www.photonics.com

October 2016

PHOTONICS spectra

Optics

Fresnel to the Future

Special Section

Art and Science

The Development and Impact of Optics

PHOTONICS MEDIA

LAURIN PUBLISHING

Low Noise Preamplifiers

Voltage Preamplifier

- ***1 MHz bandwidth***
- ***4 nV/√Hz input noise***
- ***100 MΩ input impedance***
- ***Gain from 1 to 50,000***
- ***RS-232 interface***
- ***$2595** (U.S. list)*

Current Preamplifier

- ***1 MHz bandwidth***
- ***5 fA/√Hz input noise***
- ***1 pA/V maximum gain***
- ***Adjustable DC bias voltage***
- ***Line or battery operation***
- ***$2595** (U.S. list)*

SR560 Low-Noise Voltage Preamplifier

The SR560 is ideal in applications where noise matters — like low-temperature or optical detection measurements. The SR560 offers a true-differential (or single ended) front-end, configurable high/low pass filtering, and rechargeable batteries that provide up 15 hours of line-free operation. With a microprocessor that 'sleeps' except when the instrument's setup is changed, no digital noise will contaminate your low-level analog signals.

SR570 Low-Noise Current Preamplifier

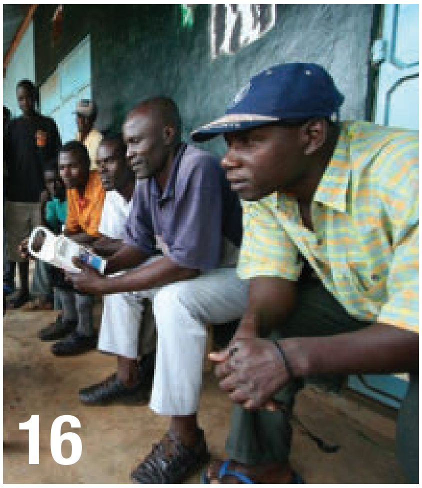
Designed for low-noise signal recovery experiments, the SR570 Current Preamplifier is the industry's standard. It offers current gain up to 1 pA/V, configurable high and low pass filtering, and input offset current control. The SR570 can be powered from the AC line or its built-in batteries, and is programmable over RS-232. High-bandwidth, low-noise, and low-drift gain modes allow you to optimize the instrument for different applications.

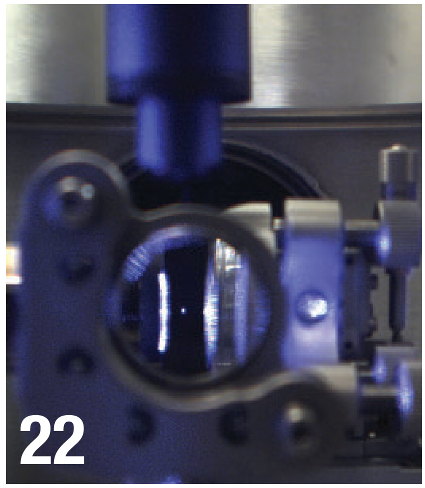
SRS **Stanford Research Systems, Inc.**
1290-D Reamwood Avenue, Sunnyvale, CA 94089

Phone: (408)744-9040
www.thinkSRS.com

Content

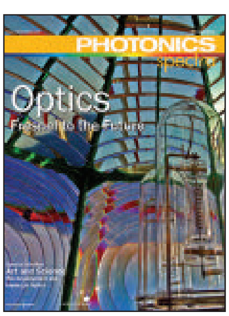
OCTOBER 2016 www.photonics.com VOLUME 50 ISSUE 10





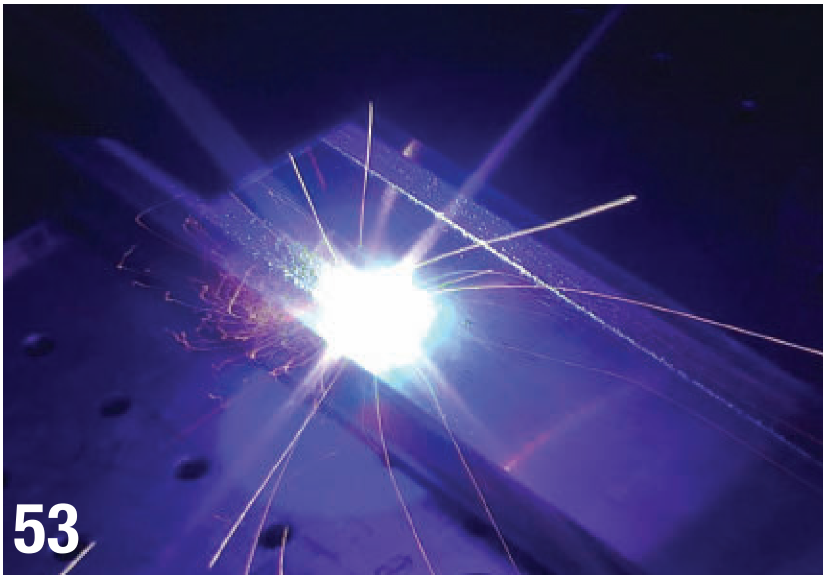
Departments & Columns

THE COVER
A Fresnel lens, named after its inventor, Augustin-Jean Fresnel. Cover design by Senior Art Director Lisa N. Comstock.



PHOTONICS SPECTRA ISSN-0731-1230, (USPS 448870) IS PUBLISHED MONTHLY BY Laurin Publishing Co. Inc., 100 West Street, PO Box 4949, Pittsfield, MA 01202, +1 413-499-0514; fax: +1 413-442-3180; e-mail: photonics@photonics. com. TITLE reg. in US Library of Congress. Copyright ® 2016 by Laurin Publishing Co. Inc. All rights reserved. Copies of Photonics Spectra on microfilm are available from University Microfilm, 300 North Zeeb Road, Ann Arbor, MI 48103. Photonics Spectra articles are indexed in the Engineering Index. **POSTMASTER:** Send form 3579 to Photonics Spectra, 100 West Street, PO Box 4949, Pittsfield, MA 01202. Periodicals postage paid at Pittsfield, MA, and at additional mailing offices. **CIRCULATION POLICY:** Photonics Spectra is distributed without charge to qualified scientists, engineers, technicians, and management personnel. Eligibility requests must be returned with your business card or organization's letterhead. Rates for others as follows: $122 per year, prepaid. Overseas postage: $28 surface mail, $108 airmail per year. Inquire for multiyear subscription rates. Publisher reserves the right to refuse nonqualified subscriptions. **ARTICLES FOR PUBLICATION:** Scientists, engineers, educators, technical executives and technical writers are invited to contribute articles on optical, laser, fiber optic, electro-optical, imaging, optoelectronics and related fields. Communications regarding the editorial content of Photonics Spectra should be addressed to the managing editor. Contributed statements and opinions expressed in Photonics Spectra are those of the contributors – the publisher assumes no responsibility for them.

PHOTONICS: The technology of generating and harnessing light and other forms of radiant energy whose quantum unit is the photon. The range of applications of photonics extends from energy generation to detection to communications and information processing.



Features

PHOTONICS spectra

Group Publisher Karen A. Newman

Editorial Staff

Managing Editor Michael D. Wheeler
Senior Editor Justine Murphy
Multimedia/Web Editor Robin Riley
Senior Copy Editor Mary Beth McMahon
Copy Editor Carol McKenna
Contributing Editors Hank Hogan
Marie Freebody

Creative Staff

Senior Art Director Lisa N. Comstock
BioPhotonics Art Director Suzanne L. Schmidt
Designer Janice R. Tynan

Digital Media & IT Staff

Director of Publishing Operations Kathleen A. Alibozek

Digital & IT Development Manager Brian L. LeMire
Digital Project Manager Alan W. Shepherd
Digital Developer & IT Support Brian A. Bilodeau
Digital Designer Brian Healey
Computer Specialist & Digital Support Angel L. Martinez

Editorial Offices

100 West Street, PO Box 4949
Pittsfield, MA 01202-4949
+1 413-499-0514; fax: +1 413-442-3180
www.photonics.com

News releases should be directed to our main office. If you would like an editor to contact you, please notify us at the main office, and we will put you in touch with the editorial office nearest you.

Editorial email: editorial@photonics.com
Advertising email: advertising@photonics.com
Press releases: pr@photonics.com
Event listings: events@photonics.com

More Than 95,000 Distributed Internationally

BPA WORLDWIDE Connectiv

www.photonics.com

PHOTONICS spectra

Corporate Staff

President/CEO	Thomas F. Laurin
Vice President	Kristina A. Laurin
Vice President	Ryan F. Laurin
Internal Audit Officer	Mollie M. Armstrong
Controller	Lynne M. Lemanski
Accounts Receivable Manager	Kathleen G. Paczosa
Business Manager	Elaine M. Filiault
HR/Office Assistant	Carol J. Atwater
Administrative Assistant	Marge Rivard

Business Staff

Associate Director of Sales	Rebecca L. Pontier
Trade Show Coordinator	Allison M. Mikaniewicz
Director of Audience Development	Heidi L. Miller
Assistant Circulation Manager	Melissa J. Liebenow
Circulation Assistants	Alice M. White
	Kimberly M. LaFleur
	Theresa A. Horn
Traffic Manager	Daniel P. Weslowski

Advertising Offices

Main Office 100 West Street, PO Box 4949
Pittsfield, MA 01202-4949
+1 413-499-0514
Fax: +1 413-443-0472
advertising@photonics.com

Japan Sakae Shibasaki
The Optronics Co. Ltd.
Sanken Bldg., 5-5 Shin Ogawamachi
Shinjuku-ku, Tokyo 162-0814, Japan
+81 3-3269-3550
Fax: +81 3-5229-7253
s_shiba@optronics.co.jp

For individual advertising contacts' information, view listings next to advertiser index.

www.photonics.com

editorial COMMENT

A century — and more — of innovation

This month, the Optical Society of America (OSA) will hold its annual meeting in Rochester, N.Y., at Frontiers in Optics, the capstone event of a year-long celebration of the society's 100th anniversary. Rochester is a fitting venue, after all, as it was the site of the society's founding in 1916 by physicist Perley Nutting.

It's hard to imagine that Nutting could have foreseen the profound impact the optics field would have on science and technology in the century that followed. Optics were critical to NASA's space program that led to man's first steps on the moon. The telecom revolution of the '90s and early 2000s stemmed from advancements in optics. And today, researchers are making astounding breakthroughs in cancer research and afflictions of the brain.

In a nod to OSA's milestone birthday, our special section this month is dedicated entirely to optics. Senior Editor Justine Murphy interviewed current OSA president Alan Willner, who reflected on breakthroughs of the last 30 years and shared his predictions on the role of optics in the photonic integrated circuit revolution of the coming decades. See "3 Questions Interview," page 58.

Past and present are the themes of Murphy's feature, "Art and Science: The Development and Impact of Optics," on page 59. Nineteenth century physicists Thomas Young, Augustin-Jean Fresnel and Hermann L.F. von Helmholtz formulated the wave theory of light and polarization, which would lay the groundwork for today's advances in quantum dot technology and advancements in materials science.

In keeping with our optics focus, our cover story, "Great Strides in Optical Fabrication," page 42, by contributing editor Marie Freebody, takes a closer look at this evolving and dynamic field, focusing on new approaches to molding, surface process optimization and freeform capable tools.

Other articles in this issue include:

- "3D Displays Get Closer but Face Hurdles," by Hank Hogan, page 34.
- "Two-Dimensional MEMS Arrays Pave Way for Mobile Spectrometers," by Mike Walker of Texas Instruments and Hakki Refai of Optecks, page 38.
- "Maximum Exposure: Ray-Tracing Software Optimizes Reflector Design," by Michael Gauvin of Lambda Research, page 48.
- "New Milestone in Laser Bonding," by Trumpf's Florian Kiefer, page 53.

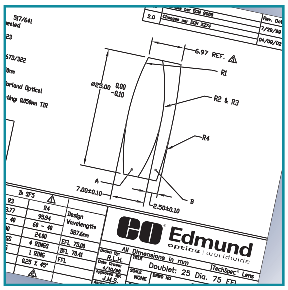
We hope you enjoy the issue. Here's to the next century of optics advances!

Michael D. Wheeler
michael.wheeler@photonics.com

Submit your press releases to **pr@photonics.com**, or use our online submission form at **Photonics.com/prsubmit**.

STOCK & CUSTOM OPTICS

From DESIGN to PROTOTYPE to VOLUME PRODUCTION



Complete design data available

Quickly build prototypes with stock components

Vertically integrated manufacturing for your custom assemblies

Craig Ament
Optical Coating Engineer
Barrington, NJ USA

Contact Us to Discuss Your Application!
+1 (856) 547 3488
www.edmundoptics.com/manufacturing

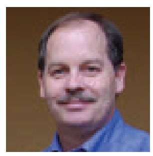
Edmund® optics | worldwide

PHOTONICS spectra

CONTRIBUTORS

Marie Freebody
Regular contributing editor Marie Freebody is a freelance science and technology journalist with a master's degree in physics with a concentration in nuclear astrophysics from the University of Surrey. Page 42

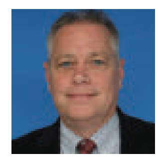
Justine Murphy
Justine Murphy is Photonics Media senior editor. She is an award-winning journalist with more than 15 years of experience in the field. Page 59



Michael Gauvin
Michael Gauvin is the vice president of sales and marketing at Lambda Research Corp. with over 30 years of optical engineering experience. Page 48

Hakki Refai
Hakki Refai, Ph.D., is chief technology officer for Optecks. Refai has more than 10 years of experience in the design and development of optical, electronic and software systems for DLP-based systems. Page 38

Hank Hogan
Regular contributing editor Hank Hogan holds a Bachelor of Science degree in physics from the University of Texas at Austin. He worked in the semiconductor industry and now writes about science and technology. Page 34.



Mike Walker
Mike Walker is a business development manager for Texas Instruments' DLP Products, leading its spectroscopy business. Prior to this role, Mike spent more than 30 years leading multiple technical and business teams at Texas Instruments. Page 38

Florian Kiefer
Florian Kiefer is a senior application engineer at Trumpf Inc. in Farmington, Conn. In this role, he supports Trumpf's short- and ultrashort-pulse solid-state laser product portfolio. Page 53

In the November issue of
Photonics Spectra...

- **Quantum Cascade Lasers**
- **Astronomical Imaging**
- **Flow Cytometry**
- **Optical Materials**
- **Optogenetics**

You'll also find all the news that affects your industry, from tech trends and market reports to the latest products and media.

Check out a sample of the digital version of *Photonics Spectra* magazine at www.photonics.com/DigitalSample. It's a whole new world of information for people in the global photonics industry.


SPIE. PHOTONICS WEST
CONNECTING MINDS. ADVANCING LIGHT.
2017
PHOTONICS WEST
THE PREMIER EVENT FOR THE PHOTONICS AND LASER INDUSTRIES
Register Today
www.spie.org/2017pw
BiOS—Biomedical Optics
BRAIN—Neurophotonics
Translational Research
LASE—Lasers and Sources
OPTO—Optoelectronic Devices
3D Printing
Industry Sessions
The Moscone Center
San Francisco, California, USA
Conferences & Courses
28 January–2 February 2017
Photonics West Exhibition
31 January–2 February 2017
BiOS EXPO
28–29 January 2017

Welcome to photonics.com

The online companion to *Photonics Spectra*

What's Online:

New!

"Breaking Through" is a Photonics Media podcast that examines the role of women in photonics. This series, hosted by Photonics Media Senior Editor Justine Murphy, focuses on women working in photonics and how they rise above the challenges they face to help future generations succeed.
To listen to this free podcast, visit: **www.photonics.com/V280**.

Vision Guided Robotics

REGISTER NOW

Thursday, Oct. 6, at 1 p.m. EDT

David Bruce will discuss the two subsets of VGR, 2D and 3D, and review the proper techniques for selecting and implementing vision guidance systems. He will cover the steps required to set up and execute 2D and 3D VGR, the advantages of using virtual VGR, and the trade-offs to consider when selecting a VGR system.

Bruce is an engineering manager at FANUC America Corp. (FAC). He has an M.S. from Oakland University and a B.A.Sc. from the University of Windsor.

To register, visit **www.photonics.com/W97**.

Choosing the Right LED for Medical Diagnostics and Bioanalytical Systems

Wednesday, Oct. 19, at 1 p.m. EDT

Presented by Excelitas Technologies

This webinar will examine the key factors to consider when determining which light source is best suited for your application, including wavelengths, uniformity, technology, thermal management, light delivery, power budget and economy of space.

Presenter **Kavita Aswani** is the senior applications scientist for the Life Sciences products at Excelitas Technologies. She holds a Ph.D. from the University of Iowa. **Tom Papanek** is director of global product development for Excelitas Technologies, Solid State Lighting. He holds a Ph.D. in mechanical and biomedical engineering from the Massachusetts Institute of Technology.

To register, visit **www.photonics.com/W99**.

Intracoronary NIRF Molecular Imaging

Monday, Oct. 24, at 1 p.m. EDT

Dr. Farouc Jaffer will speak on novel approaches to imaging technology that could ultimately help prevent heart attacks and strokes. Dr. Jaffer holds a B.S. from Stanford University, and an M.D. and Ph.D. in biophysics from the University of Pennsylvania. He is an associate professor at Harvard Medical School, an attending cardiologist at Massachusetts General Hospital (MGH) and a principal investigator in the MGH Cardiovascular Research Center and medical director of the MGH Coronary Artery Disease Program.

To register, visit **www.photonics.com/101**.

Solar lighting could create 2 million jobs in developing countries

A shift to solar LED systems and away from fuel-based lighting in the developing world may spur economic development as well as environmental improvements, creating an estimated 2 million solar-based jobs in some of the world's poorest regions.

A survey of major solar LED lighting companies, conducted by Evan Mills at Lawrence Berkeley National Laboratory (Berkeley Lab), found that 38 solar-related jobs are created for each 10,000 people living off-grid and for whom stand-alone solar LED lights are suitable.

Solar LED lanterns and flashlights are gaining in popularity in the developing world, thanks to being "a rugged, affordable, reliable, compact and very manufacturable technology and one that is effectively wireless," said Mills.

Mills calculated that the number of new jobs already created from the increased use of solar-LED lighting in developing regions has matched the current employment associated with fuel-based lighting in those regions (approximately 150,000 jobs). Current statistics point to the potential creation of 2 million new jobs to fully serve the 112 million households globally that currently lack electricity access, are unlikely to become connected to a grid, and are unable to afford even a mini solar home system. Mills' study may be the first global analysis focusing on how the transition to solar LED lighting may impact employment and job creation in the developing world.

Berkeley Lab

A focus group with rural Kenyans on solar-LED lanterns, from a 2009 Berkeley Lab study.

Humboldt State University, Schatz Energy Research Center

Sample solar LED lights in a testing lab.

"People like to talk about making jobs with solar energy, but it's rare that the flip side of the question is asked — how many people will lose jobs who are selling the fuels that solar will replace?" said Mills. "We set out to quantify the net job creation. The good news is, we found that we will see many more jobs created than we lose."

The research further found that the jobs created by the emerging solar LED industry would be healthier, more stable and of overall higher quality than the current jobs for fuel-based lighting available in developing regions of the world.

While there will be some overlap in terms of skill sets required for the new jobs, retraining and education will be necessary. "The challenge of re-employing some of these people is not trivial," Mills said.

A transition to solar LED lighting technologies could have immense benefits for the health and education of these populations. Solar lanterns provide more and better light than fuel-based lighting sources, allowing children to study in the evening and businesses to stay open after dark.

"As long as people are using kerosene lanterns, candles and other fuels for light, it's actually reinforcing poverty because they're spending so much on energy and getting so little in return," said Mills.

The potential environmental benefits are also enormous. A study Mills published in *Science* in 2005 estimated global off-grid lighting energy expenditure at $38 billion per year. That corresponds to CO_2 emissions of 190 million metric tons per year, or the equivalent of those from about 30 million typical American cars.

"All of this energy and pollution can potentially be saved with a conversion to solar LED systems," he said.

The research was published in *Energy for Sustainable Development* (doi:10.1016/j.esd.2016.06.001).

NASA selects companies for Mars orbiter studies

NASA has selected five U.S. aerospace companies to conduct concept studies for a potential future Mars orbiter mission.

The companies contracted for the four-month studies include The Boeing Co., Lockheed Martin Space Systems, Northrop Grumman Aerospace Systems, Orbital ATK and Space Systems/Loral. The goal of the orbiter mission is to continue telecommunications and global high-resolution imaging in support of the agency's "Journey to Mars" project, which aims to send humans to the second-smallest planet in the solar system in the 2030s.

The studies will address how a potential new Mars orbiter mission could best provide communications, imaging and operational capabilities. They also will assess the possibilities for supporting additional scientific instruments and functionalities, in addition to optical communications. The orbiter concept under study would use solar electric propulsion to provide flexible launch, mission and orbit capabilities. Robotic spacecraft include two active rovers, three active orbiters, the InSight lander (planned for launch in 2018) and the Mars 2020 rover.

NASA's Jet Propulsion Laboratory in Pasadena, Calif., is managing the concept studies under the direction of the agency's Mars Exploration Program.

• Glencoe, Zeiss partner for JPEG XR software • Idex acquires SFC Koenig •

Submit your press releases to pr@photonics.com, or use our online submission form at Photonics.com/prsubmit.

Obsolete Samsung TOLED panel makes waves in display market

As a result of Samsung's transparent OLED (TOLED) display panel reaching the "end-of-life" (EOL) obsolete designation, display designer Crystal Display Systems Ltd. has announced that they can no longer offer the product.

"The EOL of TOLED is a really unfortunate situation for all concerned," said Tony Large, director of Crystal Display Systems. "Such is the nature of large-scale manufacture that without large volume take up on products, fabrication becomes impossible. Coupled with issues of production yield and fragility, the outcome is not entirely unexpected. We are working closely with clients to develop alternative technologies based on proven TLCD [transparent LCD] technology."

The TOLED display panel is used in all TOLED products available on the market. To those who have already committed to this product, Crystal Display Systems suggests that they should try to cancel or return the order, if possible, due to the lack of product or support. If that is not an option, the company suggests obtaining a three-year warranty for parts and labor.

Crystal Display Systems designs and distributes flat panel display solutions.

Infinera deploys network across MENA

Intelligent transport network provider Infinera has deployed its DTN-X XTC series across the Middle East and North Africa (MENA) Submarine Cable Systems' subsea network.

The series integrates the subsea network connecting the Mediterranean and Middle East with MENA's existing Infinera terrestrial network. It features FlexCoherent technology and instant bandwidth, with MENA rapidly deploying increments of 100 Gb/s of bandwidth, differentiating services and managing costs as it scales network capacity.

"This subsea network upgrade integrated with MENA's existing terrestrial network enables MENA to deliver bandwidth quickly and efficiently on a critical route between Europe, Middle East and Arabian Gulf countries," said Kamran Malik, CEO of MENA. "The Infinera DTN-X XTC Series provides robust reliability, flexibility and scalability, meeting the high standards that MENA seeks in a vendor. This helps MENA offer wholesale customers bandwidth as needed in 100-G increments."

MENA, a subsidiary of Orascom Telecom Media and Technology, owns and operates a submarine telecommunications system connecting Europe to the Middle East and Southeast Asia. Spanning three continents, MENA's infrastructure provides wholesale capacity to global networks via Asia and the Middle East. With the upgrade of the Infinera Intelligent Transport Network on its subsea route, MENA is equipped to provide wholesale carriers with a range of connectivity services from Synchronous Transport Module level-1 at 155 Mb/s to 100 Gb/s over terabit capacity cables.

"We are pleased to collaborate with MENA on its subsea network upgrade, integrating with the existing terrestrial network," said Nick Walden, senior vice president of Europe, the Middle East and Africa at Infinera. "This network upgrade enables MENA to provide differentiated wholesale international capacity in its markets and supports the growth of the Mediterranean and Middle East economy with on-demand scale and efficiency."

Infinera is a manufacturer of high-capacity optical transmission equipment, using large-scale photonic integration to create digital optical networks.

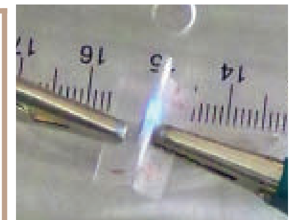
$2.1B

— size of global dental imaging equipment market in 2016, according to Future Market Insights

This month in history

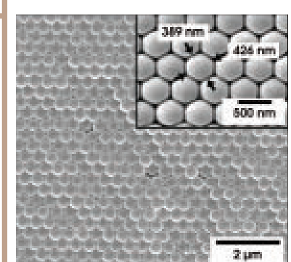
What were you working on five, 10, 20 or even 30 years ago? *Photonics Spectra* editors perused past October issues and unearthed the following:

2011



An intrinsically stretchable polymer LED was demonstrated by engineers at the UCLA Henry Samueli School of Engineering and Applied Science. A simple process was created to fabricate the devices using single-walled carbon nanotube polymer composite electrodes.

2006



Using spincast polystyrene beads as a template, researchers at South Korea's Sungkyunkwa University and LG Chem Ltd.'s Research Park fabricated two-dimensional arrays of microlenses using soft lithography.

1996

Researchers at the U.S. Department of Energy's Oak Ridge National Laboratory said they had found a way to use microcantilevers as sensors to allow affordable night-vision cameras into automobiles.

1986

Dartmouth College in Hanover, N.H., announced the establishment of a Center for Remote Sensing to serve as a central point for remote sensing studies in the earth sciences, geography and physics departments in the environmental studies program, as well as in the Thayer School of Engineering.

UbiQD awarded NSF small business grant

Quantum dot (QD) manufacturer UbiQD LLC has been awarded a Small Business Innovation Research (SBIR) Phase I grant by the National Science Foundation.

The 12-month, $225,000 award is intended to help fund the R&D of luminescent solar concentrating glass windows with QD coatings. In July, the company expanded its license to include the proof-of-concept work on the technology, originally developed at Los Alamos National Laboratory, in collaboration with Italy's University of Milano-Bicocca.

UbiQD

New Mexico-based quantum dot developer UbiQD was awarded a SBIR Phase I grant by the National Science Foundation.

"It's a privilege to receive an SBIR award through the National Science Foundation because it enables us to accelerate our growth and focus on a particularly large market opportunity for our low-hazard, low-cost quantum dot technology," said Hunter McDaniel, founder and president of UbiQD. "Our vision is to turn ubiquitous, everyday windows into sunlight harvesters. Think of skyscrapers that power cities."

U.S. Sen. Martin Heinrich of New Mexico remarked that the award is an example of how technology developed at national laboratories can spur industry and create jobs within the state, adding that New Mexico, with its abundant solar resources, could be at the epicenter of the country's clean energy economy.

UbiQD manufactures low-hazard QDs and nanocomposites.

UTC awarded study contract for U.S. Air Force integration

Integrated systems provider UTC Aerospace Systems has been awarded a study contract to complete the integration of its MS-177 sensor system into the U.S. Air Force's Distributed Common Ground System (DCGS).

Awarded by Lockheed Martin, the contract will support the Air Force while providing next-generation image processing, command and control, and situational awareness tools for combat operations. UTC is focused on delivering an open-architecture solution to the DCGS' modernization effort and reducing long-term sustainment costs by utilizing the new agile process for acquisition and delivery of critical capabilities.

"This contract is an interdependent effort with our Global Hawk MS-177 program that will provide DCGS operators and analysts with very similar capabilities to those employed by the U2's Senior Year Electro-Optical Reconnaissance System (SYERS) mission operatives," said Kevin Raftery, vice president of UTC.

The MS-177 product line is the next generation in intelligence gathering and imaging technology, with origins in the Air Force's SYERS system currently flown on the U-2S platform. The sensor features a new wide-area field of view and higher resolution imaging performance. It also provides motion imagery modality that adds on-target persistence throughout the field of regard, providing both combat identification and tracking information of moving targets. These technological advances will contribute to a more detailed and accurate common operating picture for the DCGS.

UTC Aerospace Systems designs, manufactures and services integrated systems and components for the aerospace and defense industries.

European Space Imaging, Vricon partner for Earth data

Satellite imagery provider European Space Imaging has entered into an agreement with 3D model developer Vricon for access to its "Globe in 3D" geospatial Earth data.

The partnership aims to give European government and security customers access to the "truest representation" of the Earth. Vricon technology incorporates the extensive archive of satellite imagery provided by DigitalGlobe, a partner of European Space Imaging.

"European Space Imaging always aims to give our customers and key partners access to the best technology and highest resolution imagery solutions on the market," said Adrian Zevenbergen, managing director of European Space Imaging. "The new agreement with Vricon brings accurate terrain data and 3D imagery of Earth to support defense and intelligence customers, and will provide a huge benefit for anyone looking for up-to-date complete 3D geo-solutions."

"We are honored to team with European Space Imaging," said Magnus Brege, CEO of Vricon. "This is a natural partnership that greatly benefits our clients. It enables our European customers to team with a trusted authority in remote sensing and receive superior service. In addition to Vricon's Data Suite, our European customers will gain exceptional value through our relationship with European Space Imaging, too."

