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September 2016

PHOTONICS spectra

Aspheres Measure Up

2016 Education Issue

- Q&A with Educators
- Community College Directory
- Teddi C. Laurin Scholarship Unveiled

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Content

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Departments & Columns

THE COVER
State-of-the-art metrology ensures asphere surface accuracy. Courtesy of Edmund Optics. Cover design by Senior Art Director Lisa N. Comstock.

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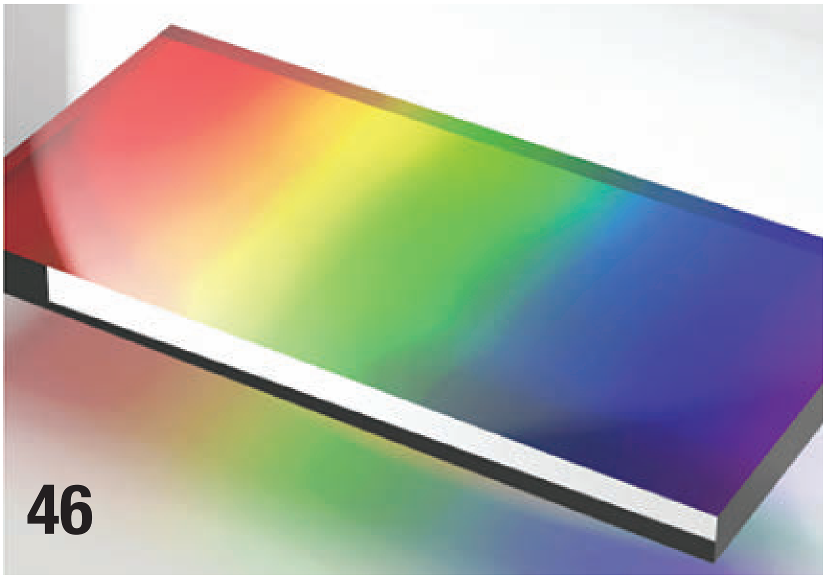
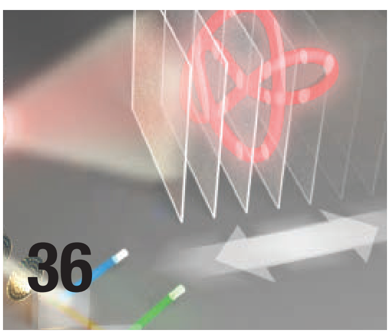
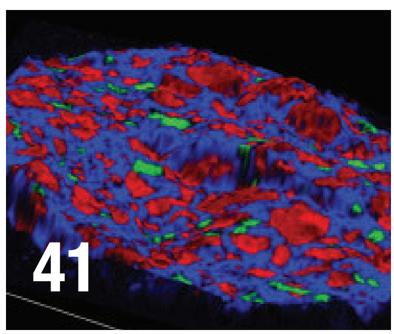
PHOTONICS: The technology of generating and harnessing light and other forms of radiant energy whose quantum unit is the photon. The range of applications of photonics extends from energy generation to detection to communications and information processing.







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editorial
COMMENT

Measuring Up: From Aspheres to Education

The first lenses shown to have aspheric surfaces were discovered in several Viking graves on the island of Gotland in Sweden. Known as the Visby lenses, the rock crystal lenses date to the 11th or 12th century, according to “The Eye in History” by Frank Joseph Goes. It’s not entirely clear what the origin or purpose of these lenses were. What is clear, a thousand years later, is the special role aspheres play in a growing number of systems. With their unique ability to reduce spherical aberrations and focus light, a single asphere can often replace a much more complex multi-lens system. That’s a boon to manufacturers where smaller and lighter often mean better.

As with all optics, aspheres must conform to certain standards of performance — and for that, engineers turn to metrology. As we learn in this month’s cover story by Edmund Optics’ Amy Frantz, manufacturers must look beyond conventional interferometry, and weigh inspection constraints and the nature of the part before choosing a method. See “The Long and the Short of It: Techniques for Measuring Aspheres” on page 32.

We shift our focus to two features that explore innovations in Raman spectroscopy, a technique prized for analyzing chemical structures without damaging the sample. In “Innovation in Surface Tracking Opens Doors to Raman Imaging Applications,” on page 41, Renishaw’s Tim Batten examines improvements in focusing technology that have eliminated some of the limitations posed by rapid Raman imaging. On the subject of improvement, in cases where rugged and low-cost Raman systems are called for, linear variable filters pose an attractive alternative to gratings. See “For Compactness and Ruggedness, Linear Variable Filters Fit the Bill,” on page 46.

Economic realities played a role in the discontinuation of commercial display technologies based on MEMS interferometric modulators and shutters. What is new, as we learn in contributing editor Hank Hogan’s “For MEMS Displays, Projections of Success,” on page 36, is the growing role of digital micromirror devices (DMDs) in today’s projectors used in MEMS displays.

When it comes to manufacturing high-resolution displays, no ordinary laser will do. Coherent’s Rainer Paetzel and Ralph Delmdahl give us an “under the hood” look at the multiple lasers used in a multi-oscillator design required for laser annealing in “Testing the Limits of Excimer Lasers: Annealing for Advanced Displays,” on p. 50.

Just in time for back to school, this month’s special section includes a listing of community colleges with programs in photonics and optics, found on p. 61. Senior Editor Justine Murphy spoke with professors at several of these institutions for their take on the role of these programs in preparing tomorrow’s workforce. See “Community Colleges: Preparing the Future Photonics Workforce” on page 56.

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

Michael D. Wheeler
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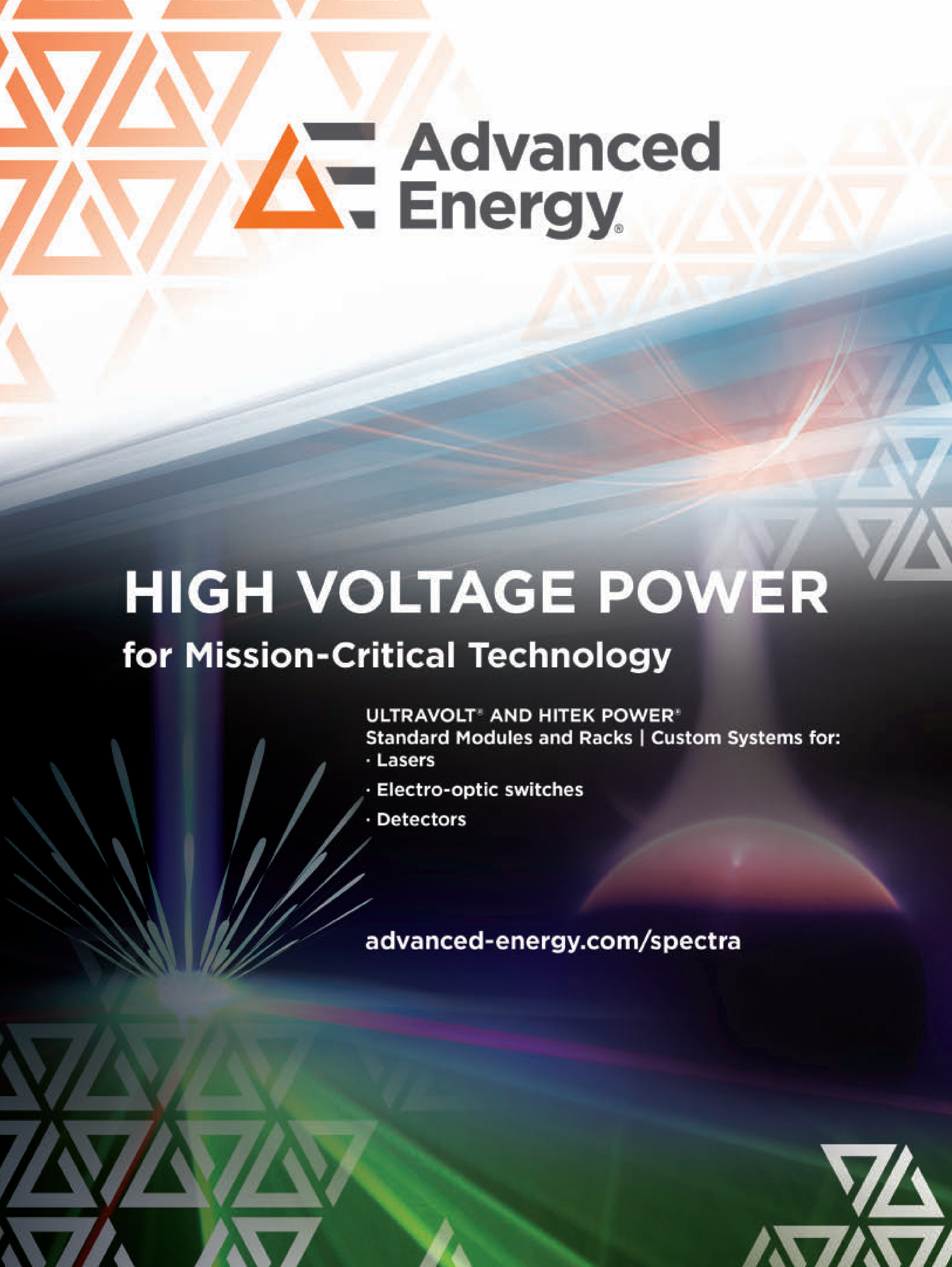
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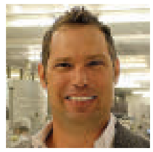
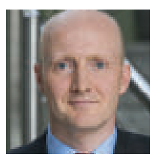


Eric Baltz
Eric Baltz is a senior R&D engineer with expertise in thin-film design, layer thickness control and LVF manufacture for Research Electro-Optics Inc. Page 46.

Roger Kirschner
Roger Kirschner is the business development manager at Research Electro-Optics Inc., with expertise in optical engineering and assembly. Page 46.

Tim Batten
Tim Batten is senior application scientist at Renishaw PLC. He specializes in the application of Raman spectroscopy to material systems, carbons, 2D materials, semiconductors, etc. Page 41.

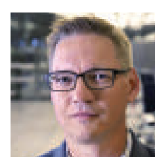
Justine Murphy
Justine Murphy is Photonics Media senior editor, whose responsibilities include *EuroPhotonics*. She is an award-winning journalist with more than 15 years of experience in the field. Page 56.



Ralph Delmdahl
Ralph Delmdahl is product marketing manager for the Coherent Excimer Business Group. He has spent 15 years in the laser industry. He earned a Ph.D. in physical chemistry from the Braunschweig University of Technology. Page 50.

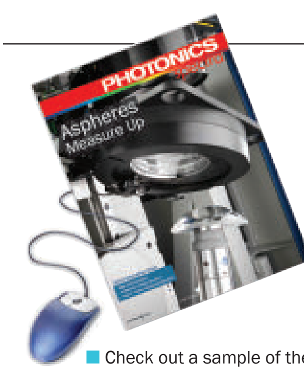
Rainer Paetzel
Rainer Paetzel is director of strategic marketing for Coherent LaserSystems GmbH & Co KG in Goettingen, Germany. His focus is on laser systems used in flat panel display and micro-electronics manufacturing. Page 50.

Amy Frantz
Amy Frantz is an optical engineer at Edmund Optics Inc. in Singapore. Page 32.



Trey Turner
Trey Turner is the chief technology officer at Research Electro-Optics Inc., with core expertise in IBS coatings. Page 46.

Hank Hogan
Regular contributing editor Hank Hogan holds a Bachelor of Science degree in physics from the University of Texas at Austin. He worked in the semiconductor industry and now writes about science and technology. Page 36.



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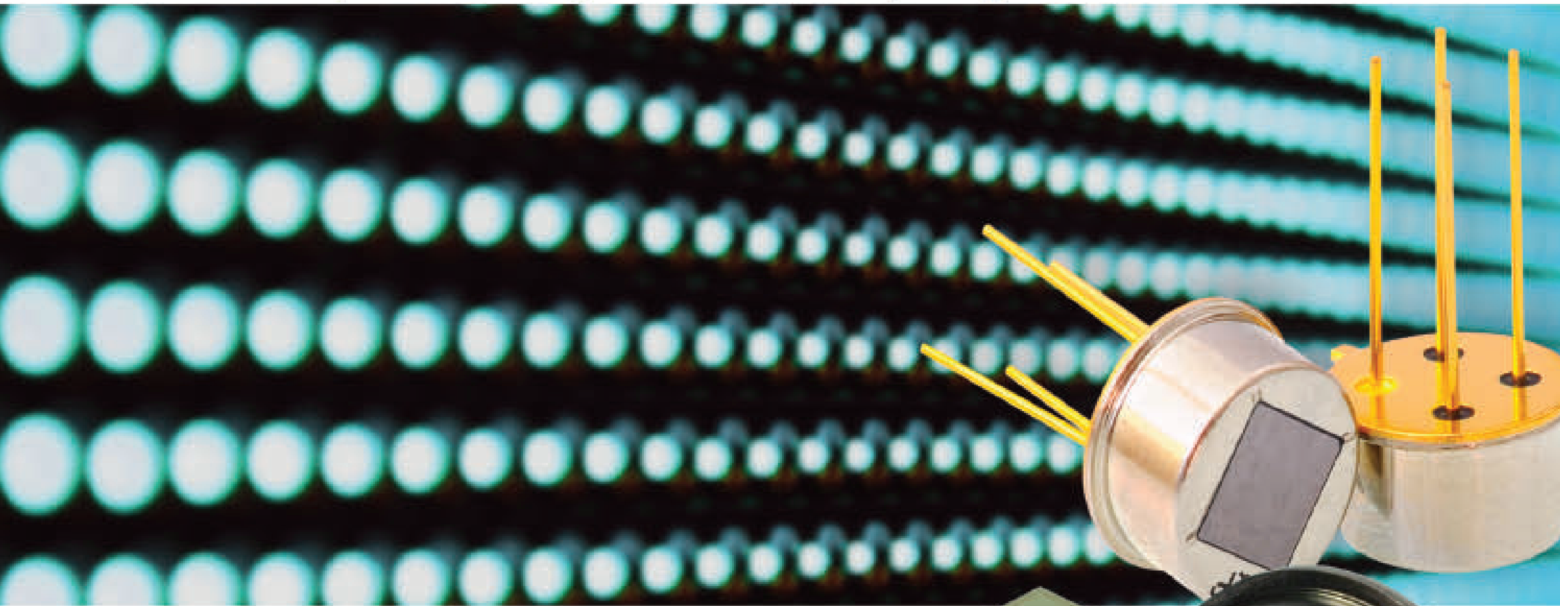

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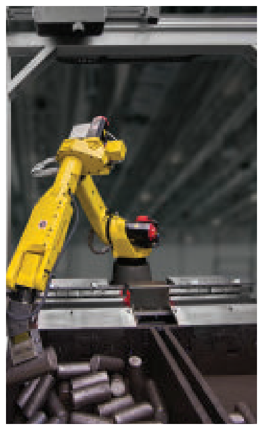

Vision guided robotics (VGR) has fast become an enabling technology for the automation of many different processes, across a range of industries. In this webinar, speaker David Bruce of FANUC America will discuss the two subsets of VGR, 2D and 3D, and review the proper techniques for selecting and implementing a vision guidance system that includes the latest advances in the technology.

Bruce will discuss the steps required to set up and execute 2D and 3D VGR, including 2D pick and place and 3D bin picking. He will review the advantages of using virtual VGR in the engineering phase of large and small automation projects and provide real-world examples. He will also discuss the different software packages that can be used for VGR and the trade-offs to consider when selecting a VGR system.

Presenter David Bruce has been with FANUC America Corp. (FAC) since 1997. He is currently an engineering manager for a group of engineers that supports FANUC integrators and end users with iRVision applications. Bruce has a M.S. in computer science from Oakland University and a B.S. in electrical engineering from the University of Windsor.

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3D printing focus of Nanoscribe US user meeting

Nanoscribe GmbH, a 3D printer manufacturer headquartered in Eggenstein-Leopoldshafen, Germany, held its first U.S. user meeting — a two-day seminar — at Harvard University in Cambridge, Mass.

In collaboration with the university's Center for Nanoscale Systems (CNS), which houses a Nanoscribe laser lithography system, attendees were shown the latest software and hardware developments, along with areas of application for the Photonic Professional GT 3D printer. The technological possibilities range from the manufacture of extremely high-resolution mesoscale objects to applications in photonics and plasmonics, requiring structure sizes of just a few hundred nanometers.

"The presentations by our clients on their various applications were the absolute highlight for me," said Martin Hermatschweiler, CEO of Nanoscribe. "It is incredibly fascinating and enlightening to discover firsthand what different disciplinary fields are making use of our devices, which operate based on the principle of two-photon polymerization. The full scope of applications ranged from printing nanostructures at the CNS, to producing plasmonic displays at the University of Florida, to engineering new types of materials whose creation would have previously been impossible, as the scientists at [California Institute of Technology] presented."

Nanoscribe develops compact tabletop laser lithography systems for 3D nanostructures.

Nanoscribe GmbH

Attendees at Nanoscribe's first U.S. user meeting.

Nanoscribe GmbH

California Institute of Technology researcher Lucas Meza delivers a talk at Nanoscribe's event.

Jenoptik expands traffic safety system in Canada

Jenoptik AG of Jena, Germany, has reported that its Traffic Solutions Division received the order to continue and expand the operation of digital camera systems for red-light monitoring in Canada.

A new contract between the Jenoptik subsidiary Traffipax LLC and the City of Toronto, Ontario, will continue 10 years of successful cooperation from 2017 onward. The contract will run for a period of five years starting on Jan. 1, 2017, and includes an optional extension for another five years. Negotiations will be started soon with seven other municipalities in Canada's Ontario province, Jenoptik said.

In Toronto, Jenoptik will install 79 additional digital camera systems for red-light monitoring by the end of this year. Under the new series of agreements, the scope of supply is expected to increase to about 250 systems with the other municipalities participating. These systems will be used for replacing existing sites as well as for establishing additional ones. According to Jenoptik, the contract value for the first five years totals an amount in the mid-double-digit million euro range.

• Gooch & Housego acquires Kent Periscopes and laser defense and security system firm Alfalight •

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or use our online submission form at Photonics.com/prsubmit.

LightPath wins $200K SBIR award for graphene coating

Optical and IR components firm LightPath Technologies Inc. of Orlando, Fla., has won a $200,000 subaward from the National Science Foundation (NSF) for its Small Business Innovation Research project, "Carbide bonded graphene coating for enhanced glass molding."

LightPath is part of the research team led by the primary grantee of Nanomaterial Innovation Limited (NIL), a spinoff from Ohio State University. During Phase I, NIL showed that the graphene coating provided potential advantages for molding both visible and infrared glasses when used for mold release. Now in Phase II, LightPath joins NIL as an industrial partner and will use its experience in molding optics to apply the coating to a production environment.

Anticipated benefits of the coating include enhanced mold lifetimes, improved molding yields, and, therefore, reduced costs for both visible and infrared optics. The work will focus on molding both singlet lenses as well as multicavity optics. The optical components may be critical as an enabling factor for driving enhanced functionality and lower cost for end products used in military, public safety, medical, industrial and automotive markets.

The NSF Small Business Innovation Research Small Business Technology Transfer program seeks to transform scientific discovery into societal and economic benefit by catalyzing private sector commercialization of technological innovations.

Block MEMS receives $9.8M government contract

IR detection systems developer Block MEMS LLC of Marlborough, Mass., has reported its award of a $9.8 million contract from the Intelligence Advanced Research Projects Activity (IARPA) within the Office of the Director of National Intelligence, part of the U.S. government.

Under the contract, the company will develop a system that can detect trace quantities of chemicals at standoff distances of at least 100 ft. The award is part of IARPA's Standoff Illuminator for Measuring Absorbance and Reflectance Infrared Light Signatures (SILMARILS) program, and is managed by the U.S. Air Force Research Laboratory at Wright-Patterson Air Force Base in Ohio.

Block will develop a new class of widely tunable, high-pulse energy quantum cascade lasers (QCL) and also next-generation detection algorithms to detect and identify hundreds of chemicals on a wide range of surfaces.

Dr. Anish Goyal, vice president of technology and principal investigator of the contract at Block MEMS, cited standoff detection of trace chemicals, such as explosive residues, chemical warfare agents and toxic industrial materials as a critical unmet need in U.S. intelligence and government defense communities.

Block MEMS is an engineering and development company focusing on the R&D of QCLs and Fourier transform IR spectrometers.

Versalume to develop Corning's light-diffusing fiber

Corning Inc. of Corning, N.Y., has invested in optical fiber developer Versalume LLC to create smart, integrated products and technologies based on Corning's Fibrance light-diffusing fiber. Financial terms of the investment were not disclosed.

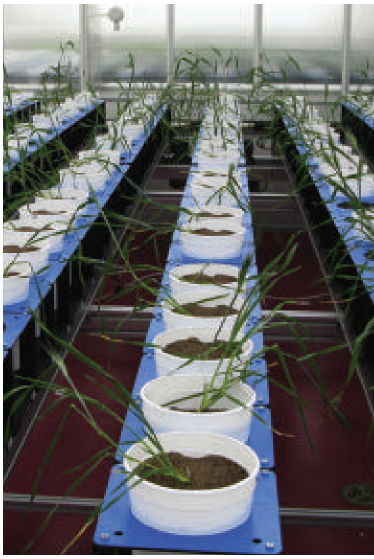
Versalume will lead all commercial development efforts for Fibrance, serve as its exclusive distributor and offer integrated technology solutions. Corning will leverage its glass and materials science expertise to manufacture Fibrance. Corning representatives also will serve on Versalume's board of directors.

