www.photonics.com

June 2016

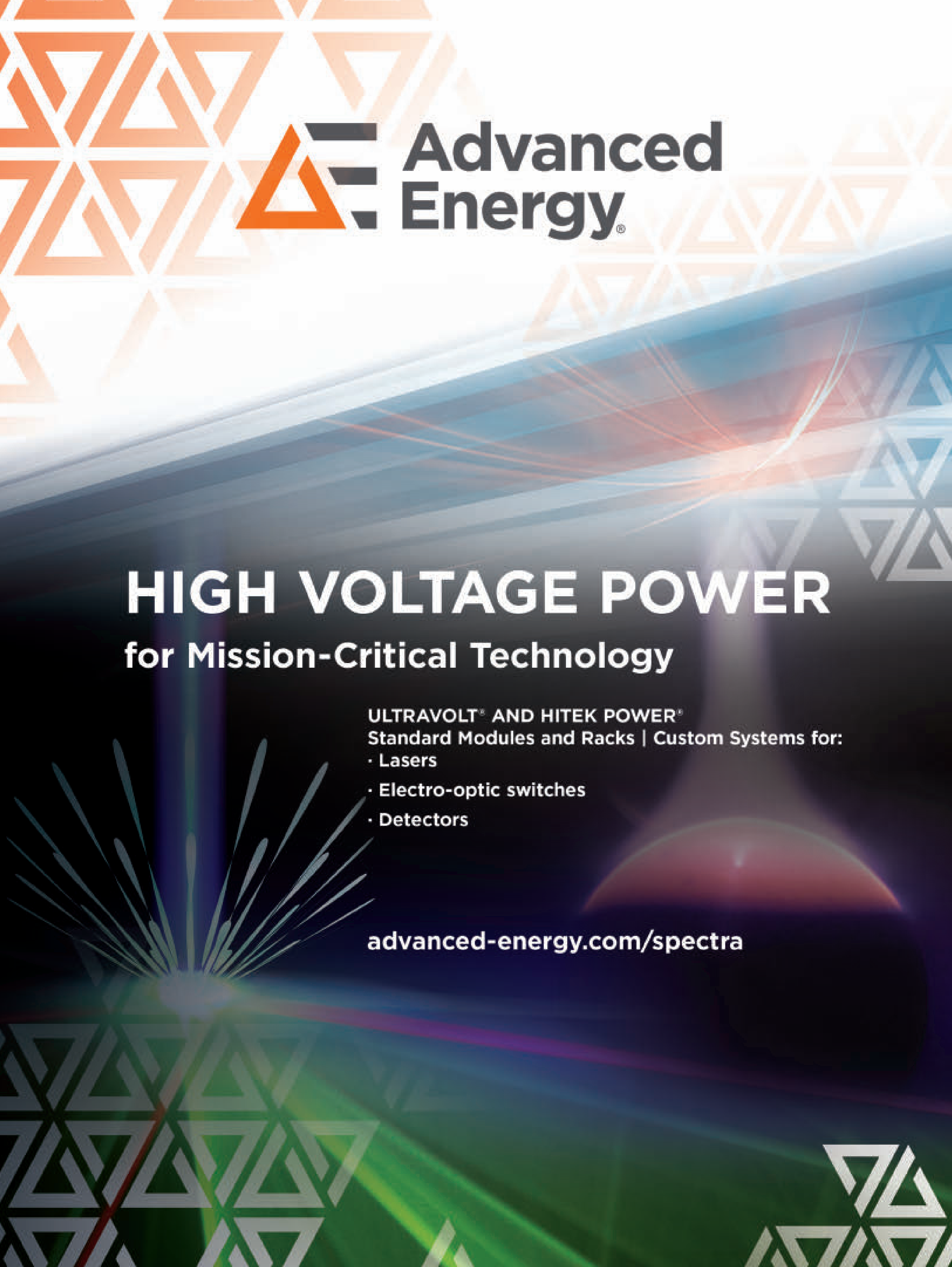
PHOTONICS spectra

Microscopy
Opening Up New Worlds

Microscopy
Growth & Demand Revealed

PHOTONICS MEDIA

LAURIN PUBLISHING

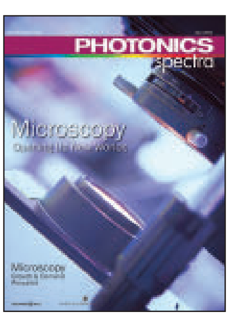

Advanced Energy®
HIGH VOLTAGE POWER
for Mission-Critical Technology
ULTRAVOLT® AND HITEK POWER®
Standard Modules and Racks | Custom Systems for:
· Lasers
· Electro-optic switches
· Detectors
advanced-energy.com/spectra

Content

JUNE 2016 www.photonics.com VOLUME 50 ISSUE 6

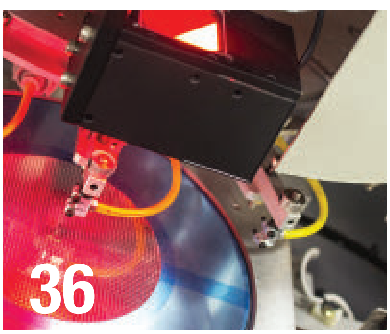
Departments & Columns

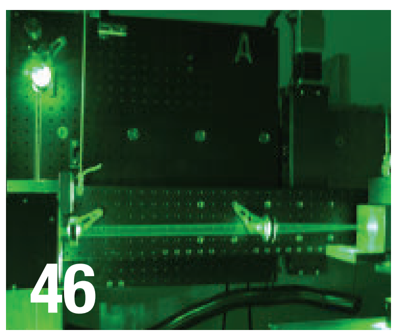
THE COVER
Microscopy is expanding beyond the life sciences, into applications once thought impossible. Cover design by Senior Art Director Lisa N. Comstock.



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, Berkshire Common, 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
News/Departments Editor Julia Germaine
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

www.photonics.com

Corporate Staff

President/CEO Thomas F. Laurin
Vice President Kristina A. Laurin
Vice President Ryan F. Laurin
Internal Audit Officer Mollie M. Armstrong
Controller Wendy R. Zieba
Accounts Receivable Manager Kathleen G. Paczosa
Business Manager Elaine M. Filiault
Accounting Clerk 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
Subscriptions Janice L. Butler
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.

editorial
COMMENT

Microscopy brings new worlds into focus

Though the father-son duo of Hans and Zacharias Janssen is widely credited with developing the first microscope in the late 16th century, it was the English scholar Robert Hooke who inspired widespread public interest in the new science of microscopy. His seminal work, "Micrographia," published in 1665, included never-before-seen illustrations of magnified insects and plants, just as he saw them from his microscope.

"By the help of microscopes, there is nothing so small as to escape our inquiry; hence, there is a new visable world discovered to the understanding," he wrote.

As in Hooke's day, microscopy continues to open up new worlds of understanding.

Senior editor Justine Murphy spoke with three luminaries in the field: Aydogan Ozcan, Ph.D., of UCLA; David K. Welsh, M.D., Ph.D., of UC San Diego; and Nestor J. Zaluzec of the Argonne National Laboratory. They shared their insights into the latest super-resolution and cryomicroscopy techniques and more in "Illuminating Microscopy Growth and Demand" on page 52.

Speaking of illumination, lighting sources have changed significantly from the rudimentary oil lamps used in Hooke's day. Contributing editor Marie Freebody's "Lighting up Microscopes: Advances and Emerging Sources" on page 30 examines the increasing popularity of LED light sources, especially for bright-field transmitted light techniques, and the use of optically pumped semiconductor lasers and laser diodes for fluorescent lifetime imaging microscopy (FLIM).

We shift from the microscopic world to the vast expanse of the universe, where floated borosilicate glass is proving critical in the operation of the Hobby-Eberly Telescope. Schott North America's Tina Gallo hints at things to come in "Specialized Optical Mirrors Set to Unlock the Universe's Darkest Mysteries," on page 41.

We round out the issue with a closer look at how the development of better sensors, more powerful processors and sophisticated algorithms, along with LEDs, are benefiting machine vision applications, in Hank Hogan's "For Vision Systems, Lighting and Other Advances Up Capabilities and Cut Costs" on page 36.

Finally, the presence of increasingly fast and powerful ultrashort pulse laser systems on the market presents a new challenge: avoiding the accumulation of too many pulses in one spot. Florian Harth, Thomas Herrmann, Bernhard Henrich and Johannes A. L'huillier of the Photonik-Zentrum Kaiserslautern eV and Research Center Optimas reveal how users of these systems can achieve a dynamically and synchronously adaptable pulse repetition rate in the MHz range — critical to achieving higher output. Be sure to read, "Ultrashort Pulse Laser Micromachining Surpasses Previous Limitations" on page 46.

Enjoy the issue!

michael.wheeler@photonics.com


Delivering light has been the cornerstone of our inspiration
From providing historical silicone nylon to modern fluoropolymers comes the innovation of our patent pending smart flat-top beam delivery technology.
Nufern beam delivery fibers offer:
• Consistent Quality
• Proven Reliability
• Maintenance and Adjustment Free
Opportunities yet to be discovered
Contact us at inspire@nufern.com or visit us at www.nufern.com
NUFERN®
866.466.0214 / www.nufern.com
OPTICAL FIBERS | FIBER LASERS & AMPLIFIERS | FIBER GYRO COILS | DEFENSE TECHNOLOGY

PHOTONICS spectra

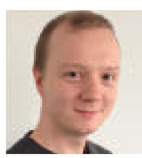
CONTRIBUTORS

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, England. Page 30.

Thomas Herrmann
Thomas Herrmann studied physics at the University of Kaiserslautern and received his Ph.D. degree in 1999. He was co-founder of Lumera Laser GmbH (now Coherent Kaiserslautern). In 2009, he joined the Photonik-Zentrum Kaiserslautern eV and is responsible for the micromachining application center. Page 46.

Tina Gallo
Tina Gallo is applications manager for Schott North America Inc. in Louisville, Ky. She earned her master's degree in materials science from RWTH Aachen University, Germany. Page 41.

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 36.



Florian Harth
Florian Harth received his degree in experimental physics at the Technical University of Kaiserslautern in Germany. Since 2009, he has worked the in the field of ultrafast laser source development and micromachining at the Photonik-Zentrum Kaiserslautern eV. Page 46.

Johannes L'huillier
Johannes L'huillier studied physics at the University of Kaiserslautern, Germany, where he received his Ph.D. in 2003. Since 2009 he has served as the CEO of the Photonik-Zentrum Kaiserslautern eV. Page 46.

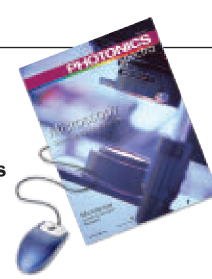
Bernhard Henrich
Bernhard Henrich studied physics and received his Ph.D. at the University of Kaiserslautern in 2000. He is co-founder of Lumera Laser GmbH (now Coherent Kaiserslautern). In 2013, he joined the Photonik-Zentrum Kaiserslautern eV as technology manager. Page 46.

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 52.

In the July issue of
Photonics Spectra...

- **UVC LEDs**
- **Terahertz Quantum Cascade Lasers**
- **Airy Light Sheet Microscopy**
- **Imaging Advances**
- **Line Scan Polarization Imaging**

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.

OSA
The Optical Society
100
Since 1916

WRITE THE FUTURE

Join the "Write the Future" story contest and share your vision of optics and photonics

To enter, write a short fiction story in 300–500 words on the future of our field. The winner's story will be published in *OPN* and will be recognized at OSA's 100th annual meeting, Frontiers in Optics, 17–21 October, in Rochester, New York, USA.

Submission deadline: **30 June 2016**

Send entry with your name, affiliation, email and story title to writethefuture@osa.org

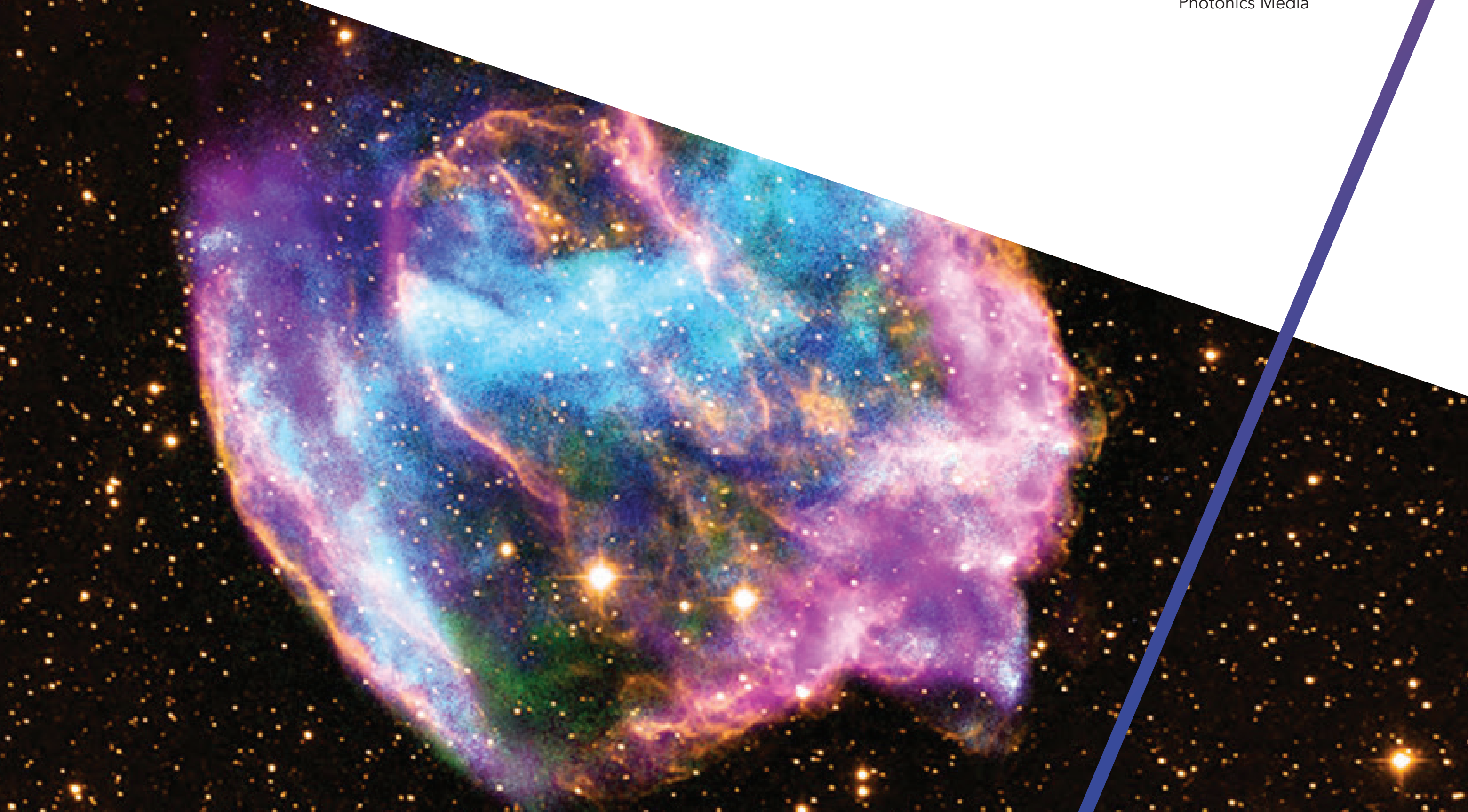
For detailed contest guidelines go to osa.org/storycontest

Diamond Sponsor
Thorlabs, Inc.

Gold Sponsor
Corning, Inc.

Silver Sponsors
Edmund Optics
Go!Foton Corporation
Hamamatsu Corporation
IDEX Corporation
Navitar, Inc.
OFS
Optimax Systems
RPC Photonics, Inc.
Synopsys, Inc.
TOPTICA Photonics, Inc.
TRUMPF, Inc.
Zygo Corporation

Media Partners
Business Wire
Laser Focus World
Photonics Media



Welcome to photonics.com

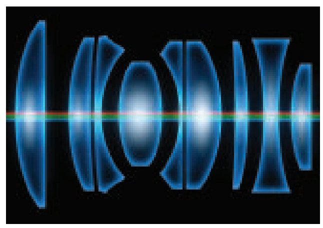
The online companion to *Photonics Spectra*

REGISTER NOW

What's Online:

Join us for a FREE webinar: Thursday, June 30, 1 p.m. EDT

New Optics Drawing Standards



Dave Aikens, the leader of the project to adopt ISO 10110 as an American National Standard, will provide an introduction of OP1.0110, the American National Standard for optics drawings. In 2015, the United States joined the international community by adopting a version of ISO 10110 as the American National Standard for optics drawings. This new method is a great boon for an industry in need of standardization, but can be confusing to the uninitiated. Mr. Aikens, the president and founder of Savvy Optics Corp., has been involved in optics drawings and specifications for over 30 years. He is the head of the American delegation to ISO TC 172 SC1, which published ISO 10110, and is the secretary of the American Standards Council for Optics.

BioPhotonics Digital Conference

Thursday, June 9, noon to 3:15 pm EDT

Photonics for Ophthalmology

This event will feature several 15-minute online presentations on the use of light-based imaging and surgical techniques for diagnosing and treating eye conditions. Brief question-and-answer sessions will follow each presentation. Presentation topics will include photo-mediated ultrasound therapy, ophthalmologic lasers, intraocular lenses, photobiomodulation and various aspects of optical coherence tomography.

Available on Demand

To register or for more information, and to watch past presentations, visit **photonics.com/webinars**.

FINALIST
JESSE H. NEAL AWARDS
Est. 1955

Best Range of Work by a Single Author, James F. Lowe, on Photonics.com


PHOTONICS MEDIA
photonics.com
LATEST HEADLINES
EDITORS' PICKS
pco.
Optogenetics Explored for Chronic Pain Treatment
PWR/MUTE
MODE
DIM
PIP
NAVI
EJECT

Ford autonomous vehicle forgoes headlights for lidar

A recent test at the Ford Motor Co.'s Wittmann, Ariz., Proving Ground demonstrated the Ford Focus' ability to use lidar sensor technology and 3D maps to drive in the dark without headlights.

Ford said the development shows that even without light-dependent cameras, the lidar system and virtual driver software can successfully steer around winding roads. While it's ideal to have all three available modes of sensors — radar, cameras and lidar — the latter can function independently on roads without stoplights.

To navigate in the dark, self-driving cars use high-resolution 3D maps with information about the road, road markings, geography, topography and landmarks like signs, buildings and trees. The vehicle uses lidar pulses to pinpoint itself on the map in real time, and additional data from radar gets fused with that of lidar to complete the full sensing capability of the autonomous vehicle.

For the desert test, Ford engineers sporting night-vision goggles monitored the Fusion from inside and outside the vehicle. Night vision allowed them to see the lidar performing in the form of a grid of IR laser beams projected around the vehicle as it drove past. Lidar sensors shoot out 2.8 million laser pulses a second to precisely scan the surrounding environment, Ford said.

Business Wire

Under the cover of night, a Ford Fusion Hybrid autonomous research vehicle — with no headlights on — navigated along lonely desert roads, performing a task that would be perilous for a human driver.

"Inside the car, I could feel it moving, but when I looked out the window, I only saw darkness," said Wayne Williams, a Ford research scientist and engineer. "As I rode in the back seat, I was following the car's progression in real time using computer monitoring. Sure enough, it stayed precisely on track along those winding roads."

The automaker's research in autonomous vehicles has been ongoing for about a decade, and the company said it's working toward fully autonomous driving capability, which, as defined by SAE International Level 4, does not require the driver to intervene and take control of the vehicle.

Ford said it will triple its autonomous vehicle test fleet in 2016, bringing the number to about 30 self-driving Fusion Hybrid sedans for testing on roads in California, Arizona and Michigan.

NREL raises rooftop PV potential estimate

The U.S. Department of Energy's National Renewable Energy Laboratory (NREL) has used detailed lidar data for 128 cities nationwide, along with improved data analysis methods and simulation tools, to update its estimate of total U.S. technical potential for rooftop photovoltaic (PV) systems.

The analysis reveals a technical potential of 1,118 GW of capacity and 1432 TWh of annual energy generation, equivalent to 39 percent of the nation's electricity sales. This estimate is significantly greater than that of a previous NREL analysis, which estimated 664 GW of installed capacity and 800 TWh of annual energy generation.

Analysts attribute the new findings to increases in module power density, improved estimation of building suitability, higher estimates of the total number of buildings, and improvements in PV performance simulation tools.

Within the 128 cities studied, the researchers found that 83 percent of small buildings have a suitable location for PV installation, but only 26 percent of those buildings' total rooftop area is suitable for development. Because of the sheer number of this class of building across the country, however, small buildings actually provide the greatest combined technical potential. Altogether small building rooftops could accommodate up to 731 GW of PV capacity and generate 926 TWh per year of PV energy — approximately 65 percent of the country's total rooftop technical potential.

• Rochester Lab for Laser Energetics appoints Stavros Demos senior scientist •

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

Heliospectra's water-cooled LED grow lights head into space

Intelligent horticultural lighting firm Heliospectra AB of Gothenburg, Sweden, has developed a water-cooled, high-intensity version of the popular LX60 LED grow light, for use in future space exploration and commercial applications.

The system was developed as part of an EDEN Institute of Space Systems (ISS) project to develop a controlled environment agriculture (CEA) system for safe food production on board the International Space Station and for future human space exploration missions.

The LED will reflect many of the benefits of the standard LX60 Series, including wireless monitoring and remote spectral tuning control, and a wide, uniform light distribution pattern as well as low heat emissions. It comes in a more compact form factor as a result of the water-cooled heat dissipation solution. The first production deliveries of the new light for the EDEN ISS project are scheduled for August/September.

Heliospectra said the collaboration will provide a creative work environment, and should yield valuable information on aspects of a controlled environment agriculture, enabling the company to develop technologies applicable to larger commercial markets.

"The market shows an increased demand for improved environmental control and optimized use of resources," said CEO Staffan Hillberg. "For areas lacking a proper water supply, like the Middle East, or areas with contaminated soil and water like in China, CEA could make a huge difference in utilizing resources. Water-cooled LED lights enable growers to grow crops in a more environmentally friendly way by reusing the heat from the light and reducing the HVAC demand on the system."

RPMC signs distribution agreement with Laser Point

Laser distributor RPMC Lasers Inc. of O'Fallon, Mo., has announced an exclusive distribution agreement with Laser Point srl, a Milan-based laser R&D and manufacturing company.

The agreement includes the North American distribution of Laser Point's power and energy sensors, meters, and its fiber-coupled laser diode modules and accessories. Laser Point has introduced new absorbers to resist the disruptive power densities of multi-kW, high-brightness lasers, focusing on materials science technologies and thermal modeling.

Laser Point supplies OEM solutions for industrial and medical applications. RPMC Lasers supplies millisecond, microsecond, nanosecond, picosecond, femtosecond, continuous wave solid state and fiber lasers.

Tempus wins NASA/JPL spectrometer contract

Tempus Applied Solutions Holdings Inc. of Williamsburg, Va., said it has been awarded an aircraft modification contract with NASA's Jet Propulsion Laboratory (JPL) in Pasadena, Calif. Financial terms of the contract were not provided.

Under the contract, Tempus will design, engineer, modify and seek Federal Aviation Administration certification of a Gulfstream IV aircraft integrated with a portable remote imaging spectrometer (PRISM), a specialized hyperspectral sensor developed by NASA and JPL, to survey the condition of the coral reef systems around the world as part of a NASA field expedition.

Modifications are taking place at Tempus' Brunswick, Maine, facility. The 84,000-sq-ft facility enables execution of the required modifications, including airframe structure, interior design, electrical changes, primary and secondary controls, and avionics.

Tempus will fly the aircraft several hundred hours annually in a variety of locations around the world in support of the sensor operations and data collection efforts of NASA and JPL.

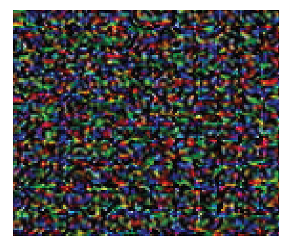
This month in history

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

2011

A "sighted" wheelchair developed at Lulea University of Technology used a laser scanner to 3D-map surroundings, enabling a visually impaired driver to navigate around obstacles.

2006



Researchers from SUNY Binghamton applied to patent a method that linked an individual digital camera to the images it produced by examining noise patterns resulting from inhomogeneities in the image sensor's silicon wafer.

1996

LightSeam Technologies' laser-enhanced bonding technique was used to create watertight, breathable, stretchable seams in materials. Red Ball Inc. was an early adopter, applying the technique to manufacture fishing waders and wetsuits.

1986

In a technique commonly used to measure the craniofacial bones of orthodontic patients, lasers and x-rays combined forces to identify a poorly preserved Egyptian mummy as King Tutankhamen's half-brother Smenkhare.

AIM Photonics' call for integrated photonics proposals, deadline July 15

The American Institute for Manufacturing Integrated Photonics' (AIM Photonics) 2016 call for proposals is open, with a July 15th deadline for submissions.