• Centrotherm revenues decrease while photovoltaic segment rises •

Jenoptik, Western Australia Police partner for traffic monitoring

Jenoptik's Traffic Solutions division has signed a contract with the Western Australia Police for the delivery, installation, maintenance and operation of 81 traffic monitoring systems.

The contract will run for a period of seven years with an option for extension and additional camera systems, totaling $28 million AUD ($21.5 million), with a potential total volume of $60 million AUD ($46.1 million). The devices deployed will include Jenoptik's camera systems of the TraffiStar series based on radar or laser technology for mobile and stationary speed enforcement, as well as red-light monitoring.

Jenoptik is an integrated photonics group that caters to optical systems, healthcare and industry, automotive, traffic solutions and defense and civil systems fields.

SPIE Photonics West drives next-generation technologies

New technologies that enable advancements in global health care, manufacturing, communication and consumer electronics are at the core of SPIE Photonics West, Jan. 28 to Feb. 2, 2017, the world's largest multidisciplinary event focusing on photonics technologies.

On a continuing growth trend, total attendance at Photonics West 2017 is expected to top 23,000. Attendees will have access to technical sessions, two exhibitions, 25 industry events, 70 courses, 40 special events, 17 plenary sessions, and 4,900 papers (96 conferences) on biomedical optics, optoelectronics, industrial lasers, nanophotonics, MOEMS-MEMs and more.

The week kicks off with BiOS Expo, Jan. 28-29, 2017, the world's largest biomedical optics and biophotonics exhibition, held Saturday and Sunday. The latest technologies from more than 235 companies in the thriving biomedical optics and photonics industries will be on display.

Photonics West Exhibition, Jan. 31 to Feb. 2, 2017, more than 1,300 companies exhibit at the essential photonics and laser show. Visitors from around the globe make their way to San Francisco to see the largest concentration of devices and components for applications in the industry.

The BiOS 2017 technical program, the largest symposium under the Photonics West umbrella, includes 2,300 technical presentations in tracks on photonic therapeutics and diagnostics, neurophotonics, neurosurgery, optogenetics, clinical technologies and systems, tissue optics, laser-tissue interaction, tissue engineering, biomedical spectroscopy, microscopy and imaging, nano/biophotonics, and brain research. Featured sessions will begin with the popular BiOS Hot Topics session on Saturday night.

LASE 2017 will showcase the latest fundamental and applied research on new laser sources and applications. Topics include the latest laser manufacturing technologies, laser materials processing, micro-nanoengineering, fiber, high-power and solid-state lasers, laser resonators, ultrafast optics, nonlinear optics, 3D printing and more.

OPTO 2017 addresses the latest in silicon photonics, semiconductor lasers

PEOPLE IN THE NEWS


SPI Lasers UK Ltd.

Fiber laser developer SPI Lasers UK Ltd. has appointed **Matt Shakespeare** as head of service, responsible for leading customer support teams across the globe. Shakespeare brings over 20 years of experience in innovating and delivering services for customers in the semiconductor and scientific instrument sectors. Most recently, he served as service business manager at Oxford Instruments, and previously held roles in service management, product management and business development at Edwards Vacuum and Thermo Electron Corp.


Deposition Sciences Inc.

Optical thin-film filter coating developer Deposition Sciences Inc. has named **James Giacobazzi** as its new president. Giacobazzi brings more than 15 years of executive management experience in advanced technology companies. He was previously the division president at L-3 Communications and general manager at LumaSense Technologies. He holds a bachelor's degree in finance from Denver University. He also studied international trade at the University of California, Los Angeles, and high tech business strategy at the Massachusetts Institute of Technology's Sloan School of Management.


Fibercore Ltd.

Specialty fiber developer Fibercore Ltd. has appointed **Rogerio Ramos** as its new chief technology officer. Ramos holds a master's degree and Ph.D. in lasers and optical fiber sensors. He has held senior posts within Schlumberger and Coventry University. Rogerio has also generated more than 50 granted patents in optical fiber-related fields, along with numerous conference papers and publications.

Techcomp Ltd. has appointed **Roger Fenske** as the new CEO of laser and spectrometer developer Edinburgh Instruments. Fenske has worked for Edinburgh Instruments for more than 14 years, bringing a wealth of customer application and technology experience to the role. He replaces the outgoing CEO, Mark Vosloo, who led the operation's reorganization.


Ikegami Tsushinki Co. Ltd.

Camera manufacturer Ikegami Tsushinki Co. Ltd. has appointed **Kris Hill** as the general manager of its U.K. office, taking over from Mark Capstick. Hill will be responsible for heading up operations, as well as managing all key customer accounts, system integrators and channel partners across the U.K., Ireland and Africa. He previously worked in sales roles across the broadcast industry and brings experience with acquisition, monitoring and production from his five years at JVC Professional Europe Ltd. as the U.K. and Ireland sales manager. Hill also held sales roles at TVU Networks, Vitec Videocom and Fineline Media Finance.

Graphene technology developer Nanotech Energy Inc. has named **Mahi de Silva** to its board of directors. De Silva was the CEO of Opera Mediaworks Inc.; the co-founder, chairman and CEO of Frengo Corp.; and the co-founder and CEO of AdMarvel Inc. He was senior vice president and general manager of wireless and digital content services for VeriSign and served in various leadership roles at Taligent, Apple and NCR Corp. He served as chairman and director of PreCash Inc. and is a member of the advisory board of The Merger Strategiewerkstatt GmbH.

• Quanergy acquires Raytheon people-tracking software • NeoPhotonics announces flat Q2 earnings •

and LEDs, nanotechnologies, MOEMS-MEMs, quantum applications, displays and optical communications. Other topics include optoelectronic materials and devices, photonic integration, nanotechnologies in photonics, displays and holography, 3D printing, and more.

Translational Research 2017 will highlight papers from BiOS that showcase the latest photonics technologies, tools, and techniques with high potential to impact global health care.

Brain Research 2017 will highlight papers from BiOS, LASE and OPTO that describe the development of innovative technologies that will increase our understanding of brain function.

Applications of 3D Printing will highlight papers from BiOS, LASE and OPTO that showcase innovative ways to apply this multidimensional/multidisciplinary technology.

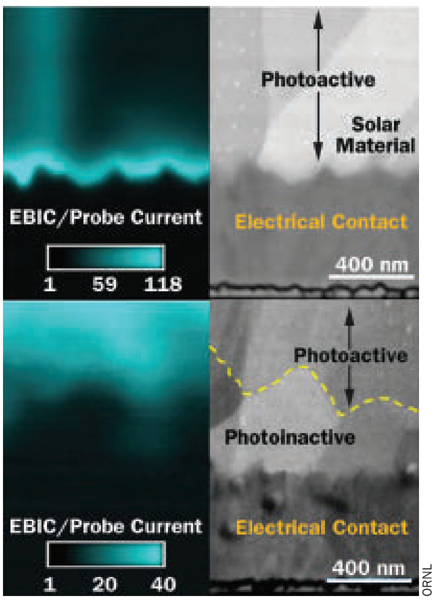
SPIE Photonics West gives visitors an opportunity to see the potential of photonics and its role as a key enabling technology. The event features more than 4,900 presentations and events, two world-class exhibitions, industry events (from business seminars to the Prism Awards), and six days to network and collaborate. Register today for SPIE Photonics West, the largest international laser, photonics, and biomedical optics conference. SPIE Photonics West will be held Jan. 28 to Feb. 2, 2017 at The Moscone Center, San Francisco. For more information, go to **www.spie.org/pw.**

Michael D. Wheeler

Microscopy uncovers potential improvement to solar cell efficiency

OAK RIDGE, Tenn. — Advanced microscopy techniques have been used to show that adding the optimum amount of selenium (Se) may help increase efficiency in cadium (Cd)- and tellurium (Te)-based solar cells from the current approximate 22 percent to levels approaching the theoretical limit of 30 to 33 percent.

To study the effect of Se content on the photoactive properties of bandgap-graded CdTe cells, researchers at Oak Ridge National Laboratory used a combination of techniques including atom probe tomography, transmission electron microscopy and electron-beam-induced current.



The entire solar material for the sample with less than or equal to 30 percent selenium is photoactive **(top)**, while the bottom of the solar material for the image below contains greater than 35 percent selenium and has reduced photoactivity.

"Using different microscopy methods, we were able to gain a better understanding of the phases, compositions and crystalline structures that allow these materials to convert light into electricity more efficiently," said team leader Jonathan Poplawsky. "In some instances, adding too much selenium changes the crystalline structure of cadmium-tellurium and dramatically reduces the conversion efficiency."

The research team studied four solar cells with contents of 50-, 100-, 200- and 400-nm-thick cadmium selenium (CdSe) layers to determine the formation, growth, composition, structure and photoactivity of the $CdTe_xSe_{1-x}$ alloy with respect to Se diffusion. The carrier separation properties of the cells prepared with the varied CdSe layer thicknesses were measured with 30- to 50-nm resolution using scanning electron microscopy (SEM)-based electron-beam-induced current, while the crystallography and Se concentration were measured at the nanoscale using transmission electron microscopy selected area diffraction (TEM-SAD) and atom probe tomography (APT), respectively. The results showed an interdependence between the layer's ability to convert photons into electricity and the Se content and crystalline structure of the layer.

The cell with the alloy composition of approximately 50 percent Cd, 25 percent Te and 25 percent Se performed best. The cell with the highest level of Se did not perform well; nor did the cell with the lowest Se content.

"We have shown that the amount of selenium incorporated into the cadmium-tellurium controls whether the small crystals inside the solar cell form as crystal structure A or crystal structure B," Poplawsky said. "This information can be used as a road map for solar cell producers to make improved cadmium-tellurium solar cells that use selenium additions, and hopefully increase the overall efficiency."

Poplawsky noted that solar panels typically use silicon as the material for converting sunlight into electricity. CdTe can absorb the same amount of sunlight as silicon using 98 percent less semiconducting material, thus reducing the overall cost of the solar panel. The ability to increase the power conversion efficiency of CdTe-based solar modules without increasing the production costs will make solar power generation more competitive with fossil fuels.

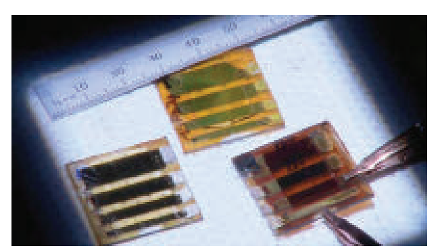
The research was published in *Nature Communications* (doi:10.1038/ncomms12537).

2D perovskite opens horizons for photovoltaics, optoelectronics

LOS ALAMOS, N.M. — A 2D layered perovskite with crystalline properties has demonstrated more than triple the efficiency of previous 2D perovskites, while also demonstrating significantly more stability than 3D perovskite material. The technology shows promise not only for photovoltaic applications, but also for high-performance optoelectronic devices.

To create 2D perovskites with high efficiency and stability, researchers at Los Alamos National Laboratory produced thin films of near-single-crystalline quality. The crystallographic planes of the inorganic perovskite component had an out-of-plane alignment relative to the contacts in planar solar cells, facilitating efficient charge transport. To achieve crystalline orientation, the researchers devised a method to flip the crystal without the need for any post-processing. They controlled the crystalline orientation of the perovskite systematically using a hot spinning approach.

"Crystal orientation has been a puzzle for more than two decades, and this is the first time we've been able to flip the crystal in the actual casting process," said researcher Hsinhan Tsai. "This is our breakthrough, using our spin-casting



Three types of large-area solar cells are made out of two-dimensional perovskites.

technique to create layered crystals whose electrons flow vertically down the material without being blocked, midlayer, by organic cations."

The 2D crystals were previously studied by researchers at Northwestern University, where the 2D perovskite material was originated. In the Northwestern studies, the perovskite lost power when the organic cations hit the sandwiched gap between the layers, knocking the cells down to a 4.73 percent conversion efficiency due to the out-of-plane alignment of the crystals. The Los Alamos researchers' application of the hot spinning technique to create a vertically aligned 2D material has raised the conversion efficiency to greater than 12 percent.

The 2D perovskite has also demonstrated significantly greater stability than its 3D counterpart when subjected to light, humidity and heat stress tests. Unencapsulated 2D perovskite devices were shown to retain over 60 percent of their efficiency for over 2,250 hours under constant, standard illumination, and to exhibit greater tolerance to 65 percent relative humidity, compared to 3D devices. When the devices were encapsulated, the layered devices did not show degradation under constant illumination or humidity.

"The new 2D perovskite is both more efficient and more stable, both under constant lighting and in exposure to the air, than the existing 3D organic-inorganic crystals," said researcher Wanyi Nie.

Spectroscopy was used to determine how light was excited and absorbed by the perovskite, and how light was transported. Lasers were used to interrogate the device locally, from all positions, to reveal any possible issues and the location of any issue.

Because of the crystalline properties of the perovskite, the researchers anticipate applications for it beyond photovoltaic, such as in light-emitting diode and lasing applications. The perovskite's optoelectronic properties may also make it useful for photo detector and particle detector applications.

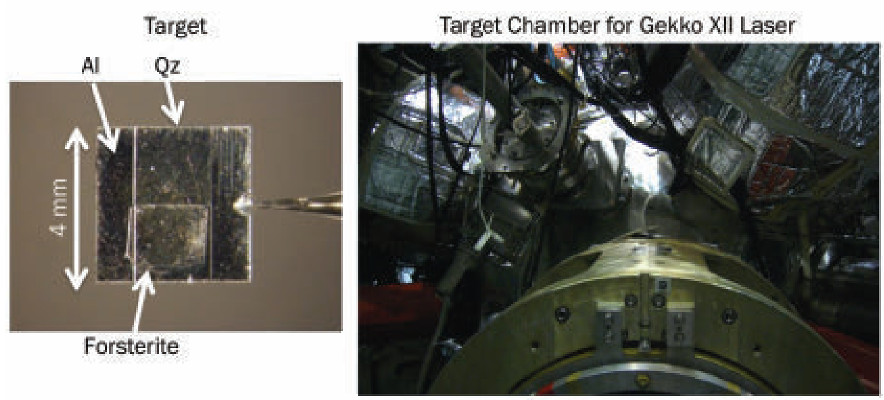
"The 2D perovskite opens up a new dimension in perovskite research. It opens new horizons for next-generation stable solar cell devices and new optoelectronic devices such as light-emitting diodes, lasers and sensors," said Mercouri G. Kanatzidis, professor of chemistry at Northwestern University.

"We seek to produce single-crystalline thin films that will not only be relevant for photovoltaics but also for high-efficiency light-emitting applications, allowing us to compete with current technologies," said senior researcher Aditya Mohite.

The research was published in *Nature* (doi: 10.1038/nature18306).

Laser shock technique replicates extreme pressures of planet formation

HIROSHIMA, Japan — A laser shock wave technique has been used to create pressures and temperatures comparable to the extreme collisions between objects in space in order to measure the shock response of forsterite, a major planetary material and the most abundant constituent of Earth's mantle. Previous studies, performed without the laser shock technique, only measured the properties of forsterite at shock pressures below 200 giga-pascals (GPa). The experiments using laser shock compression put forsterite crystals under pressures between approximately 250 and 970 GPa. The pressure at the center of Earth, in comparison, is estimated to be 360 GPa.



Researchers observed the melting of forsterite, the most common constituent of Earth's mantle, to understand how the cores of planets form and develop. The laser is able to create pressures representative of the extreme collisions between objects in space. The target is a 4-mm square. Al is aluminum and Qz is quartz.

Toshimori Sekine, Hiroshima University

The use of the laser shock technique will potentially enable researchers to better understand the development of planets too distant for satellites to explore.

In a collaborative endeavor, researchers at Hiroshima University, Osaka University, Ehime University, University of Tokyo and the Chiba Institute of Technology used a high-powered laser to irradiate a block of forsterite to measure its behavior under extreme conditions comparable to planetary impact events. They found that energy from the irradiation caused an abrupt expansion of the forsterite's molecules. This expansion generated a shock wave with enough heat and light to melt the forstertite in a manner comparable to the intense conditions that turn minerals into magma.

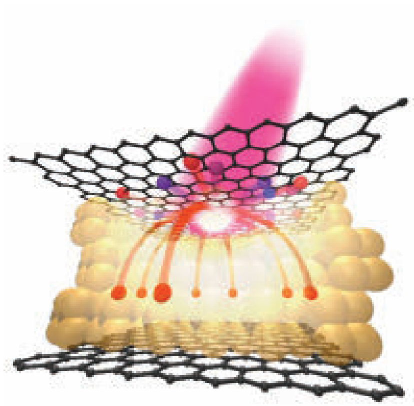
Researchers measured the pressure, temperature, density and reflectivity of the laser-shocked forsterite and reported a shock response of forstertite above about 250 GPa. They simultaneously measured the Hugoniot and temperature of shocked forsterite and interpreted the results to suggest incongruent crystallization of magnesium oxide (MgO) at 271 to 285 GPa; phase transition of MgO at 85 to 344 GPa; and remelting above about 470 to 500 GPa.

The findings may lead to increased knowledge of the interior processes of large rocky planets, how material is transformed by impact and how planetary systems are formed. With new details of forsterite's melting behavior, researchers may be able to predict how minerals separate into different layers of magma and which minerals may be close enough to react.

"Our results provide a better understanding of how impact-generated magmas evolve and allow us to model Earth-type planets' inner structures. Collisions at these extreme temperatures and pressures created our own Earth and may have also formed the mantles of other Super Earth planets, for example CoRoT-7b and Kepler-10b," said Toshimori Sekine, professor at Hiroshima University.

The research was published in *Science Advances* (doi: 10.1126/sciadv.1600157).

Graphene photodetectors offer path to novel optoelectronics



ICFO/Fabien Vialla

Artistic view of the photo-thermionic effect in a graphene-WSe2-graphene heterostructure.

BARCELONA, Spain — A novel way to detect and harvest low-energy photons using heterostructures made of 2D materials and graphene may overcome the limitations of conventional semiconductor devices, and could lead to greater speed and efficiency in optoelectronic applications. The technique — termed the photo-thermionic effect — makes use of the optical properties of graphene including graphene's broadband absorption, ultrafast response and gate tunability.

A number of photodetectors rely on the emission of photoexcited charge carriers. These carriers are typically injected over a Schottky barrier between a metal and a semiconductor, allowing the detection of photons with energy lower than the semiconductor bandgap. However, the efficiency of this mechanism drops for photon energy lower than the Schottky barrier height ΦB and is limited by the ability to extract the carriers before they lose their initial energy.

To overcome such limitations when detecting and harvesting low-energy photons, researchers at the Institute of Photonic Sciences (ICFO) and its Catalan Institute of Research and Advanced Studies (ICREA) made vertical heterostructures by stacking graphene and other 2D semiconducting materials. They studied the photoresponse in these structures, demonstrating that it is possible to generate a current by heating electrons in graphene with IR light and extracting the hottest electrons over a vertical energy barrier.

The researchers found that heterostructures made of 2D materials and graphene can be used to detect low-energy photons, which could lead to novel optoelectronic applications such as high-speed integrated communication systems and IR energy harvesting.

The absorbed photon energy in graphene was transferred to the electron bath, leading to a thermalized hot carrier distribution. Carriers with energy higher than the Schottky barrier between graphene and WSe_2 could be emitted over the barrier, thus creating photocurrent.

The researchers demonstrated that the photo-thermionic effect may enable detection of sub-bandgap photons. Devices relying on this effect make use of the entire surface of graphene, and can potentially be scaled up and integrated with flexible or rigid platforms.

"This is just the tip of the iceberg," said Frank Koppens, a professor at ICREA. "These 2D sandwiches still have a lot to reveal."

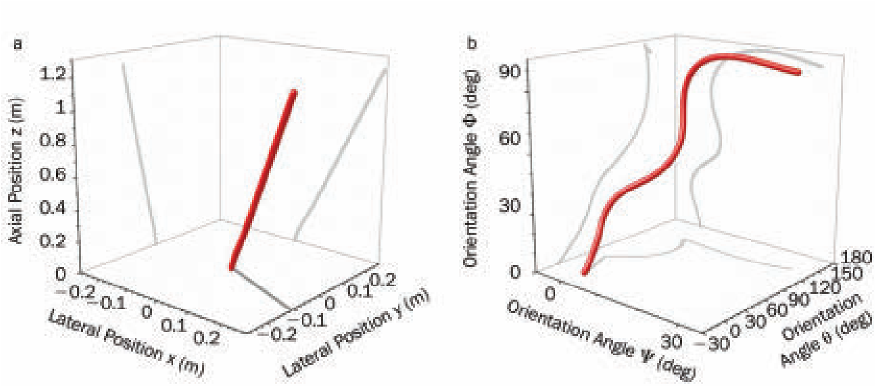
The research was published in *Nature Communications* (doi: 10.1038/ncomms12174).

Lasers may remove space debris using novel approach

COLOGNE, Germany — Laser ablation can be used to remove interference in satellite communications by pushing pieces of space debris into the Earth's atmosphere, where the debris is destroyed. A novel approach to laser ablation of space objects focuses on a secondary effect of laser-induced damage, which is not immediately apparent in experiments on Earth but becomes relevant in the weightlessness of space: When laser-induced material ablation occurs, the recoil of the ablation plume yields momentum transfer to the target. Irregularly shaped objects (typical of most space debris) that are randomly oriented in space pose a challenge in that it is difficult to predict the amount and direction of the laser impulse to impart to the target.

An important piece of information needed for space-debris removal is the position of the fragment. Current methods for determining position use reflections caused by the space debris. While radar-based methods use the reflection of the radio waves sent out by the radar stations themselves, optical detection depends on the reflection of sunlight from the debris target in question.

Researchers at the German Aerospace Center simulated laser-ablative impulse coupling to space debris targets with the goal of modifying the debris' orbit and achieving its removal by burn-up in the Earth's atmosphere. They developed a simulation code, Examination Program



Stefan Scharring, Jascha Wilken and Hans-Albert Eckel

This figure shows the trajectory of **(a)** position and **(b)** orientation of pliers under repetitive laser irradiation without tracking. Gray lines indicate the projections of the trajectory in the respective coordinate planes.

for Irregularly Shaped Debris Targets (EXPEDIT), to use in the investigation of the thrust generation through laser ablation with variable parameters.

They investigated simple targets and realistic space debris targets with respect to momentum generation. The predictability of the momentum was analyzed in a Monte Carlo study. Results showed that even slight variations of the initial debris position and orientation could lead to significant differences in the trajectories.

The researchers identified targets that were relatively easy to remove by laser ablation, as well as targets that were strongly dependent on orientation. They found that the optimum impulse receiver for laser-induced momentum generation appeared to be a perfectly flat plate oriented perpendicular to the incoming laser beam. By contrast, surface elements whose normals were inclined against the laser beam received a lower laser fluence. Moreover, the corresponding impulse vector contained a lateral component oriented perpendicular to the beam propagation axis.

One way to account for the effects of decreasing fluence and deviating thrust direction, referred to as the area matrix concept, provides for the analytical calculation of laser-induced momentum that is applied to a target exhibiting a simple geometric shape. However, this approach neglects to account for the effects caused by geometrically complex and randomly oriented targets.

"Our work constitutes the transition from laboratory experiments with idealized flat targets and optimum laser alignment towards simulations of the real world scenario with arbitrarily shaped debris and limited laser pointing accuracy," said the researchers, Stefan Scharring, Jascha Wilken and Hans-Albert Eckel.

Despite limited predictability for the motion of a particular debris object, the researchers found that a laser-based approach appears to be suitable for space debris removal, when using a probabilistic and not a deterministic treatment of the resulting trajectory modifications.

Because of their high speeds, up to 15 kilometers per second, small pieces of debris pose a significant threat to space flight and satellite operations. While the locations of major space debris are known, fragments smaller than 10 centimeters are difficult to catalog, and there are 10 times more small pieces than large ones. Deorbiting debris piece-by-piece using laser pulses may be one building block in a large-scale effort to remove debris from space. The research was published in *Optical Engineering* (doi:10.1117/1.OE.56.1.011007).

Metamaterial switches states in response to light

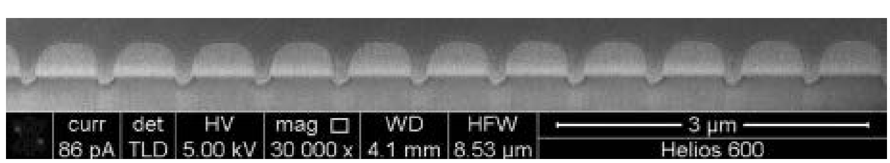
SOUTHAMPTON, England — A metamaterial has been designed with a switchable metasurface that allows it to either block or transmit light waves in response to light pulses. Developed by researchers at the University of Southampton, the optically switchable metamaterial uses the phase-change medium germanium antimony telluride (GST) to change properties, a capability that may be useful for a range of optical devices.

Switchable metamaterials have previously included a metal component that is structurally engineered to provide the desired optical properties, as well as a phase change component that can be used to tune the properties. Metals tend to absorb light at visible and IR wavelengths, making them unsuitable for many optical device applications. Melting points are suppressed in nanostructured metals, making the metamaterials susceptible to damage from laser beams. Some metals used in metamaterials, such as gold, are not compatible with CMOS technology used for making many integrated devices.

The new switchable metamaterial uses GST, but does not use metal.

The researchers created metamaterial grating patterns in an amorphous GST film 300-nm thick, with lines 750 to 950 nm apart. This line spacing has allowed the surfaces to selectively block the transmission of light at NIR wavelengths (between 1300 and 1600 nm). When a green laser converted the surfaces into a crystalline state, they became transparent at these wavelengths. Laser light pulses were used to switch the structure of the GST between nonvolatile random, amorphous or crystalline states.

The team showed that nanostructured, subwavelength-thickness films of GST provide high-quality (Q ≥ 20) NIR resonances that could be spectrally shifted by optically induced crystallization to deliver reflection and transmission



Karvounis/Gholipour/MacDonald/Zheludev/Optoelectronics Research Centre, University of Southampton

A cross-sectional scanning electron microscopy image of a 750-nm period grating, fabricated by focused ion beam milling in a 300-nm-thick amorphous germanium antimony telluride film on silica.

switching contrast ratios up to 5:1 (7 dB) at visible/NIR wavelengths selected by design.

The metasurfaces using chalcogenide demonstrated high-contrast, non-volatile, optically induced switching of their NIR resonant reflectivity and transmission characteristics. With the novel metamaterial, chalcogenides such as GST may offer a flexible platform for the realization of optically switchable metamaterials.

"What we've done now is structure the phase-change material itself," said Southampton researcher Kevin MacDonald. "We have created what is known as an all-dielectric metamaterial, with the added benefit of GST's nonvolatile phase-switching behavior."

GST, a material with an established industrial footprint in optical and electronic data storage, can readily be structured for telecommunications applications at 1550 nm, while other members of the chalcogenide family may provide similar active, all-dielectric metasurface functionality in the visible range and at IR wavelengths out to 20 µm.

The ability of a single medium to provide both high and low reflectivity and transmission levels in the same phase state, such that they can be simultaneously inverted via a homogeneous, sample-wide structural transition, may be useful in image processing, as well as metasurface optics applications, according to the researchers. By dynamically controlling the optical properties of materials, the various characteristics of light beams such as intensity, phase, color and direction can be modulated, selected or switched.

The research team is now working to make metamaterials that can switch back and forth over many cycles. They are also planning increasingly complex structures to deliver more sophisticated optical functions, including switchable ultrathin metasurface lenses and other flat optical components.

"Technologies based upon the control and manipulation of light are all around us and of fundamental importance to modern society," MacDonald said. "Metamaterials are part of the process of finding new ways to use light and do new things with it — they are an enabling technology platform for 21st century optics."

The research was published in *Applied Physics Letters* (doi: org/10.1063/1.4959272).

Electron spin control of nanoparticles could advance sensor technology

WEST LAFAYETTE, Ind. — A technique used to detect and control the electron spin resonance (ESR) of nanodiamonds in a vacuum chamber may lead to the development of novel sensors for detecting, measuring and monitoring gases. It may also provide a future template for the testing of quantum physics at the macroscopic level using nanoparticles.

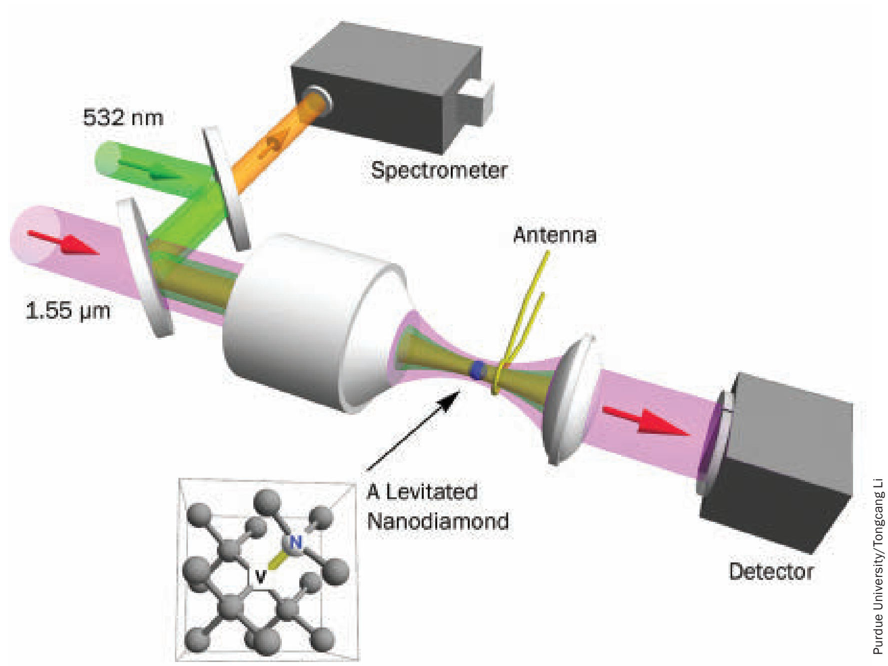
Researchers at Purdue University demonstrated the electron spin control and direct temperature measurement of nitrogen vacancy centers (NVCs) in nanodiamonds, which they optically levitated in a low vacuum using a 1550-nm laser.

