Building Interiors, Avideh Zakhor1; 1Univ. of California Berkeley, USA. We develop an architecture and associated algorithms for fast, automatic, photo-realistic 3D models of building interiors using a human operated backpack system made of a suite of sensors such as laser scanners, gyro and cameras.

17:30–19:30
OSA Corporate Associates: Executive Speaker Series
Michael Silver, CEO of American Elements
The Dolphins on the Upper Plaza
08:00–09:40
**ATH1A • Spectroscopy, Lasers, and Imaging, Oh My!**
Jess Ford; Weatherford International Ltd, USA, Presider

**ATH1A.1 • 08:00**
Proposal of a Three-dimensional and Long Range Tomography using Optical Frequency Comb Interferometry, Tuan Q. Banh1, Tatsutoshi Shioda1, Kohei Suzuki1, Munehiro Kimura1; 1Nagaoka Univ. of Technology, Japan. Coherence property of a broadband, near-infrared light is enhanced to construct a 3-dimensional tomography with the consideration of the measurement depth expansion, the measurement time reduction, and the sample scattering problem.

**ATH1A.2 • 08:20**
Invited
Trace Gas Detection Using a Broadband Continuous Wave - Cavity Ringdown Spectrometer, Evika Coyne1, Yu Chen1, Hongting Chen1; 1Tiger Optics, USA. Cavity ring-down spectroscopy is a field-proven analytical technique for trace gas detection. Tiger Optics’ newest instrument, the Prismatic, utilizes Brewster’s angle prism retro-reflectors creating a broadband cavity for multi-species detection with high sensitivity.

**ATH1A.3 • 09:00**
Invited
Compact and Portable Spectroscopy Systems for Counterfeit and Illicit Materials Detection, Jason M. Eichenholz1; 1Ocean Optics Inc., USA. To make optics based anti-counterfeit systems effective, they need to be small, compact, and portable. We will discuss our latest ultracompact Raman and Absorption spectroscopy optical engine developments as well as their systems architectures.

08:00–10:00
**STh1B • Optical Chemical and Biological Sensors: I**
Ken Ewing; US Naval Research Lab, USA, Presider

**STh1B.1 • 08:00**
Invited
Spectroscopic Techniques for Proximal Hazard Detection, Paul M. Pellegrino1, John J. Brady1, Ellen Holloff2; 1US Army Research Laboratory, USA. Recent hazards both in the civilian and military settings have exposed the necessity to develop sensor systems with increased sensitivity and selectivity for use at proximal ranges. This talk will examine new efforts dedicated towards these goals.

**STh1B.2 • 08:30**
Invited
Immu-SERS Microscopy: From the Design of Metal Nanoparticle Probes to Histopathology, Sebastian Schlucker1, Mohammad Saelani1, Dennis Steingrow1, Max Schild1, Jens Packels1, Alexander Marx1, Philipp Stroh1; 1Univ. of Onabrueck, Germany; 2Medical Center, Germany; 3Institute of Pathology, Univ. Hospital, Germany. This contribution covers the most recent developments in our laboratories, in particular the design of SERS nanoparticle probes with defined optical and chemical properties, together with their application for tissue imaging of prostate cancer biopsies.

**STh1B.3 • 08:45**
Invited
Aerosol Threat Detection: Single Particle Scattering and Spectroscopy, Jay D. Eversole1; 1US Naval Research Laboratory, USA. Achieving low detection thresholds for biological/chemical agent aerosols, drives sensor designs to single-particle classification approaches, and short response times suggest optical, on-the-fly interrogation. Spectroscopic methods discussed include fluorescence and IR absorption.

10:00–10:30 Coffee Break, Cypress Foyer on Lower Terrace
Chemical and Topographic Sample Analysis for the Milli- and Micrometer Range, Jinyong Yang, Wei Liu, Thomas Dwing, Ute Schmidt, Olaf Hellwich; WITec Instruments Corp, USA; WITec GmbH, Germany. High Confinement in Raman imaging always results in high focus sensitivity and this can make measurements difficult with rough/inclined samples. Here we present solutions for true confocal Raman imaging on microscopic rough and inclined samples.

Photo-cosmetic Applications Using Semiconductor Diode Lasers, Stewart Wilson; Palomar Medical Technologies, Inc., USA. Semiconductor diode laser devices are well known to be used in a variety of industries; such as telecommunication, military, medical and industrial such as car manufacturing. They are also seeing applications in photo-cosmetic industry as well. Historically, the photo-cosmetic applications have been limited to professional use only; but now some are making their way into home use consumer applications as well. I will present an overview of both professional and home use applications.

Model Guided Multi-modal Multi-scale Image Integration for Head and Neck Anatomy, Anand Santhanam, Jannick P. Rolland, Kye S. Lee, Huimin Zhao, Daniel Ennis, Daniel Low, Sherrif Ibrahim; Palomar Medical Technologies, Inc., USA. Biomechanical models are employed for guiding the image integration of macro-scale images obtained from Magnetic Resonance Imaging (MRI) with micro-scale images obtained from Optical Coherence Microscopy (OCM) designed for use in image-guided clinical interventions for the head and neck region.

Medical Diagnostics and Prognostics via Infrared and Raman Spectral Imaging, Max Diem, Jacob Piehler; Universitat Osnabrück, Germany. We have employed multicolor single molecule imaging techniques for probing the assembly of cytokine receptor complexes in the plasma membrane of living cells. Thus, the diffusion and interaction dynamics of individual signaling complexes were unraveled.

We present simulations and models of asynchrony in single molecule imaging experiments for these systems. We discuss the implications of these results for the biological context and the impact of the findings on the design of future experiments.

Infrared Optical Fibers for Sensors, J. S. Sanghera, L. B. Shaw, R. Gattass, L. E. Bua; Naval Research Laboratory, USA; Soteira Defense Solutions, USA; Univ. of North Carolina at Charlotte, USA. We demonstrate detection of 250 attomoles of Rhodamine 6G using an inkjet-fabricated SERS-active paper-based surface swab-dipstick. The fabrication simplicity and ease of use of this device is unprecedented for SERS-based analytics.

Illuminating Epidermal Growth Factor Receptor Densities on Filopodia through Plasmon Coupling, Feng Wang, Svelana V. Borisina, Hangyun Wang, Bjorn M. Reinhard; Department of Chemistry and The Photonics Center, Boston Univ., USA. We designed a multivalent immune-labeling strategy using Au nanoparticles and investigated the distribution of the epidermal growth factor receptor density on filopodia and dorsal cell membrane of A431 human epidermoid carcinoma cells through plasmon coupling.

Infrared Optical Fibers for Sensors, J. S. Sanghera, L. B. Shaw, R. Gattass, L. E. Bua; Naval Research Laboratory, USA; Soteira Defense Solutions, USA; Univ. of North Carolina at Charlotte, USA. We demonstrate detection of 250 attomoles of Rhodamine 6G using an inkjet-fabricated SERS-active paper-based surface swab-dipstick. The fabrication simplicity and ease of use of this device is unprecedented for SERS-based analytics.

CO2 Sensing with a 2005 nm Thulium Holmium Co-doped Fiber Laser, Benjie Zhou, Steve McKeown, Benjamin G. Gribbin, Rassaha Amnuayponsakul, Haibo Huang, Steven Eckhoff, Daniel Wasserman, Lynford L. Goddard; Micro and Nanotechnology Laboratory, Univ. of Illinois, USA; Department of Agricultural and Biological Engineering, Univ. of Illinois, USA. We demonstrate an all-fiber thulium holmium co-doped fiber laser emitting at 2005 nm. By modulating the temperature of its fiber Bragg grating mirrors, we performed wavelength modulation spectroscopy and quantified CO2 concentration down to 2%.

Palladium Based Fabry-Pérot Etalons for Hydrogen Sensing, Manan Raval, Steve McKeown, Amir Arbabi, Lynford L. Goddard; Univ. of Illinois at Urbana-Champaign, USA. We present simulations and measurements of palladium coated etalon sensors for detection of hydrogen gas. Hydrogen concentration can be determined by the shift in the wavelength or amplitude of the minima in the interference pattern.

Imaging the Assembly and Dynamics of Individual Protein Complexes in Living Cells, Jacob Piehler; Universitat Osnabrück, Germany. We have employed multicolor single molecule imaging techniques for probing the assembly of cytokine receptor complexes in the plasma membrane of living cells. Thus, the diffusion and interaction dynamics of individual signaling complexes were unraveled.

Real-Time Blood-Flow Characterization Using Laser Speckle Imaging, Bernard Choi; Université de California Irvine, USA. Analysis of the contrast in laser speckle images, is a growing area of interest in the biomedical community. Here, I discuss recent work designed to translate laser speckle imaging concepts from the laboratory to the clinic.
Added Presentations
Tuesday, 26 June
RTu2E.2 • 10:45 (is not withdrawn)
Analysis of LiDAR Data for Emergency Management and Disaster Response, Chris Clasen¹, Fred A. Kruse², Angela Kim¹; ¹Remote Sensing Center, Naval Postgraduate School, USA; ²Physics, Naval Postgraduate School, USA. Light detection and ranging (LiDAR) data demonstrate how derived horizontal and vertical coordinates of the ground and objects above the ground can be used to provide detailed information for improved emergency management and disaster response.

Wednesday, 27 June
16:00-16:40 (Point Lobos)
OW4D.1, Tutorial: Recent Advances in Ion Beam and Plasma Jet Processing, Axel Schindler, Leibniz-Institute of Surface Modification, Germany. Tutorial will highlight recent advances in R&D of Ion beam figuring (IBF), Ion Beam Smoothing (IBS), Reactive Ion Beam Etching (RIBE) and atmospheric Plasma Jet Machining (PJM) (deep aspherization, nanometer shape correction, smoothing, film deposition).

Withdraw Presentations
IM2C.3, Polymer GRIN Lens Design
RTu2E.3, NASA’s High-altitude, Swath-mapping Laser Altimeter Capability, Sensor Fusion, and the Development of Technologies to Enable Space-based Lidar Mapping of the Earth’s Surface
JTu5A.14, LANDSAFE® Precision Flight Instrumentation System
JTu5A.20, Radial Slope Measurement of Transparent Samples
AW3B.2, Use of Hyperspectral Imaging for Pharmaceutical Formulation Development
OW3D.6, Stress polishing of E-ELT segments: LAM demonstrator
OW1D.4, Aspheric and Freeform Hybrid Glass-polymer Optics
STh3B.1, Medical Diagnostics and Prognostics via Infrared and Raman Spectral Imaging

Presenter Changes
Brigid Mullany will present OM4D.5, Evaluating the Effect of Single Frequency Vibrations on Pitch Polishing Outcomes. Also, it is removed from the OF&T student paper contest.
Balaji Srinivasan will present Stu3F.3, Carrier Suppressed Modulation for Brillouin Gain Spectrum Analysis
Matthew Fishburn will present ITu4C.1, SPAD Image Sensors: From Architectures to Applications
Daniele Spiga will present OW3D.4, X-ray Optics for Astronomy
Andrea Colaco1 will present JW3A.5, CDAC: Compressive Depth Acquisition using a Single Time-resolved Sensor

Presider Changes
Samuel Thurman will be the presider for CTu2B, Image Restoration
Bai-Ou Guan will be the presider for STu4F, Micro and Nano-Engineered Sensors

Schedule Changes
On Tuesday, 26 June the morning COSI sessions are in Cypress 3. The morning IS sessions are in Cypress 1 & 2.