The call for proposals is extended to AIM Photonics' members seeking federal funding in 2017 on a matched basis to implement tactical projects targeting AIM Photonics' technology goals.

These high-level goals include the provision of a venue for U.S. cooperative development of advanced integrated photonics manufacturing solutions; catalyzing the maturation and stratification of the integrated photonics ecosystem; and the provision of world-leading photonic integration technology access/on-ramps to U.S. industry, including the subject matter expertise and entrepreneurial sectors, as well as government and academic communities.

AIM Photonics is an industry-driven public-private partnership headquartered in Rochester, N.Y. For more information, visit www.aimphotonics.com/2016-call-for-proposals.

20%

— projected compound annual growth rate of the global VCSELs market for the period 2015-2020, according to BCC Research

PEOPLE IN THE NEWS

Light manufacturer Osram Licht AG has appointed **Stefan Kampmann** as its chief technology officer and has announced the departure of Klaus Patzak as chief financial officer, with a replacement search underway. Kampmann holds a doctorate degree in engineering and brings experience in the management of large-scale R&D units' innovation processes. At Osram, he will be in charge of R&D, technology and cross-divisional functions such as quality management. Kampmann held positions at Bosch for more than 20 years, where he engaged in automotive business research before assuming segment responsibility for power electronics, sensor technology and semiconductor devices.

Purdue University/ Rebecca Wilcox

Professor **Michael Manfra** of Purdue University has been selected to lead Station Q Purdue, an elite team assembled by Microsoft's Station Q to pursue quantum computing. Mathematician and Fields Medal winner Michael Freedman leads Microsoft Station Q, which includes an internal team of theorists coupled to four satellite Station Q experimental groups and two satellite Station Q theory teams working in close collaboration. Manfra is a professor of physics and astronomy, as well as materials engineering, and electrical and computer engineering. His research focus is on the creation and study of new materials to be used in quantum computers. With Microsoft's support, Manfra and his team will use molecular beam epitaxy to create new platforms for topological qubits.

Mi-Light, the Michigan Photonics Cluster, a nonprofit organization serving Michigan's photonics industry, has hired **Diane Durance** as executive director. Durance has more than 10 years of experience with nonprofit business development organizations. In addition to having been the president of the Ann Arbor IT Zone and executive director of Great Lakes Entrepreneur's Quest, Durance has been a successful entrepreneur with businesses in several industries. She assumed the position in February, and her main duties include marketing communications, managing membership and meetings of the board of directors, recruiting new members and sponsors, and co-chairing multiple working groups. For more information, visit www.mi-light.org.

Color-shift OTF thread bolsters banknote security

The National Bank of Kazakhstan has received Reconnaissance International's Regional Banknote of the Year Award, which recognizes outstanding achievement in the design, technical sophistication, and security of a banknote for its 20,000 Tenge note. The banknote features Vancouver, B.C.-based Nanotech Security Corp.'s secure color shift optical thin-film (OTF) technology.

Nanotech's magenta-to-green color shift OTF thread was incorporated into the composite substrate of the banknote. The company said it is one of the most durable overt security features, with little to no loss in its characteristics when crumpled or printed on.

Nanotech offers six standard color shifts, and over 200 shades of these colors can be tuned to customers' specific requirements. The threads can be used in both composite paper-polymer-paper and cotton banknote paper. The company said its color-shift threads and patches have been designed into more than 10 banknotes around the world.

Nanotech

Nanotech Security Corp.'s magenta-to-green color-shift optical thin-film thread shown in unprinted composite banknote material.

• Organic solar cell pioneer Thuc-Quyen Nguyen receives Humboldt Research Award •

Imec, Crystal Solar report 22.5% solar cell efficiency

Nanoelectronics research center Imec of Leuven, Belgium, and direct wafer developer Crystal Solar of Santa Clara, Calif., have reported 22.5 percent cell efficiency with nPERT silicon solar cells manufactured on 6-in. mono-crystalline epitaxially grown kerfless wafers.

The companies cite the demonstration as the highest efficiency to date for homo-junction solar cells on epitaxially grown silicon wafers. Crystal Solar's Direct Gas manufacturing technology enables direct conversion of feedstock gas to mono-crystalline silicon wafers by high throughput epitaxial growth. By skipping the polysilicon, ingoting and wire-sawing steps, the approach results in lower costs and enables the growth of high-quality p-n junctions in situ.

Imec adapted its nPERT silicon solar cell process to align with the properties of Crystal Solar's kerfless wafers. The cells were fabricated on 160- to 180-µm thick grown n-type wafers with built-in rear p+ emitter. Imec's n-PERT process included a selective front surface field realized by laser doping, advanced emitter surface passivation by Al2O3, and Ni/Cu plated contacts. Imec and Crystal Solar said the novel process also enabled a record open-circuit voltage of 700 mV.

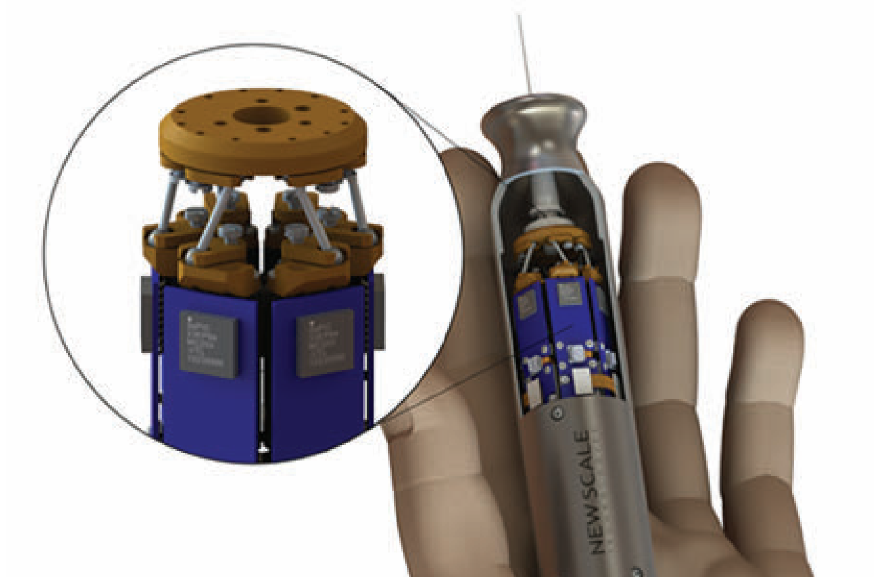
Crystal Solar

Crystal Solar's epitaxial system.

Imec

Imec's solar cell.

New Scale to develop hexapod under SBIR grant



New Scale Technologies

New Scale Technologies Inc. has been awarded a Small Business Innovative Research grant from the National Eye Institute of the National Institutes of Health to develop a miniature commercial hexapod, a tiny six-degree-of-freedom micromanipulator.

New Scale Technologies Inc. of Victor, N.Y., is developing what it said will be the world's smallest commercial hexapod under a Small Business Innovative Research (SBIR) grant.

Awarded by the National Eye Institute of the National Institutes of Health (NIH), the grant funds development of a clinically compatible, six-degree-of-freedom, handheld micromanipulator for hand tremor cancellation in microsurgical systems.

A prototype micromanipulator was developed at the Robotics Institute at Carnegie Mellon University with New Scale contributions. At less than 25 mm in diameter, it was the first hexapod or Gough-Stewart platform small enough for use in a hand-held instrument. New Scale is using the grant to develop an improved system with the same small size of the prototype, but preparing for a clinically compatible product ready for commercialization.

The hexapod system includes miniature bearing assemblies, motor mounts, flexures, spring preloads, miniature drive electronics and six piezoelectric SQUIGGLE micromotors. Specific aims include improved dynamic performance, higher precision and integration of a microcontroller with local feedback and motion control. Applications include microsurgery, use as a robotic end-effector for testing and manufacture of MEMS and photonics accessories, and positioning and alignment of collimated fibers or assemblies.

New Scale Technologies develops and manufactures small, precise, closed-loop positioning solutions.

> The web version of this story features a video animation of the hexapod's motion: **www.photonics.com/a60593**.

$18B

— value of the global photonics sensor market by 2021, representing a compound annual growth rate of 17% for the 2016-2021 period, as predicted by Allied Market Research

Denso invests in Trilumina's automotive tech

Looking to speed up the adoption of lidar and driver monitoring technologies in advanced driver assistance systems, Denso International America Inc. of Southfield, Mich., said it has invested in Trilumina Corp. of Albuquerque, N.M., a semiconductor laser technology company that provides light sources for lidar and interior illumination products. Terms of the investment were not disclosed.

Trilumina has developed eye-safe semiconductor lasers, helping to accelerate the automotive industry's adoption of semiautonomous and autonomous vehicles by providing lasers for 100 percent solid-state lidar products and advanced driver monitoring systems. The company is also targeting depth sensing and gesture control for the industrial robotics, commercial and consumer electronics markets.

Denso provides automotive advanced technology, systems and components in the thermal, powertrain control, electronic and information fields.

$137B

— value of the global optoelectronic components industry by 2023, as projected by Transparency Market Research

MOVES AND EXPANSIONS

Teledyne Technologies Inc. of Thousand Oaks, Calif., said it has entered into an agreement to acquire the assets of **Quantum Data Inc.**, headquartered in Elgin, Ill. Quantum Data provides electronic test and measurement instruments, as well as video protocol analysis test tools used to troubleshoot data communication systems and test device interoperability, compliance and interference.

Teledyne concurrently announced plans to acquire **Caris** of Fredericton, New Brunswick, Canada, a developer of geospatial software designed for the hydrographic and marine community, as a wholly owned subsidiary. Caris will become part of Teledyne's Digital Imaging segment, and will maintain and expand its advanced software products and support for a range of sensor platforms, data formats and acquisition software.

Teledyne Technologies provides instrumentation, digital imaging products and software, aerospace and defense electronics, and engineered systems. Its operations are primarily located in the U.S., Canada, U.K., and Western and Northern Europe.

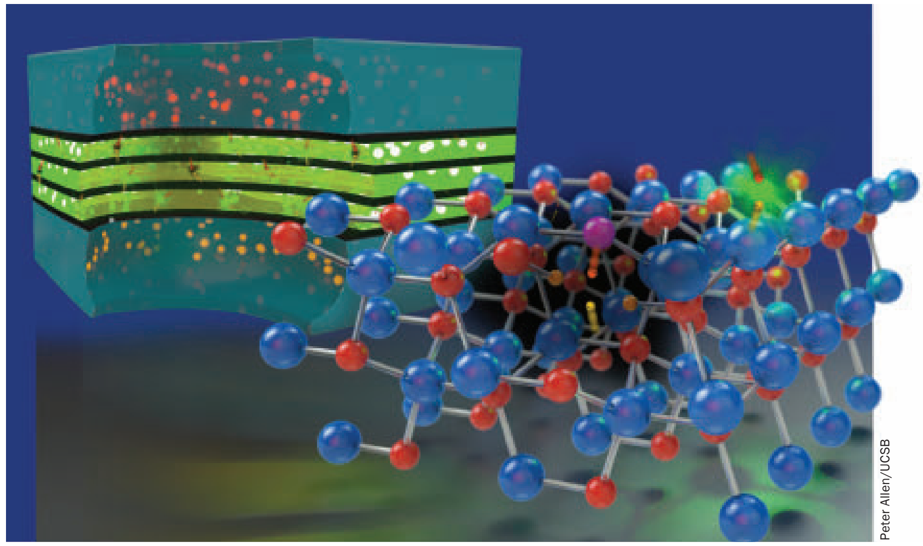
Photonics and optics technology firm **Newport Corp.** said it has completed a capacity expansion and upgrade of its Corion optical filter and replicated mirror manufacturing facility in Franklin, Mass. The renovation added new coating chambers and dedicated space for future technology upgrades, with the goal of providing rapid prototyping of new products for both end-user and OEM customers, and to provide space for manufacturing these critical components. The new coating chambers can provide fully dense thin-film coatings in prototype and production quantities.

Further improvements to the facility are planned in 2016 and will focus on the upgrade of its optical assembly lab and product test areas, Newport said.

Mobility, transport and processing technology firm **Continental AG** of Santa Barbara, Calif., has acquired the ASCar division — which develops lidar systems for the automotive industry — of **Advanced Scientific Concepts LLC** (ASC), also of Santa Barbara.

With the acquisition, Continental plans to mass-produce flash lidars at an affordable price to support the commercial automotive industry. ASC will continue to focus on providing 3D flash lidar custom and standard product solutions for space, manned airborne and underwater applications, including providing unmanned aerial systems, autonomous vehicle and 3D-mapping technology for domestic and international military markets.

Theoretical technique identifies LED material defects



A conceptual illustration of how defects in a crystal lattice might contribute to nonradiative recombination of electrons and holes in LEDs.

SANTA BARBARA, Calif. — The discovery and characterization of a specific type of defect in the atomic structure of an LED that results in less efficient performance could enable fabrication of even more efficient, longer-lasting light sources. Improving the internal quantum efficiency of such LEDs is a vital step for developing and proliferating optoelectronic devices.

"In an LED, electrons are injected from one side, holes from the other," said professor and research group leader Chris Van de Walle of the University of California Santa Barbara.

As the two elements travel across the crystal lattice of the semiconductor — in this case GaN-based material — the meeting of electrons and holes (the absence of electrons) is what is responsible for the light that is emitted by the diode: As electron meets hole, it transitions to a lower state of energy, releasing a photon along the way.

Occasionally, the researchers said, the charge carriers meet and do not emit light, resulting in the so-called Shockley-Read-Hall (SRH) recombination. The charge carriers are captured at defects in the lattice where they combine, but without emitting light.

The UCSB team identified defects involving complexes of gallium vacancies with oxygen and hydrogen. These defects had been previously observed in nitride semiconductors, but until now, their detrimental effects were not understood, the researchers said.

"It was the combination of the intuition that we have developed over many years of studying point defects with these new theoretical capabilities that enabled this breakthrough," said Van de Walle, who credited co-author Audrius Alkauskas with the development of a theoretical formalism necessary to calculate the rate at which defects capture electrons and holes.

The method lends itself to future work identifying other defects and mechanisms by which SRH recombination occurs, said Van de Walle. The researchers do not believe the gallium vacancy complexes to be the only detriment defects, and will apply their methodology to investigating other potential defects to assess their impact on nonradiative recombination.

The research was published in *Applied Physics Letters* (doi: 10.1063/1.4942674).

Thermal capacity of photon condensate measured, aligns with theory

BONN, Germany — Better understanding the thermal capacity of Bose-Einstein photon condensates could enable the development of ultraprecise thermometers.

The drop in the heat-storage capacity of liquid water as it changes phase to gas or solid is well-understood, but now physicists at the University of Bonn have observed similar behavior in a trapped 2D photon gas.

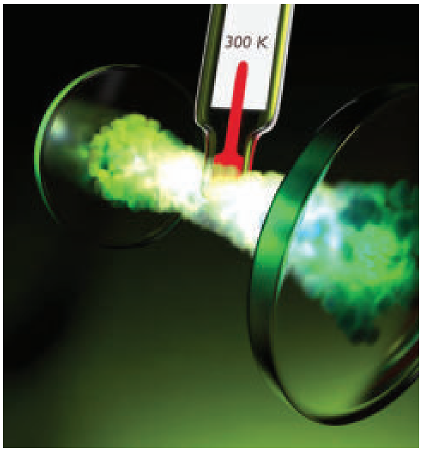
If they are cooled sufficiently, photons can also condense, and many thousands of these light packets then fuse into a Bose-Einstein condensate — a kind of super-photon with unusual characteristics. The Bonn researchers reported that photon gas at this phase transition behaves according to the theoretical predictions of Bose and Einstein: Similar to water, it abruptly changes its heat storage capacity.

Atoms can also form a Bose-Einstein condensate, at which point they become indistinguishable from each other, behaving like a single giant atom. The change in heat capacity of atoms during the phase transition can be measured, but only imprecisely. Jan Klärs, formerly at Bonn and now at ETZH Zurich, said the thermal capacity measurements of the photon condensate are substantially better.

The heat capacity of a material is calculated from the energy needed to heat it by one degree and is generally determined by measuring the temperature of the substance before and after adding a defined amount of energy. However, the temperature of a gas of light cannot be measured with a thermometer; but that is also not necessary.

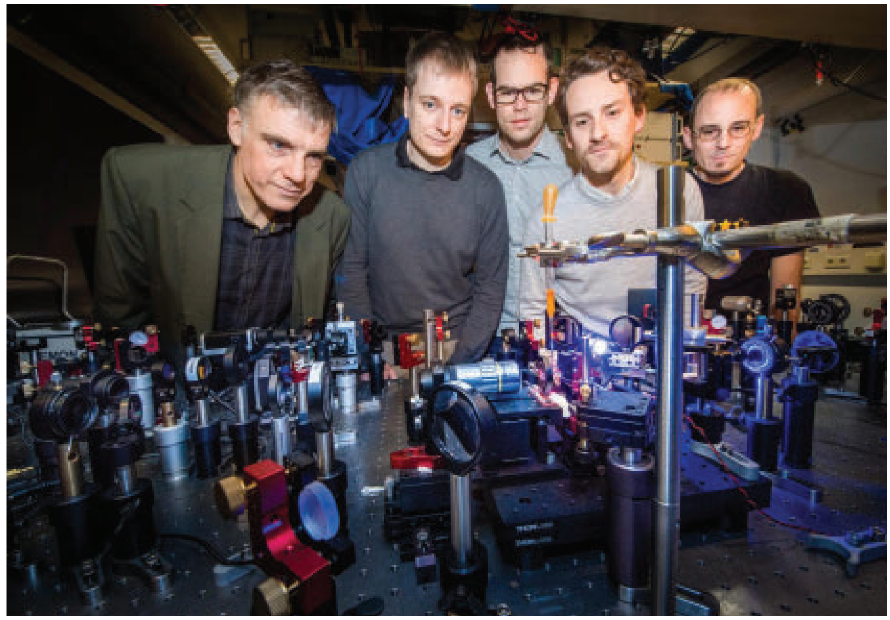
"In order to determine the temperature of the gas, it is only necessary to know the different wavelengths of the light particles — the distribution of its colors," said Klärs.

In the experiment, photons were captured inside a microcavity consisting of two spherically curved mirrors while repeatedly being absorbed and re-emitted by an embedded dye medium. The cavity length was of the same order as the wavelength itself, which caused a large frequency gap between the longitudinal resonator modes (free spectral range),



Tobias Damm

Researchers at the Institute of Applied Physics of the University of Bonn have measured the temperature of a gas of light, when it condenses. The thermometer is figurative; the temperature was determined by recording the wavelengths of the light.



Volker Lannert/Uni Bonn

At the measurement apparatus are Martin Weitz, Tobias Damm, David Dung, Julian Schmitt and Frank Vewinger of the Institute of Applied Physics of the University of Bonn.

comparable to the emission bandwidth of the dye molecules.

Thermal equilibrium of the photon gas with the cavity environment at room temperature was achieved via repeated absorption and emission processes by the dye molecules, which established a thermal contact between photon gas and the optical medium. Bose-Einstein condensation was triggered by increasing the photon number above the saturation level at a given temperature.

The team reported that their experimental heat-capacity measurements at the transition from photon gas to Bose-Einstein condensate matched the theoretical predictions exactly. The heat content of the photon gas changed not only upon condensation to a super-photon but also continuously with the ambient temperature.

The research was published in *Nature Communications* (doi: 10.1038/ncomms11340).

Optogenetic technique prevents, treats tumors in animal model

MEDFORD, Mass. — By using light to control electrical signaling among cells on a frog model, researchers have demonstrated that it is possible to use optogenetics to prevent tumors from forming and to normalize tumors after they have formed. The work is the first reported use of optogenetics to specifically manipulate bioelectrical signals to both prevent and cause regression of tumors induced by oncogenes.

Working on embryos of the frog species *Xenopus laevis*, researchers from Tufts University first injected cells with RNA that encoded a mutant RAS oncogene known to cause cancer-like growths.

They then used blue light to activate positively charged ion channels, which induced an electric current that caused the cells to go from a cancer-like depolarized state to a normal, more negative polarized state. They repeated this process using a green light-activated proton pump, Archaerhodopsin. Activation of both agents significantly lowered the incidence of tumor formation and also increased the frequency with which tumors regressed into normal tissue.

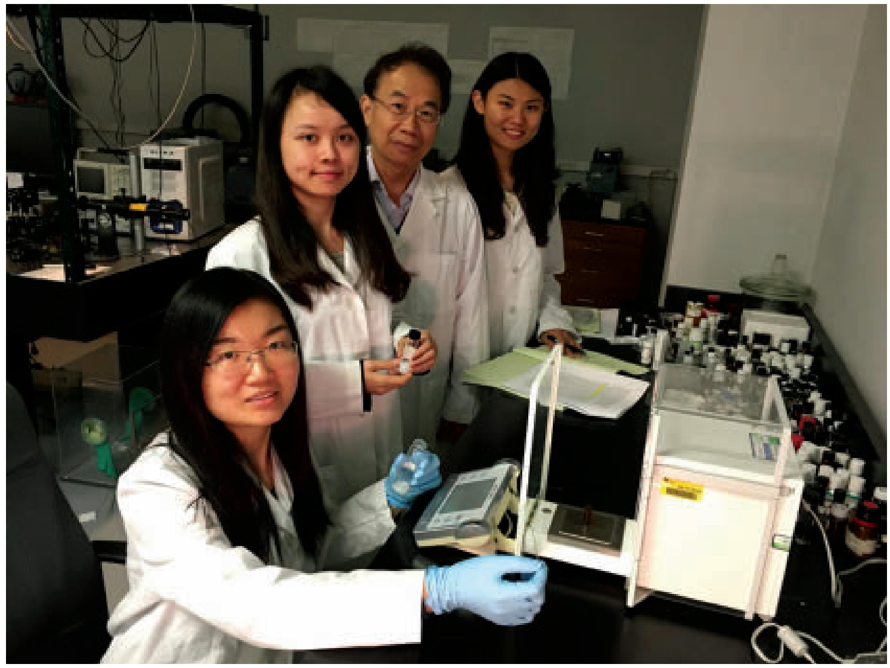
Virtually all healthy cells maintain a more negative voltage in the cell interior compared with the cell exterior. However, the opening and closing of ion channels in the cell membrane can cause the voltage to become more positive (depolarizing the cell) or more negative (polarizing the cell). This allows tumors to be detected by their abnormal bioelectrical signature before they are otherwise apparent.

"These electrical properties are not merely byproducts of oncogenic processes. They actively regulate the deviations of cells from their normal anatomical roles towards tumor growth and metastatic spread," said professor Michael Levin. "Discovering new ways to specifically control this bioelectrical signaling could be an important path towards new biomedical approaches to cancer."

"This provides proof of principle for a novel class of therapies which use light to override the action of oncogenic mutations," Levin added. "Using light to specifically target tumors would avoid subjecting the whole body to toxic chemotherapy or similar reagents."

The research was published in *Oncotarget* (doi: 10.18632/oncotarget.8036).

Novel liquid crystal mix expands LCD operating temperature range


University of Central Florida

Professor Shin-Tson Wu and doctoral students work on liquid crystal mixtures in his lab at the University of Central Florida's College of Optics & Photonics. From left, Fenglin Peng, Yuge 'Esther' Huang, Wu and Fangwang 'Grace' Gou.

ORLANDO, Fla. — An experimental liquid crystal (LC) mixture has been shown to function properly in the temperature range of −40 to about 100 °C, an improvement over current technologies used in automobile displays, smartphones and televisions, for example, which grow blurry and sluggish in extreme temperatures.

A team of researchers led by professor Shin-Tson Wu at the University of Central Florida formulated three new LC mixtures with a wide nematic range, small visco-elastic coefficient and low activation energy.

In addition, the LC pixels are able to change their brightness level about 20 times faster than required by European automotive standards, the researchers said.

The LC mixes used four major compounds; homologues of compound 1 showed high birefringence and large dielectric anisotropy; however, their viscoelastic coefficient and activation energy were relatively large.

To reduce viscosity, the researchers doped about 50 percent nonpolar diluters (compound 2). Compounds 3 and 4 (about 30 percent) were added to obtain high clearing point and wide nematic range. Phase transition temperatures were measured by differential scanning calorimetry.

The team said these LCs could greatly improve the performance of different display devices in a car, such as a head-up projection using liquid-crystal-on-silicon with an average gray-to-gray (GTG) response time less than 1 millisecond (ms) at an elevated temperature. The average GTG response time was maintained at about 10 ms for fringing field switching LCD at 0 °C, and also about 10 ms for twisted nematic LCD at −20 °C.

Wu previously contributed to the development of LCDs that are readable in sunlight for smartphones and other devices, and is currently working on a smart brightness-control film that has applications for automobiles, planes, eyewear, windows and more.

The study was published in *Optical Materials Express* (doi: 10.1364/ome.6.000717).

Optoelectronics could benefit from monolayer semiconductors

OAK RIDGE, Tenn. — Optoelectronics applications may soon be built using monolayered 2D heterostructures made from materials using mismatched lattices.