One type of laser was used to trap and levitate the nanoparticles in a vacuum chamber, and another was used to monitor the electron spin. A millimeter-scale antenna delivered microwaves to control and flip the electron spin, and a spectrometer was used to detect changes in spin. A vacuum was used to reduce interference from air molecules.

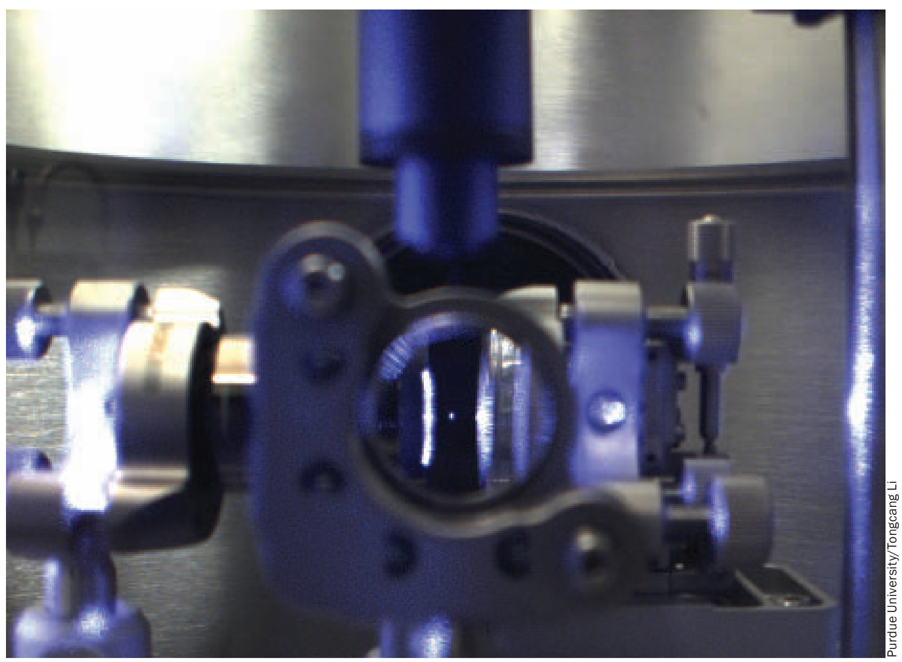
Levitating the nanodiamonds in a vacuum enabled precise control and rigorous measurement of the floating particles. The nanodiamonds, which were approximately 100 nanometers in diameter, contained NVCs (atomic-scale defects formed in the diamond lattice by substituting a nitrogen atom for a carbon atom and creating a neighboring void in the crystal lattice). The researchers exploited this feature to control the electron spin.

They studied the effect of the spin under different conditions and found that the ESR contrast of an optically levitated nanodiamond was enhanced in a vacuum environment.

The researchers attributed the enhanced ESR to a reduction in low-quality negatively charged NVCs near the surface, due to the reduction of oxygen surface



A schematic of an optical tweezer used in a vacuum chamber by Purdue University researchers, who controlled the 'electron spin' of a levitated nanodiamond.



A nanodiamond levitated in a vacuum chamber developed by Purdue University researchers, who controlled its 'electron spin.'

termination and a moderate increase in the temperature that quenches low-quality surface NVCs without significantly affecting high-quality NVCs at the the nanodiamond's center.

The research team also observed that oxygen and helium gases had different effects on the photoluminescence and ESR contrast of nanodiamond NVCs. These effects were found to be reversible, indicating that nanodiamond NVCs could potentially be used as sensors to detect and measure gases. Nanodiamond-based sensors represent a potential improvement over conventional sensors.

"We've shown how to continuously flip the electron spin in a nanodiamond levitated in a vacuum and in the presence of different gases," said Purdue professor Tongcang Li. "While more detailed studies are required to fully understand this phenomenon, our observation suggests a potential application for oxygen gas sensing."

The levitating nanodiamonds may also be used in quantum information processing, in experimental techniques to probe fundamental physics in quantum mechanics, and in the measurement of magnetic and gravitational fields.

The results of the experiment pave the way toward a levitated spin/optomechanical system for studying macroscopic quantum mechanics.

The research was published in *Nature Communications* (doi:10.1038/ncomms12250).

Laser sensor can detect damage to military assets

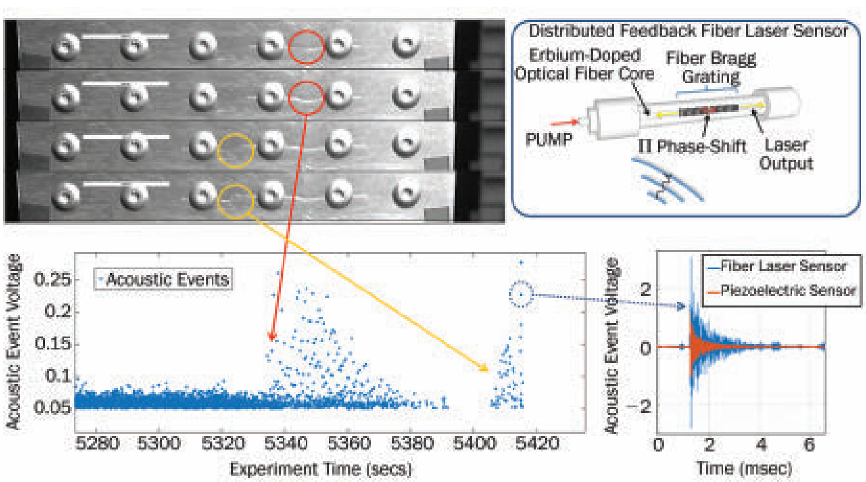
WASHINGTON, D.C. — A distributed feedback fiber laser sensor has detected acoustic emission signatures associated with cracks in riveted lap joints, demonstrating that it has the potential to uncover structural damage in U.S. Navy assets before the damage reaches critical levels.

Developed by researchers at the U.S. Naval Research Laboratory, the laser sensor consists of a single fiber, similar in width to a human hair, which is integrated into a shallow groove formed in the lap joint. The sensor has a small system footprint and can be multiplexed.

To test the technology, researchers installed the laser sensors into a series of riveted aluminum lap joints and measured acoustic emission over a bandwidth of 0.5 MHz generated during a two-hour accelerated fatigue test. They took equivalent measurements with an electrical sensor.

The embedded laser sensors demonstrated acoustic sensitivity comparable to or greater than that achieved by existing electrical sensors. The laser sensors were able to detect low-level acoustic events generated by periodic fretting from the riveted joint, in addition to acoustic emissions from crack formation. Time-lapse imagery of the lap joint revealed that the observed fracture correlated with the signals measured. In addition to crack detection, the fiber laser sensor also showed the ability to measure compromising impacts.

"Our research team has demonstrated



U.S. Naval Research Laboratory

Crack detection in riveted lap joints with fiber laser acoustic emission sensors: The initiation and growth of cracks between rivets in a lap joint is shown at top left. A fiber laser sensor, at top right, adhered to the structures, measures the acoustic emission signals generated by the cracks, and software records them as acoustic events (AE). A typical AE is shown at lower right. The amplitude of the AEs as a function of time is shown at lower left. Large increases in AE amplitude are seen when the cracks grow.

the ability of this fiber laser technology to detect acoustic emission at ultrasonic frequencies from cracks generated in a simulated fatigue environment," said Geoffrey Cranch, research physicist. "The novel part of this work is the fiber laser technology and how it is being applied."

Acoustic signals from cracks can also be measured using piezoelectric sensors, and this technology has driven the existing work on failure prediction. However, the piezoelectric technology is not practical for many applications due to its large size and limited multiplexing capability.

The fiber laser sensor system has now been expanded to multiplex many sensors onto a single fiber. Efforts are underway to interpret the acoustic emission data to calculate metrics such as probability of failure. Future enhancements may include implementing phased array beam forming techniques to facilitate crack location.

The fiber laser sensor also has the potential to integrate with existing fiber optic strain and temperature-sensing systems. Integrating the sensor with these systems would provide a multiparameter sensing capability that could meet the operational safety requirements for a structural health monitoring system at significantly lower cost.

"An automated, in-situ structural health monitoring system capable of monitoring key structural parameters such as temperature, strain, impacts and cracks, and capable of reliably detecting damage well before reaching a critical level is needed to increase safety and readiness while lowering operational cost of Navy platforms" said Cranch. "At present, none of the services are using in-situ technologies to manage the structural health of their assets."

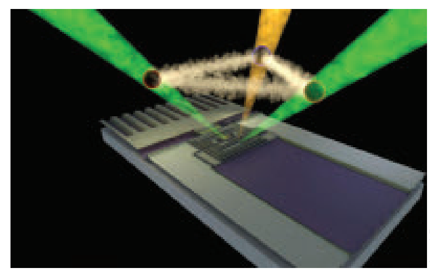
Cranch added that the laser sensor technology may have possible applications beyond the military.

"Our focus is on Navy platforms, such as aircraft, ships and submarines, but the technology could also be used on civilian aircraft," he said. "Applications to bridges and buildings are also possible if there are critical parts prone to fatigue and failure that would benefit from continuous monitoring."

Photon pairs may contribute to an alternate approach to quantum computing

ESPOO, Finland — Microwave signals comprising correlated photons could be used to code information for quantum computing and may offer an alternative use of optical systems to build quantum computers.

Researchers at Aalto University chilled a microwave resonator to nearly absolute zero temperature — the point at which any thermal motion freezes — to correspond to a state of perfect darkness. In this quantum vacuum state no photon is present, but there exist fluctuations that can bring photons in and out of existence for a very short time.



Antti Paraoanu

Artist's depiction of the generation of three correlated photons from quantum vacuum.

When the researchers converted these fluctuations into real photons, with different frequencies, they found that the photons were correlated with each other.

"This all hints at the possibility of using the different frequencies for quantum computing. The photons at different frequencies will play a similar role to the registers in classical computers, and logical gate operations can be performed between them," said professor Sorin Paraoanu.

In the vacuum state, fluctuations occurring at different frequencies were uncorrelated. However, the researchers found that if a parameter in the Lagrangian of the field was modulated by an external pump, vacuum fluctuations stimulated spontaneous down-conversion processes, creating squeezing between modes symmetric with respect to half of the frequency of the pump.

They showed that it was possible to generate coherence between photons in separate frequency modes through double parametric pumping of a superconducting microwave cavity. The coherence correlations were tunable and were established by a quantum fluctuation that stimulated the simultaneous creation of two photon pairs.

Experimental results indicated that the origin of this vacuum-induced coherence was the absence of which-way information in the frequency space.

"With our experimental setup we managed to create complex correlations of microwave signals in a controlled way," said doctoral student Pasi Lähteenmäki.

From this research, a novel approach to quantum computing may emerge — the ability to engineer the quantum vacuum to create novel devices and protocols for quantum technologies.

"Today the basic architecture of future quantum computers is being developed very intensively around the world," said professor Pertti Hakonen. "By utilizing the multifrequency microwave signals, an alternative approach can be pursued which realizes the logical gates by sequences of quantum measurements. Moreover, if we use the photons created in our resonator, the physical quantum bits or qubits become needless."

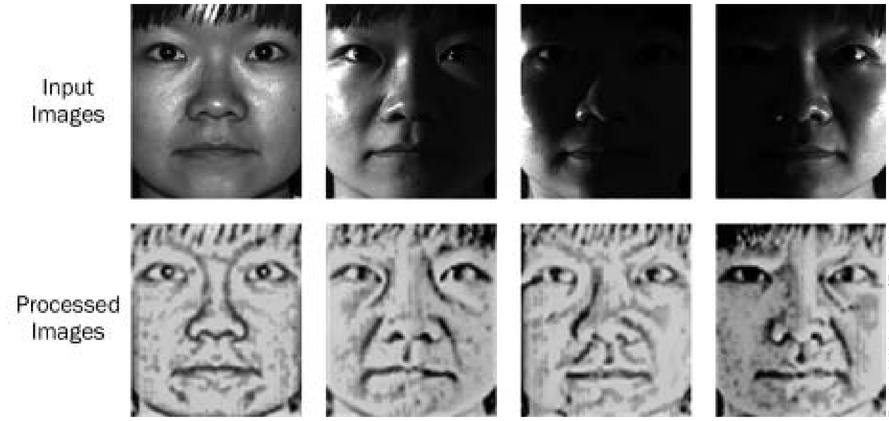
The research was published in *Nature Communications* (doi:10.1038/ncomms12548).

Imaging technique enhances face recognition in variable lighting conditions

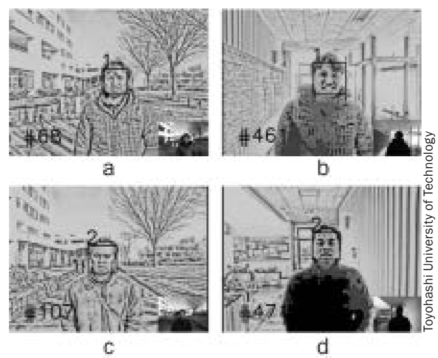
TOYOHASHI, Japan — A novel technique manages the effect of lighting on photometric-based human face recognition through a fuzzy-based illumination invariant method. The technique, named OptiFuzz, uses an extended reflectance model to adjust the effect of lighting on human faces, thereby improving face detection and recognition results under a variety of illumination conditions.

Developed by researchers at Toyohashi University of Technology, OptiFuzz has one variable, the illumination ratio, which is controlled by a fuzzy inference system (FIS). The researchers used a genetic algorithm (GA) to optimize the FIS rule to handle a range of illumination conditions.

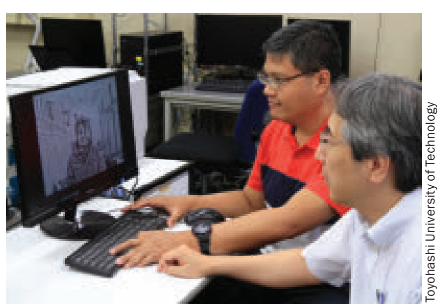
"To eliminate the effects of light, image contrast should be adjusted adaptively," said researcher Bima Sena Bayu Dewantara. "To produce an invariant face appearance under backlighting, for example, cheeks need to be brightened, while the eyeballs must be kept dark. Such an adaptive contrast adjustment can



Result of the illumination invariant face processing using Yale B Extended database: input images **(top)** and processed images **(bottom)**.



Results of illumination invariant face recognition for real implementations: **(a)** Person No. 1 outdoor, **(b)** Person No. 1 indoor, **(c)** Person No. 2 outdoor, and **(d)** Person No. 2 indoor. The small image on the bottom-right side of each image is the input image.



Professor Jun Miura **(right)** and Ph.D. candidate Bima Sena Bayu Dewantara.

be performed using the developed reflectance model, and we show that a combination of FIS and GA is very effective for implementing the model."

The researchers tested the method using Yale B Extended and CAS-PEAL face databases to represent the offline experiments. For the online indoor and outdoor experiments, they recorded several videos. They used the Viola-Jones Face Detector and the Mutual Subspace Method to run the online face detection and face recognition experiments.

The results demonstrated that the researchers' algorithm could outperform existing methods for recognizing a specific person under variable lighting conditions with a significantly improved computation time. The results also showed that illumination invariant images could improve face detection performance.

"By just adding this contrast adjustment to present face recognition systems, we can largely improve the accuracy and performance of face detection and recognition," said professor Jun Miura. "Moreover, this adjustment runs in real time, and therefore it is appropriate for real-time applications such as robot and human-interaction systems."

To date, vision-based face detection and recognition has been shown to be effective only under normal illumination conditions.

In addition to a person's identity, a face provides information such as a person's focus of attention and degree of tiredness, which can be useful for maintaining a comfortable human-machine interaction. The researchers expect that their proposed contrast adjustment method will be useful in various situations, especially under severe illumination conditions.

The research was published in *Machine Vision and Applications* (doi: 10.1007/s00138-016-0790-6).

3D Displays Get Closer but Face Hurdles

Glasses-free three-dimensional display technology is on the horizon.

BY HANK HOGAN
CONTRIBUTING EDITOR

For viewers, a trip into the third dimension is getting cheaper and more satisfying. It also could be getting a lot nearer, driven by changes in photonics, optics and the market.

Further out lies the possibility of 3D displays that mimic what is seen when looking out a window. Research and development is underway to create such displays, which would require no glasses and perhaps no screens or imaging medium.

For now, though, commercially available 3D displays are stereoscopic, presenting different images to the left and right eyes to create a three-dimensional picture. This is done through glasses that passively filter or actively switch between the two different images.

Therein lies a problem.

"About 15 percent of people can't see 3D using those current 3D technologies, which is a lot. One in seven is a lot. They get headaches, they get nauseous, or they just can't see it," said Edward Tang, chief strategy officer of Avegant Corp. of Belmont, Calif.

Privately held Avegant's solution is to ditch the screen. Its wearable displays project images directly onto the retina. The result is similar to walking around with a portable 3D movie theater, according to Tang.

He said that the company's recently launched flagship product, the Glyph, has its roots in a technology development project for the military. The Department of Defense wanted a display comfortable enough to be worn for hours while offering high resolution and low latency. The combination would enable crisp, low-eyestrain images even when viewing full-motion video.

Avegant

A near-eye display in the form similar to high-end headphones enables personal viewing of 3D content.

Ninety percent fill factor

The researchers solved this with mirrors in a microelectromechanical system, or MEMS, device from Dallas-based Texas Instruments. The micromirror devices have a fill factor of 90 percent for all colors, far above the 15 to 20 percent per color typical for panel-based displays, Tang said. That and optics make it possible to hit an angular resolution of an arc minute, the limit of human vision. In effect, the pixels disappear.

The microscopic mirrors also reflect light from the ultraviolet to the infrared, giving the Avegant developers the freedom to use inexpensive and energy-efficient LEDs as a light source. Finally, the mirrors switch on and off in microseconds.

Several years ago the developers had a prototype, but they found that the content used for evaluation didn't come from the military. "All the high-quality media that we were testing ended up being consumer media. Computer games, movies, graphics, things like that," Tang said

Consequently, the team opted to spin off Avegant to pursue commercial markets. The company's developers shrank what was a copier-sized demonstrator down into something as big and about as heavy as a pair of high-end headphones.

Some of the reasons why this could be done were ongoing improvements by Texas Instruments of the digital micromirror device in a digital light processing (DLP) chipset. Resolution has gone up, thanks in part to pixel sizes going down from 13 microns years ago to today's 5.4. Also, with the right optics, this projection technology can be very compact in size, with the distance from the chip to the screen — or retina — being only a few millimeters, said

Juan Alvarez, DLP product marketing engineer.

He noted that the chips can support the necessary frame rates for 3D, which are double that needed for 2D. The higher frame rate and resolution needed for 3D as compared to 2D impacts the entire display system.

"You have to pass more data through the whole system. But the good news is that technology has advanced not only at the display level, but also at the system technology level with faster data busses and processors," Alvarez said.

Near-eye display vendors like Avegant, Vuzix of Rochester, N.Y., Oculus VR of Menlo Park, Calif., Magic Leap of Dania Beach, Fla., and others are developing 2D and 3D displays that could be used for augmented and virtual reality applications. They may benefit from a change in the market, with consumers increasingly accessing media via smartphones and other devices with small screens. The limitations of those screens make alternatives like headgear more attractive.

Such wearable 3D displays make possible new applications, such as looking through the camera on a drone to get a bird's-eye view. By tracking where a user is looking, wearables could provide a view and enable control, creating the sensation of flying.

For all the attention that small screens garner, however, big displays represent much more real estate and a hefty market. According to IHS Markit, a technology and market research firm, large thin-film transistor LCD displays will decline in unit shipments from 2015 to 2016 but will still total more than 650 million units worldwide. Thus, there's a large potential market for big screen 3D displays.

That potential is being held back by a lack of compelling content, cost and the fact that users currently have to wear glasses when watching 3D. A number of approaches are being investigated to get around these drawbacks.

For example, Provision Interactive Technologies of Chatsworth, Calif., uses proprietary technology to create floating imagery for digital signage applications, said CEO Curt Thornton. He added that the approach is derived from a 3D holographic display projection technique.

Provision Interactive Technologies

A hologram-based projection enables floating 3D imagery for digital signage.

3DIcon

Two-photon absorption in an imaging medium gives rise to a 3D image, shown here in a medical display application.

Currently, the largest size of such displays is about 40 inches, with the image projected at a video frame rate about 36 inches away from the projector. The company is working to increase that size. A six-foot maximum would be about all that the current technology platform is capable of, Thornton said.

As for resolution, that runs about 1024 × 768 pixels. Thus, 2D displays today offer higher resolution, but what Provision Interactive Technologies provides is enough for the digital signage market, according to Thornton. He also noted that the company's 3D technology is not limited to just that application.

"The broad brush of where we can go is anywhere where there is currently a traditional 2D flat panel, LCD or LED technology. We can go in and either replace, displace or supplement that technology," Thornton said.

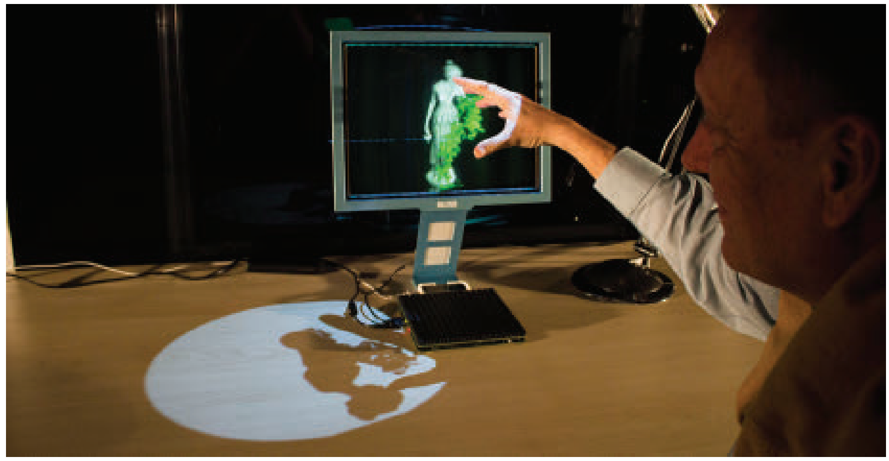
In another instance, a glasses-free three-dimensional display technology is being developed by 3DIcon Corp. of Tulsa, Okla. The company's products send two infrared laser beams into an imaging medium, today composed of rare-earth-doped ZBLAN glass. At the point where the lasers intersect, two-photon absorption gives rise to fluorescence and the result is a 3D image.

The challenge is that the imaging medium is not cheap. Hence, scaling demonstration systems up beyond a 4-cm cube is not economically practical. The company has therefore decided to develop proprietary silicone polymers, with the goal being the creation of one that has the right electrical and optical properties while meeting cost and weight targets.

"We believe we have a viable solution and that's the direction we're going right now," said Doug Freitag, vice president of technology and business development.

As is presently done with the glass, the polymer will be doped with a rare earth to give it the right properties. The dopant will probably determine the final cost of the material. Freitag noted that the current approach looks promising, but a successful prototype must still be built. He added that the company is developing a family of polymers that could have a number of other uses, including depositing silicon films for flexible transistors in displays.

A final example of a glasses-free 3D display comes from Holografika Ltd. of Budapest, Hungary. CEO Tibor Balogh said that the company's 3D light-field displays average 100 million pixels and can offer full-angle 180-degree viewing. The goal of Holografika's founders was to



Holografika

Glasses-free 3D display technology could allow people to share and interact with a scene (above and at right).

Holografika

create what Balogh characterized as the perfect 3D display.

Imagine hanging such a TV next to a window and that the scene being shown on the screen is what's visible through the window. The ideal 3D display would have to pass a simple test. "You would not be able to differentiate if you are looking at the window or you are watching your TV set," Balogh said.

He doesn't claim perfection yet, but did indicate the company's approach might make it possible. This would be done without the use of headgear, tracking or positioning and with the same comfort as watching any display today.

One problem is cost. A 3D display has many more pixels than a 2D one. In the case of Holografika's approach, the ratio is about 100 to 1. So even if the company's products are a 10th the cost on a per-pixel basis, the final price tag of its 3D displays will still be much higher than what it would be for a 2D one.

Holografika is making progress on this front, Balogh said. He added that the latest improvements in lowering costs make its displays suitable for high-end systems for professional applications. Further work could lower manufacturing expenses still more and that might lead to higher volume production and more cost-competitive displays.

He noted that while near-eye augmented and virtual reality generate publicity, such applications are inherently an isolated experience. A glasses-free approach, in contrast, enables whole groups to be immersed in what is being shown.

As Balogh said, "They can share the same 3D scene and they can interact with the scene in a natural way. With light-field you can do it."

hank@hankhogan.com

Spectroscopy is used to evaluate the chemical makeup of items in the lab and the field.

Two-Dimensional MEMS Arrays Pave Way for **Mobile Spectrometers**

A digital micromirror device serving as the spatial light modulator can overcome shortcomings of traditional spectroscopy architectures.

BY MIKE WALKER, TEXAS INSTRUMENTS INC., AND HAKKI REFAI, OPTECKS LLC

In the field of near-infrared (NIR) spectroscopy, a system that combines portability with the accuracy and functionality of high-performance laboratory systems would significantly enhance real-time analysis. The development of small handheld spectrometers, powered by a battery, could lead to more efficient monitoring of industrial processes or assessments of food ripeness in the field.

Most dispersive IR spectroscopic measurements begin in the same manner. The light to be analyzed passes through a small slit that, combined with a grating, controls the resolution of the instrument. The diffraction grating is designed specifically to reflect light of different wavelengths at known angles. This spatial separation of wavelengths allows other systems to measure the light intensity on a wavelength-by-wavelength basis.

Traditional architectures for spectroscopic measurements differ mainly in how the dispersed light is measured. Two very common methods are 1) a single element (or point) detector combined with physical scanning of the dispersed light, and 2) imaging the dispersed light onto an array of detectors.

Approach using MEMS technology

Many limitations of traditional spectroscopy methods can be overcome using a new approach based on optical microelectromechanical systems (MEMS) array technology with a single-point detector. A solid-state optical MEMS array replaces the traditional motorized grating in a single-point detector-based system with a simple, spatial wavelength filter. This approach can utilize the performance advantages of a single-point detector while eliminating the issues of a finely controlled motorized system. In recent years, such systems have been produced in which the scanning grating is eliminated and the MEMS device filters each specific wavelength into a single point detector. This method has demonstrated high performance while resulting in a more compact and robust spectrometer.

The use of an optical MEMS array has several advantages over a linear array detector architecture. First, a larger, single element detector can be used to increase light collection and greatly reduce system cost and complexity, especially for infrared systems. Also, by eliminating the array detector, the pixel-to-pixel noise is eliminated, which can be a significant improvement in the signal-to-noise ratio (SNR) performance. The increase in SNR

Images courtesy of Texas Instruments

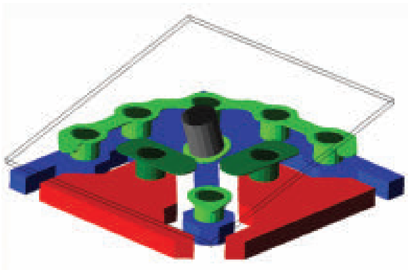


Figure 1. A micromirror structure with a 17° tilt angle.

allows more accurate measurements to be obtained in less time.

In a spectroscopy system using MEMS technology, the diffraction grating and focusing elements perform the same functions as before, but now light from the focusing element is imaged onto the MEMS array. To select a wavelength for analysis, a specific band of spectral response is activated so as to direct light to the single point detector element for collection and measurement.

The advantages are realized if the MEMS device is highly reliable and can produce a filter response that is predictable and constant over time and temperature.

Using a digital light proccessing (DLP) chip or digital micromirror device (DMD) as a spatial light modulator can overcome several challenges if used as the MEMS device in a spectrometer system architecture. First, light is switched on and off into the single point detector using an array of mirrors composed of aluminum, which is optically efficient over a wide range of wavelengths. Second, the on and off states of digital mirrors are controlled by mechanical stops and a latched circuit of complementary metal oxide semiconductor (CMOS) static random access memory (SRAM) cells, providing fixed voltage mirror control. This fixed voltage static control means the system does not require a mechanical scanning or analog control loop and can simplify calibration. It also makes the spectrometer design more resistant to sources of error such as temperature, aging or vibration.