AW3B.1, Structured Light Optical Super-Resolution: Encoding for Limited Optical Bandwidth will now be presented on Wednesday, 27 June at 14:20-14:50.

The OF&T postdeadline session on Thursday, 27 June at 16:00 has been cancelled and replaced with a new Tutorial which is listed above in “Added Presentations”.
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POSTDEADLINE PAPERS

Imaging and Applied Optics

Applied Industrial Optics: Spectroscopy, Imaging, and Metrology (AIO)
Computational Optical Sensing and Imaging (COSI)
Optical Fabrication and Testing (OF&T)
Optical Remote Sensing of the Environment (ORS)
Optical Sensors (SENSORS)


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RTu2E • ORS Postdeadline Paper  
Tuesday, 26 June, 11:30 – 11:45
Big Sur Room  
Christopher Parrish; NOAA, NGS, Remote Sensing Div, USA, Presider

RTu2E.5 • 11:30
Derivative Spectroscopy with HICO, N. Tufillaro1;  
1Oregon State Univ., USA. HICO® is hyper-spectral ocean spectrometer currently in orbit on the International Space Station. We use HICO’s detailed spectral resolution to examine applications of derivative spectroscopy to complex coastal waters with riverine inputs.

COSI Postdeadline Session  
Wednesday, 27 June, 10:30-11:00
Cypress 4 Room  
TBD, Presider

CW2C.1 • 10:30
Superresolution of Dense Quantum Dot Clusters using Independent Component Classification, A.J. Barsic1,R. Piestun1, 1Univ. of Colorado, USA. We propose a superresolution technique to resolve dense clusters of independently blinking emitters. Experiments and numerical simulations demonstrate the ability to superresolve up to five emitters located within an area of a diffraction limited spot.

CW2C.2 • 10:45
Confidence Measures of Optical Flow for Multi-Frame Image Reconstruction, A. Kanaev1, C.W. Miller2; 1US Naval Research Lab., USA; 2Tekla Research, USA. Multi-frame image processing encompasses algorithms for imaging through turbulence, super-resolution, and filtering. In-scene motion remains a challenge and requires optical flow estimation. We propose confidence measure to augment the problem of insufficient optical flow accuracy.

SENSORS Postdeadline Session  
Wednesday, 27 June, 16:00-17:45
Cypress 4 Room  
Enrique Castro Camus; Centro de Investigaciones en Optica A.C., Mexico, Presider

SW4C.1 • 16:00
Generation and Coherent Detection of Broadband Terahertz Radiation in Phase-Matched Waveguides, S. Liu1, X. Shou1, A. Agrawal1, A. Nahata1, 1University of Utah, USA. We describe novel waveguide devices that allows for broadband generation and coherent detection of THz radiation. We achieve a system with spectral content beyond 8 THz using <10 mW total average optical power.

SW4C.2 • 16:15
Polarization Modulation Time-domain Terahertz Polarimetry, C.M. Morris1, R. Valdes Aguilar1, A.V. Stier1, N. Armitage1, Dept. of Physics and Astronomy, Johns Hopkins University, USA. A polarization modulation time-domain THz polarimetry technique with a precision of 0.02° (350 μrad) will be presented, along with ongoing applications to interesting material systems such as topological insulators and quantum magnets.

SW4C.3 • 16:30
Resonant Metamaterial Detectors Utilizing THz Quantum-Cascade Lasers, A. Benz1, S. Schwarz1, M. Krall1, D. Dietze1, M. Brandstetter1, C. Deutsch1, K. Unterrainer1, H. Detz1, A.M. Andrews1, W. Schrenk1, G. Strasser1, A. Benz2; 1Technische Universität Wien, Austria; 2Sandia National Laboratories, USA. We present the design, fabrication and characterization of a resonant metamaterial detector based on a THz
quantum-cascade laser. The same active region can be used to generate and detect the light leading to miniaturized and integrated optical systems in the THz spectral range.

SW4C.4 • 16:45
Non-Destructive Evaluation of Aerospace Materials using Terahertz Time-Domain Imaging, L. Owens1, D.T. Petkie1, J.A. Deibel1, D.T. Petkie2, J.A. Deibel2; 1Physics, Wright State University, USA; 2Electrical Engineering, Wright State University, USA. THz time-domain imaging was utilized in the non-destructive evaluation of various composite materials used in aerospace structures and components for the characterization of defects and changes in material properties due to mechanical and thermal strain.

SW4C.5 • 17:00
Hydration Dynamics of Arabidopsis Thaliana under Water Deficit Conditions Monitored in-vivo by THz Spectroscopy, E. Castro Canus2, M. Palomar2, A.A. Covarrubias; 2Centro de Investigaciones en Optica AC, Mexico; 2Biolologia Molecular de Plantas, Instituto de Biotecnologia, Universidad Nacional Autonoma de Mexico, Mexico. We monitored hydration dynamics of A. thaliana under water deficit conditions. The plant showed slow dehydration over ~17h followed by rapid loss of moisture over 3h, this might be caused by a defensive mechanism of the plant that activates water availability decreases below certain thresholds.

SW4C.6 • 17:15
Recent Experimental Results of a Large Format 80x64 Pixel THz Camera Sensitive to 0.6 – 1.2 THz Radiation, D. Burdette1, C. Roedig1, H.L. Mosbacher1, J. Alverbro2, P. Fay1, K. Sertel2, G. Trichopoulos1, K. Topalli2, Y. Ni5; 1Traycer, USA; 2IRNova, Kista, Sweden; 3Notre Dame, USA; 4Ohio State Univ., USA; 5New Imaging Technologies, Buisson, France. THz applications have been limited by the lack of a cost-effective, real-time, large format THz camera. This paper discusses the recent experimental results of a real-time (100 Hz), large-format (80x64 pixel), broadband (0.6 – 1.2THz) THz camera.

SW4C.7 • 17:30
Improving the Performance of Difference Frequency THz Generation in Waveguides, P.E. Powers1, J.W. Haus2, J.W. Haus2; 1Physics Department, University of Dayton, USA; 2Electro-Optics Program, University of Dayton, USA. Improving the performance of THz generation by difference frequency generation is presented for waveguide interactions. A numerical model is used to show how to optimize THz generation and understand cascaded processes in the waveguide.

AIO Postdeadline Paper
Thursday, 28 June, 9:40 – 10:00
Cypress 3 Room
Jess Ford, Weatherford International Ltd, USA, Presider

ATH1A.4 • 9:40
Experimental Demonstration of an NIR Compressive Sensing Hyper-Spectral Imaging System, Y. Wu1, G.R. Arce1, D.W. Prather1; 1Electrical and Computer Engineering, University of Delaware, USA. We utilized the compressive sensing theory in building a hyperspectral imaging system for NIR wavelengths. This system simultaneously captures 24 spectral images for the wavelength range between 990-1450 nm without any mechanical/temporal scanning processes.
RTu2E.5 • ORS Postdeadline Paper

Tuesday, 26 June, 11:30 – 11:45
Big Sur Room
Derivative spectroscopy with HICO®

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Abstract: The Hyperspectral Imager of the Coastal Ocean — HICO® — is a visible and near-IR grating spectrometer currently in orbit on the International Space State (ISS) [1]. HICO’s 5.7 nm (binned) spectral resolution permits the application of derivative spectroscopy to the identification of remotely sensed water constituents. We examine applications of derivative spectroscopy to complex coastal waters with riverine inputs such as the Columbia and Yangtze rivers.

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OCIS codes: 000.0000, 999.9999.

1. Background
Remote sensing ocean imagers are designed to capture a dark object (water) in a bright background (atmosphere). The current generation of ocean imagers are ‘multispectral,’ and product algorithms are tuned to make use of the of the distinct spectral channels. As demonstrated by HICO [2], however, current technology permits the design of low-noise space bourne spectrometers with continuous spectral coverage, as well as enhanced spatial coverage. HICO’s typical ground sampling distance is 90 meters with a native spectral resolution of 1.9 nm, which is typically binned up to 5.7 nm. Useable spectral coverage ranges from 400 nm to 900 nm.

Derivative spectroscopy is a useful technique for the routine analysis of laboratory spectra. Derivative spectroscopy is also useful in the identification of informative remote sensing channels to aid the design of multispectral imagers [3], and initial applications also show its utility in the identification of shallow water bottom types [4].

Multispectral imagers focus on the extrema spectra of water or atmospheric constituents. Hyperspectral instruments and derivative spectroscopy allows us to quantify the shape and curvature of spectral peaks as well. For instance, the half-width of a fluorescence peak is amplified by the use of derivative spectroscopy. A peak with a smaller half-width will have a larger derivative around the maximum, and this spectral feature which is emphasized in the derivative can be used to distinguish and identify spectral features.

Care must always be taken in the numerical computation of derivaties to minimize the the impact of noise amplification. We compute the derivatives using a Savitzky-Golay filter [5]. At the same time we interpolate the data to a uniform 5 nm spacing. HICO has a signal-to-noise (SNR) of about 400 in the blue and 200 in the red [2]. To further reduce the noise in the data, where appropriate, we spatially bin the data to larger pixel sizes to further increase the SNR. Spectral features are identified by first looking at the extrema and zero crossings of the derivatives, but further analysis also includes the calculation of principal components to try to match the remote sensing spectra to lab measurements of probable minerals or pigments [6].

2. Applications
As a first example we examine an image of the Columbia River from May 2012 (Fig. 1). The fourth derivative is often used since it has the same extrema as the original spectra (the second derivative also has the same extrema but with the minimums and maximums interchanged). Pixels are chosen which are thought to represent different water masses, and the derivative is examined (Fig. 1 (c)) to find features that are used to distinguish the water masses. Then these channels can be chosen for the RGB composite to highlight differences. In this example it appears that that there are three distinct water masses, presumably occurring from sediments at three distinct depths due to tidal forcing. Choosing, for instance, a channel near 610 nm allows us to separate older water outflowing from the Columbia (red dot in Fig. 1 (a)) from newer water (green dot in Fig. 1(a)). Picking RGB channels to separate water masses results in the image Fig. 1(b). Thus, in this very simple application, we illustrate how a derivative signature can be used for image enhancement.
Fig. 1. HICO image of the Columbia River from 12 May 2012, 1:05 GMT. (a) RGB image of river outlet, (b) enhanced image highlighting plume structure, (c) use of derivative analysis in selection of channels sensitive to plume sediments.

Fig. 2. HICO image of the Yangtze River from 28 March 2012, 0:47 GMT. (a) RGB image of river outlet, (b) Atmospherically corrected spectra, (c) derivative analysis highlighting channels sensitive to bottom reflectance and algal mattes.
As a second example consider the sediment rich outflow from the Yangtze river in March of 2012 (Fig. 2). The average total dissolved solids (TDS) out of the Yangtze exceeds 250 mg/L, and causes a tan colored fan shape in the East China Sea easily seen from space. Atmospherically corrected spectra are shown in Fig. 2 (b). Salient features such as a peak of 800 nm from bottom reflectance and a peak at about 710 nm from a surface algal matte are highlighted in the second derivative (Fig. 2(c)). Although the bottom reflectance is easy to see in the original spectra (Fig. 2(b)), the 710 nm peak is not readily apparent, but is prominent in the second derivative plot (Fig. 2(c)).

References

CW2C • COSI Postdeadline Session

Wednesday, 27 June, 10:30-11:00
Cypress 4 Room
Superresolution of Dense Quantum Dot Clusters using Independent Component Classification

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Abstract:
We propose a superresolution technique to resolve dense clusters of independently blinking emitters. Experiments and numerical simulations demonstrate the ability to superresolve up to five emitters located within an area of a diffraction limited spot.