In a study led by the U.S. Department of Energy's Oak Ridge National Laboratory (ORNL), scientists synthesized a stack of atomically thin monolayers of two lattice-mismatched semiconductors. Where the two layers met, they formed an atomically sharp heterostructure, which generated a photovoltaic response by separating electron-hole pairs that were generated by light.

"Because the two layers had such a large lattice mismatch between them, we did not expect them to grow on each other in an orderly way — but they did," said researcher Xufan Li. "It's a new, potential building block for energy-efficient optoelectronics."

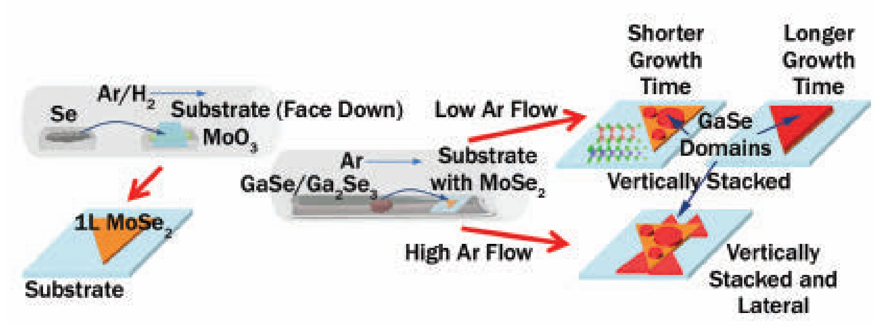
The creation of an atomically thin solar cell may facilitate synthesis of mismatched layers to enable new families of functional 2D materials. The research broadens the number of materials that can be combined, thus creating potential for a wider range of atomically thin electronic devices.

"These new 2D mismatched layered heterostructures open the door to novel building blocks for optoelectronic applications," said researcher Kai Xiao. "They will allow us to study new physics properties which cannot be discovered with other 2D heterostructures with matched lattices."

For the study, Li first grew a monolayer of molybdenum diselenide, and then grew a layer of gallium selenide on top. This technique, called van der Waals epitaxy, is named for the weak attractive forces that hold dissimilar layers together. "With van der Waals epitaxy, despite big lattice mismatches, you can still grow another layer on the first," Li said. Using scanning transmission electron microscopy, the team characterized the atomic structure of the materials and revealed the formation of Moiré patterns.

Researchers in ORNL's Functional Hybrid Nanomaterials group conducted the study with partners at Vanderbilt University, the University of Utah and Beijing Computational Science Research Center. The scientists plan to conduct future studies to explore how material composition influences properties beyond the photovoltaic response, in order to incorporate 2D materials into devices.

The research was published in *Science Advances* (doi: 10.1126/sciadv.1501882).



Xufan Li et al./*Science Advances*

Schematic illustrating the growth of monolayer $MoSe_2$ and $GaSe/MoSe_2$ heterostructures.

Twisted light explored for quantum communications

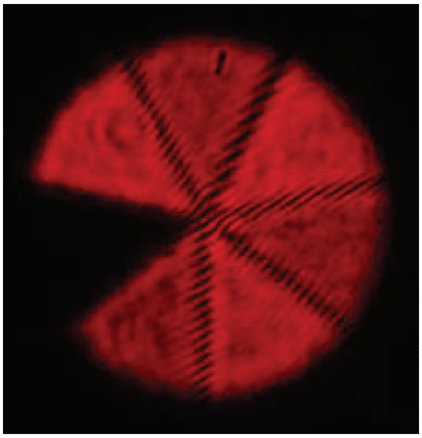
ROCHESTER, N.Y. — "Twisted" light holds promise as an enabler of quantum communication, and an exprimental technique has yielded the first characterization of the azimuthal Wigner distribution of a photon.

The discrete nature of orbital angular momentum, or OAM, a defining parameter of twisted light, makes it attractive for encoding quantum information. There is no known fundamental limit to the maximum OAM value that can be coded into a photon, which could allow for quicker communication than with other systems.

Researchers at the University of Rochester have reported a protocol to fully characterize the transverse structure of a photon in conjugate bases of OAM and azimuthal angle. The team tested the protocol by characterizing pure superpositions and incoherent mixtures of OAM modes in a 7D space.

The Wigner distribution is a mathematical construct that completely describes a system in terms of two conjugate variables, that is, two variables linked by Heisenberg's Uncertainty Principle. Postdoctoral associate Mohammad Mirhosseini and collaborators at Rochester's Institute of Optics have now shown how the Wigner distribution can be obtained for twisted light.

Other methods to obtain the wave func-



To characterize twisted light, the researchers looked at the images produced by the interference of a structured laser beam with a replica of that beam rotated by a given angle, including this 'Pac-Man.'

tion, a property that describes a quantum system in full — such as quantum tomography or direct measurements — have been demonstrated in the past. However, in their experiment, the Rochester team demonstrated that the time required for performing measurements scaled only linearly with the dimension size of the state under investigation, making the new technique suitable for quantum information applications involving a large number of OAM states.

"Apart from the potential uses in quantum communication, our work might offer a good way for describing atomic systems with quantized levels," said Mirhosseini. "The Wigner distribution of twisted light is a very complete way to understand the system. Not only does it tell us about the relation between these two linked variables, but it also tells us about the system's behavior. We showed that the Wigner distribution for twisted light superpositions contains negative values, which reveals wave-like behavior."

Mirhosseini thinks their work could also show a possible path forward for other experiments.

"Measuring time in quantum systems is not as simple as using a watch — it can prove challenging," said Mirhosseini. "The conjugate variable of OAM, angle, is in many ways similar to phase, which is itself similar to time. So perhaps the lessons learned here can be applied in other experiments to systems where we need to measure time."

The research was published in *Physical Review Letters* (doi: 10.1103/physrevlett.116.130402).

Single crystal growth method enables eye-safe laser

MOSCOW — A compact, eye-safe laser light source has been developed for practical applications in medicine, communications and ranging. The solid-state laser emits in the 1500- to 1600-nm range, and is based on a novel laboratory growth technology for single crystals.

Based on yttrium gadolinium borate crystals, the laser has a lifetime of up to 100,000 hours. The plug-and-play system doesn't require water cooling or generate vibration during operations, said researchers from Lomonosov Moscow State University and the Belarusian National Technical University.

By using a Co^{2+}:$MgAl_2O_4$ crystal as a saturable absorber, Q-switched laser pulses with a duration of 12 ns and a maximum energy of 18.7 µJ at a repetition rate of 32 kHz corresponding to an average output power of 0.6 W were obtained at 1550 nm under CW pumping. In the burst mode of operation, Q-switched laser pulses with the highest energy up to 44 µJ were realized with a pulse repetition rate of 6.5 kHz.

The light-refracting system of the eye (cornea and crystalline lens) has a sufficiently high absorption coefficient in the 1500- to 1600-nm range, so only a small fraction of the energy reaches the sensitive retina. Radiation in this range also suffers low losses passing through the atmosphere, which makes it advantageous for applications in telecommunications, the researchers said.

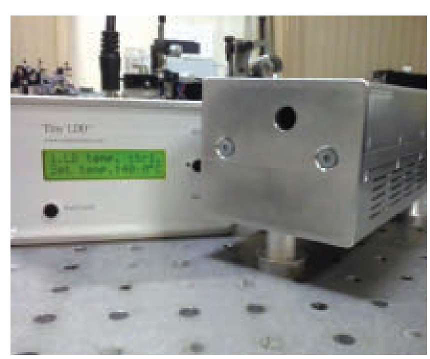
Among sources of radiation in this spectral range, the most widely used are solid-state lasers based on phosphate glasses co-doped with Er (erbium), and Yb (ytterbium) ions. Such lasers are also relatively simple, compact and capable of operating in adjusted Q-mode required for producing short impulses. The main disadvantage restricting the usage of erbium phosphate glasses in continuous diode systems is the low thermal conductivity of the matrix.

An (Er,Yb):$GdAl_3(BO_3)_4$ crystal created by using high-temperature solution growth on dipped seeds.

To overcome this limitation, the team used $GdAl_3(BO_3)_4$ single crystals co-doped with Er and Yb to improve the efficiency of generation pulse energy and repetition rate, and hence to increase the maximal measurement range, reducing errors and time spent.

The single crystals were characterized by a record value of thermal conductivity and high thermochemical stability (decomposition at temperatures of 1280 °C, resistance to corrosive environments), as well as mechanical strength.

The research was published in the *Journal of Crystal Growth* (doi: 10.1016/j.jcrysgro.2013.11.100) as well as *Optics Letters* (doi: 10.1364/ol.41.000918).



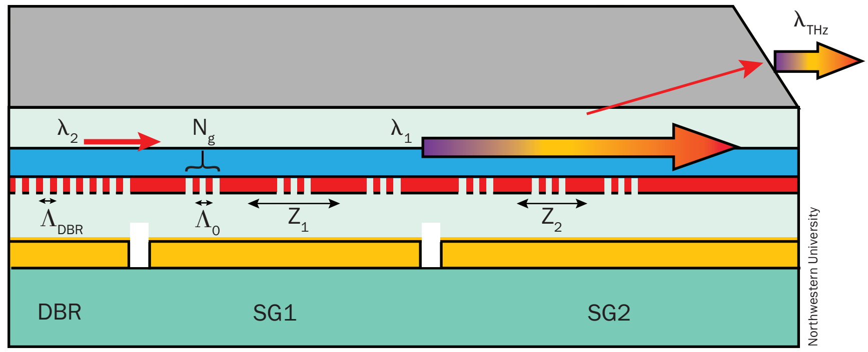
An experimental setup of the laser operating on a (Er,Yb): $GdAl_3(BO_3)_4$ crystal.

Security detection device features stable THz source

EVANSTON, Ill.— A security detection device based on a terahertz source has overcome the size, complexity and cost typical of terahertz systems. The instrument, which detects explosives, chemical agents and dangerous biological substances from safe distances, could make public spaces more secure.

"A single-component solution capable of room temperature continuous wave and widely frequency tunable operation is highly desirable to enable next generation terahertz systems," said Northwestern University professor Manijeh Razeghi.

Razeghi and her team based their system on nonlinear mixing in quantum cascade lasers. The system achieved room temperature CW emission at 3.41 THz with a side-mode suppression ratio of 30 dB and output power up to 14 μW, with a wall-plug efficiency about one order of magnitude higher than previous demonstrations.



Schematic design of professor Manijeh Razeghi's terahertz tuning source. DBR = distributed Bragg reflector. SG = sample grating.

With their design, they produced CW single-mode THz emissions with a wide frequency tuning range of 2.06 to 4.35 THz and an output power up to 4.2 μW from two monolithic 3-section sampled grating distributed feedback-distributed Bragg reflector lasers.

This research builds upon Razeghi and her group's many years of research with Northwestern's Center for Quantum Devices, including the development of the first single mode room temperature terahertz laser in 2011. The work was funded by the National Science Foundation, Department of Homeland Security, Naval Air Systems Command and NASA, and was published in *Nature Scientific Reports* (doi: 10.1038/srep23595).

Laser, modulator integrated directly on silicon

GRENOBLE, France — Information and communications R&D consortium Nanoelec Research Technological Institute (IRT), has reported co-integration of a III-V/silicon laser and silicon Mach Zehnder modulator demonstrating 25-Gbps transmission on a single channel, a transmission rate usually achieved using an external source over a 10-km single-mode fiber.

To achieve the results, silicon photonic circuits integrating the modulator were processed first on a 200-mm silicon-on-insulator wafer — although 300-mm wafers could be used in the near future, Nanoelec said. Then, a 2-in. wafer of III-V material was directly bonded on the wafer. In the third step, the hybrid wafer was processed using conventional semiconductor and/or microelectromechanical systems processing to produce an integrated modulator-and-laser transmitter.

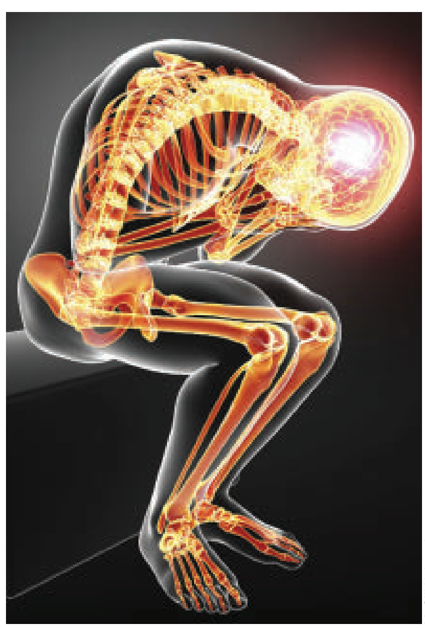
Integrating photonics capabilities on silicon chips enables increased bandwidth, density and reliability, while reducing energy consumption and managing increased data traffic. In the age of photonics-on-silicon, data transmission will be measured in terabits per second, Nanoelec said.

The capabilities of the device were jointly obtained by STMicroelectronics and Leti. Samtec and Mentor Graphics also partnered on the project.

The Nanoelec Research Technological Institute, headed by CEA-Leti, conducts research and development in the field of information and communication technologies and, specifically, micro- and nanoelectronics.

Pain relief may join growing list of optogenetics applications

MONTREAL — Optogenetics could someday provide doctors with a noninvasive, highly focused way to treat chronic pain. By making the cells responsible for pain transmission sensitive to light, the technique may be able to target, desensitize and reduce bioelectric activity in these cells.


McGill University

An optogenetic technique is being explored for noninvasive, nonpharmaceutical pain relief.

To demonstrate the potential role of optogenetics in pain management, researchers at McGill University bred a transgenic mouse model with a light-sensitive trait in the peripheral neurons that are known to transmit pain. The terminals of the peripheral nociceptors were silenced optogenetically with a high degree of spatiotemporal precision, leading to the alleviation of inflammatory and neuropathic pain.

The nociceptors of the genetically modified mouse expressed proteins called opsins, which react to light. When the nociceptors were exposed to yellow light, the opsins moved ions across the membrane, reducing the level of bioelectric activity of the cells. The yellow light stimulation reliably blocked electrically induced action potentials in dorsal root ganglion neurons in the mouse, effectively shutting off the nociceptors and decreasing the mouse's sensitivity to touch and heat in the hind paw. Basal mechanical sensitivity was not affected by the optical stimulation.

In this experiment, the activity of pain-signaling neurons was reduced in a localized part of the mouse's body, and the duration of the effect could easily be controlled by the amount of time the light was applied. An approach such as the one taken by the McGill team could be applied to functionally investigate other subsets of sensory neurons with high temporal precision.

"The opsins we added to the neurons … sense yellow light," said professor Philippe Séguéla. "When we transfer these to neurons, we can control their responses simply by illuminating the skin with innocuous yellow light."

The precision of this technique underlines potential advantages for use in humans. Light therapy based on optogenetics would have the advantage of providing on-demand analgesia to patients who could control their pain by shining light on the sensitive part of the body.

The potential for safe genetic delivery of inhibitory opsins to alleviate pain may prove useful for clinical applications. However, further advances in neuroscience are necessary to apply this method of pain relief to humans.

Séguéla says one possible way to make human neurons photosensitive would be through the use of a harmless virus that could temporarily deliver opsins to certain neurons without causing side effects.

The research was published in *eNeuro* (doi: 10.1523/eneuro.0140-15.2016)

Silicon QCL forgoes external light source

SANTA BARBARA, Calif. — A novel laser technology, consisting of a quantum cascade laser built on silicon, eliminates the need for an external light source for mid-infrared (MIR) silicon photonic devices or photonic circuits. This advance may have multiple applications that range from chemical bond spectroscopy and gas sensing to astronomy and free-space communications.

By directly bonding a III-V layer on top of a silicon wafer and then using the III-V layers to generate gain for the laser, researchers at the University of California, Santa Barbara, were able to integrate a multiple quantum well laser on silicon that operates at 2 µm. Because diode lasers are not able to go to longer wavelengths (where there are many more applications), the researchers focused instead on the development and use of quantum cascade lasers.

Building a quantum cascade laser on silicon was a challenging task made more difficult by the fact that silicon dioxide becomes heavily absorptive at longer wavelengths in the MIR.

"Not only did we have to build a different type of laser on silicon, we had to build a different silicon waveguide too," said Alexander Spott, University of California, Santa Barbara. "We built a type of waveguide called a silicon-on-nitride-on-insulator waveguide, which uses a layer of silicon nitride underneath the silicon waveguide, rather than just silicon dioxide."

The team plans to improve the design of their laser to achieve higher power and efficiency. Their next step will be to improve the heat dissipation of the quantum cascade laser, which will boost the performance of the laser and enable the team to make continuous-wave quantum cascade lasers on silicon.

"This work brings us closer to building fully integrated mid-infrared devices, such as spectrometers or gas sensors, on a silicon chip," said Spott. "This offers numerous benefits: Silicon is inexpensive, the fabrication can be scaled up to significantly reduce the cost of individual chips, and many small devices can be built on the same silicon chip — for example, many different types of sensors operating at different mid-infrared wavelengths."

Traditionally, silicon photonic devices operate at near-infrared wavelengths, with applications in data transmission and telecommunications. However, there is emerging research interest in building silicon photonic devices for longer MIR wavelengths, for a range of sensing and detection applications, such as chemical bond spectroscopy, gas sensing, astronomy, oceanographic sensing, thermal imaging, explosive detection and free-space communications.

The work was done in collaboration with the U.S. Naval Research Laboratory and the University of Wisconsin, Madison, and the researchers presented their work at CLEO: 2016 this month.

Lighting Up **Microscopes**: Advances and Emerging Sources

Spanning more wavelengths with greater intensity in ever smaller and cheaper packages, illumination systems are a make-or-break component in any modern microscope.

BY MARIE FREEBODY
CONTRIBUTING EDITOR

Microscope developers are a resourceful bunch, opting to use the light source available to them at the time to peer at or below the surface of various materials. Even dating back to the 17th century, Galileo used sunlight to produce the very first optical microscope.

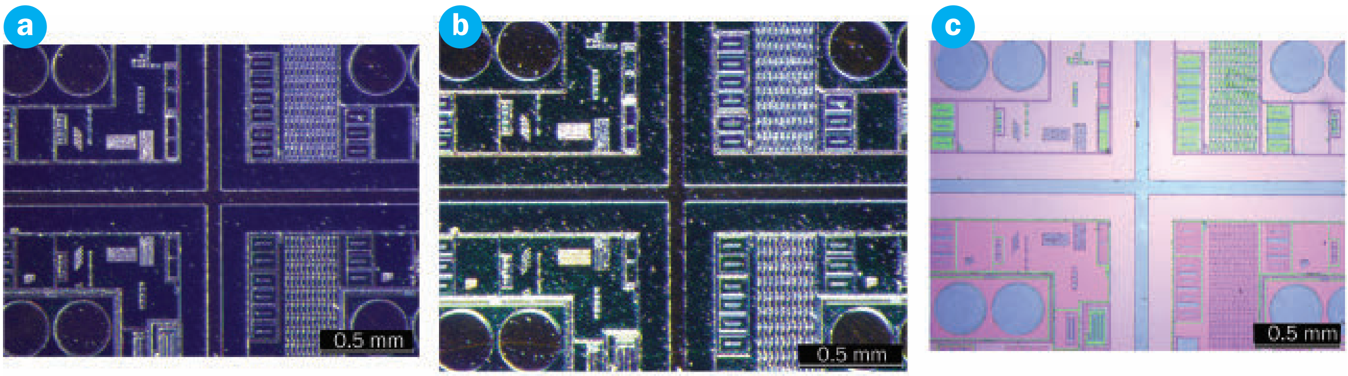
The next illumination sources to become available were lamps such as tungsten (incandescent), xenon, mercury and metal halide vapor. While such lamps can still be found in laboratories today, it was when an entirely new way of generating photons was discovered that the field of microscopy changed forever.

The year 1960 brought with it the invention of the laser. From then until today, researchers have been exploiting every variation of the laser and manipulations of its beam as they become available: from the gas laser to solid-state and the latest in quantum cascade laser (QCL)-based microscopy.

But it's not just lasers in their various forms that dominate the field; an emergence of low-cost light-emitting diodes — originally made for general lighting — means that LEDs are increasingly being adopted.

Microscopy techniques in the material and life sciences can be broadly divided into three domains:

- Transmitted-light methods for transparent specimens that are typically in the form of a thin slice, for example, tens of microns thick.
- Reflected-light contrast methods for opaque specimens, such as metals,



Stereo microscope image of a microelectronic circuit recorded with LED ring light illumination **(a)**. Stereo microscope image of the same microelectronic circuit recorded with LED near-vertical illumination **(b)**. Stereo microscope image of the same microelectronic circuit recorded with LED coaxial illumination **(c)**.

ceramics, plastics, minerals and wood, that remain opaque even when ground to a thickness of 30 microns.

• Fluorescence microscopy

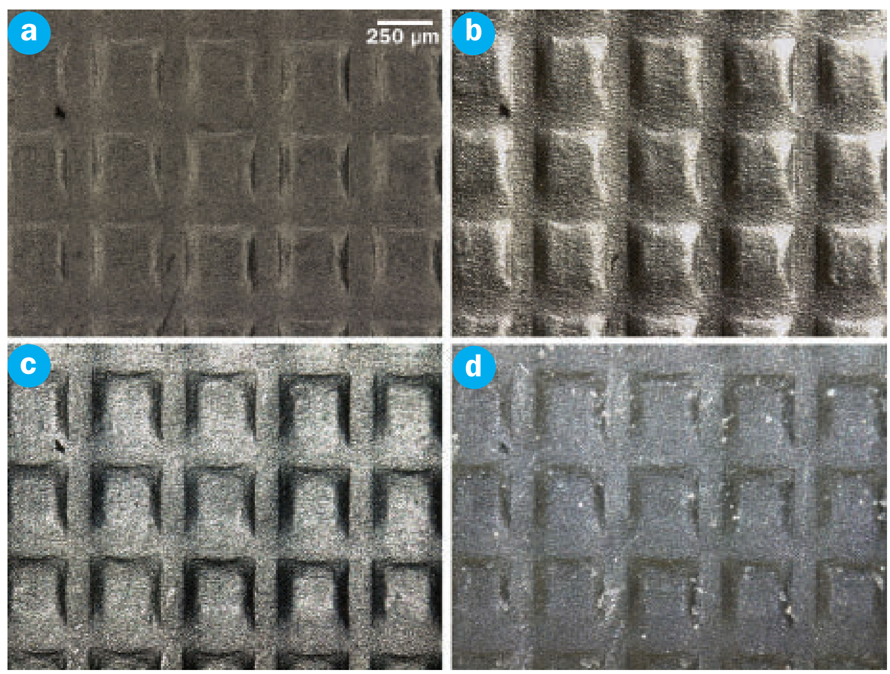
LED lighting trend

For bright-field, transmitted-light techniques, a microscope is usually equipped with an incandescent tungsten-halogen or mercury arc lamp, which is effective and cheap. But in the last decade, LED light sources have increasingly displaced such lamps.

"Besides having a similar color rendering index [CRI], LEDs have a much longer lifetime — >25,000 hours versus approximately 2,000 hours — do not need any warm-up time, and show very little fluctuation during operation. LED light sources do also offer a higher degree of flexibility for integration into hardware and software," said André Devaux, technical writer at PicoQuant GmbH, Berlin.

Despite their development in the 1950s, LEDs have only recently become more popular in microscopy. As the lighting and automotive markets continue to drive the development of brighter, more efficient and cheaper LEDs, microscope manufacturers have begun to adopt LEDs into their products.

"Globally the halogen market has been declining in the past several years due to improving LED technology," said Jennifer Wrigley, senior product manager of Industrial Microscopes at Olympus Scientific Solutions Americas. "The trend toward LED is a significant switch for the market from the traditional halogen."