Versalume's founder, Mario Paniccia, an executive and entrepreneur, has been named CEO. Paniccia has experience in the photonics and electronics industries, as well as connections to Silicon Valley.

This month in history

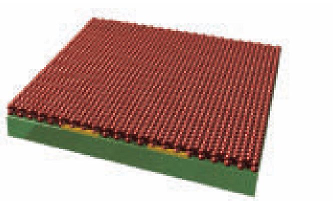
What were you working on five, 10, 20 or even 30 years ago? *Photonics Spectra* editors perused past September issues and unearthed the following:

2011



Computer scientists at the University of Adelaide developed an image-based analysis method that used 3D modeling to estimate crop yield.

2006



University of Toronto researchers had developed a manufacturing process that involved "painting" a solution of quantum dots onto gold electrodes.

1996

Using scanning electron microscopy and laser mass spectroscopy, scientists from the Johnson Space Center and Stanford discovered organic molecules in a meteorite of Martian origin.

1986

A survey conducted by the University of Michigan for the Automated Vision Association predicted the machine vision industry to grow at a whopping annual growth rate between 50 and 82 percent.

Rofin boosts fiber laser production at Hamburg facility

Rofin-Sinar Laser GmbH has expanded fiber laser production capabilities at its Hamburg, Germany, factory. By adding an additional assembly line to its facility, Rofin says it's reacting to increasing success in the market for low-power fiber lasers.

The number of assembly workplaces has been increased by 30 percent, improving production capacity and reducing lead times to prepare for the company's next fiber laser generation.

Rofin develops lasers for high-power industrial materials processing for the machine tool and automotive industries.


Rofin-Sinar Laser GmbH

Rofin has increased the number of assembly workplaces at its facility in Hamburg, Germany, by 30 percent.

• Finnish Border Guard orders EO/IR imaging systems from L-3 Communications for helicopter installation •

Lightwave Logic develops polymer photonics

Lightwave Logic Inc. of Longmont, Colo., said it has developed a polymer photonics technology platform to meet scaling metrics dictated by large data centers, telecommunications system operators and networking companies.

Lightwave's component library includes slot and ridge waveguide modulators, passive waveguides and waveguide splitters, and will expand to include multiplexers, demultiplexers and spot-size converters, necessary for telecom and datacom devices.

The combination of polymer photonics with a silicon platform, such as a slot waveguide modulator coated with a thin polymer as the active component, will enable photonics to grow in integration density faster than before, beyond 1,000 photonics devices on a single chip. Components are low-cost and high-performance, allowing for high integration scaling design rules. The company's goal is to complete its first demonstration device by the end of the year.

Lightwave Logic produces prototype electro-optic demonstration devices and is moving toward the commercialization of its organic polymers for applications in electro-optical device markets.

• Ophthalmic lens developer Essilor International SA joins See Change Challenge to improve global access to vision care •

PEOPLE IN THE NEWS


MLD Technologies LLC

OEM and custom optics manufacturer MLD Technologies LLC of Mountain View, Calif., has appointed **Michael Cumbo** general manager. Cumbo brings more than 30 years of experience in the design, development and production of thin-film coated optical components, lasers and other related instruments at publicly traded photonics companies, as well as venture-capital-funded startups.

Rochester Precision Optics LLC has appointed **Dane Hileman** president. Hileman brings more than 25 years of optics engineering and management experience to his new role, and will focus on enhancing the technical capability and production for existing and new customers as the company aims to become the main supplier for companies seeking high-performance lenses, lens assemblies and subsystems. Most recently, Hileman was the president of Vectronix Inc., where he was responsible for the day-to-day operations of facilities in New Hampshire, California and Virginia.

Quantum dot and nanomaterial manufacturer Quantum Materials Corp. has named board member **Sri Peruvemba** as its CEO. With 24 years of experience in the industry, Peruvemba has been an advocate in the advancement of electronic display technology. He is the CEO of Marketer International, a marketing services firm, and serves on the board of the Society for Information Display. Founder and previous CEO **Stephen Squires** will continue to have a strategic role, the company said, focusing on subsidiary Solterra Renewable Technologies, and will remain CEO of Quantum Materials Asia Co. Ltd.


Quantum Materials Corp.

Sri Peruvemba

L-3 to deliver EO/IR systems to military customer

L-3 Communications of Farnborough, England, said its Wescam division has received multiple orders from General Atomics Aeronautical Systems Inc. (GA-ASI) for its MXTM-15D electro-optical and infrared (EO/IR) designator systems for an international military customer. Financial terms were not disclosed.

L-3's equipment will support medium-altitude covert intelligence, surveillance and reconnaissance missions carried out by GA-ASI's Predator XP remotely piloted aircraft system. Deliveries to GA-ASI in California began earlier this year, the company said, and once fielded, the systems will be maintained by one of L-3 Wescam's 14 service centers.


GA-ASI

General Atomics Aeronautical Systems' Predator XP remotely piloted aircraft.

CDI, LLNL enter service agreement

Philadelphia-based CDI Corp.'s Aerospace and Industrial Equipment (AIE) business has entered into a long-term service agreement with Lawrence Livermore National Security LLC in support of the Lawrence Livermore National Laboratory (LLNL) National Ignition Facility in Livermore, Calif., extending the company's master services relationship begun in 2008.

CDI-AIE will provide LLNL's Ignition and Photon Science Directorate with engineering services across a wide variety of disciplines. The National Ignition Facility, with the world's largest and most energetic laser, is a critical tool for ensuring national security, performing experiments that may lead to nuclear fusion in a laboratory setting, and advancing basic science. These efforts allow scientists to help ensure the country's safety without nuclear weapon testing, define energy for the future, and gain a better understanding of the universe.

The four-year contract also allows CDI to provide engineering support to the entire LLNL complex including the defense technologies, engineering technologies, national security engineering and technology resources engineering divisions.

CDI provides engineering support to energy, chemical, infrastructure, aerospace, industrial and defense clients.

$3B

— value of the global optical imaging system market by 2024, as projected by Grand View Research

Tempus aircraft to test NASA imaging spectrometer

Aviation technology firm Tempus Applied Solutions Holdings Inc. of Williamsburg, Va., said it has begun flight operations for NASA's Jet Propulsion Laboratory (JPL), having integrated NASA and JPL's Portable Remote Imaging Spectrometer, a specialized hyperspectral sensor, into Tempus' Gulfstream IV aircraft.

Operations began off the coast of Maine before moving to Hawaii for a total mission duration of three weeks. The Tempus Gulfstream IV will operate a

MOVES AND EXPANSIONS

Embry-Riddle Aeronautical University's STEM Education Center is being built in Prescott, Ariz.

Construction has begun on a 52,500-sq-ft STEM (Science, Technology, Engineering and Mathematics) Education Center at **Embry-Riddle Aeronautical University**'s Prescott, Ariz., campus, set for completion in the fall of 2017. The building will contain classrooms, meeting rooms, a multimedia center and a planetarium dome for the campus' astronomical observatory. It will also house 20 labs for faculty and students. Robotics labs will support the fastest-growing program on campus, mechanical engineering, which launched in 2006, with biology, chemistry and physics labs to enhance undergraduate programs in biology and pre-med. The Raisbeck Engineering Design Studio will provide students with hands-on experience working on next-generation commercial aircraft, military aircraft and unmanned aerial systems. A small supercomputer system will be available for use by students and faculty in computational and simulation sciences, and a space lab will provide small satellite and space systems development.

Fulham Co. Group, a supplier of lighting components and electronics for commercial and specialty applications, said it has signed a definitive agreement to acquire certain assets of the LED driver business of Lumotech, based in Alkmaar, Netherlands, from Nualight, a manufacturer of specialty LED products. With completion of this acquisition, Lumotech will become Fulham's new European Design Center, enabling the company to offer a more extensive line of LED drivers to OEMs and distributors throughout Europe. Financial terms of the acquisition were not disclosed.

The **Australian Institute for Nanoscale Science and Technology** (AINST) has opened on the campus of the University of Sydney, headquartered at the $150 million Sydney Neuroscience Hub. In addition to teaching laboratories, lecture theaters and collaborative work spaces for students, the new facility includes research laboratories and a clean room protected from physical, electronic and thermal interference. A research and prototype foundry allows the researchers to create their structures and devices without leaving the building, with a transmission electron microscope to see materials' atomic structures. Current technologies in development include unbreakable quantum communication and ultrahigh-speed wireless computing, houses and offices acting as huge batteries, steel-framed cars slimmed by 100 kg, efficient biofuel production, and real-time targeting of cancers.

total of 223 science flight hours globally while supporting the data collection efforts of NASA/JPL over the next 12 months. After returning from Hawaii in July, the next survey mission is scheduled for September and October in Australia to survey the Great Barrier Reef.

NASA intends to develop a business jet into a multimission, multiple-sensor platform for future earth science remote sensing missions. Tempus was awarded the aircraft modification contract in April and provided more than 5,000 hours of engineering support for the modification project. The 2016 flight operations contract is valued at $1.4 million.

Tempus provides design, engineering, systems integration and flight operations technologies for U.S. aviation missions, foreign governments and select corporations.

MD-SIG publishes universal LED specs

The Module-Driver Interface Special Interest Group (MD-SIG), a lighting-industry consortium, has published its LEDset specifications. The group said its two specifications complement those developed by the Zhaga Consortium, a lighting-industry organization independent from MD-SIG.

The LEDset Power Interface Specification describes the data-sheet information that should be provided for LED modules and drivers, in terms of the output current, voltage and power ranges. With this standardized approach, luminaire makers can identify interoperable components without the risk of inaccurate matching due to poorly defined specification parameters such as temperature drift, forward-voltage tolerances and current-modulation effects. The specification also describes the testing conditions and measurement methods that should be used to verify the provided information. The LEDset1 Information Interface Specification describes a setting method that uses a resistor to configure the output current of a window driver, wherein a resistor is attached to the driver in the production line of the luminaire manufacturer.

MD-SIG is an open, global consortium consisting of leading lighting and LED driver manufacturers BAG Electronics, BJB, Helvar, Osram, Panasonic/Vossloh-Schwabe, Philips Lighting, TCI and Zumtobel/Tridonic.

26.5%

— expected compound annual growth rate of the global 3D sensors market for the period 2016 to 2022, according to MarketsandMarkets

Carbon-nanotube optics designed for space telescopes

GREENBELT, Md. — A lightweight telescope containing a carbon-nanotube mirror is being designed to fit inside a CubeSat, NASA's 4-in. nanosatellite, for scientific investigation in space.

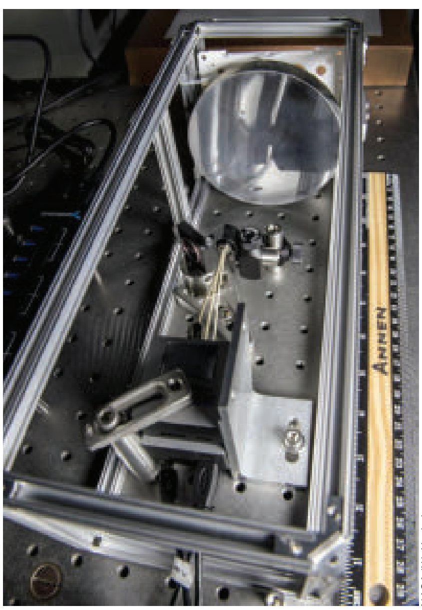
A team at NASA's Goddard Space Flight Center has created a laboratory optical bench to test the telescope's overall design, comprising three commercially available, miniaturized spectrometers optimized for UV, visible and near-infrared wavelength bands. The spectrometers were connected via fiber optic cables to the focused beam of a 3-in.-diameter carbon-nanotube mirror.

To fabricate the mirror, a mixture of epoxy and carbon nanotubes was poured into a mold and cured. Once set, the mirror was coated with a reflective material of aluminum and silicon dioxide. The mold could be used to produce many identical low-mass, highly uniform replicas at low cost, which could enable fleets of spacecraft equipped with identical optics and different detectors to be deployed for a variety of experiments. In addition to being highly stable and easily reproducible, the carbon-nanotube mirrors do not require polishing.

The researchers have also demonstrated a way to integrate actuators into the optics at the time of fabrication by applying electric fields to the resin mixture before curing the mirror, causing the formation of carbon-nanotube chains. After curing, technicians can apply power to the mirror to deform the shape of the optical surface.

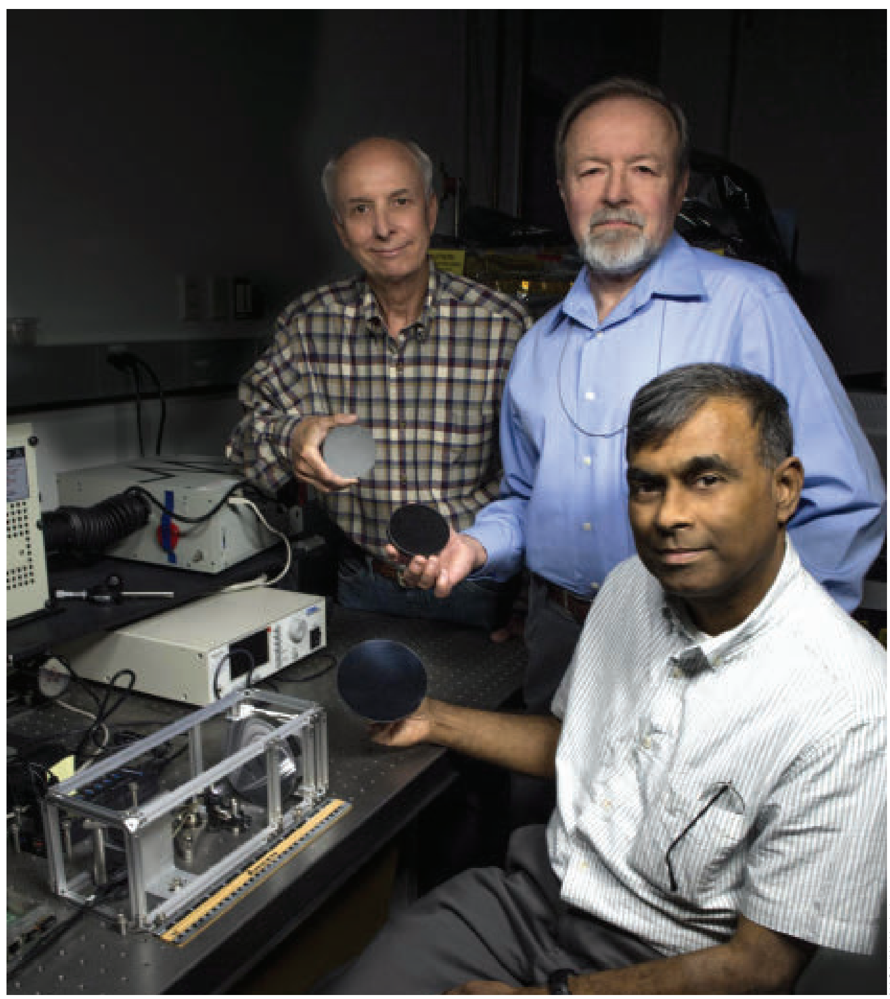
The optics technology used to develop the CubeSat telescope may be applicable to larger telescopes that have multiple mirror segments, such as the James Webb Space Telescope or the twin telescopes at the Keck Observatory in Hawaii, the researchers said. Many of the mirror segments in these large telescopes are identical, and could be produced using a single mold, eliminating the need to grind and polish individual segments to the same shape and focal length.

The research was described on NASA's website.



NASA/W. Hrybyk

This laboratory breadboard is used to test a conceptual telescope for use on CubeSat missions.



NASA/W. Hrybyk

John Kolasinski **(left)**, Theodor Kostiuk **(center)** and Tilak Hewagama hold mirrors made of carbon nanotubes in an epoxy resin. The mirror is being tested for potential use in a lightweight telescope specifically for CubeSat scientific investigations.

Terahertz QCL demonstrates record power in CW mode

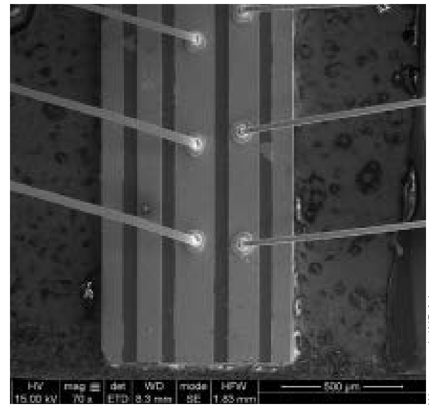
BEIJING and SICHUAN, China — The output power of a terahertz quantum cascade laser (QCL) has been effectively doubled, producing record output power of up to 230 mW in CW mode, compared to the previous record of 138 mW.

A team from the Institute of Applied Physics and Computation Mathematics and the China Academy of Engineering Physics, led by researcher Xuemin Wang, reported the results, and attributed the higher output power to the material growth and manufacturing processes they used. QCLs are made from thin layers of material, which enables tuning of the emitted wavelength.

The researchers reported a 2.9-mm-long device operating at 3.11 THz with a low threshold current density of 270 A/cm^2 at about 15 K, developed using a hybrid bound-to-continuum transition and resonant phonon extraction design. The maximum operating temperature was about 65 K in CW mode, and the internal quantum efficiencies decreased from 0.53 to 0.19 for the devices with different cavity lengths. By using one convex lens with the effective focal length of 13 mm, the beam profile was collimated for a quasi-Gaussian distribution.

The output power increase demonstrates that the team's method of controlling the growth of the laser's layers can increase output power, Wang said, and he is hopeful that future improvements could bring the continuous power above 1 W, which thus far has only been produced in terahertz QCLs operating in pulsed wave mode. A hybrid bound-to-continuum transition and resonant phonon extraction design was used.

The unique qualities of terahertz radiation make it an attractive candidate for imaging, but the ability to produce and control terahertz waves has lagged behind technology for radio, microwave and visible light. Wang believes the new laser could become a flexible source of terahertz radiation for spectroscopy, medical imaging, remote sensing and other applications.



Wang, et al./AIP Advances

A scanning electron microscope image of the terahertz quantum cascade laser.

The research was published in *AIP Advances* (doi: 10.1063/1.4959195).

Smart LEDs deliver communication and illumination

ZURICH — Consumer-grade LED light bulbs can be enhanced with basic light-receiving electronics to enable the sensing of incoming signals from other light-emitting devices. The enhanced light bulbs are powerful enough to establish a communication link across several meters between light bulbs and LED-only systems that can be integrated into many devices.

The indoor visible light communication (VLC) system, called EnLighting, enables distributed and fully connected LED light bulbs to communicate through free space optics and may be a way to both light a room and provide a communications link.

Researchers at Disney Research and ETH Zurich designed and implemented the system, demonstrating that it is a viable way to interconnect devices within a room.

"We used commercially available, off-the-shelf LED light bulbs as our starting point," said researcher Stefan Schmid. "They are readily available at low cost and can be used in any lamp with standard sockets. This leads to an easy-to-setup and flexible testbed that can be readily duplicated."

The researchers added a system-on-a-chip (SoC) running an embedded version of Linux to each bulb, as well as photodiodes to enable sensing of incoming signals and an additional power supply for the added electronics.

The individual LEDs were able to alternate between sending modulated light signals and serving as receivers of signals, creating a network of bulbs that could send messages to each other and connect to devices while having no discernible effect on room lighting. The bulb networks demonstrated the ability to support the low bandwidth applications typical of many devices.

The VLC system may offer a low-cost, nonintrusive way to extend device-to-device communication to room area networking.

A video describing EnLighting is included in the web version of this story: **www.photonics.com/A60893**.

Disney Research

Conceptual illustration of EnLighting, an indoor visible light communications system.

"LED light bulbs mounted on the ceiling or in freestanding floor lamps easily cover a room, serving as illumination while at the same time creating a room-area network that allows data exchange between light-emitting devices," said Markus Gross, vice president at Disney Research, adding that even if the bulb is switched off, it can still serve as a receiver of signals from those devices.

In the future, EnLighting may provide a practical way to connect the many devices, such as appliances, wearable devices, sensors, toys and utilities, that could comprise the Internet of Things (IoT). EnLighting can support low-bandwidth communication services beyond the room via a gateway, providing the basis for applications such as a location-based service.

Interconnecting appliances, sensors and a wide variety of devices into the Internet of Things has many potential benefits, but using radio links to do so threatens to make the radio spectrum an even scarcer resource, the researchers said. However, visible light communication networks conserve the radio spectrum, while also making it difficult to eavesdrop for anyone out of line of sight of the network.

The research was presented at the IEEE International Conference on Sensing, Communication and Networking (SECON) 2016.

Facebook develops photodetection tech for communications

MENLO PARK, Calif. — One of the primary challenges of implementing wireless communications has been how to precisely point a very small laser beam carrying the data at a tiny light detector that is some distance away. Now, researchers at the Facebook Connectivity Lab have demonstrated a method for using fluorescent materials instead of traditional optics to collect light and concentrate it onto a small photodetector with an active area of 126 cm^2. The photodetector demonstrated the ability to collect light from any direction and transmit data up to 2.1 Gb/s.

To build the detector, the researchers doped optical waveguides with wavelength-shifting dyes that were contained in a fluorescent optical fiber. Incident light (blue) was absorbed by the dye molecules and was emitted at a different wavelength (green). The fiber collected a portion of the emitted light and funneled the light to a small-area photodiode, creating a luminescent detector (LD) system that combined luminescent concentrators and the photodiode.

The intermediate scattering caused by the dye allowed efficient collection of light over a large area and enabled the light to be concentrated over an end facet with a reduced étendue. The fast speeds were possible due to a lapse of less than 2 ns between the blue light absorption and the green light emission, the researchers said.