OCIS codes: (100.6640) Superresolution; (180.2520) Fluorescence microscopy

1. Introduction
Optical microscopy has a fundamental resolution limit determined by diffraction. However, if one can assume the object consists of a collection of point-like sources, as is the case in single-molecule fluorescence imaging, the resolution paradigm is completely changed. Recent superresolution fluorescence microscopy techniques (such as PALM and STORM) rely on the ability to temporally resolve closely-spaced emitters to achieve superresolution [1,2]. The critical step is to control the experimental conditions such that unresolved emitters are switched temporally – in essence, temporal resolution is traded for spatial resolution. This allows experimentalists to spatially resolve emitters that are separated by much less than the diffraction limit. These methods still rely on the ability to resolve the emitters in time so that the diffraction limited image of each emitter does not overlap. This places a limit on the labeling density of samples.

A related technique uses a clever analysis of quantum dot blinking; by exploiting their random temporal fluctuations, two emitters spaced closer than the diffraction limit can be resolved without relying on localization [3]. This method involves performing Independent Component Analysis (ICA) on the data. The way in which ICA is able to resolve the emitters relies on the fact that the quantum dots blink randomly and independently. The ICA algorithm uses this fact to decompose the data into a small set of variables which have maximally non-Gaussian probability distribution functions. In theory, these non-Gaussian variables will correspond to the images of the independently-blinking quantum dots in the scene.

Quantum dot emitters are attractive in various types of superresolution experiments due to their high photon output, photostability, wide range of emission wavelengths, and broad absorption spectra.

Unfortunately, the ICA algorithm has one major shortcoming – in order to correctly resolve the emitters, one must know the true number of emitters in the scene (which is obviously not known in an experimental setting). This is a difficult enough hurdle to preclude the method from being implemented in any nontrivial situation. Here, we demonstrate a procedure that addresses this problem by incorporating spatial analysis of the quantum dots in addition to the stochastic temporal analysis. The algorithm uses ICA to generate a family of possible solutions and then the independent components are classified according to their spatial and temporal characteristics. The result that best matches a model of quantum dot behavior is selected – hence the name Independent Component Classification (ICC).

In this summary, we present numerical simulations to validate the superresolution capabilities of ICC. Subsequently, we apply the method to an experimental dataset in which five classically unresolvable quantum dots are successfully resolved.

2. Independent Component Classification – Numerical Simulations
In Monte Carlo simulations, several emitters were placed randomly within a diffraction limited spot, given random blinking behavior, and combined with background noise and shot noise. Then, the ICA was performed numerous times to generate a family of potential solutions. With each iteration, an increasing number of emitters was assumed. An example of such a solution set is shown in Figure 1. In this case, the true number of emitters is four. By examining the spatial characteristics of the potential solutions, a clear pattern emerges: once the number of emitters is overestimated, spurious results that do not resemble the system Point Spread Function (PSF) are returned. When the number of emitters is underestimated, the returned independent components are often a superposition of two emitters (this result is less obvious in this example where the emitters are unresolved, but simulations with easily resolved emitters clearly exhibited this tendency). ICC exploits this tendency in order to estimate the number of emitters in the scene. Each set of potential solutions is given a score that measures the maximum error of any one
of the returned components as compared to the theoretical PSF. The number of emitters in the scene is assumed to be the set of results that immediately precedes the largest first derivative of the score set. In other words, the correct solution is assumed to be the one in which no spurious components are returned. This comparison is calculated by computing the L-2 norm of the difference between the data and the ideal PSF in Fourier space; the calculation is performed in Fourier space to account for possible lateral shifts.

The results of the Monte Carlo simulations are summarized in Figure 2. For each number of emitters from one to seven, a random set of unresolved locations is generated, and the ICC algorithm attempts to determine the number of emitters and their locations; this is repeated 500 times for each number of emitters. As expected, the ability to correctly estimate the number of emitters increases with the SNR. With experimentally achievable SNRs, the ICC algorithm can reliably resolve up to five emitters within a diffraction limited spot. At higher densities, the number of emitters is often underestimated.

Figure 1: Simulation of Independent Component Classification: The average of the simulated video is shown in (a), with the centers of the unresolved quantum dots marked with x’s. In (b), the family of potential solutions is shown. Each row is a separate result from the ICA algorithm, assuming a different number of emitters (row 1 assumes two emitters, row 2 assumes three emitters, etc).

Figure 2: Results of Monte Carlo simulations for varying numbers of emitters and noise levels. Error bars show the standard deviation of the repeated simulations.
3. Experimental Superresolution Results
Experiments were performed to test this superresolution scheme. A fluorescence microscope was built using a 405nm diode laser as the excitation source, and a 1.3NA 100x Zeiss objective collected the fluorescence from the 525nm quantum dots from Invitrogen. A 100mm tube lens was selected to give 62.5x magnification on a Hamamatsu Orca-Flash 2.0 CMOS camera. This system resulted in slight over-sampling of the PSF, with 3.5 pixels across the full-width at half-maximum of the PSF. A test sample composed of quantum dots scattered across the cover slip was imaged for 500 frames with an exposure time of 200ms per frame, giving a total acquisition time of less than 2 minutes.

The results of the ICC analysis of a short video section are shown below. In the normal fluorescence image, there are no clearly-resolved emitters, but the ICC analysis suggests there are 5 unresolved emitters. Figure 3 shows the average image of the video, as well as the estimated locations of the emitters and their separated images. The distance between neighboring emitters is between 85 and 230nm in all cases, and the furthest distance between two of the emitters is 420nm. For comparison, this system’s diffraction-limited spot is 493nm in diameter. Therefore, all 5 emitters have been superresolved.

![Figure 3: Experimental results](image)

Figure 3: Experimental results: (a) shows the average of the 500-frame video of blinking quantum dots; the estimated locations of the five emitters are shown as x’s. In (b), the five independent emitter images obtained with the ICC method are displayed.

4. Summary
This paper has demonstrated a superresolution technique capable of resolving dense clusters of quantum dots. The method was validated with simulations, which exhibit the ability to resolve emitters that would normally be unresolved. Experimental data was presented in which superresolution was achieved.

References
Confidence Measures of Optical Flow for Multi-Frame Image Reconstruction

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Abstract: Multi-frame image processing encompasses algorithms for imaging through turbulence, super-resolution, and filtering. In-scene motion remains a challenge and requires optical flow estimation. We propose confidence measure to augment the problem of insufficient optical flow accuracy.

OSI codes: 100.0100 (Image processing); 100.3010 (Image reconstruction techniques); 100.6640 (Superresolution)

1. Introduction

Estimation of optical flow (OF) from an image sequence represents one of the cornerstone problems in computer vision. Its major applications include super-resolution, turbulence degraded image restoration, video compression and denoising. Numerous optical flow algorithms have been developed recently and their evaluation has been unified by the Middlebury database work \([1,2]\). The number of papers on OF during the last several years easily tops a hundred while a considerably smaller number of papers has been devoted to OF confidence measures \([3,4]\). Despite the evident progress of new generation OF techniques, their test image performance has become rather saturated. In this situation, one way to qualitatively improve effectiveness of OF utilization in multi-frame image processing is to develop and implement application driven confidence measures.

2. Optical flow, error metrics, and confidence/uncertainty measures

Two components of the OF field \(u(ut, u_t)\) are defined for each pixel of the pair of images \(I_1\) and \(I_2\) satisfying the image intensity constancy assumption relation \(I_1(r) = I_2(r + u)\). Generally, the problem of finding \(u\) is ill-posed so that the OF estimate is obtained by minimizing the error functional by incorporating certain assumptions about properties of the solution. Usually the functional consists of two parts, the data term and the regularization term. One approach to regularization term considers a fully nonlinear diffusion scheme cast into the L1 norm which is approximated by the Charbonnier penalty function \([2]\),

\[
E(u) = \|I_1(r) - I_2(r + u)\|_{L^1} + \gamma \|\nabla I_1(r) - \nabla I_2(r + u)\|_{L^1} + \lambda \|\nabla u\|_{L^1}. \tag{1}
\]

The corresponding nonlinear Euler-Lagrange equations can be solved on a multi-resolution grid using two nested fixed point linearization procedures, providing the advantage of accounting for the nonlinearized constancy assumption relation.

Several metrics for error evaluation of the obtained solution have been discussed previously \([1]\). The most widely used error metric is the endpoint or geometrical error \(EE\), which estimates the absolute value of the difference between estimated vector \(u\) and the ground truth vector \(u_t\). The second often utilized metric is the angular error \(AE\), which represents the angle between the estimated vector \(u\) and the ground truth vector \(u_t\). However, one can argue that the most important error for motion compensation is interpolation error \(IE\) in which the ground truth image is compared with the motion compensated image i.e., the image warped according to OF estimation. The later metric estimates the typical result that is passed by an OF algorithm to other image processing components. In other words, for multi-frame applications where motion compensation is required, the warping operator or OF field is implicit an intermediate result while motion compensated image is the explicit final product that is used further in the processing.

Previously proposed uncertainty (or conversely confidence) measures can be divided in two large groups, the measures that estimate the error \(a priori\) i.e., without regard to a particular OF computation and the measures that estimate the error \(a posteriori\) i.e., taking into account one or more OF computations. One such metric from the first group relies on the image gradient to gauge the aperture problem prohibiting accurate estimation of OF \(\psi_{gr} = 1/(1 + |\nabla I|)^2\) \([4]\). Other members of the same group rely on the image structure tensor eigenvalues \([3]\). If \(\lambda_1 \geq \lambda_2 \geq \lambda_3\) are the three eigenvalues of the spatiotemporal tensor formed by an image sequence, then the total coherence of the structure tensor reflecting its anisotropy and presence or absence of noise leads to another uncertainty metric \(\psi_{ct} = -(\lambda_1 - \lambda_3)/[\lambda_1 + \lambda_3]\)^2. Spatial coherence of the structure tensor quantifying the extent of the aperture problem is defined by \(\psi_{ct} = ([\lambda_1 - \lambda_2]/[\lambda_1 + \lambda_2])^2\). A corner measure can be computed from the two last measures.
\[ \psi_{cc} = -\left(\frac{\lambda_1 - \lambda_3}{\lambda_1 + \lambda_3}\right)^2 + \left(\frac{\lambda_1 - \lambda_2}{\lambda_1 + \lambda_2}\right)^2, \]

which accounts for both the aperture problem and the coherence motion or noise problem. The obvious flaw of all \textit{a priori} uncertainty measures is their inability to consider propagation of local information when solving for problematic image regions. Essentially, this translates into inability of \textit{a priori} measures to account for regularization terms of OF. One uncertainty measure from the \textit{a posteriori} group stems naturally from the variational approach to the OF estimation [4]. Indeed, functional energy minimization residue shows how well the solution follows the underlying model. Then, the logical uncertainty measure is the final functional energy after the minimization procedure.

![Fig.1 Dimetrodon image test](image1.png)

Fig.1 Dimetrodon image test (a) reference image; (b) interpolation error \(IE\); (c) endpoint error \(EE\); (d) angular error \(AE\).

We propose a “warping residue” uncertainty measure which also belongs to the \textit{a posteriori} group and which is not specific to any particular implementation of OF estimation,

\[ \psi_{wr} = \left| I_1(x, y) - I_2(x + u_x, y + u_y) \right|^2. \]

![Fig. 2 Dimetrodon set confidence measure sparsification test with respect to interpolation error](image2.png)

Fig. 2 Dimetrodon set confidence measure sparsification test with respect to interpolation error \(IE\). Subimages display the tested measures.