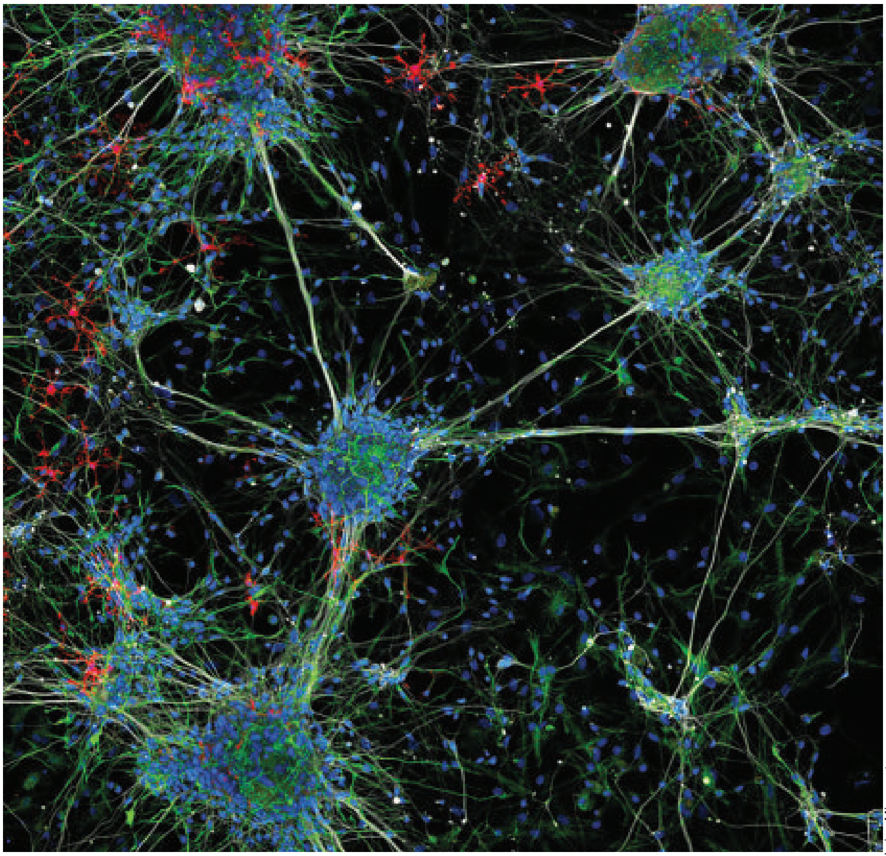


Leica DVM6 digital microscope images of embossed metal-coated paper used for food packaging. The images were acquired with different illumination contrast methods. LED full ring **(a)**. Quarter of the ring light **(b)**. LED coaxial light with polarizer open **(c)**. LED coaxial light with polarizer closed **(d)**. The quarter ring **(b)** and coaxial light with polarizer open **(c)** enhance the embossed squares, while the coaxial light with the polarizer closed **(d)** enhance the imperfections or contamination.

High-intensity LEDs provide similar intensities as halogen, but maintain a consistent color temperature regardless of intensity. This keeps the colors of features on the sample consistent for both viewing through the eyepieces and imaging with a digital camera.

Other advantages to the user are reduced cost of ownership — as LEDs use less energy than halogen; LEDs are more stable, durable and give off little heat, which is important when observing sensitive material; and LEDs can also be readily triggered to turn on and off in microseconds, without the need for shutters — a capability that has been tapped for fluorescence microscopy and live-cell imaging, and may find application in bright-field techniques as well.

Today's LEDs can be manipulated to emit single color (narrow wavelength range) light from infrared to ultraviolet


Leica Microsystems

Primary culture of rat cortical neurons, acquired with the Leica TCS SP8 X white light laser. Excitation and detection settings were adjusted to optimal image contrast.

Bright, nondivergent and available in a great variety of monochromatic wavelengths, it's little wonder that lasers are the dominant light source for confocal and fluorescence microscopy.

or can be combined in units to produce full spectrum white light.

"White light illumination systems covering the spectral range from 350 to 700 nm are available from the major manufacturers and usually consist of 4 to 16 LEDs with different wavelengths," said Devaux. "These systems also offer the advantage of fine-tunable intensity regulation, intensity stability over time and instant on/off switching."

Advances and improvements over the next few years will most likely focus on better CRI, multiple color/wavelength emission, smaller size and so on.

"LEDs will probably become better in performance, depending on the microscopy application, cheaper and more practical to use. Some light colors/wavelengths emitted by LEDs are still relatively dim," said Heinrich Bürgers, product manager for Stereo & Digital Microscopy at Leica Microsystems GmbH in Wetzlar, Germany. "For the case of fluorescence microscopy, a bright green LED is certainly needed."

For widefield applications, Oliver Schlicker, application manager of Widefield Microscopy at Leica, has found that LEDs suitable for dyes in the far red range are more and more requested as red light penetrates much deeper into thicker samples with less stray light.

"Furthermore far red light has much less energy than shorter wavelengths, which is an advantage for long-term experiments with living samples," he said.

Exploring laser light

Bright, nondivergent and available in a great variety of monochromatic wavelengths, it's little wonder that lasers are the dominant light source for applications such as confocal and fluorescence microscopy. Two different laser types are used depending on the microscopy technique: continuous wave lasers for fluorescence microscopy and pulsed lasers for nonlinear or multiphoton microscopy, which require ultrashort pulses such as femtosecond lasers.

Gas lasers were the first to be used, but in the mid-1990s they were mostly replaced by solid-state lasers starting with diode-pumped solid-state lasers. More recently, optically pumped semiconductor lasers and also laser diodes have begun to dominate, as diodes with useful visible output became available.

"Microscopy alone would probably not have spurred the completely new semiconductor materials needed for many of these laser diode wavelengths," said Matthias Schulze, director of segment marketing for OEM Components and Instrumentation at Coherent Inc. in Santa Clara, Calif. "But consumer product market demand provided the necessary economic force."

Diode-based lasers are especially valuable for any application requiring deep UV excitation, such as fluorescent lifetime imaging microscopy (FLIM), which exploits the natural emission of biomolecules. There are currently no LEDs available that could be used for this application.

Today, rapid progress in pulsed laser sources is giving access to more wavelengths (especially in the blue and deep UV), higher optical output powers, pulse widths and shapes optimized for specific applications and novel methods. Without these developments, super-resolution techniques such as stimulated emission depletion (STED), stochastic optical reconstruction microscopy, and photoactivated localization microscopy — which was recently honored with a Nobel Prize — would not have been possible.

"Pulsed laser sources continue to be in the focus [in] any time-resolved microscopy applications and the development of methods such as cross-correlation techniques," said PicoQuant's Devaux.

"Pulsed interleaved excitation methods and its combination with STED super-resolution microscopy or its use in Förster resonance energy transfer studies progress rapidly," he added. "These advances always call for laser sources with extended flexibility in wavelength, repetition rate, pulse width and generation of pulse sequences."

An emerging trend in modern microscopy includes light sources with several laser lines. These "multilaser engines" provide laser light at several different wavelengths that can be controlled independently and simultaneously.

"The integration of such a multilaser engine into a microscopy device is much easier than integrating one single laser for each line," said Tim Paasch-Colberg, director of marketing at Toptica Photonics AG, Munich. "Also, the operation of the multilaser engine for the user is straightforward, since all different laser lines can be controlled with the same software interface."

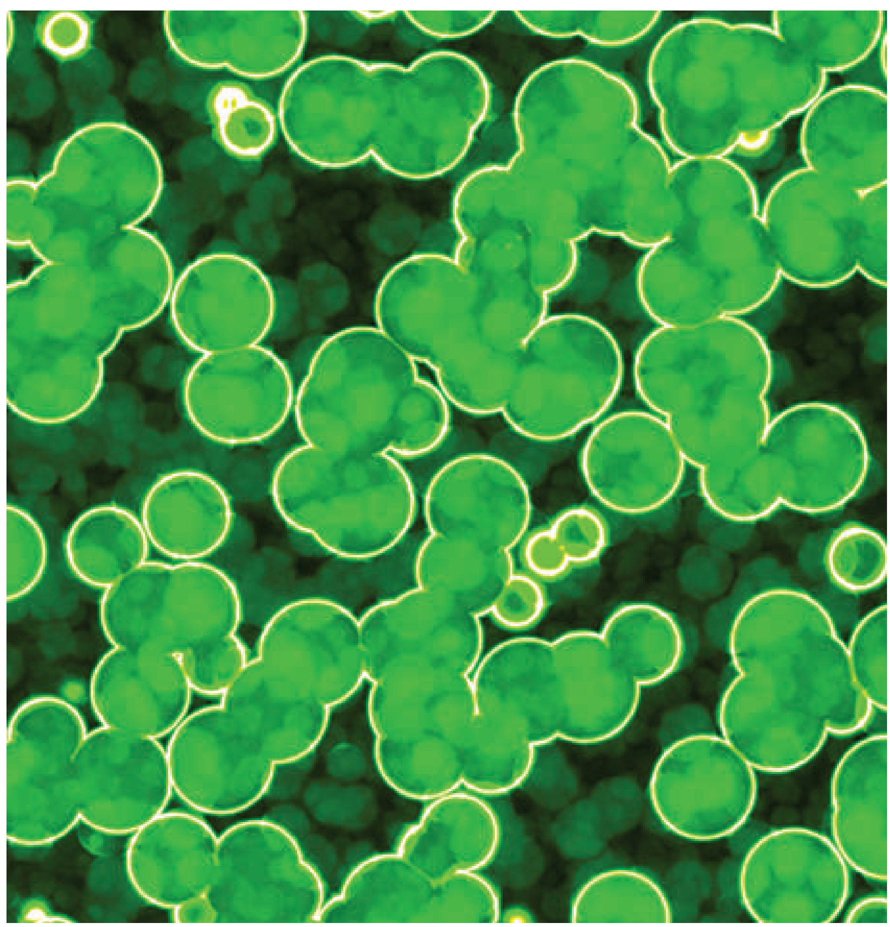
Tunable lasers are another area of development. For example, a supercontinuum laser — often referred to as white light laser — offered by Leica Microsystems or PicoQuant covers the spectrum from 470 to 670 nm. In combination with an acousto-optical beamsplitter, the Leica system offers up to eight different lines, which can be picked from the spectrum simultaneously and each line can be individually tuned in wavelength and intensity.

"Conventional laser sources provide only one or a small number of single wavelength lines. As a consequence, large gaps in the excitation spectrum limit the flexibility to excite nonstandard dyes and new fluorescent proteins," said Jochen Sieber, product manager of Superresolution Technologies at Leica Microsystems.

Mid-infrared light source specialists Daylight Solutions, based in San Diego, has turned to another laser technology to provide a broadly tunable high-brightness source for next-generation benchtop infrared microscopes. Thanks to recent advances in quality, reliability and performance predictability, QCLs now provide brighter illumination for faster data

Toptica

Toptica's multilaser engine iChrome SLE provides eight laser lines out of one box. It has two output fibers with integrated switch, automated alignment and laser cartridges that enable exchanges in the field.



Carissa Young, David Raden and Anne Robinson, University of Delaware

Confocal microscopy techniques based on laser excited fluorescence are key tools in the drive to connect molecular and cell biology. These images show simultaneous detection of endoplasmic reticulum localized soluble GFP and Golgi fusion protein Sec7-DsRed fusion proteins in the yeast S. *cerevisiae*. Image acquired with a Zeiss LSM 5 DUO at 20 frames/sec with simultaneous 488-nm and 561-nm excitation.

acquisition in an entirely new type of microscope platform.

Current infrared microscopes are based on Fourier transform infrared (FTIR) technology, which use either the relatively weak light from a globar or synchrotron radiation from large particle accelerator facilities. Such sources require cameras that need cryogenic (liquid nitrogen) cooling to achieve adequate signal-to-noise ratio.

Daylight Solutions' Spero microscope is the first and only commercially available QCL microscope on the market. Unlike in the FTIR method, not all wavelengths have to be scanned, which means the Spero provides rapid, high-resolution chemical imaging, which uses an uncooled microbolometer camera for a compact, benchtop instrument.

"The wide tunable range of the current generation QCLs is still limited, but by coupling several modules together it is possible to cover most of the infrared fingerprint spectral region, which contains most of the diagnostically useful information," said Peter Gardner, professor of Analytical and Biomedical Spectroscopy at the Manchester Institute of Biotechnology, Manchester, U.K.

"Daylight Solutions [has] done this coupling four QCL modules to cover the approximate range 1900-900 cm^{-1}. They have then coupled this to an infrared microscope and a room temperature focal plane array detector."

The last five years has seen huge investment in QCLs, which has helped boost quality, reliability and performance predictability of QCL-based systems.

"This investment was driven largely by the demanding requirements of our military-grade products, which are being tasked to protect aircraft from shoulder-fired missiles," said Jeremy Rowlette, director of Molecular Imaging at Daylight Solutions. "The infrastructure built out to support these products helped raise the bar for all of our QCL products at Daylight."

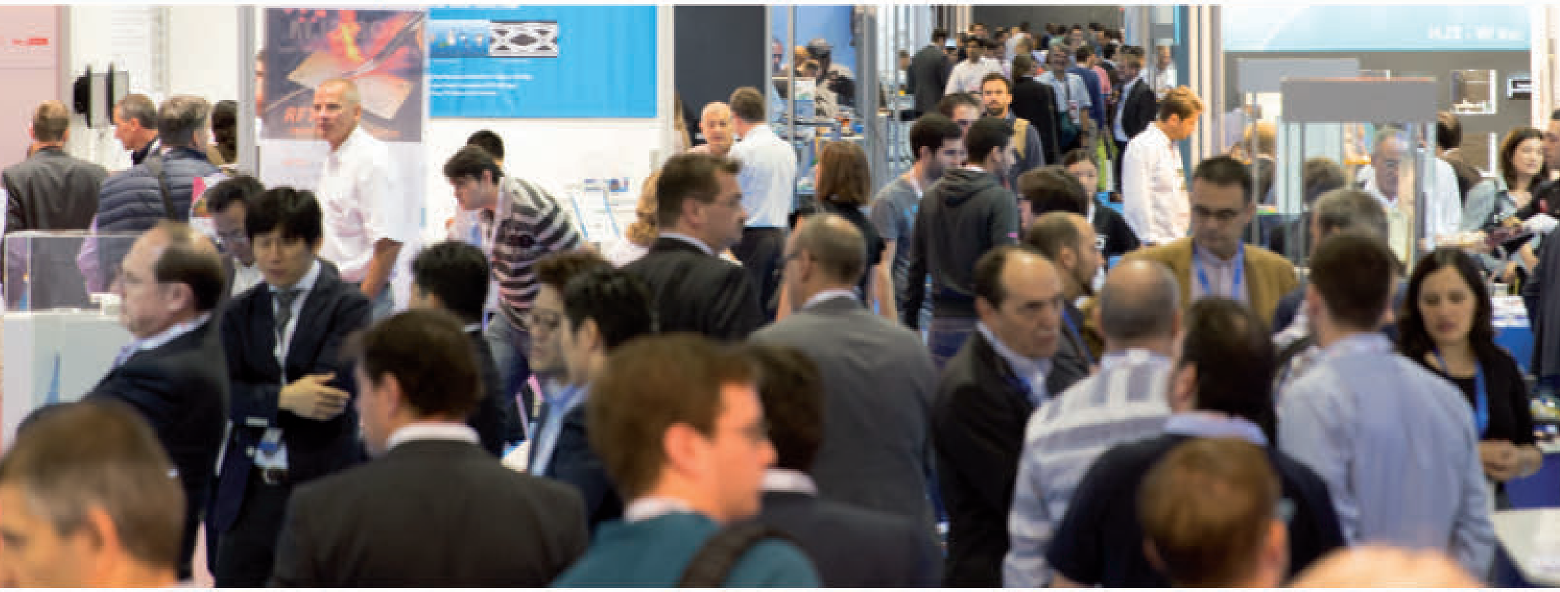
In truth, no single light source provides the optimum mix of performance and cost for every single microscopy application. Manufacturers must often offer multiple technologies and there is plenty of room for innovation in these light sources.

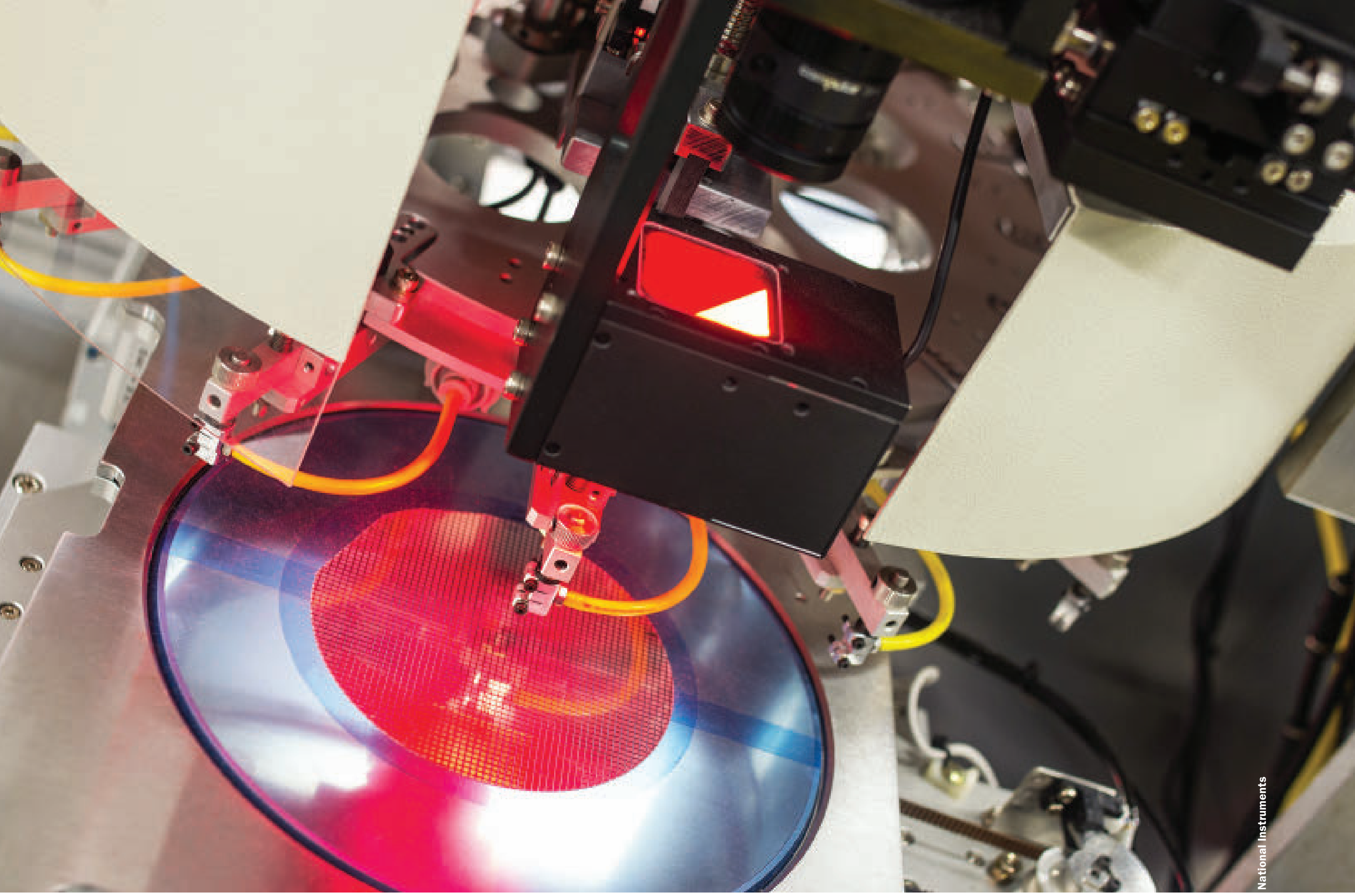
Today, both need and demand drive innovation. Researchers are multiplexing probes more, and mixing imaging modalities, even adding other analytical methods such as spectroscopy to their microscopy.

This means that light sources must keep up to enable these efforts by improving differentiation and signal-to-noise, and the demand should soon follow.

"We recognize the fundamental importance of optical microscopy. Although its roots go back hundreds of years, optical microscopy is growing faster than ever because of developments in life sciences: from well-funded initiatives like BRAIN in the area of neuroscience research, to pre-clinical and clinical diagnostic applications in support of modern higher life expectancy," Coherent's Schulze said. "We will continue to support these fields by providing the laser characteristics needed in these markets."

marie.freebody@photonics.com





National Instruments

Recent advances in sensors benefit machine vision applications. Cameras can now see in greater detail than before, which means more precision and better control for applications such as vision-guided motion, driver assistance and quality inspection.

For **Vision Systems**, Lighting and Other Advances Up Capabilities and Cut Costs

Better sensors, more powerful processors and sophisticated algorithms are advantageous in opening up new mass market applications.

BY HANK HOGAN
CONTRIBUTING EDITOR

For vision systems, lighting is critical. Now, the wide availability of LEDs offers new choices, such as being able to create complex illumination patterns. There also are new and improved sensors, processors and algorithms. Combined, these advances promise to make vision systems smaller yet more capable and affordable.

That is what Tom Brennan sees happening. He's president of Denver-based Artemis Vision, a machine vision solutions integrator.

For instance, according to Brennan, a beneficial drop in the cost of LEDs has been accompanied by an equally helpful widening availability. Before, when a supplier like Artemis Vision would have a need for nonstandard lighting, it would be difficult to even cobble together a proposed solution due to the very small volumes involved. Consequently, projects would languish, but the situation has changed.

"You can now just go on various websites and order raw LEDs and make your own lights in a way that's much easier than it was years ago. So it really opens up the avenue to design your own lighting schemes as needed," Brennan said.

With the advent of easily obtainable individual LEDs, Artemis Vision can now purchase as few as four and produce an evaluation solution. If that's successful then the lighting can be mounted in a housing and then, perhaps, turned into a standard part type that the company can produce.

"It helps a lot in terms of cost and lead time," Brennan said of the new lighting landscape.

The lighting technology advances have been complemented by improvements in the capabilities of sensors, processors and algorithms. These vision systems components have also seen price drops that have made it possible for smaller machine vision solutions suppliers to keep systems on hand strictly for testing and evaluation.

When asked about vision innovations, Eric Jalufka, product manager for vision hardware and software at National Instruments Co. of Austin, Texas, began by discussing sensor progress, such as increases in available resolution. Whereas a few years ago a 5-MP resolution would be state of the art, today sensors are moving into the 20+ MP range for area scan cameras. More pixels and higher resolution make it easier to detect fine details.

Further, sensors offering higher dynamic range with very low noise are appearing. Those sensors can also handle higher frame rate imaging, meaning that they can capture events that take place in a shorter time period than was possible before.

"Traditionally, it was hard to find those qualities all in one sensor. But now we're starting to see these nice benefits offered in a single sensor and it's something that's available to the machine vision market. It's not just constrained to a high performance, scientific lab camera," Jalufka said.

The combination of characteristics can be advantageous in opening up new mass market applications. For instance, cars routinely travel from bright sunshine to a dark tunnel or vice versa in a fraction of a second. They also are used day and night. A driver assist solution must be able to deal with this. A high dynamic range sensor helps because it means that the camera performs well when going from light to dark or back again.

Vision innovations based on lower-cost components make it possible to tackle an inspection station **(a),** a pit crew helmet with mounted cameras **(b, c)**, or other lower-volume applications.

More bits, more challenges

Such sensor innovations are not an unmitigated benefit. A higher dynamic range, a greater frame rate and higher resolution all mean that the sensor produces more bits in a given period of time. Those bits have to be transmitted. For that reason, Jalufka sees sensor technology driving the adoption of higher bandwidth communication standards, like USB 3.0.

The increased number of bits also puts a strain on processors, he added. That data has to be run through calculations and algorithms, and as the number of bits goes up that burden increases.

One way to address this problem is to use higher performance processors. Another approach, which is increasingly employed, is heterogeneous processing. Here, a traditional processor handles part of the chore and a graphics processing unit (GPU) or a field programmable gate array (FPGA) handles the rest. The key is to know which mathematical methods that turn image data into numbers and actionable information, or algorithms, should go through which calculation engine.

"We can put the algorithms that are best suited for the FPGA on the FPGA and the ones that are better suited to the CPU [central processing unit] on the CPU. Those two elements can work together to increase overall throughput so you can process that data faster. You can make decisions faster and increase your throughput," Jalufka said.

Some tasks, like thresholding for particle analysis, work well on an FPGA, he said. On the other hand, pattern matching and more advanced algorithms are more efficiently dealt with by a processor.

The higher sensor capabilities, greater processing power and improved algorithms increase imaging solution capabilities, according to Bob Voigt, chief technical officer at Resolution Technology Inc. of Dublin, Ohio. The company supplies machine vision components, systems and custom development for manufacturing applications.

For instance, inspection can now be done in three dimensions while parts move by at full speed. Pick-and-place systems used to require parts be precisely positioned and oriented in order for high accuracy recognition of items. Now, they can be randomly oriented.

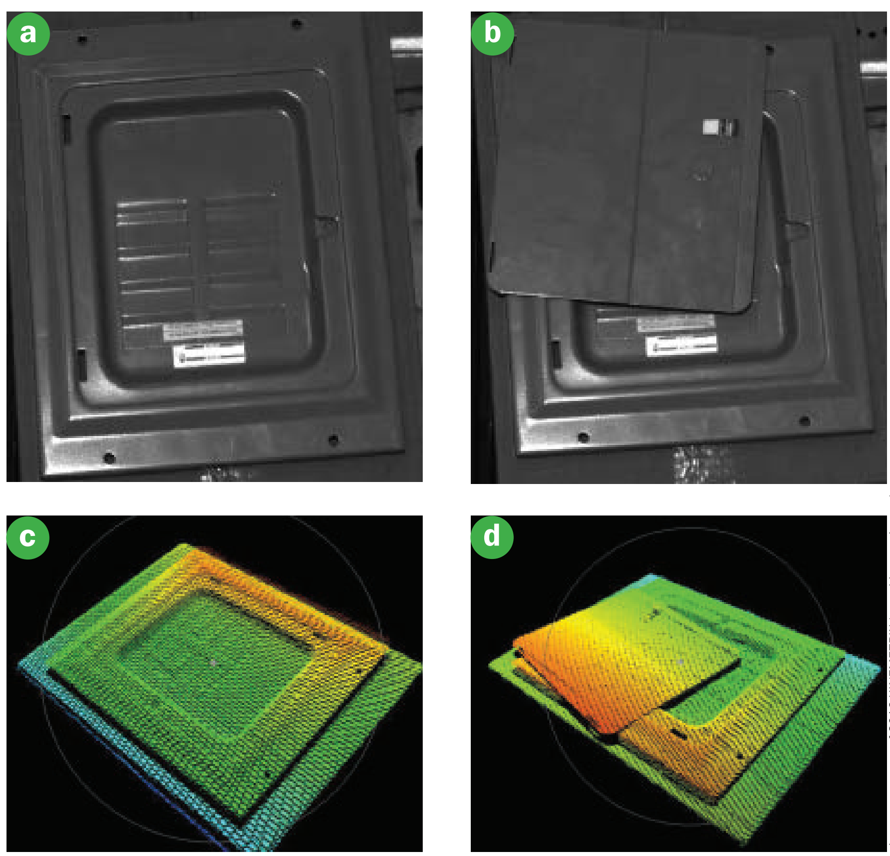
"Systems can now monitor 'made-to-order' production lines and switch inspection routines for each item coming down a line," Voigt said, in describing another example.