The programmable nature of the DMD has many advantages. One advantage occurs when designing a spectrometer architecture based on addressing columns of mirrors as a filter. Since the resolution

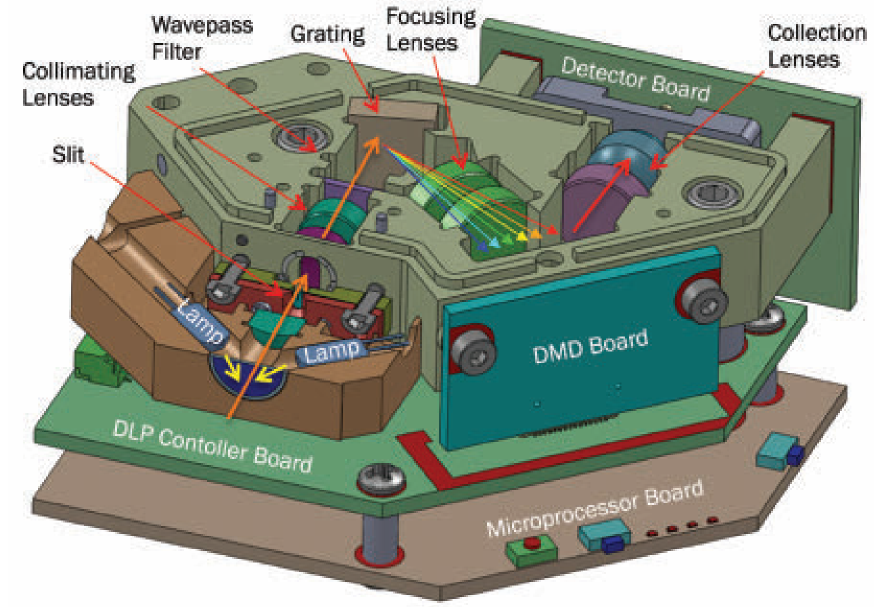


Figure 2. A spectrometer optical engine using a digital micromirror device (DMD) and single point detector.

A spectrometer is used to analyze pharmaceuticals.

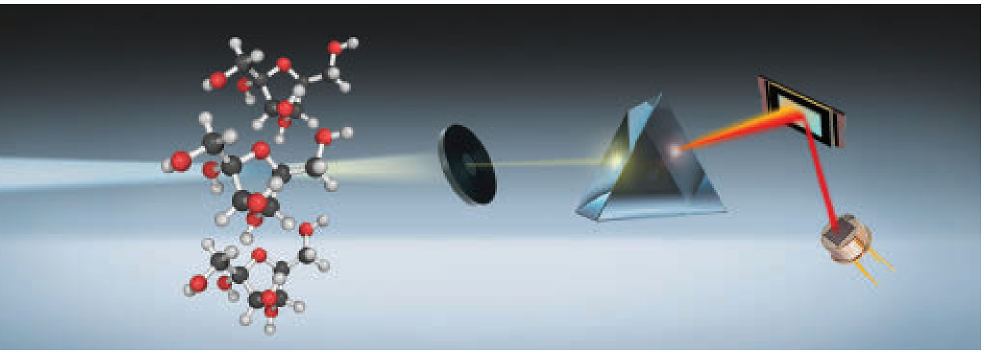
of the DMD is typically higher than the desired spectrum, the DMD area can be underfilled and the spectrum can be oversampled. This enables wavelength selection to be fully programmable and allows for extra micromirrors to be used as recalibrated columns in case of extreme mechanical shifts of the optical engine.

Also, the DMD is a two-dimensional programmable array, which provides the user a high degree of flexibility. Resolution and throughput can be adjusted by selecting a different number of columns. Scan time can be varied dynamically so that wavelengths of interest can be examined longer and in greater detail than wavelengths of little interest, making better use of instrument time and capabilities. Additionally, advanced aperture encoding techniques, such as applying Hadamard patterns, allow a high degree of flexibility and increased performance as compared to fixed filter implementations[1].

In summary, spectroscopic devices using a DMD can enable higher resolution, higher flexibility, higher robustness, a smaller form factor and lower cost than current spectroscopy systems, making them attractive for a broader range of commercial and industrial applications.

Single detector architecture eliminates noise

Today's linear array-based spectrometer is limited by two primary factors. First, the wavelength selection presented to the detector is constrained by the pixel aperture. The size of a detector determines the amount of light collected and bounds the SNR. A typical indium gallium arsenide (InGaAs) 256-pixel linear array, such as Hamamatsu G9203-256, is 50 × 500 µm. Conversely, an array of digital micromirrors is a fully programmable matrix where the number of columns and scan technique can be configured for applications. This allows a larger signal to be presented into a larger 1- or 2-mm single point detector typically used with a DMD. Filtering narrow bands of light into a linear array, which are typically 50-µm-wide pixels, may present challenges of crosstalk. Pixel-to-pixel disturbances can become the primary contributor to noise in the reading. These disturbances are eliminated by the single detector architecture. Also, by taking advantage of the digital micromirror scan speeds of 1 kHz to 4 kHz, single point scans can reach similar dwell times to



An illustration of how spectroscopy works with DLP technology.

parallel multipoint sampling. Results have shown SNR ranges >10,000:1 for compact spectrometer engines based on MEMS (or based on a DMD).

2D MEMS array key to mobile spectrometer

In order to maximize performance, the user needs to consider the overall MEMS area that can be used to reflect light into the detector. This can then be carefully matched to available single point detector aperture sizes.

A DMD exists that utilizes a 5.4-µm micromirror with over 400,000 available pixels and is optimized for wavelengths of 700 to 2500 nm. That DMD is the DLP2010NIR, which utilizes a new pixel architecture know as TRP. This pixel, seen in Figure 1, provides a 17° tilt angle. DLP2010NIR was implemented in an evaluation module that provides a unique optical architecture for spectroscopy use cases. Using an optical path that leverages the 17° on and off angles enables a high-performance sensing solution with a compact engine that minimizes stray light.

An illustration of this unique optical engine for spectroscopy use cases is seen in Figure 2. The system optimizes optical signals throughout the light path. Response from the sample is imaged onto the DMD, allowing spatial control of each wavelength. The evaluation module is intended to capture the design advantages of using a highly efficient MEMS as a high-speed 2D filter for spectroscopy. It is a compact, rugged and highly adaptable system capable of moving spectroscopic analysis out of the laboratory and directly to the field or source needing measurement. The ability to interchange measurement heads between transmissive and reflectance with the same device can enable performance benchmarking versus traditional spectrometers.

There are several illumination modules for a spectroscopic optical engine that leverage the DLP2010NIR chip, and each works in slightly different ways. In a transmission module, a light source, cuvette holder, precision cuvette and additional mounting hardware are used to facilitate the measurement of absorption and scattering properties of a transmissive sample. NIR transmittance measurements can be used for liquid samples, such as water content or presence of gaseous signatures in juices. The data can provide a wealth of information about the juices' origins. In solid samples, NIR transmittance can measure the opacity of plastic tubing, which is an important parameter in observing flow in gas and liquid delivery lines. In-line transmittance measurements are also used to analyze the water content of butter during production, which allows for timely adjustments to the butter-making process that saves time, minimizes costs and increases the quality of the end product.

Alternatively, a reflection module can be used for measurements that do not require the sample to be in contact with the spectrometer window. It gives flexibility to perform scans from several centimeters distance, such as monitoring meat quality after being wrapped in plastic. Health aspects such as blood glucose prediction can also be characterized in the NIR region using diffuse reflectance from skin.

Finally, in a fiber-coupled module, either transmittance or reflectance measurements are made via an optical fiber. This allows measurements when direct contact between the spectrometer and sample is not practical or possible. Examples of such sampling include monitoring industrial processes; measuring fluids as they are piped between vessels; and analyzing moisture fat and protein content in chicken, beef and pork. The modules greatly extend the range of applications and can provide enhanced measurement performance. Optecks has illumination module solutions that enable all of these sampling methods.

As discussed, spectroscopy devices using a DMD expand the ability to analyze, test and measure a multitude of substances. They provide a path to more accurate performance, higher resolution, more flexibility, improved robustness and smaller form factor light-sensing solutions. In addition, spectrometers using a DMD can bring increased measurement reliability that may not have been there before using traditional spectroscopy systems. Whether a user is looking to test how much water is needed for his crops on a farm, or he is trying to predict spoilage in food, spectroscopy continues to be a powerful approach for accurate, real-time analysis.

Reference

1. E. Pruett (April 2015). Latest developments in Texas Instruments DLP near-infrared spectrometers enable the next generation of embedded compact, portable systems. *SPIE*, Vol. 9482-13.

Meet the authors

Mike Walker is a business development manager for Texas Instruments' DLP Products, leading its spectroscopy business. Prior to this role, Mike spent more than 30 years leading multiple technical and business teams at Texas Instruments; email: MJWalker@ti.com. Hakki Refai, Ph.D., is chief technology officer for Optecks. Refai has more than 10 years of experience in the design and development of optical, electronic and software systems for DLP-based systems; email: hakki@optecks.com.

Artist's representation of the Giant Magellan Telescope with seven giant mirrors by GMTO Corp.

Great Strides in **Optical Fabrication**

Largely unchanged for centuries, optical fabrication is today an evolving and dynamic field with notable advances in molding, surface process optimization and freeform-capable tools.

BY MARIE FREEBODY
CONTRIBUTING EDITOR

In 2018, a six-and-a-half-meter mirror made up of 18 hexagonal segments will quietly unfurl 1.5 million km from Earth, marking the end of years of intense research and refining of optics fabrication techniques. In the silence of space, the James Webb Space Telescope will turn its giant primary mirror toward deep space, kicking off the start of man's chance to look further back in history than ever before.

Its development, and other high-tech projects like it, has led to many improvements in optics fabrication techniques in use today. From smartphones, wearable optics and head-up displays, to airborne and space-borne remote sensing and surveillance, some of the latest trends in technology have emerged thanks to impressive progress in the way optics are made.

Being the largest mirror ever to be sent to space, one of the challenges of image quality and resolution was met by the team at the Integrated Optical Systems business unit of Coherent Inc. in Richmond, Calif., currently led by Brandon Turk.

The task was to polish each of the 18 hexagonal mirror segments, which are made of ultralightweight beryllium and coated with gold for broadband IR performance. One of the biggest challenges was to ensure the optics are light enough to launch and unfurl, but sturdy enough to withstand the harsh conditions of space.

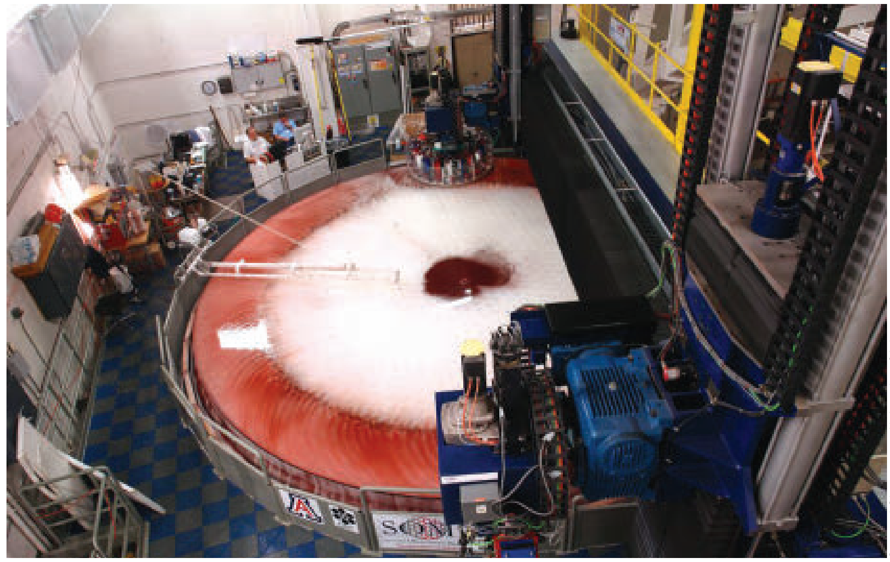
"Beryllium was chosen because it is extremely light and stiff, with low thermal expansion at the cryogenic temperatures at which the observatory will operate," Turk said. "However, beryllium is a challenging material to polish, and requires special handling because beryllium dust is a health hazard when inhaled. So we deliver the requisite image quality and resolution by finishing components to very tight figure and wavefront specifications."

Some of the fabrication and metrology methods Coherent uses today were in fact developed and matured during that program. But it's not just Coherent that has made improvements in optics fabrication; the industry as a whole has seen remarkable progress in a number of key areas:

- More predictable/deterministic figuring process for higher convergence rates, by simulating, optimizing and controlling the fabrication process.
- Faster removal process, resulting in a shorter fabrication time, using various polishing/figuring materials and slurries.
- Smarter computer-controlled opti-

Ray Bertram, Steward Observatory, University of Arizona

An 8.4-meter mirror for the Large Synoptic Survey Telescope being fabricated using a stressed lap and a non-Newtonian lap at the Richard F. Caris Mirror Lab, Steward Observatory, University of Arizona.



Steward Observatory, University of Arizona

An 8.4-m primary off-axis segment mirror for the Giant Magellan Telescope being fabricated using a stressed lap at the Richard F. Caris Mirror Lab, Steward Observatory, University of Arizona.

QED Technologies Inc.

Deterministic polishing of a large aperture lens using magnetorheological finishing.

Steward Observatory, University of Arizona

A 28-m-tall testing tower housing a set of four metrology systems that provide independent measurements of the Giant Magellan Telescope segments to guide the computer-controlled optical surfacing process at the Richard F. Caris Mirror Lab, Steward Observatory, University of Arizona.

cal surfacing process optimization for more efficient directed figuring, using different deconvolution/search methods.

- Smoother optical surface controlling low- to mid- to high-spatial-frequency surface errors, such as power spectral density (PSD) or structure function specifications, by using multiple metrology systems and overall manufacturing process control to minimize residual surface ripples.
- More stable and maintainable freeform-capable tools by introducing conformable subaperture tools.
- Better molding of IR materials.
- Improvements in critical line beam shaping optics for excimer laser annealing tools for display fabrication.

Freeform optics

Aspheric/freeform optics manufacturing has become a main theme in the optics community over the last 12 months. Defined as surface shapes that lack rotational symmetry, freeform optics allow for higher performance, such as wider field of view or better modulation transfer function and also enable reduced system envelope at the same performance level. It also means that an incredibly wide range of substrate materials can be used, including metals, glasses, composites and even organics.

The creation of nontraditional optical components has paved the way for some of the latest technologies we see today, including wearable or portable optical devices, visual display or human machine interface (HMI) systems.

"Due to their strict form factor, lightweight and optical performance requirements to fit [the] human's body and ergonomic needs, highly asymmetric/aspheric/freeform/noncircular-aperture optics become essential components to realize those post-smartphone devices," said Dae Wook Kim, principal investigator of the Large Optics Fabrication and Testing (LOFT) group and assistant professor of optical sciences at College of Optical Sciences at the University of Arizona.

"Efficient, precise and cost-effective manufacturing technology for these future optics is naturally one of the most essential technologies to deliver those various conceptual lab-demo devices to daily human life," Kim added.

"One can imagine that everyone wants smaller optics for head-worn displays," said Andrew Fisher, an optical engineer at Barrington, N.J.-based Edmund Optics Inc. "Some challenges that exist when trying to keep components small have to do with the edges of these parts. Most current optics always have a clear aperture specified that is smaller than the outer-most dimensions of the surface."

One way to reduce component size is to bring the clear aperture right to the edge of the part, which means that any coatings need to be applied all the way to the edge of a surface and that there can be no chamfers or bevels on the corners. Both of these requirements can prove very challenging, but are demands to which the industry is currently responding.

One of the biggest challenges is overcoming the hurdle of mass production of such nontraditional highly aspheric/freeform optics. With traditional optics, you

Optics Fabrication Timeline: Major Milestones

Photonics Spectra takes a look at some of the highlights in the history of optics fabrication.

1220s: Development of glass.

1222: Broad sheet glass was first produced in Sussex, England.

1500s: Development of mirrors. The method of making mirrors out of plate glass was invented by glassmakers on the island of Murano in Italy, who covered the back of the glass with mercury, obtaining near-perfect and undistorted reflection.

1810: The first known spherometer was invented by French optician Robert-Aglaé Cauchoix. They were primarily used by opticians and astronomers to help grind lenses and curved mirrors. Today's digital spherometers are a common way to measure the radius of a surface and are used iteratively when setting up a process to guarantee the shape of the part is correct.

1888: Machine-rolled glass was first developed, enabling patterns to be introduced.

1896: Although first patented in 1883 by watchmaker John Logan of Waltham, Mass., it wasn't until 13 years later that Frank Randall, another watchmaker, purchased the patent and formed a partnership with Francis Stickney to begin manufacturing dial indicators for general industry.

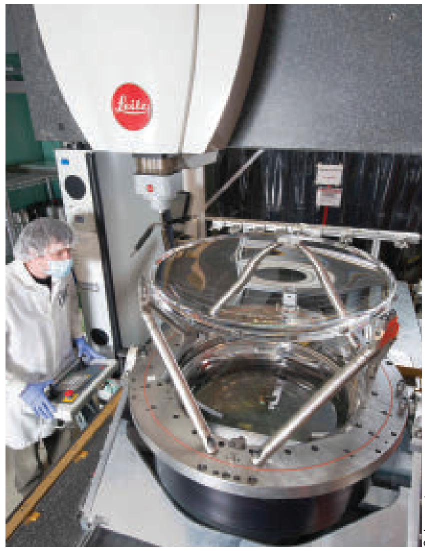
1904: Also supplying dial indicators was the German professor Ernst Abbe after establishing the measuring instrument department at the Zeiss Works. Dial indicators have become an important tool determining the runout of an outer diameter as well as assisting with centering parts on a fixture.

1957: A computer numerical control system was developed by a collaboration between the Massachusetts Institute of Technology and the Air Force Materiel Command at the Wright-Patterson Air Force Base and the Aerospace Industries Association. The invention paved the way for automated tools such as grinding, prepolishing and centering of can manufacture 10 spherical surfaces and mount 10 substrates at once, using a single large tool to polish them; but this is impossible for a freeform optic.

"The optics often suffer from mid- to high-spatial-frequency surface errors. It becomes a critical issue for advanced imaging systems targeting diffraction-limited spatial resolution such as astronomical telescopes or surveillance satellites and/or an extremely high-contrast imaging application such as exoplanet search cameras," said LOFT's Kim.

Some of the next-generation flagship optical instruments and systems such as the European Extremely Large Telescope, post-LIGO systems, space telescopes and surveillance satellites also require superior quality optics components.

"They are often large and/or highly aspheric, freeform optics, such as the Giant Magellan Telescope's 8.4-m-diameter primary mirror segment with around 13 mm of aspheric departure and a super smooth surface finish," Kim said. "Although these are not public market


Coherent

A field corrector for a ground-based telescope application.

projects with an immediate economic impact, their scientific and technological impacts will be significant."

Many of today's impressive ground-

optics, enabling cost-effective production for manufacturers.

1960s: Addition of coatings to surfaces and the development of the first optical test equipment — swept-tuned instruments.

1965: The discovery of fast Fourier transform led to the first analyzers being developed in 1967.

1970s: Interferometers or test plates are an essential tool for determining the surface accuracy of an optic. Full-aperture interferometric metrology tools have become necessary for today's modern optical fabrication. The development of digital phase-shifting interferometry in around 1970 at Bell Labs was a crucial innovation for optical fabrication. Without this technology, the high-precision optical surfaces used in semiconductor lithography tools would not be possible.

1998: The first commercially available deterministic polishing machine, the Q22 magnetorheological finishing machine, was introduced by QED Technologies of Rochester, N.Y. This machine and technology enabled the widespread use of aspheres with highly complex geometries and tighter surface specifications for high-performance optical systems.

2000s: Stressed mirror polishing is being used to apply precise forces to mirrors during their fabrication, contributing to some of today's latest ground-based astronomy programs, including the proposed Thirty Meter Telescope and the European Extremely Large Telescope.

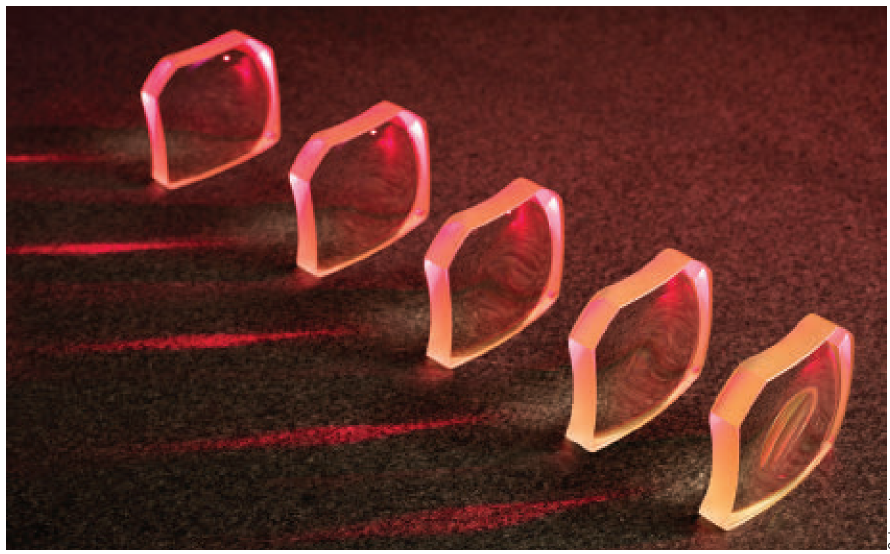
2012: Completion of the first of seven aspheric mirror segments for the 24.5-m Giant Magellan Telescope primary mirror. With a diameter of 8.4 m, its creation marks the largest ever off-axis aspheric mirror ever manufactured.

2014: Tilted wave interferometry was first presented by scientists at the Institute of Applied Optics, University of Stuttgart, and metrology specialists Mahr GmbH, both of Germany, as a completely new, patented and flexible way of measuring aspheres and freeforms.

based astronomy programs, including the Thirty Meter Telescope and the European Extremely Large Telescope, boast massive segmented primary mirrors, and even with relatively large (>1 m) segment diameters, will require many hundreds of aspheric mirror segments to be fabricated.

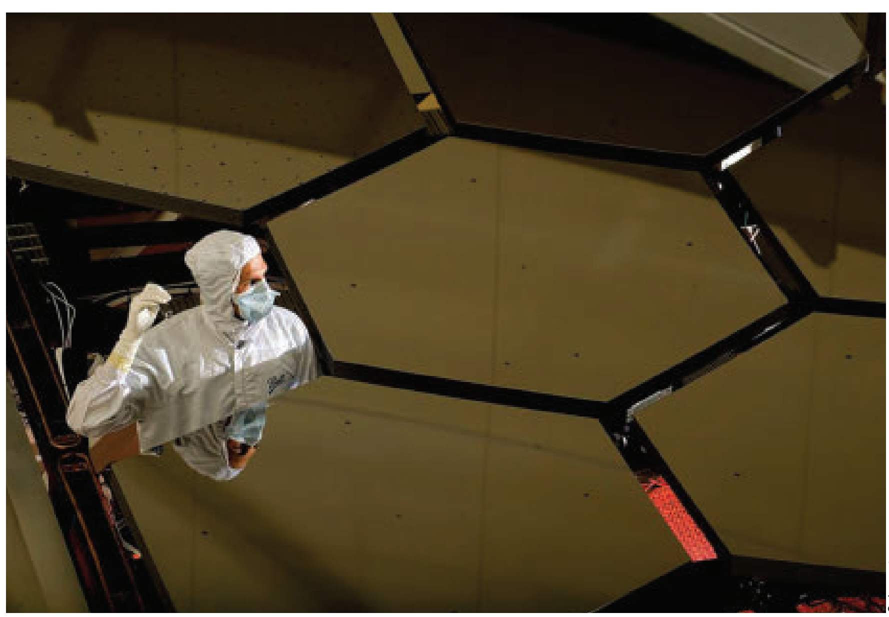
A traditional computer-numeric-control-based approach would lead to long manufacturing cycle times, increasing costs and driving capital requirements to the point of being impractical, so Coherent used a technology known as stressed mirror polishing in which specially designed fixtures apply precise forces to be applied to the mirrors during their fabrication.

"In essence, we induce stress fields in the mirror that create the inverse of the aspheric shape we want to obtain," Coherent's Turk said. "We can then use classical spherical polishing techniques to finish the optical surface and will ultimately achieve the desired aspheric shape after releasing the stress applied



Coherent

A set of relay elements for the head-up display in a fighter jet.



Coherent

Mirror segments for the James Webb Space Telescope, which will be launched in 2018 and help scientists look further back in history than ever before.

to the mirror during polishing."

The technique requires less capital investment to achieve the desired throughput rates to manufacture hundreds of very large, precise and smooth aspheres on time scales appropriate for the manufacture of these large telescopes.

Defense is the other part of aerospace with a growing demand for freeform optics. These range from imaging optics for drones, to head-up displays (HUD) for aircraft cockpits; a typical HUD incorporates several aspheric surfaces as well as a beam combiner.

Tighter specifications

A general trend for advanced security and surveillance is incorporating visible channels into traditionally IR-only optical imaging systems. This demands tighter optical surface specifications, both for figure error and surface roughness, than can be achieved with the traditional optical fabrication method, single-point diamond turning.

QED Technologies' magnetorheological finishing (MRF) platform has improved its system to take advantage of more of the wheel's surface area, which essentially broadens the envelope of surface geometries that can be processed.

"As the performance requirements of optical systems increase, more complex geometries with tighter surface specifications are demanded. Deterministic polishing processes, such as MRF, are therefore ideal for optical fabricators to meet these requirements in a predictable, cost-effective manner," said Andrew Kulawiec, president of Rochester, N.Y.-based QED Technologies.

As the saying in the industry goes, you can't make what you can't measure, which means that full-aperture interferometric metrology tools have essentially developed alongside optical fabrication technology.

Freeform optics metrology requires both high-dynamic range and fine precision, which are often competing with each other. Various non-null, high-dynamic range metrology systems have been developed such as subaperture stitching interferometers, contact type profilometers, noncontact optical sensor scanning systems, deflectometry systems and adaptive null systems.

"Higher-resolution interferometric


Edmund Optics Inc.

Precision figure correction with magnetorheological finishing, displaying deterministic polishing for superior surface control while providing increased yield.

metrology, which is critical for deterministic polishing processes as well as for characterizing mid-spatial-frequency errors, continues to find its way into more and more optical fabrication shops," Kulawiec said.

Coherent's approach to deal with the large area optics is to make subaperture measurements and then use highly customized software for stitching.

"This is not trivial," explained Coherent's Turk. "You have to avoid stitching errors and other possible systematic errors. Each test setup is unique and engineered specifically to ensure we can meet the specifications."

An emerging trend to watch is a multiwavelength interferometer built into freely moving measurement heads that allow a user to measure parts with large aspheric departure or very steep curvature with interferometric accuracies.

"Also, the recently released tilted wave interferometer is reducing full aspheric surface measurement times from minutes to seconds," Fisher said. "With newer metrology systems being able to move freely around these parts and measure the surface, some of the difficulties come in standardizing and referencing these surfaces. For instance, there is work underway to determine best methods for adding fiducials to freeform optics in order to align parts between their metrology and fabrication steps."

marie.freebody@photonics.com

Maximum Exposure: **Ray-Tracing Software** Optimizes Reflector Design

Engineers can simulate rays emitting from direct and indirect sun models to design more efficient concentrated solar power systems.

BY MICHAEL GAUVIN
LAMBDA RESEARCH CORP.

The concentrated solar market is often overshadowed by photovoltaic (PV) panels, yet the market segment is expected to grow by nearly 20 percent annually through 2020. Concentrated solar power — or CSP — has unique performance advantages over PV panels, especially when tied to the electrical grid.

CSP systems convert solar radiation to mechanical energy, which, in turn, becomes electrical energy. This is achieved when reflectors, consisting of a mirrored surface applied to a parabolic or flat structure that is mounted to a tracking system, are oriented to focus maximum solar radiation on a receiver — either a power tower or a localized element elevated above the reflectors. From there, a transfer or working fluid is heated to 1000 °F and converted into steam, which then is used to power a turbine, generating electrical energy. Unlike PV panels, CSP can provide power day and night due to thermal storage technology.

CSP engineers are well-aware of the operating principles of these systems. However, achieving maximum efficiency requires high direct solar irradiance to be focused on the receiver. Parabolic trough and Fresnel reflectors are similar in that they both utilize a local receiver instead of a power tower, though obviously differ in terms of geometry. Unlike power towers, these two CSP types are more cost-effective and have fewer installation limitations such as physical scale, geographic location and water access.

 Images courtesy of Lambda Research Corp.

Determining maximum absorption rates

The design of parabolic and Fresnel reflectors is the subject of many academic articles, though very few put the complete CSP systems into context with their physical location, published irradiance maps and turbidity conditions. As part of their installation design process, CSP engineers require a tool that can take their lens and reflector geometry and combine it with these external factors to determine the maximum absorption rates.

