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July 2016

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Sensor Advances Open Imaging Frontiers

Asia-Pacific:
Virtual Reality, Wearable Displays on the Rise

PHOTONICS MEDIA

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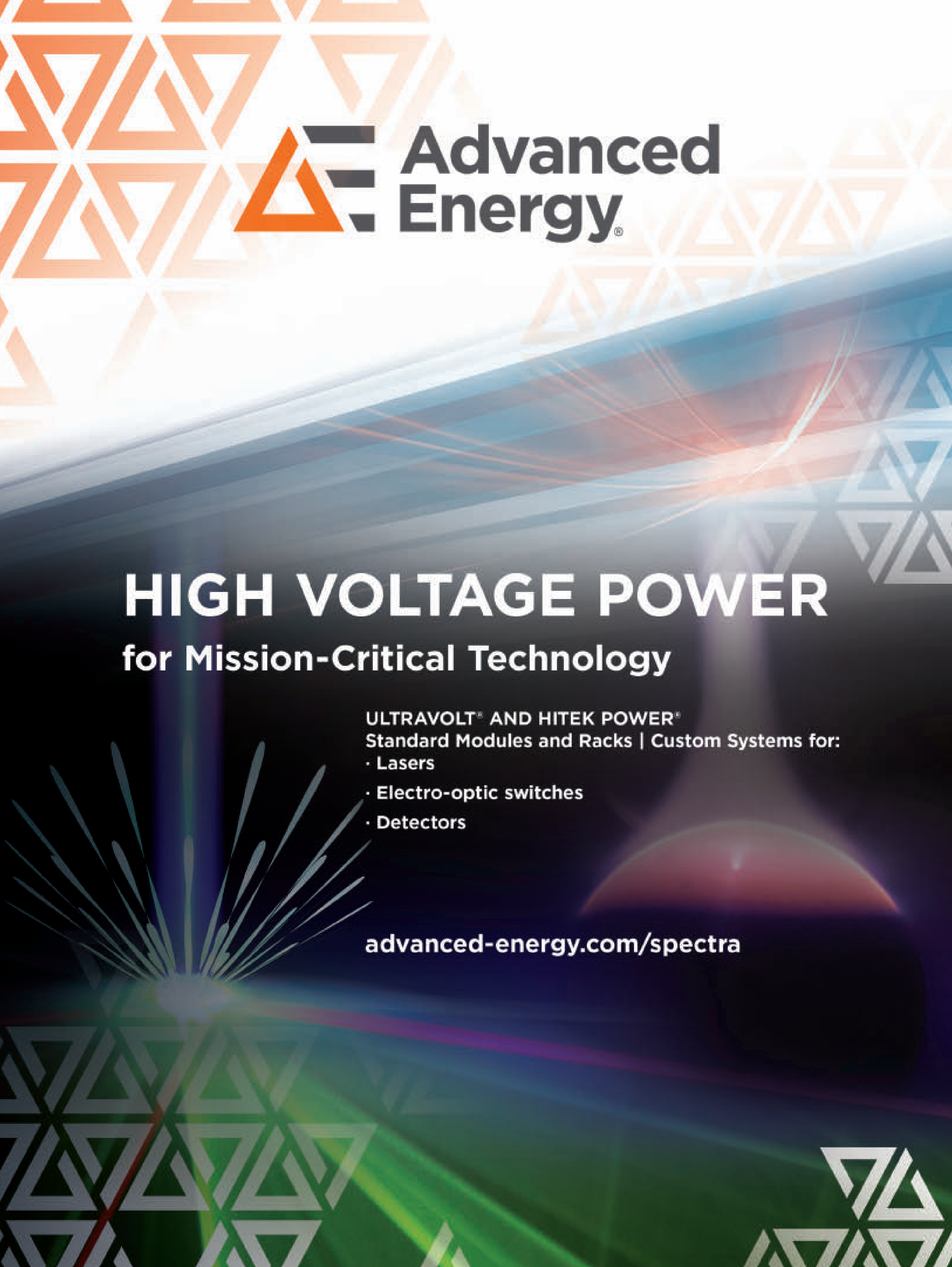
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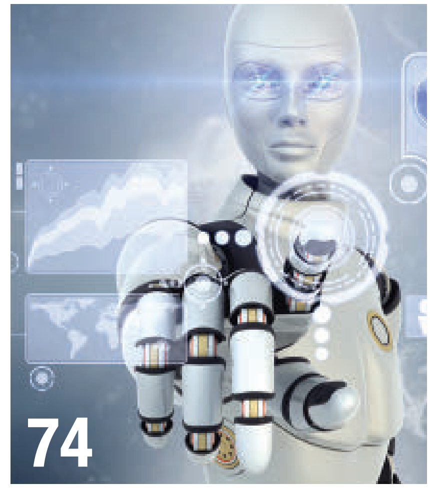

Departments & Columns

THE COVER
As sensors become smaller, they are moving to new tactical crafts. Courtesy of Headwall Photonics Inc. Cover design by Senior Art Director Lisa N. Comstock.

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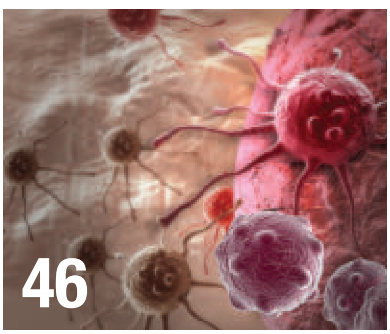
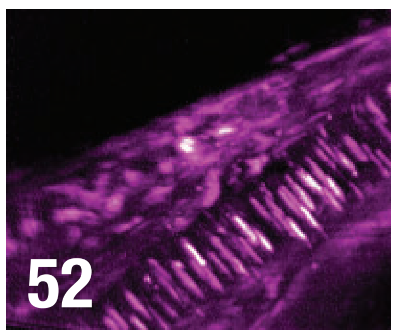
PHOTONICS: The technology of generating and harnessing light and other forms of radiant energy whose quantum unit is the photon. The range of applications of photonics extends from energy generation to detection to communications and information processing.





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editorial
COMMENT

Biomedical imaging breakthroughs

Water concentrations in human tissue, it turns out, are a good indicator of whether or not cells are cancerous. That's led to increased interest in the emerging field of terahertz imaging, which promises delineation between healthy cells and cancerous ones. The problem: limitations in the performance of current THz sources and detectors.

Which brings us to Pierre Gellie's "Breakthrough for Real-Time THz Imaging" on page 46. Gellie, a winner of a Prism Award this year, walks through enhancements made to quantum cascade lasers — from optimizing the beam profile to achieving cryogenic operating temperature — required for the compact THz sources.

Similarly, Airy light-sheet microscopy has shown tremendous promise in acquiring never-before-seen high-contrast, 3D images of human tissue. Authors from the University of St. Andrews, Scotland, and M Squared Lasers Ltd. examine how this groundbreaking method allows for high-resolution images to be acquired at high speeds, with minimal impact on the specimen. See "Airy Beam Light-Sheet Microscopy Holds Promises for Life Sciences Imaging," page 52.

Rounding out this month's imaging-themed features, contributing editor Marie Freebody explores how systems-on-chip and ever-shrinking hyperspectral and multispectral imagers are opening up new applications, from grading cranberries via drones to incorporating cameras with onboard processing into cars. See "Applications on the Upswing as Cost of Imaging Systems Comes Down," on page 30.

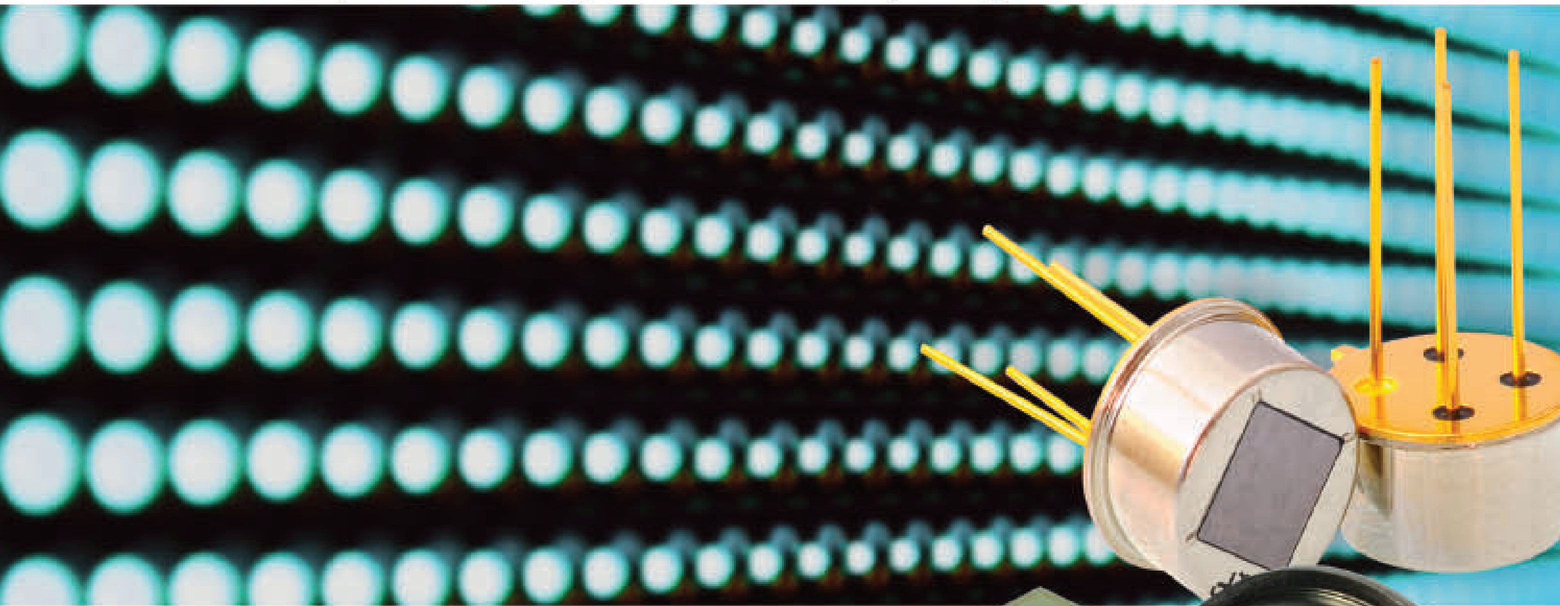
Whether grading cranberries or assessing cancer cells, success lies in achieving maximum contrast and resolution. Teledyne Dalsa's Xing-Fei He discusses how the use of micropolarizer filters in line scan polarization cameras can overcome common limitations in polarization filters available today. See "Focus on Polarization" on page 41.

We shift our focus from machine vision to the realm of spectroscopy, where UVC LEDs are supplanting lamp-based systems in high-performance liquid chromatography and water quality assessments for environmental analysis. Don't miss "High-Performance UVC LEDs Driving Innovations in Spectroscopy," by Crystal IS' Hari Venugopalan on page 36.

We wrap up our issue with a look at the booming photonics industry in the Asia-Pacific region. Senior Editor Justine Murphy explores how companies there are advancing virtual- and augmented-reality technologies, as well as wearable and flexible displays. See her "Reality Check," on page 60.

As always, thank you for reading. We hope you enjoy the issue.

Michael D. Wheeler
michael.wheeler@photonics.com



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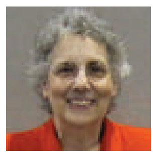

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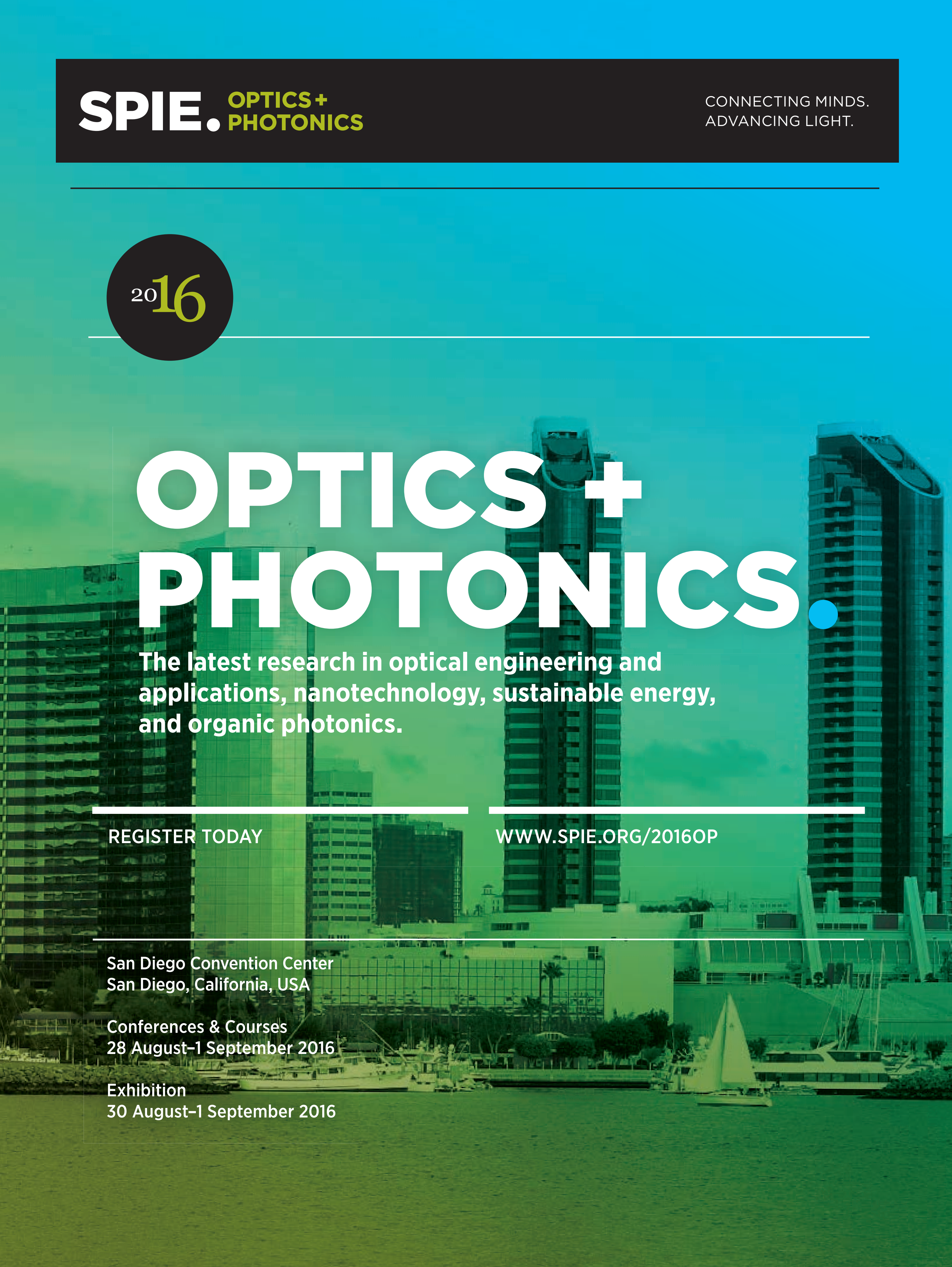
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What's Online:

Photonics for Ophthalmology Conference

If you missed our Ophthalmology Conference in June, or want to revisit any of the sessions, you can listen to a recording of the complete conference at **photonics.com/webinars**. Presentations from physicians, researchers and consultants cover laser refractive cataract surgery, photo-mediated ultrasound therapy, ophthalmologic lasers, multifocal and advanced intraocular lenses, photobiomodulation, various aspects of optical coherence tomography, and more. Ophthalmology represents one of the biggest markets for medical lasers today. This year's conference provides an excellent opportunity to catch up on innovative technologies advancing the field and to learn where photonics for ophthalmology is headed.

Coming soon, new webinars on photonics in industrial automation and aerospace and defense, and webinars focusing on imaging, optics and other areas. Be sure to check our site regularly for current and future presentations that you won't want to miss.

If you are interested in presenting a Photonics webinar, please visit our website, **Photonics.com/webinars**, to submit a brief proposal. We are always interested in presenting webinars that inform and educate our audience.

Available on Demand For more information and to watch past presentations, visit **Photonics.com/webinars**.

Light Matters

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Simon's Observatory receives $40M in funding to advance telescopes, detectors

The Simons Foundation has given $38.4 million to establish a new astronomy facility in the Antofagasta region of Chile's Atacama Desert, adding telescopes and detectors alongside existing instruments to boost ongoing studies of the evolution of the universe, from its earliest moments to today. The Heising-Simons Foundation is providing an additional $1.7 million for the project.

The Simons Observatory is a collaboration among the U.S. Department of Energy's Lawrence Berkeley National Laboratory, UC Berkeley, Princeton University, the University of California at San Diego and University of Pennsylvania, all of which are also providing financial support.

The observatory will probe cosmic microwave background (CMB) radiation, subtle properties of the universe's first light, paying particular attention to the polarization in the CMB light to better understand what took place a fraction of a second after the Big Bang.

Two existing instruments at the site — the Atacama Cosmology Telescope and the Simons Array — are currently measuring polarization. The foundation funds will merge these two experiments, expand the search and develop new technology for a fourth-stage, next-generation project — CMB-Stage 4 — that researchers believe could mine all the cosmological information in the cosmic microwave background fluctuations possible from a ground-based observatory.

University of Pennsylvania

The Simons Array will be located in Chile's High Atacama Desert, at an elevation of about 17,000 ft. The site currently hosts the Atacama Cosmology Telescope, the bowl-shaped structure at upper right, and the Simons Array, the three telescopes at bottom left, center and right. The Simons Observatory will merge these two experiments, add several new telescopes and set the stage for a next-generation experiment.

Jon Ward/University of Pennsylvania

The Milky Way's galactic plane rises above the Atacama Cosmology Telescope. The Simons Observatory is planned at the same site in Chile's High Atacama Desert and will add new telescopes and detectors.

USC, Northrop Grumman establish optical materials research institute

Northrop Grumman Corp. of Falls Church, Va., and the University of Southern California (USC) Viterbi School of Engineering in Los Angeles, will establish an advanced research institute focused on optical materials and nanophotonics devices.

The Northrop Grumman Institute of Nanophotonics and Nanomaterials (NG-ION^2) will be based on the USC campus, and will bring together researchers from the university and the aerospace industry.

Under the agreement, Northrop Grumman will contribute $500,000 to NG-ION^2 in 2016 to help foster interdisciplinary research by materials scientists, electrical engineers, physicists and chemists to develop novel materials for optical devices.

NG-ION^2 will also enable regular exchanges between USC and Northrop Grumman researchers working across projects. USC Viterbi will grant Northrop Grumman scientists visiting researcher positions, a strategy that will allow them to work collaboratively on campus with their Institute counterparts to advance science in nanomaterials and integrated photonics, the two organizations said.

Initial projects include theoretical and experimental studies on 2D materials, plasmonics and nonlinear optics.

• DOE renews $2.3M funding for Technologist-in-Residence program, addressing energy use in manufacturing. •

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DOE selects recipients of small business SSL tech awards

The U.S. Department of Energy (DOE) has granted three of its Small Business Innovation Research (SBIR) Small Business Technology Transfer (STRR) proposals SBIR-STTR FY16 Phase I Release 2 awards, targeting advances in solid-state lighting (SSL) products and components.

Lucent Optics Inc.'s ultrathin flexible LED lighting panels, Lumisyn LLC's LED downconverter phosphor chips with nanocrystals, and InnoSys Inc.'s next-generation installation/configuration software platform and novel luminaire were selected for the technical and commercial feasibility of their innovative solid-state lighting product or component. The devices were chosen because of their direct link to the price and performance goals itemized in the agency's R&D plan.

The SBIR-STTR program within the DOE Office of Science seeks to increase the participation of small businesses in federally sponsored innovative and novel research and development.

Keysight, Georgia Tech partner on software development center

Keysight Technologies Inc. of Santa Rosa, Calif., and the Georgia Institute of Technology (Georgia Tech) in Atlanta, will launch a software development center to accelerate Keysight's transformation into a software-centric solutions provider. The facility will house more than 200 developers over the next five years in Atlanta's Midtown district.

Keysight has chartered the center to develop software for use in the design and test of electronic products being created by the company's global customers. The company cited Georga Tech's top-ranking engineering program and access to resources and experience as motivation for the expanded partnership, which continues an existing relationship between the two organizations.

Todd Cutler, vice president and general manager of Keysight Software Products Organization and EEsof Electronic Design Automation, will relocate from Santa Rosa to Atlanta to lead the software development center.

NASA releases 56 patents into the public domain

NASA has released 56 formerly patented agency technologies into the public domain, making them freely available for unrestricted commercial use. In addition to the release of these technologies, a searchable database is now available that catalogs thousands of expired NASA patents already in the public domain.

The technologies were developed to advance NASA missions, but may have nonaerospace applications and be used by commercial space ventures and other companies. The release is intended to foster entrepreneurship and American leadership in high-tech manufacturing and world economies.

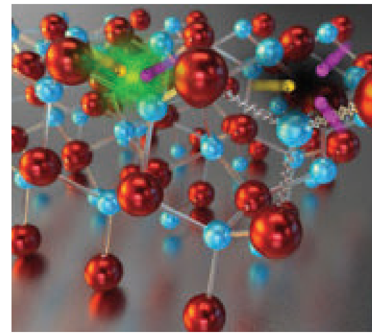
To search the database of NASA-developed technologies now in the public domain, including myriad optical and photonics technologies, visit www.technology.nasa.gov/publicdomain.

$15B — value of the global light projector market by 2020, as projected by Reportsnreports, representing a compound annual growth rate of 8.92% over the previous five years.

This month in history

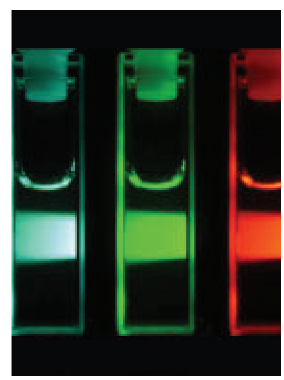
What were you working on five, 10, 20 or even 30 years ago? *Photonics Spectra* editors perused past July issues and unearthed the following:

2011



UCSB scientists investigated nitrade-based LED drops in efficiency known as "droops," attributing them to Auger recombination — a process in which three charge carriers interact without giving off light.

2006



Passivated carbon nanoparticles were being explored at Clemson University for multiplexed biolabeling applications, as well as the construction of novel LEDs.

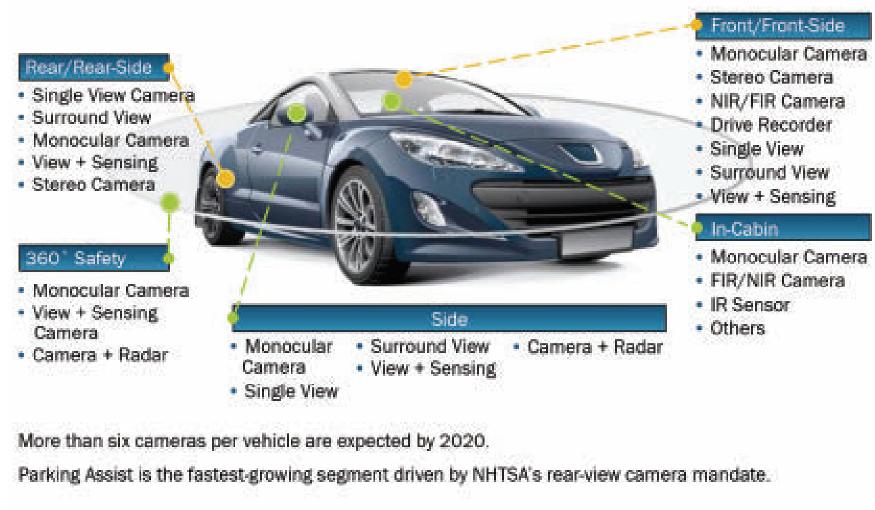
1996

A lidar-radar hybrid detection system was developed by Drexel University and the Naval Air Warfare Center for underwater surveillance experiments.

1986

Sandia and GE researchers were using lasers to cut-and-patch or draw extremely thin, short metallic interconnections in chips, challenging conventional approaches to integrated circuit packaging and prototyping.

FotoNation, Kyocera partner for intelligent driving



Techno Systems Research, Gartner, Strategy Analytics/Business Wire

FotoNation Ltd. of San Jose, Calif., has partnered with Kyocera Corp. to develop advanced, intelligent vision systems for the automotive market.

The technologies aim to enhance driver and pedestrian safety while accelerating the adoption of semi- and fully autonomous vehicles and providing a safer driving environment for occupants and pedestrians in urban areas. For its part, FotoNation said it will deliver complex computational imaging solutions for automotive applications.

FotoNation provides hardware-accelerated imaging solutions for a number of automotive applications including driver monitoring systems, driver identification, surround view, e-mirror, smart rearview cameras and 360° occupancy monitoring.

Kyocera is a supplier of electronic components, semiconductor packages, solar power generating systems, mobile phones, printers, copiers, cutting tools and industrial ceramics.

LIGO awarded Special Breakthrough Prize in Fundamental Physics

The Laser Interferometer Gravitational-Wave Observatory (LIGO) operated by Caltech and the Massachusetts Institute of Technology has been awarded the Special Breakthrough Prize in Fundamental Physics.

Designed to open the field of gravitational-wave astrophysics through the direct detection of gravitational waves predicted by Einstein's General Theory of Relativity, LIGO's multikilometer-scale gravitational-wave detectors use laser interferometry to measure the minute ripples in space-time caused by passing gravitational waves from cataclysmic cosmic sources. This year, LIGO reported observation of a gravitational wave distorting the structure of space-time as it passed through the Earth. The detected distortion was less than a billionth of a billionth of a meter in size at the two 4-km observatories. The wave emanated from two black holes with masses about 30 times that of the sun, spiraling into

MOVES AND EXPANSIONS

Lund, Sweden-based advanced materials startup **Sol Voltaics** has reported a $17 million round of equity investment and grant funding to accelerate commercialization of its nanowire solar film tandem-layer technology.