In manufacturing, almost any process that requires visual inspection by an operator or technician can now be done by an automated vision system, he said. Outside of manufacturing, these improvements mean that imaging solutions are now showing up in consumer products ranging from cars to bike helmets to ovens.

Powerful stand-alone systems emerge

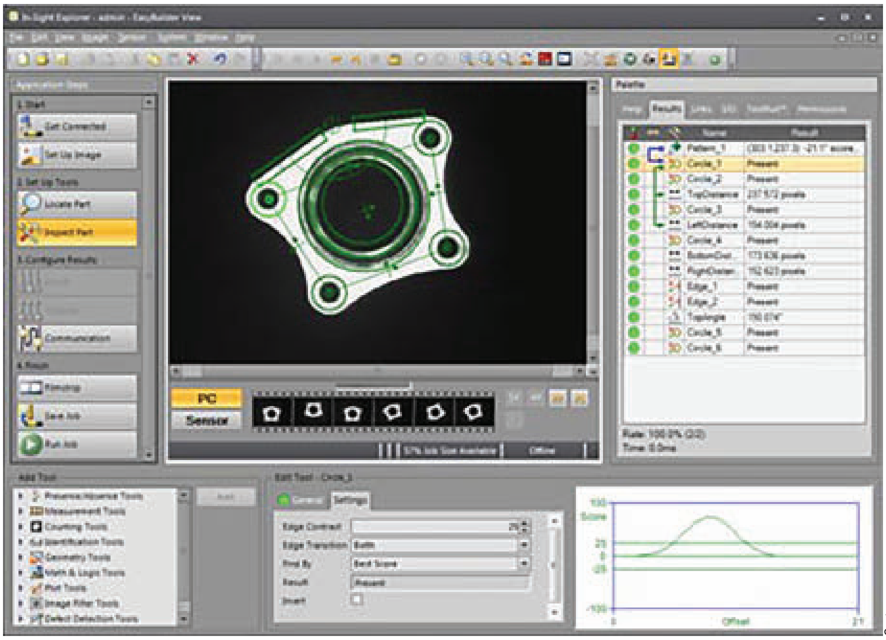
Vision systems are benefiting from developments in consumer mobile technology, said Robb Robles, principal product marketing manager at vision systems solution supplier Cognex Corp. of Natick, Mass. There is, for instance, the ongoing increase in processing power. One con-

> 'We're going to do things today with a stand-alone vision system that previously we had to use a PC for.'
>
> Robb Robles, principal product marketing manager at vision systems solution supplier Cognex Corp.



Images courtesy of 2016 KINEMETRIX (www.kinemetrix.com).

Grayscale images of parts **(a)** and **(b)** illustrate the difficulty of spotting parts. But with point cloud images **(c, d),** practical thanks to vision systems advances, identification is easy.



Software and algorithm innovations make vision systems easier to use and more powerful.

Cognex

sequence is a change in the configuration mix of vision solutions.

These can be divided into a PC-based solution or a stand-alone system. The latter combines sensor and processor along with other components to output an answer, like a part being present or not. Examples are smart cameras, embedded vision systems, and the like.

"We're going to do things today with a stand-alone vision system that previously we had to use a PC for," Robles said. "Stand-alone vision systems with embedded processors have become fast enough for the majority of applications."

However, a PC-based system might be needed for large images, like a 21-MP camera, he added. He noted that the greater power of a PC might also be needed in complex applications where a large number of cameras are used, but that a PC-based system often is more expensive to develop and deploy than a smart camera vision solution.

Another shift has taken place in the sensor space. At one time CCD was the only option. But, improvements in CMOS sensor performance mean that most applications have switched to this technology, in part because it uses less power and generates less heat.

Vision systems have also benefited from riding along with another consumer mobile technology: cameras. Kerstin Prechel, product manager at Ahrensburg, Germany-based vision systems maker Basler AG, noted that the sensors in these devices have gotten significantly higher in resolution while staying the same size or shrinking as phone makers squeeze more pixels into their devices.

For machine vision systems, the trend, which is driven by the introduction of smaller pixels, has made higher resolution possible. There also have been parallel developments in lenses, meaning that even these small pixels can now be resolved.

"This led to good usability of C-mount lenses in applications that previously needed high-quality cameras and lenses that are much more expensive," Prechel said. "A next interesting trend might be the need of the automobile industry for cameras that will need different sensor abilities."

Other trends she sees involve the arrival of 3D as well as very inexpensive vision systems. Both will expand the possible applications. Basler is also noticing a trend toward solutions that are just good enough, as price alone becomes a more and more important feature.

There are, of course, vision system aspects that still need improvement, including lenses and optics. Artemis Vision's Brennan said they tend to be a weak spot of a system, in part because over time in an industrial environment they have a ten-

Basler AG

Advances make 3D images from vision systems practical.

dency to work their way out of alignment. Resolution Technology's Voigt noted that lighting optics are often overlooked and need to be better designed.

Speaking of lighting, no matter the problems solved or the technology advancements made, one thing will still be true. Lighting will remain a key part, perhaps as much as 80 percent, of a vision solution.

Lance Riek is an engineer and co-founder of Sensory Labs. A machine vision integrator based in Bozeman, Mont., the company develops both traditional machine vision applications and aerial imaging systems for manned aircraft and drones. For its aerial projects, Sensory Labs often adapts machine vision cameras to the job, and so a background in integrating cameras is helpful, according to Riek.

Also important, no matter the task, is the proper illumination. In discussing this, Riek said, "Lighting is critical for all machine vision applications — if the lighting doesn't reveal it, the camera can't see it."

hank@hankhogan.com

The mirror of the 9.2-meter Hobby-Eberly Telescope (HET) is visible through the open louvers in this twilight view.

Specialized **Optical Mirrors** Set to Unlock the Universe's Darkest Mysteries

Optical mirrors made of floated borosilicate glass installed at the Hobby-Eberly Telescope Dark Energy Experiment will help paint a more detailed picture of dark energy and the universe's expansion.

BY TINA GALLO
SCHOTT NORTH AMERICA INC.

Large telescopes all across the world stare into the sky day and night, waiting to uncover the secrets of the cosmos. For the Hobby-Eberly Telescope, the world's third-largest optical telescope, located at The University of Texas at Austin's McDonald Observatory, that means setting its sights on one of the most mysterious forces in the universe — dark energy.

Contrary to earlier beliefs that the universe is static, it is now assumed that it expands. The force driving this expansion, which seems faster than many scientists once thought possible, is dark energy, and though we don't know much about this force, we do know that dark energy and its counterpart, dark matter, make up close to 95 percent of the universe (about 74 and 21 percent, respectively). Only about five percent of the universe is made up of normal matter — the stars, planets, and the gases that we can more easily observe.

Specialized optical mirrors installed at the Hobby-Eberly Telescope Dark Energy Experiment (HETDEX) will help advanced equipment paint a more detailed picture of the universe, which scientists hope will explain the nature of dark energy and the universe's expansion.

The performance requirements for these optical mirrors are extremely rigorous, as slight deviations can have significant impacts on research results. That's why scientists use mirrors made with a specialized floated borosilicate glass that can meet the strict demands of the telescope.

Schott

Specialized borosilicate glass was used in the 150 individual spectrograph mirrors in the Visible Integral-Field Replicable Unit Spectrograph (VIRUS) project, part of research at the Hobby-Eberly Telescope Dark Energy Experiment (HETEX).

Looking back to the Big Bang

Astronomers once believed that, following the Big Bang 13.7 billion years ago, the universe would go through rapid expansion but would then slow down. However, recent research shows that parts of the universe continue to expand at faster-than-expected rates. The theory is that dark energy contributes to this fast expansion, but it's a force we know little about. Therefore, scientists measure the expansion of the universe by studying light, which moves at a known and constant rate, in hopes that it adds to our understanding of dark energy.

The research at HETDEX is being conducted by dozens of scientists affiliated with a number of higher education institutions and public research branches from around the world. The telescope's mission is set to explore dark energy, massive black holes and the earliest stars in the universe.

One of those research projects is called the Visible Integral-Field Replicable Unit Spectrograph (VIRUS), which is comprised of 150 individual spectrograph mirrors made from specialty borosilicate glass and almost 40,000 optical fibers. Both its number of mirrors and fibers are greater than in most spectrograph arrays. The 150 spectrographs will measure the light from distant galaxies, breaking it down into individual wavelengths. The spectrograph's sensors will then analyze the light emitted from more than 1 million galaxies between 9 to 11 billion light years away.

By analyzing these wavelengths, researchers hope to better understand the chemical composition and temperature profiles of those galaxies. In addition, the spectrograph array will help determine how fast the galaxies are moving, data that will be used to create a 3D map of the universe. VIRUS is still being tested and installed, but its mission is slated to begin this year.

VIRUS is a special application that has unusual demands. Provided with sophisticated tasks and exposure to rough environments, these optical mirrors must possess a number of characteristics: high thermal stability, excellent transmission and a low refractive index. Plus, the mirrors must be extremely flat and have an exceptional surface quality so a thin, film-like coating can be applied. The material that meets such stringent requirements is Schott's patented BOROFLOAT glass, a high-quality borosilicate glass, which was further machined and specialty coated.

Added strength through the fifth element — Boron

Borosilicate's namesake is the element boron, which serves — similar to silica — as a glass network former and adds to the glass's high chemical durability and superior mechanical strength. During melting, boron and alumina are mixed with traditional silica and other components commonly used in glass production to create a stronger, more rugged glass. The high amount of boron oxide in the glass composition strengthens the chemical bonds within its network and is responsible for the exceptionally low thermal expansion behavior and low refractive index (nd = 1.471). Together with the material's superior transmission, these characteristics are key requirements for precise spectrometer measurement results required for the HETDEX project.

The chemically resistant glass is traditionally utilized wherever excellent resistance to high or changing temperatures is required, such as sight glasses for the chemical and petroleum industry. However, due to its outstanding transmission it is also used as a substrate in many optical applications, such as optical filters, hot and cold mirrors, or the VIRUS specialty spectroscope mirrors. As its thermal expansion coefficient of $3.25 \times 10^{-6}\ K^{-1}$ is perfectly matched to that of silicon, it is also the glass of choice for anodic bonding or as a carrier wafer for temporary wafer processing. The low, nonbridging oxygen holes in its glass network are responsible for a high radiation resistance (low glass darkening) making it a good candidate as a component in x-ray radiation technology.

Optical characteristics

Light transmittance is significantly impacted by the impurity levels of the raw materials used and depends on the thickness of the optical glass panel. BOROFLOAT glass is offered as thin as 0.7 mm and up to 1 in. thick and is the industrial flat glass with the lowest iron impurity level allowing for transmission values of over 90 percent (Figure 1) and reduced solarization tendency in the UV range (Figure 2). The glass was machined and coated by Precision Glass & Optics.

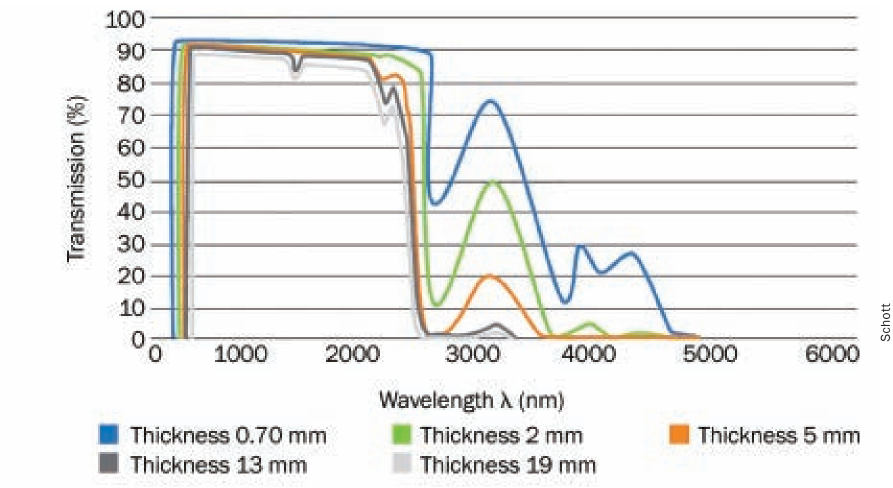


Figure 1. Low iron impurity levels result in BOROFLOAT glass' excellent optical transmission.

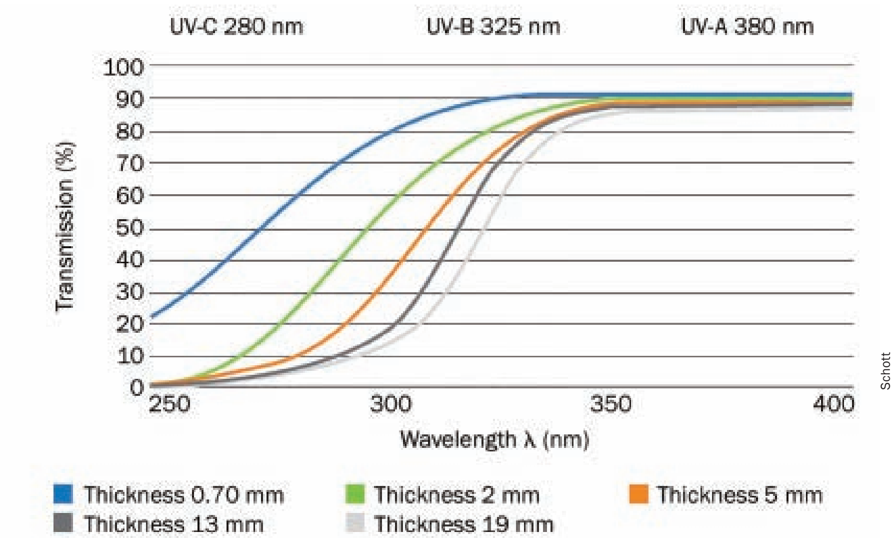


Figure 2. Exceptionally high UV transmission is a key benefit for low wavelength applications.

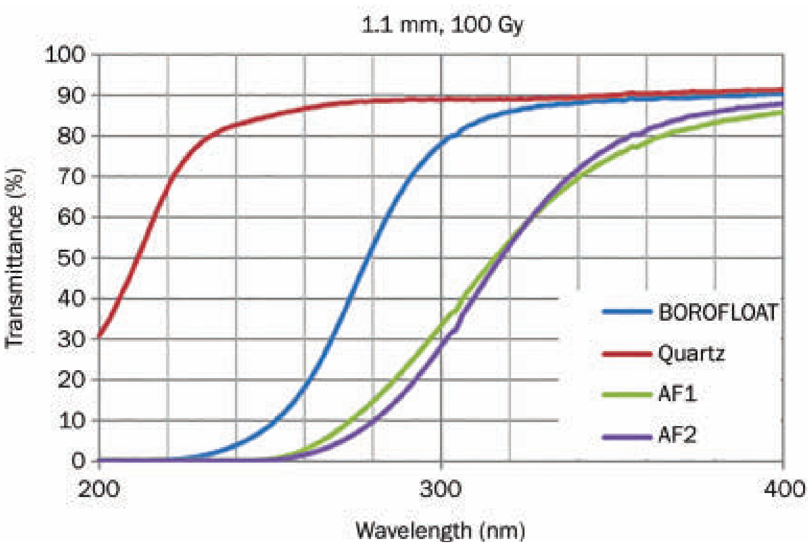
Solarization is a "glass-darkening phenomenon," which typically occurs in multicomponent glasses and depends on the glass structure, the emitted light spectrum, the radiation source and the radiation exposure dose. High energy doses can generate structural micro- and nano-electronic defects, which are then absorbed at short wavelengths resulting in a UV-cutoff shift in the light transmission curve. Such radiation-induced defects tend to solarize depending on impurity levels of polyvalent ions, such as iron (Fe^{2+}/Fe^{3+}) in the glass composition. Technical glasses usually have iron impurity levels of several hundred ppm. Pure raw materials were used in manufacturing the glass for the VIRUS mirrors, resulting in extremely low iron impurity levels (approximately 85 ppm Fe_2O_3), which tend to solarize much less intensely than other flat glasses (Figure 3).

The optical mirrors used in VIRUS capitalize on the glass' high transmission, allowing VIRUS sensors to read and record the incoming light more accurately, adding to the mission's precise data collection.

Thermal properties

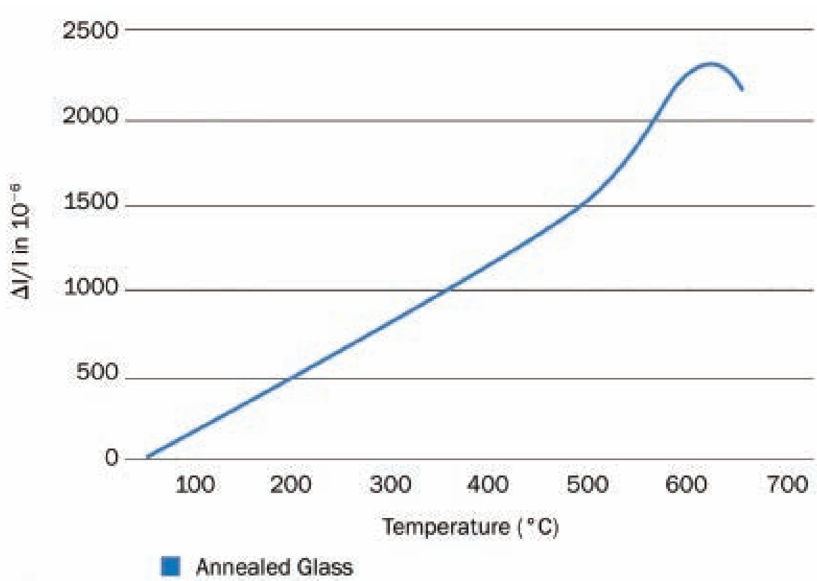
An optical mirror with high thermal stability was an especially important requirement for the HETDEX project because of its location; the Hobby-Eberly Telescope sits 6,600 ft above sea level and experiences seasonal temperature and weather fluctuations, including snow in the winter and hot sunshine in the summer. Borosilicate glass' higher concentration of silica, fewer alkali oxides, added boron trioxide and alumina create a much more compact glass network compared to regular soda-lime glasses, resulting in borosilicate glass' extraordinarily low thermal expansion behavior (Figures 4 and 5).

Boron again plays the key role in the performance of the glass, as it allows the specialty glass to easily resist the expansion and contraction stresses that temperature changes would typically cause. Hence, this borosilicate glass ensures high resolution and consistency in researchers' observations as it does not warp and delivers undistorted measurements even under the harshest environments.



Schott Nippon K.K.

Figure 3. A comparison of UV transmission after radiation exposure. Gy = gray unit.



Schott

Figure 4. The low thermal expansion coefficient results in superior resistance to thermal gradients.

Pristine surface allows for high-performance coatings

For optical mirrors the glass substrate must be extremely flat and without inconsistency or imperfection. Glass produced using a float manufacturing process, in which molten glass floats over a bed of molten metal and then cools, provides highly homogeneous and flat surfaces.

The performance requirements for optical mirrors are also highly dependent on the material's ability to reflect, absorb, enhance or modify incoming light. This can be accomplished with bulk optical glass materials or through coatings that are applied to a pristine glass substrate. Coatings usually allow significantly more freedom for customized light management design options, which can be developed even further when a flat, homogeneous and temperature-resistant glass substrate like BOROFLOAT glass is used.

The fold mirrors for the VIRUS collimator required an operational wavelength range of 345 to 700 nm and are optimized from 350 to 590 nm with average reflectivity of greater than 99 percent and exceeding 95 percent between 345 to 700 nm. The absolute reflectivity is greater than 98 percent between 350 to 590 nm and greater than 92 percent at 345 to 700 nm. The angle of incidence is 12.5±5°. In order to meet such requirements, a special 57-layer coating using Ta_2O_5 and SiO_2 was designed using electron-beam evaporation with ion assist. Other optical specifications include a surface figure of λ/8 at 632-nm root mean square (rms) surface quality at 40-20 scratch-dig and surface roughness of 2-nm rms.

This coating, applied by Precision Glass & Optics, has to perform in extreme environmental conditions (−25 °C to 66 °C) and meets Mil-C-48497 abrasion/adhesion durability standards.

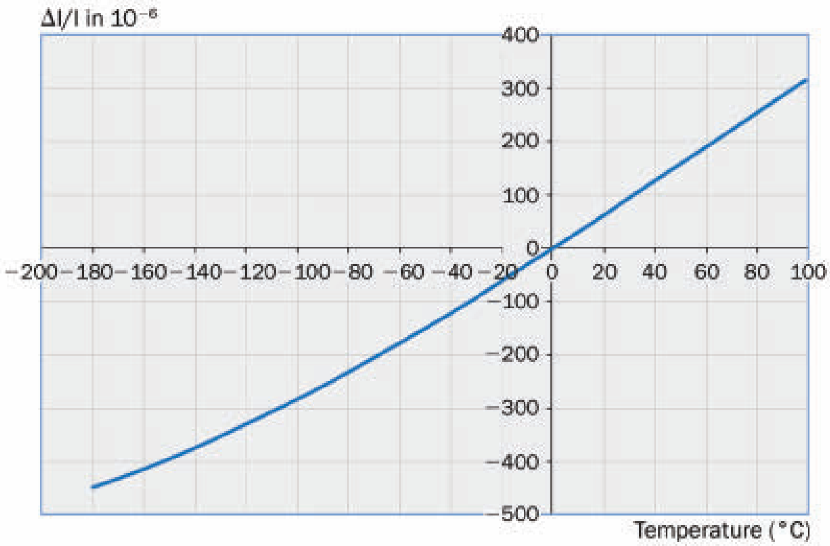
Mechanical strength and stability during processing are essential in order to produce high-precision mirrors. Borosilicate glass' exceptional surface hardness and abrasion resistance compared to other glass substrates were beneficial for the manufacturing of the VIRUS spectrograph mirrors.

A mile above sea level, searching for answers

Large-scale, modern research projects require precision instruments and materials in order to guarantee the most accurate results. The data derived from VIRUS and HETDEX could give researchers and scientists a thorough understanding of the early universe and the forces that drive its expansion.

The spectrograph mirrors in HETDEX must be made of high-precision specialty glass to ensure the longevity of each individual spectrograph in the large mirror array for many years to come. The sum of its properties make floated borosilicate glass the ideal material for such specialized optical mirrors.

The composition of this special borosilicate glass is not only tailored toward excellent optical properties, but it's also designed to exhibit minimal thermal expansion. The sophisticated coating applied to the extremely flat surface enhances properties in VIRUS spectrograph mirrors that could help researchers to finally uncover the secrets of dark matter and help us to better understand the universe.



Schott

Figure 5. The low thermal expansion coefficient contributes to excellent cryogenic behavior.

Meet the author

Tina Gallo is applications manager for Schott North America Inc. in Louisville, Ky. She earned her master's degree in materials science from RWTH Aachen University, Germany; email: tina.gallo@us.schott.com

Ultrashort Pulse Laser Micromachining Surpasses Previous Limitations

With the power of ultrashort pulse laser systems on the rise, achieving dynamically and synchronously adaptable pulse repetition rates in the MHz range is the key to higher throughput.