3. Optical flow uncertainty measure application to multi-frame processing

A common approach to uncertainty or, conversely, confidence measure evaluation is based on sparsification [4]. The errors pertaining to each pixel are ordered according to the uncertainty measure being tested and the mean error is calculated using only a given percentile of the best values. Such a procedure estimates correctness of both the spatial distribution and the histogram of the confidence measure with respect to the true error. OF uncertainty measures presented here are evaluated using the sparsification test with the Dimetrodon images from Middlebury database [1]. The result for only one pair of images is presented due to the space constrains. The OF algorithm based on Eq. (1) is employed [2]. Figure 1 displays the reference image \(I_1\) (Fig. 1a) and the absolute values of the optical flow errors \(IE, EE,\) and \(AE\) (Figs. 1b-d). Comparison of the three error metrics shows that the latter-two have little correlation with the former, emphasizing the fact that different OF errors require separate error measures. Uncertainty measures computed with the methods introduced in the Chapter 2 are shown on subimages of Fig. 2 also presenting sparsification test results with respect to interpolation error. The “warping residue” measure values are the closest to those of \(IE\) therefore they provide the most accurate representation of the interpolation error.

The proposed OF confidence measure has been incorporated into multi-frame algorithm for restoration of imagery degraded by underwater turbulence [5]. The restoration technique uses synthesis of nonlinear gain “lucky
region” fusion and optical flow based image warping. A typical underwater image distorted by extreme turbulence is presented on Fig. 3a. The sequence of ten distorted underwater images is used to obtain the final higher-resolution estimate. Imagery motion between the frames caused by extreme refraction index fluctuations underwater makes OF estimation difficult as constancy assumption often becomes invalid. This leads to spurious artifacts evident on Fig. 3b. In this case, the proposed confidence measure based on estimation of optical flow using nonlocal approach [1] is used to tune the anisotropic gain, which results in significant image quality improvement as shown on Fig. 3c.

Fig. 3 Multi-frame restoration of images degraded by underwater turbulence: (a) typical frame, (b) restored image, (c) image restored with confidence measure.

Another important OF application area is multi-frame super-resolution. Multi-frame super-resolution of images containing complex motion fields remains an elusive target requiring precise estimation of such motion between the frames. Although accuracy of OF algorithms has been increasing steadily it is not yet sufficient to provide confident subpixel resolution enhancement during super-resolution reconstruction. One way to improve the super-resolved image quality is to incorporate confidence measures of OF into the processing. A variational super-resolution algorithm with anisotropic smoothness term based on local image structure tensor has been augmented with weights that depend on the OF confidence level $W \sim \exp(-\psi_{anr})$. Eight low-resolution frames obtained by 4X downsampling and blurring of a high-resolution image sequence have been used for 4X super-resolution processing. A typical low-resolution image is presented on Fig. 4a and the super-resolved image is displayed on Fig. 4b. Lower accuracy of OF estimation around right hand and left leg of the man figure in the image results in artifacts that are eliminated if the confidence measure of optical flow is used (Fig. 4c).

Fig. 4 Results of multi-frame super-resolution (a) typical frame; (b) 4X super-resolved; (c) 4X super-resolved using proposed confidence measure.

In conclusion, a confidence measure of OF estimation suitable for multi-frame image processing is proposed. Using a sparsification test it has been proved that the proposed warping residue measure is an accurate representation of the OF interpolation error. Practical application of the confidence measure has been demonstrated for two OF algorithms ([1] and [2]) and two examples: restoration of imagery degraded by underwater turbulence, where confidence level thresholding has been used and multi-frame super-resolution of scene containing complex motion, where the confidence defined weights have been introduced into the minimization procedure.

4. References


SW4C • SENSORS Postdeadline Session

Wednesday, 27 June, 16:00-17:45
Cypress 4
Generation and Coherent Detection of Broadband Terahertz Radiation in Phase-Matched Waveguides

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Abstract: We describe novel waveguide devices that allows for broadband generation and coherent detection of THz radiation. We achieve a system with spectral content beyond 8 THz using <10 mW total average optical power.

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OCIS codes: Nonlinear optics, devices; (250.5460) Polymer waveguides; (190.7110) Ultrafast nonlinear optics.

Terahertz time-domain spectroscopy (THz TDS) is an extremely sensitive and flexible technique for determining far-infrared spectral and time-resolved properties of materials [1]. A common approach constructing such a system uses nonlinear optical materials that exhibit a macroscopic second-order nonlinearity for both generation and coherently detection of broadband terahertz (THz) radiation. This approach is attractive, because it allows one to capture a large fraction of the driving optical bandwidth. However, generation and detection processes using conventional nonlinear optical media, such as ZnTe, typically require 100’s of mW in average optical power [2]. Given the dramatic advances in developing small form-factor ultrafast lasers, that often deliver relatively low average power, there is significant incentive to devices that would enable similarly small form-factor broadband THz time-domain spectrometers. However, the nonlinear conversion efficiency for second-order nonlinear processes, such as optical rectification and electro-optic sampling are fundamentally dependent upon the driving optical intensity and the phase-matched interaction length. Therefore, instead of using bulk crystals with freely-propagating radiation, waveguides offer the possibility of requiring significantly lower optical power over long interaction lengths. In fact, broadband THz radiation has been generated using parallel plate waveguides with embedded nonlinear optical materials [3,4]. However, such an approach only confines the radiation along one axis.

In this submission, we demonstrate novel guided-wave devices that confine both the optical and THz beams along two axes. The approach is used for generation and coherent detection of broadband THz radiation based on metal waveguide structures that allow for single-mode propagation of broadband THz radiation, as well as low-loss single-mode propagation of the optical pump and probe beams, enabling phase-matched interaction of the beams over long interaction lengths. Since the beams are strongly confined by the waveguide geometry, significantly lower optical power is required for efficient nonlinear conversion than in typical free-space geometries. For example, we find that by using <10 mW of total average power for both waveguide structures, we are able to create a THz time-domain spectroscopy system with spectral content beyond 8 THz. Thus, this waveguide approach overcomes the aforementioned problems of source power, detector sensitivity and THz frequency response.

In Fig. 1(a), we show a schematic diagram of the waveguide geometry using a modified microstrip structure. Conventional microstrip waveguide geometries do not allow for true TEM guided-wave propagation, because of the dielectric discontinuity at the dielectric-air interface adjacent to the upper electrode [5]. However, if we overcoat the device with the same dielectric medium (acylate polymer), the device will support true TEM mode propagation. In the schematic, the total waveguide design thickness (top metal electrode to ground plane separation) for this prototype device is ~10 µm, with a 2D 3 µm x 3 µm nonlinear optical (poled polymer [6]) waveguide core embedded between the metal electrodes. The core dimensions were chosen in order to ensure that the 2D waveguide allows for single mode propagation of the ultrafast optical pump beam. The basic experimental geometry for generation and coherent detection of broadband THz radiation is shown in Figure 1(b). Broadband THz pulses were generated using a waveguide emitter and coupled into the detection waveguide using a hyper-hemispherical sapphire lens and a dipole antenna that was fabricated on the end face of the waveguide. The same lens was used to couple the optical probe beam into the nonlinear core. Within this detection device, the polarization of the optical probe beam is altered through an electro-optic interaction with the broadband THz beam and measured using a conventional amplitude modulator arrangement. The measured time-domain waveform obtained using 1 mm long waveguides for generation and detection is shown in Figure 1(c). The corresponding amplitude spectrum is shown as an inset. We note that in the absence of the dipole antenna on the waveguide endface, no THz waveform was coupled into the waveguide.
A fundamental consideration in the operation of these devices for either generation or coherent detection of broadband THz radiation is the issue of phase-matching. The general phase-matching condition for the generation of THz via difference frequency mixing and coherent detection via electro-optic sampling within this waveguide structure is given by

$$\bar{\beta}(\omega_{\text{opt}} + \omega_{\text{THz}}) - \bar{\beta}(\omega_{\text{opt}}) = \bar{\beta}(\omega_{\text{THz}}).$$  \hfill (1)

Here, $\beta$ corresponds to the propagation vector within the waveguide structure, $\omega_{\text{opt}}$ and $\omega_{\text{THz}}$ are the optical and THz frequencies, respectively, and $\omega_{\text{opt}}$ and $(\omega_{\text{opt}} + \omega_{\text{THz}})$ both lie within the optical spectrum of the optical pulse. We will show that the resulting constraint is identical to that for free space i.e. the optical group velocity within the waveguide should equal the THz phase velocity. Correspondingly, the coherence length, $\ell_c (= \pi/\Delta \beta)$, for the generation of broadband THz via difference frequency mixing (and coherent detection of broadband THz radiation via electro-optic sampling) within this waveguide structure may approximately be written as [2]

$$\ell_c = \frac{\pi c}{\omega_{\text{THz}} n_g - n_{\text{eff}}^{\text{THz}}}. \hfill (2)$$

Here $n_g = c/|d\omega/d\beta|$ is the group index at the optical pump frequency, and $n_{\text{eff}}^{\text{THz}}$ is the effective refractive index of the dielectric medium within the metal waveguide at THz frequencies.
In summary, we have demonstrated that modified microstrip waveguide devices that incorporate 2D nonlinear optical cores are well suited for developing broadband THz TDS systems. By using optimized poled polymers, we expect that the total optical power required for a high sensitivity THz TDS system can be significantly <10 mW.

This work was supported through the National Science Foundation MRSEC program under grant #DMR-1121252.

References
Polarization modulation time-domain terahertz polarimetry

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Abstract: A polarization modulation time-domain THz polarimetry technique with a precision of 0.02° (350 μrad) will be presented, along with ongoing applications to interesting material systems such as topological insulators and quantum magnets.

Picosecond (10^{-12} s) timescales are one of the most ubiquitous in condensed matter systems. In recent years, advances in time-domain THz spectroscopy (TDTS) have dramatically increased the ease of investigation of this time-scale, creating a rapidly expanding area of optical and materials research with a broad range of applications [1].

Despite the considerable progress in this field, a number of challenges remain. For example, highly accurate measurement of polarization states in the THz range is challenging [2]. Specialized multi-pole devices and calibrated wire-grid polarizer measurements have pushed the precision to ~ 0.2°. However, investigations of fundamental effects such as extremely small Kerr and Faraday rotations in many materials at the forefront of condensed matter physics require an increased level of precision by approximately one order of magnitude [5]. Additionally, easy high precision determination of terahertz polarization states would set the stage for entirely new spectroscopic techniques such as THz ellipsometry.

Here we present a polarization modulation technique employing a fast rotator in combination with photoconductive switch based time-domain THz spectroscopy. It is capable of an unprecedentedly high angular precision of better than 0.02° and an accuracy of 0.05° in the frequency range from 0.1 to 1.25 THz, a sensitivity that opens the door to a new class of terahertz measurements. Additionally x and y direction electric fields are measured simultaneously which decreases measurement times.

Figure 1 shows the experimental setup. The generation and detection of the terahertz waveform is accomplished by a standard time-domain terahertz spectrometer using photoconductive antennas. A femtosecond laser pulse excites a biased Auston switch THz emitter, creating a linearly polarized electromagnetic pulse a few picoseconds in duration (with THz frequency Fourier components from 0.1 to 3 THz). The pulse propagates through space and interacts with a sample under test. The linearly polarized light passing through the sample becomes elliptically polarized according to the properties of the particular sample. The elliptically polarized terahertz light passes through a rotating wire-grid polarizer, which modulates the elliptical
polarization at twice the rotation frequency $\Omega$. A second photoexcited Auston switch is used to detect the final electric field waveform.