The ideal solar analysis tool to simulate CSP systems is a 3D computer-aided design (CAD)-based ray-tracing engine including a solar utility to calculate absorption rates on the collector for both direct and indirect solar contribution over time and with consideration of turbidity and aiming apparatus. This tool validates a system by providing a visualization of the rays emitting from direct and indirect sun models that propagate light through the CSP geometry until they reach the target solar collection. The normal workflow in Lambda Research Corp.'s TracePro software, for example, is to evaluate a CSP system starting with the creation of the 3D geometry. Basic geometric CAD primitive shapes are used to create the optical elements in the CSP model. These built-in elements include standard lens types, Fresnel lenses and conic or trough reflectors. A 3D modeler is also included to sketch in 2D surface profiles and extrude or revolve these shapes into optical solid primitives. The user then adds optical properties, creates a sun source model and then does a ray trace to perform an initial evaluation of the system and to verify the model (Figure 1).

After system verification, the solar utility can evaluate the system over time. The CSP's global position is specified using either Google Map positioning or by directly entering the unit's longitude and latitude (Figure 2). The user then enters the time period and interval to be evaluated, system orientation respective to the Earth's zenith and azimuth, entrance pupil size, sun-tracking options and, if available, turbidity conditions over the specified time period.

The standard setup analysis procedure to create the direct and indirect solar contribution for the solar simulation process is to specify the direct and indirect sun models. TracePro has the full National Renewable Energy Laboratory (NREL) solar spectrum model and both the Igawa and Darula & Kittler indirect sun models including definitions for clear, cloudy and partly cloudy sky conditions.

Interactive dialogues define turbidity conditions to calculate changing atmospheric conditions, such as cloudiness, using user-defined percentages per time interval and fully supporting sun-tracking capability of aim to sun, uniaxial, and uniaxial with aim to sun methods.

The CSP engineer then enters the data for an entrance port specifying the zenith and azimuth orientation of the CSP along with the entrance pupil size and shape.

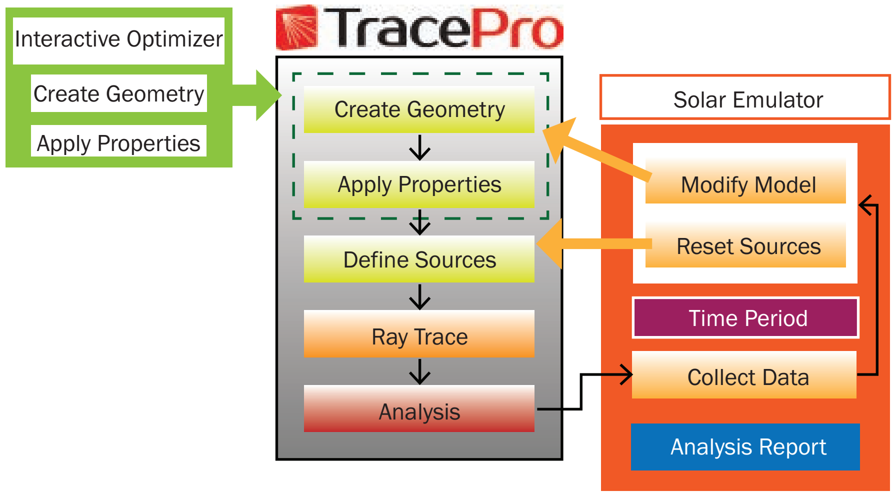


Figure 1. TracePro workflow using solar emulator utility.

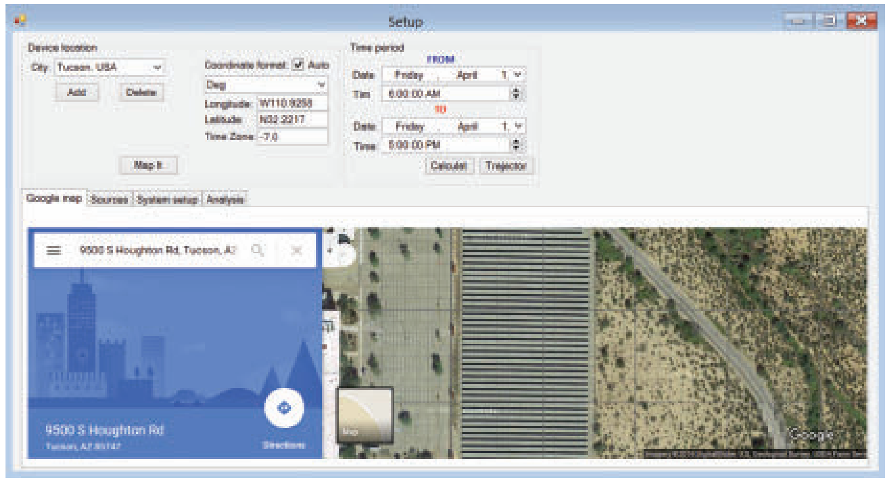


Figure 2. Google Map positioning in the solar utility.

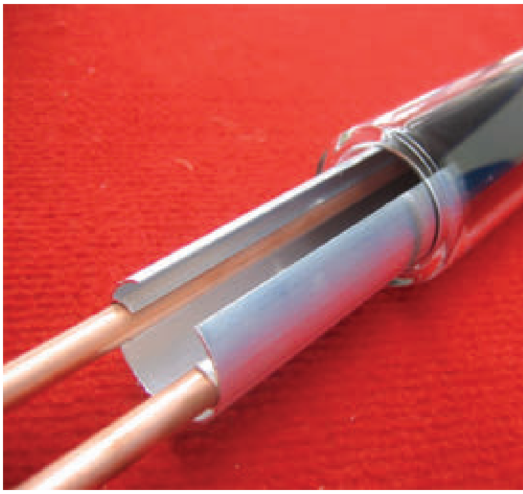
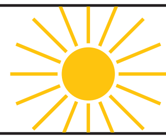
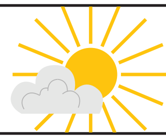


Figure 3. Exploded view of the internal workings of the actual concentrated solar power.

Table 1.
Weather Conditions as Percentages for Taiwan
April through September 2014

			
Month/Turbidity	**2.5**	**12**	**45**
April	25%	25%	50%
May	10%	30%	60%
June	75%	15%	10%
July	60%	15%	25%
Aug.	60%	20%	20%
Sept.	80%	10%	10%

Source: Lambda Research Corp.

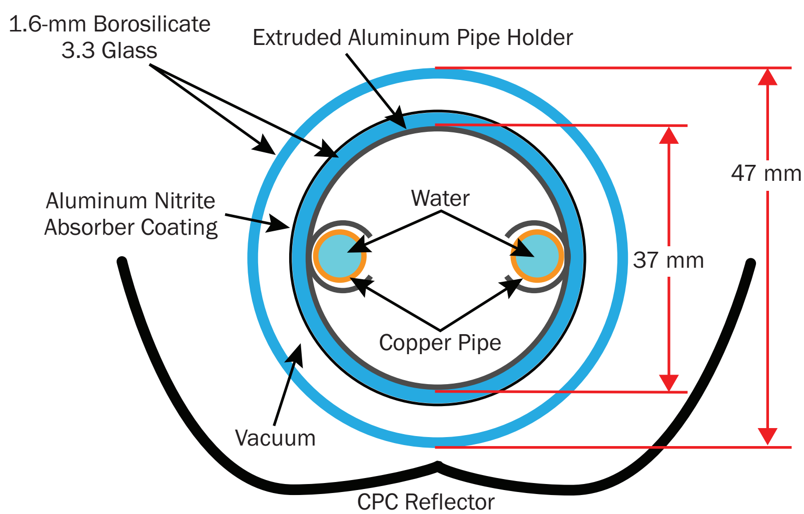


Figure 4. 2D profile of the concentrated solar power system. CPC = compound parabolic concentrator.

Figure 5. Complete manufactured system in the field.

Next, a filter can be set up that specifies the percentage of sunny, partly cloudy and cloudy days per interval period to completely define the turbidity conditions that the unit will encounter over the time period. Lastly, CSP engineers can visualize the results through irradiance and candela maps, as well as run flux reports on total collected energy in graphical and tabular formats over the calculated period.

Modeling the system

As an example, consider a CSP that incorporates sun-tracking and turbidity conditions over an April-to-September interval. A model is first built in ray-tracing software. An exploded view of the actual system has multiple optical elements including borosilicate glass, water, compound parabolic concentrator (CPC) reflector, copper pipe and an extruded aluminum pipe holder (Figure 3). In this system, sunlight hits the CPC reflector and reflects off the aluminum pipe holder until it is taken in by the absorber coating on the copper pipe.

Modeling the system is as simple as taking a screen capture of the end-on profile of the existing system (Figure 4) and then overlaying basic surface primitives in a 2D-sketching utility, adding profiles on top of each component in the existing model. The sketch utility enables the user to add segment and control points to each of the sketched profiles and then pull on these points until the surface profiles match the screen-captured profiles. After creating a model of all of the surface components, these profiles are then extruded or revolved to make solid objects. The next step is to add optical properties to the surfaces and solid objects to correctly mirror real-world optical behavior.

The actual working model of a singular unit (Figure 5) shows a double array of the completed manufactured system with 12 tubes in two separate banks. The software model can then be ray-traced to verify that the virtual model works as expected by visualizing the incoming rays through the optical system. In the simulated model, almost parallel red-colored rays depict incoming sunlight that then reflects off the CPC collector and propagates through the optical elements until it reaches the inner absorbing areas (Figure 6).

Continued on page 52

Continued from page 50

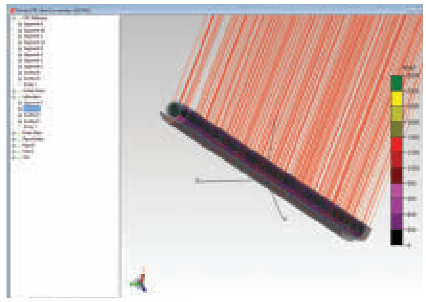


Figure 6. System as modeled in TracePro with rays shown.

After verifying the model for a singular time event, the next step involves simulating daily results for a one-month period, and then simulating the monthly contributions over an extended period.

Accounting for turbidity and sun-tracking apparatus

Here's where a lot of the painstaking work is involved. The CSP engineer must go back through multiple years of weather forecasts to compile a list of average turbidity conditions. This data is then entered as a time filter per month specifying clear, partly cloudy and cloudy conditions on average for that period into the software's filters. Table 1 (opposite page) shows turbidity conditions in Taiwan for 2014, depicting the percentages of sunny, partly cloudy and cloudy dates for April through September; the top right portion shows the data as entered into the time and turbidity filter.

The next step is to add turbidity and sun-tracking to the simulation. To correctly imitate turbidity conditions over a daily time period, the software can simulate the same CSP system for different turbidity cases. For instance, when the CSP system is simulated for a 100 percent sunny condition, the peak solar contribution in this case would occur around noon. In a second scenario where turbidity for the daily period showed sunny and cloudy conditions, the simulation would show a double peak during the day.

If the hourly and daily results are combined into full-day simulations and monthly periods, compiled results will indicate the contribution for daily periods for both 100 percent sunny conditions as shown by a slightly wavy line and for varying cloudy and sunny periods depicted by a widely varying line plot.

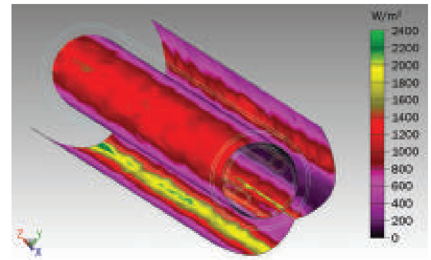


Figure 7. 3D irradiance pseudo-color plot of the power flow of the optics in the concentrated solar power system.

To add sun tracking to the simulations, a user must specify the type of tracking the collector system uses: aim to sun, uniaxial, or combined uniaxial with aim to sun tracking. Multiple daily simulations will indicate that the more accurate the sun-tracking system, the better the results.

Once a periodic performance specification is simulated, the CSP engineer can now iterate the design to improve performance. It is critical that the design engineer understand how the power flows through the optical components in their collection systems. 3D visualization is critical for understanding power flow through the collector optics, and only through visualization of the power flow can the designer understand how the sun's flux propagates through the system. A typical CSP system with parabolic trough setup reflecting solar energy to a tube containing fluid for thermal energy transfer with power flow is shown in a pseudo-color format (Figure 7).

While solar has become more competitive with traditional energy sources, financial and technical barriers must still be overcome in order to convince utilities and energy authorities of the viability of the investment in the technology. By producing simulated results based upon real-world information, CSP engineers can lessen these objections and show how their installations will ultimately benefit consumers.

Meet the author

Michael Gauvin is the vice president of sales and marketing at Lambda Research Corp. with over 30 years of optical engineering experience; email: mgauvin@lambdares.com.

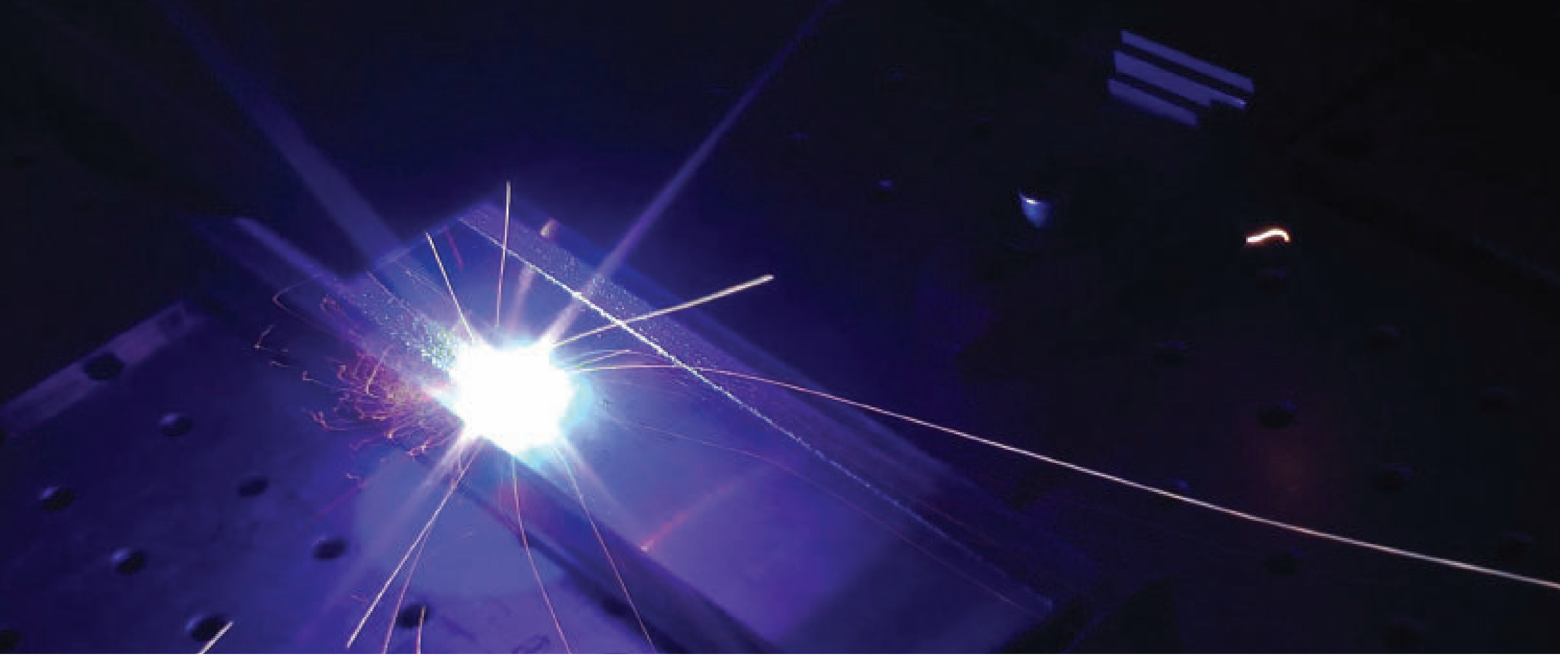


Image taken during the structuring process. The structured material appears at the left of the laser beam.

New Milestone in **Laser Bonding**

An innovative process involving a high-power, short-pulse laser is the key to creating strong metal and plastic joints for the automotive and aerospace industries.

BY FLORIAN KIEFER
TRUMPF INC.

The demand for lightweight construction and economic efficiency has led to R&D efforts in metal-plastic combinations. Although primarily driven by the automotive industry, this has become an increasingly important topic for other industries as well. By using a high-power short-pulse laser it is possible to establish a simple joint with a very high loadability. Design engineers are therefore gaining access to the completely new and innovative application possibilities of hybrid assemblies.

Prospects of hybrid assembly

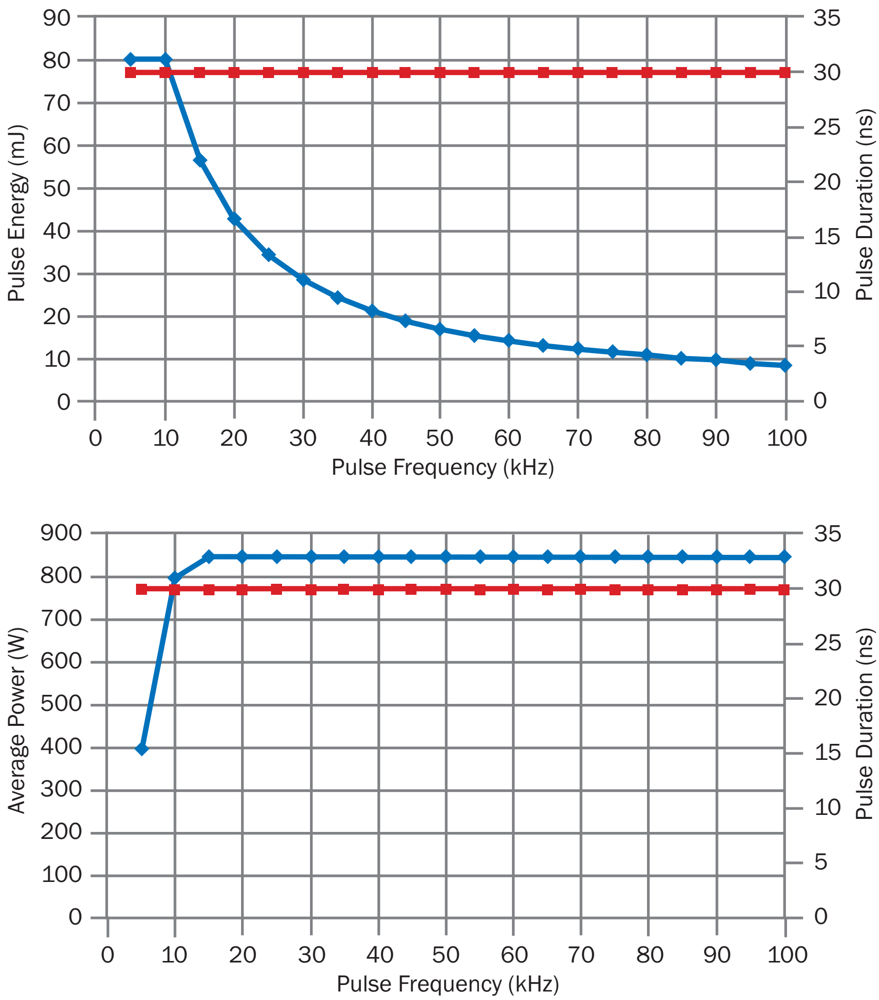
Metal is the most common material chosen for the production of load-bearing parts in the automotive and other industries, yet the continuous improvement of plastics in the last decades offers new possibilities for its use. By replacing metal parts with plastics, manufacturers can reduce the weight and costs of manufacturing. Using the automotive sector as an example, this development not only eliminates vehicle weight while reducing gas consumption, it also reduces the material and production costs overall. The crucial issue has been creating an acceptable joint between the two materials, metal and plastic.

There are primarily two different types of joining technologies for combining metal and plastic. The plastic can either be molded directly onto the metal part in a process called in-mold assembly (IMA), or the molded plastic part and the metal part can be created separately and then bonded together during an additional processing step referred to as post-mold assembly (PMA). During the IMA process, the metal part is placed in the molding tool and then the form-fit joint is created within the molding process.

Drawbacks to traditional approaches

The IMA process leads to broad constraints in design flexibility since the metal part has to be adapted to the molding process. The design of the molding tool is also significantly more sophisticated because IMA requires a sealed joining process. These reasons are likely why PMA processes are more commonly used. However with PMA, manufacturers still struggle to meet the mechanical demands and often need additional connection elements to join the materials sufficiently. Blind riveting, punch riveting and screwing are the most common processes that require this additional connection. The concern here is that this added connection is the weak point between the elements and, therefore, the point of failure. Furthermore, when a gas or watertight combination is required, sealing and additional efforts become necessary, which only contributes to the time and resources required for joining the materials. Another method of combination is adherence. In addition to the adhesive, usually a preparation of the adherend is essential to reach the mechanical demands. This solution also adds an additional processing step. A PMA method that does not require additional connection elements is, for example, riveting technology. For this, a plastic molded pin is deformed to connect metal and plastic parts. To strengthen this connection method, extremely precise positioning of the holes in the metal to the pins in the plastic is needed. Additionally, these connections tend to become loose at high temperature changes.

Images courtesy of **Trumpf Inc.**



The high-power short-pulse laser is very stable and scalable due to its architecture, which is based on a disk laser, combined with cavity dumping technology. With this technology, the pulse duration remains at 30 ns throughout the complete range of the frequency. It also allows for the average power to remain stable at 850 W with a maximum of 80 mJ.

Innovation in short-pulse lasers

The latest advancements in laser technology have enabled a completely new way of joining metal and plastic. Using a high-power nanosecond laser, it is possible to produce a metal-plastic bond that is not only highly loadable but one that also offers a wide range of mechanical advantages such as a fit that is watertight, gastight and resistant to temperature changes. Neither additional connecting elements nor complex component handling is needed. The process consists of two steps: laser structuring of the metal and joining of the metal and the plastic part.

A high-power short-pulse laser is a beam source that emits short light pulses with high energy. For laser structuring of the metal-plastic joints, a nanosecond laser is used. Light travels the distance from the Earth to the moon within one second. For comparison, the length of a nanosecond pulsed laser beam is about one foot. This short-pulse length in combination with the high-pulse energy leads to pulse peak powers of more than 2.6 megawatts, which is similar to the power of an average wind turbine. At the same time, the average output power of the laser ranges from a few watts up to hundreds of watts. The extreme difference between high peak power and average output power is possible due to a repetition rate of more than 100 kHz.

The design of the high-power short-pulse laser is based on a disk laser architecture. This grants high efficiency paired with low maintenance costs and high reliability. These solid-state disk lasers are common for industrial applications, and are most often used for laser cutting, welding and drilling. The high-power short-pulse laser is widely used in the solar industry or for laser cleaning of various parts. For these types of processes, high-pulse peak powers are particularly advantageous in removing coatings or dirt from the base material without damaging it.

Fast-moving beam

When using a high-power short-pulse laser for joining metal and plastics, the first processing step generates a microstructure on the surface of the metal. Short laser pulses with high-pulse peak powers create high energy densities that lead to both a partial evaporation and a partial melting of the material. The short pulse combined the short energy transfer leads to an immediate freezing of the molten mass. The metal freezes in barb-shaped edge beads generated by high gas pressure at the position of the laser spot (Figure 1).

Such a process is only possible if the laser beam is moved over the metal part at a fast enough speed, which is realized using scanner optics. Within the scanner optics, the laser beam hits two actuator-controlled mirrors. The slightest tilting of the mirrors moves the laser beam at a very fast rate along a distance of some millimeters. Using a special scanner movement and the right set of laser parameters, it is possible to create structure depths ranging from micrometers to 10ths of a millimeter. The resulting structure consists of many small undercuts and, depending on the demands, the generated structure can be either direction-dependent or direction-independent. By using laser pulses in the nanosecond range, the material temperature always remains low enough to avoid structural changes to the material itself. Thus, the strength of the base materials remains unchanged. Altering the energy of a pulse within the same setup, the treatment of steel, aluminum, copper and titanium is possible. In principle, every metal can be treated as long as the energy of the laser is sufficient to generate the melting phase of the metal. Furthermore, controlling the structure depth allows a fabricator to fine-tune the process velocity or the strength of the connection, which opens up a range of possibilities for applications.

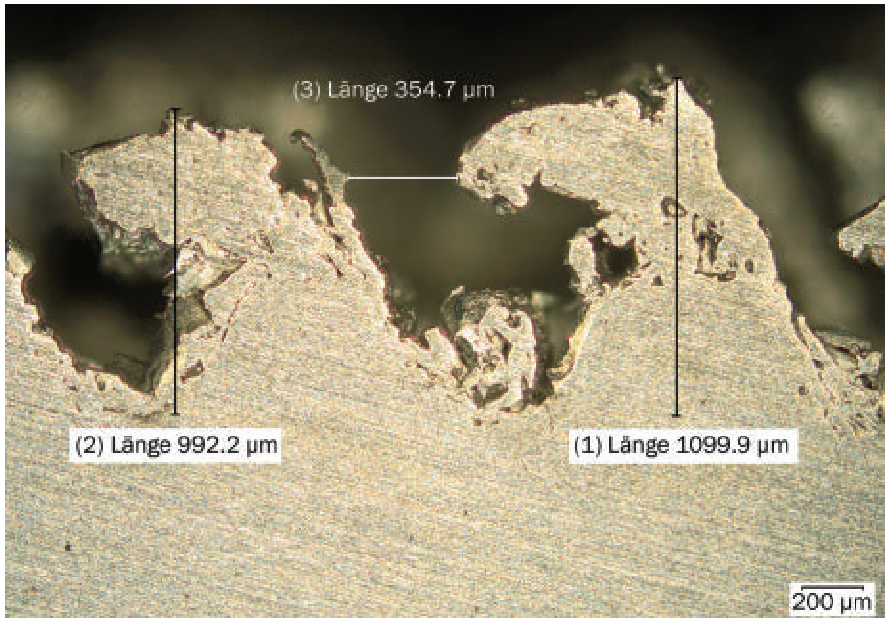
Joining process

As a second step, the structured metal is joined with the plastic. Therefore, the plastic has to melt into the prepared metal structure. The joint can either be done with the IMA-process or with the separate PMA-process. Using the IMA, the metal part is placed inside the molding tool. The plastic is injected directly onto the undercut profiled metal and the bond is created. For the PMA process, the metal part is heated locally, for example through induction or by using a laser. Considering the properties of the plastic, the correct temperature for the metal is chosen. The temperature must be high enough to melt the plastic but low enough to not cause chemical decomposition. The prepared plastic part is then pressed against the hot metal. The plastic melts and flows into the undercuts. A strong connection between the metal and plastic is formed after the plastic is refrozen. With the ability to regulate the structure depth, this process can be successfully employed for joining nearly every type of plastic. In addition, a structure with coarser roughness also enables fiber-reinforced plastic to be used. The IMA process additionally allows for use of a duroplast.

Contact-free laser treatment

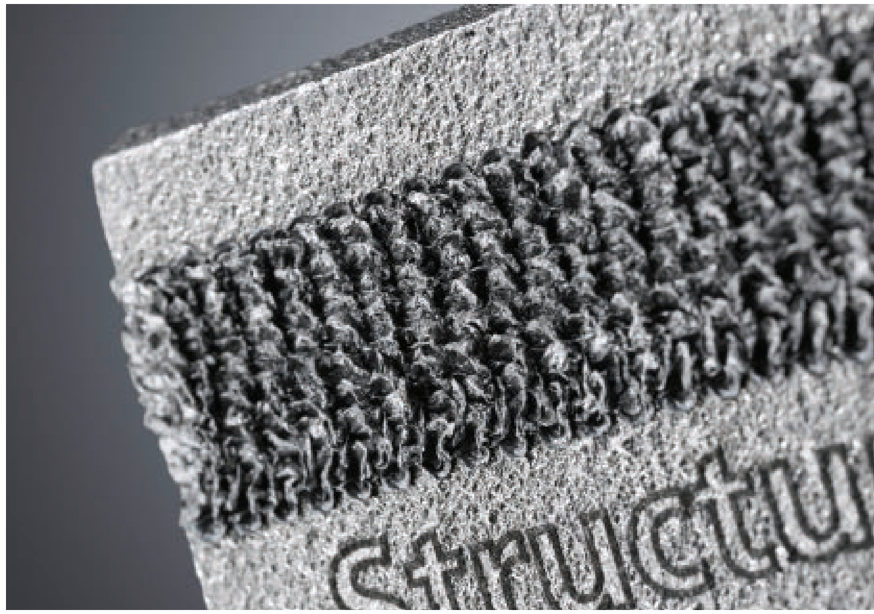
With the laser structuring process, the resulting joint resembles a zipper in that the metal and plastic parts are interlocked through small barb-shaped undercuts that are in the micrometer range. This joining method grants high cohesion with high flexibility. In addition, impressively large forces can be exerted in any direction on the complete metal-plastic part due to the structuring of anisotropic undercuts. The result is a joint that can exceed the strength of the untreated plastic. With minimal distance between connective points, the difference in thermal expansion of the metal and plastic is nearly negligible. As a result, the joint is extremely resistant against varying temperatures as well as against dynamic stress. It is also possible to design a water- and gastight metal-plastic joint.

The contact-free laser treatment of the metal enables manufacturers to structure flat, round, or even more complex parts of any form. The continuous bond created between the two materials and the resulting high loadability of the joint enables fabricators to join smaller areas and thereby achieve high joining velocities. The process velocity of a 5-mm-wide area is greater than 3 m/min, which is comparable to the velocities of a laser-welding



A cross section of an aluminum part, with dimensions indicated, after it is structured with the laser.