The Series C funding round was led by new investor Riyadh Valley Co., the venture capital investment arm of King Saud University in Riyadh, Saudi Arabia. Long-term investors Umoe, FAM, Industrifonden and Nano Future Invest contributed to the $12.5 million in equity investment. The Swedish Energy Agency and the European Union's Horizon 2020 research and innovation program also backed the company with over $4.5 million in additional grants.

Sol Voltaics recently announced a major technological breakthrough with the successful alignment of gallium-arsenide nanowires in a thin film it expects to improve photovoltaic module efficiency.

High-power fiber lasers and amplifier firm **IPG Photonics Corp.** of Oxford, Mass., said it has entered into a definitive agreement to acquire **Menara Networks Inc.**, developer of enhanced optical transmission modules and systems. The cash purchase price is $46.8 million, subject to closing adjustments. The deal is expected to finalize in the second quarter of 2016.

IPG and Menara Networks had recently announced a partnership to provide an integrated solution for simplified repeaterless 100G DWDM (dense wavelength division multiplexing) transmission for metro and data center interconnection. Menara's product suite of 10G and 100G WDM modules eliminates the need for transponder systems.

Edmund Optics Inc. of Barrington, N.J., has launched startUP, an integrated, customizable program to provide optics and photonics startups with assistance during all development stages.

Companies are provided with access to Edmund's engineering team and can collaborate with more than 250 optical, mechanical, design and manufacturing engineers to supplement in-house resources. Technical support is also available via phone, email and online chat, 24 hours a day. The program also offers customers discounts on Edmund Optics products, which include precision optics, optical assemblies and image processing components.

each other 1.3 billion light years away.

The award recognizes scientists and engineers contributing to the detection of gravitational waves. LIGO founders Ronald W. P. Drever, professor emeritus of physics at Caltech; Kip S. Thorne, the Feynman Professor Emeritus of Theoretical Physics at Caltech; and Rainer Weiss, professor emeritus of physics at MIT, will each equally share $1 million, with 1,012 other experiment contributors equally sharing $2 million in prize money.

LIGO's gravitational-wave detectors were conceived and R&D was initiated in the 1960s. LIGO was built between 1994 and 2002 through a partnership with the National Science Foundation of the United States. Breakthrough Prizes recognize the world's top scientists, and were founded by Sergey Brin and Anne Wojcicki, Jack Ma and Cathy Zhang, Mark Zuckerberg and Priscilla Chan, and Yuri and Julia Milner.

• Technavio cites increasing adoption of automobile projection systems as the driver of the global optical MEMS market. •

Lidar system deployed to evaluate turbine performance in Uruguay

Renewable NRG Systems (RNRG) of Hinesburg, Vt., and Ventus Ingeniería of Caracoles, Uruguay, have announced plans to install RNRG's Wind Iris nacelle-mounted lidar at the 20-MW Caracoles wind farm in Uruguay. The lidar system will monitor turbine performance and offer optimization solutions for the project.


RNRG Systems

RNRG and Ventus Ingeniería have partnered to install RNRG's Wind Iris lidar systems at the Caracoles wind farm in Uruguay.

The wind farm is owned by UTE, Uruguay's national utility and electricity market regulator. The measurement campaign's objective is to evaluate and quantify the performance of one specific turbine and propose solutions to improve energy production.

Caracoles presents moderately complex terrain and ambient turbine wakes, meaning proper filtering and data treatment is critical. RNRG said the Wind Iris yaw correction algorithm has already been validated in both waked and complex wind flow conditions.

Ventus Ingeniería is a Uruguayan company whose main aim is to provide engineering and consultancy services for energy projects, especially those related to wind and solar power. RNRG measurement products and services address wind and solar project development, from site assessment to commercial operation.

• IEEE Standards Association launches project to develop image quality standards for intelligent vehicles. •

26.5%

— compound annual growth rate of the global night vision (IR) surveillance camera market from 2016 to 2024, based on projections by Transparency Market Research.

PTI, Biotek win President's 'E' Award for exports

Power Technology Inc. (PTI) of Little Rock, Ark., and Biotek Instruments Inc. of Winooski, Vt., have received the President's "E" Award for Exports, the highest recognition a U.S. entity can receive for making a significant contribution to the expansion of U.S. exports.

The awards committee cited PTI's innovative scientific instrument technologies, adaption of its product line to maintain compliance with international regulations and the company's contributions to the economy and job growth. PTI said that in 2015 it exported to 37 countries and every continent except Antarctica, and that exports directly support over a quarter of jobs at the company's primary manufacturing facility.

Established in 1969, PTI manufactures and exports lasers for OEM cinema; semiconductor inspection; defense and security; and analytical, biomedical, industrial and machine vision applications.

Biotek received the award for its scientific instrument technologies and business model that emphasizes exports, which account for a significant percentage of the privately held company's annual revenues. Biotek designs, manufactures and sells microplate instrumentation and software for the quantification of molecules in life sciences research, drug discovery and analysis applications.

In 1961, President Kennedy signed an executive order reviving the World War II "E" symbol of excellence to honor and provide recognition to America's exporters.

$1B+

— expected value of the global SiC and GaN power semiconductor market by 2020, according to IHS Inc., with demand driven by hybrid and electric vehicles, power supplies, and PV inverters.

PEOPLE IN THE NEWS

Faro Technologies Inc., developer of 3D measurement, imaging and realization technology, has promoted **Kathleen J. Hall** to chief operating officer and **Joe Arezone** to chief commercial officer.

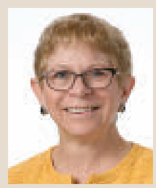
Hall has served as Faro's senior vice president, managing director of the Americas region, since 2013. Prior to joining Faro, Hall served as vice president and general manager at Avery Dennison Corp. from 2008 to 2012. As COO, she will lead the company's global operations team.

Arezone will be responsible for accelerating market-driven innovation, better leveraging Faro's sales organization through process modernization, developing sales strategies and training, and driving the corporate marketing function to enable future growth. Mr. Arezone has served as senior vice president, managing director for EMEA and Asia-Pacific, since 2014.

Faro develops 3D measurement, imaging and realization technology.

Software developer Rudolph Technologies Inc. has appointed **Debbora Ahlgren** vice president of global customer operations, leading the company's sales and service organization.

Ahlgren has more than 25 years of experience in the semiconductor and related electronics industries.



Rudolph Technologies Inc.

Prior to joining Rudolph Technologies, she served in a variety of executive roles, including vice president and general manager for field operations for Agilent Technologies, and vice president of sales and marketing for OptimalPlus.

Rudolph designs, develops, manufactures and supports process control metrology systems used in semiconductor device manufacturing.

High-precision laser component developer Raylase AG has appointed **Philipp Schön**, **Christoph von Jan** and **Berthold Dambacher** to its executive board.

Schön has been with Raylase since April 2015, bringing years of experience as director of a Swiss technology company. He will focus on the development of new business segments and markets, ensuring the company's long-term customer and market focus with responsibility for marketing, sales and strategic positioning.

Von Jan has been with Raylase for 16 years. He will be the head of operations, focusing on production, quality management, finance and all other central services.

Dambacher will be responsible for all research and development activities for the company's innovative components and solutions. He has held a senior position at Raylase for more than three years, developing products and bringing them to series production.

Raylase

Raylase AG has appointed **(from left to right)** Christoph von Jan, Philipp Schön and Berthold Dambacher to its executive board.

Air Force awards Raytheon $90M multispectral targeting contract

Waltham, Mass.-based Raytheon Corp. has been awarded a first-lot production contract by the U.S. Air Force valued at about $90M for the AN/DAS-4 EO/IR Turret, the latest variant of Raytheon's multispectral targeting system.

The DAS-4 system allows mission commanders to use HD data from an airborne tactical sensor to identify and engage targets with greater accuracy, improving overall mission effectiveness. Major improvements include four HD cameras covering five spectral bands, a three-color diode pump laser designator/rangefinder, laser spot search and track capability, automated sensor and laser bore sight alignment, three-mode target tracker, and built-in provisions for future growth.


Raytheon

Raytheon's AN/DAS-4 EO/IR Turret, shown here deployed on the MQ-9 Reaper.

• MarketsandMarkets projects the global laser technology market value will reach $14.67B by 2022. •

GSI changes name to Novanta

Laser, motion and vision technology provider GSI Group Inc. of Bedford, Mass., has changed its corporate name to Novanta Inc. Novanta's shareholders approved the corporate name change at their annual meeting.

"The name Novanta stands for the innovation advantage, as innovation and technical collaboration with customers are at the core of the company's value proposition, and our new logo signifies our focus on growth," CEO John Roush said.

The company designs, develops and manufactures precision photonic and motion-control components and subsystems.

$1.31B

— value of the global photonics integrated circuits market by 2022, as projected by Credence Research Inc. The company described the nascent market as "highly fragmented and competitive."

$1.7B

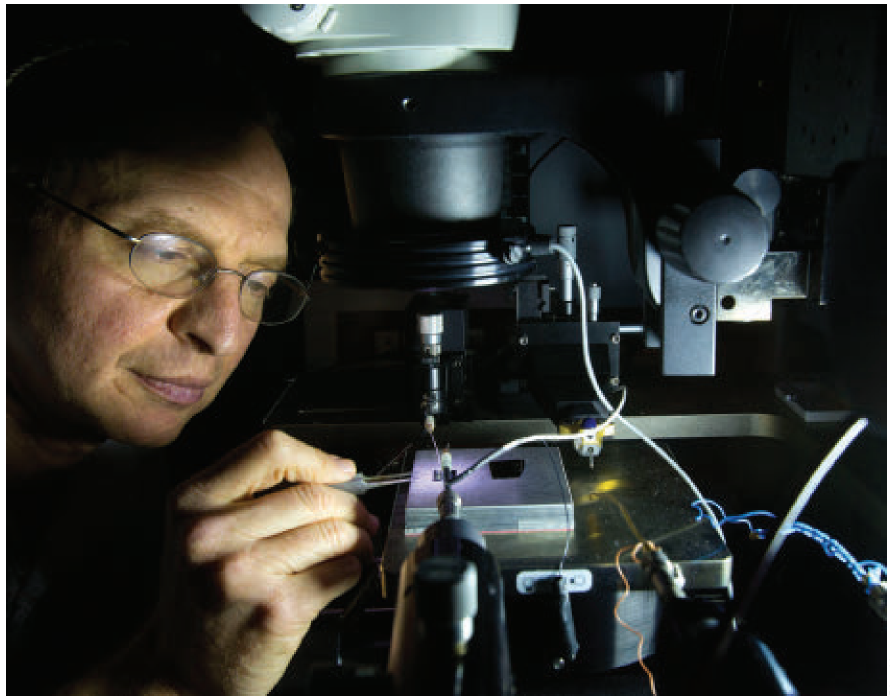
— value of the global photoelectric sensors market by 2024 based on revenue. Industrial automation and the semiconductor industry are both driving market growth, according to Transparency Market Research.

Electrochromic polymers brighten flat-panel displays

ALBUQUERQUE, N.M. — The use of super-thin layers of inexpensive electrochromic polymers to generate sharp colors that can be quickly changed may lead to a less expensive way to develop flat-panel displays that are also brighter, clearer and more energy-efficient. Researchers at the Center for Nanoscale Science and Technology demonstrated high contrast, fast monochromatic and full-color electrochromic switching using two different electrochromic polymers, known as PANI and PolyProDOT-Me_2.

The researchers significantly enhanced the interaction of light propagating as deep-subwavelength-confined surface plasmon polaritons using arrays of metallic nanoslits. They created plasmonic arrays of vertical nanoscale slits perpendicular to the direction of the incoming light. The slits were cut into a very thin aluminum track, coated with an electrochromic polymer. When light hit the aluminum nanoslits, it was converted into surface plasmon polaritons (SPPs) that contained frequencies of the visible spectrum that could travel along the dielectric interfaces of aluminum and the electrochromic polymer. The distance between the slits in each array (pitch) corresponded exactly to the wavelengths of red, green and blue light. The pitch determined which wavelength — red, blue or green — was transmitted down through the array, traveling along the interface between the thin polymer layer and the aluminum substrate.

By controlling the pitch of the nanoslit arrays, it was possible to achieve a full-color response with high-contrast and fast switching speeds, while relying on just one electrochromic polymer.


Dino Vournas

Sandia National Laboratories researcher Alec Talin inspects a plasmonic array sample using a probe station microscope.

Because the light traveled a relatively long distance along the surface of the aluminum slits coated with the thin polymer, it saw a much thicker polymer layer. The material turned a desirable deep black when a tiny electric current sent across the top of the slit cut off the entering light, and did so in milliseconds. When the current was flicked off, light frequencies passed through the slits and instantly turned on the pixel. Because the carefully spaced slits let in light only at a particular frequency, a single kind of polymer coating served in a neutral capacity to deliver all three emanated colors.

“These very inexpensive, bright, low-energy micropixels can be turned on and off in milliseconds, making them fit candidates to provide improved viewing on future generations of screens and displays,” said researcher Alec Talin. “The nanoslits improve the optical contrast in a thin electrochromic layer from approximately 10 percent to over 80 percent.”

The work was supported at Sandia by Nanostructures for Electrical Energy Storage, an Energy Frontier Research Center of the Department of Energy, and was published in *Nature Communications* (doi: 10.1038/ncomms10479).

Optical prism expands vision field for the sight-impaired

BOSTON — A series of novel optical designs may address the limitations of current peripheral prism eyeglasses and help further expand the field of vision for patients with hemianopia, a condition in which the visual fields of both eyes are cut in half.

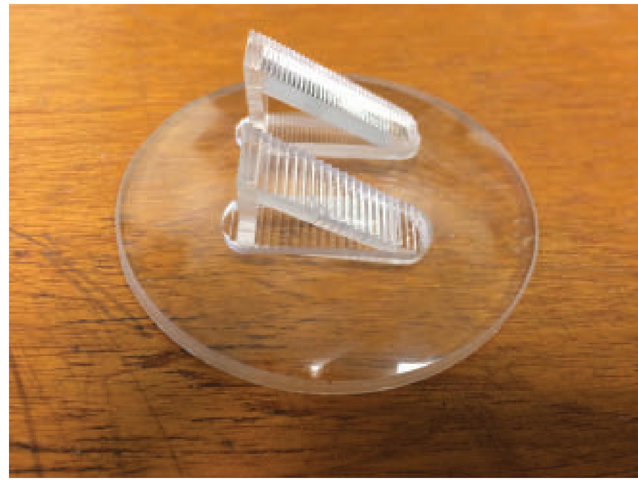
Current high power prism segments embedded in a regular spectacle lens can expand the upper and lower visual fields of patients by as much as 30°. However, this technology does not expand the central area of the visual field.

With the goal of increasing the visual field provided by current technology, researchers from the Schepens Eye Research Institute of Massachusetts Eye and Ear and Harvard Medical School explored new optical techniques to create even higher power image-shifting devices designed to bend the light farther than the 30° limit of conventional prisms. They developed, implemented and tested three novel eyeglass designs aimed at increasing the prism power to reduce the central gap in the vision field while maintaining wide lateral expansion.

“The new optical devices can improve the functionality of the current prism devices used for visual field expansion

Massachusetts Eye and Ear

By embedding the current prism in a spectacle lens that has prismatic power in the opposite direction, the image-shifting effect is increased by the summation of the power of both prism types. This design allows for up to 36° of expansion to the visual field on the patient's blind side.



Massachusetts Eye and Ear

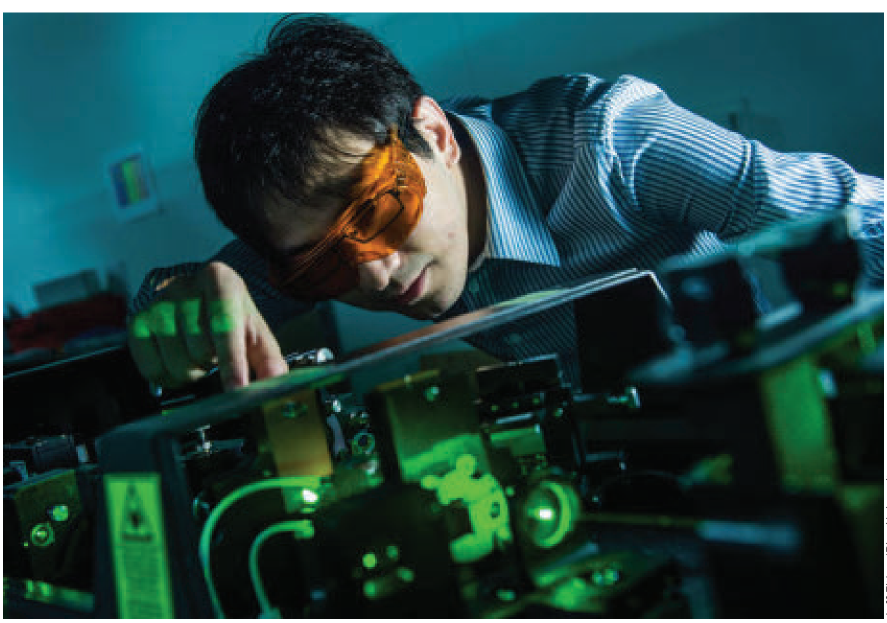
To increase the power of the peripheral prism, the bi-part double Fresnel prism combines two prism segments angled to each other. This design allows for up to 43° of expansion to the visual field on the patient's blind side and an increase to 14° scanning range into the blind side.

and may find use in various other field expansion applications such as a mobility aid for patients with tunnel vision," said Schepens researcher Dr. Eli Peli. "It's not just that we need a device with a higher angle of light shifting to let patients see farther. We also want the new devices to provide the additional range of vision when the patient scans their eyes in both directions. The current prism devices support such flexibility only when scanning into the seeing side."

A research team led by Dr. Peli has been developing prism devices for hemianopia patients for more than 15 years. In 2013, they introduced peripheral prism glasses, which optically shift objects from the blind side of the visual field to the seeing side, expanding the visual fields of patients by as much as 30°. The researchers intend to fully design and implement the mirror-based periscopic prism and begin testing all three novel designs in patients with hemianopia.

The research was published in *Optometry and Vision Science* (doi: 10.1097/opx.0000000000000820).

Plasmons enable tunable IR light source



Jeff Fitlow/Rice University

Study lead author Yu Zhang.

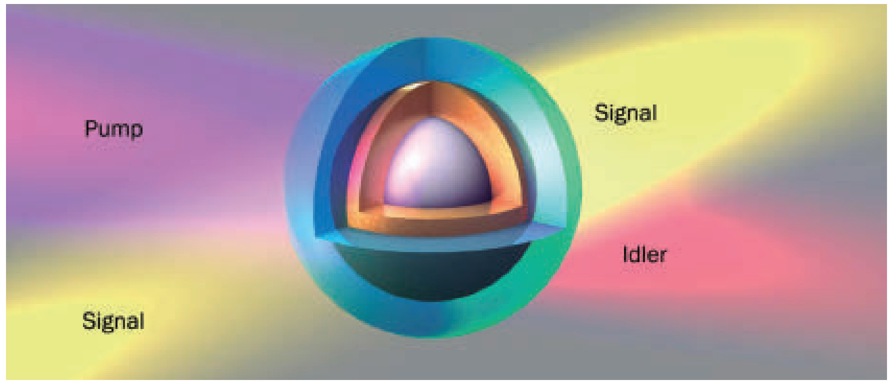
HOUSTON — A nanoscale optical parametric amplifier (OPA) has been demonstrated to function as a tunable IR light source. The device functions much like a laser; but while lasers have a fixed output frequency, the output from the nanoscale OPA can be tuned over a range of frequencies, including a portion of the IR spectrum. The device boosts the output of one light by capturing and converting energy from a second light.

Rice University researchers developed the single-nanoparticle OPA by generating a surface plasmon-enhanced difference frequency by integrating a nonlinear optical medium, $BaTiO_3$, in nanocrystalline form within a plasmonic nanocavity.

These nanoengineered composite structures provided large enhancements of the confined fields and efficient coupling of the wavelength-converted idler radiation to the far-field. The result was a nanocomplex that worked as a nanoscale tunable IR light source.

"There are intrinsic inefficiencies in the OPA process, but we were able to make up for these by designing a surface plasmon with triple resonances at the pump, signal and idler frequencies," said researcher Yu Zhang.

While the pump laser in Rice's device has a fixed wavelength, both the signal and idler frequencies are tunable. The researchers believe it's the first instance of a tunable nanoscale IR light source. Commercially available tunable IR OPA light sources cost around $100,000 and have a large footprint; the Rice device is about 400 nm in diameter. Zhang said that shrinking an IR light source to such a small scale may open doors to new kinds of chemical sensing and molecular imaging that are not possible with today's nanoscale IR spectroscopy.



Alejandro Manjavacas/Rice University

Rice University's light-amplifying nanoparticle consists of a 190-nm-diameter sphere of barium tin oxide surrounded by a 30-nm-thick shell of gold.

The research was published in *Nano Letters* (doi: 10.1021/acs.nanolett.6b01095).

3-color photodetector explored for IR color TV

EVANSTON, Ill. — A three-color, shortwave-midwave-longwave IR photodetector could be used to create IR color televisions and imaging systems.

"A device capable of detecting different IR wavebands is highly desirable in next-generation IR imaging systems," said professor Manijeh Razeghi of Northwestern University.

Razeghi and her team invented and investigated the design for three-color photodiodes without using additional terminal contacts. The resulting device is based on InAs/GaSb/AlSb type-II superlattices. As the applied bias voltage varied, the photodetector sequentially exhibited the behavior of three different colors, corresponding to the bandgap of three absorbers, and achieved well-defined cut-off wavelengths and high-quantum efficiency in each channel, the researchers said.

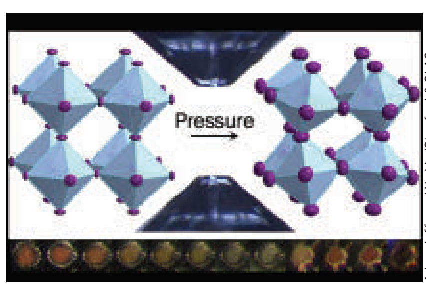
The research, published in *Scientific Reports* (doi: 10.1038/srep24144), builds on Razeghi group's many years of work in Northwestern's Center for Quantum Devices, including the development of the first single-color, short-wavelength IR photodetector and two-color, shortwave-midwave IR photodetector based on type-II superlattices.

Pressure tunes absorption by perovskite solar cells

STANFORD, Calif. — The voltage and electronic conductivity of perovskite solar cells have been shown to increase under high pressure. The findings suggest that either chemical or mechanical compression could enable tunable perovskite solar cells capable of absorbing different wavelengths of light.

Perovskites — metallic crystalline structures — come in several structures, including hybrids made of lead, iodine or bromine, and organic compounds. The inexpensive materials have potential applications in LEDs and lasers, but one of the most popular areas of research involves solar cells. Hybrid perovskites absorb sunlight and convert it to electricity, with reported efficiencies over 20 percent, rivaling commercial silicon solar cells.

Now researchers at Stanford University have assessed how pressure affects the



Adam Jaffe and Yu Lin/Stanford & SLAC

Top: A normal perovskite crystal **(left)** bends and twists after being squeezed between two diamonds. **Bottom:** The orange perovskite crystal changes color as pressure is applied, indicating that different wavelengths of light are being absorbed.

way hybrid perovskites respond to light. To do so, they loaded perovskite samples in a diamond-anvil cell, a high-pressure device consisting of two opposing diamonds. Each sample was placed between the diamonds and squeezed at very high pressures.

The results were visible. One sample, normally orange, turned lighter in color under compression, an indication that the perovskite was absorbing higher-energy light waves. As pressure increased, the sample darkened, indicating that lower-energy light was also being absorbed.

"By tracking the positions of atoms upon compression using x-ray diffraction, we can explain exactly how the materials' structure responds to pressure," professor Hemamala Karunadasa said. "Overall this work shows that pressure is a tuning knob for improving the properties of perovskite absorbers in a predictable way."

Several research groups have been developing low-cost tandem solar cells made of perovskite stacked on top of silicon, but obtaining the high voltages required for high-efficiency tandem cells has proven difficult. Results of the Stanford study suggest that pressure can increase the voltages of perovskite solar cells and should be investigated further.

The research was published in *ACS Central Science* (doi: 10.1021/acscentsci.6b00055).

Superprecise mirror arrives at European XFEL

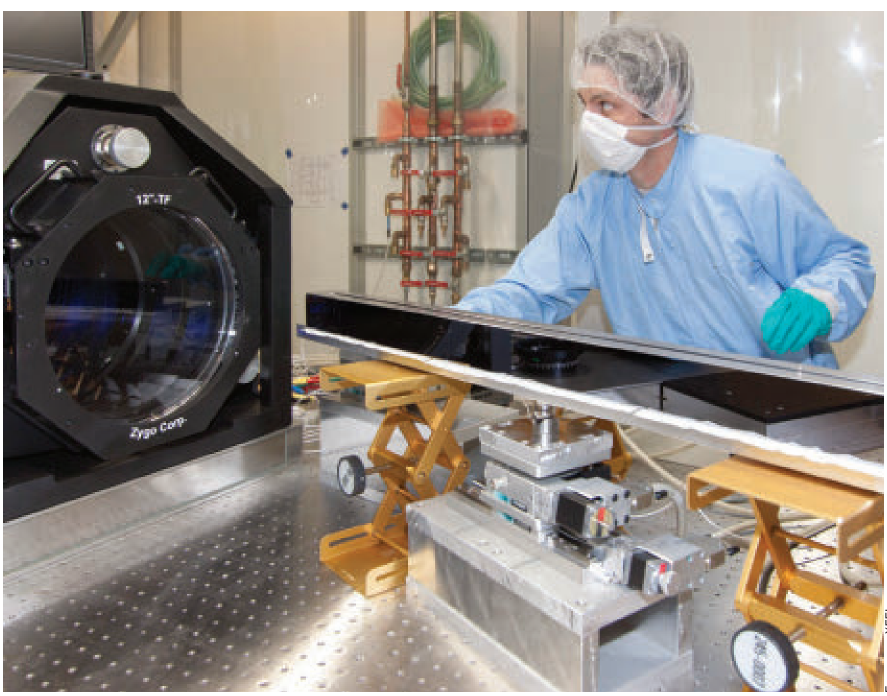
HAMBURG, Germany — X-ray laser research facility European XFEL has received a 95-cm-long mirror reported to be the most precise of its kind ever built. The mirror's production is the culmination of a lengthy R&D process involving institutes and companies in Japan, France, Italy and Germany.