BY FLORIAN HARTH, THOMAS HERRMANN, BERNHARD HENRICH AND JOHANNES A. L'HUILLIER
PHOTONIK-ZENTRUM KAISERSLAUTERN EV AND RESEARCH CENTER OPTIMAS

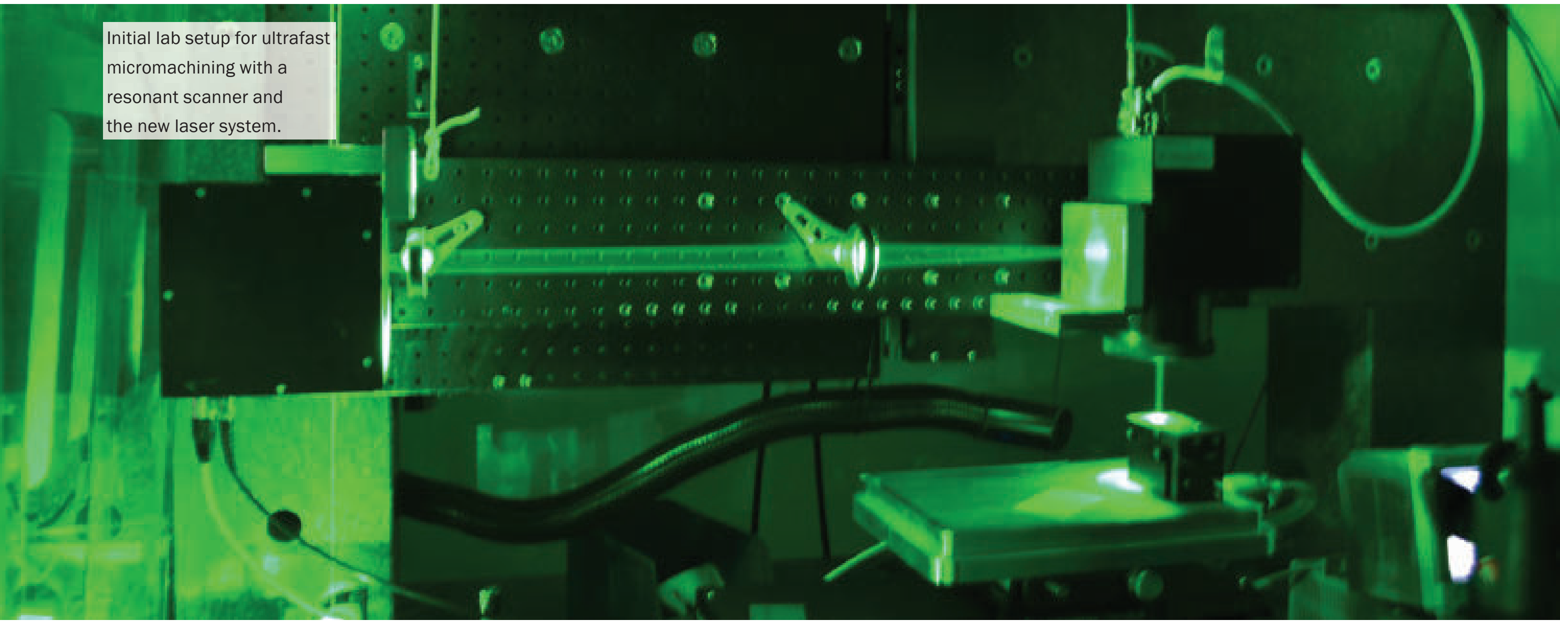
To fulfill current and future customer needs in the ultrashort pulse (USP) laser micromachining market, faster processing time is critical. In only the last few years the average power of these lasers has risen continuously, reaching an average power of 1 kW or more. The higher output power allows for an increased pulse repetition rate (PRR), while maintaining the necessary pulse energy for efficient material ablation. This means more ablation per second, strongly increasing throughput.

However, with a highly increased PRR comes a new challenge: It's increasingly difficult to avoid the accumulation of too many pulses on one spot of the workpiece. The ultrahigh PRR of modern laser systems simply exceeds the deflection capability of galvanometer-based scanning systems. Resonant and other scanner technologies, reach extremely high scan speeds of more than 1000 m/s, but they suffer from a sinusoidal varying scan speed, leading to an inconsistent spot distance on the workpiece.

To overcome this drawback, the nonlinearity of the resonant scanners can be compensated by a dynamically and synchronously adaptable PRR. In this way a uniform spot distance across the whole scanning range becomes possible. Modern laser systems with dynamically adaptable pulse repetition rates, combined with ultrafast resonant scanners, are great candidates for breaking through the current limitations of high-speed micromachining.

USP laser systems with dynamic PRRs have shown great potential in other applications, like speeding up the processing of narrow curves[1], or homogenizing the ablation with a laser turning machine[2]. In that case, a variable PRR in the kHz range is achieved by picking pulses out of a pulse train with a given base PRR. An important consideration for future applications is whether it is possible to scale this approach to the MHz range.

The following addresses the require-



Initial lab setup for ultrafast micromachining with a resonant scanner and the new laser system.

 Images courtesy of Photonik-Zentrum Kaiserslautern eV.

ments, possible approaches and a working setup for next-generation USP lasers, capable of adapting the pulse repetition rate in the MHz range with a very fine resolution. The requirements will be specified for the resonant scanner, since these are the highest among the possible applications.

Dynamically variable pulse repetition rate

The laser deflection speed in the focal plane of a resonant scanner-based micromachining setup can be described by a sinusoidal function. Since the spot distance is proportional to the scanning speed ($\Delta s = v/PRR$), a repetition rate, which changes proportionally to the deflection speed, leads to a fixed spot distance across the whole scanning range. Moreover, since a resonant scanner typically oscillates in the 10-kHz range, the laser's PRR has to be changed more than 10,000 times per second. Due to the very high velocity of the deflected beam of about 1000 m/s, a high PRR in the MHz range is required to reach an adequate pulse overlap. In order to maintain high accuracy and a precise positioning on the workpiece, the PRR ideally has to be tuned continuously in this range.

In a mode-locked-based USP laser system, the PRR is given by the cavity round-trip time of the laser oscillator. Therefore, the variation of the PRR of these USP lasers is done by pulse picking with the help of fast electro-optical or acousto-optical modulators, suitable for high-power operation. The base PRR can be divided by integers and is reduced to an effective PRR. This is shown in Figure 2 for a base PRR of 10 MHz, 100 MHz, 1000 MHz and a true arbitrary pulse-on-demand operation.

A typical USP laser, operating at a fundamental PRR of 100 MHz, offers very few effective PRRs in the MHz range. If the application requires a PRR variation between 10 MHz and 5 MHz, only 11 individual repetition rates are accessible. This is not enough to ensure high positioning accuracy after the resonant scanner. Only a much higher base PRR — or even an arbitrary pulse-on-demand technology — can fulfill this requirement (Figure 3).

The accuracy of the spots for a base PRR of 100 MHz is only $\Delta s = \pm 4.1$ µm, which is too poor for high precision surface structuring with focus diameters in the 10-µm range. A base PRR of 1 GHz allows for a much higher accuracy of $\Delta s = \pm 0.4$ µm.

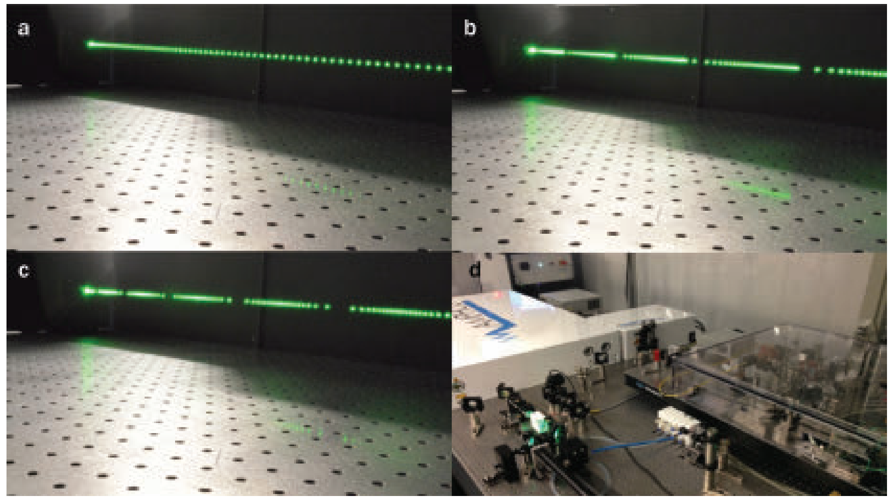


Figure 1. Schematic picture of a pulse train with **(a)** a constant pulse repetition rate (PRR), **(b)** a linear sweep of the PRR, **(c)** a periodic modulation of the PRR and **(d)** a picture of the lab setup of the prototype.

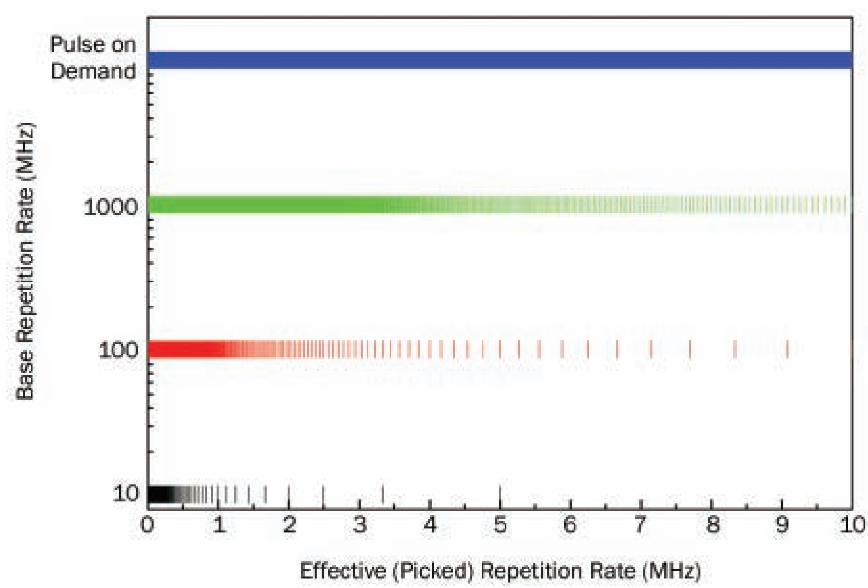


Figure 2. Achievable repetition rates with different seed sources by pulse picking. A higher base PRR enables more possible effective PRRs in the upper MHz range.

This accuracy is competitive with current technologies and sufficient for USP laser micromachining applications.

This calculation also holds true for speeding up the processing of narrow curves or homogenizing the ablation with laser turning machine applications. Processing narrow curves with variable PRRs in the 100-kHz range already ensures high accuracy, since the granularity is fine enough (compare to Figure 2). A true scaling to the MHz range, however, is only achieved if the base PRR is strongly increased or an arbitrary pulse-on-demand setup is used. Increasing the throughput of these applications by an order of magnitude leads to a reduction of a 10-second production process to just one second.

Evaluating semiconductor lasers, ultrafast pulse picking

Using a high-base PRR with ultrafast pulse picking or an arbitrary pulse on-demand technique are the best approaches. A pulse repetition rate in the GHz range requires a short cavity length of a few mm, making semiconductor lasers a feasible option. However, a key challenge is

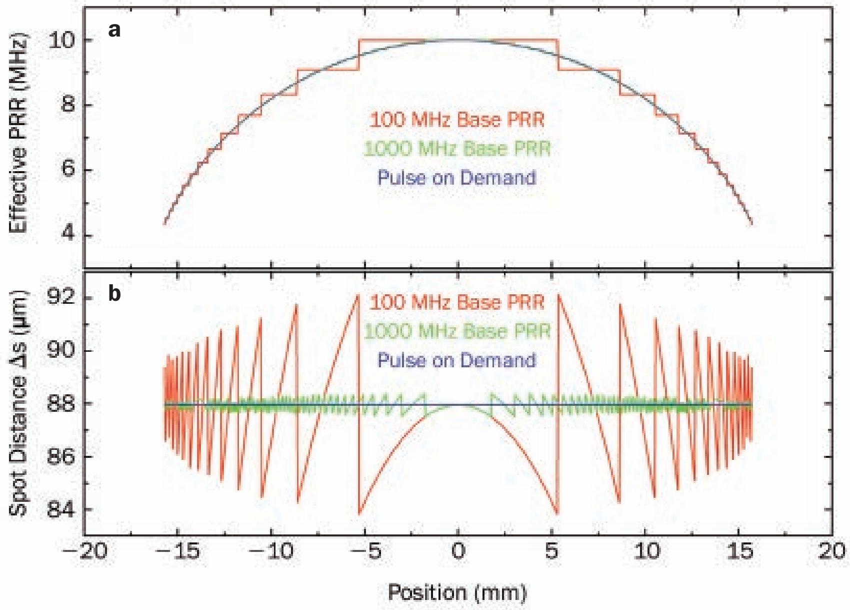


Figure 3. Variation of the repetition rate as the resonant scanner scans the workpiece. As the scan-speed decreases at the turning points, a lower PRR is necessary to maintain the spot distance Δs. Only discrete values are possible for a low base PRR **(a)**. Discrete repetition rates lead to large deviations from the desired spot distance Δs = v/PRR, where v is the continuously varying scan-speed **(b)**.

the amplification of these pulses, with energies in the range of a few pJ, to the required µJ pulse energies. In general, a regenerative amplifier would provide the necessary amplification, but the high and dynamical variable PRR would get lost. So the most feasible way is a combination of a semiconductor oscillator and a linear amplifier chain, consisting, for example, of a fiber pre-amplifier and a solid-state power amplifier. A combination of the best concepts derived from different state-of-the-art technologies will do the job.

USP semiconductor lasers with PRRs between 1 to 10 GHz and ultrafast pulse picking were developed years ago[3] and since then the technology has matured. A mode-locked semiconductor laser oscillator with a base PRR of 4.3 GHz, for instance, was developed by FBH Berlin[4]. Mode locking was achieved in a monolithic Fabry-Perot diode laser resonator. Pulse picking was done by ultrafast pumping of a subsequent waveguide preamplifier beyond the transparency level and back. Gate widths of 200 ps were achieved, short enough for picking single pulses out of the 4.3-GHz pulse train. The setup delivers ultrashort pulses in the 10-ps range with adjustable PRR.

If there is a demand for finer granularity, operators can leave the mode-locking technique and use gain-switching instead. Gain-switching delivers arbitrary pulses on demand, so a discrete base PRR is no longer a concern. The accuracy, then, is only limited by the temporal jitter between the trigger and the emission time of the corresponding pulse, which typically is extremely low. Looking back to the resonant scanner application, the spot distance Δs would be absolutely constant across the whole working range (Figure 3).

The drawback of gain-switching diodes is pulse length. The shortest pulses, directly obtained by gain-switching, are in the range of approximately 40 ps. Many applications would be adversely impacted by the longer pulse duration, in terms of ablation efficiency and thermal impact. Nevertheless, the authors showed that even processing of transparent media is possible with these pulses[5].

Figure 4 shows a schematic of an actual setup, based on gain-switching, that was recently demonstrated[6]. The amplifier chain consists of a fiber pre-amplifier, and an InnoSlab power booster. An optional SHG-stage can convert the 1030-nm radiation to the green spectral range, depending on the application.

Varying pulse energies

A crucial issue for most applications is maintaining a constant pulse energy while changing the pulse repetition rate. Since the PRR is altered in front of the amplifier chain, a closer look at the pulse energy dynamics is required. In general, a lower PRR would result in higher pulse energy for a constant average output power. Varying pulse energies during large-scale processing, however, would have a strong impact on the quality of machined parts.

The very high processing speed helps in addressing this problem. On the one hand, typical laser active media, commonly used in the amplifier chain, exhibit a long upper state lifetime in the ms range. Conversely, the laser's PRR changes more than 10,000 times per second, which means that the repetition rate changes so fast that the amplifier cannot adapt to the new situation. An average, and nearly constant, pulse energy, independent of the PRR, is emitted.

In practice, the relaxation time of the overall amplifier chain depends on a number of parameters, like the number of stages, the pump saturation of each individual stage and the input power. Unfortunately, all of these parameters increase the relaxation rate of the amplifier, so entirely constant pulse energies are typically not achieved. However, an optimized design of the amplifier chain allows for an effective damping of the pulse energy variation (Figure 5). Especially at high sweep-frequencies, a quite constant value is possible. The remaining variation can easily be actively compensated, if necessary.

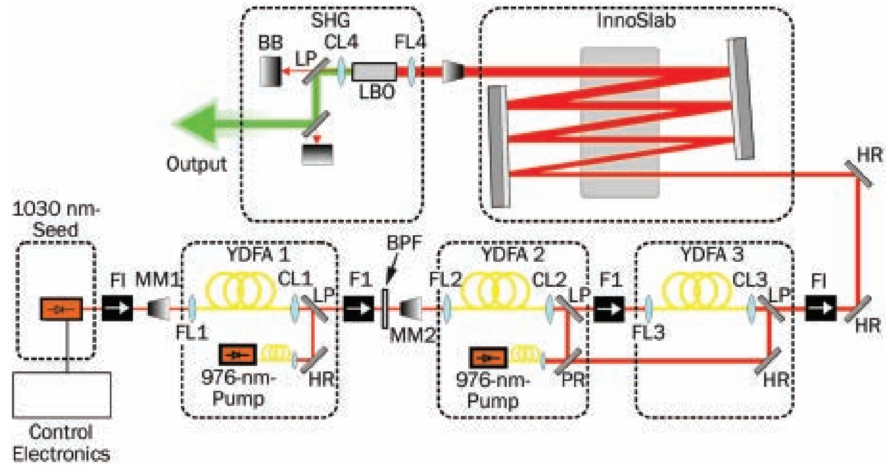


Figure 4. Schematic setup of a highly dynamic laser system. The fiber pre-amplifier was optimized to provide a large small-signal gain combined with minimized amplified spontaneous emission. The output power was 200 W in the IR or 130 W after an optional SHG stage.

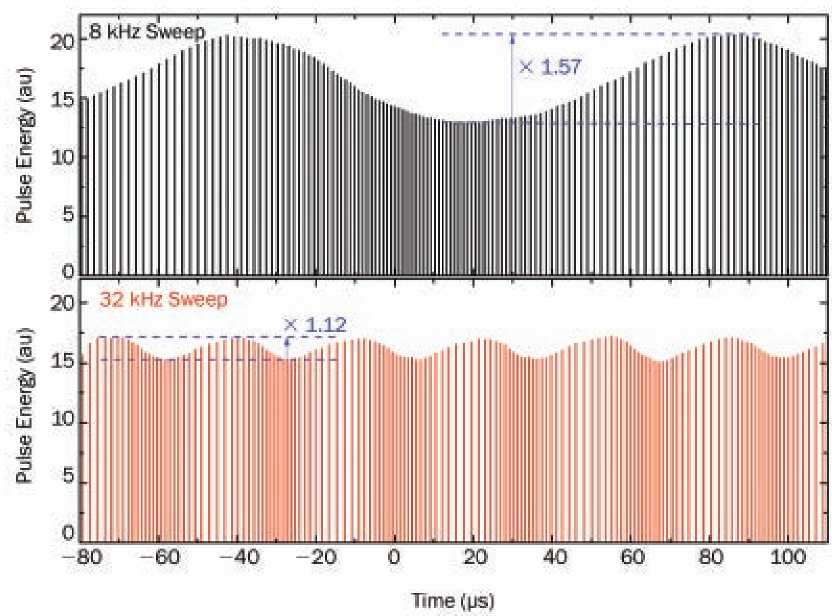


Figure 5. Temporal evolution of the pulse energy for PRRs between 5 MHz and 10 MHz at different sweep-frequencies. For visibility reasons only every 10th pulse is plotted.

Range of pulse repetition rates widens

A USP laser with an average power of more than 200 W with pulse duration of 40 ps or less, depending on the oscillator, has been realized. The PRR can be changed more than 30,000 times per second between 5 MHz and 10 MHz with a pulse energy variation of less than 10 percent without an active compensation. An even wider sweep range of the PRR between a few 100 kHz and 40 MHz and average output powers of more than 400 W are currently under development in a governmental funded project[7]. There, a new type of energy controller is also developed, which operates passively and further smoothens the pulse energy.

With the present system, ultrafast, on-the-fly micromachining of scattering centers for illumination applications have been demonstrated. More than 1.6 million dots per second were written in a polymethyl methacrylate plate with a reproducibility of 1 µm[8]. Further applications, especially with tight trajectories, where the advantages of the new type of laser system are obvious, are under development.

References

1. GFH GmbH (April 2013). UKP-Laser mit hoher Bahngeschwindigkeit, Mikroproduktion.
2. GFH GmbH (January 2016). Der Laserstrahl als Drehwerkzeug, Mikroproduktion.
3. BMBF, Erforschung und Entwicklung von innovativen hybrid-integrierten Diodenlaser-Komponenten und Systemen (INDILAS), 13N9817.
4. A. Klehr et al. (2011). Compact ps-pulse laser source with free adjustable repetition rate and nJ pulse energy on microbench. *Proc SPIE*, Vol. 7953, No. 79531D.
5. F. Harth et al. (2016). Ultra high-speed micromachining of transparent materials using high PRF ultrafast lasers and new resonant scanning systems. *Proc SPIE*, Vol. 9736, No. 97360N.
6. F. Harth et al. (2016). Ultrafast laser with an average power of 120 W at 515 nm and a highly dynamic repetition rate in the MHz range for novel applications in micromachining. *Proc SPIE*, Vol. 9726, No. 972612.
7. Hochleistungs-UKP-Laser zur Mikromaterialbearbeitung mit variabler Pulsfolgefrequenz (HiPoRep), BMWi, VP2837408AB4.
8. F. Harth et al. (2016). Ultra high-speed micromachining of transparent materials using high PRF ultrafast lasers and new resonant scanning systems.

Meet the authors

Florian Harth received his degree in experimental physics at the Technical University of Kaiserslautern in Germany. Since 2009, he has worked in the field of ultrafast laser source development and micromachining at the Photonik-Zentrum Kaiserslautern eV (PZKL); email: florian.harth@pzkl.de.

Thomas Herrmann studied physics at the University of Kaiserslautern and received his Ph.D. degree in 1999. He was co-founder of the ultrafast laser company Lumera Laser GmbH (now Coherent Kaiserslautern) and was head of Lumera's application lab from 2003 to 2009. In 2009, he joined the PZKL and is responsible for the micromachining application center; email: thomas.herrmann@pzkl.de.

Bernhard Henrich studied physics and received his Ph.D. at the University of Kaiserslautern in 2000. He is co-founder of the Lumera Laser GmbH, and developed the first RAPID laser. In 2013, he joined the PZKL as technology manager; email: bernhard.henrich@pzkl.de.

Johannes L'huillier studied physics at the University of Kaiserslautern where he received his Ph.D. in 2003. His research is focused on optical parametric processes, ultrashort laser pulse as well as on laser micromachining. Since 2009 he has served as the CEO of the PZKL; email: johannes.lhuillier@pzkl.de.

Microscopy

Advances in microscopy technology are expanding beyond the life sciences, into applications once thought impossible.

Illuminating **Microscopy** Growth and Demand

Advances in microscopy technology are expanding beyond the life sciences, into applications that were once thought impossible.

BY JUSTINE MURPHY
SENIOR EDITOR

A new mini microscope that uses fluorescence imaging is allowing researchers from the Salk Institute for Biological Studies in La Jolla, Calif., to look deeper into the central nervous system. This could lead to novel pain treatments for spinal cord injuries and neurodegenerative diseases such as ALS. With this and other such work, microscopy is vital technology in the life sciences. But now, microscope advances are being applied in industry, R&D, the consumer market and applications that were not possible before, including digitalization and sensing interfaces.

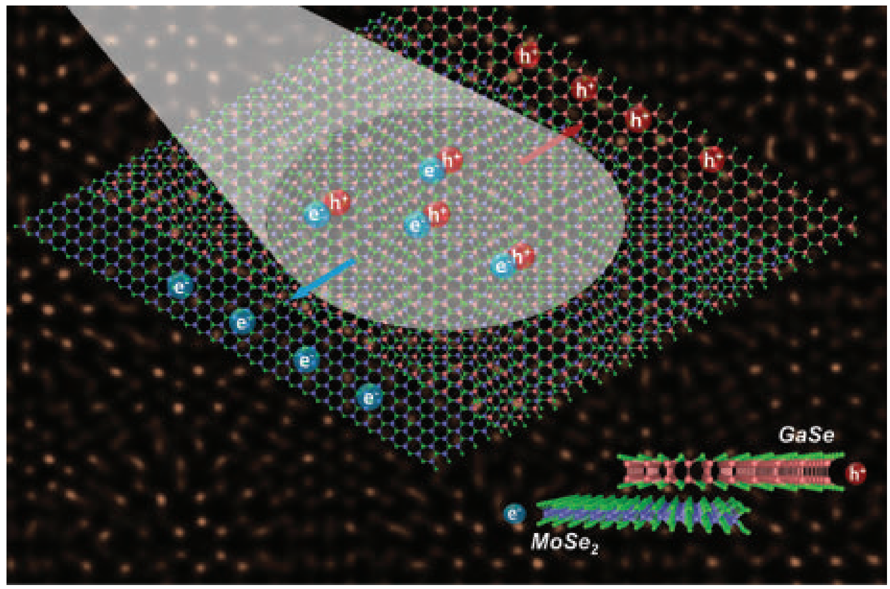
And growth is expected to continue. A recent report by market research firm ReportBuyer sees the global microscopy market expanding at a CAGR of 8.9 percent between 2015 and 2020, pushing it to just over $6.83 billion. The market has seen a considerable increase in R&D funding from the public and private sectors, according to the report, and there has been a rapid shift from conventional tools to integrated digital image analysis systems, in turn boosting demand for innovative microscopy devices.