“The fact that these fluorescent optical fibers emit a different color than they absorb makes it possible to increase the brightness of the light entering the system,” said researcher Tobias Tiecke. “This approach has been used in luminescent concentrators for solar light harvesting, where the speed of the color conversion doesn’t matter. We showed that the same concept can be used for communication to circumvent pointing and tracking problems while accomplishing very high speeds.”

The use of luminescent concentrators increased the active area and response time of the LD, allowing high-data-rate communication rates without the need for accurate pointing and tracking. Since the detector has omnidirectional sensitivity and is insensitive to the spatial mode of the incident light, it has the potential to support mobile applications and to use diffuse light sources and multimode optical fields (e.g., arising from propagation through a turbulent atmosphere).

The researchers sent up to 2.1 Gb/s despite the system’s bandwidth of 100 MHz by incorporating orthogonal frequency division multiplexing (OFDM), which allowed them to modulate signals and encode digital data so that multiple data streams could be transmitted at once. Although OFDM is commonly used for wired and wireless communication, it is not typically used with laser communication.

If materials were developed to operate in the IR part of the spectrum, the approach could theoretically allow free-space optical data rates of more than 10 Gb/s, Tiecke said. In addition to working with partners to develop new materials, the research team is planning to move the technology out of the lab by developing a prototype that could be tested in a real-world situation.

The research was published in *Optica*, a journal of The Optical Society (doi: 10.1364/optica.3.000787).

Field study compares portable microscopes for parasite diagnosis

TORONTO — Handheld, mobile-phone-based microscopes could be used in developing countries after minimal training of community laboratory technicians to diagnose intestinal parasites quickly and accurately.

A community-based study conducted by researchers from Toronto General Hospital and Toronto General Research Institute in the Republic of Ivory Coast, West Africa, found that two different handheld microscopes could both effectively rule in individuals infected by parasites — important in allocating resources for public health screening — and are also varied in their sensitivity to detect all cases of an illness, in comparison to a conventional laboratory microscope.

Microscopes are vital in the diagnosis and surveillance of many parasitic infections, and are a staple in every clinical and public health lab worldwide, except in developing countries where parasitic infections are common.

The research team tested two portable handheld microscopes: a commercial Newton Nm1 portable field microscope, and a mobile-phone-based CellScope, essentially a smartphone with a special custom-fitted lens attached over the camera and light source, developed by University of California engineers to detect intestinal parasites.

Local laboratory technicians were trained to operate the two handheld microscopes. In total, the technicians ex-

University Health Network

A local laboratory technician in the Ivory Coast is trained on a portable, handheld microscope to detect intestinal parasites in a remote, rural community. These parasites affect almost 2 billion people worldwide, predominantly in areas with poor sanitation and unclean water.

amined stool and urine samples from 226 individuals for the detection of parasites. The accuracy of all slides was evaluated using each microscope: the two handheld devices, as well as a conventional, standard microscope.

The researchers reported that both handheld microscopes were very good at ruling in infections, and the Newton portable microscope was able to detect even very-low-burden infections. The CellScope missed some low-burden infections; however, newer iterations of this device are currently being tested to increase its sensitivity.

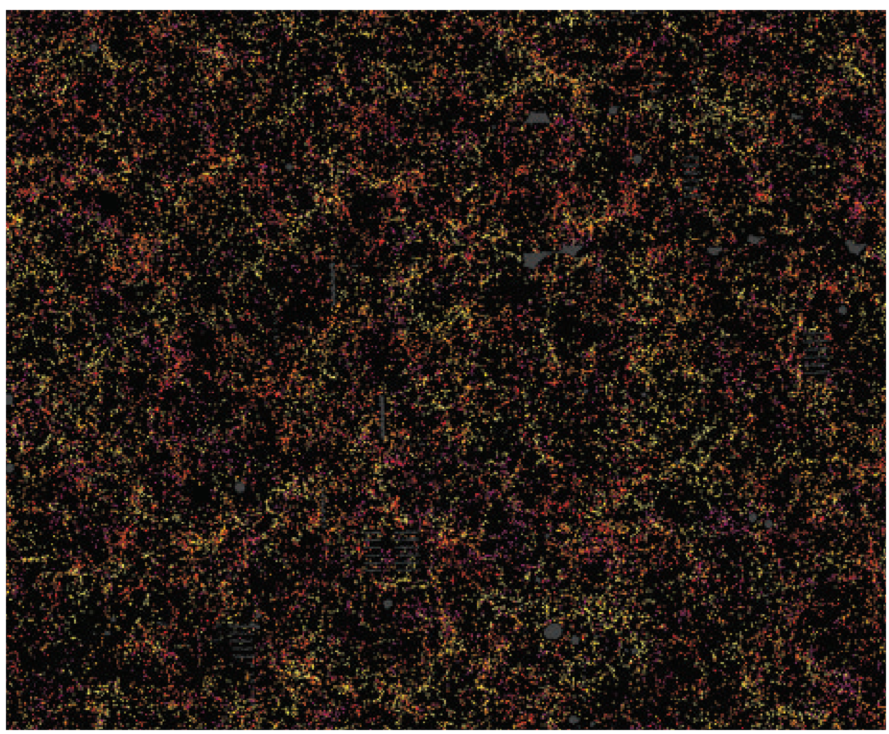
The research was published in *PLOS Neglected Tropical Diseases* (doi: 10.1371/journal.pntd.0004768).

"It was heartwarming to see how well and easily these portable, handheld field microscopes were adopted and used in a rural setting," said Dr. Isaac Bogoch, senior author and physician in Internal Medicine and Infectious Diseases at Toronto General Hospital, University Health Network.

Bogoch said that novel diagnostic approaches for common parasitic infections could have a profound impact on care of patients, as well as on public health approaches to screening in resource-poor areas.

Spectroscopic 3D survey maps 1.2M galaxies

BERKELEY, Calif. — The largest-ever 3D map of distant galaxies has been constructed with measurements made by the Baryon Oscillation Spectroscopic Survey (BOSS) program of the Sloan Digital Sky Survey-III, headquartered at Lawrence Berkeley National Lab. Hundreds of astronomers and scientists spent five years



Daniel Eisenstein and SDSS-III

One slice through the map of the large-scale structure of the universe from the Sloan Digital Sky Survey and its Baryon Oscillation Spectroscopic Survey. Each dot in this picture indicates the position of a galaxy 6 billion years into the past. The image covers about 1/20th of the sky, a slice of the universe 6 billion light-years wide, 4.5 billion light-years high and 500 million light-years thick. Color indicates distance from Earth, ranging from yellow on the near side of the slice to purple on the far side. Galaxies are highly clustered, revealing superclusters and voids whose presence is seeded in the first fraction of a second after the Big Bang. This image contains 48,741 galaxies, about 3 percent of the full survey dataset. Gray patches are small regions without survey data.

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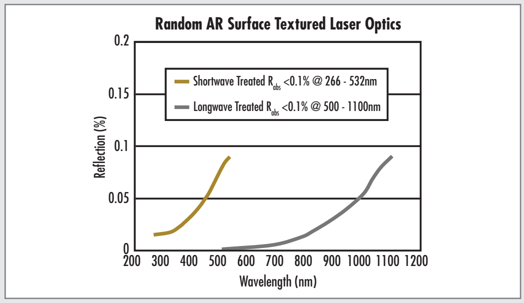
TECHNICAL NOTE

RANDOM AR SURFACE TEXTURED LASER OPTICS

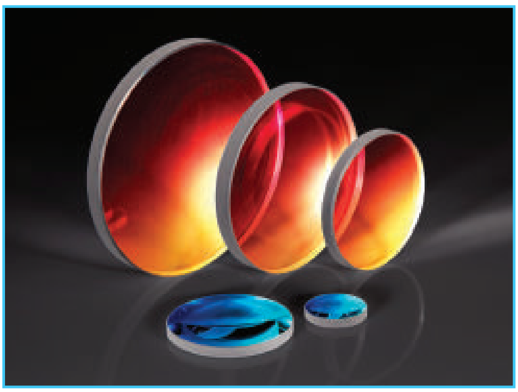
Random AR Surface Textured Laser Optics reduce external reflections to extremely low levels over exceptionally wide bandwidths compared to traditional thin-film AR coatings. Consisting of nanometer scale surface relief features packed in a dense texture etched into the polished optic surface, Random AR textures provide a graded index function that inherits the superior optical, chemical, and mechanical durability of the fused silica optic material. Random AR Surface Textured Laser Optics are available in either Shortwave (SW) or Longwave (LW) versions with per surface reflection loss below 0.1% over the entire specified wavelength range. The Random AR graded-index function provides a single material solution with high damage threshold for both pulsed and CW lasers, by adding no surface absorption, allowing the optics to reliably transmit or focus high intensity laser illumination with low temperature, no thermal lensing, and no damage.

Note: The textured surfaces of these optics require special attention when cleaning. Conventional cleaning techniques used for coatings such as the drop-and-drag method or physical wiping can result in further contamination from solvent residues being forced deeper into the textures. Random AR Surface Textured Laser Optics can only be cleaned by solvent or soapy water rinsing or immersion. Highly contaminated textures can be very aggressively cleaned by immersion in acid solutions such as a mix of sulfuric acid and hydrogen peroxide. In all cases the cleaning of textured optics should be completed by rinsing with isopropyl alcohol followed by air drying under cover or nitrogen blow drying.



RANDOM AR SURFACE TEXTURED LASER OPTICS

NEW



Material Type:	Fused Silica, Fine Annealed
	Inclusion Class 0
	Homogeneity Grade A
Diameter Tolerance:	±0.00/-0.20mm
Center Thickness Tolerance:	±0.1mm
AR Treatment:	
Shortwave Treated:	R_{abs} <0.1% @ 266 - 532nm
Longwave Treated:	R_{abs} <0.1% @ 500 - 1100nm
Irregularity (P-V):	λ/10
Surface Quality:	10-5
Clear Aperture:	85%
Edges:	Fine Ground, Protective Bevel as Needed

RANDOM AR SURFACE TEXTURED LASER LENSES

Diameter (mm)	Effective Focal Length (mm)	Center Thickness (mm)	Shortwave Treated Stock No.	Longwave Treated Stock No.	Price		
					1-5	6-25	26+
12.7	18	5.80	#34-326	#34-335	$250.00	$200.00	Call for OEM Quantity Pricing
12.7	25	4.85	#34-327	#34-336	$250.00	$200.00	
12.7	36	4.33	#34-328	#34-337	$250.00	$200.00	
12.7	50	4.00	#34-329	#34-338	$250.00	$200.00	
25.4	38	8.30	#34-330	#34-339	$295.00	$236.00	
25.4	50	6.85	#34-331	#34-340	$295.00	$236.00	
25.4	75	5.55	#34-332	#34-341	$295.00	$236.00	
25.4	100	4.95	#34-333	#34-342	$295.00	$236.00	
25.4	150	4.40	#34-334	#34-343	$295.00	$236.00	

RANDOM AR SURFACE TEXTURED LASER WINDOWS

Diameter (mm)	Thickness (mm)	Shortwave Treated Stock No.	Longwave Treated Stock No.	Price		
				1-5	6-25	26+
5.0	3	#34-261	#34-270	$185.00	$148.00	Call for OEM Quantity Pricing
10.0	3	#34-262	#34-271	$195.00	$156.00	
12.5	3	#34-263	#34-272	$205.00	$164.00	
15.0	3	#34-264	#34-273	$215.00	$172.00	
20.0	3	#34-265	#34-274	$225.00	$180.00	
25.0	3	#34-266	#34-275	$235.00	$188.00	
30.0	4	#34-267	#34-276	$345.00	$276.00	
40.0	4	#34-268	#34-277	$375.00	$300.00	
50.0	5	#34-269	#34-278	$395.00	$316.00	

TECHSPEC® LASER LINE COATED FUSED SILICA PCX LENSES

- **<0.25% Reflection at Design Wavelength**
- **Coatings Available for Diode, HeNe, and Nd:YAG Laser Sources**
- **Large Variety of Diameters and Focal lengths Available**

TECHSPEC® Laser Line Coated Fused Silica PCX Lenses are available in a variety of laser line V-Coat AR coating options. Designed for maximum throughput at the specified laser wavelength, these lenses are ideal for applications utilizing low power HeNe, Diode, and Nd:YAG laser sources. With a maximum reflection of <0.25% per surface at the design wavelength, the lenses will provide superior transmission in applications utilizing multiple optical components.

NEW

Material Grade:	UV Fused Silica
Diameter Tolerance:	+0.000/-0.025mm
Center Thickness Tolerance:	
5.0 - 12.0mm Diameter	±0.05mm
12.01 - 50.0mm Diameter	±0.10mm
Coating Specification:	R_{abs} <0.25% @ Design Wavelength
Power (P-V):	1.5λ
Irregularity (P-V):	λ/4
Surface Quality:	40-20
Clear Aperture:	
5.01 - 10.0mm Diameter	≤90% of Diameter
10.01 - 50.00mm Diameter	Diameter - 1.0mm
Centration:	≤1 arcmin
Focal Length Tolerance:	±1%
Edges:	Fine Ground, Protective Bevel as Needed

TECHSPEC® LASER LINE COATED FUSED SILICA PCX LENSES

Diameter (mm)	Effective Focal Length (mm)	Back Focal Length (mm)	Center Thickness (mm)	405nm Stock No.	532nm Stock No.	633nm Stock No.	1064nm Stock No.	1550nm Stock No.	Price 1-5	Price 6-25	Price 26+
5.0	10.0	8.63	2.00	#34-060	#34-083	#34-106	#34-129	#34-152	$100.00	$80.00	Call for OEM Quantity Pricing
5.0	15.0	13.83	1.70	#34-061	#34-084	#34-107	#34-130	#34-153	$100.00	$80.00	
5.0	20.0	18.97	1.50	#34-062	#34-085	#34-108	#34-131	#34-154	$100.00	$80.00	
5.0	25.0	23.97	1.50	#34-063	#34-086	#34-109	#34-132	#34-155	$100.00	$80.00	
12.0	18.0	15.26	4.00	#34-064	#34-087	#34-110	#34-133	#34-156	$110.00	$88.00	
12.0	25.0	22.31	3.92	#34-065	#34-088	#34-111	#34-134	#34-157	$110.00	$88.00	
12.0	30.0	27.56	3.55	#34-066	#34-089	#34-112	#34-135	#34-158	$110.00	$88.00	
12.0	36.0	34.29	2.50	#34-067	#34-090	#34-113	#34-136	#34-159	$110.00	$88.00	
12.0	50.0	48.01	2.90	#34-068	#34-091	#34-114	#34-137	#34-160	$110.00	$88.00	
12.0	100.0	98.33	2.44	#34-069	#34-092	#34-115	#34-138	#34-161	$110.00	$88.00	
25.0	38.0	33.03	7.25	#34-070	#34-093	#34-116	#34-139	#34-162	$115.00	$92.00	
25.0	50.0	46.00	5.84	#34-071	#34-094	#34-117	#34-140	#34-163	$115.00	$92.00	
25.0	60.0	56.92	4.50	#34-072	#34-095	#34-118	#34-141	#34-164	$115.00	$92.00	
25.0	75.0	71.96	4.43	#34-073	#34-096	#34-119	#34-142	#34-165	$115.00	$92.00	
25.0	100.0	97.40	3.79	#34-074	#34-097	#34-120	#34-143	#34-166	$115.00	$92.00	
25.0	125.0	122.65	3.42	#34-075	#34-098	#34-121	#34-144	#34-167	$115.00	$92.00	
25.0	150.0	147.82	3.18	#34-076	#34-099	#34-122	#34-145	#34-168	$115.00	$92.00	
25.0	200.0	198.02	2.88	#34-077	#34-100	#34-123	#34-146	#34-169	$115.00	$92.00	
50.0	75.0	66.43	12.50	#34-078	#34-101	#34-124	#34-147	#34-170	$230.00	$184.00	
50.0	100.0	93.84	9.00	#34-079	#34-102	#34-125	#34-148	#34-171	$230.00	$184.00	
50.0	150.0	145.20	7.00	#34-080	#34-103	#34-126	#34-149	#34-172	$230.00	$184.00	
50.0	200.0	195.19	7.00	#34-081	#34-104	#34-127	#34-150	#34-173	$230.00	$184.00	
50.0	250.0	245.21	7.00	#34-082	#34-105	#34-128	#34-151	#34-174	$230.00	$184.00	

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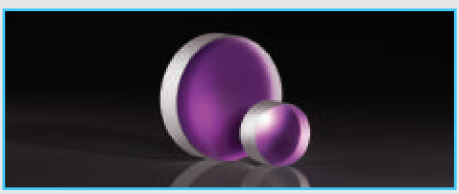

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- High Damage Thresholds

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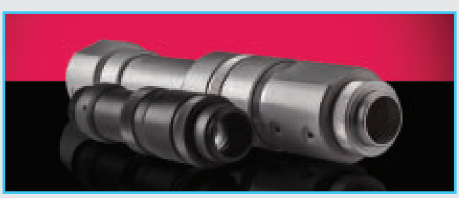
- <0.25% Reflection at 532nm and 1064nm
- High Laser Damage Threshold



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- Excellent Responsivity from 0.19 - 20μm

TECHSPEC® λ/20 FIRST SURFACE MIRRORS

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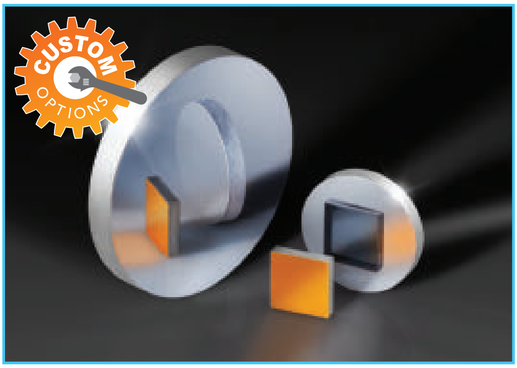

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- **Variety of Sizes and Coating Options Available**
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TECHSPEC® λ/20 First Surface Mirrors are ideal for demanding beam steering and reflection applications in the visible and IR spectra. With a precision fused silica substrate, the mirrors feature a low coefficient of thermal expansion while being highly durable and resistant to abrasion.

Substrate:	Fused Silica
Dimensional Tolerance:	+0.00/-0.20mm
Thickness Tolerance:	±0.20mm
Surface Flatness:	λ/20
Surface Quality:	20-10
Edges:	Ground, Protective Bevel as Needed
Clear Aperture:	90%
Parallelism:	30 arcsec
Back Surface:	Commercial Polish

TECHSPEC® λ/20 FIRST SURFACE MIRRORS

Dimensions (mm)	Thickness (mm)	Enhanced Aluminum				Protected Gold				Protected Silver			
		Stock No.	1-5	6-25	26+	Stock No.	1-5	6-25	26+	Stock No.	1-5	6-25	26+
10 Dia	2.0	#34-354	$95.00	$76.00	Call for OEM Quantity Pricing	#34-370	$120.00	$96.00	Call for OEM Quantity Pricing	#34-386	$115.00	$92.00	Call for OEM Quantity Pricing
10 x 10	2.0	#34-355	$95.00	$76.00		#34-371	$120.00	$96.00		#34-387	$115.00	$92.00	
15 Dia	3.0	#34-356	$100.00	$80.00		#34-372	$130.00	$104.00		#34-388	$120.00	$96.00	
15 x 15	3.0	#34-357	$100.00	$80.00		#34-373	$130.00	$104.00		#34-389	$120.00	$96.00	
20 Dia	3.0	#34-358	$110.00	$88.00		#34-374	$135.00	$108.00		#34-390	$130.00	$104.00	
20 x 20	3.0	#34-359	$110.00	$88.00		#34-375	$135.00	$108.00		#34-391	$130.00	$104.00	
25 Dia	4.0	#34-360	$115.00	$92.00		#34-376	$175.00	$140.00		#34-392	$150.00	$120.00	
25 x 25	4.0	#34-361	$115.00	$92.00		#34-377	$175.00	$140.00		#34-393	$150.00	$120.00	
30 Dia	5.0	#34-362	$150.00	$120.00		#34-378	$200.00	$160.00		#34-394	$165.00	$132.00	
30 x 30	5.0	#34-363	$150.00	$120.00		#34-379	$200.00	$160.00		#34-395	$165.00	$132.00	
40 Dia	5.0	#34-364	$180.00	$144.00		#34-380	$240.00	$192.00		#34-396	$220.00	$176.00	
40 x 40	5.0	#34-365	$180.00	$144.00		#34-381	$240.00	$192.00		#34-397	$220.00	$176.00	
50 Dia	5.0	#34-366	$195.00	$156.00		#34-382	$270.00	$216.00		#34-398	$245.00	$196.00	
50 x 50	5.0	#34-367	$195.00	$156.00		#34-383	$270.00	$216.00		#34-399	$245.00	$196.00	
75 Dia	7.5	#34-368	$395.00	$316.00		#34-384	$525.00	$420.00		#34-400	$485.00	$388.00	
75 x 75	7.5	#34-369	$395.00	$316.00		#34-385	$525.00	$420.00		#34-401	$485.00	$388.00	

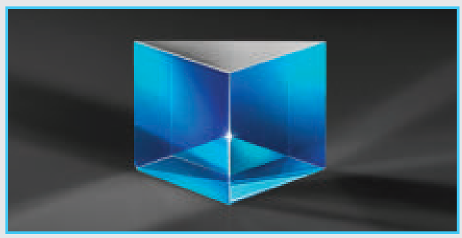
SO MUCH MORE ONLINE . . . www.edmundoptics.com/new-products

NEW

HIGH PERFORMANCE OD 4.0 UV LONGPASS FILTERS

- **New Cut-On Wavelengths of 325nm, 350nm, and 375nm**
- **Cut-On Slope <1%**
- **Rejection OD >4.0**

NEW



BBAR HYPOTENUSE RA PRISMS

- **Single Axis Retroreflector**
- **Right-Handed Image**
- **VIS and NIR Options Available**

NEW

POLARIZATION ROTATORS

- **Rotates Polarization by a Fixed Angle Regardless of Incident Polarization Angle**
- **Convenient Replacement of Half-Waveplate For Narrow Waveband Lasers**
- **1064nm, 532nm, and 355nm Anti-Reflection Coatings Available in both 45° and 90° Rotation Angles**

NEW

5X HR MITUTOYO OBJECTIVE

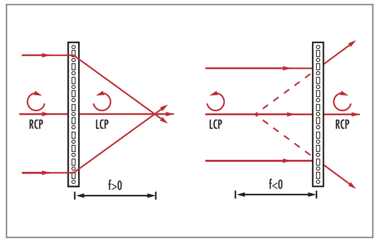
- **New 5X / 0.21 NA M Plan Apo High Resolution Objective**
- **Increased Resolving Power and Numerical Aperture**
- **Apochromat Design with Flat Image Across Entire Field of View**

POLARIZATION DIRECTED FLAT LENSES

- **Unique Flat Lens Design**
- **Polarization Dependent Focal Length**
- **Excellent Transmission from 450 - 650nm**

Polarization Directed Flat Lenses are flat lenses formed with polymerized liquid crystal thin-films that create a focal length that is dependent on polarization state. These unique lenses will have either a positive or negative focal length depending on the phase of the input polarization. With right handed circularly polarized light, the lenses will produce one focal length, while left handed circularly polarized light will present a focal length with the opposite sign. Unpolarized light will produce a positive and negative focal length at the same time. Both output waves are circularly polarized and orthogonal to each other. These Polarization Directed Flat Lenses are approximately 0.45mm thick, effectively simulating an ideal thin lens and are free from spherical aberration. **Note:** To discuss custom phase profiles, please contact technical support.