The mirror is superflat and does not deviate from its surface quality by more than 1 nm, and is one of several required to allow scientists to use what will be the world's brightest x-ray laser light for research into ultrafast chemical processes, complex molecular structures and extreme states of matter. The first delivered mirror will be used to filter light.

The mirror body, with a 95-cm-long and 5.2-cm-wide reflective face, is made from a single crystal of silicon crafted by industrial partners in France and Italy. To polish a mirror to European XFEL's nanometer specification, optics firm JTEC Corp. in Osaka, Japan, employed a new polishing method using a pressurized fluid bath capable of stripping atom-thick layers off of the crystal. The polishing technique alone took nearly a year to develop to a point where the extreme quality could be reached.

Other mirrors in this series will be used to deflect x-rays by up to a few tenths of a degree into the European XFEL's six scientific instruments in its underground experiment facility in Schenefeld, Germany. The instruments, which are situated parallel to each other, will eventually be able to operate in parallel, enabling scientists to have greater access to the facility and its unique x-ray light. Similar mirrors will focus the x-rays within some of the facility's instruments.

The mirror will be measured at European XFEL and Helmholtz Zentrum Berlin for additional verification of its specifications.



European XFEL

European XFEL scientist Maurizio Vannoni inspects the delivered superflat mirror, which does not deviate from a perfect surface by more than 1 nm.

JWST's giant golden mirror is unveiled

GREENBELT, Md. — As part of the integrating and testing of the James Webb Space Telescope (JWST), NASA engineers have unveiled the giant golden mirror of the IR telescope — it is heralded as the largest mirror yet sent into space.

The 18 mirrors that make up the primary mirror were individually protected with black covers when they were assembled on the telescope structure, and now, for the first time since the primary mirror was completed, the covers have been lifted.

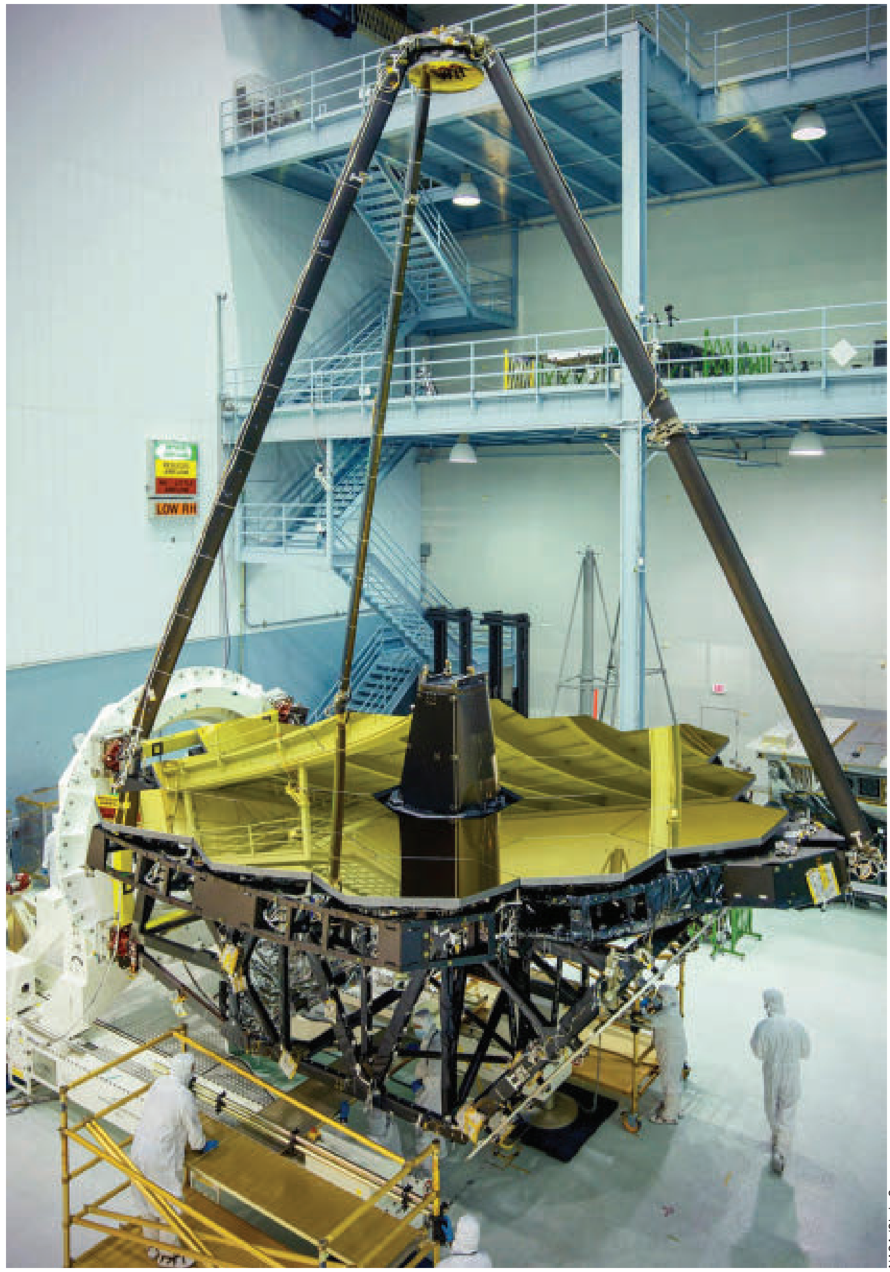
Each mirror is made of strong, light beryllium, and each mirror segment is about the size of a coffee table and weighs approximately 20 kg. A very fine film of vaporized gold coats each segment to improve the mirror's reflection of IR light. The fully assembled mirror is larger than any rocket, so the two sides of it fold up. Behind each mirror are several motors to enable focusing in space.

JWST will be used to capture images and spectra of the first galaxies to appear in the early universe, over 13.5 billion years ago, as well as the full range of astronomical sources such as star-forming nebulae, exoplanets, and even moons and planets within Earth's solar system.

The telescope is targeted to launch from French Guiana aboard an Ariane 5 rocket in 2018.

NASA said JWST is the successor to the Hubble Space Telescope, and will be the most powerful space telescope ever built. Its mission is to study universal history to better understand the formation of Earth's solar systems and other systems capable of supporting life.

The international project is led by NASA in partnership with the European and Canadian space agencies.



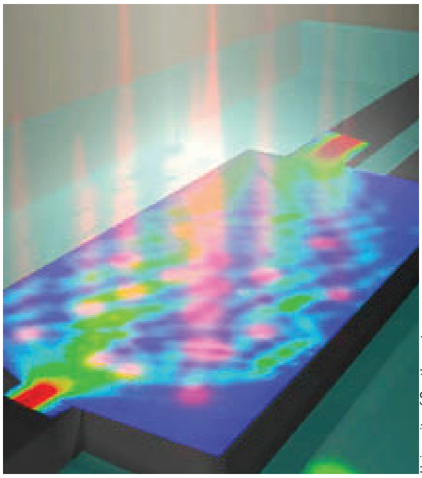
NASA/Chris Gunn

The James Webb Space Telescope's primary mirror will be the largest ever sent into space.

Reconfigurable silicon PCs control light patterns

SOUTHAMPTON, England — The ability to control light in a silicon chip could enable novel applications in programmable photonic circuits, including applications for optical testing and data communication. The development of flexible integrated-optic circuits that can be externally controlled was made possible using an all-optical spatial light modulator to reconfigure photonic devices, making them capable of routing the flow of light.

Researchers at the University of Southampton and the Institut d'Optique in Bordeaux, France, demonstrated that light could be routed between the ports of a multimode interference (MMI) power splitter with more than 97 percent total efficiency and negligible losses. The intricate interplay between many modes traveling through the MMI was dynamically controlled. A pattern of local perturbations, induced by femtosecond laser, was used to shape the transmitted light,


University of Southampton

Artistic rendering of a silicon-on-insulator 1 × 2 multimode interference splitter with a projected pattern of perturbations induced by femtosecond laser. The perturbation pattern achieved routing of light to a single output port with 97 percent efficiency.

demonstrating that all-optical wavefront shaping in integrated silicon-on-insulator photonic devices is possible.

By employing UV pulsed laser excitation to modify the spatial refractive index profile, the research team was able to maintain control of the optical transfer of telecommunication-wavelength light traveling through the device, thus allowing the functionality of the light to be redefined.

Photonic chip (PC) functionality is typically hardwired. Reconfigurable optical elements that would provide the ability to freely route light in a static silicon element offer an important building block for field-programmable photonics, the researchers said.

Future applications of this technology may include all-optical reconfigurable routers, ultrafast optical modulators and switches for optical networks and microwave photonic circuits, as well as wafer-scale optical testing of photonic chips. Silicon photonics form the backbone of next-generation on-chip technologies and optical telecommunication, which are aimed at a wide range of emerging applications including optical interconnects, microwave photonic circuits and integrated optical sensors.

The research was published in *Optica*, a publication of The Optical Society (OSA) (doi: 10.1364/optica.3.000396).

Binocular vision system enables UAV auto-refueling

BEIJING — A binocular vision-based platform has simulated autonomous aerial refueling between two unmanned aerial vehicles (UAVs) in real time, using a boom approach. The platform is the first step toward a vision-based sensor and navigation system for in-air refueling of UAVs without pilot assistance.

Researchers at Beihang University built and tested an integrated vision-based platform consisting of a tanker UAV, a receiver UAV and a ground station. An octocoptor serving as the tanker was equipped with cameras and a visual measurement system. When the UAV serving as the receiver came within the visual field of the cameras on the tanker (approximately five meters), the binocular vision system was able to capture pictures of the markers on the receiver UAV and extract and generate the pixel coordinates of the markers. An on-board next unit computing (NUC) device processed the pixel coordinates and estimated the position of the receiver. The visual information obtained from the binocular vision system was transferred to the flight controller and boom controller, which used the pictures to control the flight of both UAVs and the movement of the boom toward the fuel receptacle. Micro air vehicle (MAV) link protocol was used to control communication between the ground station and the UAVs and between the UAV subcomponents.

The researchers based their binocular vision system on two primary procedures: feature extraction and pose estimation. The pixel coordinates of the markers on the receiver UAV, which were painted red, were generated after feature extraction. The generated pixel coordinates were utilized in pose estimation, and the pose estimation was used to calculate the relation between the binocular vision system and the marker coordination system.

Transformation from the red-green-blue (RGB) to the hue-saturation-value (HSV) color model was implemented to process each captured image. In order to segment the regions of image containing red markers, the upper and lower bound of hue and saturation channels of HSV image were selected to conduct the threshold segmentation.

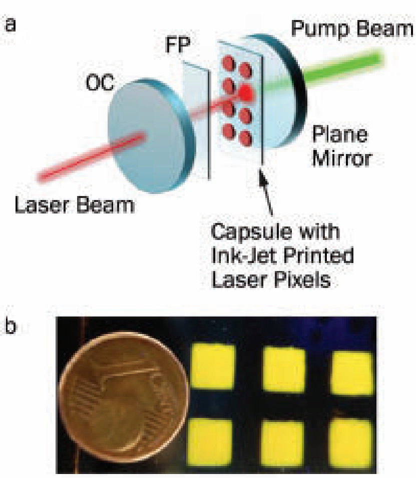
To confirm the effectiveness of the vision algorithm, the researchers simulated a refueling boom system. After the frame sequences of the markers were obtained and pose and position were estimated, an arm microcontroller used this information to determine the control level needed to control steering engines. The refueling boom pointed at the receptacle in the resolved pose and position, and successfully implemented in-air connection.

Flight tests were conducted outdoors under various conditions, including in conditions of strong and weak light. To ensure safety and ease of observation, the flight height of the UAVs was approximately 10 meters. The results of the experiment showed that a binocular vision system for AAR of UAVs using a boom approach is feasible. The research team plans to focus its future efforts on improving the stability and accuracy of their binocular vision measurements in more complicated environments.

The research was published in *Science China* (doi: 10.1007/s11432-016-5553-5).

A video showing the refueling platform in action is available at www.photonics.com/A60705.

Inkjet-printing produces disposable organic lasers



Sébastien Sanaur et al./Journal of Applied Physics

Inkjet-printed lasing capsules serve as the core of an organic laser. Figure **(a)** shows a schematic of the laser setup; **(b)** shows actual lasing capsules, which would cost only a few cents to produce. OC = output coupler and FP = Fabry-Perot etalon.

PROVENCE, France — An ultralow-cost fabrication method using an inkjet printer has produced “lasing capsules” for external-cavity vertically emitting thin-film organic lasers, a development that could enable disposable laser chips.

One obstacle that has limited widespread adoption of organic lasers is that they degrade relatively quickly, which could be overcome if the lasers are inexpensive enough to dispose of upon failure.

Researchers from the Ecole Nationale Supérieure des Mines de Saint-Étienne, the Université Paris and Semilab Semiconductor Physics Laboratory Co. Ltd. in Budapest, Hungary, used a piezoelectric inkjet-printing technique to create a gain medium. A commercial-grade ink served as the optical host matrix, exhibiting a refractive index of 1.5 and an absorption coefficient of 0.66 cm^{-1} at 550 to 680 nm.

The ink was mixed with dyes and then printed in small square shapes onto a quartz slide. These uniform 50-mm^2 “printed pixels” had a roughness measuring as low as 1.5 nm in different locations of a 50 × 50-µm atomic force microscope scan.

This printed, disposable component is referred to as the lasing capsule, and the researchers estimated it could be produced for a few cents. The two different types of dyes produced laser emissions ranging from yellow to deep red. Other dyes could cover the blue and green part of the spectrum, they said.

The organic laser produced a diffraction-limited beam with output energy as high as 33.6 µJ with a slope efficiency of 34 percent. Laser emission was shown to be continuously tunable from 570 to 670 nm using an intracavity polymer-based Fabry-Perot etalon.

With further development, the researchers said the inkjet-printed laser could send data over short plastic fibers, and serve as a tool for analyzing chemical or biological samples.

The research was published in the *Journal of Applied Physics* (doi: 10.1063/1.49468260).

For daily news updates, visit **www.photonics.com**

Bourbon draws flavors from IR-treated oak barrels

FRANKFORT, Ky. — Buffalo Trace Distillery has released its Experimental Collection of bourbon that used IR light to treat the aging barrels before they were charred. The IR-light experiment's goal was to learn how new and different flavors could be imparted from the oak barrels into the bourbon.

Working with barrel cooper Independent Stave Co. in 2009, eight special barrels were constructed according to Buffalo Trace's standard: Wooden staves — individual planks — were open-air seasoned for six months before being made into barrels.

The barrels were divided into two groups and subjected to two levels of IR light waves. The first group of four barrels underwent 15 minutes of short- and midwave frequency at 70 percent power. The second group was subjected to 30 minutes of short- and midwave frequency at 60 percent power. The barrels were then given a 15-second char before being filled with Buffalo Trace's Bourbon Mash No. 1.

After six-and-a-half years of aging, the bourbon from both barrels expressed distinct flavor notes of wood, caramel and vanilla, as well as pepper flavors drawn from the oak. Another observation from the experiment was that the shortwave-IR light seemed to affect more of the inner layers of the wood, while the midwave-IR light affected the surface and medium layers.

Tasting notes described the 15-minute IR light barrels as having a floral nose followed by a complex flavor profile.

Buffalo Trace Distillery is family-owned and dates back to 1773. Its Warehouse X facility is designed to explore the extent of environmental influences on the flavor profiles of whiskey. For more information, visit www.buffalotrace distillery.com.

Buffalo Trace Distillery

A bottle from Buffalo Trace Distillery's Experimental Collection of bourbon, which underwent IR-light treatment during the aging process.

Applications on the Upswing as Cost of **Imaging Systems** Comes Down

Headwall Photonics Inc.

From picking the juiciest and most colorful cranberries for consumption to detecting one of the most elusive of cancers — brain cancer — imaging systems are gathering momentum, largely thanks to shrinking size and cost.

BY MARIE FREEBODY
CONTRIBUTING EDITOR

Every autumn — usually from mid-September until around mid-November in North America and March through May in South America — cranberries reach their peak of color and flavor and are ready for harvesting. It's then the turn of hyperspectral imagers to ensure only the best grade cranberries make it through to production from the millions of kilos that are harvested.

In March 2015, spectral-imaging specialist Headwall Photonics Inc., based in Massachusetts, began a collaboration with a well-known cranberry-products maker to begin testing new spectral-imaging/machine vision technologies targeted at providing growers and farmers with the technology necessary to improve product quality and agricultural yield.

But they're not just spotting foreign material for extraction. Headwall's hyperspectral imagers are now grading produce with a high degree of specificity so that food processors can inspect and classify inbound products and make use of different grades of crop for different end use products.

"Rather than simply 'good vs. bad,' hyperspectral imaging allows for a more granular distinction across the inspected line of food products," said David Bannon, CEO of Headwall Photonics. "Headwall's sensors are based upon what is called a 'push broom' design, or a 'line-scanning' optical design simply using precise diffraction gratings and concentric mirrors."

While the method may not be new — spectral imaging has been used by the military for many years — Bannon points out applying this spectral instrumentation to commercial applications takes some extra effort to develop "actionable" data maps for commercial end users. It is the ability to apply spectral mapping for critical vision applications that is attracting industry and academia alike to the power of advanced machine vision sensors. One such example is the HELICoiD Project, which is a European collaborative funded by the Research Executive Agency, through the Future and Emerging Technologies (FET-Open) program, under the 7th Framework Program of the European Union.

Its aim is to use hyperspectral imaging for real-time identification of tumor margins during neurosurgery, helping surgeons extract the entire tumor and to spare as much of the healthy tissue as possible.

"Brain cancer is among the hardest of all to detect, with 'good' cells looking almost indistinguishable from cancerous ones. But the specificity of hyperspectral imaging to 'see' this cellular distinction represents a tremendous breakthrough," Bannon said.

'Payload-friendly' systems

Reductions in sensor instrument size are another enabler pushing the faster adoption of hyperspectral and multispectral imagers into new applications. As sensors move down in size, weight and cost, they also move from traditional strategic platforms such as satellites and manned aircraft to more tactical craft such as hand-launched unmanned aerial vehicles (UAVs).

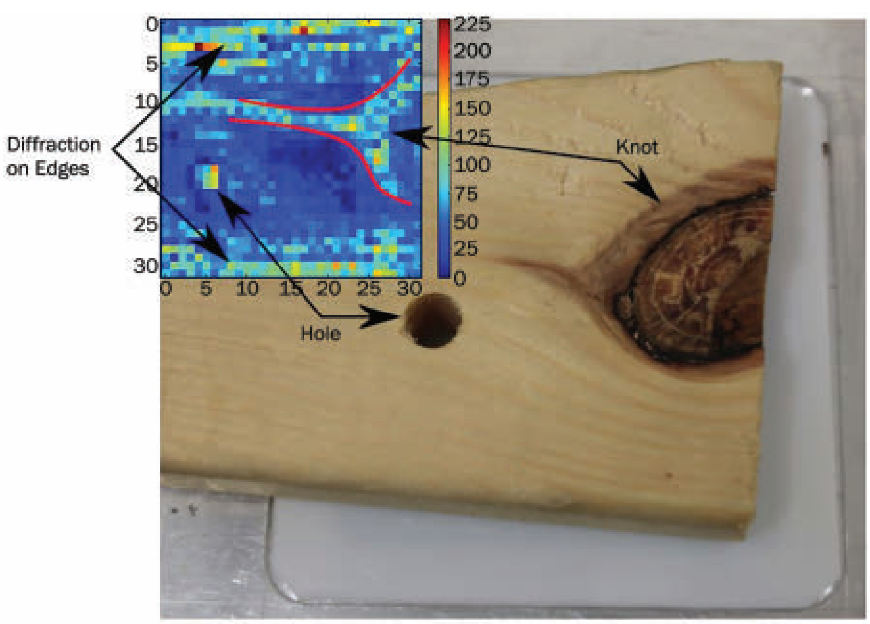
Such airborne (remote sensing) applications include everything from precision agriculture, geological exploration, environmental monitoring and infrastructure inspection to pollution mitigation, ISR (intelligence, surveillance and reconnaissance) and climatology.

More ground can be covered, and more actionable spectral data can be collected, when a fleet of equipped UAVs supplements a very costly satellite mission or high-flying reconnaissance aircraft.

"Precision agriculture is benefiting from the simple adoption of the UAV and sensors that are 'payload-friendly,'" Bannon said. "By making the sensors smaller, lighter and more affordable, more users can take advantage of hyperspectral [imaging], which basically is a new set of eyes for the remote sensing community."

Headwall Photonics Inc.

At the southeastern Massachusetts Cranberry Station, the X6 from German artificial intelligence and robotics specialist Aibotix GmbH is about to gather spectral data on a test flight, as seen in front image.



TeraSense Group Inc.

Terahertz imagers can be used to detect internal defects such as holes/knots in this 20-mm thick piece of pine wood.

At Barrington, N.J.-based Edmund Optics Inc., the trends of shrinking size and cost are also opening up new application spaces. Cameras are pushing toward smaller sensors with smaller pixels and larger sensors with higher resolutions. The result is a new take on lens design.

"Pixel sizes are getting smaller. Customers will require [a] higher-resolution imaging lens to fully utilize the smaller pixels," said Lisa Tsang, product line manager of Imaging at Edmund Optics. "We've introduced a new family of high-resolution, small format fixed focal length lenses — our new UC Series Lenses."

Designed for pixels that are ≤2.2 µm and optimized for 1/2.5-in. sensors, these lenses provide high levels of resolution (>200 lp/mm) across the sensor, making them ideal for inspection, factory automation, biomedical instrumentation and a broad range of other applications.

At Flir Systems Inc., based in Wilsonville, Ore., Chief Technical Officer Pierre Boulanger points out that going forward, providing just a pretty thermal image may not be enough. If the final functionality needs to be realized with a second subsystem, those systems may not be competitive.

"Advancements and the availability of high-performing, yet inexpensive, sensors, optics and systems-on-chip are enabling the implementation of imagers as systems that execute beyond simply generating an image. They now solve problems," he said.

System-on-chip enabling new capabilities

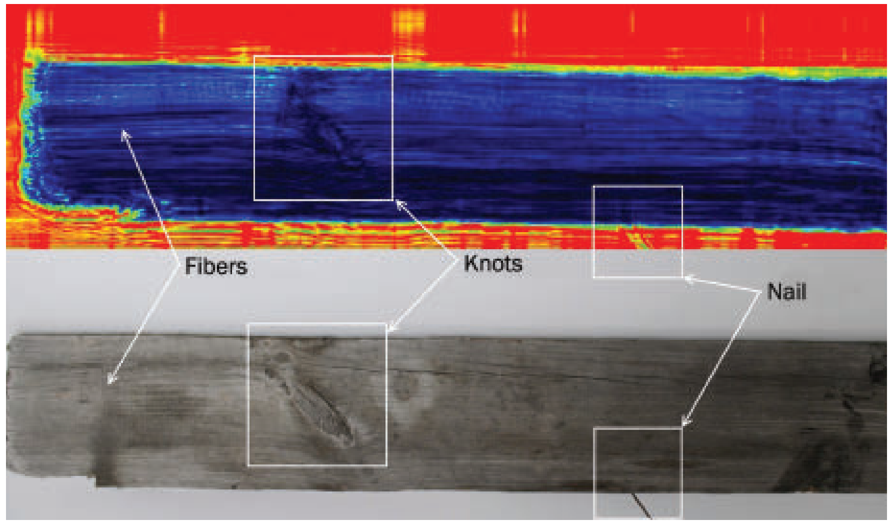
As showcased in April at the 2016 SPIE Defense and Commercial Sensing Conference in Baltimore, Flir's Boson Thermal Camera is the first of its type to incorporate a low-power multicore vision processor. The tiny camera offers onboard processing capabilities and can be implemented into OEM devices such as cars, security systems, unmanned air systems or military equipment such as rifle scopes.

"The system-on-chips are becoming more capable, enabling imagers to perform specific tasks for customers. More and more useful end-function systems based on image sensor data will become possible," Boulanger said. "The video analytics algorithms still need to improve their performance. Several function very well today, such as for pedestrian detection in automotive markets, or virtual fence protection in security applications, but as uses become more diversified, we must design new algorithms."

Demand for consolidation and integration is echoed by Bannon: "Consolidation comes from taking what were previously 'connected' elements and packing them inside the sensor housing."

In the case of Headwall's Nano-Hyperspec, 480 GB of embedded storage and direct-attached GPS/IMU (inertial measurement unit) means that an outboard computer (plus related cabling) are now rendered unnecessary, optimizing the payload budget for other related instruments such as lidar, or a FODIS (fiber-optic downwelling irradiance sensor), RGB (red, green, blue) sensors/cameras and more.

"Integration is also key because putting specialized and sensitive instruments



TeraSense Group Inc.

Cracks, nails and knots in wood can be detected using terahertz imagers.

aboard a UAV can be a costly, drawn-out process. Headwall is providing turnkey packages to customers who need the UAV plus hyperspectral, lidar and full software control capability," Bannon said.

While hyperspectral sensors collect literally hundreds of spectral bands of data, important decision-making in the realm of remote sensing depends on collecting other data streams as well as post-processing software, which attaches the real value into the data collection process.

Another emerging trend to watch is the increasing connectivity to the cloud, which

Flir Systems Inc.