One can show [3] that the modulation of the polarization allows for direct detection of the $x$ and $y$ components of the electric field simultaneously on the in- and out-of-phase components respectively of a lock-in amplifier detecting at $2\Omega$. This simultaneous detection of both electric field polarizations is advantageous, as the phase sensitive nature of TDTS means that unlike conventional polarimetry, only two orthogonal directions have to be measured to resolve the complete transfer matrix for a polarized wave.

![Figure 2](image)

Fig. 2. a) A test polarizer angle is used in place of a sample, with an angle of $\sim 2^\circ$, showing 0.05° accuracy and 0.02° precision up to 1.25 THz. The shaded area indicates the measurement precision. b) A single polarization modulation measurement of a wafer of R-cut sapphire, oriented at 45° to the vertical x-axis. The sample birefringence of this orientation produces a time-domain electric field waveform that rotates in time.

The effect of the sample on the polarization state of the terahertz electric fields can be described by the sample transfer matrix $T$:

$$T(\omega) = \begin{pmatrix} l_{xx}(\omega) & l_{xy}(\omega) \\ l_{yx}(\omega) & l_{yy}(\omega) \end{pmatrix}$$

The elements of this matrix are determined by the physics of the investigated sample, and their measurement is the main goal of the polarimetry described here. Properties of the sample such as the complex conductivity can be directly extracted from the elements of this matrix. With the technique presented, a single measurement yields two elements of the transfer matrix with the signals on the $X$ and $Y$ channels of the lock-in detector [3]:

$$S_X(\omega) \sim E_x^0(\omega) l_{xx}(\omega)$$
$$S_Y(\omega) \sim E_y^0(\omega) l_{yx}(\omega)$$

where $E_x^0(\omega)$ is the frequency domain representation of the original electric field. This single rotator measurement accomplishes the same as two static polarizer measurements. While for some samples the full matrix must be resolved, for simple effects such as Faraday and Kerr rotation only one diagonal and one off-diagonal matrix element needs to be measured.

A wire-grid polarizer in a static rotation mount was used as a reference sample to characterize the performance of the system. Figure 2(a) shows a measurement for a polarizer angle of $2^\circ$, demonstrating the ultimate accuracy and precision of the system. Note that in the Vernier scale rotation mount used here, the test polarizer angle can only be set with an accuracy of $\sim 0.1^\circ$, producing the small offset angle from $2^\circ$. Given this constraint, the measurement accuracy is instead described as the flatness of the angle over the...
measurement frequencies, as the polarizer should produce the same polarization angle for all frequencies. The level of variation from this is the inaccuracy of the measurement. As usual, the precision is determined by the standard deviation of repeated measurements from the mean angle. The solid curve presented in Fig. 2(a) is the average of several scans. The standard deviation of these scans is plotted as the shaded blue area around the curve. From 0.1 – 1.25 THz, the precision is \( \sim 0.02^\circ \) (350 \( \mu \)rad). The precision of the system is thus far only limited by the averaging time. The averaged scan shown in Fig. 2(a) accounts for 20 minutes of measurement, a reasonable time-scale for many experiments.

To test the technique on a real sample, the birefringent response of a piece of R-cut sapphire was measured. The sample was placed with the ordinary and extraordinary axes at 45\(^\circ\) with respect to the initial vertical (\( x \)) light polarization. This crystal orientation produces a phase delay between the electric field projections on the two axes, changing the polarization from linear to elliptical. Figure 2(b) shows the measurement of the \( x \) and \( y \) electric fields that occurs in the two lock-in channels in a single measurement, which is then used to reconstruct the time domain electric field polarization state. The transfer matrix elements can then be used to directly determine the difference in the index of refraction between the two birefringent axes. As the R-cut is a somewhat complicated projection of multiple crystallographic axes, we forgoe that treatment here. This measurement clearly demonstrates the conversion of the initial linearly polarized THz pulse into a more complex elliptically polarized state.

The high precision technique for measurement of polarization states presented here will have a wide applicability to a number of materials systems at the cutting edge of condensed matter physics, such as high-\( T_c \) superconductors [4], quantum magnets, and topological insulators [5]. Many of these systems are predicted to have extremely small Kerr or Faraday rotations in the THz range that should be signatures of their fundamental materials properties, however thus far the size of such rotations has precluded measurements. We will describe our ongoing measurements using this high precision THz polarimetry to look for these effects in these interesting material systems.

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References
Resonant Metamaterial Detectors Utilizing THz Quantum-Cascade Lasers

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Abstract: We present the design, fabrication and characterization of a resonant metamaterial detector based on a THz quantum-cascade laser. The same active region can be used to generate and detect the light leading to miniaturized and integrated optical systems in the THz spectral range.

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1. Introduction and Background

The terahertz (THz) spectral region shows a huge potential for applications such as spectroscopy, chemical sensing or real-time imaging. THz quantum-cascade lasers (QCLs) have become the preferred compact sources covering the frequencies from 1.2 to 5 THz. They show great potential for local chemical sensors [1]. Nevertheless, the integration of a THz source and detector is still challenging. The large wavelengths in combination with small semiconductor structures leads to divergent emission fields and extensive collection optics. A monolithic integration of both components eases the requirements on beam collimation and focusing.

Here, we present the use of conventional THz-QCLs as resonant metamaterial detectors emitting and detecting in the same spectral region. The metamaterial allows us to couple normal incidence radiation resonantly to the intersubband transitions. Furthermore, the resonance frequency of the metamaterial is defined by geometry resulting in a highly designable detector. In a second step, this approach allows the realization of integrated optical sensor systems. The source and the detector are realized on the same chip using the same active region.

2. Experimental results

The detector region is based on a GaAs/Al$_{15}$Ga$_{85}$As heterostructure grown by molecular beam epitaxy. The underlying THz-QCL exploits the longitudinal-optical phonon depopulation scheme [2] and is designed to operate at an applied field of 10 kV/cm in the frequency range from 2.6 to 3.2 THz [3]. The same structure is used as a detector at zero bias; it shows three dominant transitions at 16.8, 42.9 and 88.9 meV. Light below and above the reststrahlen band can be detected.

Metamaterials have proven to be an excellent way of coupling free-space radiation to intersubband transitions in the THz range [4, 5]. The polarization of the incoming radiation is rotated in the near-field making it compatible with the intersubband selection rules. The electric field distribution inside the active region is illustrated in Fig. 1(a). The strong z-field component for an incoming $E_x$ polarization is clearly visible. We process the metamaterial directly into the top contact using optical lithography; a scanning electron microscope image of one single meta-atom is presented in the inset of Fig. 1(b). Throughout this work we use the complementary metamaterial which shows a similar frequency response as the conventional one [6]. The big advantage is the naturally forming uninterrupted top-contact layer; this ensures a homogeneous electric field distribution across the entire active region. To increase the optical confinement further, we process our devices into double-metal waveguides [7].
Fig. 1. Metamaterial field distribution and spectra. (a) Calculated $E_z$ (left half) and $H_y$ (right half) fields inside the active region for an excitation frequency of 10 THz. The white dashed lines indicate the position of the metamaterial. (b) Metamaterial spectrum for a period of 9.15 $\mu$m. The solid line represents the experimental results, the dotted one the simulation. The inset shows a scanning electron microscope image of one meta-atom.

The detector response is an overlap of the intersubband energies and the metamaterial response. Since both systems, the quantum-wells and the metamaterial, are defined purely by design, the resulting devices are highly flexible and can be adopted to the problem. The theoretical and experimental results for a metamaterial with a period of 9.15 $\mu$m are presented in Fig. 1(b). The detector shows a broad response around 10 THz corresponding to one of the three dominant transitions. The double split-ring shows a polarization dependent response due to its asymmetry. At an incident $E_y$ polarization the peaks at 9.2 and 10 THz are suppressed; the dominant peak is red-shifted to 10.2 THz. Depending on the metamaterial period we can also excite the quantum-well transitions at 16.8 and 88.9 meV.

3. Conclusion

In conclusion we have designed and realized resonant metamaterial detectors based on THz-QCLs. They are sensitive below and above the reststrahlen band. The metamaterial is processed directly into the top-contact and used to couple radiation to the intersubband transitions. It allows the realization of an integrated optical system consisting of source, waveguide and detector on the same chip.

References


Non-Destructive Evaluation of Aerospace Materials using Terahertz Time-Domain Imaging
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Abstract: THz time-domain imaging was utilized in the non-destructive evaluation of various composite materials used in aerospace structures and components for the characterization of defects and changes in material properties due to mechanical and thermal strain.

OCIS codes: (110.6795) Terahertz imaging; (300.6495) Spectroscopy, terahertz.

1. Introduction
While the use of terahertz (THz) imaging as an evaluation tool for novel materials and systems has found much success in recent years [1-3], there remain several possible application areas still in need of thorough investigation. Here, we investigate the use of terahertz imaging for the characterization and evaluation of materials and components used in advanced aerospace components. Defects present in a protective coating/paint layer covering a metal surface, a coating similar to that used on airframes, were located using THz imaging. Fiberglass composite materials were evaluated with THz light to determine and characterize defects such as voids, burns, and delamination. While suggested as a potential NDE tool for use in the field of ceramic and ceramic matrix composite materials, the use of THz spectroscopy and imaging in the examination of the effects of mechanical and thermally induced strain on ceramic composite materials is not well established. THz time-domain reflection imaging was performed to do non-destructive evaluation on ceramic composite materials in order to characterize changes in material properties due to mechanical and thermal strain [4-5].

THz time-domain images were acquired using a commercial system manufactured by Teraview. Ultrafast laser pulses with an 800 nm center wavelength and 100 fs pulse width triggered a fiber-coupled GaAs photoconductive antenna (PCA). Collimated THz light from the PC antenna transmitter was focused via a 50 mm focal length lens ($f/# = 2$) onto the samples at a near-normal incident angle. The reflected radiation was detected by a PCA receiver module, based on LT-GaAs, with an identical lens configuration. When the system is optimized and calibrated using a metal reference reflection target, the typical bandwidth of the detected THz pulse exceeds 3 THz.

2. THz NDE of Protective Coatings
The ability of terahertz radiation to penetrate obscurants such as paints, oils, etc. has often been cited as a primary benefit for its use as an NDE tool. The surface of a metallic plate was covered with a protective coating/paint often used in the aerospace field. An “X” pattern was scored across the sample thus providing exposure such that the ambient environment could induce corrosion (top half of Fig. 1). The rest of Fig. 1 shows a THz image, in which the magnitude of each pixel is based on the maximum amplitude of the THz pulse, of this sample with delamination and blistering present on the paint which is evident in both images. While the “X” and delamination’s were clearly visible to the eye, there were several defects identified in the THz image that were not seen in the visible light image.

3. Defect Detection in Fiberglass Composite Materials
Fiberglass composite samples, designated here as the KT samples, were characterized to determine if THz imaging was a useful technique for detecting delamination’s, burns, and other defects in composite materials. These materials were characterized previously using transmissive THz imaging over much smaller spatial scan areas [6]. The work described here was performed in reflection as described in the first section. Fig. 2(a) shows imaging results from three of these samples. KT2 and KT3 were both burned in isolated areas. The darkened portions of the samples seen in these THz images clearly show evidence of the defects due to burning. Fig. 2(b) shows zoomed-in views of both visible and THz images of the KT-3 sample which was burned at 830°F for 4 minutes in the circular area as marked. KT4 was a sample composed of five layers of varying thickness. By comparing the arrival time of the pulse through each of the layers, the layer thickness was able to be determined for each section.