Dimensions:	25 x 25mm	**Coating Specification:**	R_{abs} <0.5% @ 450 - 650nm
Diameter Tolerance:	±0.25mm	**Surface Quality:**	60-40
Thickness:	0.45mm	**Design Wavelength:**	550nm
Thickness Tolerance:	±0.25mm	**Substrate:**	D263
Lens Aperture:	24.5mm Diameter		



POLARIZATION DIRECTED FLAT LENSES

f/#	Focal Length (mm)	Stock No.	Price 1-5	Price 6-25
1.8	45	#34-463	$175.00	$140.00
2	50	#34-464	$175.00	$140.00
3	75	#34-465	$175.00	$140.00
4	100	#34-466	$175.00	$140.00

TECHSPEC® VARIABLE BEAM EXPANDERS

- **1X - 3X and 2X - 8X Continuous Magnification**
- **Non-Rotating Lenses Minimize Beam Wander**
- **Compact Galilean Designs with Fixed Housing Length**

TECHSPEC® Variable Beam Expanders are ideal for high power laser applications where magnification changes may be required, such as prototyping or R&D. TECHSPEC® Variable Beam Expanders feature λ/4 transmitted wavefront, Galilean designs, lockable magnification, and high laser damage threshold AR coatings to ensure maximum transmittance while minimizing ghost reflections. Additionally, these beam expanders use internal translation and focusing mechanisms to continuously adjust magnification and laser divergence without affecting overall housing length. This compact design removes the need to make system accommodations for changes in length and eases system integration. **Note:** For optimal performance, center the laser beam to the entrance lens and ensure that the beam is parallel to the beam expander's optical axis.

ACCESSORIES

1X - 3X Mounting Clamp	#89-294	$150.00
2X - 8X Mounting Clamp	#89-295	$150.00

Visit our Website for Additional Wavelengths and Fixed Beam Expanders

TECHSPEC® VARIABLE BEAM EXPANDERS

*15mm Max Input for 2X - 8X

Design Wavelength:	266nm	355nm	Broadband NIR (DWL 785nm)
Coating:	266nm V-Coat, R_{abs} <0.25%	355nm V-Coat, R_{abs} <0.25%	750 - 1100nm, R_{avg} <1%
Total Transmission:	>97.5%	>97.5%	>95%
Transmitted Wavefront (P-V @ DWL):	<λ/4 for input Beam ≤ 6mm	<λ/4 for Input Beam ≤ 6mm	<λ/5 for Input Beam ≤ 6mm
Maximum Input Aperture:	10mm	10mm (15mm)*	10mm (15mm)*
Maximum Output Aperture:	30mm	30mm	30mm
Maximum Input Beam Tilt:	1mrad	1mrad	1mrad
1X - 3X Stock No. / Price	#87-559 / $1,095.00	#87-560 / $1,095.00	#87-564 / $1,095.00
2X - 8X Stock No. / Price	–	#87-566 / $1,295.00	#87-570 / $1,295.00

Call for OEM Quantity Pricing

TECHSPEC® VARIABLE BEAM EXPANDERS

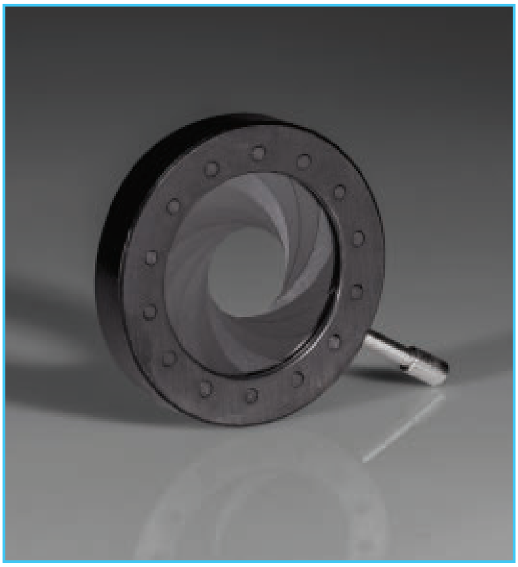
*15mm Max Input for 2X - 8X

Design Wavelength:	532nm	1064nm	Broadband VIS
Coating:	532nm V-Coat, R_{abs} <0.25%	1064nm V-Coat, R_{abs} <0.25%	425 - 700nm, R_{avg} <1%
Total Transmission:	>97.5%	>97.5%	>95%
Transmitted Wavefront (P-V @ DWL):	<λ/4 for Input Beam ≤6mm (1X-3X) <λ/4 for Input Beam ≤ 4mm (2X-6X) <λ/4 for Input Beam ≤2mm (>6X)	<λ/4 for Input Beam ≤6mm (1X-3X) <λ/7 for Input Beam ≤4mm (2X-6X) <λ/7 for Input Beam ≤2mm (>6X)	<λ/4 for Input Beam ≤6mm (1X-3X) <λ/4 for Input Beam ≤ 4mm (2X-6X) <λ/4 for Input Beam ≤2mm (>6X)
Maximum Input Aperture:	10mm (15mm)*	10mm (15mm)*	10mm (15mm)*
Maximum Output Aperture:	30mm	30mm	30mm
Maximum Input Beam Tilt:	1mrad	1mrad	1mrad
1X - 3X Stock No. / Price	#87-561 / $1,095.00	#87-562 / $1,095.00	#87-563 / $1,095.00
2X - 8X Stock No. / Price	#87-567 / $1,295.00	#87-568 / $1,295.00	#87-569 / $1,295.00

Call for OEM Quantity Pricing

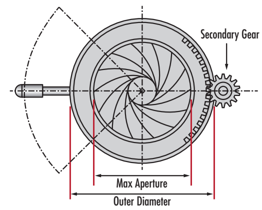
TECHSPEC® HIGH PERFORMANCE MOTORIZABLE IRISES

NEW



- **Fast Accurate Repeatable Motion**
- **Dual Control Gear and Lever Mechanics**
- **Blue Tempered Spring Steel Leaves**

TECHSPEC® High Performance Motorizable Irises are designed for integration into custom applications and for use in a lab environment. These irises include two methods for controlling the aperture size: one by a standard pin which enables standard angular deviation and the other that duplicates the movement of the pin by replicating the teeth of a spur gear on the inner housing of the iris. This feature allows for custom motion control in conjunction with a compatible spur gear. These TECHSPEC® High Performance Motorizable Irises maintain fast, accurate, and repeatable movement to any location through the iris's range of motion. **Note:** Iris Diaphragm Mounts sold separately. Gear shown for reference only. Visit our website to view our selection of gears and additional specifications.



TECHSPEC® HIGH PERFORMANCE MOTORIZABLE IRISES

Outer Diameter (mm)	Maximum Aperture (mm)	Minimum Aperture (mm)	Thickness (mm)	Number of Leaves	Drive Type	Housing Material	Stock No.	Price
12.0	7	0.5	4.5	8	Pin/Gear	Brass	#34-286	$90.00
14.8	8	0.7	4.5	8	Pin/Gear	Brass	#34-287	$55.00
19.8	12	0.8	5.0	10	Pin/Gear	Brass	#34-288	$60.00
24.0	15	0.8	5.0	12	Pin/Gear	Brass	#34-289	$60.00
28.0	18	0.8	5.0	12	Pin/Gear	Brass	#34-290	$60.00
33.0	22	0.8	5.5	14	Pin/Gear	Brass	#34-291	$75.00
37.0	25	0.8	5.5	14	Pin/Gear	Brass	#34-292	$75.00
40.0	28	1.2	5.5	16	Pin/Gear	Brass	#34-293	$80.00
49.0	34	1.5	6.5	14	Pin/Gear	Brass	#34-294	$90.00

VARIABLE FOCUS LIQUID LENSES

NEW

- **Variable Focus Length by Applied Voltage**
- **Ideal for Machine Vision Autofocus Applications**
- **Less Power Required than Traditional Autofocus Lenses**

Variable Focus Liquid Lenses consist of a set of two liquids, of equal density, but of different refractive index. The radius of the spherical interface between the two liquids can be changed with voltage, providing variable focus, or autofocus. These lenses are designed with a stable optical axis, can operate regardless of orientation, and feature AR Coatings optimized for excellent transmission between 400 and 700nm. Variable Focus Liquid Lenses are ideal for autofocus applications, and with no moving parts, they are faster, more durable, and consume less power than traditionally actuated autofocus lenses. A 2.5mm aperture lens for high speed applications and a 3.9mm aperture lens for long focal lengths, large sensor size, and laser applications are offered. The lenses are also available in development kits which include lenses, drive electronics, cables, and software for easy use and integration.

VARIABLE FOCUS LIQUID LENSES

Model:	Arctic A25H0		Arctic 39N0	
Diameter (mm):	9.4		15.2	
Thickness (mm):	3.5		5.2	
Clear Aperture (mm):	2.5		3.9	
Focus Range (diopters):	-5 to +13		-5 to +15	
Transmitted Wavefront Error, RMS (nm):	45		50	
Transmission (%):	97% @ 587nm		97% @ 587nm	
Storage Temperature (°C):	-40 to +85		-40 to +85	
Operating Temperature (°C):	-30 to +85		-20 to +60	
Individual Lens Stock No./Price	#34-282	$95.00	#34-283	$125.00
Development Kit Stock No./Price	#34-284	$795.00	#34-285	$795.00

TECHSPEC® UC SERIES FIXED FOCAL LENGTH LENSES

NEW IMAGING LENSES

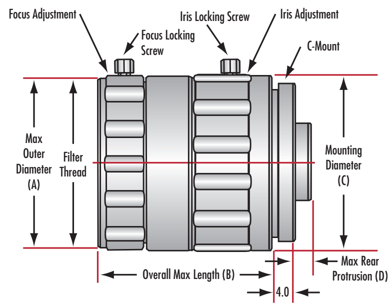
- **Ultra-Compact (UC) Form Factor**
- **4K Resolution Designed for Small Pixels (≤2.2μm)**
- **Optimized for 1/2.5" Sensors and Supports up to 1/1.8"**

Our ultra-compact, TECHSPEC® UC Series Fixed Focal Length Lenses are designed to optimize performance, cost, and size without sacrificing quality or feel. Designed for pixels that are ≤2.2μm, these lenses provide high levels of resolution (>200 lp/mm) across the sensor and are compatible with all standard C-Mount cameras. TECHSPEC® UC Series Fixed Focal Length Lenses feature focus and iris adjustments, as well as recessed set screws, and are manufactured for use at typical machine vision working distances. While they are optimized for 1/2.5" sensors, many focal lengths will work on sensors up to 1/1.8". The TECHSPEC® UC Series lenses are an outstanding option for use on all smaller format camera sensors, along with both short and long working distance applications, making them ideal for inspection, factory automation, biomedical devices, and a broad range of other applications.

NEW

DIMENSIONS

Focal Length (mm)	A	B	C	D	Filter Thread
4	40	40.6	30	2.8	M62.0 x 0.75 with required filter adapter #33-308
6	36	40.9	30	3.2	M34.0 x 0.5
8	30	34.52	30	3.2	M39.0 x 0.5 with required filter adapter #33-309
12	30	32.48	30	2.7	M25.5 x 0.5
16	30	29.13	30	3.38	M25.5 x 0.5
25	30	31.28	30	0	M25.5 x 0.5



TECHSPEC® UC SERIES FIXED FOCAL LENGTH LENSES

Focal Length:	4mm	6mm	8mm	12mm	16mm	25mm
Max Sensor Format:	½"	½"	½"	1/1.8"	1/1.8"	1/1.8"
Optimized Sensor Format:	1/2.5"	1/2.5"	1/2.5"	1/2.5"	1/2.5"	1/2.5"
FOV on 1/2.5" Sensor:	19.4mm – 71.2°	62.54mm – 52.78°	35.65mm – 39.24°	53.2mm – 26°	71.3mm – 20.21°	46.74mm – 12.54°
FOV on ½" Sensor:	22.9mm – 79.5°	71.38mm –58.97°	40mm – 43.6°	60.2mm – 29.2°	80mm – 22.62°	52.5mm – 14.08°
FOV on 1/1.8" Sensor:	–	–	–	68mm – 32.8°	90mm – 25.36°	59.14mm – 15.87°
Working Distance:	0mm - ∞	50mm - ∞	50mm - ∞	100mm - ∞	200mm - ∞	200mm - ∞
Aperture (f/#):	f/1.8 - f/11	f/1.85 - f/11	f/1.8 - f/11	f/1.8 - f/11	f/1.8 - f/11	f/1.85 - f/16
Stock No.	#33-300	#33-301	#33-302	#33-303	#33-304	#33-305
Price 1-5	$195.00	$180.00	$150.00	$165.00	$165.00	$180.00

6+ Call for OEM Quantity Pricing

FILTER ADAPTER

	4mm	6mm	8mm	12mm	16mm	25mm
Stock No./Price	#33-308 $30.00	–	#33-309 $30.00	–	–	–

TECHSPEC® Cx SERIES FIXED FOCAL LENGTH LENSES

NEW

- **Compact Flexible (Cx) Housing Design**
- **Modular 3-Piece Design**
- **Accommodates Interchangeable Accessories such as Liquid Lenses**

TECHSPEC® Cx Series Fixed Focal Length Lenses are designed with simplicity and versatility to easily integrate into a range of application types. The modular 3-piece design allows for flexibility to integrate precision fixed apertures, internal filter holders, or liquid lenses into the assembly. These lenses also feature a simplified focus mechanism with easy to use lock nut and recessed set screws to lock focus position into place. The Cx Series lenses are ideal for applications such as machine vision, factory automation, and Research and Development. For further documentation information or questions regarding ease of assembly and design support, please visit our website or contact technical support.

Note: One accessory is required for use with the Cx Series Lens.

TECHSPEC® Cx SERIES FIXED FOCAL LENGTH LENSES

Focal Length:	12mm	16mm	25mm	35mm
Maximum Camera Sensor Format:	⅔"	⅔"	⅔"	⅔"
Field of View, ⅔" Sensor:	40.7°	29.7°	18.7°	13.3°
Field of View, ½" Sensor:	30°	21.8°	13.6°	9.7°
Field of View, ⅓" Sensor:	22.7°	16.4°	10.2°	7.3°
Working Distance:	100mm - ∞	100mm - ∞	150mm - ∞	225mm - ∞
Number of Elements (Groups):	7 (7)	7 (6)	7 (6)	7 (6)
Coating:	425 - 675nm BBAR	425 - 675nm BBAR	425 - 675nm BBAR	425 - 675nm BBAR
Mount:	C-Mount	C-Mount	C-Mount	C-Mount
Lens Stock No.	#33-562	#33-563	#33-564	#33-565
Price	$280.00	$280.00	$280.00	$280.00

LIQUID LENS HOLDER ACCESSORY

	12mm	16mm	25mm	35mm
Stock No.*	#33-631	#33-645	#33-660	#33-674
Price	$30.00	$30.00	$30.00	$30.00

*See page 6 for more information on our Variable Focus Liquid Lenses. 35mm Liquid Lens Holder is compatible with Arctic 39N0. 25mm, 16mm, and 12mm are compatible with Arctic A25H0.

FILTER HOLDER ACCESSORY

For 12.5 diameter, 2mm thick filters

Aperture (f/#)	12mm	16mm	25mm	35mm
f/1.8	#33-594	#33-601	#33-608	–
f/2.8	#33-595	#33-602	#33-609	#33-615
f/4.0	#33-596	#33-603	#33-610	#33-616
f/5.6	#33-597	#33-604	#33-611	#33-617
f/8.0	#33-598	#33-605	#33-612	#33-618
f/11.0	#33-599	#33-606	#33-613	#33-619
f/16.0	#33-600	#33-607	#33-614	#33-620
Price	$30.00	$30.00	$30.00	$30.00

APERTURE ACCESSORY

Aperture (f/#)	12mm	16mm	25mm	35mm
f/1.5	–	33-637	–	–
f/1.65	–	–	–	#33-666
f/1.8	#33-624	#33-638	#33-653	#33-667
f/2.8	#33-625	#33-639	#33-654	#33-668
f/4.0	#33-626	#33-640	#33-655	#33-669
f/5.6	#33-627	#33-641	#33-656	#33-670
f/8.0	#33-628	#33-642	#33-657	#33-671
f/11.0	#33-629	#33-643	#33-658	#33-672
f/16.0	#33-630	#33-644	#33-659	#33-673
Price	$9.95	$9.95	$9.95	$9.95

collecting measurements of 1.2 million galaxies over one-quarter of the sky to map out the structure of the universe over a volume of 650 cubic billion light years.

Shaped by a continuous tug-of-war between dark matter and dark energy, the map revealed by BOSS allows scientists to measure the expansion rate of the universe and thus determine the amount of matter and dark energy that make up the present-day universe.

The research was published in Monthly Notices of the Royal Astronomical Society.

BOSS measures the expansion rate of the universe by determining the size of the baryonic acoustic oscillations (BAO) in the 3D distribution of galaxies. The original BAO size is determined by pressure waves that traveled through the young universe up to when it was only 400,000 years old, at which point they became frozen in the matter distribution of the universe. The end result is that galaxies have a slight preference to be separated by a characteristic distance that astronomers call the acoustic scale.

The size of the acoustic scale at 13.4 billion years ago has been exquisitely determined from observations of the cosmic microwave background from the light emitted when the pressure waves became frozen. Measuring the distribution of galaxies since that time allows astronomers to measure how dark matter and dark energy have competed to govern the rate of expansion of the universe.

"Measuring the acoustic scale across cosmic history gives a direct ruler with which to measure the universe's expansion rate. With BOSS, we have traced the BAO's subtle imprint on the distribution of galaxies spanning a range of time from 2 [billion] to 7 billion years ago," said Ariel Sanchez of the Max-Planck Institute of Extraterrestrial Physics.

SDSS-III is managed by the Astrophysical Research Consortium for the Participating Institutions of the SDSS-III Collaboration. For more information, visit www.sdss3.org.

$AgBiS_2$ explored for cheaper, greener solar cells

BARCELONA, Spain — Solution-processed inorganic solar cells based on nontoxic and abundant $AgBiS_2$ nanocrystals could be a low-cost alternative to first-generation solar cells.

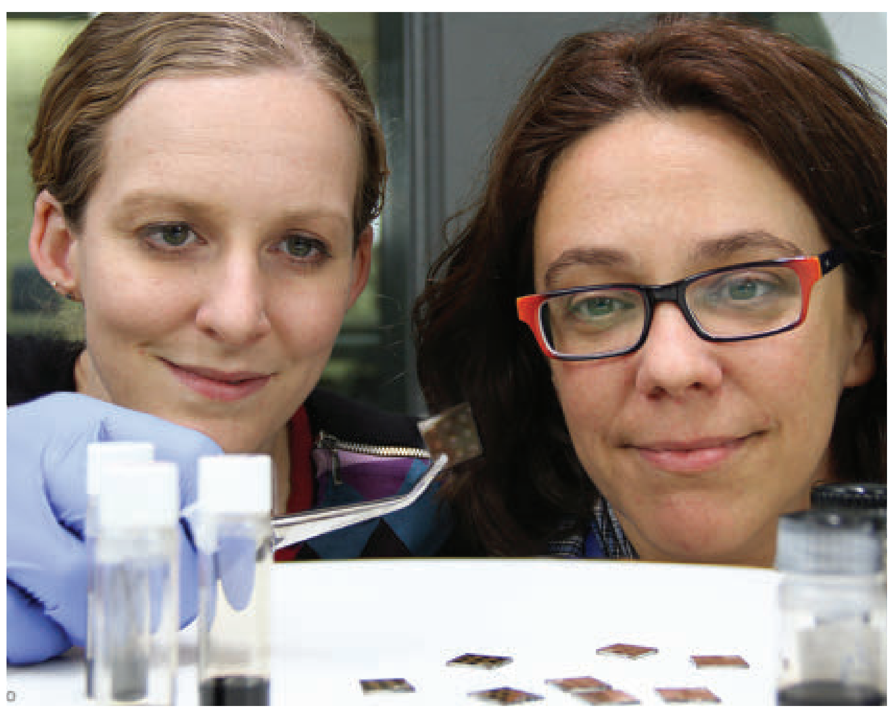
The most common inorganic solar cells for rooftop installation are made of silicon. The production of silicon solar cells can be expensive and energy demanding, and the modules are heavy and bulky. Many lower-cost thin-film solar cells, alternatives to silicon, are composed of toxic elements such as lead or cadmium, or contain scarce elements such as indium or tellurium.