While Flir's Boson camera remains in its early launch stage, these images represent the type of analytics that Boson will make available all within the core. The images show men walking in and out of alarm zones and a man walking in a parking lot.

Edmund Optics Inc.

TECHSPEC Ultra-Compact (UC) Series Fixed Focal Length Lenses. Designed and optimized for sensors with smaller pixels.

will allow users to execute advanced functions on images. For example, Flir's cloud-based service, called RapidRecap, compresses a full day of video from its consumer Flir FX security camera into a single minute where only events of interest are displayed.

"In security applications, you can watch all that occurs at your house and expand on specific occurrences, like when the solicitor knocked at the front door," Boulanger said. "The cloud offers limitless processing capability and more original services will become available through it; services that cannot yet be embedded."

Targeting wavelengths

As the cost of sensors continues to decrease, it is now possible to blend different wavelengths into a single image or sensor system, providing the best that each wavelength has to offer or allowing concentration on a certain spectral range of interest.

For example, Headwall's airborne chlorophyll fluorescence sensor targets the very narrow range where chlorophyll fluoresces (755 to 775 nm), which can allow the scientific research community to learn more about crop health and agricultural yield.

"It allows the precision agriculture people to make better decisions with respect to irrigation, fertilization, plant stress and the presence of crop diseases because they now have near real-time access to the underpinnings of the photosynthetic process through hyperspectral image data," Bannon added.

Alternatively, targeting a somewhat underutilized yet promising slice of the electromagnetic spectrum is the goal for companies focusing on the troublesome terahertz regime. Sitting between the microwave and optical frequencies is the part of the spectrum that is commonly referred to as the terahertz gap.

While technically the gap has been explored and mastered, the majority of devices employing T-rays (terahertz radiation) remain expensive. But just as in the case of the more well-utilized regimes, terahertz-based equipment is also becoming cheaper, raising its attractiveness for industrial applications.

"As far as we can see it, there are two major cost drivers influencing [the] THz imaging industry," said Viacheslav Muravev, vice president of Terasense Group Inc. in San Jose, Calif. "First, it is the cost of crystals and chips that are used for production of pixels for our THz detectors and THz imaging cameras. We can make THz cameras with sensor arrays of almost any configuration. It's like a Meccano for kids, where we simply add modules."

When calculating the price for a custom-tailored solution (sensor array), estimates are based on the price per pixel, ranging from $7 to $10, depending on the size of array.

"Second, it is the cost of [the] THz generator, and it'd better be powerful enough to support THz imaging. Power output of [the] THz emitter is one of the most critical factors determining the quality of THz image and penetration capability," continued Muravev. "Our generators — IMPATT diodes — are capable of ensuring power output of 80 to 100 mW (at the frequency of 100 GHz) and cost over $5,000. Of course, many customers would love to see some improvement in this aspect."

Since releasing its first terahertz imager in 2012, Terasense has developed its TeraFAST-256-HS high-speed linear camera, which was designed specifically to fill the needs in nondestructive testing and quality control for various industrial applications. But the company's Holy Grail is to develop a marketable full-body screener system.

While still at the proof-of-concept stage, Terasense is busy working toward building an entire people-screening system. Crucial to this is developing a powerful enough emitter to generate the penetration capability and image quality needed.

Today, its most powerful source offers tunable frequency (within dedicated ranges 80 to 360 GHz) at a power output of up to 1 W. But at a retail price of over $50,000, Muravev admits that sales may be slow.

"The first manufacturer who claims to have created a comprehensive solution for a safe and harmless full-body scanner for [security] screening or NDT [nondestructive testing] application will indisputably strike a bonanza," Muravev said.

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High-Performance **UVC LEDs** Driving Spectroscopy Innovations

UVC LEDs are supplanting lamp-based systems for high-performance liquid chromatography, water-quality assessment and process monitoring in the food and beverage industry.

BY HARI VENUGOPALAN
CRYSTAL IS INC.

UVC LEDs are fast becoming the technology of choice for designers developing a new breed of spectroscopy devices that are smaller, less costly and more energy-efficient, while still delivering precise, real-time measurements. With efficiency and performance levels that rival traditional lamp-based systems, UVC LEDs are an integral component in new instruments for a range of applications, including high-performance liquid chromatography (HPLC), water-quality monitoring and process monitoring in the food and beverage industry.

Granted, LEDs are an established technology, offering a small footprint, ease of alignment and enhanced end-user productivity. But adoption of earlier sapphire substrate UVC LEDs in the 250- to 280-nm range was relatively limited due to performance and reliability issues.

Crystal IS Inc.

UV fluorometry is used to monitor oil and hydrocarbons in water because the aromatic component in these substances fluoresce under UV light. UVC LEDs offer narrow wavelenghts for selective, targeted measurements; allow for a small footprint for easy inline monitoring of water quality; and offer high light output for trace detection at the parts-per-billion level.

To improve performance, new lattice-matched single-crystal aluminum nitride (AlN) substrates were developed. With approximately 10,000 fewer defects per square centimeter, LEDs based on native AIN substrates provide enhanced light generation and a substantially longer service life.

As a result, UVC LEDs are now used in a growing number of spectrometers, especially in life sciences applications where fast, accurate and dependable measurements are required. This is especially true in applications that rely on quantitative analysis through absorption spectroscopy, such as HPLC and DNA concentration and purity measurements.

Leveraging lattice-matched UVC LEDs, Lenexa, Kan.-based Marion Research LLC recently developed a portable HPLC detector that exceeds the performance of traditional fixed wavelength detectors, but at less than half the cost, and less than one-tenth the size, weight and power consumption. The new LEDs helped Marion Research designers overcome a number of technical hurdles. Traditional HPLC systems use deuterium (D_2) lamps, which deliver a very stable light output. However, new LED designs are more stable than high-end deuterium lamps (Figure 1). With UVC LEDs, light fluctuations are 0.002 percent, while deuterium lamps range from 0.005 to 0.05 percent. UVC LEDs also provide higher light intensity at specific wavelengths, which makes the instrument's measurements more sensitive.

In addition, many common chromatography applications require only one or two fixed wavelengths. Traditional, deuterium lamp-based HPLC systems offer a wide range of wavelengths — usually more wavelengths than are needed. UVC LEDs, which emit light in a narrow wavelength range rather than the broad spectrum of a deuterium lamp, allowed Marion Research to develop new, smaller devices that target specific applications.

The system is designed for wavelength applications in the 250- to 280-nm range. Employing UVC LEDs helped the company simplify the design of the optical train and use fewer, less costly components. The power supply and photodiode is less expensive when compared to a traditional deuterium lamp-based system, which requires a costly power supply, a monochromator to filter out other wavelengths, and a photodiode array for detection.

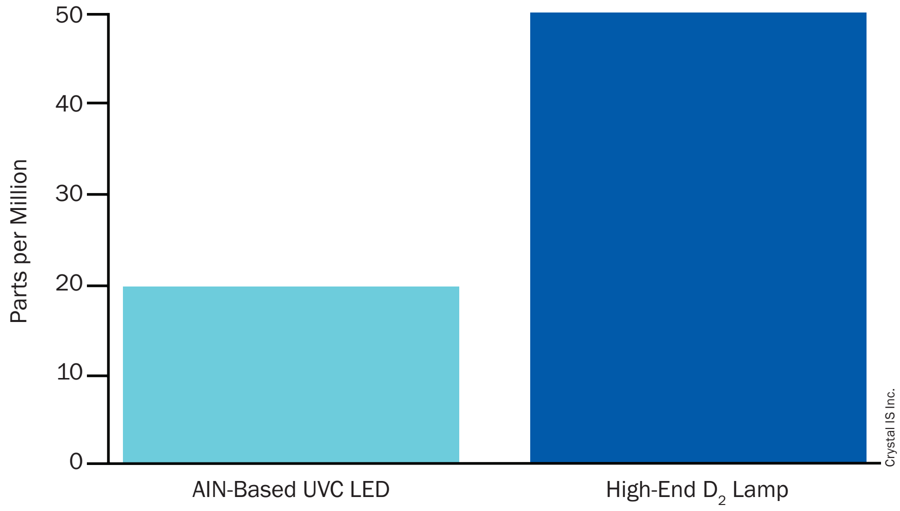

Figure 1. Comparison of light output fluctuation (stability) between an AIN (aluminum nitride)-based UVC LED and a high-end deuterium (D_2) lamp. Peak-to-peak fluctuation within each 30-second interval is measured and averaged over a 15-minute time frame.

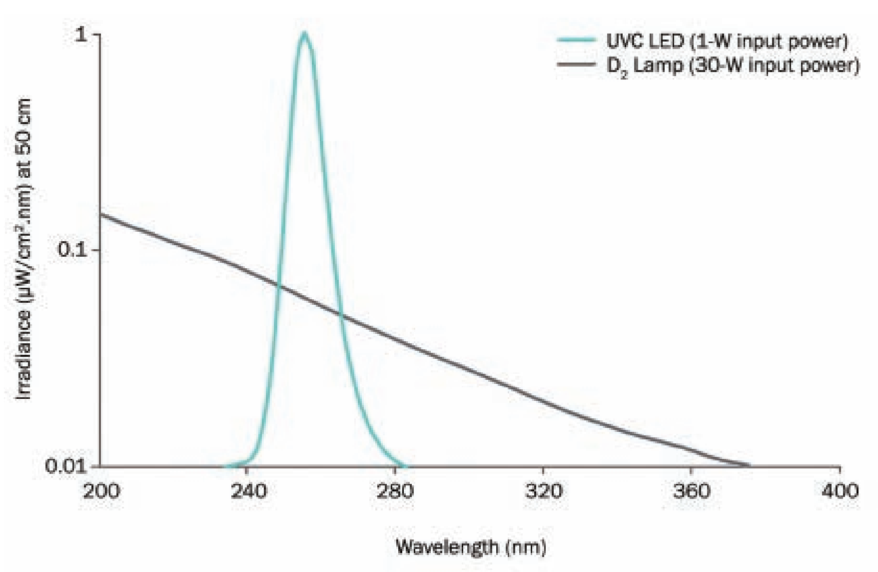

Figure 2. Irradiance comparison of a UVC LED with a peak at 255 nm versus a typical deuterium lamp.

Because of the near-monochromaticity of the LEDs, Marion Research designers selected the wavelength to match the absorption spectrum of the compound of interest. Compared to the broader spectrum of deuterium lamps, the LEDs offered more irradiance at a specific wavelength in the deep UV range (Figure 2) and the detector successfully delivered the high level of sensitivity required for the application.

The UVC LEDs also allowed the company to simplify the instrument's optical design with fewer components, and less bulky power supplies. The result is an extremely compact (44-mm diameter × 44-mm long), low-cost detector, one that can be used in the lab, or the field for environmental or point-of-care diagnostics.

Monitoring pollution

UVC LEDs are also helping the shipping industry monitor and substantially reduce its emissions footprint.

Shipping companies have been burning high-sulfur bunker fuel for decades, releasing nitrogen oxides (NO_x), sulfur oxides (SO_x), polycyclic aromatic hydrocarbons (PAHs) and particulates into the atmosphere. By one estimate, the 15 largest ships in the world create more pollution than all the cars in the world. Further, shipping industry pollution impacts the health of communities in coastal and inland regions around the globe, producing emissions that cause some 60,000 deaths annually. With 70 percent of ship-borne pollution occurring within 250 miles of land, half of all SO_x-generated smog in the Los Angeles area is attributed to ships.

In response, the International Maritime Organization has instituted new regulations that will force shipping lines to burn marine fuel with sulfur content levels of 0.5 percent by 2020. To comply, shipping companies will have to either switch to more expensive low sulfur fuel (with an economic impact estimated at tens of billions of dollars annually), or install relatively lower cost exhaust-gas cleaning systems.

These cleaning systems employ wet gas scrubbers to "scrub" the flue gas and reduce diesel engine emissions, including SO_x and PAHs. However, since PAHs are harmful to people and the environment, shipping companies will also need a way to ensure the PAHs in the scrubber system's wash water have been properly treated before discharging the water into the ocean.

Enter U.K.-based Chelsea Technologies Group Ltd. (CTG), which designs and manufactures sensors and systems for a range of global markets. CTG recently developed a highly precise UviLux fluorescence spectroscopy system that employs UVC LEDs to measure the PAH content in the wash water.

Fluorescence spectroscopy at 255-nm excitation is an ideal solution because it can measure even low concentration levels of PAHs, such as phenanthrene. In fluorescence spectroscopy, the emission intensity, or signal, is directly proportional to the concentration of the fluorescent compound over a wide range of concentrations. The emission intensity also depends on the intensity of excitation, so the greater the intensity of the light source at 255 nm, the greater the sensitivity of detection (Figure 3).

Fluorometers operating in the deep UV wavelengths typically employ xenon flash or deuterium lamps, which require more complex circuitry and typically have a higher cost of ownership than solid-state light sources like LEDs. As a result, CTG chose high light output, long lifetime lattice-matched UVC LEDs for its UviLux fluorometer.

In addition to PAHs, the UviLux fluorometer can also be configured to measure other wash water parameters, including colored dissolved organic matter, tryptophan-like fluorescence/biological oxygen demand and optical brightening agents (Figure 4).

By combining absorbance and turbidity measurements, a correction is made for attenuation effects in the sample, which can be problematic in wash water with high color and/or turbidity. The company has demonstrated that with the system's absorbance and turbidity correction algorithm, PAHs can be monitored over the required range of 0 to 4500 µg/L phenanthrene equivalence, in water turbidity up to 1000 formazin turbidity units (FNUs).

By addressing all four parameters, the system allows CTG customers, therefore, to meet the IMO's environmental regulations by accurately monitoring wash water for PAHs (defined as phenanthrene fluorescence equivalence), as well as pH, turbidity and temperature.

Real-time process monitoring

UVC LED-based devices are also improving real-time process monitoring.

For example, due to the FDA's Food Safety Modernization Act — which aims to ensure the U.S. food supply is safe by shifting the focus from responding to contamination to preventing it — the food and beverage industry is facing many challenges. These regulatory changes, combined with ongoing consumer pressures, require a fresh look at food safety, shelf-life management, product quality, process control and product traceability.

As a result, food and beverage companies are now employing compact, lower-cost spectroscopic sensors — mounted directly within their process flows — for real-time monitoring. The sensors are much more cost-effective, efficient and reliable than traditional methods, which include diverting the flow into special piping, or "grab sampling," where samples are manually selected and brought to a lab for testing.

Which spectroscopic method is used — UV-VIS, Fourier transform infrared or Raman — depends on what's being sampled. UV-VIS technology, for example, is ideal for quantitative and qualitative sample analyses in absorption, transmission and reflection measurement modes.

Until recently, deep UV or UVC (with a wavelength range of 200 to 280 nm) measurement devices employed deuterium or xenon flash lamps. While the lamps provide adequate light in the UVC wavelengths, they require costly filters and bulky power supplies. As an alternative, food industry sensor manufacturers now employ UVC LEDs to reduce sensor size and costs — while providing the same level of precision.

UVC LED-based technology is also helping the industry monitor the quality

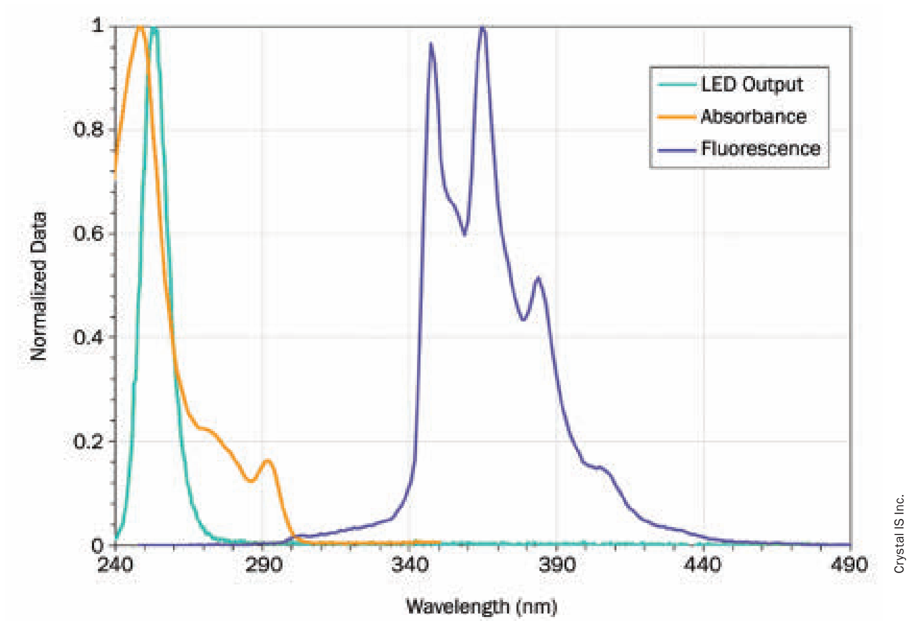

Figure 3. Absorbance and fluorescence spectrum of phenanthrene, with an overlay of the Crystal IS 255-nm Optan LED spectrum.

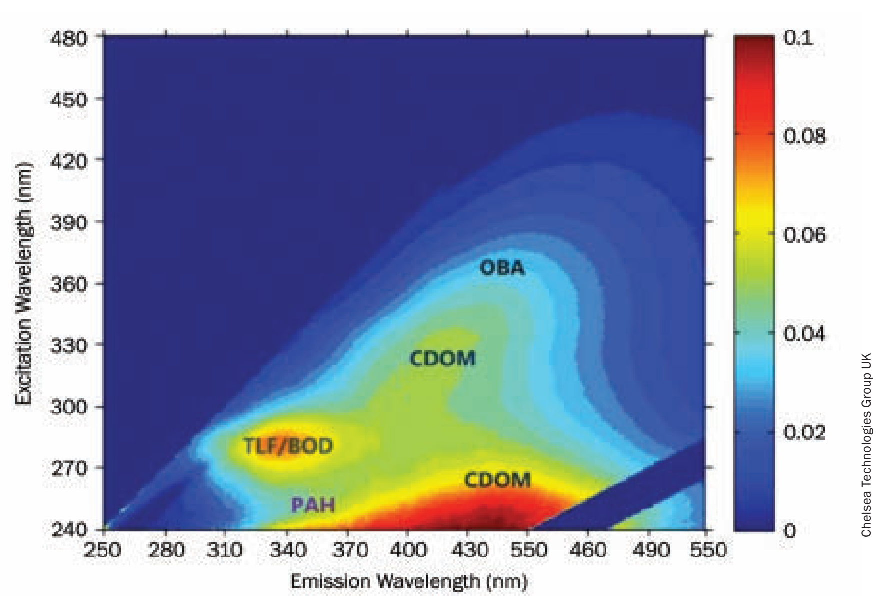

Figure 4. Fluorescence excitation-emission matrix of a natural freshwater sample, indicating polycyclic aromatic hydrocarbon (PAH); tryptophan-like fluorescence/biological oxygen demand (TLF/BOD); colored dissolved organic matter (CDOM); and optical brightening agents (OBA).

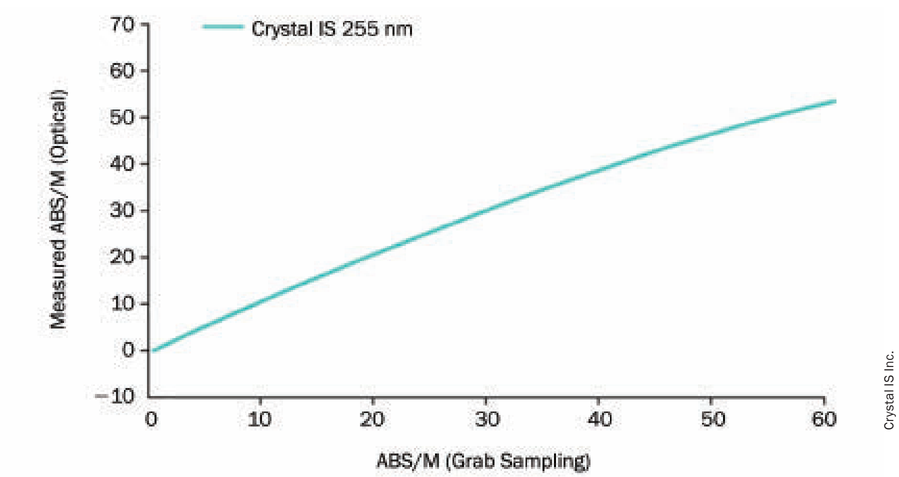

Figure 5. Total organic carbon (TOC) measurement (in absorbance/meter) using a Crystal IS UVC LED at 255 nm that shows the correlation between the optical methods of water-quality measurement with the reference chemical-grab sampling performed in the lab.

of process water — one of the most common ingredients in food. Ironically, while food and beverage producers require a certificate of analysis (COA) for other ingredients, they often overlook water quality. And that's a major oversight because water characteristics can vary over time with regard to taste, odor, chemistry and the presence of microbes — all of which can alter the product's taste.

Further, it's not uncommon for process water to become contaminated with organics during manufacturing. And as food processing expands globally, water quality is becoming even more critical to product consistency. Water utilities in many countries have limited monitoring capability and/or employ unreliable analytical techniques.

To resolve these water-related issues, food and beverage companies employ total organic carbon (TOC) analyses — either by chemical methods or, spectroscopy at 255 nm — to maintain water quality throughout the manufacturing process. Chemical analyses based on persulfate oxidation are expensive, require more time between measurements, and have high consumable costs.

Until recently, UV systems using xenon flash lamps have been the preferred spectroscopy methodology. However, while these instruments offer precise, accurate measurements, the functionality exceeds what is needed at most food industry plants. The same analyses are now being performed using UVC LED devices, which employ a less costly detector and consume less power. In fact, high-performance UVC LEDs offer linearity of measurement (Figure 5) that matches the performance of expensive xenon flash lamps, but at 40 to 80 percent of the cost.

With the life expectancy and performance issues now resolved, instruments equipped with today's UVC LEDs match and often exceed the performance of those equipped with UV lamps, while delivering higher efficiency and reduced costs for fixed wavelength applications. As a result, those in the LED industry see the fast-growing list of new applications as merely the tip of the iceberg.

Whether it's a new, more precise system for monitoring product quality; a lower-cost lab device that lasts longer, takes up less room and improves overall productivity; or helping the shipping industry do its part to be more environmentally friendly, UVC LED technologies are expected to drive new and exciting innovations across an ever-increasing range of diverse, global applications.

Meet the author

Hari Venugopalan is director of product management at Crystal IS Inc., Green Island, N.Y. He has more than 10 years of experience in visible and UV LEDs; email: venugopalan@cisuvc.com.

Focus on **Polarization**

With spatial correction, line scan polarization cameras detect birefringence, stress, surface roughness and physical properties that cannot be detected with conventional imaging.

BY XING-FEI HE
TELEDYNE DALSA

There are three fundamental properties of light: intensity, wavelength and polarization. Almost all cameras today are designed for monochrome or color imaging. A monochrome camera is used to measure the intensity of light over a broadband spectrum at pixel level[1], while a color or multispectral camera is used to detect the intensities of light at the red, green, blue and near-IR wavelength bands[2,3]. Similarly, a polarization camera captures the intensity of light at multiple polarization states.

According to a recent AIA market study, worldwide camera sales in machine vision reached $760 million in 2015, with about 80 percent from monochrome cameras and 20 percent from color cameras. While polarizers are commonly used in machine vision, until now there have not been line scan polarization cameras that capture images of multiple polarization states.

Polarization offers numerous benefits, not only detecting geometry and surface, but measuring physical properties that are not detectable using conventional imaging. In machine vision, it can be used to enhance contrast for objects that are difficult to distinguish otherwise. When combined with phase detection, polarization imaging is much more sensitive than conventional imaging.

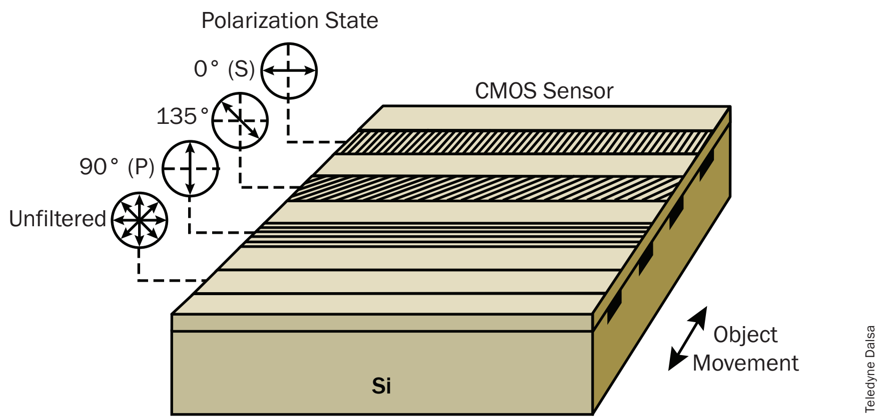

Figure 1. Schematic of Teledyne Dalsa's Piranha polarization camera sensor architecture. The nanowire micropolarizer filters are placed on top of silicon (Si), which define 0° (s), 135°, and 90° (p) polarization states, respectively, on the first three linear arrays. The fourth array is an unfiltered channel that records a conventional unfiltered image.

Polarization filter technologies

Like human eyes, silicon cannot determine light polarization. Therefore, a polarization filter is required in front of the image sensor; the image sensor detects the intensity of light with the polarization state defined by the filter.

Most common types of polarization filters fall into one of three categories: division of time, division of amplitude or division of focal plane (Table 1). For division of time polarimetry, data is acquired sequentially in time as a polarization element, such as a liquid crystal, polarizer or a photoelastic modulator, is rotated or modulated. The speed is limited by the modulation. In many applications today, a high line rate of about 100 kHz is required; division of time filters have inherent limitations. Cost is also high due to complicated designs.

For division of amplitude filters, light is split into different optical paths, where each path has a separate sensor. A prism is the most commonly used component where accurate registration is often difficult to achieve. Also, the housing is usually large in order to accommodate the prism.