Photonics Spectra spoke with several industry experts for their take on the state of the microscopy market, as well as trends in research and other advancements in this field.

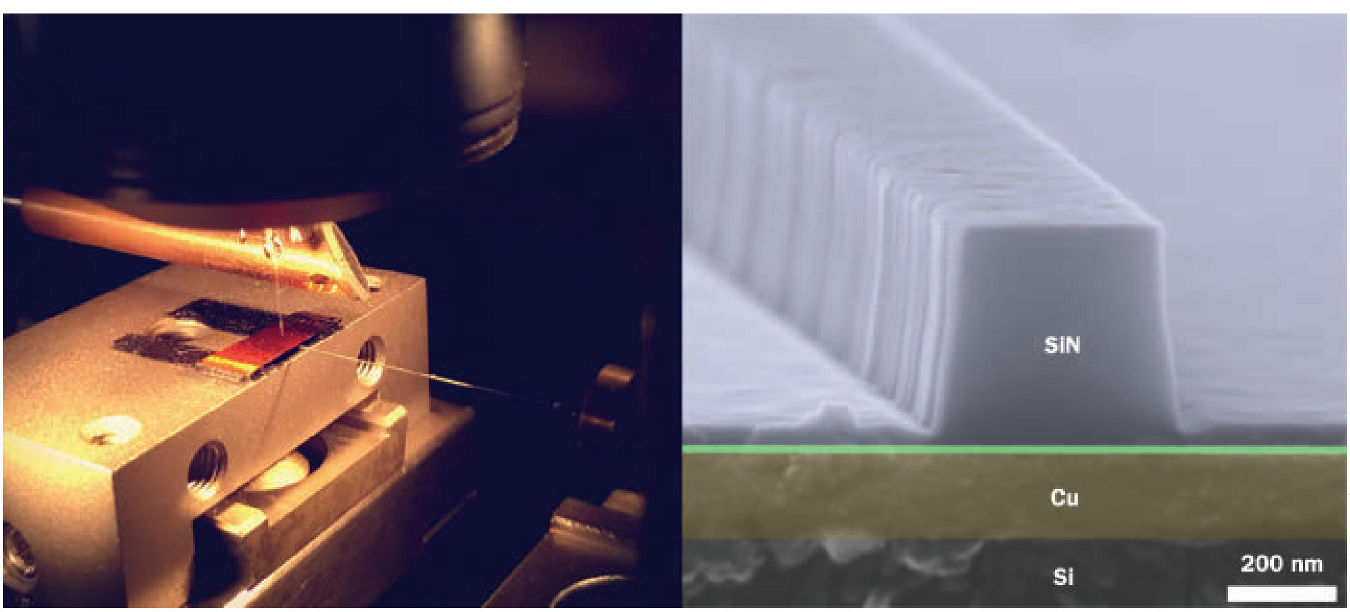
Aydogan Ozcan, Ph.D., Chancellor's Professor in the UCLA Electrical Engineering & Bioengineering departments, HHMI professor at the Howard Hughes Medical Institute, associate director of the California NanoSystems Institute (CNSI) and founder of Holomic/Cellmic LLC.

David K. Welsh, M.D., Ph.D., associate professor of psychiatry at UC San Diego who studies circadian rhythms in single cells using bioluminescence imaging.

Nestor J. Zaluzec, senior materials scientist in the Electron Microscopy Center and Center for Nanoscale



Light drives the migration of charge carriers at the juncture between semiconductors with mismatched crystal lattices. These heterostructures hold promise for advancing optoelectronics and exploring new physics. The schematic's background is a scanning transmission electron microscope image showing the bilayer in atomic-scale resolution.



Nanoscale copper plasmonic waveguides on a silicon chip in a scanning near-field optical microscope **(left)** and their image obtained using electron microscopy **(right)**.

Materials, NanoScience and Technology Division at Argonne National Laboratory.

***Photonics Spectra*: What are some prevalent trends you are seeing in the field of microscopy?**

Welsh: Growth areas are superresolution microscopy, automated EM [electron microscopy] for 3D reconstruction, CLARITY method to prepare 3D samples for imaging, in vivo microscopy of the brain in freely moving mice, and voltage-sensitive fluorescent proteins.

Ozcan: Computational approaches are creating various exciting opportunities to improve microscopy, while at the same time making the designs and instrumentation much more cost-effective, compact and mobile. These open up new opportunities to translate microscopy tools into new areas/applications that were not feasible before.

Zaluzec: There are a lot of trends going on. One of the important things is what we call correlative microscopy, and that is looking at materials, looking at everything in context using what I would call multimodal and multidimensional imaging and characterization — any one image, any one spectra is no longer sufficient to give us all the information we need to fully understand a microstructure, whatever it is, whether it's a cell or a semiconductor, whether it's an atomic resolution image or a low [megapixel] image. Today's technological problems that are impacting society need more than one answer. Cryomicroscopy is being used routinely now to do exciting work in the structure of biological systems. The ability to study materials in near-native environments under conditions that are approaching real world or can be extrapolated in the real world, [is] becoming more and more important, and we're doing those sort of things. The biggest problem I see in many research organizations these days is that they're operating with blinders, [saying] "We've always done things this way. We only use electron systems," or "We only use light." Well, nowadays, we're getting people who at least appreciate the fact that [one type of] microscopy isn't the solution to every problem; we have to use multiple sources. That's where, at least from my perspective, things are going, and it's certainly the direction I'm leaning toward.

***PS*: Some market reports anticipate an increased demand for microscopy devices and systems as the electronic and renewable energy industries grow. Do you find this to be true, and what do you anticipate for the future of microscopy?**

Ozcan: I see an enormous need for microscopy tools in industry, research market, as well as consumer space. I believe our homes, offices, buildings, public spaces, airports, etc. will all benefit from various emerging microscopy-based techniques to get smarter for monitoring chronic patients, elderly populations, or protecting human health using ubiquitous imaging and related sensing interfaces that will work at the background, without many people noticing.

***PS*: Microscopy is a key system in the life sciences. For what applications in particular can microscopy provide the most benefit now, and in what direction should this expand in the future?**

Zaluzec: It comes down to what the relationship is to the properties of the material and structure. You can't understand one without the other. Nowadays everyone is saying, "Well, we can calculate everything." But you can only calculate what you know is right. So you use observations to validate the calculations, then use the calculations to make a prediction, and then you go back to your microstructural analysis to say, "My prediction is this, the microstructure is this, and the properties are this." You've got properties, you've got observations, you've got predictions, and then you've got methodology making something. All of those are interrelated. We have to … try to figure out where we're going, and [determine] what we're trying to do. We want to make a better battery, we want to make a better semiconductor, we want to make a better photovoltaic, better catalyst.

justine.murphy@photonics.com

Holotomography enables real-time visualization of cells

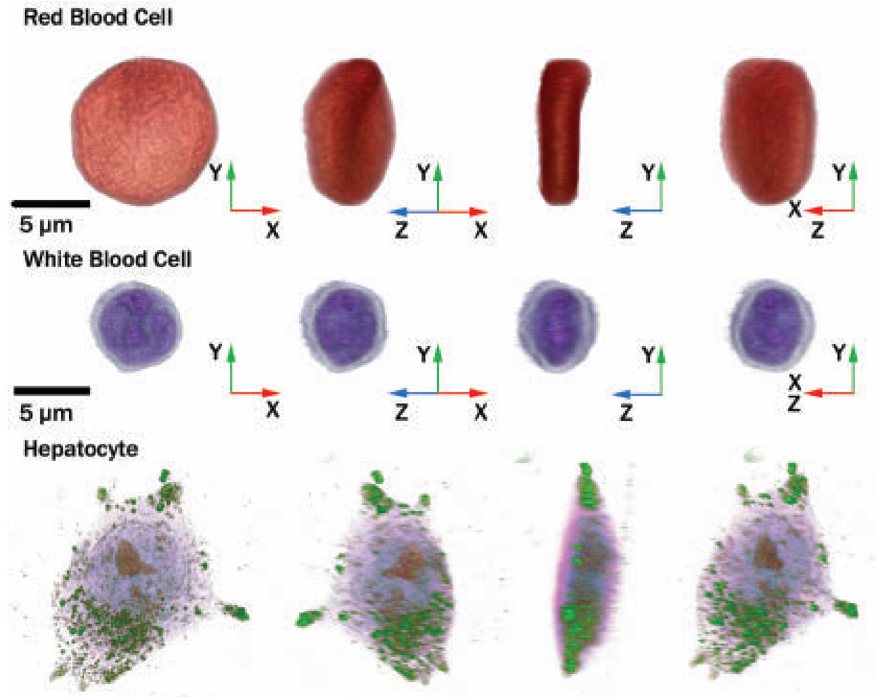
DAEJON, South Korea — A powerful method for imaging live cells without staining now employs a 2D/3D/4D holographic microscope, which allows real-time, label-free visualization of biological samples. A team led by professor Yong-Keun Park of the Korea Advanced Institute of Science and Technology (KAIST), in collaboration with TomoCube (founded by Park), developed the system, which they described as the optical analogy of x-ray computed tomography (CT). The microscopy tool, called holotomography (HT)-1, uses laser illumination, whereas x-ray CT uses x-ray beams.

From the HT-1's measurement of multiple 2D holograms of a cell, coupled with various angles of laser illumination, the 3D refractive index (RI) distribution of the cell can be reconstructed, according to the researchers. The reconstructed 3D RI map provides structural and chemical information of the cell including mass, morphology, protein concentration and dynamics of the cellular membrane.

Among other applications, the team reported on the use of the HT-1 for simultaneous 3D visualization and position tracking of optically trapped particles.

Park said that current fluorescence confocal microscopy techniques require the use of exogenous labeling agents to render high-contrast molecular information, which can lead to high preparation times, photobleaching and phototoxicity, as well as interference with normal molecular activities. Immune or stem cells that need to be reinjected into the body are particularly difficult to employ with fluorescence microscopy.

The Seoul National University Hospital in Bundang, South Korea, and Boramae Hospital in Seoul are now using HT-1, and Park expects that tomographic microscopy will be more widely applied in pharmaceuticals, neuroscience, immunology, hematology and cell biology.



Three-dimensional images of a red blood cell, white blood cell and hepatocyte.

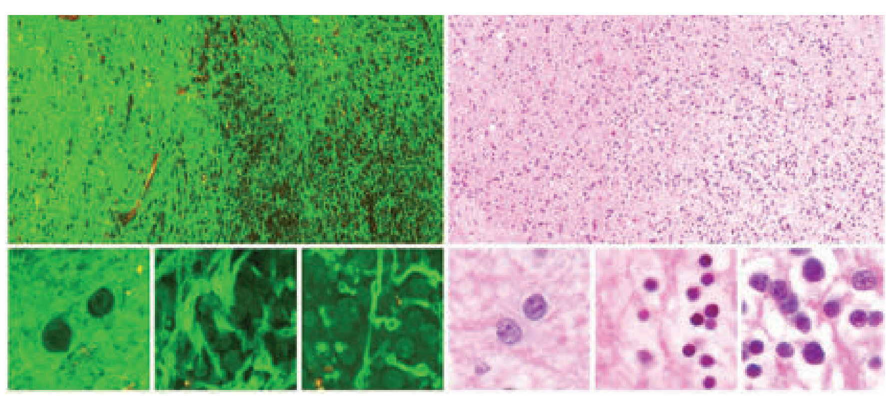
KAIST

Third-harmonic generation microscopy images brain tumors in situ

AMSTERDAM — Neurosurgeons could image and assess brain tumor boundaries during surgery, thanks to a new technique involving third-harmonic generation microscopy. This would provide optical biopsies in near real-time, increasing the accuracy of tissue removal.

Researchers from VU University Amsterdam, led by professor Marloes Groot, have demonstrated a label-free optical method for imaging cancerous brain tissue. They produced most images in under a minute; smaller ones took under one second, while larger images of a few square millimeters took five minutes.

In the study, 200-fs, 1200-nm laser pulses were fired into the tissue. When



Tissue from a patient diagnosed with low-grade glioma. The green image is taken with the new method, while the pink uses conventional hematoxylin and eosin staining. From the upper left to the lower right, both images show increasing cell density due to more tumor tissue. The insets reveal the high density of tumor cells.

N.V. Kuzmin et al./VU University Amsterdam three photons converged at the same time and place, they interacted with the non-linear optical properties of the tissue. Through the phenomena of third-harmonic generation, the interactions produced a single 400- or 600-nm photon (third- or second-harmonic, respectively). The shorter wavelength photon scattered in the tissue, and upon reaching a detector — in this case a high-sensitivity GaAsP photomultiplier tube — the inside of the tissue could be seen. The resulting images enabled clear recognition of cellularity, nuclear pleomorphism and rarefaction of neuropil in the tissue.

Typically, pathologists use staining methods for such imaging, in which chemicals like hematoxylin and eosin turn different tissue components blue and red to reveal the structure and presence of tumor cells. A definitive diagnosis can take up to 24 hours with this existing method, and surgeons may not realize some cancerous tissue has escaped from their attention until after surgery. Brain tumors — specifically glial brain tumors — are often spread out and mixed in with the healthy tissue, presenting a particular challenge. Surgery, irradiation and chemotherapy often cause substantial damage to the surrounding brain tissue.

While the new technique has been used in other applications already — for imaging insects and fish embryos, for example — the researchers said this is the first time it's been used to analyze glial brain tumors.

Hamilton Thorne's sales, net income rise in 2015

BEVERLY, Mass. — Hamilton Thorne Ltd. has reported a record $9.03 million in sales for the 2015 fiscal year, up 4 percent from the previous year. The company attributed the growth to strong sales of computer-assisted sperm analysis products and LYKOS clinical laser systems. It also cited increased revenues from after-sale services and a growing contribution from its newly acquired Oosight product line from PerkinElmer, which allows the user to visualize and quantify structures within an unfertilized egg that are not visible with conventional microscopy.

Fiscal 2015 reported net income totaled $1.03 million, a 20 percent increase over the prior year. Cash flow from operations increased to $1.06 million, up 58 percent for the year, and total cash as of Dec. 31, 2015, increased to $4.3 million.

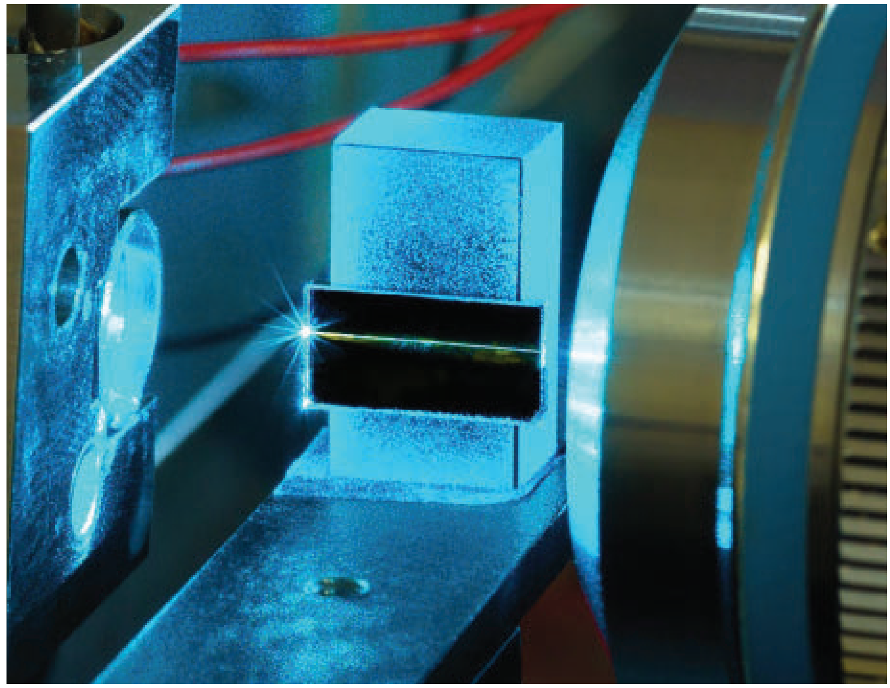
Hamilton Thorne provides precision laser devices and image analysis systems for assisted reproductive technologies, regenerative medicine and developmental biology markets.

Toptica to support laser miniaturization project

MUNICH — Toptica Photonics AG will provide semiconductor laser sources and integration services to PIX4life, a pilot line focused on the development of a compact, fully integrated photonic device; it would replace bulky, expensive optical systems that currently dominate the life sciences sector.

Based on newly developed production technology for CMOS-compatible SiN photonic integrated circuits (PIC), the device will enable advanced biophotonics techniques like optical coherence tomography or multilaser engines on-a-chip for microscopy and cytometry. Toptica plans to provide the required semiconductor laser sources at 405, 488, 561 and 640 nm, and integrate the optical subcomponents into prototypes for microscopy and cytometry.

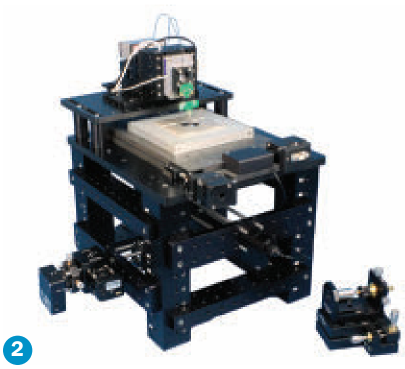
PIX4life is funded by the European Union's Photonics21 program, which has pledged €8.5 million (about $9.6 million) to a consortium of academic and industry partners.


Toptica Photonics

A photonic integrated circuit.

microscopy new products

1



2

1 Toolmakers' Microscope

Mitutoyo America Corp. has announced the TM Microscope Series for toolmakers, designed for measuring dimensions and angles of machined metals. The device can also be used to check the shape of screws and gears by attaching an optional reticle. A compact body allows for use on shop floors with limited space. A C-mount camera can be connected to the eyepiece through an adapter, turning the microscopes into video inspection systems. Newly designed LED illuminators provide enhanced observation for high accuracy and resolution.

www.mitutoyo.com

2 NSOM Microscope

Mad City Labs Inc.'s MCL-NSOM is a near-field scanning optical microscope (NSOM). The aperture NSOM is built on the company's RM21 inverted optical microscope, enabling conversion of the system to aperture-less NSOM, atomic force microscopy and fluorescence optical microscopy. Six axes of automated positioning are provided, including independent automation for fiber alignment to the optical axis, and are controlled with LabVIEW-based software. The system includes a fiber launch with excitation source, alignment camera and detection avalanche photodiode, but can also accommodate user ancillary excitation and detection optics.

sales@madcitylabs.com

microscopy events

JUNE

● **CLEO (June 5-10)** San Jose, Calif. Contact +1 202-416-1907, info@cleoconference.org; www.cleoconference.org.

● **Optatec (June 7-9)** Frankfurt, Germany. Contact +49 0-7025-9206-0, info@schall-messen.de; www.optatec-messe.de.

JULY

● **Microscopy & Microanalysis (July 24-28)** Columbus, Ohio. Contact +1 703-234-4115, associationmanagement@microscopy.org; www.microscopy.org/MandM/2016.

AUGUST

OSA Latin America Optics & Photonics Conference (Aug. 22-25) Medellin, Colombia. Contact +1 202-223-8130, info@osa.org; www.osa.org/meetings.

OCTOBER

● **Photonex 2016 (Oct. 12-13)** Coventry, England. Contact +44 0-1372-750555, info@xmarkmedia.com; www.photonex.org.

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

NOVEMBER

● **Vision 2016 (Nov. 8-10)** Stuttgart, Germany. Contact +49 711-18560-0, info@messe-stuttgart.de; www.messe-stuttgart.de/vision.

● **Neuroscience 2016 (Nov. 12-16)** San Diego. Contact +1 202-962-4000, program@sfn.org; www.sfn.org.

DECEMBER

● **ASCB Annual Meeting 2016 (Dec. 3-7)** San Francisco. Contact +1 301-347-9300, ascbinfo@ascb.org; www.ascb.org.

● Indicates shows **Photonics Media** will be attending.

Microscopes for Materials Research Directory

Photonics Spectra presents a select list of companies from around the world that manufacture or supply microscopes for materials research and microscope stages. The list was compiled using data submitted for the 2016 *Photonics Buyers' Guide*. For more information, visit PhotonicsBuyersGuide.com.

Microscope Stages

Applied Scientific Instrumentation Inc.
Eugene, Ore.
www.asiimaging.com

Buehler Ltd.
Lake Bluff, Ill.
www.buehler.com

Chromaphor Analysen-Technik GmbH
Oberhausen, Germany
www.chromaphor.de

Clemex Technologies Inc.
Longueuil, Quebec, Canada
www.clemex.com

Delmic BV
Delft, Netherlands
www.delmic.com

Leica Microsystems GmbH
Wetzlar, Germany
www.leica-microsystems.com

Mad City Labs Inc.
Madison, Wis.
www.madcitylabs.com

McBain Systems
Simi Valley, Calif.
www.mcbainsystems.com

Meiji Techno America
San Jose, Calif.
www.meijitechno.com

Nanosurf AG
Liestal, Switzerland
www.nanosurf.com

Optophase
Lyon, France
www.optophase.com

piezosystem jena GmbH
Jena, Germany
www.piezosystem.com

piezosystem jena Inc.
Hopedale, Mass.
www.piezo-usa.com

Prior Scientific Inc.
Rockland, Mass.
www.prior.com

Prior Scientific Instruments Ltd.
Cambridge, England
www.prior.com

Santa Barbara Imaging LLC
Santa Barbara, Calif.
www.santabarbaraimaging.com

Scientifica Ltd.
Uckfield, England
www.scientifica.uk.com

SmarAct GmbH
Oldenburg, Germany
www.smaract.de

TOFRA Inc.
Palo Alto, Calif.
www.tofrainc.net

Microscopes, Atomic Force

Accurion GmbH
Goettingen, Germany
www.accurion.com

Accurion Inc.
Linthicum Heights, Md.
www.accurion.com

AIST-NT Inc.
Novato, Calif.
www.aist-nt.com

Asylum Research
Santa Barbara, Calif.
www.asylumresearch.com

Bruker Nano Surfaces
Tucson, Ariz.
www.bruker.com/nano

Hitachi High Technologies America Inc., Life Sciences and Nanotechnology Div.
Dallas
www.hitachi-hightech.com

Mad City Labs Inc.
Madison, Wis.
www.madcitylabs.com

Molecular Vista Inc.
San Jose, Calif.
www.molecularvista.com

Nanonics Imaging Ltd.
Jerusalem
www.nanonics.co.il

Nanoscience Instruments Inc.
Phoenix
www.nanoscience.com

Nanosurf AG
Liestal, Switzerland
www.nanosurf.com

SciTech Pty. Ltd.
Preston, Australia
www.scitech.com.au

VLSI Standards Inc.
Milpitas, Calif.
www.vlsistandards.com

WITec GmbH
Ulm, Germany
www.witec.de

Microscopes, Metallurgical

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

Buehler Ltd.
Lake Bluff, Ill.
www.buehler.com

Capovani Brothers Inc.
Scotia, N.Y.
www.capovani.com

Clemex Technologies Inc.
Longueuil, Quebec, Canada
www.clemex.com

Excel Technologies Inc.
Enfield, Conn.
www.extec.com

KEYENCE Microscopes
Itasca, Ill.
www.digitalmicroscope.com

Labovision Microscopes
Ambala, India
www.labovision.in

LECO Corp.
Saint Joseph, Mich.
www.leco.com

Leica Microsystems AG, Industry Div.
Heerbrugg, Switzerland
www.leica-microsystems.com

Leica Microsystems GmbH
Wetzlar, Germany
www.leica-microsystems.com

Meiji Techno America
San Jose, Calif.
www.meijitechno.com

Microscience Group Inc.
St. Albans, W.Va.
www.preiser.com

MIS Inc.
Villa Park, Ill.
www.paxit.com

Olympus Scientific Solutions Americas, Industrial Microscopes
Waltham, Mass.
www.olympus-ims.com

Opto GmbH
Graefelfing, Germany
www.opto.de

UNITRON Ltd.
Commack, N.Y.
www.unitronusa.com

Vision Engineering Inc.
New Milford, Conn.
www.visioneng.us

Microscopes, Polarizing

Carl Zeiss Microscopy GmbH, Microscopy
Jena, Germany
www.zeiss.com/microscopy

Guangzhou Micro-shot Technology Co. Ltd.
Guangzhou, China
www.m-shot.com

Labovision Microscopes
Ambala, India
www.labovision.in

Leica Microsystems
Buffalo Grove, Ill.
www.leica-microsystems.com

Leica Microsystems AG, Industry Div.
Heerbrugg, Switzerland
www.leica-microsystems.com

Meiji Techno America
San Jose, Calif.
www.meijitechno.com

The McCrone Group
Westmont, Ill.
www.mccrone.com/instrument-sales

Microscopes, Scanning Electron

Capovani Brothers Inc.
Scotia, N.Y.
www.capovani.com

Carl Zeiss Microscopy GmbH, Microscopy
Jena, Germany
www.zeiss.com/microscopy

Delmic BV
Delft, Netherlands
www.delmic.com

Herzan
Laguna Hills, Calif.
www.herzan.com

Hitachi High Technologies America Inc., Life Sciences and Nanotechnology Div.
Dallas
www.hitachi-hightech.com