The $AgBiS_2$-based cells were fabricated under ambient conditions at low temperatures of 100 °C. Researchers from The Institute of Photonic Sciences (ICFO) demonstrated devices with a certified power conversion efficiency of 6.3 percent, with no hysteresis and a short-circuit current density of about 22 mA cm^{-2} for an active layer thickness of only about 35 nm.

The temperature required for synthesis is an order of magnitude lower than that required for production of silicon-based solar cells, the researchers said. Their hot-injection synthetic procedure involved first dispersing $AgBiS_2$ nanocrystals into organic solvents, where the solutions showed to be stable for months without


ICFO

A semitransparent solar cell based on $AgBiS_2$ nanocrystals.


ICFO

Researchers Nicky Miller **(left)** and Maria Bernechea hold a semitransparent solar cell.

any losses in the device performance. Then, the nanocrystals were deposited onto a thin film of ZnO and ITO, the most commonly used transparent conductive oxide, in a layer-by-layer deposition process to a thickness of approximately 35 nm.

The solar cell material meets demands for nontoxicity, abundance and low-temperature solution processing, and the researchers are working toward a milestone efficiency of greater than 12 percent.

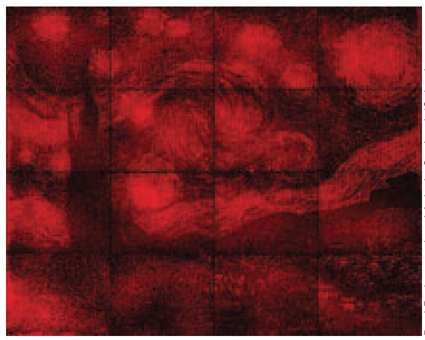
The research was published in *Nature Photonics* (doi: 10.1038/nphoton.2016.108).

DNA origami enables glowing photonic crystal cavities

PASADENA, Calif. — A microscopic, glowing image of Vincent van Gogh's "The Starry Night" has been fabricated in a demonstration of directed self-assembly of DNA origami onto lithographically patterned binding sites. The technique could enable reliable and controllable coupling of molecular emitters to photonic crystal cavities (PCCs).

The tiny reproduction contains 65,536 glowing pixels and demonstrates the scalability of the method, which aims to address a challenge in the fabrication of nanophotonics devices — how to incorporate large numbers of chemically diverse functional components into microfabricated resonators at precise locations.

DNA origami is a technique developed at California Institute of Technology



Paul Rothemund and Ashwin Gopinath/Caltech

This reproduction of Vincent van Gogh's "The Starry Night" contains 65,536 glowing pixels and measures less than 20 mm in diameter.

(Caltech) that entails folding long strands of DNA into a desired shape. The folded DNA then acts as a scaffold onto which researchers can attach and organize nanometer-scale components, such as fluorescent molecules, electrically conductive carbon nanotubes and drugs.

Over the past seven years, Caltech professor Paul Rothemund — who pioneered the technique — and postdoctoral researcher Ashwin Gopinath have been refining and extending the technique so that DNA shapes can be precisely positioned on almost any surface used in the manufacture of computer chips. Using DNA origami to install fluorescent molecules into microscopic light sources is the first reported application of the technique.

To create the device, the researchers used microfabricated PCCs, which were tuned to resonate at around 660 nm, corresponding to a deep shade of the color red. Created within a thin glass-like membrane, a PCC takes the form of a bacterium-shaped defect within an otherwise perfect honeycomb of holes. Fluorescent molecules tuned to glow at a similar wavelength illuminate the PCC "lamps," provided they are properly placed within the PCC.

By moving DNA origami through the PCCs in 20-nm steps, the researchers said that they could map out a checkerboard pattern of hot and cold spots, where the molecular light bulbs either glowed weakly or strongly. As a result, they were able to use DNA origami to position fluorescent molecules to make lamps of varying intensity. Similar structures have been proposed to power quantum computers and for use in other optical applications that require many tiny light sources integrated together on a single chip.

"All previous work coupling light emitters to PCCs only successfully created a handful of working lamps, owing to the extraordinary difficulty of reproducibly controlling the number and position of emitters in a cavity," said Gopinath.

By creating PCCs with different numbers of binding sites, the researchers were able to install any number from zero to seven DNA origami, allowing digital control of the brightness of each lamp. By treating each lamp as a pixel with one of eight different intensities, they produced the array of 65,536 of the PCC pixels (a 256 × 256-pixel grid).

The team said their ongoing work includes improving the light emitters, which currently fluoresce for about 45 seconds before reacting with oxygen and burning out, and they emit a few shades of red rather than a single pure color. Such improvements could enable the technique's use in quantum computing applications.

Satellite mission tests quantum light source

SINGAPORE — A technology that carries a quantum light source into space may be able to preserve the quantum properties of light as it travels through an optical link from space to Earth. It could provide the basis for establishing a secure global quantum network in space that can reach from one end of Earth to the other.

Researchers at the National University of Singapore and University of Strathclyde, U.K, built a space-qualified light source that could fit on a nanosatellite by redesigning a table-top quantum setup to be small and robust enough to fly inside a satellite the size of a shoebox and weighing just 1.65 kg.

The team then demonstrated the in-orbit operation of a photon pair source

Centre for Quantum Technologies, National University of Singapore

Researchers at the National University of Singapore and University of Strathclyde, U.K., have launched a satellite that is testing technology for a global quantum network. This image combines a photograph of the quantum device with an artist's illustration of nanosatellites establishing a space-based quantum network. **Inset:** Ph.D. students Zhongkan Tang **(left)** and Rakhitha Chandrasekara at the Centre for Quantum Technologies, National University of Singapore, are pictured working on a SPEQS unit.

aboard the nanosatellite, laying the groundwork for future entangled-photon experiments. The device inside the satellite, known as Small Photon-Entangling Quantum System (SPEQS) and comprising a laser diode, crystals, mirrors and photon detectors, takes photons from a BluRay laser and splits them in two, then measures the pair's properties. The research team demonstrated photon pair generation and polarization correlation under space conditions. The in-orbit photon correlations exhibited a contrast of 97 ±2 percent, matching ground-based tests.

Further testing and refinement may lead to a way to use entangled photons beamed from satellites to connect points on opposite sides of the planet. A fleet of nanosatellites carrying sources of entangled photons would be used to enable private encryption keys between any two points on Earth. The team's plans call for a series of launches, with the next spacebound SPEQS slated to produce entangled photons.

With subsequent satellites, the researchers will try sending entangled photons to Earth and to other satellites. The team is working with standard CubeSat nanosatellites, which can be sent into space as rocket ballast. Ultimately, completing a global network would mean having a fleet of satellites in orbit and an array of ground stations.

The research appeared in *Physical Review Applied* (doi: 10.1103/PhysRevApplied.5.054022).

The web version of this article includes a video describing the research: **www.photonics.com/A60871**

Very Large Telescope reveals low-mass bodies in Orion Nebula

ANTOFAGASTA, Chile — The HAWK-I IR instrument on the European Southern Observatory's (ESO) Very Large Telescope (VLT) has been used to produce the deepest and most comprehensive view of the Orion Nebula to date. The striking images reveal an abundance of faint brown dwarf planets and isolated planetary-mass objects, and the presence of such low-mass bodies provides insight into the history of star formation within the nebula itself.

The Orion Nebula spans about 24 light-years within the constellation of Orion, and is visible from Earth with the naked eye as a fuzzy patch in Orion's sword. Its relative proximity makes it an ideal testbed to better understand the process and history of star formation, and to determine how many stars of different masses form. Some nebulae, like Orion, are strongly illuminated by UV radiation from the many hot stars born within them, such that the gas is ionized and glows brightly.

Researchers from Ruhr-Universität Bochum and Max-Planck Institut für Astronomie in Germany, and Pontificia Universidad Católica de Chile and Universidad de Valparaíso in Chile, who produced and analyzed the image, said that understanding how many low-mass objects are found in the Orion Nebula is very important to constrain current theories of star formation.

The image helped elucidate the way the formation of such low-mass objects

ESO

The European Southern Observatory Very Large Telescope (VLT) during observations. In this picture, taken from the VLT platform looking north-northwest at twilight, the four 8.2-m unit telescopes are visible.

depends on their environment, and the researchers said the Orion Nebula may be forming proportionally far more low-mass objects than closer and less active star formation regions.

These observations also hint that the number of planet-sized objects might be far greater than previously thought, and for which effective observation technology does not yet exist. ESO's European Extremely Large Telescope (E-ELT), scheduled to begin operations in 2024, is designed to observe these objects.

ESO/H. Drass, et al.

An image of the Orion Nebula star-formation region obtained from multiple exposures using the HAWK-I IR camera on the European Southern Observatory's Very Large Telescope in Chile. This is the deepest view ever of this region and reveals more very faint planetary-mass objects than expected.

Aspheric lenses are designed to maximize performance in high-power Nd:YAG laser applications.

The Long and the Short of It: Techniques for **Measuring Aspheres**

The metrology method should match the nature of the part and the inspection constraints.

BY AMY FRANTZ
EDMUND OPTICS INC.

The benefits of aspheric lenses are numerous: They allow for a reduction in spherical aberrations and are ideal for focusing or collimating light, as they can achieve a low *f*-number. Aspheres also allow the same or better performance using fewer lenses, which often translates to a reduction in both size and weight in a system.

New applications in imaging increasingly require the use of aspheres, due to performance and size constraints. Manufacturing these surfaces requires equally innovative metrology methods. It is important to assess the strengths and weaknesses of the most common metrology methods that are used to quantify the surface accuracy of aspheres, and identify the criteria for selecting the most appropriate technique to measure specific classes of optical surfaces.

The interferometry that is typically used to measure the surface accuracy of optical components requires a planar reference wave to measure planar parts, or a spherical reference wave to measure spherical parts. Neither of these two approaches is ideal for measuring aspheres. The aspheric departure, or distance between the best fit radius of the asphere and its actual aspheric surface, creates very densely spaced interference fringes that are challenging to resolve. Because a spherical reference wave that matches the best fit radius of the asphere in question cannot always provide acceptable measurements, alternate methods to measure aspheric surfaces must be used.

 Images courtesy of Edmund Optics.

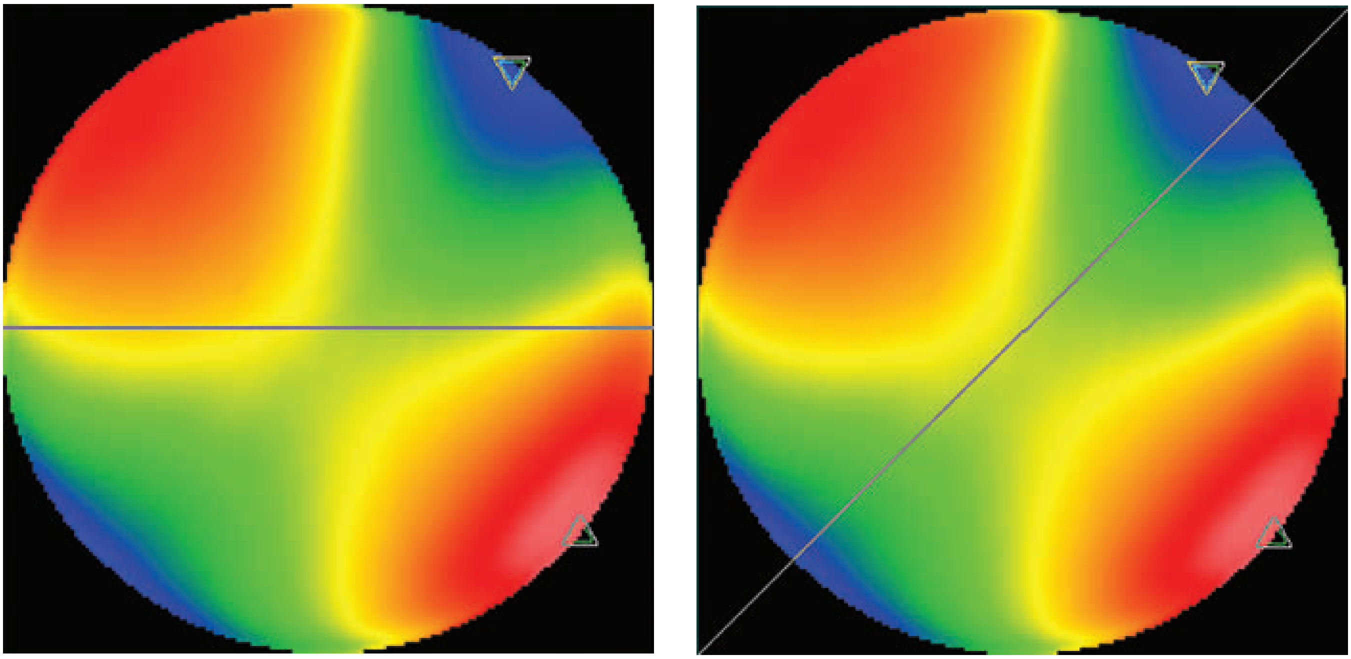


Figure 1. Interferogram with sample 2D traces. **(Left)** Horizontal: PV = 0.790λ, rms = 0.195λ. **(Right)** Diagonal: PV = 1.841λ, rms = 0.546λ. (PV = peak-to-valley, rms = root mean square)

To compare the performance of several asphere metrology methods, as well as the practical aspects of implementing their use in a production environment, consider the following methods:

- **Contact profilometry**, which records the position of a stylus as it traces a 2D path across the surface of a lens.
- **Stitching interferometry**, which combines multiple subaperture interferograms to create a complete, highly accurate map of the optic.
- **Computer-generated holography**, which performs standard interferometry on an aspheric component by using a computer-generated diffractive optical element to convert a spherical wavefront to an aspheric reference wavefront that matches the desired part profile.
- **Chromatic confocal sensing**, which illuminates a surface with a white light point source and senses the wavelength reflected from a surface to perform noncontact profilometry.
- **Multiwavelength interferometry**, which performs distance measurements using several discrete wavelengths to enhance the accuracy of surface reconstruction.

The above metrology techniques are all capable of measuring the peak-to-valley (PV) and root mean square (rms) accuracy

Comparison of asphere metrology with key factors

Metrology Method	Full Surface Map		rms	Flexible Lens Geometry	Measurement Time	Precision	Cost
2D Contact Profilometry		✔	✔	✔✔✔	🕐	✔✔✔	$
Stitching Interferometry	✔	✔	✔	✔✔	🕐🕐🕐	✔✔✔	$$$
Computer-Generated Holography	✔	✔	✔	✔	🕐🕐	✔✔	$-$$$*
Chromatic Confocal Sensing	✔	✔	✔	✔✔	🕐🕐🕐	✔	$$
Multiwavelength Interferometry	✔	✔	✔	✔✔	🕐	✔✔✔	$$$

Source: Edmund Optics

PV = peak-to-valley, rms = root mean square

* Relative cost of computer-generated holography will depend on the variety of designs of measured parts.

of an optic compared to the nominal design. The key things to consider when selecting a measurement method are precision, speed of measurement, cost, and whether the part in question is within the geometrical space that can be adequately characterized by a given technology.

Stylus method suited for ground optics

In contact profilometry, a stylus is physically dragged across the surface of an optic. The other end of the stylus features a diffraction grating. Using the deflection of a laser directed toward the grating, the displacement of the stylus is recorded in a 2D trace. Contact profilometry is ideal for ground optics that do not reflect enough light to be measured with standard interferometry. Because the stylus is in contact with the optic, there are very few limitations to what shapes can be measured in terms of aspheric departure and points of inflection, although very steep slopes may not be measurable.

Contact profilometry has long been the industry standard to measure aspheric surfaces and it is cost-effective, but the method has some serious shortcomings: A single line through the center of a lens will not give an accurate depiction unless the errors in the lens are completely rotationally symmetric, which is rarely the case. This can lead to a misrepresentation of the part in question.

As an example, an interferogram of an actual lens is shown in Figure 1. Two traces are simulated: the first horizontally through the center and the second at a 45° diagonal through the center. Due to the astigmatism and other nonrotationally symmetric aberrations in this lens, the PV irregularity difference in these two values is greater than a factor of two. The rms values are similarly inconsistent. Although it is possible to take multiple traces at different orientations, this is time-consuming and will still lead to large untested areas. In some manufacturing protocols, it is necessary to have feedback on the surface accuracy of a part while it is in process, so that corrections can be made. Three-dimensional data is necessary to locate areas of excess material to be removed with deterministic tooling. In addition, because the stylus is in physical contact with the part, there may be a possibility of damaging softer materials or coatings if too much pressure is applied. For these reasons, it is advantageous to explore asphere metrology that derives its measurements from noncontact 3D surface profiles.

Stitching interferometry is a common method of obtaining a profile of a lens. This method uses standard phase shifting interferometry on smaller subsections of the lens, and then uses software to stitch the pieces together. By gathering interferometric data from smaller subsections, a greater density of interference fringes over the surface of the optic can be interpreted. This is necessary because in addition to the fringes that arise from surface errors, aspheres tested with spherical wavefronts also produce fringes due to their geometrical departure from spheres.

In order to gather these data, one machine uses overlapping circular subapertures to form a complete map. Others may use concentric rings to form the total measurement. The machine is capable of removing its own system errors, so a highly accurate map of the surface can be achieved. Stitching interferometry is often limited by part geometry, and may struggle to measure lenses with large aspheric departure or steep slopes. Some lenses may require in the range of 100 individual subapertures, so measurement times may take upward of 20 minutes per part. It may be necessary to purchase a wide range of transmission elements with different focal lengths in order to accommodate a variety of geometries of the manufactured parts, and base units are costly.

Computer-generated holograms (CGHs) may be used to adapt an interferometer for use with aspheric surfaces. The spherical wavefront from the transmission element of the interferometer is altered by a CGH to form an apsheric wavefront that exactly matches the nominal optic surface profile. This is done by using a computer to fabricate a pattern onto a substrate that diffracts a wavefront to create a null reference wave. The surface accuracy that can be measured may be limited by the transmission element used with the interferometer or by the density of diffractive features that can be manufactured onto the CGH. A new CGH must be purchased for each asphere design, so this is a prohibitively expensive test method except when the same part is made in large volume. Once the CGH is aligned, testing a part can be completed in a few minutes, as only one interferogram is needed. CGHs are not able to test parts that have points of inflection and will not provide accurate data on the radius of curvature of the optic without additional precision location measurements of the test part along the optical axis.

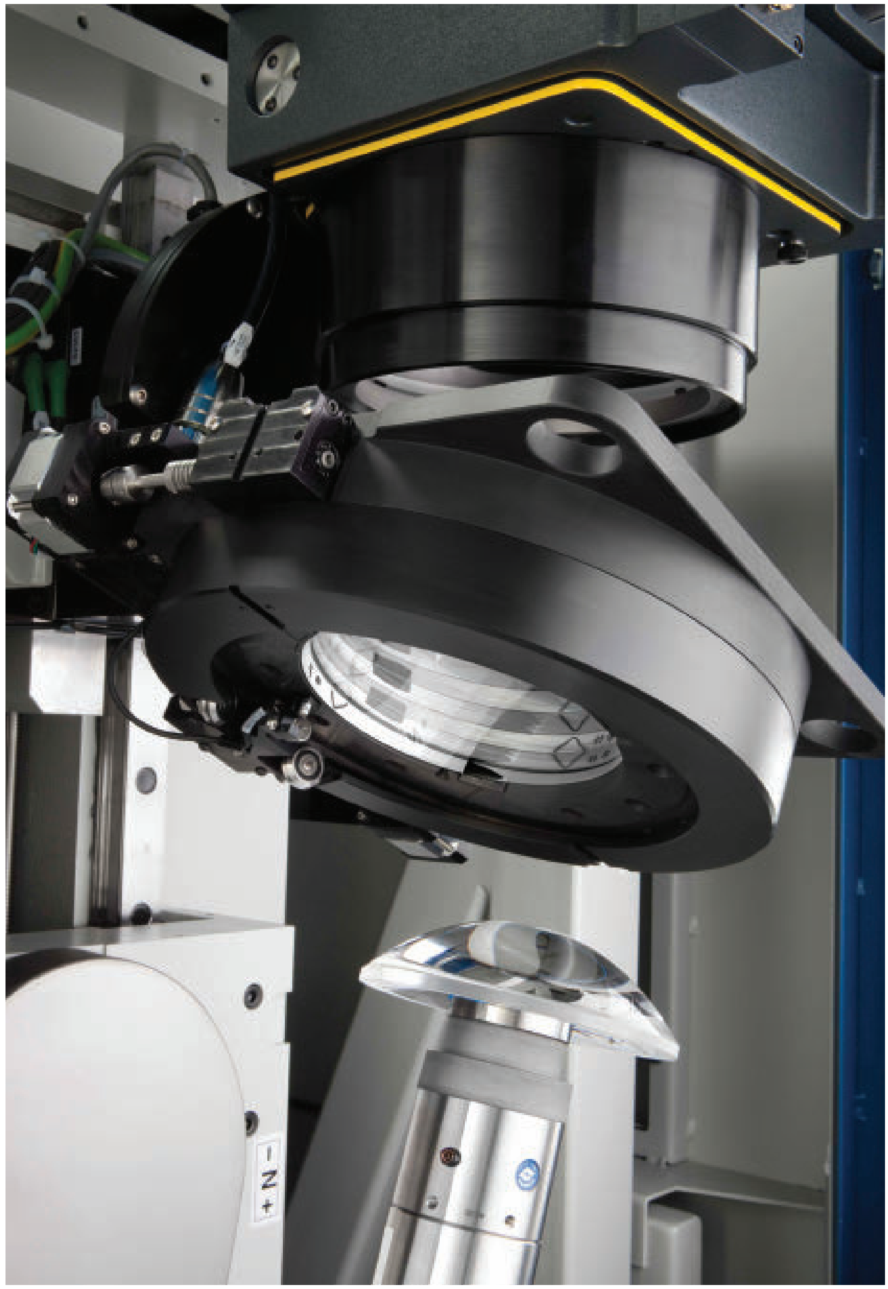
Chromatic confocal sensing uses a chromatic pen that emits white light to take distance measurements. Due to dispersion, which is the difference in index of refraction in a glass based on wavelength, the focal length of an uncorrected lens will vary by wavelength. This causes different wavelengths of light to focus at different axial distances. Usually this chromatic aberration is an error that must be compensated for, but in chromatic confocal sensing, the effect is critical. Based on the wavelength of the light that is focused onto the sensor after it has made a return trip from the pen to the test optic, the distance to the optic can be determined. Chromatic confocal sensing allows great flexibility in the range of shapes that can be measured. Full hemispheres, large aspheric departures, and points of inflection will not pose a problem. Measurement of aspheric parts are likely to take around 20 minutes, and PV accuracies may not be much better than a half of a micron.