Table 1.
Comparison of Polarization Filter Technologies

	Division of Time	Division of Amplitude	Division of Focal Plane
Principle	Data is acquired sequentially in time as a polarization element is rotated or modulated.	Light is split into different optical paths where each path has a separate sensor.	Micropolarizer filters are placed on pixel level to define different polarization states.
Speed	Limited by the polarization element	No limit	No limit
Robustness	Low	Low	High
Cost	High	High	Low

Source: Teledyne Dalsa

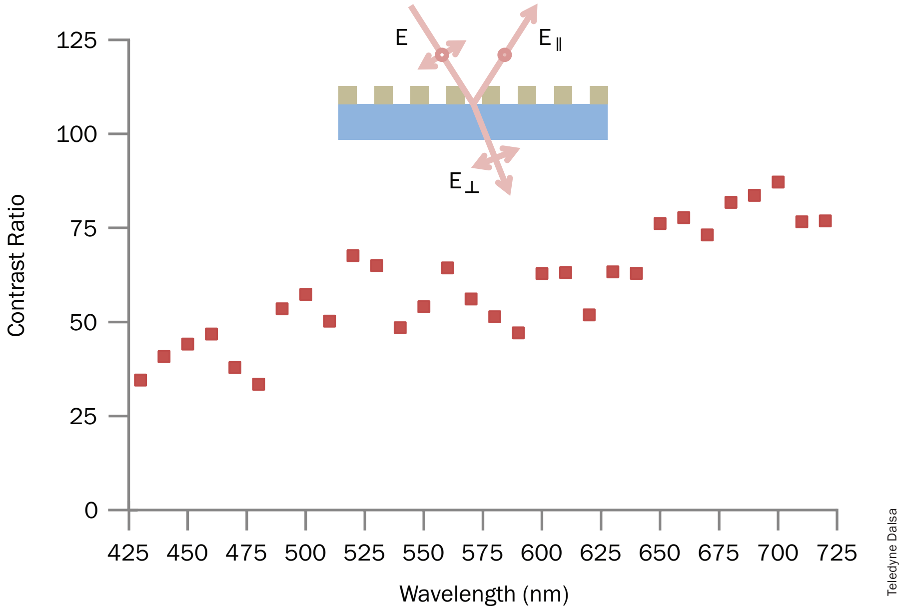

Figure 2. Contrast ratio of nanowire-based micropolarizer filters.

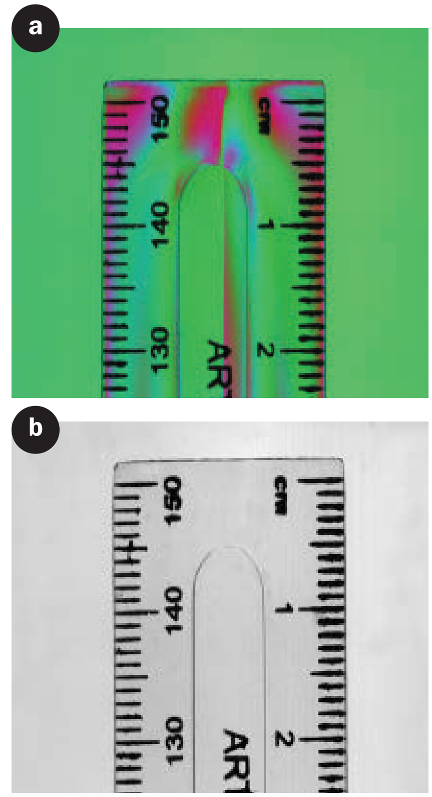

Figure 3. Color-coded polarization image **(a)** compared with a conventional, unfiltered image **(b)** of a plastic ruler captured by Piranha polarization camera. In the polarization image, RGB represent 0°(s), 90°(p), and 135° polarization state, respectively.

For division of focal plane filters, a micropolarizer array is placed on the focal plane to define different polarization states. The technology is suitable for compact, robust and low-cost designs. However, for area scan imagers there are inherent disadvantages in spatial resolution as each pixel only provides data for one native polarization state. Algorithms are used to interpolate others.

Line scan polarization cameras using micropolarizer filters overcome the shortcomings mentioned above. In line scan, multiple arrays with different polarization filter orientations capture images simultaneously but at slightly different positions. Spatial correction allows the camera to align all channels at the same object point. The advantage of line scan over area scan is that it provides multiple native polarization state data without any digital manipulation.

Sensor architecture

Teledyne Dalsa's Piranha polarization camera (Figure 1) incorporates a CMOS sensor with a quadlinear architecture. A micropolarizer array consisting of nanowires is placed on top of the silicon; the nanowires have a pitch of 140 nm and a width of 70 nm, while the orientation of the micropolarizer filters is 0°, 135° and 90°, respectively, on the first three linear arrays. The intensity of the filtered light is recorded by the underlying arrays. The fourth channel is an unfiltered array, which captures the total intensity, equivalent to a conventional image, while the gaps in between the active arrays reduce spatial crosstalk.

Light is an electromagnetic wave. Its electrical field, magnetic field and propagation direction are orthogonal to one another. Polarization direction is defined as the electrical field direction. Light, with its electrical field oscillating perpendicular to the nanowires, passes through the filter while that in the parallel direction is rejected. When the line scan camera is mounted at an angle to the web in a reflection configuration, the 0° channel transmits s-polarized light (polarization perpendicular to the plane of incidence) while the 90° channel transmits p-polarized light (polarization parallel to the plane of incidence). Assuming the camera outputs I_0, I_{90}, I_{135} and I_{uf}, from 0°, 90°, 135° polarization and unfiltered channel, respectively, the intensity of s-polarized and p-polarized states are:

$$I_s = I_0$$
$$I_p = I_{90}$$

The key differentiation between line scan and area scan using micropolarizer filters is the number of native polarization state data per pixel. An area scan imager generally uses 0°, 45°, 90° and 135° polarization filters arranged in a so-called super-pixel format[4], where each pixel captures one native polarization state. Interpolation algorithms are then used to calculate the three other states based on the information from neighboring pixels. This results in poor data accuracy because of the loss of spatial resolution. For line scan cameras, on the other hand, each polarization state has 100 percent sampling. Multiple native polarization state data are physically measured. The contrast ratio of the nanowire micropolarizer filters are shown in Figure 2. A contrast ratio of 30~90 is observed depending on wavelength. Higher contrast ratio can be realized with future designs.

Stokes parameters, S_0, S_1, S_2, etc., are often used to analyze physical properties of materials. Differential polarization, degree of linear polarization (DoLP) and angle of polarization (AoP) are all useful parameters.

Image visualization

Polarization images are largely uncorrelated to conventional images based on intensity. In a vision system, data processing could be implemented in each specific polarization state or their combinations. It's useful to have a representation of polarization images considering human's inability to see it. Color-coded polarization images are probably the most popular as they not only give visual perception but also utilize the standard data structure and transfer protocols in color imaging.

Figure 3 shows a color-coded polarization image of a plastic ruler captured by the Piranha polarization camera, where RGB represent 0° (s-polarized), 90° (p-polarized) and 135° polarization state, respectively. A conventional image captured by the unfiltered channel is also compared. Obviously, the polarization imaging reveals built-up stress inside the plastic ruler that cannot be detected by conventional imaging.

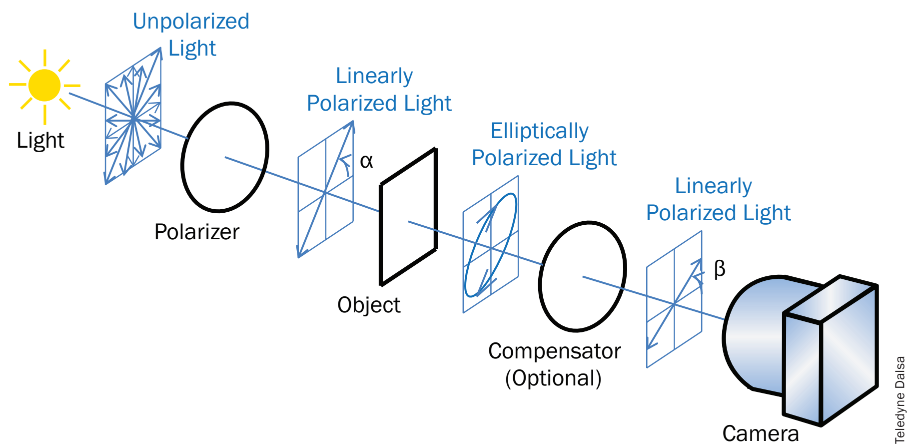

Figure 4. Transmission configuration: A polarizer converts the light source into linearly polarized light. When the linearly polarized light transmits through the object, it generally becomes elliptically polarized due to birefringence. An optional compensator, e.g., λ/4 plate, can be used. Finally the image is captured by the polarization camera.

Detectability

Today, the machine vision industry is facing many challenges in detectability as speed reaches to about a 100-kHz line rate and object resolution shrinks to submicron. Different technologies have been developed, such as time delay integration to improve signal-to-noise ratio, and color and multispectral imaging to obtain spectral characteristics. However, higher contrast is required based on the physical properties of materials. Polarization plays a key role here as it is very sensitive to any change on the surface or interface. Because of phase detection, polarization-based imaging is much more sensitive than intensity-based imaging.

A transmission configuration (Figure 4) is commonly used for transparent materials such as glasses and films. Generally, a polarizer is used to convert the light source into linearly polarized light. When the linearly polarized light passes through the object, it generally becomes elliptically polarized due to birefringence of the object. An optional compensator such as a λ/4 plate could also be used in the optical path. Finally the image is captured by the polarization camera. The angles of polarizer and compensator can be adjusted for optimum performance.

A reflection configuration (Figure 5) is used for opaque materials. Reflected light from many materials such as semiconductors and metals are polarization-dependent. A polarizer converts the light source into linearly polarized light. When the linearly polarized light is reflected from the object, the reflected light generally becomes elliptically polarized. By rotating the angles of polarizer and compensator, one can achieve a linearly polarized light that reaches the camera. The configuration is similar to ellipsometry[5]. The difference is that rather than using a rotating analyzer, the camera captures different polarization states, simultaneously, with lateral spatial resolution. Light is a linear light source rather than point source.

In either of the configurations, when the physical property of the object changes due to defects, for example, the change alters the polarization state differently from the rest of the object. This change is then detected by the polarization camera with high sensitivity.

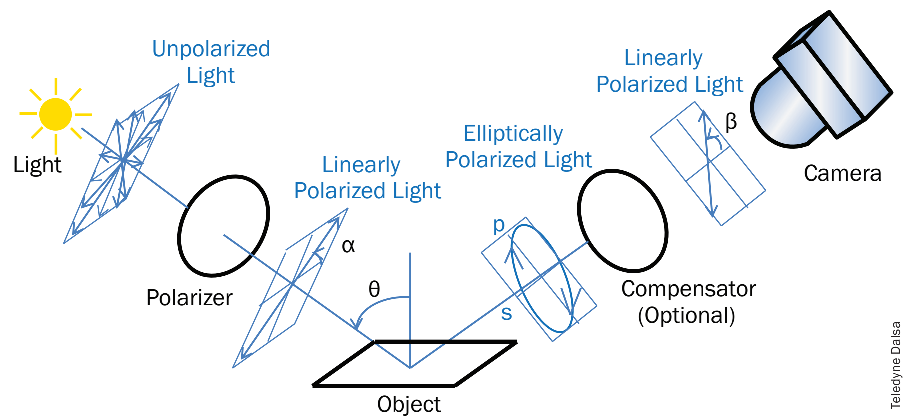

Figure 5. Reflection configuration: A polarizer converts the light source into linearly polarized light. When the linearly polarized light is reflected from the object, the reflected light generally becomes elliptically polarized. Rotate the angles of polarizer and compensator for optimal performance.

Mechanical force results in birefringence that changes the polarization state of transmitted light, as can be seen in the screws inducing stress on a pair of glasses (Figure 6). As can be seen in the unfiltered channel, conventional imaging cannot detect such stress. Note the image of electronic circuitry that contains scratches on the surface (Figure 7). In the polarization image, the surface defects are much more obvious due to contrast enhancement.

Line scan polarization imaging combines the power of ellipsometry with truly lateral resolution. Developed in the 1970s, ellipsometry is a very sensitive optical technique with vertical resolution of a fraction of a nanometer. It has been widely used to determine physical properties of materials such as film thickness, material composition, surface morphology, optical constants and even crystal disorder[6,7]. Imaging ellipsometry, developed later, adds a certain degree of lateral resolution. However, because of the point light source, it has a very small field of view (micron-millimeter) and is only suitable in microscopy. Line scan polarization imaging using a linear sensor and a linear light source overcomes this limitation.

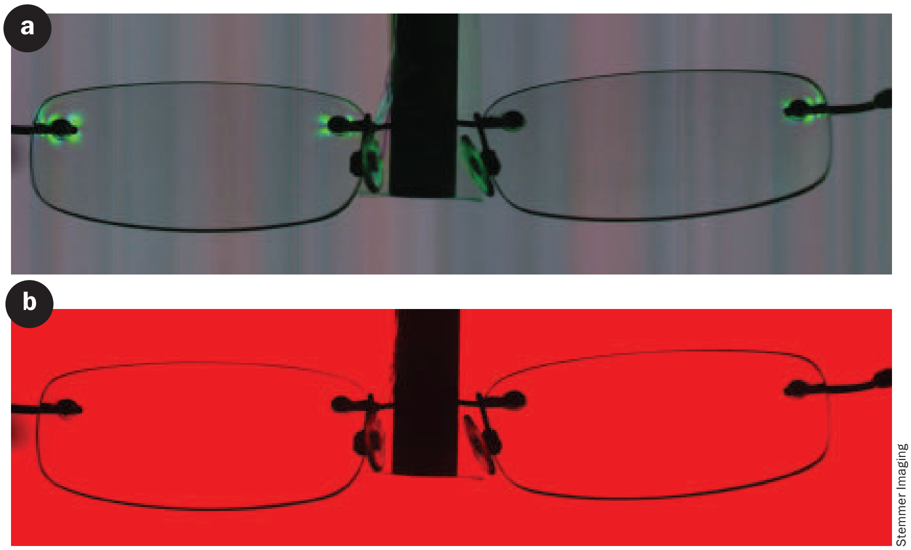

Figure 6. Polarization image **(a)** compared with a conventional, unfiltered image (**b**) of a pair of glasses. Stress surrounding the screws shows up in the polarization image while it could not be seen in the conventional image.

Brewster's angle imaging

The angle of incidence in ellipsometry is generally chosen to be close to the Brewster's angle, θ_B = arctan (n), where n is the refractive index of the object and is wavelength dependent. For glass, n ≈ 1.52 and $\theta_B \approx 56°$, and for silicon, n ≈ 3.44 and $\theta_B \approx 74°$ at 633 nm.

At the Brewster's angle, reflection of p-polarized light is minimized and the difference between the reflectance of the s-polarized state and p-polarized state is maximized. This gives the highest sensitivity. When unpolarized light is incident under the Brewster's angle and the camera is installed at the specular angle, the p-channel captures a dark signal while the s-channel still captures a normal signal from reflection. If completely p-polarized light is incident under the Brewster's angle, the camera installed at the same angle captures a dark background. Any deviation on the surface due to defects or impurities, etc., will result in a bright region. High-contrast images can then be achieved. One challenge for line scan, though, is that the condition cannot be met when the field of view is much larger than the length of the sensor.

In summary, by combining high sensitivity of polarization phase detection and truly lateral resolution, line scan polarization imaging provides the detectability for next-generation vision systems in many demanding applications.

Meet the author

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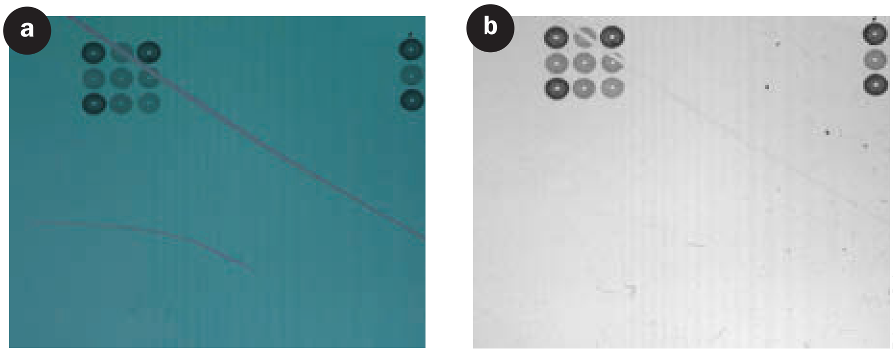

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Figure 7. Polarization image **(a)** compared with a conventional, unfiltered image **(b)** of a printed circuitry. Contrast enhancement using polarization imaging reveals small scratches on the surface that cannot be detected with conventional imaging.

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Breakthrough for Real-Time **THz Imaging**

When paired with fast detectors, terahertz quantum cascade lasers are ideally suited for industrial nondestructive testing and real-time biomedical imaging.

BY PIERRE GELLIE
LYTID SAS

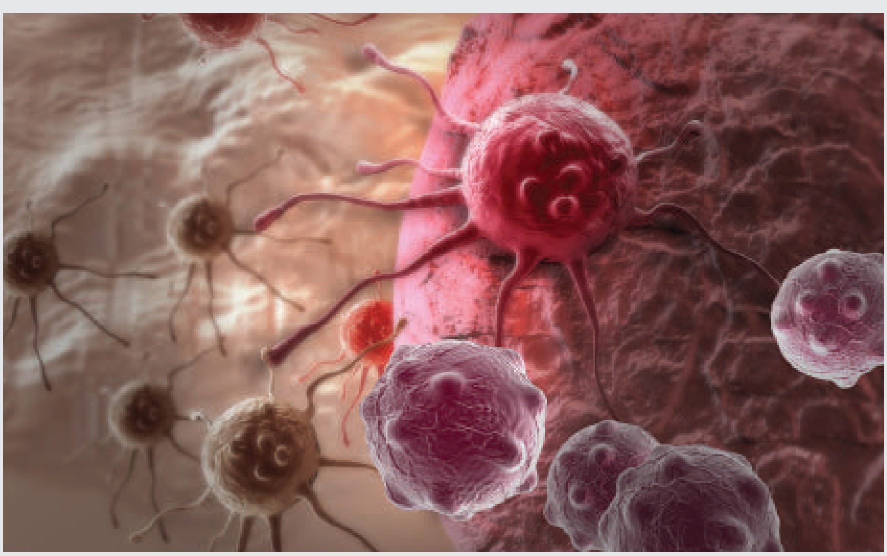
Terahertz (THz) technologies have become a major field of applied research, driven by the tremendous potential of applications such as nondestructive testing (NDT), biomedical imaging, security screening and telecommunications. Imaging using THz radiation has garnered increasing attention, as it promises penetrating, contactless and submillimeter diffraction-limited imaging that is suitable for dry, nonpolar, nonmetallic materials such as plastics and ceramics. The main challenge in achieving the full potential of THz imaging: the limitations in the performance of current THz sources and detectors.

THz quantum cascade lasers (QCLs) are electrically pumped unipolar semiconductor lasers. Their operation mechanism differs fundamentally from standard semiconductor diodes as they exploit intersubband transitions in cascaded quantum well structures to generate terahertz radiation between 2 to 5 THz or 150 to 60 µm in wavelength. Unlike standard diode lasers where the emission frequency is determined by the energy bandgap difference between the materials used, QCL emission frequency is determined by the engineered band structure — the size and width of the quantum wells — and is independent of the materials used. The cascaded structure, hence the name QCL, allows for quantum efficiencies greater than unity. Each electron that goes through the structure will emit N THz photon, where N is the number

Cancer and Burn Diagnoses to Benefit from THz Imaging

THz radiation's deep penetration combined with its strong water absorption has attracted a lot of attention in the biomedical field. That's in large part due to the fact that water concentrations reveal a lot about the health of human tissue, with water content in cancerous cells higher than in healthy cells.

Monitoring this biological marker through imaging could help with the assessment of excision margins when tumors are surgically removed and provide information more quickly than today's histopathology techniques do. Another crucial aspect is the reduced risk of additional surgery if the margins are badly delimited. Similarly, differentiating between second- and third-degree skin burns is very challenging as they are morphologically indistinguishable. This issue is of particular importance as second-degree skin burns will heal — but third-degree will not.

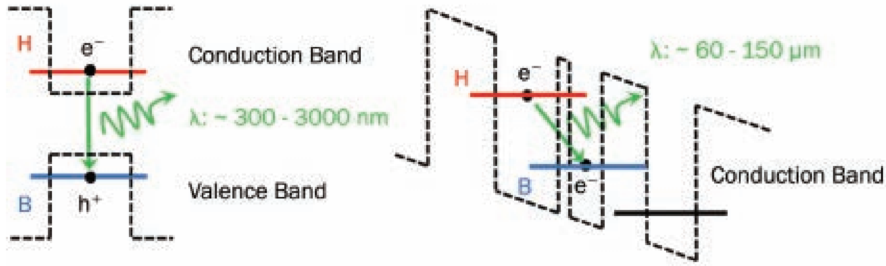


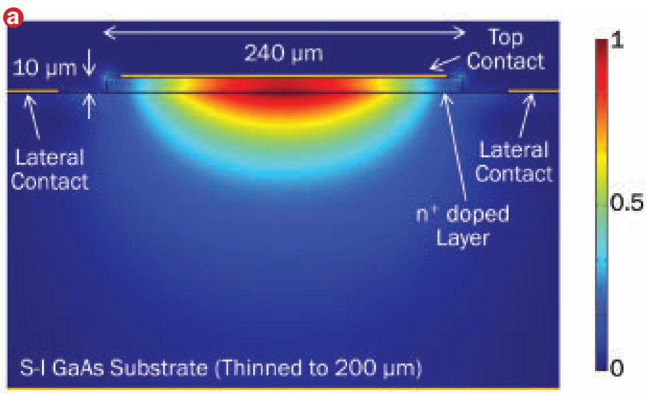
Water content variation and skin rehydration speed is the key to understanding and assessing whether skin will heal or not. Research has shown that THz radiation could be used to that end, but some challenges have to be addressed first. Most of the advanced studies were conducted on in-vivo tissue samples and faced the difficulty of focal plane variations due to the subject's micromovements originating from breathing and heart pulse. In these studies, images were acquired using slow raster scanning systems, which take several minutes to complete and are therefore affected by patient movements.

The focal plane changes reduced the quality of the results and render interpretation difficult or nonconclusive in some cases. Real-time imaging systems using high-power sources such as THz QCL and THz cameras could be the key to solving this issue and might lead to the development of new tools for biomedical THz imaging applications.

All images courtesy of Lytid SAS.

Figure 1. Standard semiconductor laser diode using interband transitions to generate radiation between 300 and 1000 nm **(right)**. This range is limited by the energy bandgap difference of the materials used. Schematic **(far right)** of a single QCL period exploiting an intersubband transition between two adjacent coupled quantum wells to generate directly THz radiation between 60 and 150 μm (2 to 5 THz).





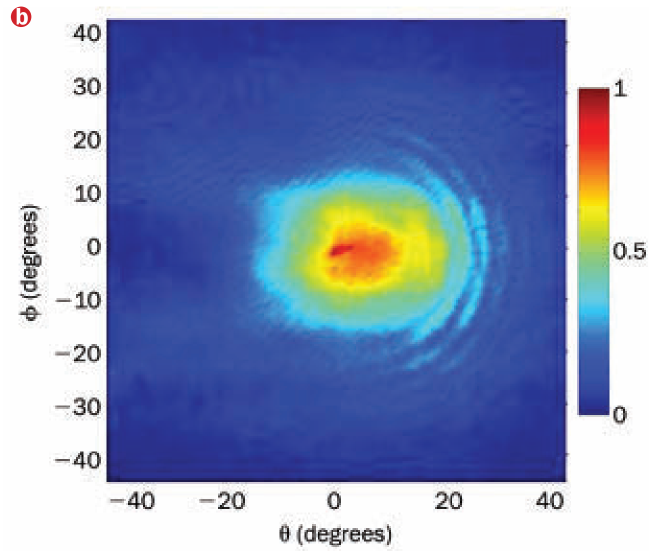
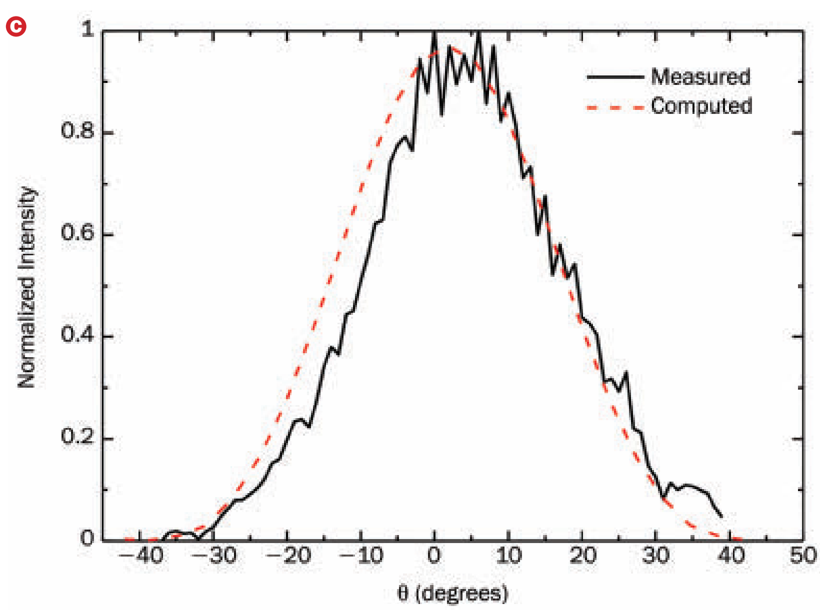


Figure 2. Computed intensity mode profile of THz QCL **(a)** in a surface plasmon waveguide. The optical mode is confined between a top metallic layer and a bottom highly doped contact layer. The optical mode can leak into the underlying substrate because the doped layer thickness is smaller than the skin depth. Typical measured far-field beam profiles of THz QCLs **(b)** provided by Lytid using surface plasmon waveguide design. The beam profile **(c)** offered by these waveguides is quasi-Gaussian.



of periods in the laser. Typically, the value of N is around 100. The Ga/As Al/Ga/As material system used for THz QCLs offers excellent growth control as well as mature processing technology.