A metal-plastic bond is generated using a high-power nanosecond laser designed by Trumpf.



A microstructure is created on the surface of the metal through partial evaporation and partial melting of the material by the laser.

process. After setting the process-specific parameters to perform at its optimum level, the joining process is both fast and easy to reproduce. The high degree of flexibility when it comes to choosing a suitable material, combined with the steadily increasing areas of usage for plastics, make this laser joining process applicable for any industry.

Laser structuring applications can easily be found from the aerospace and automotive sectors to energy engineering — virtually any place where metal meets plastic. Furthermore, laser structuring is not only a convenient and innovative solution for joining metal and plastic; it can also be used to increase friction between two components. Laser structuring is especially well-suited for this application since the various materials can all be structured using a single laser. By adjusting the structure depth, the friction can also be fine-tuned to a specific value, depending on the desired result. Laser structuring can also be used as a preparation step for coatings. With this technique to increase the contact surface between the materials, the bond between a metal part and a ceramics coating can be made significantly stronger. As an added benefit, the heat transfer between base material and coating also improved. The possibilities of laser structuring are endless. For many parts, completely new perspectives will arise as the mechanical properties of metal-plastic joints and additional applications for laser structuring are further understood and applied in manufacturing.

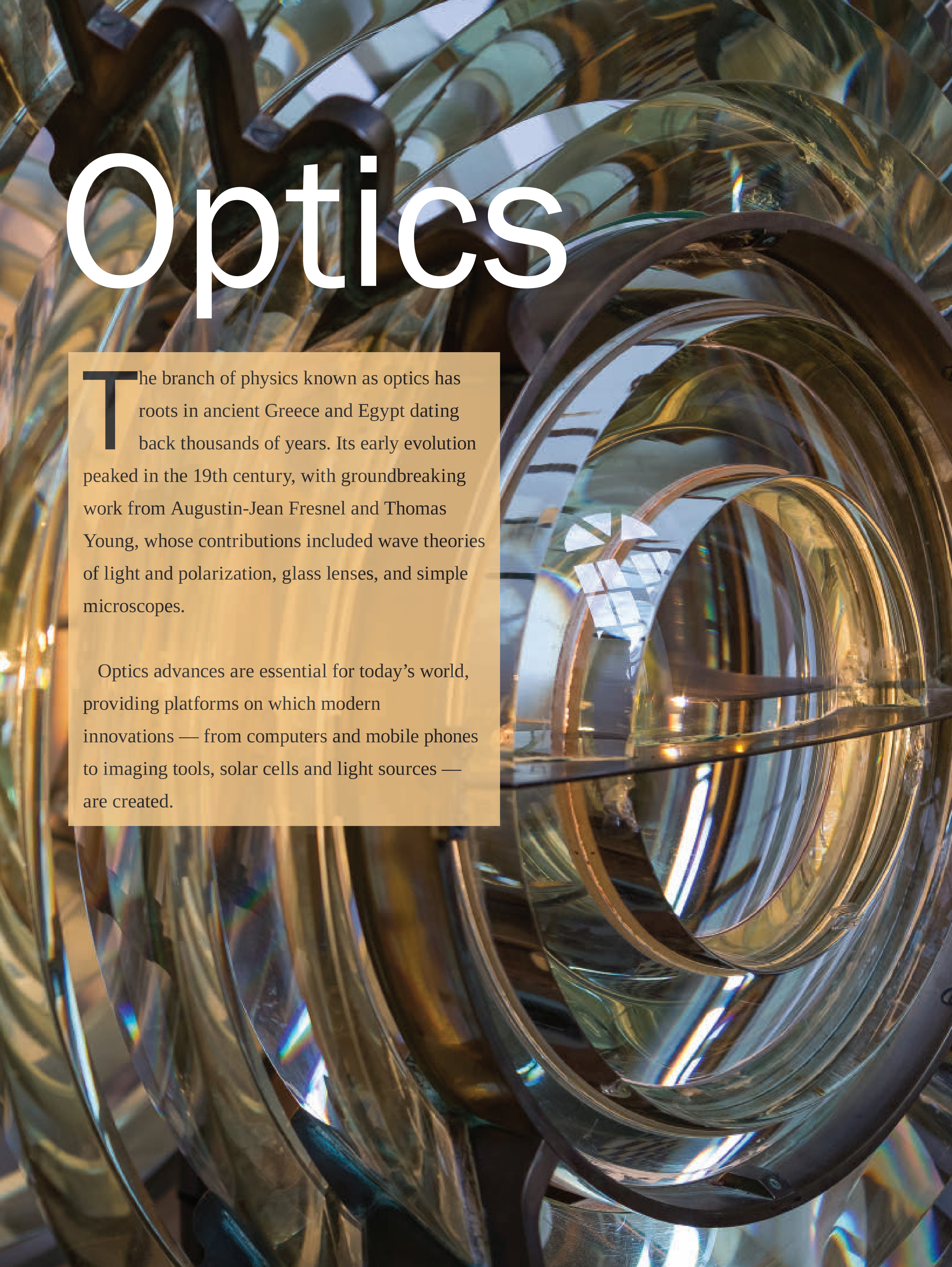
Meet the author

Florian Kiefer is a senior application engineer at Trumpf Inc. in Farmington, Conn. In this role, he supports Trumpf's short- and ultra-short-pulse solid-state laser product portfolio; email: florian.kiefer@us.trumpf.com.

Optics

The branch of physics known as optics has roots in ancient Greece and Egypt dating back thousands of years. Its early evolution peaked in the 19th century, with groundbreaking work from Augustin-Jean Fresnel and Thomas Young, whose contributions included wave theories of light and polarization, glass lenses, and simple microscopes.

Optics advances are essential for today's world, providing platforms on which modern innovations — from computers and mobile phones to imaging tools, solar cells and light sources — are created.



The Optical Society (OSA)

3 Questions INTERVIEW

Alan Willner, 2016 president of The Optical Society (OSA), entered the field of optics about 30 years ago, receiving a Ph.D. in electrical engineering from Columbia University in 1988. He is a former post-doctoral member of the technical staff at AT&T Bell Labs and a member of the technical staff at Bellcore. He joined the University of Southern California in 1992 and is currently the Steven and Kathryn Sample Chair in Engineering.

Willner has numerous awards to his credit throughout his decades-long career; among them, the OSA Paul Forman Engineering Excellence Award, the Presidential Faculty Fellows Award from the White House, a Fulbright Foundation Senior Scholar Fellowship, the SPIE President's Award and the USC Associates Award for University-Wide Creativity in Research.

Photonics Spectra spoke with Willner about his time in the optics field, and what he anticipates for the future.*

Q: In what ways have optics evolved since you entered the field?

A: Over the past 100 years, the field of optics has produced astounding scientific and engineering feats. I've been involved with [OSA] for the past 30 years. In 2016, we are celebrating our 100th birthday and a century of optics innovation and inventors. I entered into the industry in the late 1980s and I have experienced a true transformation in the way we communicate using optics.

When I started my career, there was a lot of potential for optics. Optics is now cemented in the way it touches us every day — from displays to mobile to the internet. With the nature of optical science and ubiquity of communications in our world, there is much reason to hope that this rate of technical progress and impactful applications will continue for many years to come.

Q: What are the implications of emerging optics research and technologies for the industry?

A: It is quite likely that advances in the coming decades in the performance and mass production of photonic integrated circuits will enable optics to be ubiquitously deployed wherever and whenever it can bring benefit to the system, just as we use electronic integrated circuits today without a thought. Furthermore, optics will bring low-loss and high-bandwidth connections between and within computer chips.

In many disciplines of optics, there have been orders of magnitudes of advancements, yet there are always limitations that need to be overcome to move forward. Similar to the semiconductor industry's commitment to meet Moore's Law, the optics industry must continue to push the envelope and explore.

Q: What does the future hold for the optics field?

A: We enable so much of what people use every day and we have serious technical hurdles to overcome in the future. Just like semiconductors, we are "too important to fail," and this requires that the public understand our value and future potential.

In 2015, the U.N. declared it to be the International Year of Light. In the same year, both the Nobel Prizes in Physics and Chemistry went to optics people for optics work. This was not a one-time thing. Optics really is an essential technology for our world, and will only get more so in the future — and need strategic investment so that future will emerge.

A Fresnel lens, named for its creator, Augustin-Jean Fresnel.

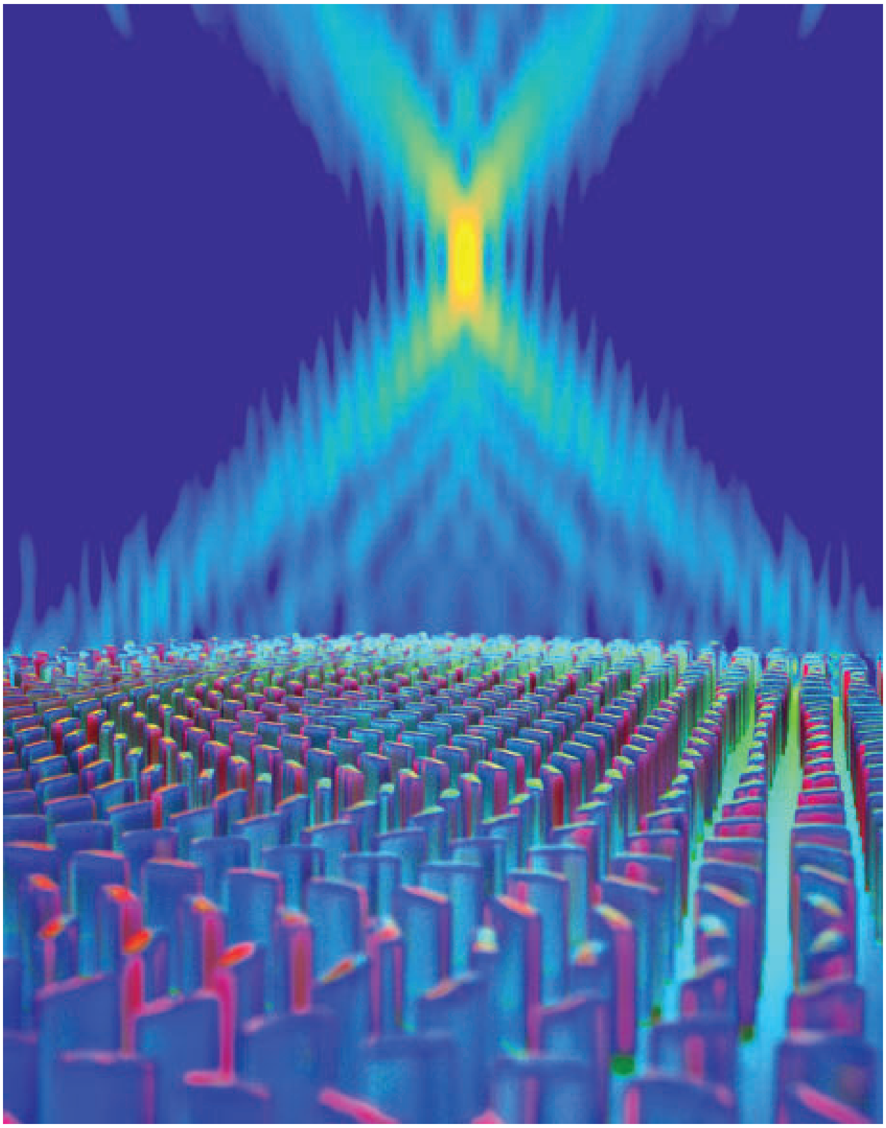
Art and Science: The Development and Impact of **Optics**

"Optics — developing in us through study — teach us to see."

French artist Paul Cézanne

BY JUSTINE MURPHY
SENIOR EDITOR

It is said that French painter Paul Cézanne (1839-1906) found inspiration in the optics of color and geometry, and that theories about light and vision informed his work. His paintings, in turn, influenced the work of other artists including Picasso and Braque. Long before Cézanne captured the French countryside on canvas, however, Isaac Newton, Thomas Young, Augustin-Jean Fresnel and others studied light, vision and optics, with far-reaching effects.



A schematic showing the ultrathin meta-lens, which consists of titanium dioxide nanofins on a glass substrate. The meta-lens focuses an incident light (entering from bottom and propagating upward) to a spot **(yellow area)** that is smaller than the incident wavelength.

Theories of Light

The early study of optics dates back thousands of years to lens development in ancient Greece, Egypt and elsewhere. And in more recent history, the science of light and optics has advanced and flourished.

Fresnel was a 19th century French physicist whose research added to the establishment of the wave theory of light and polarization. The lens (and many variations of it) that bears his name was originally developed for use in lighthouses. It remains popular for many products today, such as imaging cameras, solar cells and light sources, as well as for applications in biophotonics, defense and security. Lighthouses also still use these lenses.

British physicist Young, who was also a physician studying optical and sense perception, performed work similar to that of Fresnel and ultimately reached the same conclusions relating to the wave theory of light. Beyond that, he established the principle of interference of light in the early 1800s — specifically, that light beams spread apart and overlap when passing through closely set pinholes on a screen. Bands of bright light thus alternate with bands of darkness.

Young's work subsequently established the wave theory of light and polarization (to which Fresnel contributed). His theories additionally led to his study of how color is perceived and how thin films relate to wavelengths of light. Young's findings, along with those of German physicist Hermann L.F. von Helmholtz, prompted the Young-Helmholtz three-color theory.

Carl Zeiss is another significant contributor to the field of optics. Founder of the Carl Zeiss AG and Carl Zeiss GmbH companies in Germany in the mid-1800s, he was a mechanic and optics product developer. Among his achievements were production of simple and compound microscopes, performed in a Jena, Germany, workshop he opened in 1846. Zeiss's work also included design, manufacture and even repair of physical and chemical instruments. He collaborated with German physicist and mathematician Ernst Abbe whose contributions to optics include the design of lenses for optical microscopy. The pair together designed and fabricated advanced optical systems, such as an "illumination apparatus" in 1869 that was meant to improve the performance of microscope illumination.

The recent acquisition by the Zeiss companies of a simple microscope that dates back to 1850 keeps that history alive today. It's highly likely it was designed and built by Carl Zeiss himself, given its age and style, according to the companies' archives department. The microscope has been very well-preserved — it is still secured onto a wooden base, and features original lenses, hand supports and a rotating diaphragm. This rare artifact is the first of its kind in the company's collection of historical instruments, and is now part of a touring exhibition called Carl Zeiss: A Visionary Entrepreneur.

Modern R&D continues to build upon the optics foundation laid by Zeiss, Abbe and others.

At the Scripps Institution of Oceanography at the University of California, San Diego, researchers have developed an underwater optical system for imaging the ocean and seafloor at microscale. The system — the Benthic Underwater Microscope (BUM) — aims to help scientists better understand the dynamic ecological processes taking place underwater on a microscopic scale. This assists in the

Jürgen Scheere/Zeiss

Dr. Wolfgang Wimmer, head of the Zeiss Archives **(left)** and Manfred Eichel display a simple microscope that dates back to 1850, likely built by Carl Zeiss himself.

study of animal behavior, and enables temporal and spatial analysis of ecologically significant phenomena at scales previously unseen in a natural environment.

A new IR optical sensor — the SCiO, developed by Israel-based startup Consumer Physics — allows the average consumer to instantly, and affordably, analyze physical materials; this includes learning how many calories and proteins are in a certain food, what a drink's alcohol content is, whether a plant is healthy, or what exactly is in a medication. The device essentially scans the molecular fingerprint of an object, reading the chemical makeup of the materials. It's nonintrusive and requires no physical contact with the object being scanned.

At the front lines of discovery

Clearly things have advanced dramatically. Nick Vamivakas, an associate professor of quantum optics and quantum physics at the University of Rochester's Institute of Optics, has observed several major evolutions in the field.

"The first is the availability of tremendous computing power and inexpensive data storage capability. The former has resulted in fantastic advances in computational imaging, as well as 'smart' systems that can process optical information in real time and react accordingly," he said. "This marriage of optics hardware and sophisticated computing is continuing to make things that previously seemed impossible, possible."

Zeiss

A historical Zeiss compound microscope.

Vamivakas also mentions the industry's increasing ability to "structure materials on exceedingly smaller length scales — roughly 100 times smaller than visible wavelengths," making it possible to tailor nanoscopic quantum processes for best macroscale optical responses. Researchers and scientists are also now embracing the quantum features of light as a resource that can be exploited for information technology and sensing.

There have been other global changes in the field over the past several decades, according to Bill Brocklesby, an associate professor at the Optoelectronics Research Centre of the University of Southampton, England. He got his start in the industry in the mid-1980s, and has seen some very specific transformations.

Brief Optics Timeline

1823 The first Fresnel lens is installed in the Cordouan Lighthouse in Gironde, France.

1846 Carl Zeiss opens his first workshop for precision mechanics and optics in Jena, Germany, where he began producing simple microscopes the following year.

1916 The Optical Society of America (OSA) is formally established.

1929 The Institute of Optics is established at the University of Rochester, making it the first optics education program in the U.S.

1967 Laurin Publishing debuts *Optical Spectra* magazine; its name was changed to *Photonics Spectra* in 1982.

1983 NASA launches the first infrared telescope into space.

1986 Physicists Gerd Binnig and Heinrich Rohrer are awarded the Nobel Prize in Physics for their design of the scanning tunneling microscope.

1994 A team at Bell Labs develops and demonstrates the first quantum cascade laser.

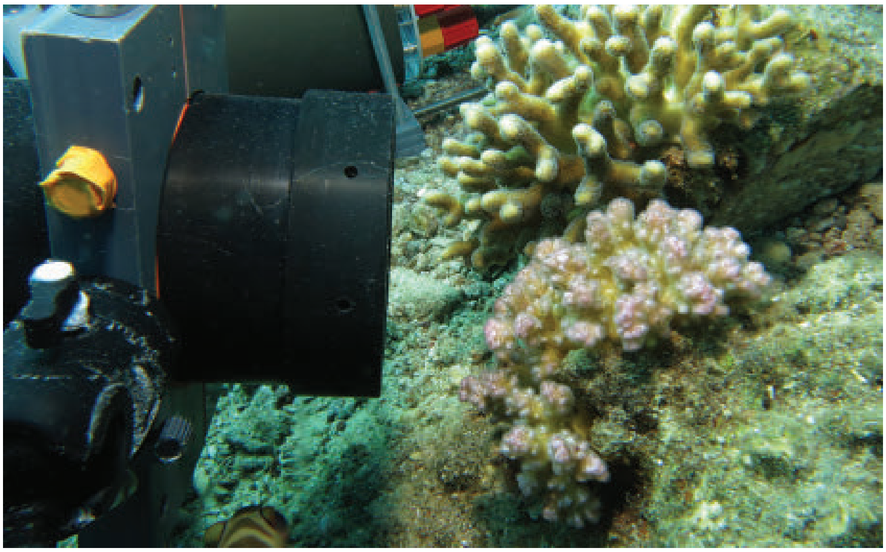
1997 The Fiber Optic Link Around the Globe (FLAG) becomes the longest single fiber optic cable network in the world, providing infrastructure for the next generation of internet applications.

2005 SPIE marks its 50th anniversary in San Diego.

2016 The Optical Society celebrates its 100th anniversary, marking a century of innovation.

"I think that the biggest factor in changes to the way we work [in optics], for me, has been the advent of cheap pump photons. This has changed so many areas across the [optics] field in terms of light sources, and mostly has been driven by the rise of the laser diode, and continues to do so," he said.

Professor Yasuhiko Arakawa, director of the University of Tokyo's Institute for Nano Quantum Information Electronics and its Nanoelectronics Collaborative Research Center, has also seen changes and evolution in other areas of optics during his more than three decades as an industry player. Among them, quantum well lasers (quantum size effect lasers) for telecommunications and blue laser applications.



The Benthic Underwater Microscope (BUM) is positioned to study coral competition.

Jaffe Laboratory for Underwater Imaging/Scripps Institution of Oceanography, UC San Diego

"The quantum dot lasers have a variety of superior performance to conventional lasers, such as high temperature operation, low-power consumption and low-cost productivity," Arawaka said. He added that quantum dot lasers hold potential in silicon photonics applications, in particular.

Such technologies are expanding throughout many areas of the optics field.

"I think trying to develop platforms to enable quantum information science technologies has been exciting — both working toward physical implementations of quantum bits, as well as novel approaches to communication and security based on quantum states of light," Vamivakas said, adding that such technology is opening pathways toward new approaches to sensing and metrology.

The future of optics

Such changes and advancement in optics are being relayed to the next generation of engineers. Monroe Community College in Rochester, N.Y., offers programs that aim to further develop the optics workforce. Alexis Vogt, an associate professor of optics and chair of the optics and photonics program there, said she and fellow professors bring optics innovations into classrooms and labs through curriculum, state-of-the-art equipment, and visits to area optics companies.

Nicholas Massa — a professor in the Laser Electro-Optics Technology Department at Springfield Technical Community College in Springfield, Mass., and a principal investigator for the U.S. National Science Foundation's PBL Projects: Skills for the 21st Century — offers similar education and training in his classes and programs, emphasizing practical hands-on applications.

These types of optics training programs are popping up at community colleges and other such institutions worldwide. Educators and engineers hope that the changes and regular advancements in optics research and technologies will help attract more students to this quickly growing field.

"Optics really is an essential technology for our world, and will only get more so in the future," said Alan Willner, 2016 president of The Optical Society, and Steven and Kathryn Sample Chair in Engineering at the University of Southern California, who has seen great transformation in optics technology and research in his 30-year career.

Vamivakas, who also has much experience in optics, sees the field going in several directions. He cites the potential for on-chip approaches that will become more commonplace. Augmented and virtual reality displays will continue to mature, as well, and should become more interactive and immersive. He added that smart systems that optimize optics hardware with data collection and analysis "in a holistic way" will lead to various technological developments.

"I think the major emerging application areas are in information technology — communication and computing, multifunctional optical sensors [and] interactive displays," Vamivakas said. "I also expect unconventional optical elements will start to replace traditional lenses, mirrors, polarizers, etc."


Consumer Physics

The SCiO miniature IR optical sensor by Consumer Physics allows the average consumer to instantly analyze things like how many calories and proteins are in a certain food, what a drink's alcohol content is, whether a plant is healthy, or what exactly is in a medication.

Brocklesby names imaging among optics-related fields as an area of future growth. Change in this area could include the wide-scale application of advanced mathematical techniques to relatively simple imaging devices, "changing the critical elements of an imaging system from finely engineered optics to effective algorithms." An example of this is lensless imaging, Brocklesby said, in which no objective lenses are used, although quantitative images can still be produced.

Quantum dot technology, such as quantum lasers, will become more crucial in the future, Arawaka said, for telecommunications and data communications. Other anticipations for the future of optics include advancements in materials science.

This discipline has taken a huge step forward in 2016, with the potential to replace glass lenses with metasurface materials that are not only more practical to manufacture, but can also produce aberration-free, subwavelength-resolution images. This planar metalens material could ultimately replace traditional optics in smartphones, digital cameras and microscopes, enabling further miniaturization of such devices. The work was performed in the lab of Harvard University physics and applied engineering professor Federico Capasso, whose other contributions to the field of photonics include the quantum cascade laser.

The research realm should evolve, too, according to Andrea Armani, an associate professor of both chemical engineering and materials science, and electrical engineering and electrophysics at the University of Southern California. As optical components, such as lasers and cameras, have become more accessible and easy to use, they have enabled numerous research efforts, she said, particularly interdisciplinary research in which optics serves as a tool of discovery. The synergy between component accessibility and identified technology is advancing the field, and as more components become broadly accessible, the field will continue to accelerate.

"The future is always shaped by the next generation," Armani said. "Students today … want to develop technologies that solve societal problems. The future of optics will mirror … these goals."

justine.murphy@photonics.com

Nonlinear light manipulation could provide basis for optical nanodevices

ST. PETERSBURG, Russia — Ultrafast nanoantenna switching between different light-scattering modes, caused by the interaction between an intense laser pulse and the silicon of a nanostructure, could lead to devices that would enable ultrafast all-optical signal processing.

To demonstrate ultrafast nanoantenna switching, researchers from ITMO University and the Moscow Institute of Physics and Technology (MIPT) manipulated the optical properties of a nonlinear silicon nanoantenna. They irradiated an array of silicon nanoparticles with a short and intense laser pulse, altering the properties of the material and the behavior of the silicon nanoantenna, and causing it to scatter light in the direction of the incident pulse.

Thus, by exposing a particle to a short and intense pulse, the researchers found that its behavior as an antenna could be dynamically controlled.

Based on these results, the researchers developed an analytical model to describe the ultrafast nonlinear dynamics of the nanoantenna, as well as the generation and relaxation of electron plasma in silicon. According to the model, a radical change in the scattering diagram of the antenna occurs within a short period of time — on the order of 100 femtoseconds. Before the pulse arrival, the amount of energy scattered by the particle in the forward direction is nearly the same as in the backward direction. However, when driven by a short pulse, the antenna switches to almost perfectly unidirectional forward-scattering.

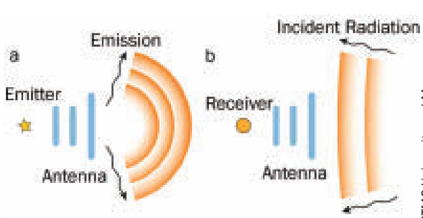
Theoretical predictions backed by the experimental data suggest that an antenna of this kind would have a bandwidth of about 250 Gbps, whereas conventional silicon-based electronics rely on components with bandwidths limited to only tens of Gbps.

"It is a top priority — and at the same time a major challenge — to develop such tunable antennas operating at infrared and optical frequencies," said Denis Baranov, a researcher at MIPT. "Nowadays, we can already transmit information through fiber optics at incredible speeds of up to hundreds of Gbps. However, silicon-based electronics are unable to process the incoming data at that rate. Nonlinear nanoantennas that work at optical wavelengths could help us to resolve this problem and make ultrafast all-optical signal processing possible."

"The research shows that silicon nanoparticles might well become the basis for developing ultrafast optical nanodevices," said Sergey Makarov, a researcher at ITMO University. "Our model can be used to design nanostructures containing silicon particles that are more complex, which would enable us to manipulate light in a most unusual way. For example, we hope to eventually control not just the amplitude of an optical signal but also its direction. We expect to be able to 'turn' it by a specified angle on an ultrafast timescale."

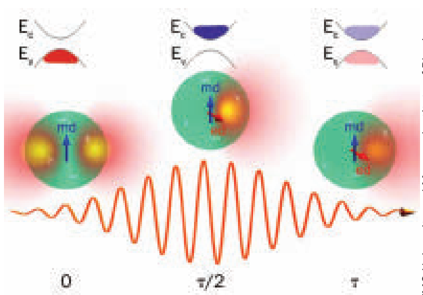
The use of a nonlinear antenna, which could be switched by the incident light itself, lays the foundation for the development of novel optical devices with a wide range of functionalities. Silicon nanoparticle-based devices could be integrated into microchips to enable ultrafast, all-optical signal processing in optical communication lines and in the next generation of optical computers.

The research was published in *ACS Photonics* (doi: 10.1021/acsphotonics.6b00358).



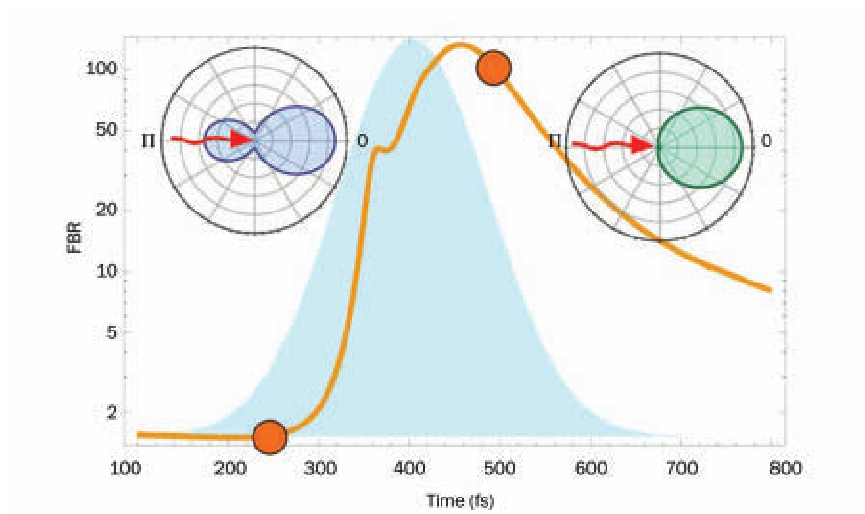
ITMO University and Moscow Institute of Physics and Technology

Electromagnetic antenna in transmitting **(a)** and receiving **(b)** modes.