Tests were conducted on both oxide-based and silicon nitride carbon based ceramic matrix composite (CMC) samples [4]. A 5.9 x 17.4 cm area was scanned, containing both an aluminum reference and the CMC sample. A full time-domain waveform, 250 ps long, was acquired for each 0.5 x 0.5 mm pixel. For this comprehensive study, there were multiple rounds of data acquisition. The first round consisted of initial spectroscopic imaging of all of the samples. Additional rounds consisted of imaging of the samples following treatments of either thermally or mechanically induced stress of varying magnitudes and also combinations of the two differing types of stress. Comparison of the data both in the time-domain and frequency-domain acquired from this imaging of both the untreated and treated samples was used to assess whether or not the magnitude and extent of stress-induced changes can be monitored using terahertz imaging and spectroscopy.

Fig. 3 (a) is an image based on the frequency weighted reflectivity from an oxide CMC sample prior to any stress treatment. Note that the textured weave on the surface of the sample is clearly visible. Quantitative analysis is also accomplished by producing graphs of normalized reflectivity (averaged over the entirety of the sample) as a function of frequency. In all cases, the reflectivity is based on comparison of a THz pulse reflected from a CMC sample compared to the aluminum reference. In Fig. 3(b), Sample B-87, which was heat treated at 1200°C for 100 hours, showed no obvious variation from the baseline measurement. Sample B-60 was fatigue treated under 225 MPa of pressure at 1 Hz for 1000 cycles, and shows decreased reflectivity.
5. Summary
In this talk, we report on recent progress on the use of terahertz imaging for the characterization and evaluation of materials and components used in the aerospace industry. Defects hidden underneath protective coatings such as paint can be detected with THz imaging in addition to defects present in the interiors and on the surfaces of composite materials. Finally, we will update progress on efforts to demonstrate characterization of ceramic composite materials using terahertz time-domain reflection imaging.

6. References

7. Acknowledgements
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Hydration dynamics of *Arabidopsis thaliana* under water deficit conditions monitored *in-vivo* by THz spectroscopy.

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Abstract: Terahertz time-domain spectroscopy was used to monitor the tissue hydration dynamics of *Arabidopsis thaliana* under water deficit conditions. Terahertz spectroscopy is found to be an excellent non-destructive *in-vivo* probe of hydration. The plant leaves showed very slow dehydration over the first 16 to 18 hours while a very rapid loss of moisture was seen over the following 3 hours, this transient behavior might be caused by a defensive mechanism of the organism that activates when the soil moisture decreases below certain threshold.

**OCIS codes:** (300.0300) Spectroscopy; (300.6495) Spectroscopy, terahertz

Water stress in plants represents an area of research that has attracted enormous attention recently [1] given the need of crops that can grow in areas where water supply is limited and capable of resisting drought periods. At present, a number of physiologic, metabolic and molecular responses have been described in various plant species when they are subjected to water deficit conditions [2]. *Arabidopsis thaliana* is a small flowering plant with a relatively short life cycle and small genome, which is considered a model system in plant biology, where many different processes have been characterized, including the plant response to environmental stress. [3] These studies and those carried out in other plant species have led to establish that the plant response to water limitation is a complex process that involves many changes at different functional levels and that depends on many different factors [4]. A better understanding of this complex response needs of more detailed analyses combining the application of different techniques, which could allow an integration of the molecular and physiological plant reactions to water deficit.

So far most of the studies requiring monitoring moisture dynamics in plant tissues have used destructive methods to quantify the amount of water present in them. In this work we present terahertz time-domain spectroscopy (THz-TDS) for dynamic *in-vivo* determination of hydration dynamics in vegetative tissue which is a non-contact and non-destructive technique.

Wild type *Arabidopsis thaliana* (*Lansberg erecta* ecotype) (AT) were grown in Petri dishes with MS 1X pH 5.7 (4.3 g/L Murashige and Skoog salts, 1% sucrose, 0.5g/L MES, 0.8% agar) in a chamber at controlled temperature of 21°C, 16/8 hrs light/dark photoperiod, 80 µE m⁻² s⁻¹ of light intensity and a relative humidity of 60-80% for 2 weeks. Seedlings were transplanted to a low water retention substrate (Turface) and incubated for three weeks under the conditions described before and watered with nutritive solution. When plants reached reproductive stage (approximately five-weeks), plants were exposed to progressive water lose and cauline leaves were used for analyses because their location in the stem was optimal for the study.

A standard THz-TDS system was used for this study based on a Ti:Sapphire laser oscillator (33fs, 3.0nJ/pulse, 80MHz repetition rate). Terahertz transients were generated by photo-exciting a 400 µm gap semi-insulating-GaAs photo-conductive emitter biased with a square wave (120V amplitude at 12kHz). Detection was performed using a 1mm thick [110] ZnTe electro-optic crystal.

A reference terahertz waveform $E_{\text{ref}}$ was recorded as function of the pulse delay $\delta$ before the sample was placed in the THz path. A live specimen of AT was placed next to the THz-TDS system. The stem was carefully bent and one of the cauline leaves (coming off the main stem) was fixed at the sample position using a semi-rigid card-board holder, softly pressing it to avoid any damage to plant tissues. At this moment, water supply to the plant was interrupted and a time-domain waveform $E_t$ was recorded every 5 minutes for 24 hours. All measurements were done in normal atmospheric air in order to avoid any additional stress on the plant by CO₂ deficit.
Waveforms acquired at half hour interval are shown in Fig. 1a. It is clear from the plot that the amplitude of the transmitted pulse changed significantly across the 24 hour period. Given that water presents strong absorption (causing low transmittance) these curves represent an indirect measure of the amount of water in the plant tissue at different times.

The transmittance of the leaf as a function of time at 0.9 THz is shown in Fig. 2. The plot presents a very slow riser in transmission over the first 16 to 18 hours. During the following 3 to 4 hours there is a very fast transmission increase from ~0.2 to ~0.85 related to a very fast moisture loss. This sudden change of the water content in the tissue might be associated to the activation of a defensive mechanism of the plant that resulted in a restriction of the water supply to the leaves in order to minimize the loss of moisture. This transient behavior could be a reaction not only to the water deficit experienced by the plant but also to the rate of change of water available, which is relatively fast in the case of the substrate used in these samples. By weighing another sample, we determined that the initial humidity in the substrate was of 0.28 ml/g (milliliters of water per gram of dry substrate) and that the loss of humidity was exponential with a time constant of 0.05 h⁻¹.
Terahertz time-domain spectroscopy was used to successfully monitor the *in-vivo* hydration dynamics in leaves of *A. thaliana* under water stress. It was observed that the leaves moisture shows very little susceptibility to the soil water contents unless the soil hydration goes below certain threshold, if this happens the moisture of the leaves rapidly decreases. This could be attributed to the reach of a threshold in which the ‘defensive’ responses in this leaf were lost or drastically reduced given the fast decrease in water availability in this organ during this experiment.

This technique is, to our knowledge, the first non-contact and non-destructive method to monitor *in-vivo* hydration dynamically in plant tissues. We believe it will be very useful in the future to understand the effects of water deficit on vegetable tissues. This at its time is of enormous importance to improve drought resistant crops.


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Recent Experimental Results of a Large Format 80x64 Pixel THz Camera Sensitive to 0.6 – 1.2 THz Radiation

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Abstract: THz applications have been limited by the lack of a cost-effective, real-time, large format THz camera. This paper discusses the recent experimental results of a real-time (100 Hz), large-format (80x64 pixel), broadband (0.6 – 1.2THz) THz camera.

1. Introduction
THz imaging applications have been demonstrated in fields as diverse as non-destructive evaluation, security, and medical imaging [1]; however, wide-scale adoption of these applications has not occurred due to the lack of a cost-effective, large-format, real-time THz camera. Traycer has developed THEIA (THz Engine for Imaging Applications) to fill this market need, see Fig. 1. An overview of THEIA’s technology and initial application results are the focus of this summary, followed by a brief outline of the work that is currently being conducted to further improve THEIA’s imaging performance.

2. THEIA Technology Description
THEIA is a real-time (100 Hz), 80x64 pixel (100 µm x 100 µm pitch), broadband (0.6 THz – 1.2 THz) THz camera with a measured responsivity of 1000 V/W at 0.7 THz [2,3]. The core technological innovation that makes THEIA possible is the 80x64 pixel focal plane array (FPA) of antimode based heterostructure backward diodes (Sb-HBDs) [4]. These diodes can be uniformly fabricated and impedance matched to either narrowband or broadband antenna structures in the 0.1 THz – 2.0 THz regime (depending on the THz application). The FPA is flip-chipped bonded to a readout integrated circuit (ROIC) that multiplexes the pixel outputs to an intermediate electronics board that digitizes and converts the data to a standard CAMLINK output compatible with any off-the-shelf frame grabber. A one inch diameter, high-resistivity float-zone (HRFZ) silicon hyper-hemispherical lens is coupled to the front of the FPA to both focus the incident THz light onto the FPA and to provide the necessary boundary conditions for proper pixel operation.

3. Initial Experimental Results
The experimental set-up shown in Fig. 2 was constructed as an initial demonstration of THEIA’s imaging capabilities. A backward wave oscillator (BWO) emitting 680 GHz continuous-wave THz radiation at approximately 0.75 mW is used as the THz source. The THz beam is collimated through the use of a TPX lens place 2.5 cm from the BWO. An object is placed in the collimated beam (in this case an aluminum plate with a void spelling “THZ” – the thickness of each letter is 2 mm, see Fig. 3), blocking a portion of
the THz radiation. The THz radiation passing through the slit is spread over an image plane formed on the FPA by the combined use of a TPX lens and the HRFZ hyper-hemispherical silicon lens. The transmitted THz image is shown in Fig. 3. This image is the concatenation of three, one-second data runs created by averaging 100 frames of data. Each letter of the image was collected individually and then combined together during post processing to form the final image. These steps were necessary to create the final image due to both the limited beam-width of the BWO, and the attainable field-of-view of the THEIA using the current silicon optics [3]. However, it should be noted that a similar image at this frequency using a single-pixel raster-scanning methodology at 100 µm x 100 µm resolution typically takes on the order of ten minutes to collect.

Fig. 2. Experimental set-up for transmission mode application demonstration.

Fig. 3. (Left): A photograph of an aluminum plate with 2 mm thick letters carved out of the metal (approximately 1 cm in height). (Right): THz image collected by THEIA of a metal void in transmission mode using the experimental set-up of Fig. 2 at 680 GHz.

THEIA has also been successfully demonstrated as a beam profiler for a variety of THz sources, see Fig 4. These images were collected with THEIA positioned 1 inch in front of each respective THz source using only the HRFZ silicon hyper-hemispherical lens to focus the beam onto the FPA. Each image in Fig. 4 is the average of 100 frames of data (or 1 second of data). The image on the left is of a 0.5 mW, 610 GHz Virginia diode electronic THz source. The center image was collected from a 0.75 mW Microtech BWO operated at 680 GHz. The image on the right was collected at the NIST Free Electron Laser.
Fig. 3 Images of three THz sources collected with THEIA: (left) 600 GHz Virginia Diode Source, (center) Microtech backward wave oscillator source (680 GHz), (right) NIST Free Electron Laser.

4. Conclusions and Future Work

This work has demonstrated that THEIA is a promising THz imaging technology in the 0.1–2 THz regime. Images from beam profiling and transmissive non-destructive experiments have been successfully demonstrated.