Turning state-of-the-art quantum devices into user-friendly tools

Several challenges had to be tackled before turning this quantum technology into a tool suitable for science and industry. Among them was developing compact laser drivers designed for the specific needs of THz QCLs; controlling the beam profile, especially for imaging applications; and achieving a cryogenic operating temperature.

Notably, QCLs can operate in continuous wave (CW) mode as well as quasi-CW (QCW) mode. With limited available cooling power, QCW with a high duty cycle generally provides higher average output powers. QCW operation also provides direct electrical modulation that allows THz QCL to be used in combination with any THz detector on the market without the need for a mechanical chopper. To drive these QCL structures in quasi-CW mode, short high-current electrical pulses are required.

Commercial systems exist that, in microseconds, generate up to 2-A short pulses needed to drive THz QCLs. These tend to be very bulky, housed on 19-in. rack systems, and are therefore not compatible with integration into a compact system. The goal is to design such a laser driver that would fit into the palm of a hand.

Another crucial consideration is optimizing the beam profile for imaging applications. By using custom-designed waveguides adapted to the longer THz wavelengths it's possible to obtain a quasi-Gaussian beam profile. These waveguides are based on surface plasmon confinement of the optical THz mode between metallic layers and highly doped semiconductor contact layers. As the optical THz mode is free to leak into the substrate, the resulting output beam profile is excellent and is particularly adapted to imaging applications.

As of now, THz QCLs still require cryogenic cooling to operate. Although the maximum operating temperature is around 200 K, excellent performance can be obtained at temperatures of several tens of K, accessible to closed-cycle, cryogen-free cooling engines. At these temperatures, typical output powers are in the milliwatt range, which is about three orders of magnitude higher than other available commercial THz sources, at this frequency. This is based on either pulsed THz generation or nonlinear up-conversion (CW using two distributed feedback lasers). Another important aspect is the emission frequency. As the water vapor absorption of THz radiation is very strong — especially at higher frequencies — emission in an atmospheric transmission window is highly desirable for real-life applications.

These recent technical developments in THz QCL technology have led to the development of compact, powerful, fully integrated and user-friendly commercial THz sources. These versatile and portable systems can be easily integrated into real-world medical and industrial applications.

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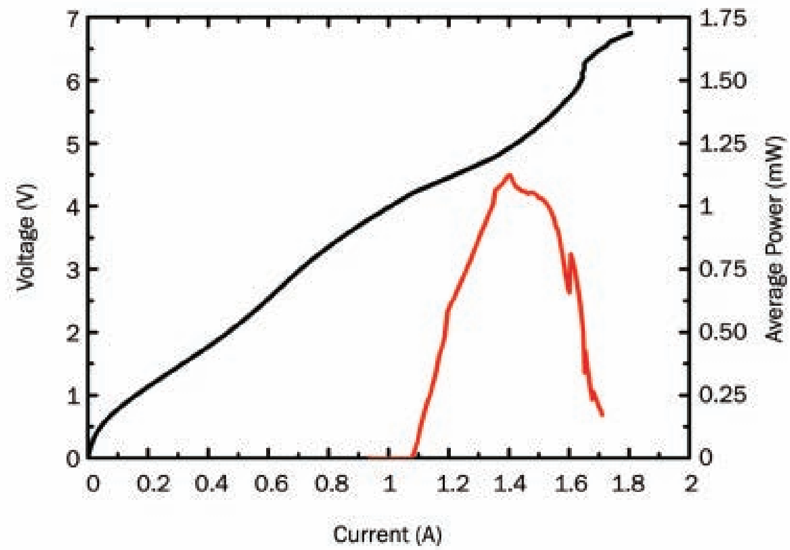


New possibilities in THz imaging

With the high output power available from THz QCL and their high emission frequency, new fields of THz imaging are opening up[1]. Higher power means faster

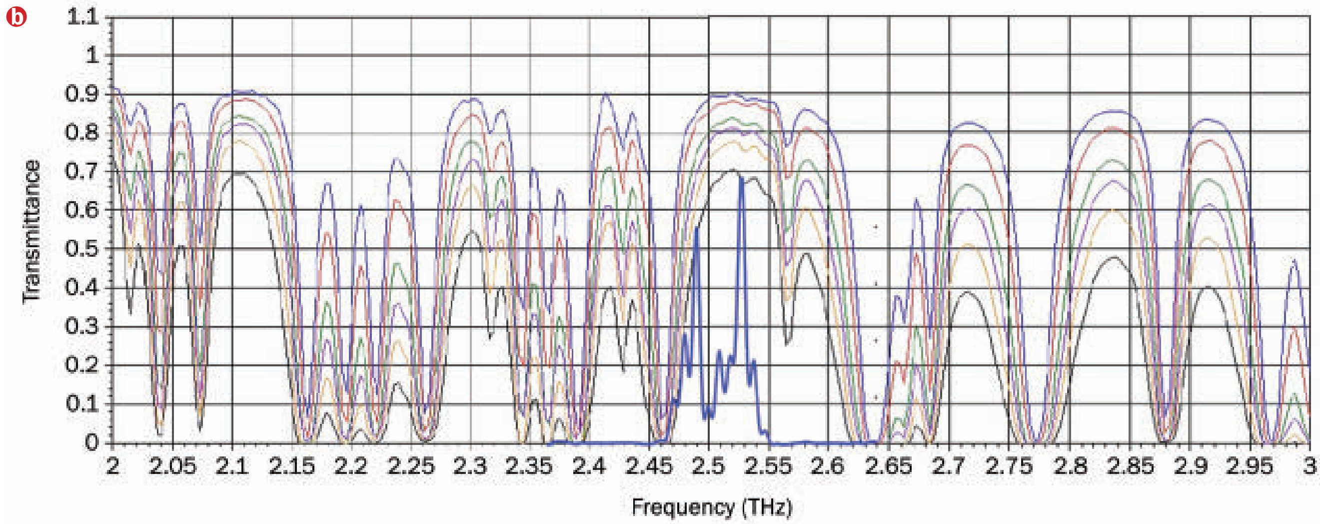


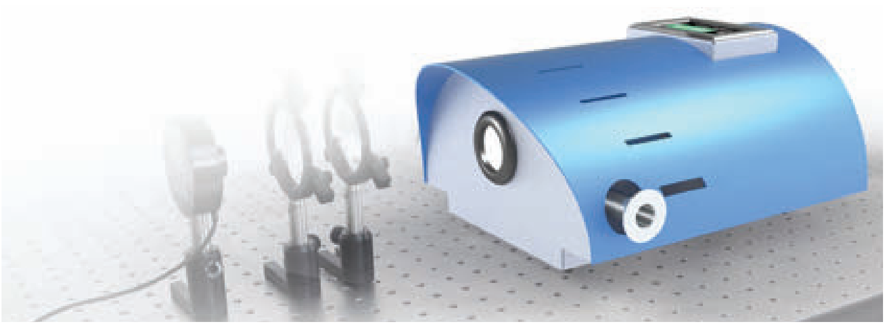
Figure 3. Light-current-voltage curve **(a, at left)** of a typical commercial THz QCL provided by Lytid. Emission frequency of THz QCL systems **(b)** should ideally be inside an atmospheric transmission window to avoid strong water vapor absorption. Lytid's QCL system emits in a 2.5-THz window.

image acquisition even with slow thermal detectors, such as pyroelectric, golay cell or bolometer detectors. It also means higher signal-to-noise ratios (SNR). With a standard room temperature operated commercial pyroelectric THz detector, SNR higher than 60 dB using lock-in amplification is possible. At frequencies higher than 2 THz, this is a few orders of magnitude better than available THz pulsed spectroscopic or CW systems. Higher frequency also allows higher imaging resolution. At 2.5 THz for instance, the diffraction limited resolution is around 250 µm and the beam waist is typically around a few hundred microns. In industrial NDT applications this allows the detection of smaller defects and the small beam size improves the measurements on highly curved surfaces compared to using a lower frequency.

In addition to speeding up classic raster scanning systems for image acquisition, the high power output of THz QCLs also enables the use of THz cameras based on microbolometer technology. These types of cameras are based on different technologies from CEA-Leti (France), INO (Canada) and NEC (Japan). Although microbolometer THz cameras offer noise equivalent powers (NEP) in the order of tens of pW, the high number of pixels (>60,000) require very high THz powers to illuminate the sensor. These cameras are also most sensitive at higher frequencies due to their large pixel size (several tens of µm).

Real-time THz imaging could enable inline THz NDT applications for the industry where both x-ray tomography (offline only) and ultrasonic system (needs physical contact) fail to provide satisfactory solutions. Compact, fully integrated THz QCL systems can be mounted on a robotic arm to provide automatic quality control, and the reliability of the coolers and QCL chips is robust enough for industrial applications. In the field of biomedical imaging, THz imaging is a strong contender for rapid, contactless detection of cancer and skin burn assessment. Real-time THz imaging could be a revolutionary tool in the biomedical field used extensively by health-care professionals.

Next-generation commercial THz QCL systems have brought this promising new technology out of the laboratories and into the hands of researchers eager to explore new THz applications, or industrials who want to implement THz solutions into their processes.



The TeraCascade 1000 series from Lytid provides mW-level of THz power in a compact, fully integrated and turnkey system. This product won a 2016 Prism Award for Photonics Innovation in the Scientific Lasers category.

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Meet the author

Pierre Gellie co-founded Lytid SAS, a company that develops terahertz sources based on quantum cascade laser technology, in 2015. He holds a Ph.D. in physics from Paris Diderot University and has 8+ years of expertise in terahertz technologies; email: p.gellie@lytid.com.

Airy Beam Light-Sheet Microscopy Holds Promise for Life Sciences Imaging

Prized for its rapid 3D imaging capability, low phototoxicity and high contrast, Airy beam light-sheet microscopy is especially well-suited for cancer biology and neuroscience

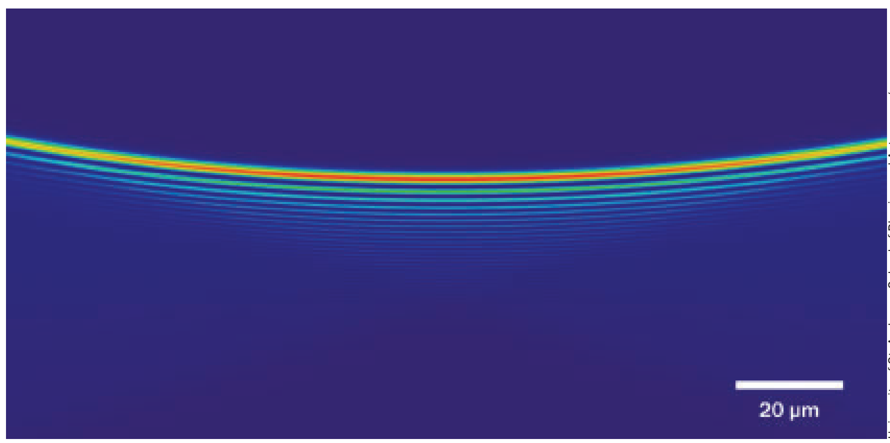
BY KISHAN DHOLAKIA and JONATHAN NYLK, UNIVERSITY OF ST. ANDREWS; PETE PITRONE, GRAEME MALCOLM and ROBERT FORSTER, M SQUARED LASERS LTD.

Airy light-sheet microscopy (ALSM) has great potential to help further research and clinical diagnoses through its ability to image larger 3D volumes of tissues and organoids. Developed in the last three years, it is best-suited to the fields of regenerative medicine, cancer biology, neuroscience and developmental biology, as ALSM can acquire images, as well as 3D datasets, with higher resolution over larger fields of view (FOV) than its predecessors.

One such predecessor is fluorescence microscopy, a powerful tool that life scientists rely on to observe biology in action. It works by using a light source that produces excitation photons of a certain energy, one of which then excites a fluorescent molecule, called a fluorophore. The fluorophore attaches to a specific location on the specimen, causing it to fluoresce, emitting a photon of a lower energy.

For example, if the fluorophore excites when exposed to blue light it would most likely emit in green, yellow, orange, or even red. For acquiring fluorescence images, one needs to block the excitation light from the detector, while collecting as much of the emission light as possible.

There are two main issues with fluorescence microscopy: phototoxicity, which damages the specimen, and limited penetration into the sample, which results in the loss of information both inbound and outbound. High concentrations of energy have phototoxic effects: High energy wavelengths in the blue-violet UV part of the spectrum cause damage to biological material, whereas bleaching, resulting from the continued toggling on/off of the excitation of the fluorophores, causes the emergence of free radicals. This can sometimes make in vivo study of fluorescent specimens challenging as cells die more quickly.



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Profile: Airy beam parked in the focal plane of the detection lens.

Light-sheet fluorescence microscopy

Light-sheet fluorescence microscopy (LSFM) is attractive because it increases the speed of data collection, and its deep penetration allows for optimal fluorescent excitation of yet larger sample areas with depth selectivity. LSFM subjects the specimen to reduced phototoxicity, which is important for sampling specimens in vivo in developmental research, and captures images at a much faster rate than point scanning confocal microscopes.

In conventional fluorescence microscopy the excitation light travels along the same path through the microscope objective that the emission light comes back on. Due to the fact that the excitation light is always so much more intense than emission light is, and the way it is directed into the sample, a 3D hourglass shape is excited in front of the objective with the focus being the smallest point. LSFM decouples the illumination path from the detection path by 90 degrees and illuminates only the focal plane of the detection lens with a "2D" sheet of light. This is achieved in one of two ways: by creating a static light sheet with cylindrical lens optics, or by rapidly scanning a beam across the field in a direction perpendicular to both the illumination and detection axes.

Superresolution

Some of the challenges in applying microscopy to scientific research, industrial applications and other contexts go well beyond just acquiring images at a high magnification. One of these challenges is resolution. With visible light, the diffraction limit presents obstacles to imaging at a resolution any finer than 200 nm. One can resolve smaller structures by using superresolution microscopy techniques.

There are two approaches. The first technique introduces known patterns to the back focal plane of the microscope objective to tease out details that allow researchers to resolve distinctions at a distance of 100 to 120 nm apart (a factor of 2× better than the diffraction limit). This requires multiple images of the same plane, so it takes much longer to acquire.

The second method involves localizing individual fluorescent markers by randomly toggling them on and off, using a technique called stochastic optical reconstruction microscopy (STORM). In contrast, photo-activated localization microscopy (PALM) utilizes fluorophores that can be photo-activated to change their characteristics, allowing researchers to resolve distinct objects as separate at a distance of only 20 to 50 nm apart (a factor of 5 to 10× better). However it requires thousands of images to calculate where the objects are exactly.

Volumetric and multidimensional imaging

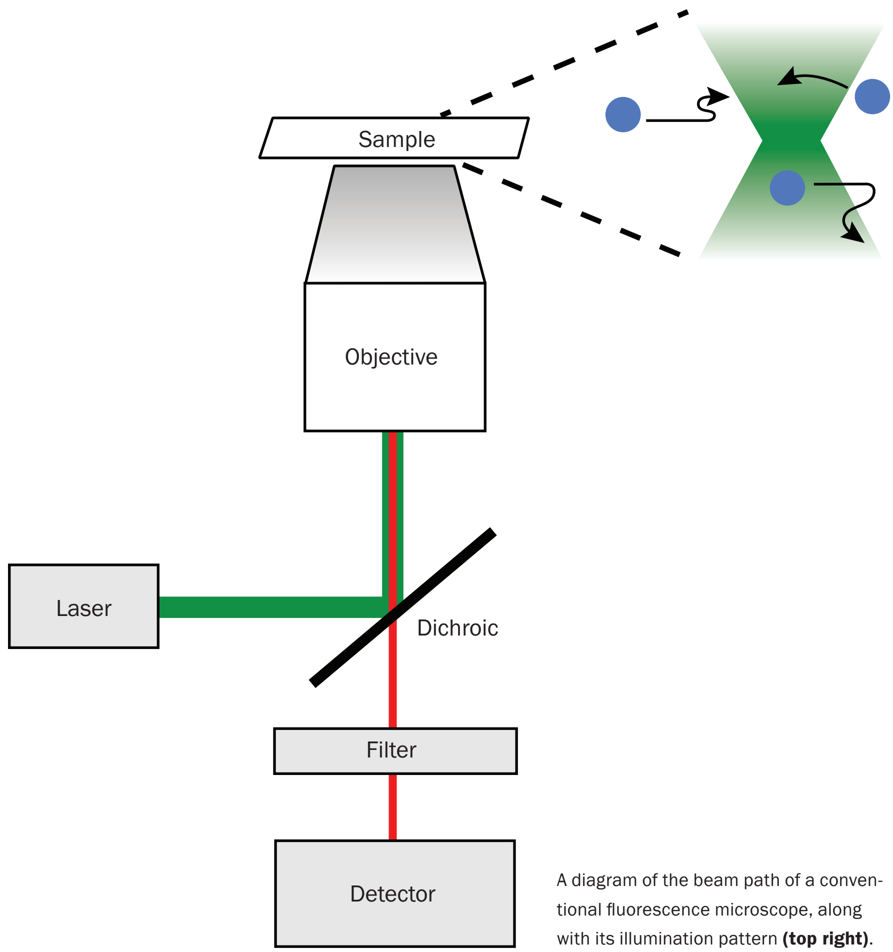
Another challenge is presented when producing volumetric images or data sets of biological material and live specimens. Conventional optics only allows for the development of two-dimensional images, but volumetric imaging capabilities are a key requirement in many areas of biological and biomedical research. This requirement goes beyond the conventional "relatively" two-dimensional imaging of cells grown on a cover glass, and moves into the volumetric imaging of tissues and organoids. Volumetric imaging requires a means of detecting objects having been fluorescently labeled from different depths of the tissue, rather than only the surface plane/area.

Volumetric imaging is achieved by changing the distance of the specimen and detection objective in stages, selecting the depth by adjusting the focus, and recording each individual step to create a new Z-stack.

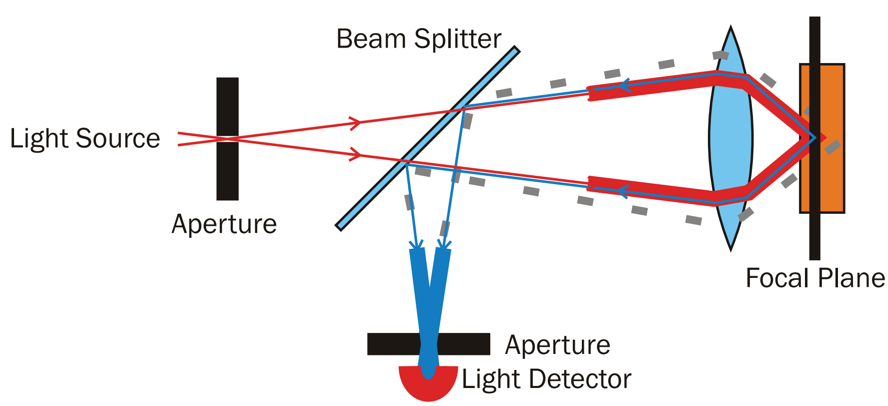
Due to the use of digital imaging detectors, a computer with the appropriate software can be used to tell the system when to acquire a volumetric stack. This creates time-lapse data that can be used to observe the development of a living specimen. If the system comes equipped with multiple excitation light sources, then multicolor channels can give yet another dimension.

Optical sectioning

Confocal microscopes can collect very high-resolution information with great contrast by removing out-of-focus information via a pinhole placed in front of the detector. However, because the illumination and detection objective are one and



A diagram of the beam path of a conventional fluorescence microscope, along with its illumination pattern **(top right)**.



A diagram of the beam path of a confocal microscope, the pinhole in the detection path blocks any out-of-focus light from around a diffraction limited spot (down to 200-nm laterally, and 600-nm axially).

the same (as it is essentially a conventional fluorescent microscope with sophisticated acquisition tools), objects that were not detected were still illuminated. This contributed to higher levels of phototoxicity and photobleaching.

ALSM, as with other light-sheet modalities, circumvents this issue by illuminating only the plane of interest instead of the whole volume, thus reducing phototoxic effects.

Another concern with confocal microscopy is the role biological tissue samples have in scattering and absorbing light, thus causing problems in both the illumination path and detection path. The deeper/further the light has to travel, the more likely it is to deviate off course, which causes fuzzy/blurry images. ALSM uses an excitation beam shape that continues on its path (mostly) unimpeded, which is discussed below.

Beam breakdown

There are three principle types of beam that have been used in light-sheet microscopy: Gaussian, Bessel and Airy. Both the Bessel beam and the Airy beam are significantly different from the Gaussian beam light sheet.

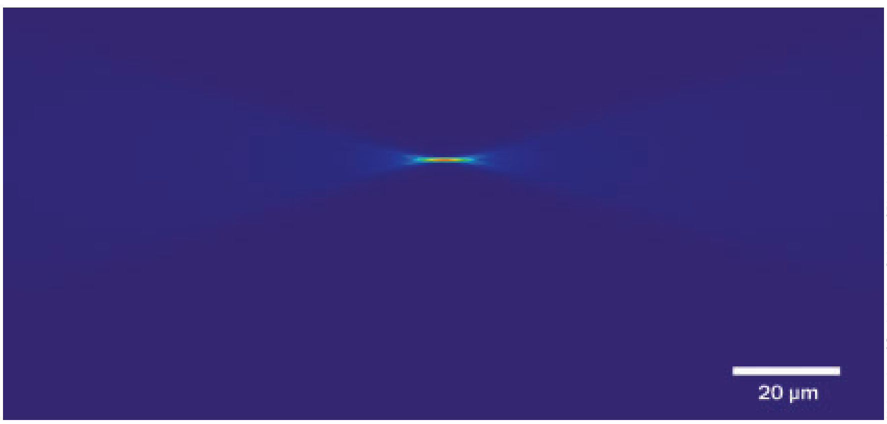
By producing a very thin, uniform sheet of excitation laser light (hundreds of nanometers to a few micrometers thick), fluorophores from the specimen are only excited in the plane of the light sheet. This technique of volumetric imaging is known as Gaussian light-sheet microscopy. In this type of microscopy, the sample can be stepped along the detection axis at varying distances, building up a multidimensional volumetric image of the specimen with digital assistance.

Both the Bessel beam and Airy beam generate intricate, yet distinct, patterns of light near the central order beam. Both penetrate deeper through the specimen than a Gaussian beam.

Each type of waveform operates in a different modality, distributing energy in different positions and intensities along the beam. The amount of energy and the peak irradiance of each form of emission is crucial in understanding the setbacks and trade-offs in light-sheet microscopy and the reasons why ALSM yields benefits that other forms do not.

Gaussian light sheets can resolve the smallest details, producing the crispest volumetric images. However, geometrical limitations prevent the Gaussian light sheet from providing high-resolution light-sheet volumetric images. Its high-resolution images are produced within a limited FOV, owing to the beam's restrictive Rayleigh range. Increasing the FOV is done by lowering the numerical aperture of the beam, which results in compromising axial resolution and the quality of the final image.

Furthermore, a greater exposure time — or peak irradiance — is required to produce an image at the limits of depth penetration, resulting in greater saturation for some areas of the image and the loss of information altogether in some re-



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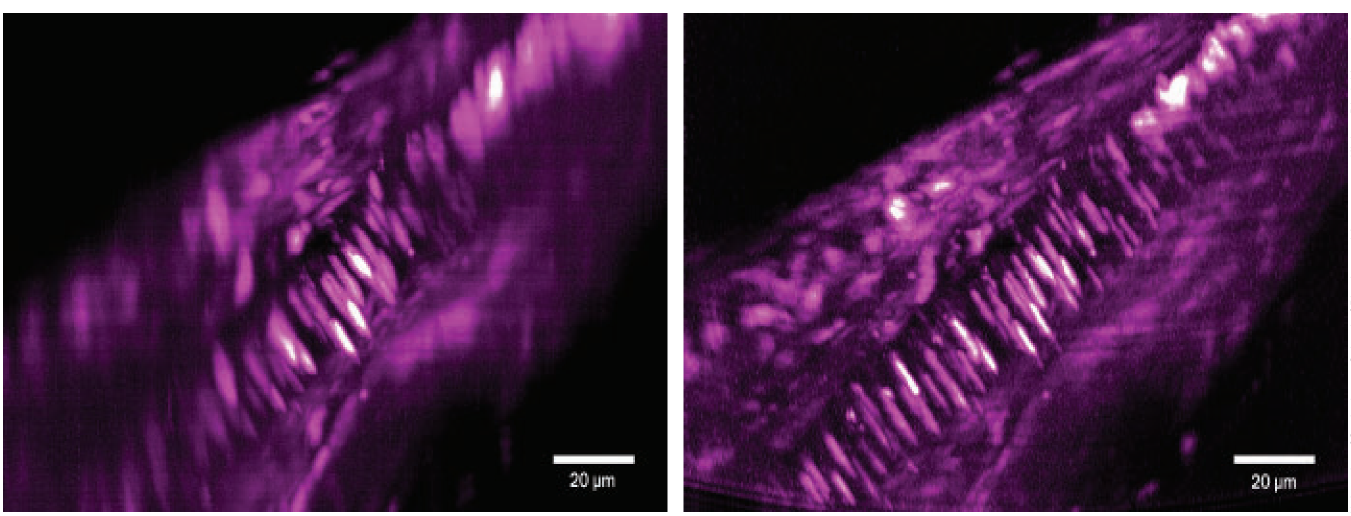
Profile: Gaussian beam parked in the focal plane of the detection lens.