Multiwavelength interferometry uses the well-known practice of making length measurements with a single wavelength of light, and adds additional wavelengths to increase the accuracy of the measurement. Current units available have similar flexibility in shape to chromatic confocal sensing, but can achieve accuracies of a full surface to fractions of a micron in 2 to 3 minutes. The flexibility, precision and speed of this method make it appealing if the project justifies a large monetary investment into the machine.

A comparison of the capabilities of the methods of asphere metrology discussed in this article is available in the accompanying table as a guide for selecting a machine based on the primary concerns of the operation.

The use of aspheres continues to grow in applications that have requirements including aberration minimization, high-resolution imaging with fewer optical components, and elements with low f-numbers. Two-dimensional contact profilometry has long been the standard for measuring the surface form of aspheric optics, but as the demand for higher precision aspheres continues, so does the need for better asphere metrology that provides full 3D surface data.

With increasingly tight requirements for asphere surface accuracy, it is important to consider what method of asphere metrology is best-suited to the application at hand.


Stock optics can be customized by size, shape and edges, improving the surface figure or accuracy of the optical surface.

Meet the author

Amy Frantz is an optical engineer at Edmund Optics Inc. in Singapore; email: afrantz@ edmundoptics.com.

For **MEMS Displays,** Projections of Success

Smaller pixels, better optics result in brighter, higher-contrast images from today's MEMS-based displays.

BY HANK HOGAN
CONTRIBUTING EDITOR

When it comes to microelectromechanical systems (MEMS)-based displays, what's old is new — and now the only game in town. The old, and now only, technology involves projectors, which exploit MEMS chips to create images by bouncing light off either an array of tiny mirrors or a single microscopic mirror. Some of these displays are as big as movie screens. Others are small, near-eye displays. Still others are in-between, such as head-up displays in cars.

What are no longer around, at least commercially, are display technologies based on MEMS interferometric modulators and shutters, such as Qualcomm Inc.'s Mirasol and Pixtronix. San Diego-based semiconductor and telecommunications equipment maker Qualcomm quietly abandoned its MEMS-based display efforts in mid-2015 after years of trying to develop a viable business.

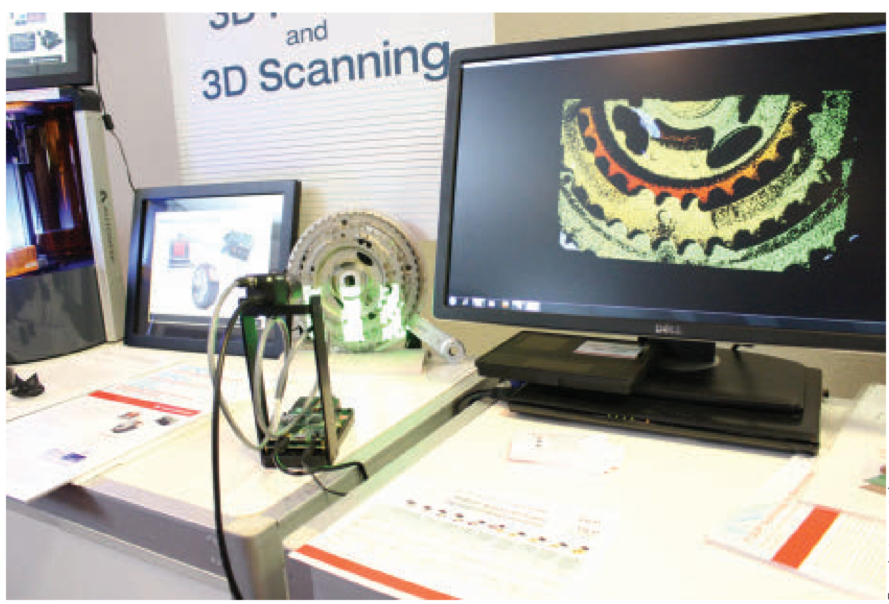
"The main problem was that they compete against LCD flat panels, which have been in huge volume production for a long time. MEMS flat panel displays are much more expensive to manufacture," said Jérémie Bouchaud, senior principal analyst for MEMS & Sensors at market and technology research firm IHS Markit Ltd.

The abandoned technology did create high-quality images, consume little power and work in bright sunlight — all important attributes for mobile applications. In the end, though, the price differential proved too much, Bouchaud said.

Projection technologies, on the other hand, are still going strong, with the mar-

Texas Instruments Inc.

Manufacturing advances have resulted in smaller MEMS feature sizes, which in turn means that projection display chips have gotten smaller.



Texas Instruments Inc.

A MEMS digital micromirror device, camera and other peripherals enables 3D scanning through the use of structured light.

ket forecast to grow from $823 million in 2015 to $1.02 billion in 2019 according to IHS Markit. Bouchaud said that growth will be due to an expansion of picoprojectors. These attach to or are part of a phone, tablet or computer. They create a display on a nearby wall or other surface that can be viewed by a group.

Picoprojectors have been around for years, but their adoption in smartphones has been somewhat stymied by the advent of tablets and phones with bigger screens. Recent advances in resolution and other characteristics of MEMS-based display technology, however, promise to improve the appeal of picoprojectors. Those same developments could help power head-up and near-eye displays.

An example of these improvements comes from Texas Instruments (TI). The Dallas-based semiconductor company debuted its digital micromirror technology, now called DLP technology, decades ago. In the devices, a mirror measuring microns across is attached to a hinge and rotates on demand in response to an electrical signal, allowing individual pixels to be on or off.

Smaller form factor

At one time the cell size was 13 microns. Now it's 5.4 microns, said Kent Novak, senior vice president and general manager for DLP Products at TI.

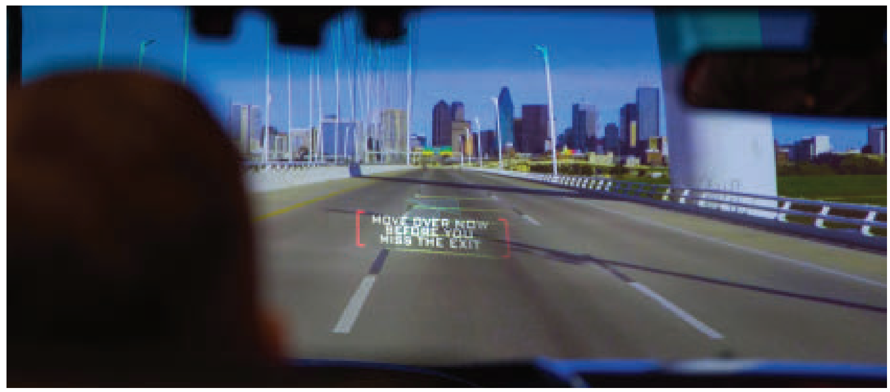
"What that allows us to do is clearly put more resolution inside a smaller form factor. That's one of the enabling technologies," he said.

The smaller pixel size makes it possible to cost-effectively manufacture a 4K chip, according to Novak. This means the resolution of the projected image is roughly 4000 pixels in the horizontal and 2000 pixels in the vertical, a more than fourfold increase over high definition, which comes in at about 1000 pixels in the vertical.

Several other innovations should also contribute to expanding the MEMS-display market. One is an increase in the image intensity, with picoprojector lumens rising from about 8 lumens per watt several years ago to 25 now, leading to an output of up to 1000 lumens. That makes the projected image more readily visible in varied settings.

Another advance is better optics and optical engineering, which together lead to a decrease in the distance between the projector and display surface. It's now possible to put a MEMS-based projector 12 inches away from a wall and then create a 70- or 80-inch image on it, Novak said.

In Texas Instruments' case, a projection display uses an array of millions of micromirrors. A different approach is to use a single MEMS mirror and red, green and blue lasers, with the combination rapidly moving a point through space to trace out an image.



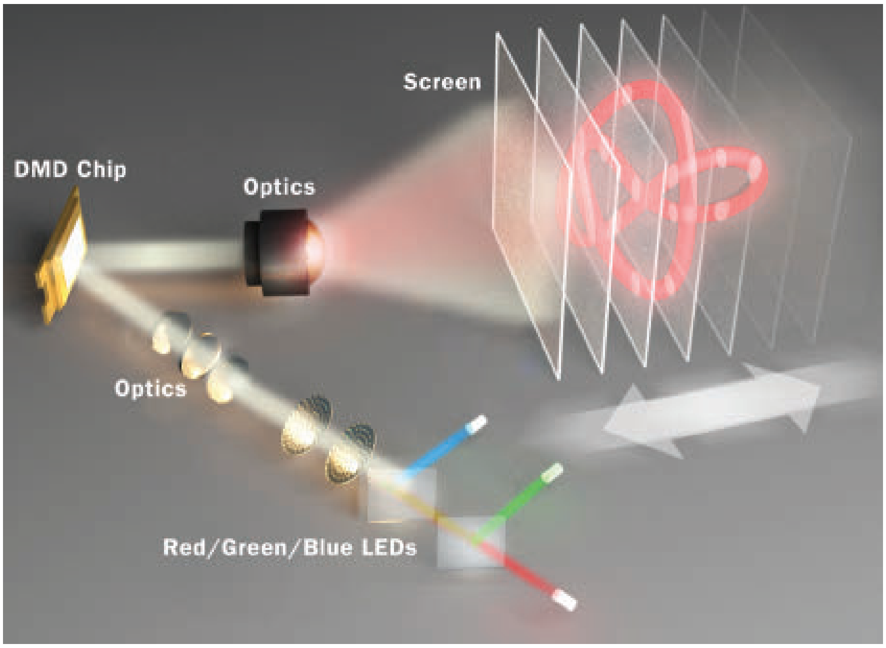
Texas Instruments Inc.

MEMS projection technology powers high-brightness and interactive head-up displays to enhance driving.

MicroVision Inc.

MEMS-based scanning technology enables tabletop projection. Smart projectors with integrated mobile operating systems could allow for interaction with the projected image.

That's the concept behind MEMS-based displays from Redmond, Wash.-based MicroVision Inc. Thanks to faster scanning speed, the company's products have quadrupled in resolution over the past few years, said Dawn Goetter, director of marketing communications for MicroVision. She added that they also have more than doubled in brightness from 15 to 32 lumens, but that doesn't convey the whole story.



Optecks

MEMS-technology can create 3D displays by maintaining image quality over several centimeters in depth.

"By using lasers with the MEMS, the display appears brighter than indicated simply by the ANSI [American National Standards Institute] lumens rating due to the intense contrast ratio of 80,000:1 and wide color gamut. Therefore, the products in the market with our technology are equivalent to LED-based displays with far higher lumens ratings," Goetter said.

She noted that in addition to being used in a display, a MEMS-based technology can also be used for image capture. For example, coupling a red-green-blue laser with an infrared one would enable an image to be projected and interacted with by tracking where and when fingers touch the image.

Extensions of this sensing idea could include extracting three-dimensional information by creating patterns of light and imaging the result. Another use case is spectroscopy. This is possible because micromirrors are highly reflective, and therefore allow the manipulation of light ranging from the ultraviolet through the infrared.

Applications in augmented reality

As for the future, one potential application of MEMS-based displays is in augmented reality. As shown by the Pokémon GO craze, there is a great deal of interest, and possible market, for applications that overlay virtual digital information onto the real world.

Vuzix Corp. of Rochester, N.Y., makes augmented reality products that are incorporated into glasses and elsewhere. According to the company's president, Paul Travers, Vuzix uses different display technologies but finds MEMS-based ones among the best because of their ability to deliver high contrast and brightness.

Augmented reality is already being used to speed picking parts out of a warehouse. A shipper or internet retailer, for instance, may have a large array of packages or products stored in a warehouse. When an order comes in, someone will be dispatched to retrieve the needed items. With augmented reality, the correct item can be highlighted as soon as its barcode is visible and the pick transac-

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tion automatically completed with limited need for user input. Reports indicate savings in retrieval time run 20 to 30 percent, according to Travers.

Another example comes from the world of air conditioning. A large industrial unit will have interlocks to protect the equipment. The knowledge of how to safely bypass these in all situations may only be available after years of hands-on experience. With augmented reality, even new technicians in the field can receive a marked-up real-time video feed detailing exactly how to trip thermal locks and gain access to the innards of an air conditioner in order to repair it in minutes instead of hours.

"That's two hours of downtime saved by connecting the knowledge to do it anywhere, anytime," Travers said.

Other companies are also turning to MEMS-based displays. One such company is Optecks LLC of Tulsa, Okla. An engineering firm, Optecks develops solutions using Texas Instruments' DLP technology. Optecks' recent projects include three-dimensional, near-eye displays, as well as 3D printing and 3D scanning applications, according to Hakki Refai, chief technical officer.

"The increased resolution in MEMS-based displays has significantly opened up the range of applications," he said.

Refai pointed out that the optics design in these projects must account for the working distance, the image size desired, the depth of focus and other factors. Suppose the goal is to produce a large image at a short distance while maintaining image quality over several centimeters in depth for a 3D display application. That calls for particular choices with regard to lens focal lengths and positions of aperture stops, as well as lens shape and size. In contrast, another application may need to create an image at a much larger distance mainly at a single plane, such as projection onto a fixed screen. That calls for a different combination of optical elements.

In addition to near-eye displays, another likely future application of MEMS-based technology is in head-up displays, said Bob O'Brien, president of Austin, Texas-based Display Supply Chain Consultants LLC. For success, the display quality must be good over a wide range of conditions with systems that meet size and cost targets, O'Brien noted.

These head-up displays can be considered a version of augmented reality. By way of illustration, when giving directions, such a setup might include an arrow superimposed over the intersection where a turn should be made.

The possible market in head-up displays could be large and the growth rate high. Today less than a 10th of the 80 or so million cars sold worldwide annually have such a feature, O'Brien said. The situation, though, is expected to change rapidly, potentially benefiting MEMS-based technologies.

"Within five years you could see that going from less than 10 percent to somewhere between 20 and 30 percent having head-up displays. So from less than 5 million to somewhere in the15 to 25 million units per year. So that could be pretty substantial," O'Brien said.

hank@hankhogan.com

Innovation in **Surface Tracking** Opens Doors to Raman Imaging Applications

A new approach to surface tracking continuously adjusts the sample stage height, allowing for high-speed Raman imaging on a wider range of samples than ever before.

BY TIM BATTEN
RENISHAW PLC

Scientists dream of being able to probe variations in the chemical composition and structure of materials without any form of sample preparation. Raman spectroscopy, a noncontact, nondestructive analysis tool that yields information on the chemical, vibrational, crystal and electronic structure of materials at the submicron scale, promises this. The primary hurdle has been keeping samples in optical focus during imaging measurement.

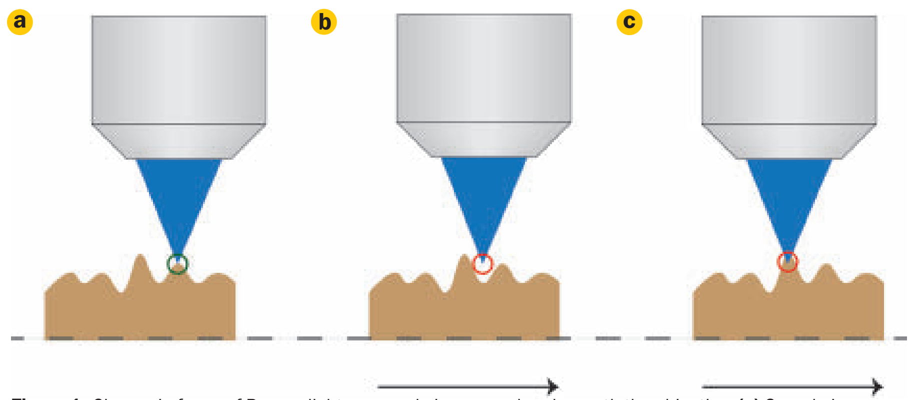


Figure 1. Change in focus of Raman light as sample is scanned underneath the objective: **(a)** Sample in focus, **(b)** focused above sample and **(c)** focused into the sample. In all cases, the sample volume probed and the Raman intensity will vary.

Most commercial Raman systems use an objective lens to focus laser light onto a sample and to collect the Raman scattered light. One of the key strengths of Raman is that it does not require any sample preparation; provided the laser can be shone on the sample, data can be collected from it. This allows Raman measurements to be conducted on both liquids and solids, on macroscopic and microscopic objects, through glass windows and into reactors.

In the last decade, advancements in instrument and laser technology have significantly increased the speed of Raman spectroscopy, allowing large area Raman imaging (or mapping) to become routine. These measurements are conducted by moving the sample using a motorized stage and taking an array of Raman spectra at regular intervals. An image is then generated by applying a metric to these spectra, for instance the intensity of a Raman band, and then turning the data into a false color image.

Rapid Raman imaging is now used in a wide range of applications, with people

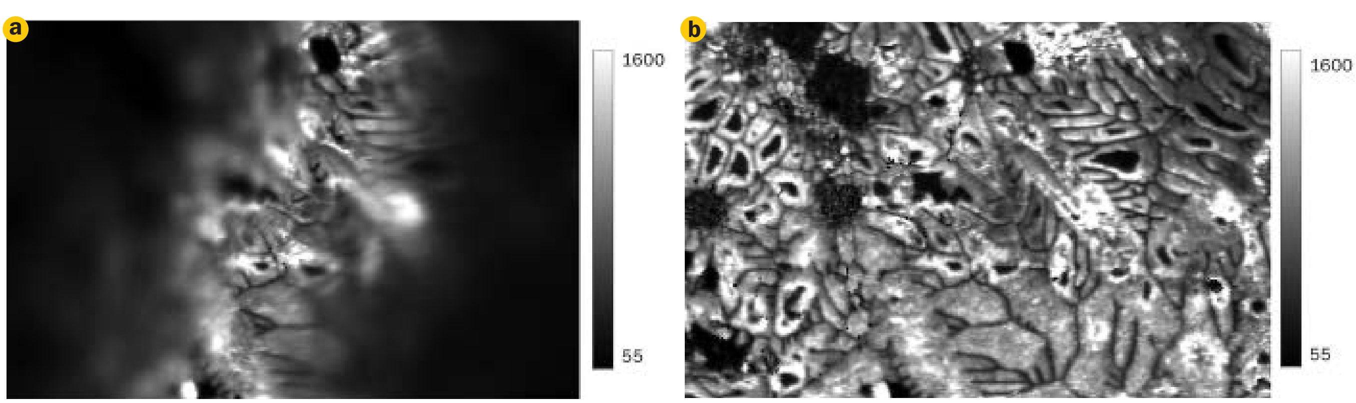


Figure 2. Raman images illustrating the intensity of the graphene 2D band collected from a sample of graphene on copper. **(a)** Due to the change in height across the sample, only a strip at the center of the image is in focus. Further from focus, the image becomes blurred, obscuring the morphology. Finally, no Raman signal is returned, resulting in complete loss of information. **(b)** The same area collected using LiveTrack. Here the sample height is adjusted during measurement to ensure that all Raman spectra are collected in focus, allowing accurate Raman information to be collected and enabling the full morphology to be seen.