It is important to note that the results depicted in this study were collected with the initial THEIA prototype that does not have optimized THz optics or reduced noise readout electronics. It is expected that four orders of magnitude improvement to the current signal-to-noise ratio is possible by optimizing the THz optics and the readout electronics. These improvements include the use of digital signal processing (DSP) and Digital Image Processing (DIP) algorithms, the use of a chopper to employ lock-in integration techniques, an optimized redesign of the readout ROIC and back-end intermediate electronics, and modifying the FPA antenna geometry to remove spherical aberrations inherent in the use of hyper-hemispherical lenses [5].

5. References


Improving the Performance of Difference Frequency THz Generation in Waveguides

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Abstract: Improving the performance of THz generation by difference frequency generation is presented for waveguide interactions. A numerical model is used to show how to optimize THz generation and understand cascaded processes in the waveguide.

OCIS codes: (300.6495) THz Spectroscopy; (190.0190) Nonlinear Optics; (190.4975) Parametric Processes

THz sources, detectors, and applications have grown steadily over the past decade to the point where commercial THz systems are available from several companies. However, certain applications still require further source development. For example, stand-off imaging systems need to address power loss due to significant water vapor absorption. For this and similar applications a narrow line width THz source provides distinct advantages over broadband sources. By tuning between water lines, one is able to minimize (but not eliminate) the absorption thus allowing for larger imaging distances. THz sources based on difference frequency generation (DFG) provide narrow linewidth and tunability covering the entire THz spectral region. DFG sources can benefit from further refinement to improve the output power while simplifying the overall system architecture. Here, we focus on techniques to improve the performance of narrow band systems based on DFG in waveguides.

THz generation by means of DFG between two near-IR lasers has two main problems that stem from the large difference in the frequencies of the inputs and that of the THz output. In a typical DFG setup, one focuses the inputs into a crystal to generate the DFG output. When applied to THz generation, the THz beam has a diffraction that is approximately 100 times or greater than that of the inputs. This rapid diffraction reduces the overlap of the interacting beams and reduces the parametric gain. Another issue arising from the large frequency difference is illustrated by the expression for DFG described in terms of photon energy, \( h\omega_p = h\omega_s + h\omega_{THz} \) where \( \omega_p \) and \( \omega_s \) are the pump and signal input angular frequencies for the DFG process, and \( \omega_{THz} \) is the output THz angular frequency. This expression shows that the maximum conversion efficiency to the THz is given by \( \eta_{max} = \frac{\omega_{THz}}{\omega_p} = \frac{\lambda_p}{\lambda_{THz}} \).

Because of the large wavelength differences between the THz and the pump input, the DFG process for generating THz has a large quantum defect. Both the large divergence and large quantum defect may be addressed by confining the process in a waveguide structure.

Our approach to studying THz generation in waveguides is using a numerical model. This model uses parameters that one would encounter in a laboratory setting for difference frequency generation. We assume two lasers are co-aligned and focused at the input face of the waveguide structure and these beams then are numerically propagated through the structure. This approach better simulates the laboratory setting where lasers with Gaussian beam profiles are focused into the waveguide. In this case many modes of the waveguide, including nonpropagating modes, are potentially excited depending on the mode matching of the input laser beams to the waveguide modes. In our simulations, no assumptions are made with regard to modes, instead we let the field propagate based on the wave equation and waveguide index of refraction structure.

The model uses the split-step technique [1], which has been successfully implemented to numerically model three-wave interactions for a large range of applications. Extending the model to the THz regime is straightforward with the requirement that, for bulk interactions, the numerical grid be large enough to account for the rapid THz diffraction. In the case of a THz waveguide, this criterion is relaxed to require that the grid be large enough to accurately sample the input beams as well as the guided THz field. In many cases a two-dimensional cross-sectional grid is employed to allow for asymmetric effects such as Poynting vector walk-off. However, in some cases, symmetry in the process may allow for a one-dimensional grid. In the current study, we assume cylindrical symmetry, which allows us to use a 1D grid. Figure 1 a) shows the basic geometry. Cylindrical symmetry is appropriate, for example, for LP modes in a cylindrical waveguide. These types of modes are a natural
consideration for nonlinear mixing in a waveguide where phase matching dictates linearly polarized modes. Going to a cylindrical coordinate system for these cases allows for a 1D numerical grid, but it also requires the use of Hankel transforms instead of Fourier transforms in order to model diffraction [2]. The Hankel transform is not as fast as an FFT, so the advantage of the 1D grid is lessened by the longer computation time of the Hankel transform. But overall, the computation time is decreased when compared to an equivalent 2D grid with the same point spacing. The 1D cylindrically symmetric case is especially useful for optimization since many simulation runs may be required.

The large wavelength difference for THz generation by way of DFG introduces challenges to waveguide design. Because of large THz wavelengths, on the order of one hundred to hundreds of microns, the waveguide core size will be of the same order. In this regime, the THz waveguide looks like a bulk crystal or a highly multi-mode structure to the NIR inputs. THz waveguide lengths are limited by practical considerations such as material absorption in the THz and the restriction that the waveguide is fabricated on a substrate, which in turn dictates the maximum waveguide length to several cm. For such structures, instead of launching waveguide modes for the NIR inputs, it is more appropriate to consider focusing the near-infrared inputs into the structure to maximize the nonlinear interactions while avoiding clipping on the structure. The design is then a combination of optimizing the nonlinear interaction by adjusting the THz waveguide size and input spot sizes. Figure 1 a) shows a scenario for a cylindrical waveguide, and Figure 1 b) shows the output for the ranges of input beam sizes and waveguide diameters. The waveguide consists of a core-air interface and does not have a cladding because of the difficulty in fabricating a cylindrical waveguide with a closely matched cladding for THz frequencies.

The particular simulation shown in Figure 1 was run for a 1 cm crystal assuming that the process was either birefringently phase matched or quasi-phase matched (QPM). The peak powers used in the simulation were 50 kW, which is a common power level for nsec pulsed lasers (approximately 500 μJ in 10 nsec). The simulation was run using a 1.8 THz DFG output (the inputs were ~1.8 μm). Because the THz field sees a waveguide, it experiences waveguide dispersion. Hence as the waveguide size is decreased, the phase matching or quasi-phase matching has to be adjusted accordingly. For each point in the figure, Δk was optimized for maximum output. This figure shows that tight focusing is the best strategy for obtaining high output power. This result makes sense considering the short 1 cm length, which is smaller than the confocal parameter for the beam sizes considered here. The lower limit on the spot size was estimated to be the minimum based on material damage threshold. The figure also shows that the waveguide diameter has a large range where the performance is high. When compared with a bulk interaction, the waveguide results here are approximately 2.5 times more efficient.

It is possible in principle to achieve even higher conversion efficiency by working around the quantum defect inherent in the DFG process. Nearly all of the pump energy in THz DFG goes to amplifying the signal. A common strategy for mid-wave infrared and near-infrared is to use a second stage to amplify the DFG output at the expense of the amplified signal beam [3]. In the mid-wave infrared the phase matching condition for these two processes is

![Diagram](image_url)
different thus requiring two phase matching regions for the principal DFG stage and the second cascaded stage. In the case of THz generation the situation is somewhat different. Here the coherence length of the DFG process and the cascaded process are nearly the same and may be a significant fraction of the overall crystal length. For example, coherence lengths on the order of 0.5 mm are typical. In this situation, the cascaded process runs in parallel with the principal DFG process. In this regard, the best strategy is to use as long a crystal as possible with a fixed quasi-phase matching period. In this way, both processes build up coherently. Such a situation only arises to a significant degree when the DFG process starts to deplete the pump. For lower energies, the cascaded processes do not become appreciable.

In the high conversion efficiency limit, as has been encountered with MW peak powers [4], we also consider multiple cascaded processes. For example, the THz field may sum-frequency mix with the pump. In our simulation we consider 6 fields as shown in the inset of Figure 2 (THz field not shown). Other cascaded orders are not included since the crystal length used here won’t allow them to become appreciable. Although the coherence lengths of these processes are all similar, the coherence length for generating a second THz field at twice the frequency is significantly different. Therefore we do not include outputs at multiples of the THz frequency. As an example, we consider a GaP waveguide with a 180 μm diameter, and two inputs with 50 KW peak power, 65 μm beam radii, and wavelengths of 1.8 and 1.82 μm (yielding a 1.8 THz output). Figure 2 a) shows the NIR fields, while Figure 2b) shows the THz field. In the figure the inputs are at ωp (pump) and ωs (signal) while the cascaded frequencies are given by ω4=ωs−ωTHz, ω5=ω4−ωTHz, and ω6=ωp+ωTHz. These relationships show that all the fields are coupled to each other via the THz field. The simulation shows that it is possible to nearly deplete both the pump and signal, and when this occurs the other cascaded frequencies grow in amplitude. For higher peak powers, the scale becomes shorter and the observation of the cascaded frequencies becomes more likely. In the higher peak power limit, there is an optimum crystal length for maximum THz output because of back conversion of the THz.

In conclusion this presentation shows a method to optimize THz generation in waveguides using a numerical model. The model is extended to include cascaded THz processes, which show that it is possible to nearly deplete both the pump and signal to help boost the THz output. The authors would like to acknowledge discussions with Wei Shi and Arturo Chavez-Pirson from NP Photonics that helped to give context to ideas presented in this talk.

ATH1A.4 • AIO Postdeadline Paper

Thursday, 28 June, 9:40 – 10:00
Cypress 3
Experimental Demonstration of an NIR Compressive Sensing Hyper-Spectral Imaging System

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Abstract: We utilized the compressive sensing theory in building a hyperspectral imaging system for NIR wavelengths. This system simultaneously captures 24 spectral images for the wavelength range between 990-1450 nm without any mechanical/temporal scanning processes.

OCIS codes: (110.4234) Multispectral and hyperspectral imaging; (300.6340) Spectroscopy, infrared

1. Introduction

Current NIR Hyper-Spectral Imaging (HSI) systems usually rely on some mechanical or temporal scanning processes to acquire the complete spatial/spectral information of the imaging scene [1]. The scanning process unavoidably carries a time penalty and undermines the performance of HSI systems in low light or high speed imaging applications.

In visible wavelengths, Coded Aperture Snapshot Spectral Imaging (CASSI) systems were developed to circumvent the scanning processes used in conventional HSI systems [2-4]. In this work, we report a CASSI system for NIR hyperspectral imaging applications. Specifically, we are interested in the wavelength range from 990-1450 nm. We use a photomask, which implements a Compressive Sensing (CS) measurement pattern, to impose intensity modulation on NIR optical images. The modulated image intensity is then collected into an NIR Relay lens/double-Amici Prism (R/P) structure. On the image plane of the R/P structure, an NIR FPA is used to capture the spectrally dispersed image of the modulated image intensity, which represents a set of CS measurement result for the original image cube. The original image cube can be reconstructed from the CS measurement result by solving an $l_1$-regularized minimization problem [2-4]. We introduce the optical design and experimental realization of the NIR CASSI system and present an NIR image cube reconstructed from our experimental setup.

2. NIR CASSI System

Figure 1 shows the schematic drawing of the NIR CASSI system.