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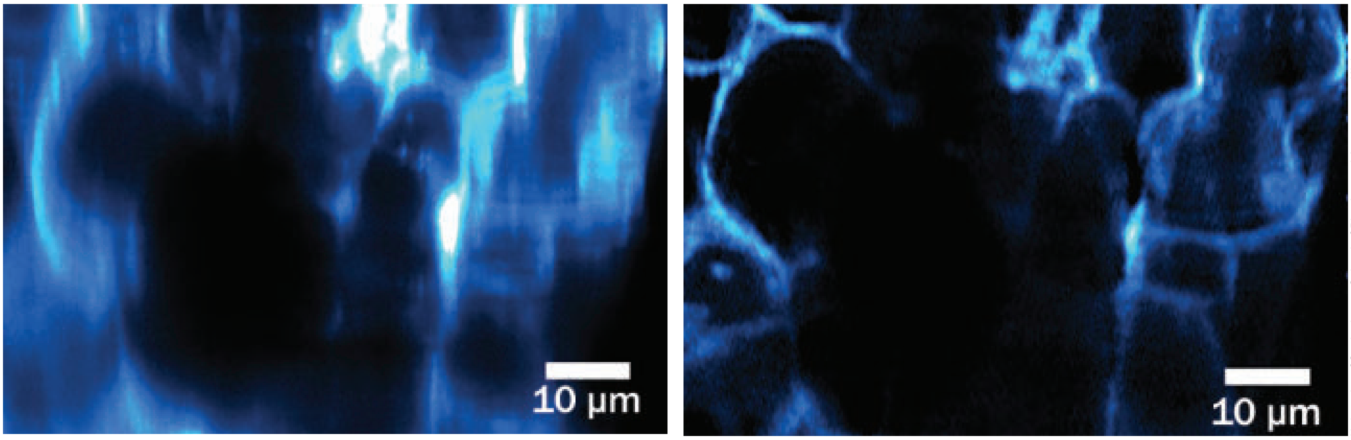
X-Z maximum intensity projections of a volumetric image of a section of fixed tissue from the tail of a juvenile amphioxus (*Branchistoma lanceolatum*) labeled with propidium iodide to reveal nuclei. The morphological differences between the notochord (well-ordered, elongated nuclei) and the surrounding muscle tissue are only clearly resolved with Airy illumination. Gaussian profile light-sheet image stack with maximum intensity projection, and scale bar for size **(left)**. Airy profile light-sheet image stack with maximum intensity projection, and scale bar for size **(right)**.



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X-Z image slice from a volumetric image of an ACHN cell spheroid, fixed and stained with Alexa Fluor 488 WGA to reveal cellular membranes. Gaussian profile light-sheet image stack with maximum intensity projection, and scale bar for size **(left)**. Airy profile light-sheet image stack with maximum intensity projection, and scale bar for size **(right)**.

gions of the final image. This means that, though the Gaussian light-sheet produced the first considerable time savings in producing volumetric images of the same sample size, it is not a viable alternative to confocal scanning. Such an alternative would need to penetrate to a greater depth without providing harmful effects on the specimen or saturation of the image.

Peak irradiance for Bessel and Airy beams is only a fraction of that of the Gaussian light sheet, giving them greater penetration at lower laser power levels, sparing both the phototoxic effects of irradiation on the sample, and the greater levels of saturation in the resulting image.

Similarly, the FOV of the optical system of both Bessel and Airy light sheets is determined geometrically by the numerical aperture along with other factors, and corresponds to the amount of recorded data that can be deconvolved and turned into a useful, high-resolution image.

The Bessel beam is propagation-invariant, solving the Gaussian beam's issues of divergence, widening the possible field of view. One researcher noted, "Propagation invariant light fields such as Bessel beams can create a thinner light sheet but the transversal outer ring structure of the Bessel beam produces background fluorescence and precludes high axial resolution unless two-photon excitation is used. Single-photon Bessel beam approaches can reclaim contrast using structured illumination or confocal scanning, but the transversal structure of the Bessel beam still unnecessarily irradiates the sample."[1]

Advantages of Airy light-sheet microscopy

Airy light-sheet lobes can carry the optimal pattern of energy through the sample area to produce a clean, crisp volumetric image without photobleaching or phototoxic effects after post processing/deconvolution.

Airy beams propagate as bent lobes, resulting in considerable distortion in the recorded image. Since the airy light sheet propagates in lobes, rather than beams, the blurring effects that restrict the Gaussian beam's FOV are avoided. Powerful algorithms can then deconvolve this image, with uniformly effective results across the field of view.

The Airy light sheet also retains higher spatial frequencies on propagation, unlike the Bessel beam, so the Airy light sheets extend through the sample field in a uniformly thin emission, ensuring optical uniformity in the image quality (isotropic resolution), even when close to the diffraction limit. The field of view has been considerably increased, without losing the high resolution provided by the Gaussian beam.

The lobes issued by the Airy light-sheet microscope reach far lower peak irradiance and can therefore penetrate far deeper sample areas with minimal photobleaching, providing the highest quality volumetric image of the sample field.

As a result, the Airy light-sheet microscope can collect a large number of volumetric images at a rapid rate of acquisition and at high resolution, with minimal photo-toxic effect on the specimen. This opens up the possibility of the live imaging of delicate samples, for much longer time periods, that would be otherwise destroyed or at least badly damaged by laser scanning confocal microscopy or conventional fluorescence microscopy.

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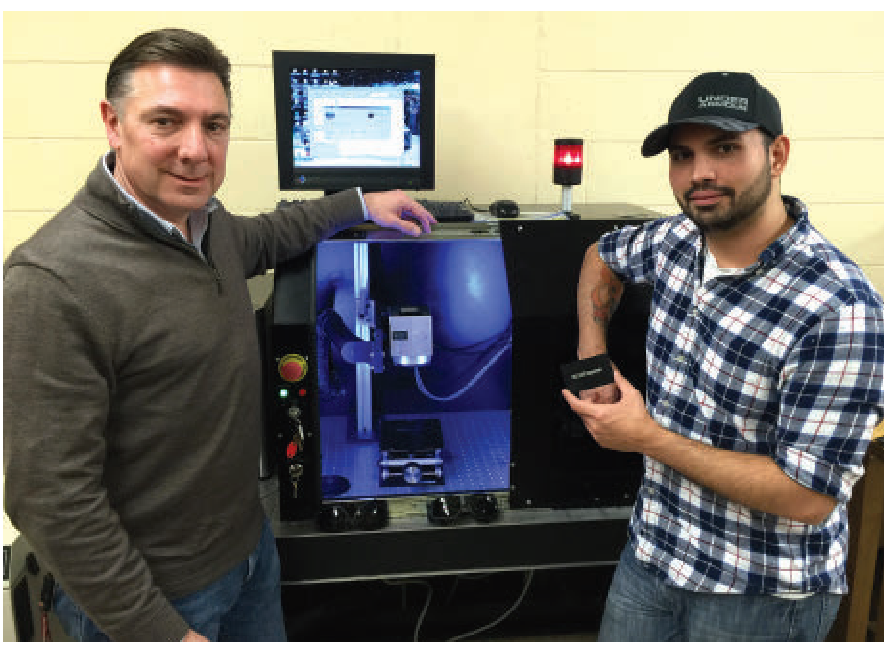
Springfield Tech's Laser Program Set to Expand

BY JUDY DONNELLY
CONTRIBUTING EDITOR

One of the oldest laser electro-optic technology associate degree programs in the U.S. will soon be seeing changes as the result of a $500,000 grant. Springfield Technical Community College (STCC) in Springfield, MA, will create an advanced laser machining laboratory and one-year laser materials processing certificate training program to meet the needs of the rapidly growing laser manufacturing industry in Massachusetts and southern New England. The name of the Laser Electro-Optics Technology Program will change to Optics and Photonics Technology, reflecting its growing scope.

Instituted in 1976 in response to growing demand from United Technologies Research Center in nearby East Hartford, Conn., STCC's two-year associate degree program has supplied more than 1,000 skilled laser technicians to United Technologies' spinoff companies such as United Technology Photonics (now Lumentum) and DeMaria ElectroOptics Systems Inc. (now Coherent) as well as optics/photonics companies across the U.S.

In 1991 the program received one of the first National Science Foundation (NSF) Instrumentation and Laboratory Improvement Program grants awarded to community colleges to build a holographic nondestructive testing lab. According to Nicholas Massa, who has been a STCC professor and program coordinator since 1986, the program has received well over $1 million in additional NSF grant funding and equipment donations from the photonics industry.



Nick Massa **(left)**, a professor at Springfield Technical Community College, and his student Alex Rivera, stand in front of a 20-watt fiber laser marking and etching system built by Massa's students.

STCC has long working relationships with many of southern New England's leading photonics manufacturers. Nufern, IPG Photonics and Prima Electro are among those who hire laser technicians almost exclusively from STCC's program. They, along with other companies, sponsor internships and senior projects each year and provide equipment, tours and student mentoring. Company employees also actively serve on the LEOT (Laser Electro-Optics Technology) industry advisory board.

"I've always tried to maintain a very close working relationship with the companies that hire my graduates. In fact, many of the hiring managers are former students, so they are invested in helping to make sure that our curriculum is relevant and we are preparing our current students with the knowledge, skills and attitudes they need to be successful," said Massa.

Partnership with Quinsigamond

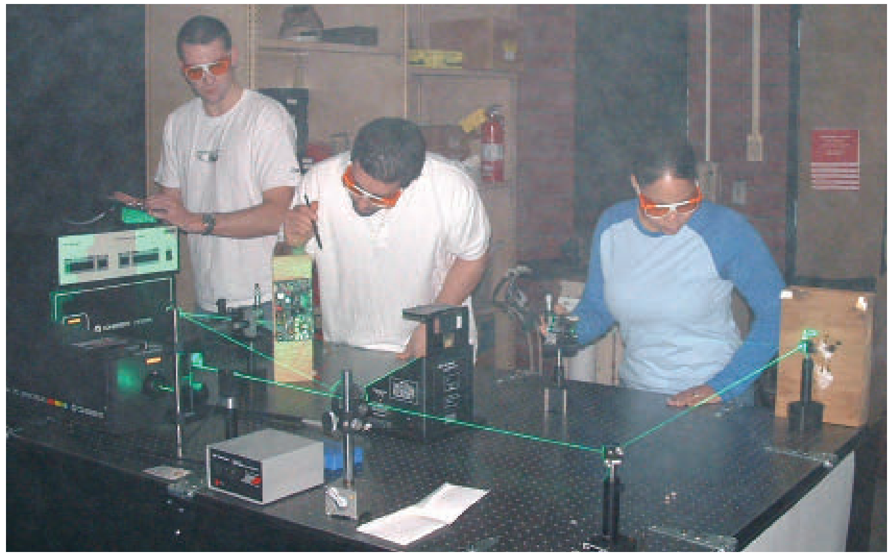
STCC also works closely with Worcester, Mass.-based Quinsigamond Community College, lead community college in the Integrated Photonics Institute for Manufacturing Innovation and the NSF Regional Center for Next Generation Manufacturing. The new laser manufacturing facility will be used to support the professional development for secondary and post-secondary faculty as well as workforce development in the Northeast.

In addition to the ongoing development of state-of-the art laboratories, the STCC program has taken the lead in developing a student-centered curriculum in response to industry demands for technicians with strong critical thinking, problem-solving and communication skills, and the ability to work well in teams. While working on a Ph.D. in Educational Leadership/Adult Learning at the University of Connecti-

Images courtesy of Springfield Technical Community College.

cut, Massa became interested in problem-based learning (PBL), an educational method that allows students to practice real-world skills by working in teams to collaboratively solve complex open-ended problems. All students in the program solve a number of such problems during their two years at STCC, many of them developed as part of the New England Board of Higher Education's NSF-funded PBL Projects. Examples include designing a system to laser strip and cut 50-µm copper wires or a 100-hour unattended burn-in facility for high-power fiber lasers.

These so-called "Challenges" were developed in collaboration with photonics companies throughout the U.S. and feature real technical problems that were faced by the industry partners. Students who practice using structured problem-solving techniques to solve authentic industry problems are well-prepared to tackle complex problems from the start as new employees, according to Massa.



Students at work in the Laser Electro-Optics Technology Program at Springfield Technical Community College.

An aerial view of Springfield Technical Community College.

Demand for technicians

According to a recent study conducted by Deloitte Consulting and the New England Council, the Northeast region, including New England and New York, has unique capabilities in advanced manufacturing in a broad range of industries including aerospace and defense, optics and fiber optics, lasers, medical devices and biotechnology, and semiconductors and precision machining. Critical to these industries is the integrated application of lasers and photonics in the manufacturing process, for example, precision laser cutting, welding and drilling; additive manufacturing; 3D scanning; precision laser-based metrology; and machine vision/sensing. Currently, STCC is home of the only two-year laser program educating technicians in New England. Two more programs are located in New York, according to the NSF's OP-TEC Center. With only three technician programs, the Northeast region has a far greater demand for photonics technicians than the total number of graduates produced annually.

Typically, community college students run the gamut from traditional college-age students through senior citizens, and the students in the STCC laser electro-optic technology program are no exception, ranging in age from 18 to 70. They include recent high school graduates, older individuals who have been laid off or are looking for a career change, and experienced individuals with advanced degrees in a variety of fields including electrical engineering, physics, chemistry and business, who are seeking to acquire the knowledge and skills needed to get into the optics and photonics field.

Encouraging high school students to explore technical careers can be a challenge, especially for study at the associate degree level. Students, teachers and counselors often have some idea of careers that require four-year engineering degrees, but the important role of two-year technicians in advanced manufacturing is often a complete unknown. STCC partners with West Springfield High School and Agawam High School through a Career Pathways program sponsored by the Hampden County Regional Employment Board. Through interactions with college faculty, students are exposed to career opportunities available to them in two STCC programs: Mechanical Engineering Technology (Advanced Manufacturing and Precision Computer Numerical Control [CNC] Machining) and Laser Electro-Optics Technology. In addition, STCC is currently developing several Career Pathway programs with local high schools and four-year institutions focused on increasing the STEM pipeline from high school to university.

New lab and certificate

The new laser materials processing lab will allow for the integration of industrial laser technology into STCC's laser electro-optic technology program, mechanical and manufacturing engineering technology program, and biomedical device manufacturing program, leading to a truly interdisciplinary curricula. This new partnership will allow students to gain valuable hands-on experience in the use of lasers in the manufacturing process. Through the $500,000 Mass Skills Grant, STCC will purchase two large-format high-powered CO_2 and fiber laser cutting systems; two smaller format fiber and CO_2 laser marking and etching systems; a DPSS laser welding system; two 3D printers; as well as a variety of sheet metal bending, precision metrology and laser test and measurement equipment. Two new courses will be developed and integrated into existing programs: Laser Materials Processing and SolidWorks for Sheet Metal Fabrication.

The new Certificate of Completion in Laser Materials Processing will prepare students for careers in advanced manufacturing using state-of-the-art laser materials processing equipment. Students will be qualified to pursue careers in fields such as aerospace and defense, biomedical device manufacturing, rapid prototyping, opto-mechanics and semiconductor manufacturing, custom sheet metal fabrication, and other micromachining machining fields where laser precision is paramount. Building on existing course offerings in the mechanical and laser technology programs, students will learn about the many different applications of lasers in advanced manufacturing including laser welding and surface treatment, cutting and material removal, surface annealing, additive manufacturing laser marking and etching, and precision laser-based metrology. Students will gain hands-on experience in programming and using state-of-the-art laser materials processing. Quality concepts will be applied throughout the program to ensure product integrity and compliance with engineering standards.

STCC has a 40-year demonstrated history of working closely with the advanced manufacturing and laser industry in southern New England to establish working relationships aimed at improving the employability and workforce opportunities of its graduates. With the addition of the Advanced Laser Machining Laboratory and one-year Laser Materials Processing Certificate training program, STCC will be uniquely positioned to build on these relationships to increase the number of skilled graduates and expand its reach to companies throughout Massachusetts and the surrounding region.

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Asia-Pacific

Special Section

The **Asia-Pacific** region is becoming a major player in photonics technologies, as trend forecasters see it growing faster than any other in the coming years in areas such as augmented reality, flexible displays and more. In this special bonus section, we examine technology trends and how those in this region could set the global pace.

Featuring:

- **Reality Check — Trending Technologies** by Justine Murphy
- **News**
- **New Products**
- **Events**

Reality Check

The photonics industry in the Asia-Pacific region is booming, and advances in virtual and augmented reality, as well as wearable and flexible displays, are generating excitement in global technology trend forecasts.

BY JUSTINE MURPHY
SENIOR EDITOR

Germany is known as "the land of ideas" in the photonics industry. France has become a top contender in optics and photonics innovation. And now, Australia, China, Japan and others in the Asia-Pacific region are swiftly emerging as major players in photonics technology, research and development.

In a May 2016 report, global market research firm MarketsandMarkets notes that this region is the fastest-growing in several markets, including virtual and augmented reality, and wearable, head-mounted and flexible displays. Transparency Market Research, another global research company, has similar expectations, predicting Asia-Pacific will grow at a nearly 50 percent compound annual growth rate (CAGR) through 2022.

This market augmentation is being attributed to skyrocketing consumer demand for these and other novel optics- and photonics-related technologies.

Top tech trends

Virtual reality — computer-generated simulation of a 3D image or environment that users can interact with in a seemingly real or physical way using special electronic equipment — is among the sectors seeing a global push, as such technology continues to emerge and evolve. It offers a totally immersive experience for users in gaming and entertainment, and in addition to interaction with other gamers, may someday allow interaction with online shops and other remote users.

HTC Corp., headquartered in Taoyuan City, Taiwan, is among the front-runners in this market with its Vive virtual reality system. The system includes a headset with front-facing camera that "blends real-world elements into the virtual world." The device offers a 110° field of view, and its 32 sensors provide 360° motion tracking. According to HTC, there is a 2160 × 1200 combined resolution with a 90-Hz refresh rate for smooth, natural navigation. Two motion-tracked handheld controllers, both of which feature 24 sensors and multifunction trackpads for “effortless precision,” and a set of speakers complete the Vive system.

Vive is a fully immersive virtual reality system that can be used for game play and accessing apps, and enables real-world views without having to take off the headset. It was unveiled at the Mobile World Congress in Barcelona, Spain, earlier this year.

PlayStation VR from Sony — originally named Project Morpheus — is another virtual reality system. It was developed for online gaming, and offers seamless visuals via an OLED display that runs at up to 120 fps. These systems also feature 3D audio, rounding out the complete experience of being inside that virtual world.

A number of other virtual reality systems are emerging, including Rift. This system features a fully immersive head-mounted display, along with sensitive tracked controllers. Developed by Oculus VR LLC, a California-based virtual reality technology company, the system lets users play games or watch movies.

Augmented reality, which differs from virtual reality in that it overlays computer-generated information onto what the user is already seeing, is advancing, too, finding applications including 3D presentation of data, outdoor actions, or in conjunction with wearable display systems.

A laser scanning projection system by MicroVision Inc. enables augmented reality in products including head-up and retinal scanning displays. Such technology is growing globally as consumer costs, as well as those associated with development and manufacturing, are decreasing, and additional practical uses are being discovered.

Smartphone apps are getting in on the action, too. Circus Company of Seoul, South Korea, has introduced the circusAR app that recognizes objects such as images and shapes, using them in various ways including for education, entertainment, travel, gaming and art. ModiFace Inc. — a company that specializes in skin analysis and facial visualization, and has recently expanded into Asia — is another to offer augmented reality technology via smartphone app. Its IPSA Makeup Simulator allows users to virtually try different IPSA cosmetic products on their personal photos.

HTC Vive virtual reality system.

HTC

The new HTC Vive virtual reality system is equipped with gaming and other such apps, including this Job Simulator.

HTC

Innovative progress

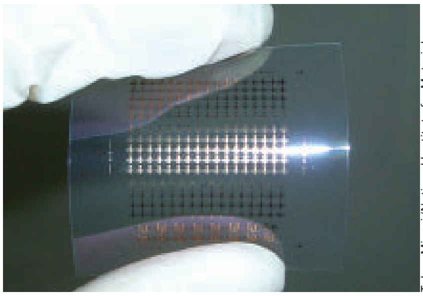
The Consumer Technology Association’s Consumer Electronics Show (CES) earlier this year saw the unveiling of Royole-X Smart Mobile Theater, an immersive virtual reality system. Developed by Royole Corp. (via its Shenzhen, China, facility), a company that specializes in display technologies and related electronic products, this virtual mobile theater system touts the highest resolution display in the world, and allows users to stream movies and TV shows through nearly every streaming program, including Netflix, Hulu and YouTube. The system also features a portable, foldable, noise-blocking headset, and can be used with gaming platforms such as PlayStation, Xbox and Wii.

Beyond virtual reality, advances in display technologies originating in the region, particularly flexible displays, are quickly making their way toward the mainstream.

CES 2016 introduced numerous innovations in this technology, including the rollable OLED display by Seoul, South Korea-based LG Display Co. Ltd. It is the world’s first 30R 18-in. display that can be rolled up like a newspaper, according to the company. This new technology features an HD resolution of 1200 × 810 with almost a million megapixels. It can be rolled up to 3 cm without affecting the function of the display.

Flexible displays are finding applications in solar and photovoltaic technologies, too. Recently, a team from the University of New South Wales in Australia developed a thin-film technology called CZTS (copper-zinc-tin-sulfur) that has been applied to photovoltaics to achieve 7.6 percent efficiency in a 1-cm^2 solar cell. This achievement marks a milestone for thin-film photovoltaic technology — which is being explored for zero-energy buildings, among other applications — on its path toward commercially competitive 20 percent efficiency.

According to the researchers, thin-film solar cell technologies are attractive because they are physically flexible, increasing the number of potential applications, such as curved surfaces, roofing membranes, or transparent and translucent structures like windows and skylights. The CZTS cells tout a higher bandgap, and "can be deposited directly onto materials as thin layers that are 50 times thinner than a human hair, so there's no need to manufacture silicon 'wafer' cells and interconnect them separately," said UNSW professor Martin Green, director of the Australian National Energy Agency-supported Center for Advanced Photovoltaics. "They also respond better than silicon to blue wavelengths of light, and can be stacked as a thin film on top of silicon cells to ultimately improve the overall performance."



Takeo Minari/National Institute for Materials Science

Flexible organic thin-film transistors enable printing of test structures on paper and could be used to create flexible, wearable displays.

The performance of wearable and head-mounted display technology continues to advance, as demonstrated by MicroVision. The Redmond, Wash.-based projection display maker, which has collaborated with Taiwan's Asia Optical Co. Inc. on such display work in the past, has a laser beam scanning technology that can be incorporated into head-up and retinal-scanning displays, as well as augmented reality products.

"We've been ready for a long time," said Bharath Rajagopalan, general manager for business development and marketing at MicroVision.

Originally developed for the military and defense industry, MicroVision's lightweight head-worn displays deliver images that appear to the user as though on a see-through computer screen. This enables, for instance, a technician to view instructions on jet engine repair while performing the task.

Forward thinking

Applications in the defense industry could also benefit from recent break-

Asia-Pacific Market: By the Numbers

The Asia-Pacific region is exhibiting the fastest growth in several photonics-related technology markets, thanks to increasing demand from various consumer segments. And this growth will only continue, according to market research.

The unveiling of new products — specifically virtual and augmented reality systems, flexible and wearable displays, and biomedical optics devices (among others) — is pushing this market growth in the Asia-Pacific region, amid formidable development worldwide.

The global market for augmented reality — a technology that superimposes computer-generated images on a user's view of the real world, in turn providing a composite view, with sensors, displays, cameras and software — is expected to grow to about $117 billion by 2022, according to a May 2016 report by market research firm MarketsandMarkets. This amounts to a nearly 76 percent compound annual growth rate (CAGR) between 2016 and 2022. The related market for virtual reality — computer-generated simulation of a 3D image or environment that users can interact with in a seemingly real or physical way using special electronic equipment — should see considerable progress, as well. MarketsandMarkets, in the same report, anticipates that the virtual reality realm will reach almost $34 billion by 2022, at a CAGR of nearly 58 percent.

Overall, Asia-Pacific should experience "high growth during the forecast period [2016-2022] and hold the largest market share," according to the recent MarketsandMarkets report. This growth can be attributed to the expanding consumer market for augmented and virtual reality systems throughout countries such as China, Japan and South Korea. At this point, Samsung Electronics Co. Ltd., headquartered in South Korea, is among several "major players" in these markets. Others include Infinity Augmented Reality Inc. and Oculus VR Inc., both based in the U.S.

The increasing popularity and advancement of head-mounted display systems is another area in which the Asia-Pacific market is intensifying. Transparency Market Research, a global market research company, expects the global market for this particular technology to reach $20.5 billion by 2022. And while the U.S. is expected to hold the largest part of the head-mounted display market, Asia-Pacific is poised to exhibit the fastest growth, climbing by almost 50 percent annually between 2014 and 2022.

This region is expected to experience significant growth in the optical imaging market, too. This market, according to research firm Allied Market Research, should see a CAGR of about 12 percent through 2020, from about $915 million in 2012. This market is also currently dominated by U.S. companies, although Asia-Pacific is likely to experience significant growth, as incidences of cancer and other diseases rise.

And as other consumer needs develop alongside technological advances, Asia-Pacific's anticipated significant growth will make the region a major player worldwide in both the market and R&D.

throughs in night vision (IR) technology. Researchers from the University of Sydney, in collaboration with the Australia National University and the University of Technology Sydney, have demonstrated a dramatic increase in the absorption efficiency of light in a layer of semiconductor that is only a few hundred atoms thick — to almost 99 percent light absorption from the current inefficient 7.7 percent.

"Conventional absorbers add bulk and cost to the IR detector, as well as the need for continuous power to keep the temperature down," said University of Sydney professor Martijn de Sterke. "The ultrathin absorbers can reduce these drawbacks."