ITMO University and Moscow Institute of Physics and Technology

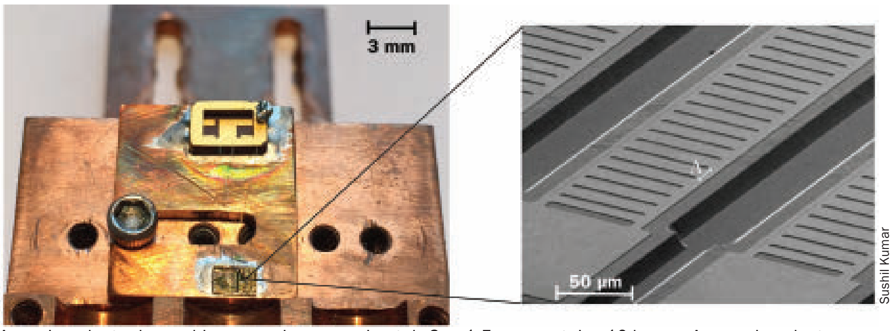
Schematic representation of the system studied by ITMO University and Moscow Institute of Physics and Technology researchers. Photoexcitation of a silicon nanoparticle by a femtosecond laser pulse. Intense irradiation excites electrons in the silicon nanoparticle into the conduction band, which alters the optical properties of the particle (amplitudes of electric and magnetic dipole resonance) in a way that enables unidirectional scattering of incident light.



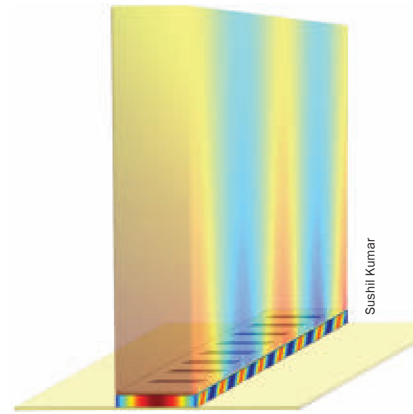
ITMO University and Moscow Institute of Physics and Technology.

Dynamical reconfiguration of a nonlinear silicon nanoantenna. This graph shows the front-to-back ratio (FBR) of a nanoparticle, i.e., the ratio of the power transmitted in the forward direction to the power transmitted in the backward direction. The light-blue shaded area in the background represents the envelope of the pulse intensity. The two insets contain the scattering diagrams of the antenna for two different times with the red arrows representing the incident beam.

Periodic photonic structures focus spaser light for nanoscale optics



A semiconductor laser chip measuring approximately 3 × 1.5 mm contains 10 lasers. A scanning electron microscopy magnification **(right)** shows one of the laser cavities. Periodic slits in the thin-film top metal layer provide the distributed feedback in the cavity.



In this illustration of a terahertz plasmonic laser, the laser cavity is enclosed between two metal films (with periodic slits on the top film). The colors represent coherent SPP light waves. One wave is confined inside the 10-µm-thick cavity. The other, with a large spatial extent, is located on top of the cavity.

BETHLEHEM, Pa. — Single-mode operation in plasmonic lasers has been demonstrated using a technique that implements distributed feedback (DFB) in a novel way — it couples the resonant surface plasmon polariton (SPP) mode of the laser to a highly directional far-field radiation pattern, integrating hybrid SPPs in the surrounding medium into the laser's operation.

Researchers at Lehigh University have implemented DFB on a terahertz quantum cascade laser (QCL), a type of plasmonic laser that emits long-wavelength THz radiation.

They have demonstrated single-mode THz QCLs with a beam divergence as small as 4° × 4°, which may be the narrowest beam reported for any THz QCL to date.

To implement DFB in the laser, researchers used periodic structures with broad-area emission of both short wavelength spasers and THz QCLs. They made periodic gratings in one of the metal claddings that encased the laser's cavity.

The light energy was confined inside the cavity and sandwiched between two metallic plates separated by a distance of 10 µm. The periodicity in the laser cavity provided feedback for sustained laser oscillations.

In contrast to the radiative field in conventional photonic band-edge lasers, in which the periodicity follows the integer multiple of half-wavelengths inside the active medium, the researchers' technique — termed antenna-feedback — exceeded the integer limit and enhanced the radiative field of the lasing mode.

"Our technique allows a plasmonic laser to radiate in a narrow beam, very much like a phased-array antenna," said professor Sushil Kumar. "The period we choose depends on the desired wavelength of light from the laser, the refractive index of the cavity medium and the refractive index of the surrounding medium."

The periodicity establishes an intense SPP wave, which occupies the surrounding medium of the laser's cavity while remaining tied to its metal cladding, and propagates in tandem with the SPP wave inside the cavity.

"All plasmonic lasers have SPPs inside their cavities," Kumar said. "Our laser also generates SPPs in the air, or any other medium that may surround the laser. The large size of the SPP wave in the surrounding medium leads to a highly directive radiation pattern from the plasmonic laser."

According to the Fraunhofer diffraction formula, when the near field is narrow, the far field is broad and vice versa. The researchers, by creating a near-field with a large spatial extent, have created a far-field, or focused beam.

By giving the laser a periodic structure, the researchers have made it possible for the laser to emit light at just one wave-

Visimax adds Buhler chamber

CLEVELAND — Optical coating facility Visimax Technologies Inc. has upgraded its coating facilities with the addition of a Buhler SYRUSpro 1350 chamber.

The system provides optical monitoring capabilities that will expand Visimax's product offering to include higher-precision optical coatings. The new chamber also provides high accuracy and high yield levels for precision optics, which will allow Visimax to deliver on uninterrupted, 24/7 volume production of optical filters.

The new equipment arrived from Germany in July and has been installed in the company's 18,000-sq-ft facility that holds elite, computer-controlled, high-volume coating systems. Acquired by new leadership in 2010, Visimax has promised a renewed focus on customer commitment and consistency in order to improve and perfect their processes.

"We are thrilled to be adding the Buhler chamber to our lab," said Brian Murphy, owner of Visimax. "All of our associates are eager to explore the new capabilities and production options. … The company is excited to work with the new chamber and looks forward to seeing how it fits into their processes."

Visimax is a precision optical coating services facility with expertise in thin-film processes for glass and plastic optical components.

length, enabling a spectrally pure, single-mode laser application. The periodic structure may also enhance the quality of the laser beam by channeling light intensely into a tight spot.

Light can be delivered to a location where it is needed most, shine for long distances and be redirected more easily to desired locations.

The antenna-feedback technique may be applied to any plasmonic laser with a Fabry-Perot cavity, regardless of its operating wavelength.

Kumar and Chongzhao Wu have filed a patent application for the invention. This may lead to commercial applications for plasmonic lasers and THz QCLs with narrow beams, which could be used for integrated and standoff THz spectroscopy and sensing, as well as for ultrafast digital communications.

The research was published in *Optica*, a journal of The Optical Society (doi: 10.1364/optica.3.000734).

Jenoptik Group revenue up 3.4%

JENA, Germany — Optical technology developer Jenoptik AG has ended the first half of 2016 with a 3.4 percent rise in group revenue to €326.8 million ($366 million).

"Over the first six months of 2016, we successfully pushed on with our course of profitable growth," said Michael Mertin, president and CEO of Jenoptik. "The group's interdisciplinary technological expertise, strong position on the domestic market and increasing internationalization enabled growth in line with the business figures we set out to achieve."

Jenoptik supplies technology for the semiconductor, automotive, medical, defense, security and aviation industries.

Arizona Technology Council, AOIA partner for industry promotion

PHOENIX — The Arizona Technology Council and the Arizona Optics Industry Association (AOIA) have signed a collaborative agreement to form the Arizona Optics Industry Committee for industry advocacy.

The committee will promote the interests of the industry by holding optics-focused events and lobbying for legislative policy at local, state and federal levels.

It also aims to develop a road map for the optics industry sector in Arizona and use the council's established leadership and infrastructure to address critical issues.

"The council has proven its ability to be an advocate and collective voice for science and technology companies throughout our state," said Steven G. Zylstra, president and CEO of the Arizona Technology Council. "By working together with the AOIA, we are well-positioned to refocus the agenda and industry ecosystem to grow the optics industry hub that has long existed in Arizona."

The Arizona Technology Council is Arizona's premier trade association for science and technology companies. With a diverse professional business community, the council's members work to further advance technology statewide through leadership, education, legislation and social action.

"We are excited to leverage our history of success and leadership with the Council's statewide reach," said Bob Breault, president of AOIA. "The Council's membership base is diverse, which, in the end, will benefit our members. The agreement we have reached is really the next step in our vision. We want industry leaders connected and working together on a mix of very diverse projects, all here in Arizona."

The AOIA is a nonprofit organization that acts to foster the continued growth of the optics industry in Arizona. Members are part of more than 300 companies and organizations covering a broad range of products and services statewide, contributing approximately $2.2 billion per year to the state's economy.

"Our goal is to catalyze, convene and connect the optics industry sector across Arizona, building on AOIA's long-term success," said Alex Rodriguez, vice president of the Arizona Technology Council's Southern Arizona office. "We look forward to playing an integral part of the ongoing collaboration between Tucson's optics companies and The University of Arizona's College of Optical Sciences. The college graduates more highly qualified scientists with master's and doctorate degrees than any other in the nation and our desire is to keep them right here in Arizona. The Council and the optics companies are in a terrific position to continue to build momentum for this vital Arizona industry."

Lightpath acquires ISP

ORLANDO, Fla. — Optical and infrared component developer Lightpath Technologies Inc. has acquired infrared component developer ISP Optics Corp. for $18 million.

The acquisition will combine Lightpath's high-volume molding technology with ISP's high-value diamond turning, coatings and polishing capabilities. It also expands Lightpath's market reach to major operations in Asia, North America and Europe.

"The collective technological capabilities of Lightpath and ISP position us for continued high growth, with concentration in key markets for infrared sensors, global military electro-optical infrared products and infrared imaging cameras, among other mission critical and broad-based applications," said Mark Lifshotz, CEO of ISP.

ISP is a vertically integrated manufacturer offering a full range of infrared products, from high-performance MWIR and LWIR lenses to lens assemblies. Lightpath provides optics and photonics solutions for the industrial, defense, telecommunications, testing and measurement, and medical industries.

Sandruck appointed European sales manager at Bristol

VICTOR, N.Y. — Optical instrumentation developer Bristol Instruments Inc. has appointed Scott Sandruck as its European sales manager.

Sandruck brings more than 20 years of experience in the optics and photonics industry to the role. Before joining Bristol Instruments, he was the director of inside sales and application engineering for Semrock Inc. He previously held positions in sales, account management, program management and engineering at MicroE Systems, BAE Systems, Zygo Corp. and the Laboratory for Laser Energetics at the University of Rochester. Sandruck holds a bachelor's degree in optical engineering from the Institute of Optics and an MBA from the William E. Simon School of Business Administration, both at the University of Rochester.

Bristol Instruments Inc.

Scott Sandruck.

"We are excited to have Mr. Sandruck on board to help lead the expansion of our worldwide sales effort," said Brian Samoriski, vice president of sales and marketing at Bristol Instruments. "His capabilities will serve our European customers well."

SEDI-ATI acquired by J-F Vinchant Holding

COURCOURONNES, France — J-F Vinchant Holding Strategy has acquired optical fiber-based component manufacturer SEDI-ATI Fibres Optiques.

The acquisition aims to bring a new dynamic to the optical fiber-based component market, focusing on applications with harsh environments and medical applications with an export emphasis.

SEDI-ATI designs, develops and manufactures optical fiber-based components such as couplers and wavelength filters of fiber bundle assemblies for harsh environments such as military, aeronautics, space, industrial, medical, communication and astronomy applications. J-F Vonchant Holding Strategy is an active holding company.

Max Levy, II-VI merge

SAXONBURG, Pa. — Patterning developer Max Levy Autograph Inc. has merged with II-VI Optical Systems.

The merger aims to combine the patterning expertise of Max Levy Autograph with the material, optical systems design and fabrication knowledge of II-VI Optical Systems to offer a greater breadth and depth of resources to transform optical materials into innovative solutions.

All legal documents and transactions, including new orders and invoices, will use the II-VI Optical Systems name. The Max Levy name will be retained in product lines for reticles and precision targets.

II-VI serves UV through long-wavelength infrared (LWIR) applications by providing comprehensive electro-optical solutions from design engineering and raw materials through complete assemblies and systems. Max Levy manufactures stock and custom reticles, measuring scales, rules, targets, grids, ronchi rulings, encoder disks, apertures, electroformed and diamond machined structures for industrial and aerospace applications.

Lens Mounts

Cooke Optics Ltd. offers multiple mounts for its miniS4/i lenses, including Canon EF, Nikon F, Sony E and micro 4/3. A single mount will fit every focal length lens in the miniS4/i series. For existing miniS4/i lenses, users can simply unbolt the PL mount that comes as standard, bolt on the replacement mount, and shim as required. The mounts can be used on any miniS4/i lens, regardless of delivery date. For new miniS4/i deliveries, the lenses will be available with the mount of choice from the factory. The mounts are designed for the MIRRORless cameras.
lenses@cookeoptics.com

Hard-Coated Filters

Edmund Optics Inc. has released three new TECHSPEC Hard-Coated Filters: High Performance OD 4 Shortpass Filters, High Performance OD 4 Longpass Filters and Imaging Filters. TECHSPEC High Performance OD 4 Shortpass Filters and Longpass Filters both feature a cut-off slope of <1 percent with a rejection of OD$>$4.0 and 91 percent transmission in the pass band. TECHSPEC Imaging Filters are designed to meet demanding machine vision and imaging applications. Optimized for use with popular LEDs, the imaging filters pass or block specific UV, visible or IR wavelengths to provide very wide angles of incidence. The new lines join existing Hard-Coated OD 4 Bandpass Filters with series at 10, 25 and 50 nm. The filters have the advantage of fabrication using hard-coated plasma deposition technology, which ensures high perfor-mance and allows for exceptional durability. They provide high transmission of designated wavelengths and deep blocking of unwanted wavelengths, featuring maximum blocking within a few nanometers of the laser wavelength to isolate narrow spectral regions in a wide variety of applications.
jliolin@lionadv.com

Radiation-Hard Lens Design

Resolve Optics Ltd. has announced a radiation-hard lens design for color sensors. The compact f/2 lens is able to produce near-natural color images while withstanding long-term exposure to radiation up to a dose of 100 million radians and

temperatures to 55 °C without discoloration. The lens design enables the customer to further improve plant inspection with access to high-clarity, natural color images.
sales@resolveoptics.com

Optical Metrology System

Stellarnet Inc.'s StellarHaze is a preconfigured optical metrology system for haze, total transmittance percentage and color measurements. The system includes a compact fiber optic spectrometer, high-intensity light source, collimating lens and custom haze measurement sphere with diffuse transmission port and sample attachment clips. The system comes complete with StellarHaze software for Microsoft Excel that calculates transmission and haze at once while also displaying spectral transmission curves. The StellarHaze can be set up in line with production to easily test batches of samples, and can be packed away in a small case when not in use. It is adaptable to many sample types such as filters and plastic sheets, thin films and bags, liquids via cuvettes, diffusing plastics for lighting, automotive glass, windows, and beverages.
contactus@stellarnet.us

Reflectance Target Coating

Sphereoptics GmbH has announced the new Permaflect reflectance target coating, unifying the positive properties of optical polytetrafluoroethylene with the highly cost-efficient and easy-to-use properties of barium sulfate. Permaflect can be used under harsh environmental conditions, be exposed to water, UV radiation and dust. It maintains excellent optical characteristics with a nearly lambertian reflection over 94 percent, and uniform and constant reflection over the surface area and over the wavelength range of 350 to 1150 nm. The coating can also be applied to complex-shaped surfaces.
info@sphereoptics.de

Custom Optics Fabricators and Fabrication Machinery Directory

A select list of companies that fabricate custom optics, as well as companies that manufacture or supply the equipment and machinery needed to fabricate optics. The list was compiled using data submitted for the *Photonics Buyers' Guide*. For more information, visit PhotonicsBuyersGuide.com.

This directory is sponsored by:

Applied Optics Center (AOC)
9827 Chartwell Drive
Dallas, TX 75243
Tel: (972) 629-1717
bbates@optexsys.com
www.optexsys.com/aoc
See our ad on page 52

BMV Optical Technologies Inc.
26 Concourse Gate
Ottawa, Ontario K2E 7T7
Canada
Tel: 613-228-2442
info@bmvoptical.com
www.bmvoptical.com
See our ad on page 67

Diverse Optics Inc.
10310 Regis Court
Rancho Cucamonga, Calif. 91730
Tel: 909-480-3800
info@diverseoptics.com
www.diverseoptics.com
See our ad on page 27

Edmund Optics Inc.
101 E. Gloucester Pike
Barrington, N.J.08007
Tel: 856-547-3488
sales@edmundoptics.com
www.edmundoptics.com
See our ad on page 11

Esco Optics
95 Chamberlain Road
Oak Ridge, N.J. 07438
Tel: 973-697-3700
sales@escooptics.com
www.escooptics.com
See our ad on page 14

FISBA AG
Rorschacher Str. 268
CH-9016 St. Gallen
Switzerland
Tel: +41 71-282-31-31
info@fisba.com
www.fisba.com
See our ad on page 41

Fresnel Technologies Inc.
101 W. Morningside Drive
Fort Worth, Texas 76110
Tel: 817-926-7474
info@fresneltech.com
www.fresneltech.com
See our ad on page 6

LaCroix Optical Co.
P.O. Box 2556
Batesville, Ark. 72503-2556
Tel: 870-698-1881
info@lacroixoptical.com
www.lacroixoptical.com
See our ad on page C2

Meller Optics Inc.
120 Corliss St.
Providence, R.I. 02904
Tel: 401-331-3717
sales@melleroptics.com
www.melleroptics.com
See our ad on page 56

Optimax Systems Inc.
6367 Dean Parkway
Ontario, N.Y. 14519-8939
Tel: 585-265-1020
sales@optimaxsi.com
www.optimaxsi.com
See our ad on page 77

Penn Optical Coatings
1055 Mensch Dam Road
Pennsburg, Pa. 18073
Tel: 267-923-8798
sales@pennoc.com
www.pennoc.com
See our ad on page 30

Rainbow Research Optics Inc.
6830 S. Dawson Circle
Centennial, Colo. 80112
Tel: 303-371-3000
sales@rr-optics.com
www.rr-optics.com
See our ad on page 47

Schneider Optics
285 Oser Ave.
Hauppauge, N.Y. 11788
Tel: 631-761-5000
industrial@schneideroptics.com
www.schneiderindustrialoptics.com
See our ad on page 75

United Lens Co. Inc.
259 Worcester St.
Southbridge, Mass. 01550-1325
Tel: 508-765-5421
info@unitedlens.com
www.unitedlens.com
See our ad on page 31

Centering and Edging Machines

E. McGrath Inc.
Salem, Mass.
www.emcgrath.com

Mildex Inc.
Rochester, N.Y.
www.mildex.com

OptiPro Systems
Ontario, N.Y.
www.optipro.com

OptoTech Optical Machinery Inc., Precision Optics
Palm, Pa.
www.optotech.us

Satisloh GmbH
Wetzlar, Germany
www.satisloh.com

Satisloh North America Inc.
Germantown, Wis.
www.satisloh.com

Schneider Optical Machines Inc.
Frisco, Texas
www.schneider-om.com

Tech-Alloy Associates
Auburn, Calif.
www.tech-alloy.com

TRIOPTICS GmbH
Wedel, Germany
www.trioptics.com

Diamond Tools and Machining Equipment

Accurate Diamond Tool Corp.
Emerson, N.J.
www.accuratediamondtool.com

AMETEK Precitech Inc.
Keene, N.H.
www.precitech.com

Chardon Tool
Chardon, Ohio
www.chardontool.com

Contour Fine Tooling Inc.
Marlborough, N.H.
www.contour-diamonds.com

DAC International Inc.
Carpinteria, Calif.
www.dac-intl.com

DCM Tech Inc.
Winona, Minn.
www.dcm-tech.com

Delaware Diamond Knives Inc.
Wilmington, Del.
www.ddk.com

Diacut Inc.
Palmer Lake, Colo.
www.diacut.com

Diamond Industrial Tools.com
Lincolnwood, Ill.
www.todit.com

Diatome U.S.
Hatfield, Pa.
www.emsdiasum.com

Engis Corp.
Wheeling, Ill.
www.engis.com

Kinetic Ceramics LLC
Hayward, Calif.
www.kineticceramics.com

LEL Diamond Tools International Inc., UKAM Industrial Superhard Tools
Valencia, Calif.
www.ukam.com/photonics.htm

Lensmaster Optical Co. Inc.
Southbridge, Mass.
www.lensmastertooling.com

Lunzer Technologies Inc.
New York, N.Y.
www.lunzer.com

Mildex Inc.
Rochester, N.Y.
www.mildex.com

Minitool Inc.
Los Gatos, Calif.
www.minitoolinc.com

Moore Nanotechnology Systems LLC
Swanzey, N.H.
www.nanotechsys.com

my-Chip Production GmbH
Rudolstadt, Germany
www.german-my-chip.com

OptiPro Systems
Ontario, N.Y.
www.optipro.com

OptoTech Optical Machinery Inc., Precision Optics
Palm, Pa.
www.optotech.us

PIKE Technologies Inc.
Madison, Wis.
www.piketech.com/optics

Satisloh GmbH
Wetzlar, Germany
www.satisloh.com

Schneider Optical Machines Inc.
Frisco, Texas
www.schneider-om.com

Spartan Felt Co. Inc., Surface Preparation
Roebuck, S.C.
www.spartanfelt.com

Starlite Industries Inc.
Rosemont, Pa.
www.starliteindustries.com

Struers Inc.
Westlake, Ohio
www.struers.com

Tech-Alloy Associates
Auburn, Calif.
www.tech-alloy.com

Technodiamant USA
Tranquility, N.J.
www.technodiamant.com

ZIRCAR Refractory Composites Inc.
Florida, N.Y.
www.zrci.com

Grinding and Polishing Machinery

Allied High Tech Products Inc.
Rancho Dominguez, Calif.
www.alliedhightech.com

AMETEK Precitech Inc.
Keene, N.H.
www.precitech.com

Axus Technology
Chandler, Ariz.
www.axustech.com

DCM Tech Inc.
Winona, Minn.
www.dcm-tech.com

Diacut Inc.
Palmer Lake, Colo.
www.diacut.com

Diamond Industrial Tools.com
Lincolnwood, Ill.
www.todit.com

E. McGrath Inc.
Salem, Mass.
www.emcgrath.com

Engis Corp.
Wheeling, Ill.
www.engis.com

Fritsch GmbH - Milling and Sizing
Idar-Oberstein, Germany
www.fritsch.de

GigaMat Technologies Inc.
Fremont, Calif.
www.gigamat.com

GTI Technologies Inc.
Shelton, Conn.
www.gti-usa.com

Larsen Equipment Design Inc.
Seattle
www.larsenequipment.com

Lensmaster Optical Co. Inc.
Southbridge, Mass.
www.lensmastertooling.com

Logitech Ltd.
Old Kilpatrick, Scotland
www.logitech.uk.com

Mildex Inc.
Rochester, N.Y.
www.mildex.com

Moore Nanotechnology Systems LLC
Swanzey, N.H.
www.nanotechsys.com

my-Chip Production GmbH
Rudolstadt, Germany
www.german-my-chip.com

Opteg GmbH
Leipzig, Germany
www.opteg.de

OptiPro Systems
Ontario, N.Y.
www.optipro.com

OptoTech Optical Machinery Inc., Precision Optics
Palm, Pa.
www.optotech.us

P.R. Hoffman Machine Products Inc.
Carlisle, Pa.
www.prhoffman.com

PIKE Technologies Inc.
Madison, Wis.
www.piketech.com/optics

Pynco Inc.
Bedford, Ind.
www.pynco.com

QED Optics
Rochester, N.Y.
www.qedoptics.com

Satisloh GmbH
Wetzlar, Germany
www.satisloh.com

Schneider Optical Machines Inc.
Frisco, Texas
www.schneider-om.com

Spartan Felt Co. Inc., Surface Preparation
Roebuck, S.C.
www.spartanfelt.com

Struers Inc.
Westlake, Ohio
www.struers.com

Tech-Alloy Associates
Auburn, Calif.
www.tech-alloy.com

U.S. Stoneware
East Palestine, Ohio
www.usstoneware.com

Ultra Tec Mfg. Inc., Surface Technology
Santa Ana, Calif.
www.ultratecusa.com

Universal Photonics Inc.
Central Islip, N.Y.
www.universalphotonics.com

Westwind Air Bearings
Poole, England
www.westwind-airbearings.com

Optics, Custom Fabrication

II-VI Inc., II-VI Infrared
Saxonburg, Pa.
www.iiviinfrared.com

II-VI Optical Systems
Murrieta, Calif.
www.opticalsystems.com

A.R.W. Optical Corp.
Wilmington, N.C.
www.arwoptical.com

Abrisa Technologies
Santa Paula, Calif.
www.abrisatechnologies.com

Acrolite
Elbridge, N.Y.
www.acrolite.net

Advanced Optics Inc.
Pewaukee, Wis.
www.advancedoptics.com

Aero Research Associates Inc.
Holbrook, N.Y.
www.aerorese.com

AFO Research Inc.
Vero Beach, Fla.
www.aforesearch.com

Almaz Optics Inc.
Marlton, N.J.
www.almazoptics.com

Amax Precision Optic Pte. Ltd.
Shah Alam, Malaysia
www.amaxoptics.com

Angstrom Precision Optics Inc.
Rochester, N.Y.
www.apoptics.com

Apollo Optical Systems Inc.
West Henrietta, N.Y.
www.ApolloOptical.com

Berliner Glas KGaA Herbert Kubatz GmbH & Co.
Berlin
www.berlinerglas.com

Bern Optics Inc.
Westfield, Mass.
www.bernoptics.com

BMVOPTICAL TECHNOLOGIES

BMV Optical Technologies Inc.
Ottawa, Ontario, Canada
www.bmvoptical.com

Bond Optics LLC
Lebanon, N.H.
www.bondoptics.com

CASIX Inc.
Fuzhou, China
www.casix.com

CMPC Surface Finishes
Addison, Ill.
www.surfacefinishes.com

COE Optics Inc.
Murrieta, Calif.
www.coeoptics.com

Collimated Holes Inc.
Campbell, Calif.
www.collimatedholes.com

Colusa Science
Woodland, Calif.
www.col-sci.com

Corning Advanced Optics
Corning, N.Y.
www.corning.com/advanced-optics

Corning Specialty Materials, Aerospace and Defense
Keene, N.H.
www.corning.com

Crystal GmbH
Berlin
www.crystal-gmbh.com

Crystran Ltd.
Poole, England
www.crystran.co.uk

DFM Engineering Inc.
Longmont, Colo.
www.dfmengineering.com

DIVERSE OPTICS polymer optics perfected

Diverse Optics Inc.
Rancho Cucamonga, Calif.
www.diverseoptics.com

Edmund optics | worldwide

Edmund Optics Inc.
Barrington, N.J.
www.edmundoptics.com

EKSMA Optics
Vilnius, Lithuania
www.eksmaoptics.com

ESCO optics

Esco Optics
Oak Ridge, N.J.
www.escooptics.com

Ferson Technologies Inc.
Ocean Springs, Miss.
www.ferson.com

FISBA Innovators in Photonics

FISBA AG
St. Gallen, Switzerland
www.fisba.com

fresnel technologies inc.

Fresnel Technologies Inc.
Fort Worth, Texas
www.fresneltech.com

FujiFilm Corp., Industrial Products Div.
Tokyo
www.fujifilm.com

G5 Infrared
Hudson, N.H.
www.g5ir.com

Glass Fab Inc.
Rochester, N.Y.
www.glassfab.com

GS Plastic Optics
Rochester, N.Y.
www.gsoptics.com

Guild Optical Associates Inc.
Amherst, N.H.
www.guildoptics.com

Inrad Optics Inc.
Northvale, N.J.
www.inradoptics.com

Insaco Inc.
Quakertown, Pa.
www.insaco.com

InSync Inc.
Albuquerque, N.M.
www.insyncoptics.com

ios Optics
Santa Clara, Calif.
www.iosoptics.com

IRD Glass
Litchfield, Minn.
www.irdglass.com

ISP Optics Corp.
Irvington, N.Y.
www.ispoptics.com

J.R. Cumberland Inc.
Marlow Heights, Md.
www.cumberlandoptical.com

JENOPTIK Optical Systems GmbH
Jena, Germany
www.jenoptik.com/os

JENOPTIK Optical Systems LLC
Jupiter, Fla.
www.jenoptik-inc.com

K&S Optics Inc.
Greene, N.Y.
www.kandsoptics.com

Keo Scientific Ltd.
Calgary, Alberta, Canada
www.keoscientific.com

L-3 Brashear
Pittsburgh
www.L-3com.com/Brashear

LaCroix Optical Co.