Imina Technologies SA
Lausanne, Switzerland
www.imina.ch

JEOL USA Inc.
Peabody, Mass.
www.jeolusa.com

Nanoscience Instruments Inc.
Phoenix
www.nanoscience.com

Nanounity
Santa Clara, Calif.
www.nanounity.com

Particle Technology Labs (PTL)
Downers Grove, Ill.
www.particletechlabs.com

Quartz Imaging Corp.
Vancouver, British Columbia, Canada
www.quartzimaging.com

Raith America Inc.
Islandia, N.Y.
www.raith.com

Staib Instruments Inc.
Williamsburg, Va.
www.staibinstruments.com

TESCAN Brno sro
Brno, Czech Republic
www.tescan.com

Microscopes, Scanning Probe

AIST-NT Inc.
Novato, Calif.
www.aist-nt.com

Asylum Research
Santa Barbara, Calif.
www.asylumresearch.com

Bruker Nano Surfaces
Tucson, Ariz.
www.bruker.com/nano

Delta Photonics
Ottawa, Ontario, Canada
www.deltaphotonics.com

Fries Research & Technology (FRT) GmbH
Bergisch Gladbach, Germany
www.frt-gmbh.com

Herzan
Laguna Hills, Calif.
www.herzan.com

LOT-QuantumDesign Ltd.
Leatherhead, England
www.lot-qd.co.uk

Mad City Labs Inc.
Madison, Wis.
www.madcitylabs.com

Molecular Vista Inc.
San Jose, Calif.
www.molecularvista.com

Nanonics Imaging Ltd.
Jerusalem
www.nanonics.co.il

Nanoscience Instruments Inc.
Phoenix
www.nanoscience.com

Nanounity
Santa Clara, Calif.
www.nanounity.com

Oxford Instruments, Nanoscience
Abingdon, England
www.oxford-instruments.com/nanoscience

WITec GmbH
Ulm, Germany
www.witec.de

Microscopes, Scanning Tunneling

Asylum Research
Santa Barbara, Calif.
www.asylumresearch.com

Bruker Nano Surfaces
Tucson, Ariz.
www.bruker.com/nano

Molecular Vista Inc.
San Jose, Calif.
www.molecularvista.com

Nanoscience Instruments Inc.
Phoenix
www.nanoscience.com

Oxford Instruments, Nanoscience
Abingdon, England
www.oxford-instruments.com/nanoscience

Microscopes, Stereo

Advanced Imaging Concepts Inc.
Princeton, N.J.
www.aic-imagecentral.com

AVEN

Aven Inc.
Ann Arbor, Mich.
www.aveninc.com

Buehler Ltd.
Lake Bluff, Ill.
www.buehler.com

Capovani Brothers Inc.
Scotia, N.Y.
www.capovani.com

Carl Zeiss Microscopy GmbH, Microscopy
Jena, Germany
www.zeiss.com/microscopy

Excel Technologies Inc.
Enfield, Conn.
www.extec.com

Guangzhou Micro-shot Technology Co. Ltd.
Guangzhou, China
www.m-shot.com

Labovision Microscopes
Ambala, India
www.labovision.in

LECO Corp.
Saint Joseph, Mich.
www.leco.com

Leica Microsystems
Buffalo Grove, Ill.
www.leica-microsystems.com

Leica Microsystems AG, Industry Div.
Heerbrugg, Switzerland
www.leica-microsystems.com

Leica Microsystems GmbH
Wetzlar, Germany
www.leica-microsystems.com

Meiji Techno America
San Jose, Calif.
www.meijitechno.com

Microscience Group Inc.
St. Albans, W.Va.
www.preiser.com

MIS Inc.
Villa Park, Ill.
www.paxit.com

Olympus Scientific Solutions Americas, Industrial Microscopes
Waltham, Mass.
www.olympus-ims.com

Opto GmbH
Graefelfing, Germany
www.opto.de

The McCrone Group
Westmont, Ill.
www.mccrone.com/instrument-sales

UNITRON Ltd.
Commack, N.Y.
www.unitronusa.com

Vision Engineering Inc.
New Milford, Conn.
www.visioneng.us

Vision Engineering Ltd.
Woking, England
www.visioneng.com

Vitro Technology Ltd.
Milford, Conn.
www.vitrotech.com

White Bear Photonics LLC
White Bear Lake, Minn.
www.whitebearphotonics.com

Microscopes, Transmission Electron

Hitachi High Technologies America Inc., Life Sciences and Nanotechnology Div.
Dallas
www.hitachi-hightech.com

JEOL USA Inc.
Peabody, Mass.
www.jeolusa.com

1

2

3

4

5

6

1 Absorption Sensor

Ushio America Inc. offers the PAS-110 PiCOEXPLORER, a palm-top photoabsorption sensor that can be controlled by a smartphone or tablet. Allowing quick density measurement and detection of protein, heavy metals, endocrine disruptors and DNA, this fluorescence detections system does not require use of a pipette. Measurement and analysis is enabled in an unopened PCR tube, incorporating a communications function that allows display of the result in a mobile device.
gbaer@ushio.com

2 Hexapod

The HEX500-350HL high-load, precision hexapod from **Aerotech Inc.**'s HexGen series is designed for applications in x-ray diffraction, sensor testing and high-force device manipulation. Aerotech's A3200 motion control software drives the hexapod, which is actuated with 6 high-accuracy struts built with precision preloaded bearings, ball screws and drive components. The HEX500-350HL is designed with a 150-mm-diameter clear aperture in both the platform and base to allow for workpiece access from the bottom. The hexapod can be vacuum prepared for applications in synchrotron sample or optics adjustment, semiconductor manufacturing and inspection, or satellite sensor testing.
smclane@aerotech.com

3 Silver Mirrors

Newport Corp. offers FemtoOptics femtosecond optimized silver mirrors, available flat or concave with a radius of curvature ranging from 100 to 3000 mm. The 1-in. mirrors have been optimized for the 0 to 45° angle of incidence steering of ultrafast laser beams, providing R>99 percent from 600 to 1100 nm or R>97 percent from 470 to 1000 nm. A proprietary coating design provides near zero group velocity dispersion across the full specified wavelength range.
anna.wang@newport.com

4 2D Measurement Device

Titan Tool Supply Inc. distributes the V-CAD Rapid 2D optical measurement device from Schneider Messtechnik GmbH, for accurate and precise measurement of workpieces. The device automatically recognizes geometric primitives without preselection and with no need for manual alignment of workpieces. Features include a 5-MP CCD black and white camera, a telecentric four-step motorized zoom lens, four different fields of view, telecentric LED transmitted light illumination and LED ring light illumination for incident light measurement. Multiple processing and analysis software options are available.
info@titantoolsupply.com

5 Optical Attenuator

GLsun Science and **Tech Co. Ltd.** have announced the Micro-Electro-Mechanical System Variable Optical Attenuator (MEMS VOA), a precise and adjustable voltage-driven optical component. The device features a MEMS chip, and low cross-talk and insertion loss. Driving voltage produces electrostatic force to drive the chip's micromirror and adjust output optical power. The compact package can be easily integrated into high-density optical communications systems.
song@glsun.com

6 Spectrum Analyzer

Resolution Spectra Systems offers WIDE Spectra, an ultrahigh-resolution laser spectrum analyzer for widely tunable lasers. The instrument is designed to monitor lasers over tens or hundreds of nanometers in the visual to near-infrared range of 630 to 1100 nm. It is compatible with continuous and pulsed laser sources, including single pulse, and can also operate as a multiwavelength meter.
delphine.simiand@resolutionspectra.com

Bias Controller

Coherent Solutions Ltd. offers IQABC, an automatic bias controller for IQ modulators. Enabling full automatic control of an IQ modulator's direct current biases, the device is modulation format-independent, allowing simple generation of optical signals. It also maintains optimization against any bias drifts or changes to the driving signal. The device is targeted toward optical engineers working on coherent optical communications.
sales@coherent-solutions.com

Camera Board

Euresys SA has announced the Coaxlink Duo PCIe/104 commercial off-the-shelf CoaXPress board with two CXP-6 camera connections and a PCIe 2.0 ×4 bus. A single coaxial cable is used to transmit data at speeds of 625 MBps, simultaneously transmitting control data and triggers, providing up to 13 W of power to the camera. An extended temperature range from −40 to 71 °C is featured with conduction cooling. Ambient temperature is measured outside the enclosure. The device is stackable card compliant and ruggedized for high levels of shock and vibration in defense and high-end surveillance applications.
sales.america@euresys.com

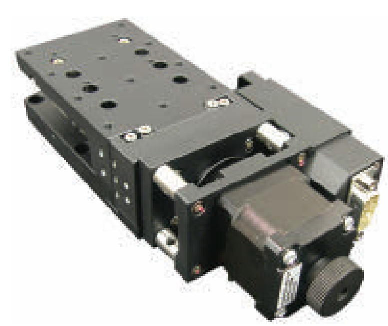
LED Controller

Linear Technology Corp.'s LT8391 synchronous buck-boost DC/DC LED controller regulates LED

current from input voltages above, below and equal to the output voltage. Its 4- to 60-V input voltage range makes it ideal for automotive, industrial and architectural lighting applications. Output voltage can be set from 0 to 60 V, enabling the driving of a wide range of LEDs in a single string. An internal four-switch buck-boost controller, combined with four external C-channel metal-oxide-semiconductor field-effect transistors, deliver 10 to over 100 W of LED power.
jhamburger@linear.com

Illuminance Spectrophotometer

The ILT350 illuminance spectrophotometer from **International Light Technologies Inc.** is a low-cost, handheld lux and color measurement spectrophotometer with NIST-traceable and ISO 17025-accredited calibration designed for making light measurements in the field. It offers three measurement speeds in the range of 380 to 780 nm, a dynamic range of 20 to 10,000 lux, and data storage for up to 100 readings. It comes with a built-in 12-mm-diameter cosine correcting receptor and magnetic protective cover. The spectral bandwidth is about 2.5 nm (half bandwidth) with ± 0.3-nm wavelength accuracy.
www.intl-lighttech.com



Elevator Stage

The AZ60-A motorized vertical elevator stage from **Optimal Engineering Systems Inc.** is a low-profile,

compact device for applications requiring precise vertical positioning. The 60 × 95-mm drilled and tapped stage has a vertical travel of 4 mm. Six crossed roller guides and a precision ground 8-mm, 250-µm/turn lead ball screw provide smooth, straight vertical motion to <5 µm. High resolution for full step is 1.25 µm, with 0.625 µm for half step and 0.125 µm for microstep. Travel speeds are featured up to 2.5 mm/s. Applications include optical positioning, test and inspection, and laser drilling and machining for industrial, medical, semiconductor and research uses.
sales@oesincorp.com

Thermal Camera

Boson, an uncooled thermal camera from **Flir Systems Inc.** provides high-resolution thermal imaging for OEMs. Boson offers 15 field-of-view options, a 12-µm pixel pitch detector, inputs for other sensors, and many video and image-processing features, such as superresolution algorithms, noise reduction, contrast enhancement and image blending. OEMs can use the camera in areas such as firefighting, automotive, maritime, hunting, military and unmanned aerial systems.
www.flir.com

Fiber-Blowing System

Fiber Optic Center Inc. has announced a line of fiber-blowing solutions to address challenges in existing infrastructure and in the ground. The Miniflow Rapid is compact and capable of installing fiber cable at speeds of up to 100 m/min. and up to a distance of 3.5 km. The Multiflow is designed for the blowing of multiple combinations of duct and microducts. The Microflow features protection technology to stop the machine if the fiber cable meets an obstacle. The Powerflow can blow cables with a speed of up to 80 m/min. with distances up to 10 km, installing fiber optic cables using either air or water.
sales@focenter.com

Spectral Light Meter

The MSC15 spectral light meter from **Gigahertz-Optik Inc.** is designed for conventional and LED light-source qualification.The meter measures scotopic and photopic (S and P) illuminance, S/P ratio, color, photosynthetically active radiation, Bilirubin and light spectra. It features color touch-

screen operation and dark current cancellation without a zeroing cap. The device is designed for lighting engineers, designers and manufacturers/distributors, as well as facility managers, safety officers, architects and interior designers.
n.angelo@gigahertz-optik.com

H_2O Analyzer

Tiger Optics LLC offers the Aloha+ H_2O analyzer, refining the detection of moisture in ammonia to levels down to 2 parts per billion, achieving five times the sensitivity of incumbent technology. The analyzer addresses the needs of high-brightness LED makers, tool manufacturers, purifier makers and the gas companies that supply ammonia for GaN semiconductor wafers. The compact analyzer fits two to a 19-in. rack and features laser-based technology.
lyang@tigeroptics.com

Fiber Laser Optics

Mate Precision Tooling offers the Fibermax Lens and Fibershield Windows for high-power fiber laser systems. Featuring OEM-approved, UV-grade fused

silica material, sizes are available for most OEM brand fiber lasers. Designed for high performance, the lenses feature ultralow absorption coating to provide focal stability, less distortion and thermal lensing. Fibershield Windows are designed with extra durability to handle harsh manufacturing environments. The antireflection-coated windows have tight tolerance surfaces, diameter and edge thickness, with clear apertures for maximum absorption and reflection.
marketing@mate.com

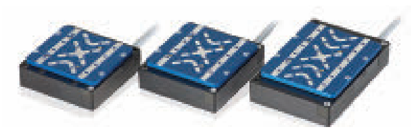
DFB Laser Diodes

Oclaro Inc. has qualified its nonhermetic 25-Gbps, 1.3-µm distributed feedback (DFB) laser diodes for 25- and 100-Gbps optical transceivers used in transmission client interface, high-end spine switch/core router interfaces and large-scale data center meshed networks. Featuring low operating current at high temperatures, the DFB is a key component for enabling data center operators to transition faster to highly meshed 100-Gbps connections over single-mode fiber.
americas@oclaro.com

Image Sensor

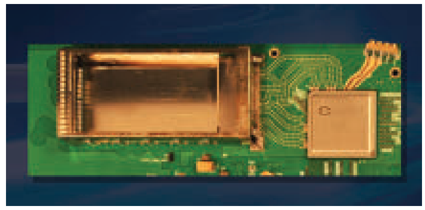
Ambarella Inc. offers the S5 System-on-Chip (SoC) for 4K and multi-imager IP (Internet Protocol) cameras for the surveillance industry. The S5 offers advanced features including 4K multiexpo-

sure high dynamic range fusion, 360° dewarp and ultralow-light processing. Maximum performance is 4Kp120 or 8Kp30 of H.264/AVC and 4Kp60 frames of H.265/HEVC, while supporting flexible multistreaming, rate control and transcoding functions. The S5 supports the Main10 HEVC profile for representation of high-contrast scenes and a wide color gamut.
www.ambarella.com



Linear Stages

Physik Instrumente LP has announced the V-52x series of high dynamic linear stages as part of its PIMag line of products. Six variations are available with travel ranges of 5, 10 and 20 mm, as well as a maximum velocity of 250 mm/s. Frictionless drive, an integrated optical linear encoder and precision crossed roller bearings with anticreep cage assist provide high positioning resolution and guiding accuracy. The stages are designed for industry and research scanning applications such as biotechnology, laser beam control, optics scanning, lens testing and fiber optics.
sales@pi-usa.us



Networking Platform

Systems-on-chip developer **Clariphy** offers a complete 16-nm ADC and DAC platform for multiterabit data and telecom networking. The platform enables 64 QAM modulation to achieve greater than 70 Tbps per fiber and more than 50 percent power reduction to double system capacity. Its full-speed, 4-channel ADC and DAC supports variable baud rates to enable a true Flex Coherent solution programmable up to 400 G per wavelength, while delivering performance that meets or exceeds critical analog specifications such as bandwidth, effective number of bits and jitter.
sales@clariphy.com

Neutral Density Filter

The Bullseye inverted apodizing neutral density filter from **Reynard Corp.** eliminates undesirable intensity variations in optical systems. Filter density increases radially from a clear center, where light is usually at its peak intensity, to the outside edge, where it becomes completely opaque. Density gradients can be customized to suit any application. The filter can be applied to a number of different substrate types and can be designed to be used from the UV to far-infrared wavelengths. Applications include use in entertainment, imaging, photography, industry and astronomy, among other fields.
sales@reynardcorp.com

Measurement System

The OptiGauge LT noncontact thickness measurement system from **Lumetrics Inc.** no longer requires a dedicated controller and can be operated with a customer's own PC or laptop. The system has a measurement range of 12-µm to 5-mm optical thickness with an accuracy of ± 2 microns.
sales@lumetrics.com

CMOS Sensor

ON Semiconductor offers the AR1337 CMOS digital image sensor with a 1/3.2-in format and back-side illumination targeted for consumer electronics products. The sensor incorporates high-performance SuperPD phase detect autofocus pixel technology, delivering focus speeds of 300 ms or less, even in low lighting conditions below 25 lux. The active-pixel array with a 4208 × 3120 arrangement delivers realistic image quality

with a best-in-class signal-to-noise ratio. Quantum efficiency reaches 82 percent.
www.onsemi.com

Double-Clad Fiber

OFS Fitel LLC, a Furukawa company, has released TrueLase 10/130 active and passive large-mode-area double-clad optical fibers. The ytterbium-doped gain and matching passive fibers enable designers to produce high-performance, reliable, and consistent lasers and amplifiers, utilizing true single-mode fiber designs.
ddouglass@ofsoptics.com

● Happenings

JUNE

OSA Optical Interference Coatings Topical Meeting (June 19-24) Tucson, Ariz. Contact +1 202-223-8130, info@osa.org; www.osa.org/meetings.

● **Sensors Expo (June 21-23)** San Jose, Calif. Contact +1 617-219-8300, sensors@xpressreg.net; www.sensorsexpo.com.

CARS 2016 International Congress and Exhibition (June 21-25) Heidelberg, Germany. Contact +49 7742-922-434, office@cars-int.org; www.cars-int.org.

Asia Smart Wearable Devices (June 23-24) Beijing. Contact Vivi Ye, +86 21-5258-8005, Ext. 8106; vivi.ye@duxes.cn; www.duxes-events.com/swdap2.

● **SPIE Astronomical Telescopes + Instrumentation (June 26-July 1)** Edinburgh, Scotland. Contact +1 360-676-3290,customer service@spie.org; spie.org/x13662.xml.

JULY

● **SEMICON West (July 12-14)** San Francisco. +1 408-943-6900, semiconwest@semi.org; www.semiconwest.org.

OSA International Conference on Ultrafast Phenomena (July 17-22) Santa Fe, N.M. Contact +1 202-223-8130, info@osa.org; www.osa.org/meetings.

OSA Applied Industrial Optics (AIO) Conference (July 25-28) Heidelberg, Germany. Contact +1 202-223-8130, info@osa.org; www.osa.org/meetings.

CMSC (July 25-29) Nashville, Tenn. The Coordinate Metrology Society Conference. Contact CMS, +1 425-802-5720, www.cmsc.org.

AUGUST

OSA Latin America Optics & Photonics Conference (Aug. 22-25) Medellin, Colombia. Contact +1 202-223-8130, info@osa.org; www.osa.org/meetings.

IEEE International Conference on Group IV Photonics (Aug. 24-26) Shanghai. Contact +1 732-562-3895, m.figueroa@ieee.org; www.gfp-ieee.org.

● **SPIE Optics + Photonics (Aug. 28-Sept. 1)** San Diego. Contact +1 360-676-3290, customer service@spie.org; spie.org/optics-photonics.xml.

SEPTEMBER

China International Optoelectronic Exposition (CIOE) (Sept. 6-9) Shenzhen, China. Contact +86 755-86290891, cioe@cioe.cn; www.cioe.cn/en.

SEMICON Taiwan (Sept. 7-9) Taipei, Taiwan. Contact Jasmin Liu, +886 3-560-1777 Ext. 307/309; semicontaiwan@semi.org; www.semicontaiwan.org.

Executive Infrared Imaging Forum (Sept. 8) Shenzhen, China. Contact Clotilde Fabre, Yole Developpement, +33 472-83-0180, fabre@yole.fr; www.yole.fr.

● **ENOVA Paris (Sept. 14-15)** Paris. Technology exhibition focusing on electronics, embedded measurement, vision, optics and Internet of Things. Contact Nadège Venet, + 33 0-144-318-257, nadege.venet@gl-events.com; www.enova-event.com.

European MEMS Summit (Sept. 15-16) Stuttgart, Germany. Contact SEMI, +1 408-943-6900; semihq@semi.org; www.semi.org.

● **ECOC (Sept. 18-22)** Düsseldorf, Germany. 42nd European Conference and Exhibition on Optical Communication. Contact Event Administrator Luisa Margione, +44 0-1732-752125, luisa.margione@nexusmediaevents.com; www.ecoc2016.de.

Strategic Materials Conference (Sept. 20-21) Mountain View, Calif. Contact SEMI, +1 408-943-6900; semihq@semi.org; www.semi.org.

OCTOBER

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

● **OSA 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.

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.

NOVEMBER

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

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

PAPERS

SPIE Photonics West (Jan. 28-Feb. 2, 2017) San Francisco
Deadline: Abstracts, July 18
Photonics West is the world's largest multidisciplinary event focusing on photonics technologies, and features more than 4,800 papers presented in the areas of biomedical optics and biophotonics, industrial lasers and laser sources, optoelectronics devices and materials, nanophotonics, and MOEMS-MEMs. Submissions are accepted for BiOS, LASE and OPTO programs. Contact SPIE, +1 888-504-8171; customerservice@spie.org; www.spie.org/conferences-and-exhibitions/photonics-west.

Photoptics 2017 (Feb. 27-March 1, 2017) Porto, Portugal
Deadline: Regular papers, Sept. 22; position papers, Nov. 3
The 5th edition of Photoptics will feature three tracks on optics, photonics and lasers, covering both theoretical and practical aspects. Researchers, engineers and practitioners interested in any of these fields are invited to present work on new methods or technologies, advanced prototypes, systems, tools and techniques, as well as general survey papers indicating future directions. Contact Photoptics Secretariat, +351 265-520-185; photoptics.secretariat@insticc.org; www.photoptics.org.

International Laser Safety Conference (ILSC) (March 20-23, 2017) Atlanta
Deadline: Abstracts, Oct. 6
ILSC is a comprehensive four-day conference covering all aspects of laser safety practice and hazard control. Scientific sessions will address developments in regulatory, mandatory and voluntary safety standards for laser products and for laser use. A two-day Technical and two-day Medical Practical Applications Seminar (PAS) complement the scientific sessions by exploring everyday scenarios that the laser safety officer or medical laser safety officer may encounter. Contact Laser Institute of America, +1 407-380-1553; ilsc@lia.org; www.lia.org/ilsc.

● 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
Thomas 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

Smart lighting for smart kids

Most of us prefer to kick back in sunshine and not under a fluorescent bulb, and it turns out there's a scientific basis for that preference; the intensity of artificial lighting has been shown to have a range of effects not only on our mood, but also our ability to concentrate.

A recent study conducted at the Korea Advanced Institute of Science and Technology (KAIST) in Daejeon, South Korea, examined the effects of different correlated color temperatures (CCTs) on the physiological alertness of schoolchildren, as manifested in academic performance and recess activities.

CCT below 3500 K provides a warm, yellowish-white light, while a CCT over 5000 K casts cool, blueish-white light. The KAIST study, led by Kyungah Choi and Hyeon-Jeong Suk, examined the effects of 3500-, 5000- and 6000-K light, first in a simulated classroom and later in real-life classrooms. To test academic performance, fourth-grade students took timed arithmetic tests under LED lights tuned to the three CCT conditions in the lab.

Choi and Suk found no significant variation between student performances under the three conditions. In a preliminary lab study using adults, they had found that 6500-K CCT light supported the highest level of physiological alertness, as measured by electrocardiogram-recording electrodes on the wrists and ankles, and 3500-K light was the most relaxing.

Thinking length of exposure may explain the discrepancy in results, Suk and Choi studied two more groups of fourth-grade students, this time in real-life classrooms — one equipped with LED lights tuned to the three CCT conditions, and the other a control group using standard fluorescent lights. The students scored best on academic tests when they worked under the 6500 K lighting condition and performed best on recess activities under mellow 3500 K lighting.

The results aligned with the preliminary study, but also with the century-old Yerkes-Dodson Law, which predicts a curvilinear relationship between mental arousal and performance, meaning people perform best at intermediate levels of stress. The duration of exposure to each lighting condition also seems to be key.

Suk and Choi are homing in on the sweet-spot lighting for optimizing learning, and have even demonstrated a mobile-app-based dynamic lighting system with preset conditions of "easy," "standard" and "intensive" for smart learning environments, believing even small changes could dramatically improve student learning.

And here at Photonics Media headquarters, there's a new entry for the company suggestion box.

Julia Germaine
julia.germaine@photonics.com