In Fig.1, a photomask is installed on the image plane of an NIR imaging lens. The photomask implements a CS measurement pattern, which is essentially a binary random pattern. The original image cube is represented as $f(m,n,\lambda)$ and the binary translucency of the photomask is represented as $t(m,n)$. In the transmission direction of the photomask and along the optical axis of the imaging lens, we install an NIR relay lens and an NIR double-Amici prism to generate spectrally dispersed image of the modulated image intensity on an NIR FPA (Xenics, model: XEVA 2508). The optical operations realized by the photomask, the relay lens, the double-Amici prism, and the NIR FPA were modeled as a system transfer matrix $H$ in [2-4], and the spectrally dispersed image captured by the NIR FPA was represented as $g = H \cdot f$. The system transfer matrix $H$ is not a square, and thus the image reconstruction problem $f = H^{-1} \cdot g$ is not directly solvable. In this work, we utilized the Two Step Iterative
Shrinkage/Thresholding (TwIST) algorithm to accomplish the image reconstruction task, which considers the following minimization problem [5]:

$$\min_f \| H \cdot f - g \|_2^2 + \delta \cdot TV(f),$$

where $TV(f)$ is a Total Variation (TV) regularization term, which is defined as:

$$TV(f) = \sum_{j,k} \sqrt{(f(j + 1, i, k) - f(j, i, k))^2 + (f(j, i + 1, k) - f(j, i, k))^2}.$$  

$\delta$ is a regularization parameter for the TV term.

NIR imaging and relay lenses are commercially available. In our case, we used a pair of NIR achromatic lenses (Thorlabs, model: AC254-100-C-ML) to realize the functionality of optical relay. Another achromatic lens pair was used to form NIR optical images on the photomask. The NIR double-Amici prism is not commercially available. We designed it in our lab and customized it from Shanghai Optics. We defined an NIR Abbe number to quantitatively evaluate the dispersion performance of glass materials in the NIR spectrum: $\nu_{NIR} = \frac{n_2 - 1}{n_1 - n_3}$, where $n_2$, $n_1$, $n_3$ represent refractive indices of glass materials at wavelengths of 1250 nm, 950 nm, and 1450 nm, respectively [6]. Based on a comprehensive survey of glass materials from major glass vendors, we decided on using Schott glasses of N-PK52A and N-KZFS11 to build the NIR double-Amici prism. N-PK52A has a refractive index of 1.488 and an NIR Abbe number of 121.865 at 1250 nm. N-KZFS11 has a refractive index of 1.617 and an NIR Abbe number of 66.547 at 1250 nm. Both of the selected glasses have good transmissions at NIR wavelengths. Figure 2(a) shows the optical design of the NIR double-Amici prism and Fig. 2(b) shows the manufactured product. The photomask was customized from Advanced Reproduction. A binary random pattern was coated on the mask, with a pixel dimension of 128×128 and a pixel pitch of 19.8 µm. Figure 2(c) shows the design of the photomask. Figure 2(d) shows the optical assembly of the photomask, the NIR R/P structure, and the NIR FPA.

3. Experimental Result

The imaging target used in this experiment was a part of a translucent USAF resolution target. Figure 3(a) shows the imaging target and its illumination condition. This target was illuminated with two different NIR sources: in region 1, an NIR LED was used to offer illumination and in region 2, an NIR monochromator was used to offer illumination. Figure 3(b) shows a CS measurement result generated from our experimental setup when a 1050 nm LED was used to illuminate region 1 and a monochromator emission of 1400 nm was used to illuminate region 2. Figure 3(c) shows the NIR image cube reconstructed from the CS measurement result, which contains 24 spectral channels.
In the reconstructed image cube, we can see that the features of the imaging target in region 1 was reconstructed with strong intensity in spectral channels from 1030 nm to 1130 nm and features of the target in region 2 was reconstructed with strong intensity in spectral channels from 1390 nm to 1410 nm. We also evaluated the intensity variations of the reconstructed image cube at location 1 and location 2, which are located on region 1 and 2 respectively. Figure 3(d) shows those intensity variations. We can see that at location 1 of the imaging target, there is an intensity peak in the image cube at the spectral channel of 1090 nm, which is slightly different from the peak emission wavelength of the NIR LED specified in its user manual. At location 2, there is an intensity dual-peak in spectral channels of 1390 nm and 1410 nm. This is because the monochromator emission has a bandwidth of 20 nm at the wavelength of 1400 nm.

4. Conclusion

In this work, we report the development of an NIR CASSI system, which virtually does not introduce any time penalty in the process of acquiring NIR spatial/spectral image cubes. We present the optical design and the experimental realization of this system. We also verified/evaluated the system performance by presenting an image cube reconstructed for a real-world target, which contains 24 spectral channels for the wavelength range between 990-1450 nm.

5. References

Addendum

OW4D.1 • Tutorial on Recent Advances in Ion Beam and Plasma Jet Processing,
Axel Schindler; Leibniz-Institut für Oberflächenmodifizierung, Germany
Tutorial on Recent Advances in Ion Beam and Plasma Jet Processing

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Abstract: The Tutorial will highlight recent advances achieved in R&D of Ion beam figuring (IBF), ion Beam Smoothing (IBS), Reactive Ion Beam Etching (RIBE) and atmospheric Plasma Jet Machining (PJM) (deep aspherization, nanometer shape correction, smoothing, film deposition) at IOM Leipzig.

OCIS codes (220.1250) Aspherics; (220.4610) Optical fabrication; (220.5450) Polishing; (350.3850) Materials processing

1. Ion beam figuring
Ion beam figuring (IBF) for ultra precision surface finishing is well established in high end optics fabrication for lithography, space and beam-line optics and advanced optical instrument, respectively [1, 2]. IBF standard technology uses a constant and stable ion beam that moves computer controlled across the entire optic via a meander like scanning with variable scan line velocity according to the local dwell time necessary for the specified removal of material at the certain place. The beam tool size has to be adjusted according to the spatial surface error size processing. One serious disadvantage of this method is connected with the continuous and constant beam and the limitations in maximum speed and acceleration/deceleration of the mechanical multi axes motion system. This causes wasting of material removal at least in that part of the surface where no material should be removed (absolute minimum of the surface figure). Further there can be some effects of direct additional surface error production in cases of steep gradients and small surface feature sizes of the surface topology where the beam can not follow the very small dwell times due to the limitations of the dynamics of the motion system.

The new solution uses a pulsed ion beam instead of a cw one combined with pulse width modulation (PWM) for variation of the mean beam power and the control of the PWM signal by the motion control of the multi axes system that moves the ion beam (source) across the surface to be figured. Using this trick we effectively extend the limited dwell time scale realized by the mechanical motion system by two orders of magnitude to lower values.

Figure 1 shows the scheme of the new technique. New IBF processing software (DtCalc) has been developed for a two dwell times algorithm velocity driven and PWM driven, respectively.

2. Ion beam smoothing / ion beam nano-structure generation by atomic self assembly
In contrast to the stringently deterministic process of ion beam figuring, ion beam induced smoothing of micron and nano meter features is strongly coupled to atomistic processes which are characteristic for the much shorter spatial length scales and are less deterministic. Nevertheless, within the last years low-energy ion beams have been developed as alternative tools that can be beneficially used to tailor the microscopic surface roughness of solid surfaces on a nanometer and micron scale. Recently developed different ion beam assisted processes for the preparation of ultra-smooth surfaces with RMS roughness values $r \leq 0.2$ nm. Especially, ion beam direct smoothing and smoothing with planarization or sacrificial layers are demonstrated. A review is given by Frost et al. [3].

Fig. 1 left: Scheme of the motion synchronized PWM ion beam controlled ion beam figuring technique; middle: upper row: IBF simulation results of sub-nm figure mid spatial wavelength error features of a $\varnothing$ 160 mm lens using new PWM technique, bottom row: local dwell time distributions of the PWM action only (left) and the axes velocity only (right); right: histograms of the dwell times for the standard cw beam dwell time IBF and of the new combined PWM ion beam mode.
3. **Plasma Jet Machining**

There is a growing demand for aspheric and free-form optical elements with large deformations. High-Rate Plasma Jet Machining (HR-PJM) is a non-contact, local dry-etching method that can be used in the fabrication of such elements. It works best on fused silica and ULE® with material removal rates up to 50 mm³/min. Thus, also large parts can be processed to achieve strong deviations from a suitable initial surface. As key advantages of the method there are nearly no limitations by local curvatures of the parts to be machined and no sub-surface damages are generated during the machining process. The latter fact enormously reduces the polishing effort afterwards and hence the formation of related mid-spatial structures is minimized. On the other hand the etching process is very sensitive on structural defects and chemical impurities, which can be used to specifically remove such kind of imperfections [4].

At IOM there is a more than 15 years experience in local reactive plasma etching processes primarily done under rough vacuum conditions and later realized at atmospheric pressure [5, 6, 7]. During this time a broad variety of plasma jet tools with different removal rates and tool widths has been developed covering a wide range of applications. In addition to the aspherization discussed here also ultra-precision surface machining in the sub-mm spatial range with nanometers depth accuracy can be performed [8, 9, 10, 11]. Figure 3 shows the high rate PJM of a fused silica cylindrical asphere.

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Fig. 2 Illustration of the processing sequence of Zerodur used as substrates for EUVL optical elements. In a first step a shape correction was made by ion beam figuring (IBF). Due to the special composition of Zerodur this results in an increased surface roughness 0.45 nm RMS (a). In the second step the substrate is coated with a thin SiOx layer (~50 nm) by ion beam sputtering, where the surface roughness is already reduced to values of $\leq 0.4$ nm RMS (b). Finally, an ion beam direct smoothing step was applied (c). The final HSFR was now $\leq 0.2$ nm RMS. From the PSD graph (d) it is seen that surface smoothing is achieved for all spatial frequencies that are $f = 1 \times 10^{-3}$ nm⁻¹.

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Fig. 3 High-rate plasma jet machining operating in microwave excited plasma jet cw-mode up to 600 W 2.45 GHz, a) scheme, b) fabrication of a strongly curved concave plane-parabola starting from a best fit plane-cylinder optic, c) centre line error of an off-axis plane-elliptical mirror blank manufactured by plasma-jet-machining techniques using two steps (i) high rate PJM aspheric figuring and (ii) low power small tool PJM figuring error correction.
4. Plasma jet polishing

As a third example for using an atmospheric plasma jet in optical surface fabrication the smoothing of e.g. ground surfaces with nearly no material removal and hence without changing the form will be presented. The big advantage of this technique is that not only the high-spatial-frequency-roughness (HSFR) is reduced to optical quality (< 0.5 nm RMS) but also the critical mid-spatial-frequency-roughness (MSFR) is significantly reduced in many cases. Furthermore, due to the dimension of the plasma-jet-tool the smoothing can be done in a very local way. This gives the opportunity either to polish small sub-areas or small-sized and strongly curved parts. Now, the idea for the future is to establish a cost efficient two-step process chain consisting of precision grinding and plasma-jet polishing for the manufacturing of aspheres and free-forms. If higher shape accuracy is necessary, the plasma-jet based surface error correction can be included just by switching the plasma jet process from smoothing to etching. Figure 4 shows examples of plasma jet polishing of fine ground fused silica surfaces.

![Plasma jet polishing](image)

Fig. 4 Photographs of partially plasma-polished ground fused silica surfaces (a) and (c) with roughness’s of ~ 100 nm rms in the ground part and b) the surface profile along red dotted line of a) measured by optical profilometry. Waviness and roughness curves have been extracted from the raw data (profile in b) by computer filter procedures, d) AFM-measurement of a plasma-jet polished fine ground fused silica surface.

5. Conclusions

New IBF, IBS and PJM techniques have been demonstrated with large technological potential. They will certainly have important impact on ultra precision surface processing and finishing for high end optics fabrication technology next future. Further new achievements on RIBE technique development for the transfer of 3D resist mask structures into hard optical materials surfaces will be shown in the tutorial.

6. References

# Key to Authors

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