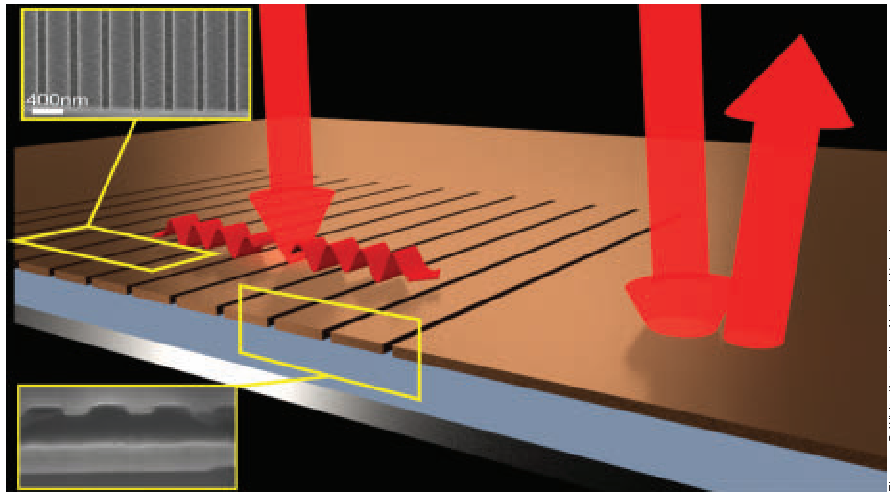
In their work, the researchers found that ultrathin gratings composed of common materials could increase the absorption efficiency of light to nearly 99 percent when thin grooves were etched into the film, directing the light sideways. The semiconductor materials are compatible with optoelectronic applications such as photodetectors and optical modulators, according to the researchers, and could make IR technology less expensive and more accessible.

"There are many applications that could greatly benefit from perfectly absorbing ultrathin films, ranging from defense and autonomous farming robots to medical tools and consumer electronics," said researcher Björn Sturmberg.

The costs of these and other such devices and systems are decreasing, making them ultimately more viable for the consumer market.

UNSW's work with thin-film, flexible solar cells has a bright future in the consumer realm, as well. While the CZTS cells are trailing other thin-film cells — CdTe (cadmium-telluride) and CIGS (copper-indium-gallium-selenide) — in efficiency and size, professor Xiaojing Hao told Photonics Media that improvements are being made. In fact, in late May, her team announced additional advancement.

"We just achieved 9.24 percent efficient pure sulfide CZTS solar cells on a smaller area cell — 0.224 cm^2 — which is a non-certified cell result and comparable with the current world record in the similar small area cell — 9.1 percent," Hao said. She added that the UNSW team anticipates developing beyond 10 percent efficient pure sulfide CZTS cells very soon.



Thomas P. White/Australian National University

When light falls on a very thin, uniform layer, almost all of it is reflected **(right-hand arrows)**. By etching thin grooves in the film, light is directed sideways and almost all of it is absorbed **(left-hand arrow)**, even though the amount of material is very small. Insets show electron micrographs of the structuring. The absorbing layer is only 0.041-µm thick.

This solar cell research, virtual reality systems, and many other technologies are skyrocketing companies in the Asia-Pacific to the top of the photonics pack. By 2022, analysts expect the market to reach billions of dollars, and this expansive region could ultimately hold the largest share.

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Fuji Pigment develops toxic-metal-free QD manufacturing process

KAWANISHI CITY, Japan — Fuji Pigment Co. Ltd., led by Ryohei Mori, has developed a large-scale manufacturing process for carbon and graphene quantum dots (QDs). Traditionally, these are made of semiconductor materials that are expensive and toxic, particularly Cd, Se and Pb. Such toxic heavy metals are even prohibited for use in some industrial areas. Fuji Pigment said its toxic-metal-free QDs exhibit a high light-emitting quantum efficiency and stability that is comparable to the toxic metal-based QDs.

Quantum yield of the carbon QDs currently exceeds 45 percent, and the company said Mori is still pursuing higher quantum efficiency. Quantum yield of the graphene quantum dot is over 80 percent.

The ability to precisely convert and tune a spectrum of light makes QDs ideal for TV displays, smartphones, tablet displays, LEDs, medical experimental imaging, bioimaging, solar cells, security tags, QD lasers, photonic crystal materials, transistors, thermoelectric materials, various types of sensors and quantum dot computers.

PRNewsFoto/Fuji Pigment Co. Ltd.

Quantum dots under UV Light.

BD, SightDX collaborate for malaria detection

NEW DELHI — Medical technology manufacturer Becton Dickinson and Co. (BD) is collaborating with medical device developer Sight Diagnostics Ltd. (SightDX) to introduce a parasite malaria detection device in India.

The SightDX Parasight Malaria Detection Platform uses computer vision technology to analyze blood samples for malarial parasites. Innovative software algorithms, specialized optics and a new sample preparation method are combined to prepare patient samples quickly, easily and reliably. The instrument automatically analyzes the sample and provides a diagnostic result within four minutes. The device can also provide information on the species of the infecting malarial parasites, and can aid clinicians in determining the severity of the illness.

Approximately 880,000 cases of malaria were reported in India in 2013, with over 128 million tests performed. The Parasight Malaria Detection Platform will be marketed in pathology labs and hospitals across the country, and applied in blood banks where malaria testing is mandatory on all blood donations. The device has undergone field-testing at a number of Indian and international laboratories, where it demonstrated a high degree of sensitivity and specificity at very low levels of infection.

South Korean delegation visits Ulis

VEUREY-VOROIZE, France — Thermal image sensor manufacturer Ulis recently welcomed 18 South Korean delegates to its manufacturing site as part of a bilateral mission to explore new opportunities between South Korea and France. Visitors included top management from Samsung Electronics France, Hyundai Motor Europe, Korean Air, Korail and Korea Hydro & Nuclear Power. Other industrial and governmental figures attended, as well, including Stéphane Na, president of the Chamber of Commerce France-Korea.

Ulis is currently working on smart buildings and automotive applications.

"Ulis has been conducting business in South Korea since 2005, where we have earned a reputation as a reliable and trusted partner," said Jean-François Delepau, the company's managing director. "This visit helps consolidate existing relationships and open the doors to new developments."

Flexible solar cell achieves 7.6% efficiency

SYDNEY — A team from the University of New South Wales (UNSW) has reached a milestone in its work with thin-film photovoltaic technology. Called CZTS, this technology has been applied to photovoltaics to achieve a world-leading 7.6 percent efficiency in a one-square-centimeter solar cell. According to the researchers (led by professor Xiaojing Hao), the achievement marks a milestone for thin-film photovoltaic (PV) technology — which is being explored for zero-energy buildings, among other applications — on its path toward commercially competitive 20 percent efficiency.

"In addition to its elements being more commonplace and environmentally benign, we're interested in these higher bandgap CZTS cells for two reasons," said UNSW professor Martin Green, director of the Center for Advanced Photovoltaics. "They can be deposited directly onto materials as thin layers that are 50 times thinner than a human hair, so there's no need to manufacture silicon 'wafer' cells and interconnect them separately. They also respond better than silicon to blue wavelengths of light, and can be stacked as a thin film on top of silicon cells to ultimately improve the overall performance."

Because they can deposit CZTS solar cells on various surfaces, the researchers believe they can create thin-film PV cells that are either rigid or flexible, and durable and cheap enough to be widely integrated into buildings to generate electricity from the sunlight that strikes structures such as glazing, facades, roof tiles and windows.

University of New South Wales

Professor Xiaojing Hao **(center)** and her CZTS Solar Cell Group at the University of New South Wales School of Photovoltaic and Renewable Energy Engineering.

Amada Miyachi America opens new headquarters

MONROVIA, Calif. — Amada Miyachi America Inc., part of Amada Miyachi Japan, has opened its new $13.5 million, 85,000-sq-ft facility in California. The headquarters include a technical center with 11 application-specific demonstration labs, a state-of-the-art training room, technology showroom, manufacturing facility, Class-10,000 clean room, and six customer laboratories. The facility also features energy-efficient equipment and climate control.

Guests of the grand opening included management from Amada Miyachi Japan; Hidehisa Horinouchi, the Consul General from the Consulate-General of Japan in Los Angeles; officials from Los Angeles County and the city of Monrovia; and key customer representatives.

Amada Miyachi America Inc.

Representatives of Amada Miyachi America, part of Amada Miyachi Japan, cut the ribbon at its new headquarters facility in California.

ASD analytical instrument service center opens in Australia

COPACABANA, Australia — ASD Inc., a Panalytical company providing analytical instrumentation and materials analysis technology, has launched an Australian service center at the office of its partner, Portable Analytical Solutions Pty. Ltd.

The new center includes service offerings for the FieldSpec, TerraSpec and LabSpec (excluding the LabSpec Pro) instrument lines, and can also repair related accessories, perform radiometric calibrations, and complete routine/annual maintenance and system checks. Such services were formerly only available from the U.S.

Touchscreen Display Projector

Shanghai Easi Computer Technology Co. Ltd. (Easitech) in China now offers the Lazertouch mini projector, transforming any surface into a finger-activated touchscreen. Weighing 5 oz., the device projects a tablet-sized, 20- to 150-in. display for meetings, presentations, 3D movies, immersive gaming, virtual reality and more. It emits an invisible laser beam parallel to the projection screen. Lazertouch also features a built-in Android OS, downloadable applications, speakers, 32 GB of storage, Bluetooth, Wi-Fi, a 13,600-mAh rechargeable battery, and ports for HDMI, USB, headphones and a Micro SD card.

easitech@hotmail.com

Communication Device

Glsun Science and Tech Co. Ltd. in Guangxi, China, has announced the CWDM communication device, featuring low insertion loss and high channel isolation. The device can expand the capacity of a single fiber to achieve bidirectional communication, which can be widely used in optical network upgrades and expansions or introduce a new comprehensive business. The system realizes the multiplexing and demultiplexing capabilities between two communication channels.

sales020@glsun.com

UV LEDs

Everlight Electronics Co. Ltd. in New Taipei City, Taiwan, has released five new UV LEDs covering wavelengths between 365 and 400 nm designed for curing equipment and home appliances. All five of the new products are based on a UV ceramic substrate to effectively improve the heat resistance. Three high-power, 1.8-W components — EAUVA35352 (3.5 × 3.5 × 2.31 mm), EAUVA35353 (3.5 × 3.5 × 3.51 mm) and EAUVA4545 (4.5 × 4.5 × 5 mm) — feature different viewing angles of 120°, 50° and 30°, respectively. Two lower-power, 0.08-W components are also available. The EAUVA3020 (3 × 2 × 0.65 mm) excels with a very uniform light pattern, and EAUVA2016 (2 × 1.6 × 0.75 mm) is the smallest choice in the portfolio.

marketing@everlight.com

Asia-Pacific: Events

SEPTEMBER

CIOE 2016 (Sept. 6-9) Shenzhen, China. Contact +86 755-2167, Ext. 4230; international01@cioe.cn; www.cioe.cn.

SEMICON Taiwan 2016 (Sept. 7-9) Taipei, Taiwan. Contact +886 3-560-1777; secmicontaiwan@semi.org; www.semicontaiwan.org.

Executive IR Imaging Forum 2016: From Niche to Large Volume Applications (Alongside CIOE 2016) (Sept. 8) Shenzhen, China. Contact Clotilde Fabre, fabre@yole.fr; www.yole.fr.

OCTOBER

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

NOVEMBER

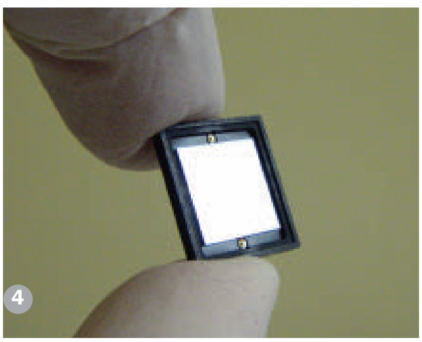
Aggregation Induced Emission Conference 2016 (Nov. 18-20) Guangzhou, China. Contact +86 105982-2317; www.rsc.org.

DECEMBER

SEMICON Japan 2016 (Dec. 14-16) Tokyo. Contact +81 3-3222-5988; jcustomer@semi.org; www.semiconjapan.org.

Complete listings at **www.photonics.com/calendar**.
Submit your event online at **Photonics.com/eventsubmit**.

new PRODUCTS



1 IR Detector

Sofradir offers the Daphnis HD, a 10-μm pixel pitch, HD IR detector for military, space, scientific and commercial applications. A 4.8-μm spectral cut-off wavelength allows exceptional signal-to-noise ratio, even in a low-temperature scenario. The detector features 1280 × 720-p resolution and read-out integrated circuit functionalities with digital output for easy integration. It is compatible with HD screen forms, and visible or shortwave-infrared camera channels.

www.sofradir.com/contact-us

2 Alignment Platform

The FiberMaxHP is a 3- to 6-axis photonics alignment platform from **Aerotech Inc.** It features noncontact, direct-drive technology for all axes for high-throughput alignment, and 2-nm linear and 0.05-μrad rotary minimum incremental motion. The platform is designed for critical photonics alignment applications in highly automated, 24/7 production environments. Speeds of up to 400 mm/s support the challenges of aligning next-generation photonics packages.

smclane@aerotech.com

3 Diamond-Cutting Machine

Synova SA offers the DCS 50, an ultracompact 5P (five-process) machine for gem diamond processing applications such as table sawing, girdling, crown coning, pavilion coning and blocking. The system uses Laser MicroJet, the company's water jet-guided laser technology, which generates a cylindrical laser beam within a hair-thin water jet, resulting in perfectly parallel walls, tight kerf widths, smooth sawing surfaces and sharp edges. It can also be used for thin and parallel slicing to any crystalline orientation of laboratory-grown diamonds such as CVD and HPHT.

pausch@synova.ch

4 Amplifier

McPherson Inc. offers the 671MX amplifier, a high-vacuum-compatible, current-to-voltage converting device developed for use with vacuum UV silicon photodiodes. With an integral socketed photodiode mount, the combination detector/amplifier hybrid can be used to measure small photogenerated currents with resolutions of 10 fA and dynamic ranges of four orders of magnitude. All amplifier components are low-tolerance, resulting in consistent current-to-voltage transfer characteristics with minimal offset voltage.

sales@mcphersoninc.com

5 Raman Spectrometer

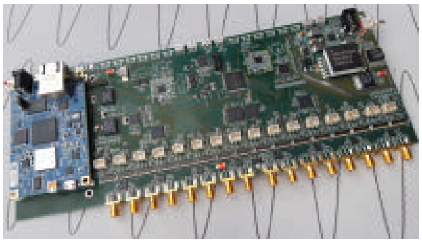
Horiba Scientific has announced the MacroRAM Raman spectrometer, a benchtop device that brings simplicity to Raman measurements without compromising the ability to handle complex samples. It includes a standard interlocked sample compartment and holders for cuvette-based liquid measurements, along with a solid sample holder. MacroRAM is designed with Horiba's 120-mm focal length spectrograph with a single aberration corrected concave grating with a flat field output. Its back-thinned scientific CCD is cooled down to −50 °C.

joanne.lowy@horiba.com

6 Kinematic Mount

Newport Corp. offers the HVM-2i, a compact vertical drive kinematic mount for 2-in.-diameter optics. Designed for industrial applications, the mount features a ball-and-wedge drive mechanism that enhances the overall performance of the optical mount by reducing stiction and backlash to negligible levels. The drive mechanism allows substantial angular tilt without adjustment screws protruding from the back of the mount, where space may be tight and fingers can block the optical path.

rick.sebastian@newport.com



A/D Board

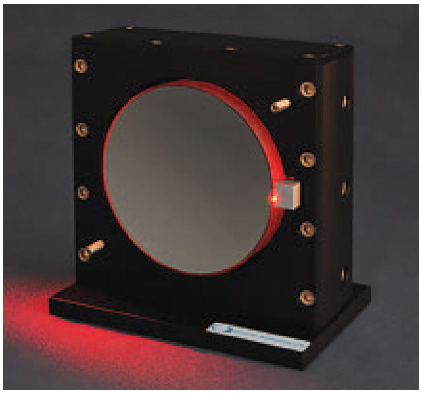
Ultraview Corp. has announced a 14-bit, 16-concurrent-channel 65 megasamples-per-second (Msps) analog-to-digital (A/D) board, the AD14-65Mx16AVE, for demanding, large-system OEM uses such as radar, imaging, nuclear instrumentation, spectrosocpy and communications systems. Two on-board, low-jitter RF synthesizers allow any A/D sampling rate between 20 to 65 Msps to be specified, while simultaneously outputting four stimulus clocks of a second frequency on SubMiniature Version A connectors that can be vectored to any combination of four external transmitters, 16 microwave pulse generators, laser modulators or other devices.
jlibove@ultraviewcorp.com

Dynamic Light Engine

LED Engin Inc. offers the LuxiTune Bluetooth low-energy (BLE), mesh-controlled tunable white solution for linear luminaires. Installed in a 4 × 4 × 48-in. fixture such as a slot or pendant, the linear light engine delivers 650 lm/ft out of the diffuser. At full intensity, the color rendering index is over 90 at 3000 K, with color uniformity of three MacAdam ellipses or better over the module length. Dimming is smooth, flicker free and goes down to 3 percent.
sales@ledengin.com

Hyperspectral Camera

Ximea GmbH has expanded its xiSpec series of cameras with the MQ022HG-IM-LS150-VISNIR hyperspectral camera. Instead of a mosaic pattern of hyperspectral filters, the device features a line-wise arrangement of 150 HSI bands between 470 and 900 nm covering the visual and near-infrared spectrum. High-speed multilinescan is featured up to 1020 lines/s.
sales@ximea.com



Mirror Mount

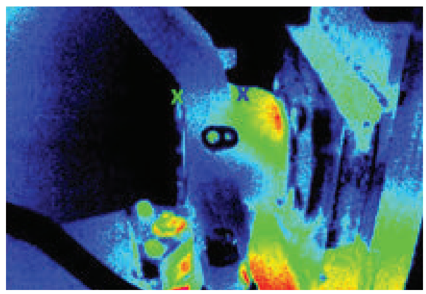
Optical Surfaces Ltd. offers the OS-Z range of mirror mounts to provide secure, stable and compact platforms for mirror diameters ranging from 90 to 250 mm. Angular alignment can be made about two axes through dual action adjusters with fine screw and ultrafine differential µm action. A base plate is included with each mirror mount. As an option to the standard 2-axis gimbal µm-driven action, OS-Z mounts can be fitted with XYZ linear stages if required. This option allows you to control positioning of mirrors in up to 5° of freedom.

sales@optisurf.com

TOLED Display

Crystal Display Systems Ltd. offers the LucidVue transparent organic LED (TOLED) display. The displays are available in a 55-in. module and offer a transmittance rate around 45 percent. Self-emissive pixels contain 4 subpixels: red, green and blue generate vibrate colors, and the final subpixel — which would typically be black — is now clear, facilitating transparency. Polysilicon thin-film transistors act as the switching method for the active matrix of OLED, generating a palette of over 1 billion colors, with a 180° viewing angle in both vertical and horizontal planes.

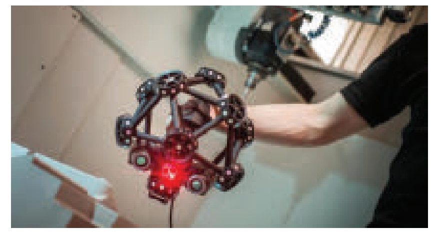
info@crystal-display.com



Thermal Imaging Camera

Flir Systems Inc. has announced the X8000sc series of thermal imaging cameras with lock-in, transient and pulse capabilities to perform advanced inspections such as nondestructive testing or stress mapping that resolve temperature differences as low as 1 mK. The cameras detect internal defects through target excitation and the observation of thermal differences on a target's surface. They also detect defects and points of failure in composites, solar cells, bridges and electronics, as well as enabling thermal mapping of stress when performing materials testing.

flir@flir.com



3D Laser Scanner

The MetraSCAN 3D from **Creaform Inc.** is designed for shop-floor operation and has been reengineered to be 12 times faster and 1.5 times more accurate than the previous model. The scanner features volumetric accuracy of 0.064 mm and a measurement rate of 480,000 measurements/s. Efficient on black, multicolored and shiny surfaces, the system

helps manufacturers to address potential quality control issues at any stage of the production cycle, regardless of part complexity and material.
info@creaform3d.com

Optical Clocks

Silicon Labs offers jitter-free attenuating clocks for 100G/400G coherent optical line card and module design. Si534xH coherent optical clocks are designed to replace discrete timing solutions that rely on expensive, large-footprint voltage-controlled SAW oscillators to provide low-jitter reference timing for data converters. The clocks operate over a wide frequency range, supporting frequencies up to 2.7 GHz without the need to change bill-of-material components. The Si5344H and Si5342H models offer typical jitter performance of 50 fs rms (1 to 40 MHz).
dale.weisman@silabs.com

Optical Breadboard

Solid aluminum, liquid-cooled optical breadboards from **Base Lab Tools** are offered in 3 sizes: 6 × 6 in., 10 × 12 in. and 12 × 18 in. Each breadboard has 1/4-20 tapped holes on 1-in. centers, and 5 counter bores for rigid mounting. The breadboards are designed for use with heat-creating components such as lasers, CPUs and LEDs. The counter bores are reversible and can be used from either side of the 3/4-in.-thick optical cooling plate, allowing for use with the copper tubing exposed for more direct cooling, or the breadboard can be turned over and be used as a solid aluminum cooled heatsink.
jenna@baselabtools.com

Day/Night Camera

The Puma 2-MP high-definition day/night camera from **Imperx Inc.** is based on the KAE-02150 Extreme CCD from **ON Semiconductor**. The device combines the Interline Transfer CCD pixel design with an electron multiplication output structure, enabling image sensor solutions that deliver sub-

electron noise performance with CCD-class image quality and uniformity for low-light imaging. The camera can capture 1080-p video in scenes with widely varying lighting conditions for light-starved applications such as surveillance, defense/military, medicine, science and intelligent transportation systems.
sales@imperx.com

LED Curing System

Phoseon Technology Inc. offers WhisperCool Technology for LED curing, delivering high-performance, air-cooled curing products with a low sound threshold. The technology uses proprietary and patented Phoseon innovations to maximize UV output while keeping the sound level to a minimum. The system's architecture combines LED array, advanced thermal management, computational fluid dynamic and electronic control.
info@phoseon.com

Happenings

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, customerservice@spie.org; www.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.

PAPERS

PacSurf 2016 (Dec. 11-15) Kohala Coast, Hawaii
Deadline: Abstracts, Aug. 5
The Pacific Rim Symposium on Surfaces, Coatings and Interfaces invites abstracts for consideration. This year's symposium is focused on recent advances in biomaterial surfaces and interfaces, energy harvesting and storage, nanomaterials, and thin films. Each topic is organized into multiple subtopics. Contact AVS, +1 530-896-0477; della@avs.org; www.pacsurf.org.

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 (ILCA) (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.

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

OCTOBER

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

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

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

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

● **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.

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

NOVEMBER

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

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

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

DECEMBER

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

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New robot comes to its senses

Robot design is often anthropocentric — the artificial agents have limbs, features and form factors analagous to our own. Surely the human body is a well-designed system, but now researchers are improving robot sensitivity by moving beyond the limits of human morphology.

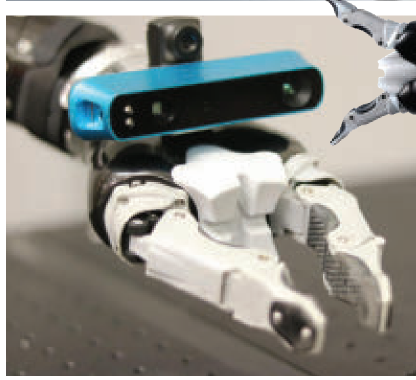
A team from Carnegie Mellon University (CMU) in Pittsburgh has added a vision system to a robot's hand, allowing it to rapidly model its environment in 3D, as well as locate its hand within that environment. As professor Siddhartha Srinivasa said, robots "usually have heads that consist of a stick with a camera on it," and can't bend over like a person to better view a space. Rather than making major structural changes, the hand-camera expands the robot's "senses" with a bit of hardware and software.

Robotics Ph.D. student Matthew Klingensmith described the goal of the research to Photonics Media.

"Accurate robot arms tend to be very rigid and heavy," Klingensmith said. "This makes them dangerous to operate around humans and limits their use to controlled environments. Safer robots designed to work around people — like the Kinova MICO we used in this work — tend to be less accurate and more 'floppy.' To make up for these inaccuracies, we use machine vision to correct for the robot's joint-angle error."

The researchers used a popular algorithm for mobile robots called simultaneous localization and mapping (SLAM), in which the robot pieces together input from sensors such as cameras, laser radars and wheel odometry to create a 3D map of the new environment and determine its own relative location.

The researchers demonstrated their articulated robot motion for SLAM (ARM-SLAM) using a small-depth camera — including the Structure Sensor from Occipital and a uEye XS RGB sensor from IDS — attached to a lightweight manipulator arm, from the Kinova MICO series. The team made a 3D model of a bookshelf, and found ARM-SLAM produced reconstructions equivalent to or better than other mapping techniques.



CMU Personal Robotics Lab

A team from Carnegie Mellon University has added a vision system to a robot's hand, allowing it to rapidly model its environment in 3D, as well as locate its hand within that environment.

Kinova Inc.

A Kinova MICO^2 robotic manipulator.

Klingensmith told Photonics Media that primary applications might include automatic calibration and tracking of a robot arm without fiducial, higher-quality 3D scans using "noisy" robot arms, and real-time visual servoing against the 3D map. His current work involves extending this system to 2D RGB sensors and calibrating additional parameters of the robot such as its camera extrinsics, joint angle offsets and the motion of its base.

Combining robotics, a vision system and complex algorithms, the collaborative effort to produce ARM-SLAM involved the personal robotics lab and field robotics center at CMU, and the Dyson Robotics Lab at Imperial College London. An open-source reference version of the system will be available soon.

Julia Germaine
julia.germaine@photonics.com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