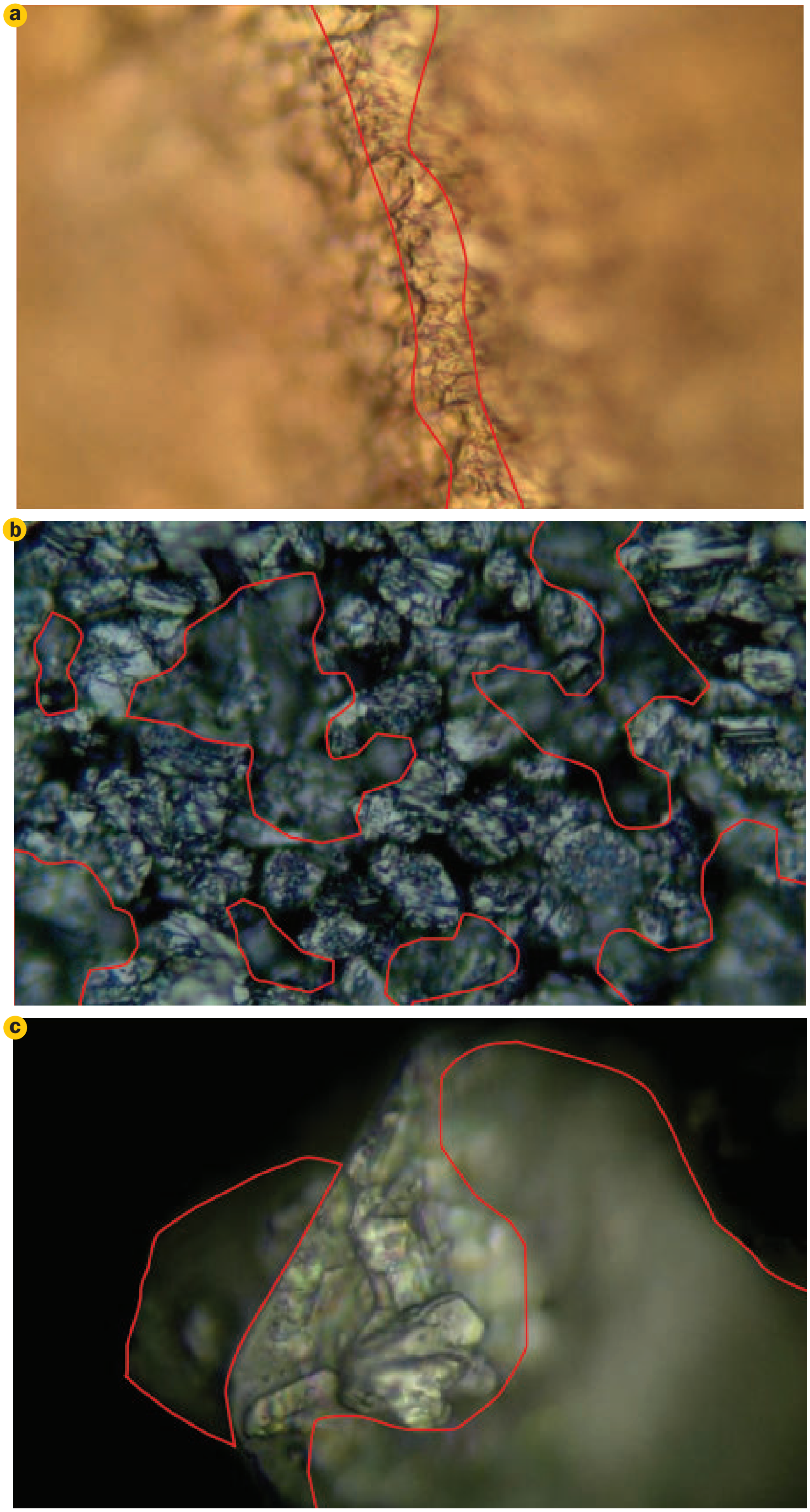


Figure 3. Optical images of **(a)** a tilted sample (graphene on a metal foil), **(b)** a rough sample (electrode from lithium ion battery) and **(c)** a sample with complicated surface geometry (a crystalline powder, l-cysteine).

imaging everything from 2D materials to teeth. This has created a new challenge: To collect accurate Raman images, it is vitally important to maintain the focus of the laser on the sample. This focus dictates the illumination of the sample with the Raman laser and the collection of Raman scattered light.

During Raman imaging the sample is scanned under the microscope and, if the sample has any variation in height, it will move in and out of focus (Figure 1). Any deviation from the true focus will decrease the amount of Raman light collected from the sample, increasing the required measurement time. As focus is lost, the volume from which the Raman scattered light is collected changes, potentially resulting in a loss of spatial resolution. In a worst-case scenario, the sample can be so far from focus that no Raman signal is collected and all the information is lost (Figure 2).

Removing 'tilt' is an arduous task

Ideally, all samples would be flat, but this is rare. Even the simplest sample, such as a silicon wafer, may have some inherent tilt when placed under the objective. While insignificant over small length scales, over tens of mm this will mean the sample will go out of focus when using a high magnification objective. In this case, the theoretical solution is simple; remove the tilt by adjusting the sample so it lies perfectly perpendicular to the microscope objective. In practice this can be very challenging depending on the precision required. For instance, removing a tilt of a micron per centimeter is an arduous task.

Samples are often tilted, rough or have complicated geometries, which makes keeping them in focus when collecting Raman images difficult. Optical images of different examples of these types of samples are shown in Figure 3.

One option to image these samples is to replace the objective lens with one that has a larger depth of field, allowing the focus to be maintained over a greater range of sample heights. This typically means reducing the numerical aperture (NA) of the lens, but this has its own drawbacks. The measured Raman intensity is proportional to the NA^2, ensuring measurement times will be longer. The lateral spatial resolution is inversely proportional to the NA and the axial spatial resolution NA^2, so the collection volume will be larger and the resolving power will be worse. In effect, changing the objective lens will increase measurement times and provide lower resolution data, but will remove any artifacts caused by poor focus.

Really difficult samples such as minerals or pharmaceutical tablets need to be mounted, sectioned and polished to ensure they are suitably flat. Any modification of the sample is extremely undesirable, as there is always a risk this preparation can affect the chemical composition of the sample. Worse still, some samples may be priceless and as such cannot be modified.

As neither of the discussed solutions is ideal, Raman spectrometer vendors have produced proprietary systems to maintain sample focus when imaging. These can be broadly separated into two categories:

- Prescan methods that determine the sample topography before Raman data are collected. During the Raman measurement the surface is fed into the

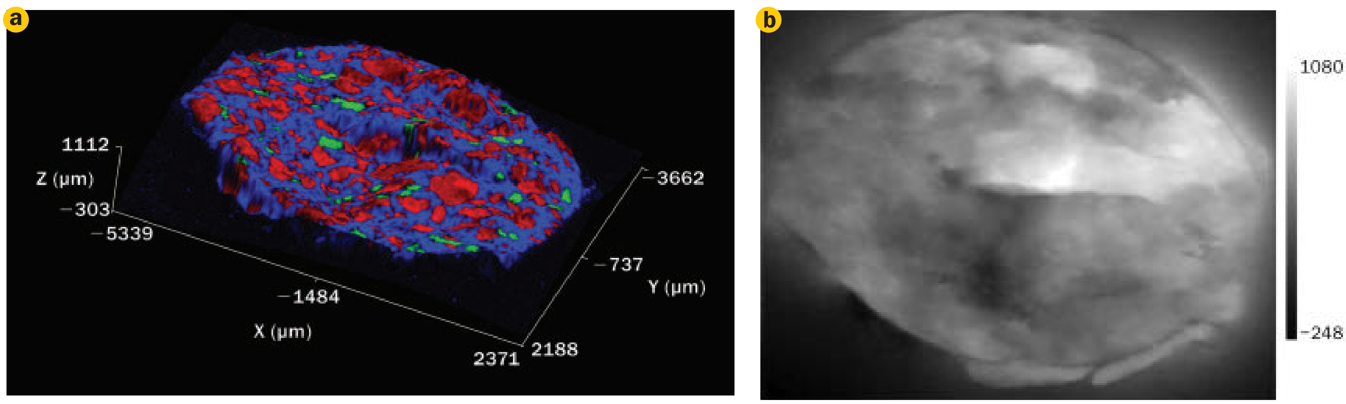


Figure 4. Raman image of an over-the-counter analgesic tablet **(a)** illustrating the distribution of acetaminophen **(blue)**, aspirin **(red)** and caffeine **(green)** within the tablet. Topography image **(b)** of tablet collected by LiveTrack.

Comparison of existing surface tracking techniques

Method Type	Method	Details	Tilt	Rough	Complex
Prescan	Manually define the sample surface.	Typically this involves defining a range of positions corresponding to a good sample focus and letting the software interpolate between them. This is adequate for simple surfaces, but for complex surfaces it may not be very accurate. In the case of rough surfaces, it is very time-consuming and effectively impractical.	✔	✗	✗
Prescan	Determine the topography of the sample using a different technique.	This involves measuring the sample using an optical profilometer or an atomic force microscope (AFM) and then feeding the surface coordinates into the Raman measurement. This works well but requires the sample to be moved between the topography measurement and the Raman measurement, and as such, registration must be accurate. The lateral resolution of this technique is not always good enough for rough samples.	✔	?	✔
Active	AFM Tracking	The most accurate way to maintain focus is to use a Raman AFM system. This is achieved practically by focusing the objective on the end of the AFM tip and scanning the sample underneath the tip. This technique, while accurate on the nm scale, suffers from a limited range of travel due to the piezo stages employed in AFM (typically 100 × 100 × 10 µm), making it unsuitable for large, complex surfaces. It is also an expensive option as it requires a dedicated AFM instrument.	✔	✔	✗
Active	Intensity-based focus method	For this technique the intensity of the Raman laser light scattered from the sample is used to gauge the quality of focus; the focus is then optimized. This can be done using either the raw intensity or by fitting a centroid to the reflected image. This technique cannot determine the optimal focus until it has passed through it. As a result, it is often too slow to use with high-speed Raman imaging.	✔	✔	✔

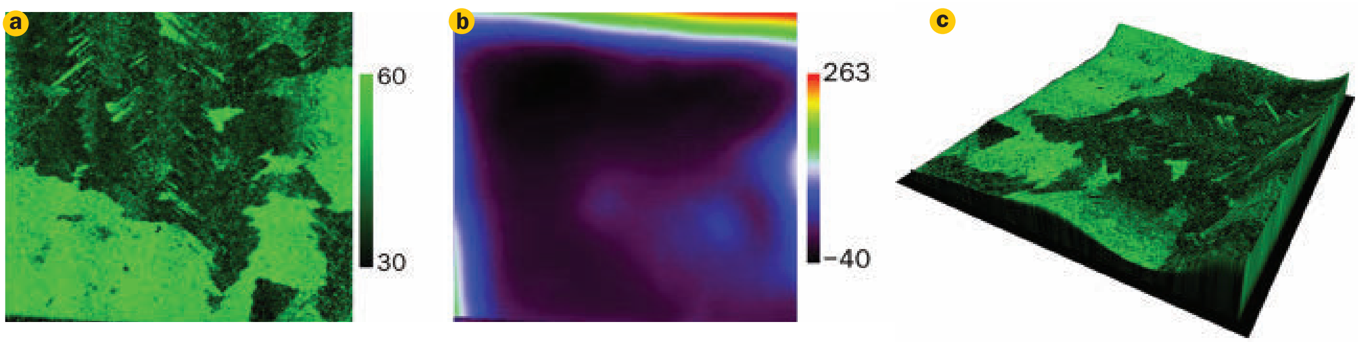


Figure 5. Raman image **(a)** of large area of graphene on copper, illustrating the width of the 2D band, which allows empirical determination of the number of graphene layers present, **(b)** topography image of the sample, and **(c)** Raman image overlaid on topography (Z-scale exaggerated to illustrate the undulating surface).

software to adjust the height of the sample at each point. If the sample changes during measurements, the collected surface will not correspond to the true surface and focus may be lost.

- Active methods in which a feedback technique is used to determine if the sample is in focus. Corrections are made either immediately before or during the Raman measurements at each point.

More detailed discussion of these techniques is made in the accompanying table.

Adjusting sample stage height

Renishaw PLC has recently released an innovative surface tracking technology called LiveTrack that takes improvements in autofocus technology from other fields and applies them to Raman spectroscopy. The technology employs a closed loop system, using optical feedback that continuously adjusts the sample stage height to maintain perfect focus on the sample during Raman measurements and when viewing the sample optically. Being able to browse the sample optically and not worry about manually maintaining focus makes it easy to locate and define regions of interest for Raman imaging. LiveTrack itself runs in parallel with Raman measurements and does not contribute to the measurement time. The feedback is directional and is sufficiently fast that it is compatible with high-speed

Raman imaging, allowing Raman imaging to be applied to a wide range of samples that would not have been practical in the past.

One such example is the use of Raman spectroscopy for assessing the distribution of the active components in pharmaceutical tablets. Figure 4 shows data from an over-the-counter analgesic tablet snapped in two so that the cross section can be measured. Snapping the tablet has resulted in a very rough surface, with height changes on the order of 1 mm. The measurements shown (Figure 4) would be impossible without the new technology and it would be necessary to modify the sample, in this case polish it flat, risking contamination or chemical modification. Figure 4a shows the distribution of acetaminophen, aspirin and caffeine within the tablet overlaid on the determined surface of the tablet. The topography information, shown separately in Figure 4b, is obtained by recording the height of the stage at each Raman measurement point, effectively using LiveTrack as an optical profilometer.

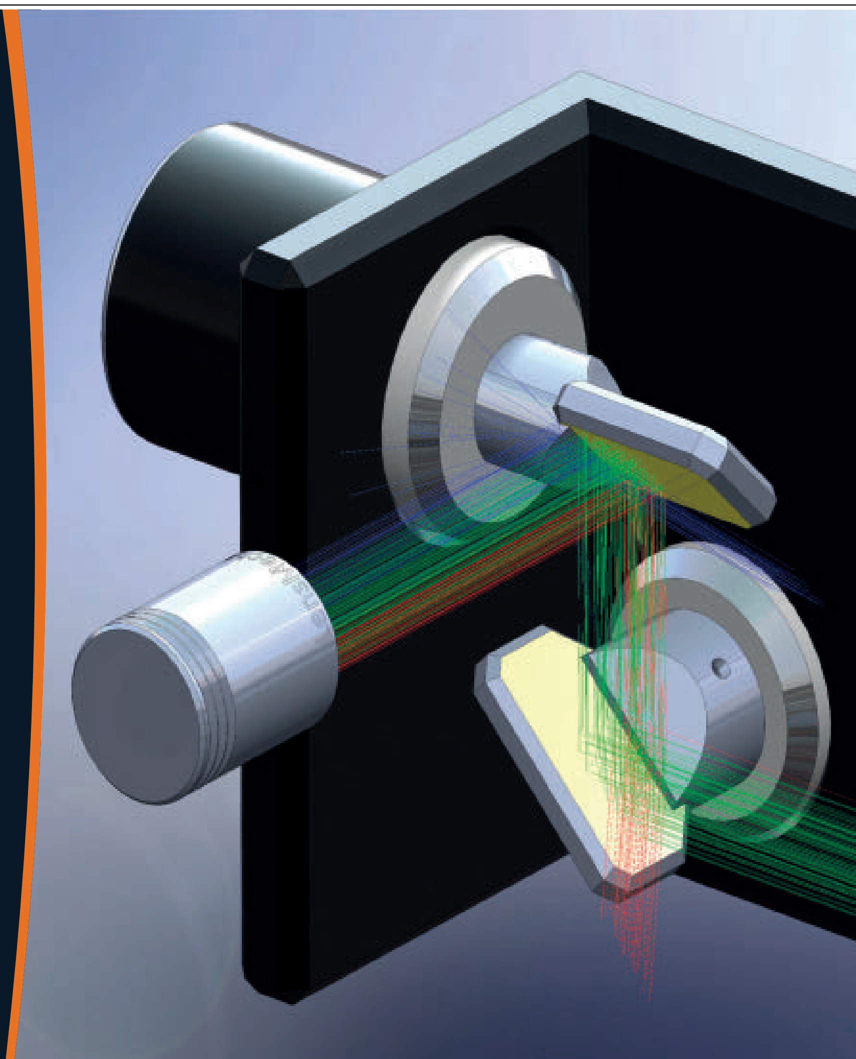
Another use comes with the analysis of graphene, which has demonstrated huge potential in a wide range of technologies, from electronics to composites. However, for this potential to be realized, improvements must be made to enable the growth of high-quality, large-area material. Industrial production of graphene is already underway with some companies growing material over large areas (more than a square meter) on copper foils. It is hard to maintain quality over these expanses; the material can become highly defective and may consist of multilayer regions.

Raman spectroscopy is the go-to technique for analyzing graphene as it can quickly provide comprehensive information on quality and the number of graphene layers. Unfortunately, graphene on copper is hard to analyze over large areas as the foils are never flat; they undulate, causing the graphene to go in and out of focus during Raman measurement. Figure 5 shows a large-area measurement of such a sample. Here, the surface height variation is about 150 µm, orders of magnitude higher than the depth of the field of the objective used (0.4 µm). The Raman image illustrates the change in width of the 2D band, which can be linked to the number of graphene layers present, in this case varying from single to multilayer.

Improvements in focusing technology have removed some of the intrinsic limitations of rapid Raman imaging, allowing it to be applied to a much wider range of samples while avoiding any sample preparation. This opens up a variety of new applications, in particular those linked to quality control applications. Advanced focus tracking adds an additional level of automation to Raman systems, allowing even novice users to collect highly accurate Raman images.

Meet the author

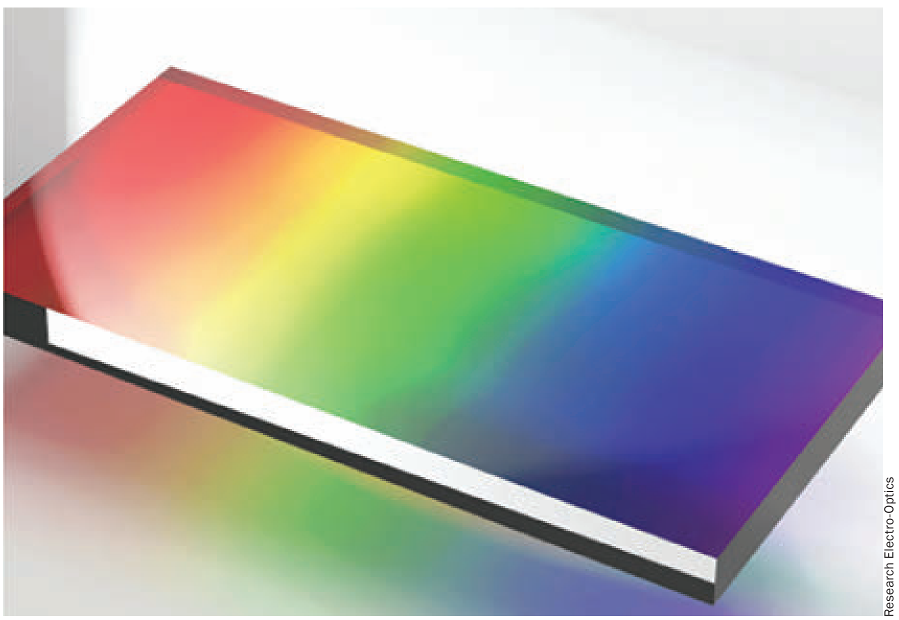
Tim Batten is senior application scientist at Renishaw PLC. He has more than 10 years' experience in Raman spectroscopy, and specializes in the application of Raman spectroscopy to material systems, carbons, 2D materials, semiconductors, etc.; email: tim.batten@renishaw.com



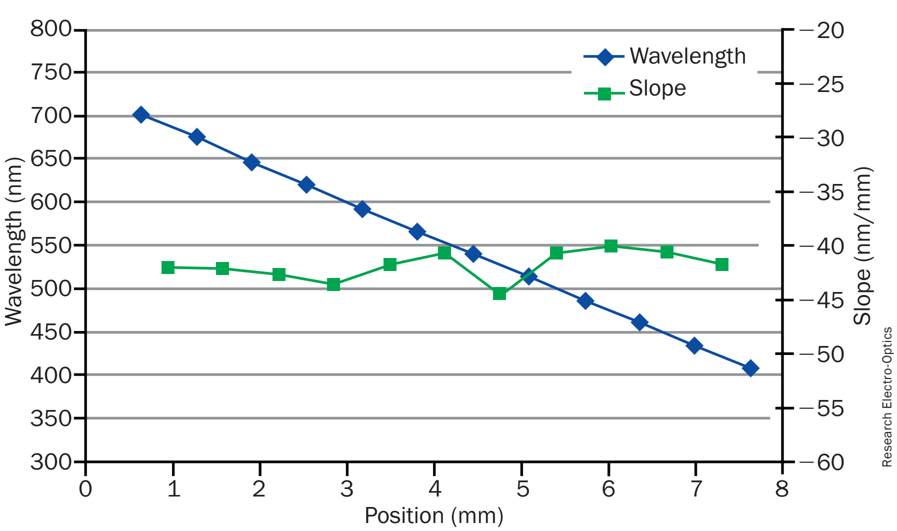
For Compactness and Ruggedness, **Linear Variable Filters** Fit the Bill

Innovations in design and scalable manufacturing have led to the development of linear variable filters that cover a broader wavelength range than ever before.

BY TREY TURNER, ERIC BALTZ and ROGER KIRSCHNER
RESEARCH ELECTRO-OPTICS INC.



Example of a linear bandpass filter.