LaCroix Optical Co.
Batesville, Ark.
www.lacroixoptical.com

Laserline Optics Canada Inc.
Osoyoos, British Columbia, Canada
www.laserlineoptics.com

LEL Diamond Tools International Inc., UKAM Industrial Superhard Tools
Valencia, Calif.
www.ukam.com/photonics.htm

Lensel Optics Pvt. Ltd.
Pune, India
www.lenseloptics.com

LightTrans GmbH
Jena, Germany
www.lighttrans.com

Lobre srl
Carpenedolo, Italy
www.lobre.it

Mark Optics Inc.
Santa Ana, Calif.
www.markoptics.com

MaxEmil Photonics Corp.
New Taipei City, Taiwan
www.maxemilphotonics.com

Meller Optics Inc.
Providence, R.I.
www.melleroptics.com

Metal Cutting Corp.
Cedar Grove, N.J.
www.metalcutting.com

Midwest Optical Systems Inc. (MidOpt)
Palatine, Ill.
www.midopt.com

Mok Optics Co. Ltd.
Fuzhou, China
www.mokoptics.com

Navitar Inc.
Rochester, N.Y.
www.navitar.com

NiPro Optics Inc.
Irvine, Calif.
www.niprooptics.com

Nu-Tek Precision Optical Corp.
Aberdeen, Md.
www.nu-tek-optics.com

Ohara Corp., Western Office
Rancho Santa Margarita, Calif.
www.oharacorp.com

Optics Fullum Inc.
Vaudreuil-Dorion, Quebec, Canada
www.normandfullumtelescope.com

Optics Masters LLC
Poway, Calif.
www.opticsmasters.net

Opto GmbH
Graefelfing, Germany
www.opto.de

Paradigm Research Optics
Loveland, Colo.
www.research-optics.com

Perkins Precision Developments LLC
Longmont, Colo.
www.perkinsprecision.com

Phila Optics Inc.
Feasterville, Pa.
www.philaoptics.com

Photonic Sense Inc.
Nashua, N.H.
www.photonic-sense.com

Photonics Solutions Group LLC
Albuquerque, N.M.
www.photonicsllc.com

Photonics4Work
Zevenaar, Netherlands
www.photonics4work.eu

PIKE Technologies Inc.
Madison, Wis.
www.piketech.com/optics

polyoptics GmbH
Kleve, Germany
www.polyoptics.de

Precision Glass & Optics (PG&O)
Santa Ana, Calif.
www.pgo.com

Precision Optical
Costa Mesa, Calif.
www.precisionoptical.com

Precision Optics Corp.
Gardner, Mass.
www.poci.com

Quartzite Processing Inc.
Malden, Mass.
www.quartziteprocessing.com

R. Mathews Optical Works Inc.
Poulsbo, Wash.
www.mathewsoptical.com

Raytheon ELCAN Optical Technologies
Midland, Ontario, Canada
www.elcan.com

Research and Industrial Optics
Wickford, England
www.rioptics.com

Research Electro-Optics Inc. (REO)
Boulder, Colo.
www.reoinc.com

Reynard Corp.
San Clemente, Calif.
www.reynardcorp.com

Rochester Precision Optics (RPO)
West Henrietta, N.Y.
www.rpoptics.com

Schneider Optics
Hauppage, N.Y.
www.schneiderindustrialoptics.com

Sinoptix
Shanghai
www.sinoptix.net

Special Optics Inc.
Denville, N.J.
www.specialoptics.com

Spectral Systems LLC
Hopewell Junction, N.Y.
www.spectral-systems.com

Spectrum Scientific Inc.
Irvine, Calif.
www.ssioptics.com

Suzhou Jiujon Optics Co. Ltd.
Suzhou, China
www.jiujon.com

Sydor Optics Inc.
Rochester, N.Y.
www.sydor.com

Tech-Alloy Associates
Auburn, Calif.
www.tech-alloy.com

Triptar Lens Co. Inc.
Rochester, N.Y.
www.triptar.com

TSP Inc.
Batavia, Ohio
www.tspinc.com

United Lens Co. Inc.
Southbridge, Mass.
www.unitedlens.com

Valley Design Corp., Headquarters
Shirley, Mass.
www.valleydesign.com

Zygo Corp., Ultra Precision Technologies
Middlefield, Conn.
www.zygo.com

Tools and Machinery, Optical Manufacturing

C-Flex Bearing Co. Inc.
Frankfort, N.Y.
www.c-flex.com

Chardon Tool
Chardon, Ohio
www.chardontool.com

Contour Fine Tooling Inc.
Marlborough, N.H.
www.contour-diamonds.com

Diacut Inc.
Palmer Lake, Colo.
www.diacut.com

Diamond Industrial Tools.com
Lincolnwood, Ill.
www.todit.com

Engis Corp.
Wheeling, Ill.
www.engis.com

Jacobsen Lenticular Tool & Cylinder Engraving Tech. Co.
Itasca, Ill.
www.jacotech.com

LEL Diamond Tools International Inc., UKAM Industrial Superhard Tools
Valencia, Calif.
www.ukam.com/photonics.htm

Lunzer Technologies Inc.
New York, N.Y.
www.lunzer.com

Midas Technology Inc.
Woburn, Mass.
www.midastechnology.com

Mildex Inc.
Rochester, N.Y.
www.mildex.com

Moore Nanotechnology Systems LLC
Swanzey, N.H.
www.nanotechsys.com

Mustang Vacuum Systems
Sarasota, Fla.
www.mustangvac.com

OptiPro Systems
Ontario, N.Y.
www.optipro.com

OptoTech Optical Machinery Inc., Precision Optics
Palm, Pa.
www.optotech.us

P.R. Hoffman Machine Products Inc.
Carlisle, Pa.
www.prhoffman.com

Satisloh GmbH
Wetzlar, Germany
www.satisloh.com

Schneider Optical Machines Inc.
Frisco, Texas
www.schneider-om.com

Technodiamant USA
Tranquility, N.J.
www.technodiamant.com

Trion Technology
Clearwater, Fla.
www.triontech.com

TRIOPTICS GmbH
Wedel, Germany
www.trioptics.com

Universal Photonics Inc.
Central Islip, N.Y.
www.universalphotonics.com

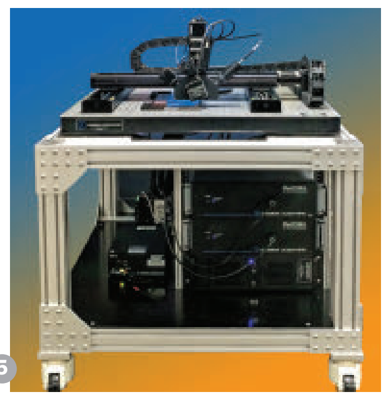
new PRODUCTS


1


2


3


4


5


6

1 Cryogenic Probe Station

Lake Shore Cryotonics Inc.'s cryogenic probe stations offer a reliable way to measure electro-optical, direct current, radio frequency or microwave properties of early-stage devices and materials, including novel photovoltaic materials, at temperatures as low as 1.6 K. Applications include research into nanostructured materials, the electro-optical spectroscopy of charge carriers and semiconductor optoelectronic devices. A number of versions are available, including cryogen-free closed-cycle refrigerator models and an entry-level Model TTPX, as well as models equipped with a superconducting magnet or electromagnet for investigating magneto-transport parameters of ferroelectric and magneto-resistive devices.

info@lakeshore.com

2 Motorized Stage

Prior Scientific Ltd.'s H101A ProScan motorized stage is designed for any upright stereo microscope or optical system, delivering precise motorized movement with a step resolution of 0.01 µm, repeatability of 0.7 µm and a large travel range of 114 × 75 mm. The H101A stage enables efficiency increases by automatically scanning specimens and storing points for later recollection and inspection. The stage can scan or inspect slides, micro well plates, semiconductor wafers or metallurgical specimens.

info@prior.com

3 Sensor Interface

Attocube Systems GmbH offers the IDS3010, which now supports BiSS-C, an open standard sensor interface that offers synchronous real-time data transmission. BiSS-C is compatible with various control systems. The IDS sensor can be integrated into broader production plants, and is suitable for connecting several IDS controllers to the master clock at multidevice facilities. The sensor supports the BiSS-C point-to-point configuration with a word length of 32 bit.

info@attocube.com

4 Test and Burn-In System

The automated high-volume test and burn-in system from **Yelo Ltd.** is designed to increase throughput for 100-G data center optical components. The system improves yield with low labor costs for manufacturers that need to scale production to 10,000, 500,000, or even 1 million components per month.

david.simms@yelo.co.uk

5 Reflectometer Measurement

The Dual Angle Reflectance Measurement System from **Gamma Scientific Inc.** delivers high-speed, automated reflectance measurements of glass for display and architectural uses. The reflectometer system provides ±0.05 percent accuracy and includes built-in second surface reflection suppression that can eliminate measurement errors on glass as thin as 0.3 mm. Built-in self-calibration enables the system to consistently produce high-accuracy data, even when used bin harsh environments. The system cobtains simultaneous reflectance measurements at both 10° and 45° incidence angles over the entire 380- to 1100-nm spectral range.

www.gamma-sci.com

6 Tunable Filter Module

Viavi Solutions Inc.'s Multiple Application Platform (MAP-200) multiport tunable filter module (mTFX-C1) simplifies test signal management for next-generation 100 G+ interfaces, subsystems and system tests. The modular Ethernet or general purpose interface bus instrument can be directly managed from a PC-based automation system. It eliminates the need to repurpose optical network technology or use complex libraries with specialized interface cards. Based on next-generation liquid crystal on silicon technology, the mTFX-C1 combines variable attenuator, switch, power meter and dense wavelength division multiplexing functions to simplify photonic testing of coherent interfaces, amplifier and multiplexing systems. Multiple parallel wavelength paths can be created without disrupting already established connections, all with sub-GHz resolution.

www.viavisolutions.com

Solid-State Lasers

Uniklasers Ltd. has released the SOLO 640 line of continuous wave, diode-pumped, solid-state lasers at 640 nm. The devices emit as a fundamental wavelength from its active laser material, and provide single frequency, ultralow noise performance in the visible red region of the electromagnetic spectrum. M2 values are shown at <1.05, with the unit producing a single longitudinal frequency and a coherence length in excess of 100 m. The laser will be available with output power levels up to 1500 mW, exhibiting near perfect Gaussian beam performance coupled with <5 μrad/°C beam pointing stability and exceptional noise figures down to <0.1 percent rms.
sales@uniklasers.com

Mirror Housing

Alpao SAS offers deformable mirror housing for mirrors with less than 100 actuators. Housing depth has been decreased from 80 to 18.6 mm. The engineering team optimized the system to reduce the weight of the final structure by two-and-a-half times, resulting in a 180-g system instead of a 480-g system. Users now have the opportunity to reduce their system size with a lighter and more compact deformable mirror for embedded adaptive optics systems.
contact@alpao.fr

Universal Control Card

The SP-ICE-3 universal control card (UCC) from **Raylase AG** simplifies and accelerates the development of laser systems. The UCC controls 2- and 3-axis deflection units, as well as all standard laser sources. Speed- and position-dependent control enable a consistently high processing quality of materials using lasers. The UCC features 2 GB DDR3 RAM for memory and field corrections in 2D and 3D, three 16 bit input/output ports for controlling up to four step motors, and 20-bit position resolution with the SL2-100 protocol (16 bit with XY2-100), allowing the mirrors to be controlled with a resolution of 0.75 μrad.
www.raylase.de/company/contact

Hyperspectral Camera

SphereOptics GmbH distributes the HySpex Mjolnir-1024 hyperspectral camera from Norsk Elektro Optikk AS. The device is a complete solution for the production of high-quality georeferenced data of scientific grade. It covers the visible to near-infrared spectral range from 400 to 1000 nm with 200 spectral bands. It is built with an optical archi-

tecture based on the HySpex ODIN system. The low noise floor, combined with high-end calibrations, makes the camera an ideal tool for scientific usage and unmanned aerial vehicles. A system includes the hyperspectral camera, a computer and the Applanix APX-15 inside a small chassis of <4.5 kg.
info@sphereoptics.de

Tracing Add-In

Lambda Research Corp.'s RayViz add-in for its SOLIDWORKS software enables design engineers working within the SOLIDWORKS CAD environment to apply and save optical properties while tracing and visualizing rays. RayViz adds ray-tracing functionality to SOLIDWORKS models to verify geometry, check for vignetting and crosstalk and for stray light issues by visualizing rays traced through optical components. Designers significantly accelerate the product development process without sacrificing performance or functionality due to RayViz's easy-to-learn interface and minimum setup time. A complete optical model can be exported for use in TracePro.
sales@lambdares.com

Custom Transmission Gratings

Holographix LLC has released custom-designed transmission gratings. These high-efficiency gratings provide a lower stray light solution, as compared to volume phase transmission gratings. A >90 percent diffraction efficiency with low stray light is featured, as well as repeatable performance.
info@holographix.com

Laser Module

Laser Components GmbH has announced the LC-LMD-650-01-T60-AX coaxially aligned, broad operating temperature range laser module in a compact form. The LC-LMD-650-01-T60-AX laser modules are manufactured to easily align with optical systems in industrial positioning, alignment and measurement applications. The output beam tolerance is less than 0.1° or 1.75 mm/m, which is at least 5× more precise than most standard products. The industrial package design tolerates a broad ambient operating temperature range from −5 to 60 °C, features a compact 9-mm-long,

4-mm-diameter design, and easily connects via the 55-mm external flying leads.
info@laser-components.com

Cable Assembly Testing Software

Optotest Corp. has announced major updates to its OPL-MAX software for testing multifiber, ribbon and specialized cable assemblies. Improvements were made to return loss calculation accuracy, second position return loss measurement, data handling, user interface, the additions of an optical time domain reflectometer-style reflection scan, angled physical contact return loss referencing, channel-by-channel real-time measurements and customer-configurable visual aids. Testing can be fully customized for wavelength, number of channels, channel order, test reports and pass/fail criteria. Data is collected and compiled into a custom formatted test report.
marketing@optotest.com

Fiber Bragg Gratings

Technica Optical Components LLC has expanded its offering of fiber Bragg gratings (FBG) to include sensors, arrays and cables. The T10-T95 specialized FBG sensors and original factory-coated or extruded T100-T140 FBG arrays and cables are available in a wide range of optical specifications. Naturally packaged directly in fiber, the sensors

can be used as they are or packaged into a variety of higher level sensors for use in optical sensing systems. They feature small size and fast response time with excellent wavelength-to-temperature and wavelength-to-strain linearity. The products can be used in security, robotics, medical, civil and geotechnical engineering for bridges, buildings, tunnels, mines, slope monitoring, oil, gas, aerospace and other areas.
info@technicasa.com

Process Design Kit

VTT Technical Research Centre of Finland Ltd. and **Phoenix Software Ltd.** have announced a process design kit that supports the development of silicon photonics. The new kit includes design rules, component examples and simulation models in the form of documents and as a software library for Phoenix Software solutions. The kit is comprehensive for the 3-µm silicon-on-insulator platform.
timo.aalto@vtt.fi

● Happenings

OCTOBER

Inpho Venture Summit, Photonics and Beyond (Oct. 6-7) Bordeaux, France. Formerly Invest in Photonics. Contact Audrey Durand, +33 (0)5-56-79-44-86, audrey@inpho-ventures.com; www.inpho-ventures.com.

Micro Photonics (Oct. 11-13) Berlin. Contact Messe Berlin GmbH, +49 30-3038-2159, micro-photonics@messe-berlin.de; www.micro-photonics.de.

Photonics Asia (Oct. 12-14) Beijing. Contact +1 360-676-3290, customerservice@spie.org; www.spie.org/x6445.xml.

● **Photonex and Hyperspectral Imaging and Applications (HSI) (Oct. 12-13)** Coventry, England. Photonex and HSI colocated. Contact Xmark Media Ltd., +44 (0)1372-750555, info@xmarkmedia.com; www.photonex.org; www.hsi2016.com.

● **Frontiers in Optics: The 100th OSA Annual Meeting and Exhibit/Laser Science XXXII (Oct. 16-20)** Rochester, N.Y. Contact +1 202-416-1907, custserv@osa.org; www.frontiersinoptics.com.

● **ICALEO (Oct. 16-20)** San Diego. The International Congress on Applications of Lasers & Electro-Optics. Contact ICALEO, +1 407-380-1553, icaleo@lia.org; www.lia.org/conferences/icaleo.

Canadian Machine Vision Conference 2016 (Oct. 20) Richmond, B.C., Canada. Contact AIA +1 734-994-6088; www.visiononline.org/2016-Canadian-Machine-Vision-Conference.

● **Image Sensors Americas Conference (Oct. 24-26)** San Francisco. Contact Smithers Apex, +44 0-1372-802000, info@smithersapex.com; www.image-sensors.com.

SEMICON Europa (Oct. 25-27) Grenoble, France. Contact Eva Weller, SEMI Europe, +49 30-3030-8077-0, eweller@semi.org; www.semiconeuropa.org.

OSA Advanced Solid State Lasers Conference and Exhibition (Oct. 30-Nov. 4) Boston. Contact +1 202-416-1907, custserv@osa.org; www.osa.org/assl.

Avionics and Vehicle Fiber Optics and Photonics Conference (Oct. 31-Nov. 3) Colocated with the IEEE International Topical Meeting on Microwave Photonics. Contact Megan Figueroa, +1 732-562-3896, m.figueroa@ieee.org; www.photonicssociety.org.

NOVEMBER

14th European Short Course on Time-Resolved Fluorescence Spectroscopy (Nov. 7-10) Berlin. Held by PicoQuant GmbH and the Center of Fluorescent Spectroscopy. Contact PicoQuant, +49 30-6392-6929, info@picoquant.com; www.picoquant.com.

● **VISION (Nov. 8-10)** Stuttgart, Germany. International trade fair for machine vision. Contact Messe Stuttgart, +49 711-18560-0, info@messe-stuttgart.de; www.messe-stuttgart.de/en/vision.

● **Neuroscience (Nov. 12-16)** San Diego. Presented by the Society for Neuroscience. Contact +1 202-962-4000, program@sfn.org; www.sfn.org/annual-meeting/neuroscience-2016.

● **OSA Congress: Light, Energy and Environment (Nov. 14-16)** Leipzig, Germany. Contact +1 202-416-1907, custserv@osa.org; www.osa.org/en-us/meetings/osa_meetings.

● **FABTECH (Nov. 16-18)** Las Vegas. Contact +1 888-394-4362, information@fabtechexpo.com; www.fabtechexpo.com.

Aggregation Induced Emission Conference (Nov. 18-20) Guangzhou, China. A Faraday Discussion of the Royal Society of Chemistry. Contact RSC, +44 0-1223-43-2254/2380, adam.kirrander@ed.ac.uk; www.rsc.org/events/detail/19001.

DECEMBER

● **Cell Biology 2016, ASCB Annual Meeting (Dec. 3-7)** San Francisco. Contact The American Society for Cell Biology, +1 301-347-9300, ascbinfo@ascb.org; www.ascb.org/2016meeting.

NANOP 2016 (Dec. 7-9) Paris. Nanophotonics and Micro/Nano Optics International Conference. Contact +33 6-16-68-24-85, nanop2016@premc.org; www.premc.org/nanop2016/.

● **MediSens 2016 (Dec. 13-14)** London. Presented by Sense Media Events. Contact +44 0-208-133-5116, enquiries@medisens-conference.com; www. medisens-conference.com/.

SEMICON Japan (Dec. 14-16) Tokyo. SEMI Japan Customer Service, +81 3-3222-5988, jcustomer@semi.org; www.semiconjapan.org.

JANUARY

● **A3 Business Forum (Jan. 18-20)** Lake Buena Vista, Fla. Contact AIA Advancing Vision & Imaging, +1 734-994-6088, info@a3automate.org; www. a3automate.org/events/a3-business-forum/.

● **SPIE BiOS (Jan. 28-29)** San Francisco. Contact +1 360-676-3290, customerservice@spie.org; www.spie.org/conferences-and-exhibitions/photonics-west/bios-expo.

● **SPIE Photonics West (Jan. 28-Feb. 2)** San Francisco. Contact +1 360-676-3290, customerservice@spie.org; www.spie.org/conferences-and-exhibitions/photonics-west.

PAPERS

International Conference on Nano-Bio Sensing, Imaging & Spectroscopy (Feb. 22-24, 2017) Jeju Island, Korea
Deadline: Abstracts, Oct. 31
SPIE's International Conference on Nano-Bio Sensing, Imaging & Spectroscopy (NBSIS 2017) is a biannual forum on cutting-edge scientific and technical issues in the field of nano-bio science and technology. NBSIS submissions focus on trending topics in nano-bio sensors, imaging techniques and advanced spectroscopies such as biomedical application of optics, nanometer scale microscopic techniques, optical coherence tomography, in vivo imaging for clinical applications, nano-bio detections and sensors. Contact SPIE, +1 360-676-3290, customerservice@spie.org; www.spie-nbsis.org/main.php.

SID Display Week (May 21-26, 2017) Los Angeles
Deadline: Abstracts, Dec. 1
Society for Information Display's Display Week 2017 comprises augmented and virtual reality, digital-signage display solutions, display materials and processes, and wearable displays. Submissions are solicited on display technologies for AR and VR systems; 3D sensing and imaging technologies; spatial tracking, localization, mapping and navigation techniques; end-to-end system integration; LED implementations leveraging flip-chip and chip-on-board solutions; automated and programmed color uniformity and calibration; down-conversion materials including quantum dots; OLED materials processing; nanofabrication and wearable applications, among others. Contact the Society for Information Display, +1 203-502-8283, jbuckley@pcm411.com; www.displayweek.org.

ETOP 2017 (May 29-31, 2017) Hangzhou, China
Deadline: Abstracts, Nov. 1
The 14th International Conference on Education and Training in Optics and Photonics comprises presentation, panel discussions, workshops and exhibits. Submissions are solicited on curriculum development; new pedagogical methods, tools and models; laboratories; education and training for multidisciplinary education; training programs for senior undergraduates; digital and internet technology; education for industry; international exchange and cooperation; assessment and evaluation of education.

● Indicates shows **Photonics Media** will be attending.
Complete listings at **www.photonics.com/calendar**.
Submit your event online at **Photonics.com/eventsubmit**.

Advertiser Index

Tell our advertisers you found them in *Photonics Spectra*.

Photonics Media Advertising Contacts

Please visit our website Photonics.com/mediakit for all our marketing opportunities.

New England
Rebecca L. Pontier
Associate Director of Sales
Voice: +1 413-499-0514, Ext. 112
Fax: +1 413-443-0472
becky.pontier@photonics.com

NY, NJ & PA
Timothy A. Dupree
Regional Account Manager
Voice: +1 413-499-0514, Ext. 111
Fax: +1 413-443-0472
tim.dupree@photonics.com

Midwest & Southeastern US, Europe & Israel
Matt Beebe
Regional Account Manager
Voice: +1 413-499-0514, Ext. 103
Fax: +1 413-443-0472
matt.beebe@photonics.com

CA, HI, AZ, CO, ID, MT, NM, UT, NV, WY & Central Canada
Kim Abair
Regional Account Manager
Voice: +1 951-926-4161
Fax: +1 951-926-4295
kim.abair@photonics.com

South Central US, AK, OR, WA, Eastern & Western Canada
Peggy L. Dysard
Regional Account Manager
Voice: +1 413-499-0514, Ext. 226
Fax: +1 413-443-0472
peggy.dysard@photonics.com

Asia (except Japan) & Florida
Tom Kotarba
Regional Account Manager
Voice: +1 413-499-0514, Ext. 229
Fax: +1 413-443-0472
thomas.kotarba@photonics.com

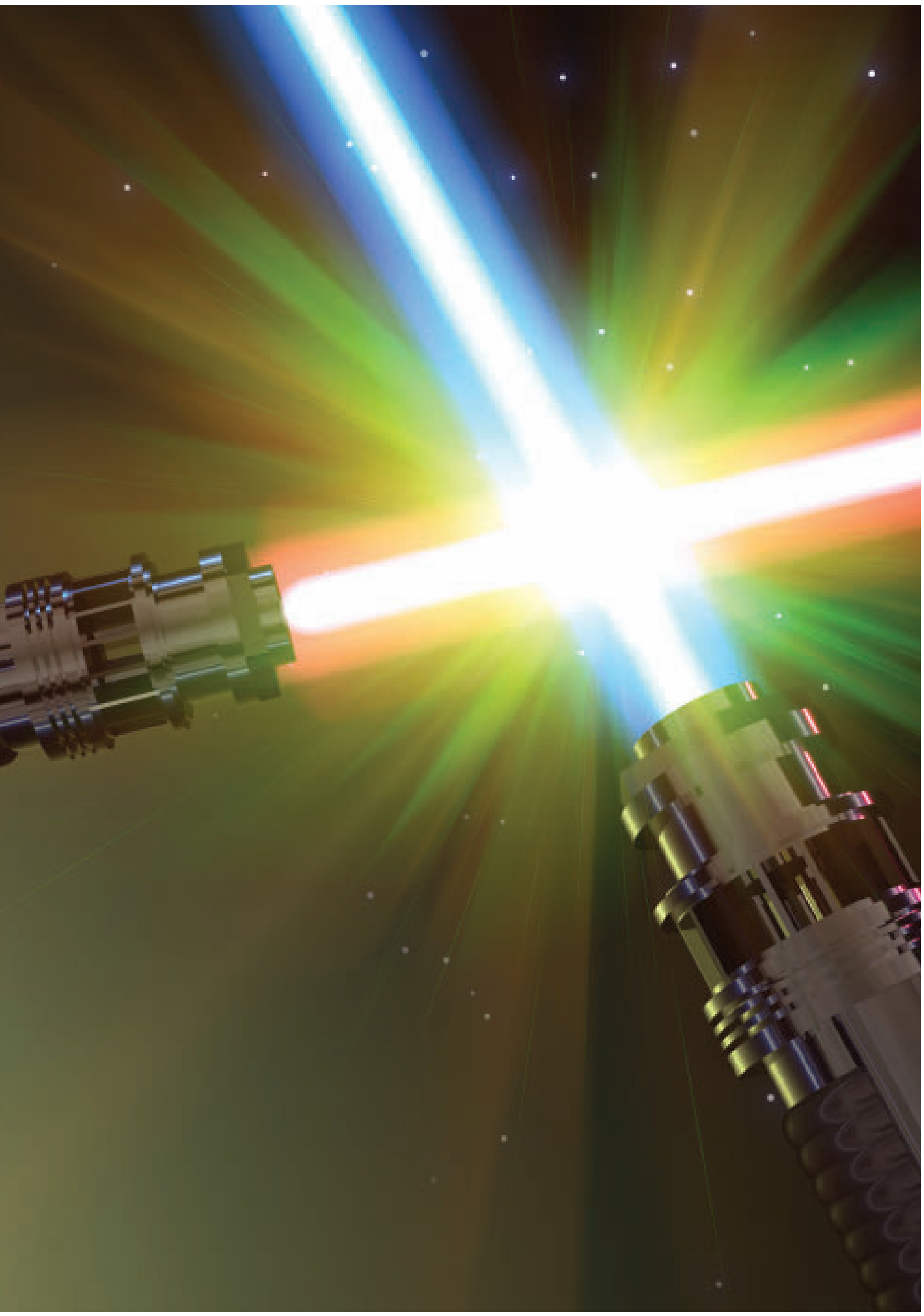
Japan
Sakae Shibasaki
Voice: +81 3-3269-3550
Fax: +81 3-5229-7253
s_shiba@optronics.co.jp

Reprint Services
Voice: +1 413-499-0514
Fax: +1 413-442-3180
editorial@photonics.com

Mailing Address
Send all contracts, insertion orders and advertising copy to:
Laurin Publishing
PO Box 4949
Pittsfield, MA 01202-4949

Street Address
Laurin Publishing
100 West Street
Pittsfield, MA 01201
Voice: +1 413-499-0514
Fax: +1 413-443-0472
advertising@photonics.com

Photonics to bring lightsaber experience to non-Jedis



The lightsaber: The elegant weapon of the Jedi Knight has captured the imagination of legions of young moviegoers over the past four decades.

If Disney has its way, "Star Wars" fans will have the chance to experience what it's like to be engaged in a lightsaber duel at one of its new Star Wars-themed parks being built at Disney World and Disneyland. The company recently filed a patent for an "audience interaction projection system" that involves drones, infrared LEDs, sensors and visible light sources.

Here's how it'll work:

Visitors will enter a fog-filled theater carrying an amulet or other device made of reflective material. This faux lightsaber will be equipped with an LED that emits IR light toward drones flying above. As the LED on the amulet is turned on, IR sensors built into the drones capture an image of the field of view. A bright spot depicts the position of the activated LED; a light source from the drone projects light through the air, made visible by the water vapor.

When the IR light intersects with visible light fired from the drones hovering above, the participant experiences an illusion of a laser beam being deflected. The lightsabers could be designed to provide some form of haptic feedback such as a vibration, when the beams intersect.

Numerous LEDs can be activated in a sequence, which will give the user the sense of deflecting multiple laser beams simultaneously. It also will allow for multiple users with multiple light beams projected toward each participant.

While at this point a timeline for the system's installation in the Disney parks remains to be seen, all of this talk of lightsaber duels is likely to excite legions of Star Wars fans.

So until the Star Wars parks open, lightsaber duels will remain the stuff of movie magic. May the Force be with us.

Michael D. Wheeler
michael.wheeler@photonics.com

Multi-Line CMOS Technology

Unmatched Performance, Unmatched Reliability

Piranha XL 16K
with Xtium CLHS

The Piranha XL 16K camera offers an unprecedented combination of speed, resolution, and responsivity with low noise. True exposure control allows consistent, superior image quality when the production line speed fluctuates. Combined with the Xtium-CLHS Series high performance frame grabbers, the Piranha XL 16K delivers line rates up to 125 kHz and breakthrough bandwidth up to 3GB/sec with field proven Trigger-to-Image-Reliability.

» Get more details on Piranha XL:
www.teledynedalsa.com/piranha-xl

TELEDYNE DALSA
Everywhereyoulook™