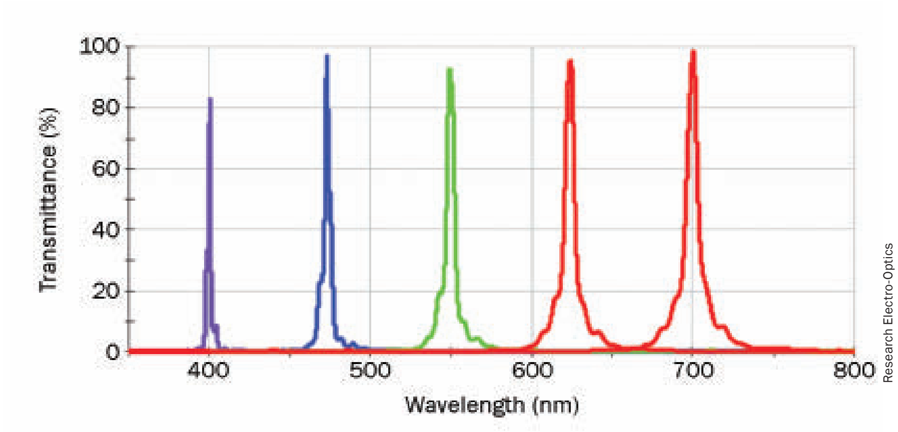
Typical linear variable filter center wavelength and slope vs. filter position.

Spectroscopic optical applications have conventionally utilized dispersive elements such as diffraction gratings and, less commonly, prisms to separate light into its constituent wavelengths for spectral interrogation. Gratings have the advantage in that a wide range of dispersion levels is made available by adjusting the grating pitch, and they can be used in ways that are light-efficient. However, as they disperse the light as a function of angle, they intrinsically require a fairly complex geometry and a relatively large footprint to allow the dispersion of light across a detector. For applications where light intensity is not of concern but compactness, ruggedness and low cost are desired, linear variable filters have become an attractive alternative.

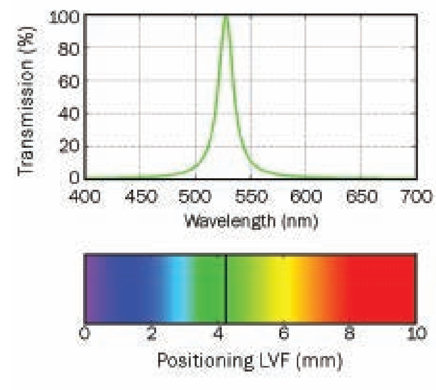
Linear variable filters have optical properties that change spectrally as a function of position on the physical surface of the filter. In principle, virtually any spectral characteristic can be designed in a way that allows it to vary smoothly across the surface. In practice, the most common and useful devices are bandpass filters, longpass filters and shortpass filters. The manufacturing process involves varying the filter's many thin-film layer thicknesses along the length of the filter's surface. As the layer thicknesses increase, the filter's spectral characteristics shift to longer wavelengths.

Limited by wide blocking range

Variable filters have been available in one form or another for many years, including radially variable filters, such as gradient reflectivity mirrors for shaping laser output, and radially variable neutral density filters for shaping the radial intensity profile of a beam. Linear and



Linear variable filter design spectra vs. wavelength indicating change of bandwidth.



Spectral scan and relative scale available for linear variable bandpass filters.

annularly variable neutral density filters have been commonly used as straight forward adjustable attenuators. Until recently, how-ever, linear variable filters have been limited in their application because the under-lying deposition technology did not allow for the production of complex filter characteristics such as very wide and deep blocking ranges. They have also been fairly expensive to manufacture, since the manu-facturing technology has not been highly scalable.

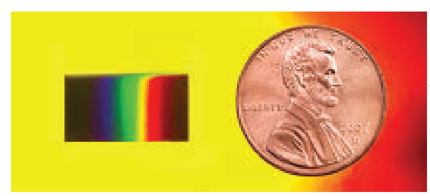
Conventionally, variable filters have been produced by tilting the substrate at an angle during deposition. This process has two limitations. First, as each filter must be individually tilted but otherwise located in the same plane, it does not allow for filters to be replicated across a substrate. Second, there is a maximum filter slope that can be achieved, which is fundamentally limited by the geometry of the deposition process.

Thin-film application using ion beam sputtering can be controlled using proprietary plume-shaping technology, which has solved these limitations and made possible filters that provide exceptionally wideband operation in a footprint as small as 1 × 3 mm — creating the potential to produce such filters directly on detector substrate wafers for high-volume applications. Users also benefit from the other well-known advantages of ion beam sputtering, such as low scatter and exceptional environmental stability.

Design trade-offs

When specifying a linear variable filter, it is important to consider certain design trade-offs. The key parameters used to specify linear variable bandpass filters are slope, wavelength range (or filter length), blocking optical density, pass band width (usually specified as full width half maximum, or FWHM) and transmission level. There will typically also be tolerances on the slope, linearity and FWHM. The FWHM will be a constant fraction of the center wavelength, meaning that the absolute width, as expressed in nm, will vary across the filter. For example, a visible range (400 to 700 nm) filter specified with a FWHM of 1.5 percent will be 6-nm wide at the 400-nm end and 10.5-nm wide at the 700-nm end (see top left).

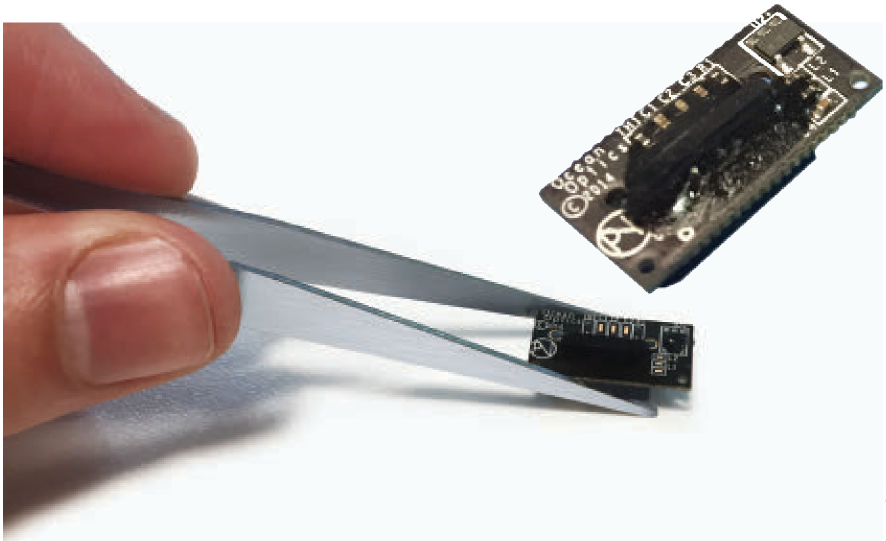
Very small filters from REO's VariFi (linear variable filter).



Transmission bandwidths of <1 percent and linearity requirements of ±1 percent are feasible over a 400- to 700-nm band. The bandwidth specification should take into account the pixel size, as it is desirable to overfill the pixels to achieve the highest spectral resolution (which can, for some applications, be higher than the resolution derived solely from the pixel density). For a broadband source, the amount of light transmitting through the filter will also depend on the FWHM, so care should be taken to ensure that it is not specified as too narrow to achieve the desired signal level.

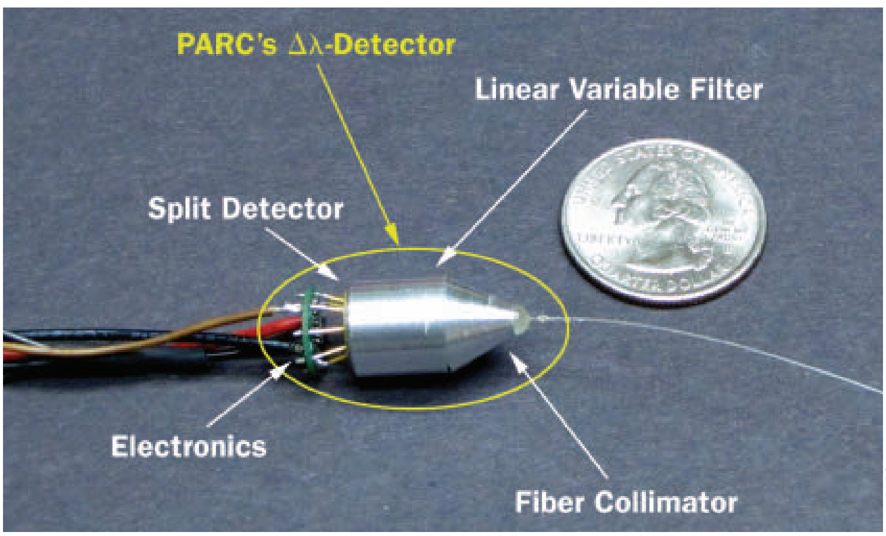
Linear variable bandpass filters can be designed to address various regions of spectral interest from the UV to the mid-IR. The chart on the opposite page provides a few example bands and linear variable filter performance parameters.

The practical limit on the range of a linear variable filter is determined by a number of factors including the required blocking depth and the wavelength band (UV, VIS or IR). In general, deeper blocking will require more layers to achieve, so given a fixed total film thickness, there is



Ocean Optics

Examples of a minispectrometer and components.



Xerox PARC

Micro-wavelength sensor.

a basic trade-off between the wavelength range and the blocking depth. Filters designed for longer wavelengths (IR) will use materials with higher refractive indices and higher index contrast so that deeper blocking can be achieved with fewer layers, but the layers are thicker (roughly constant fraction of the wavelength). In practice, the maximum achievable range will be 0.45 to 0.55 times the center of the range. For example, a filter centered at 550 nm can have a total range of about 300 nm.

High-volume measurements in minispectrometers

Linear variable filters have been incorporated into compact wavelength monitors and used in spectroscopy, gas analysis, environmental sensors, lidar and biomedical instrumentation.

One of the widest applications for the linear variable filter is in minispectrometers. A standard spectrometer has the basic components of a grating, either transmissive or reflective, and a sensor, usually a linear CCD or CMOS array. The resolution of this configuration is usually very good for most applications; however, the use of a grating requires space to enable the spectrum to separate. It also has the disadvantage of being affected environmentally by temperature changes due to mechanical movement. Alternatively, a three-color red/green/blue (RGB) filter combined with diode detectors can be small and inexpensive, but lacks the necessary resolution for many applications.

A minispectrometer with a linear variable bandpass filter mounted directly onto a linear CCD or CMOS sensor provides a compact, higher resolution device with inherent environmental stability. Several factors limiting standard spectrometers, especially physical size, are addressed with this approach. A linear variable filter/linear detector combination enables high-volume measurement in handheld or smaller sensors. Applications for these small higher-resolution sensors include absorbance, emission and fluorescence. Unlike 3-element RGB diode sensors, the entire spectrum of interest is measured with higher resolution.

Research Electro-Optics (REO) Inc.'s fabrication technology enables the manufacture of extremely small filters that can be below 1-mm physical dimension and allows the fabrication of linear variable filters as small as 1 × 3 mm on wafer-sized substrates.

Hyperspectral imaging and wavelength sensors

Linear variable filters can be applied to 2D detectors to produce a compact hyperspectral instrument for the UV to near-IR spectral range. The resultant advantages for these systems compared to classical grating-based systems are a very large aperture, excellent transmission, fast measurements, stray light suppression and very good signal-to-noise ratio, which enables short measurement times.

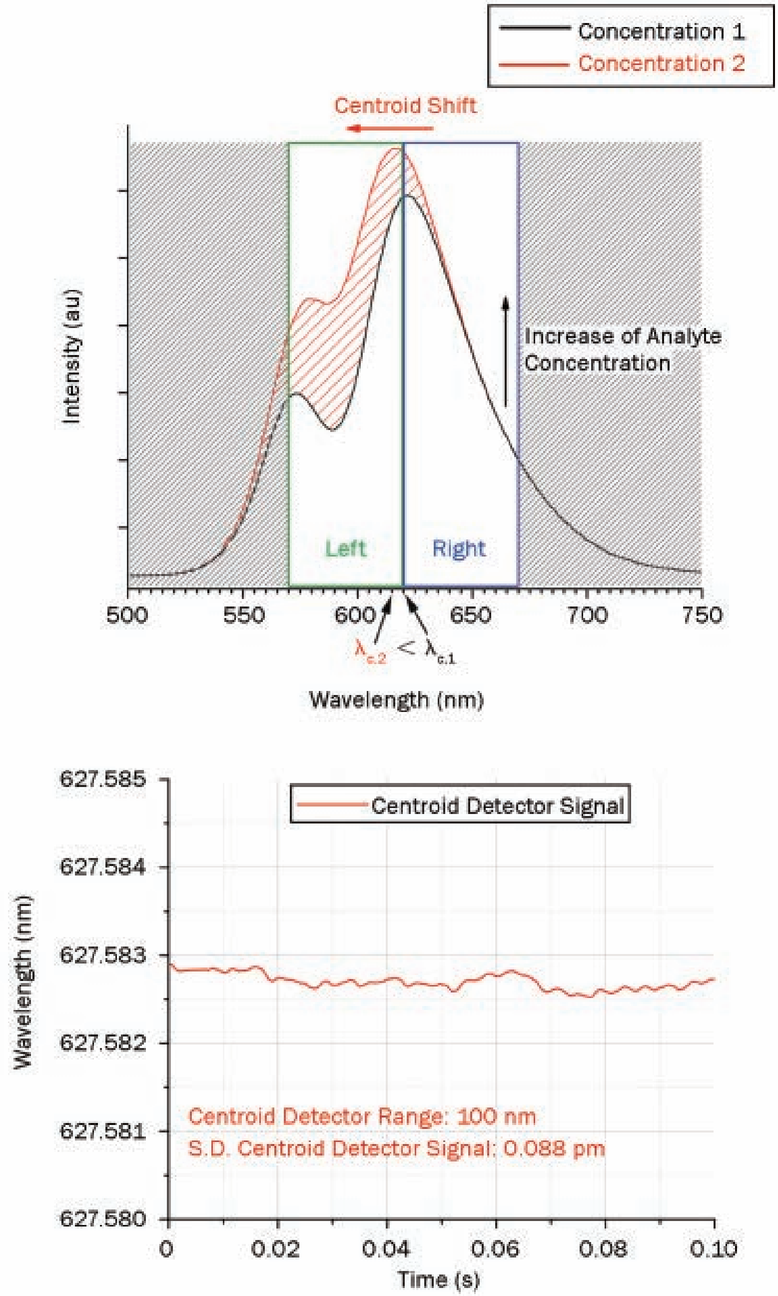
The combination of these very small linear variable filters and position sensors enable new, very accurate and low-cost wavelength sensors. Peter Kiesel, principal scientist at Palo Alto Research Center Inc. (PARC), a Xerox company, has invented a technology that can measure wavelength variations with sub-picometer resolution. It combines photodetector position sensors with a linear variable bandpass filter that converts spectral wavelength into an intensity distribution on the position sensor. A centroid calculation of the intensity distribution provides the very accurate wavelength information.

This advance has applications in remote sensing, fiber sensors, crystal sensors, laser cavity and compact spectroscopy sensors, and wavelength monitors. The initial development of this technology focused on interrogating wavelength-encoded optical fiber sensors such as fiber Bragg grating sensors. The initial prototype (see sensor image opposite page) demonstrated the ability of this technology to resolve optical wavelength shifts as small as 10 fm at 10 Hz in the C-band, which is substantially better than the state of the art. More recently PARC has demonstrated that this same concept can be used to monitor extremely small (sub-picometer) wavelength changes of the centroid of broad band light sources. This would be applicable in the monitoring of LEDs or SLEDs (superluminescent diodes) or the readout of colorimetric sensors (see right).

Advantages for space-based applications

The physical size and environmental advantages of using linear variable filters have significant application for instruments used for space and planetary instruments. Some of these include looking for organics, water-altered materials and minerology, and for doing Raman or laser-induced breakdown spectroscopy.

Advanced manufacturing technology has created the potential for new applications for linear variable filters. REO's scalable manufacturing method enables submillimeter-sized filters, which can be cost-effective for new areas of application including minispectrometers, remote sensing, compact wavelength and laser monitors, fiber sensor interrogation, and more.



Xerox PARC

Xerox PARC's sub-picometer (pm) measurement of broad light sources.

Meet the authors

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A video of a scan of a representative linear variable bandpass filter design illustrating the change in the transmission spectrum as a function of position along the filter's 10-mm length is available on the web version of this story: **www.photonics.com/A60941**.

Testing the Limits of **Excimer Lasers**: Annealing for Advanced Displays

Mass production of high-resolution displays utilizes ever-larger substrate panels, placing unique demands on the excimer laser systems used in their production.

BY RAINER PAETZEL and RALPH DELMDAHL
COHERENT INC.

Excimer lasers enable high-volume manufacturing of flexible displays; a key step is laser lift-off where high-duty cycle excimer lasers are used to release the flexible displays from a rigid temporary carrier.

High-power scaling for large format poly-Si annealing shown here with two dual-oscillator VYPER lasers, with all four beams merging into a 1300-mm length processing beam.

Low-temperature polycrystalline silicon (LTPS) is increasingly used as the thin-film transistor material on the glass backplanes of high-performance displays, particularly for smartphones. These thin films are fabricated on large glass panels that then are singulated into hundreds of individual screens. Mass production of LTPS on these panels is uniquely enabled by excimer lasers, moreover excimer lasers with extremely high pulse energies. These high pulse energies are needed in order to reach the requisite high process threshold intensity over a large area.

There is a fast-growing interest in extending LTPS to process larger area panels for several reasons: greater economy of scale, better and brighter mobile LCD screens, and the adoption of active-matrix organic light-emitting diode (AMOLED) smartphones and tablets. But as processes evolve to support ever-larger panels, new requirements are placed on the ultrapowerful excimer systems and the associated beam delivery and beam shaping optics used in the process. In what follows, the authors examine why excimer systems (laser, optics and internal diagnostics) are using modular architecture to deliver higher and higher energies with improved pulse-to-pulse stability and beam uniformity. For display manufacturers this means faster process throughput (screens per minute) and even better process consistency.

Polycrystalline silicon vs. amorphous silicon

The backplane of both active-matrix liquid crystal displays (AMLCDs) and AMOLED displays can be regarded as a type of large-scale integrated circuit, which starts as a 50-nm-thick film of amorphous silicon deposited on a thin glass sheet. For both display types, this is transformed into a

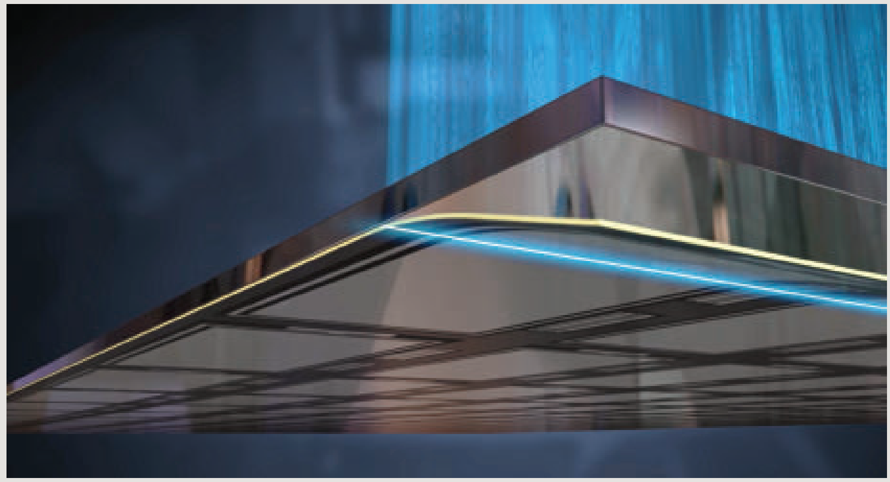
Images courtesy of Coherent Inc.

Adapting Laser Lift-Off Technique for Flexible Displays

Excimer lasers optimized for high-energy pulses have applications beyond annealing low-temperature silicon, including mask-based direct patterning of microcircuits for cost-sensitive applications like medical disposables, where every year 20 billion disposable sensor circuits are created in thin metal on a flex substrate in a reel-to-reel process. Another is laser lift-off for next-generation flexible displays.

Laser lift-off with ultraviolet lasers is well-established in microelectronics. As an example, consider blue laser diodes, where the circuitry has to be created on, then removed from, a durable carrier substrate such as sapphire. The challenge with flexible displays is the sheer size of the product, which is hundreds of times larger than a typical IC chip and needs correspondingly higher laser power to complete the lift-off in an economically practical time.

In flexible display production, a glass panel that serves as temporary carrier for handling purposes is first coated with a polymer film. Display circuitry is then created on top of this layer. Finally, laser lift-off accomplishes the transition to full flexibility by passing an excimer laser beam (one pulse per area) through the glass carrier and vaporizing the top few atomic layers of the polymer. With the appropriate excimer laser line beam system, a Generation-4-size glass carrier (730 × 920 mm) containing 60 five-in. flexible displays is rapidly and gently separated applying only a few thousand laser pulses within seconds.



The transition from rigid to flexible display manufacturing is accomplished by separating the glass panel using an excimer laser line beam.

network of thin-film transistors (TFTs) to enable each subpixel (red, green or blue) to be individually addressed.

Solid silicon can exist in three forms: single-crystal silicon, amorphous silicon (a-Si) and polycrystalline silicon (poly-Si). In single-crystal silicon, all the atoms are arranged in one giant, extended regular lattice. Large area, single-crystal silicon — as used in integrated circuit (IC) chips — is neither economically viable nor necessary for display applications. Rather, a-Si or poly-Si is used.

In amorphous silicon, the atoms are irregularly located with a high degree of disorder, resulting in the lowest electron mobility. In polycrystalline silicon, the atoms are arranged in microcrystals or grains, with discontinuities between the grains. The atoms can be highly ordered at the microscopic level, for instance, but disordered at the macroscopic level. This type has intermediate electronic properties, with the electron mobility and other parameters being highly dependent on the grain size and degree of order (e.g., grain size uniformity).

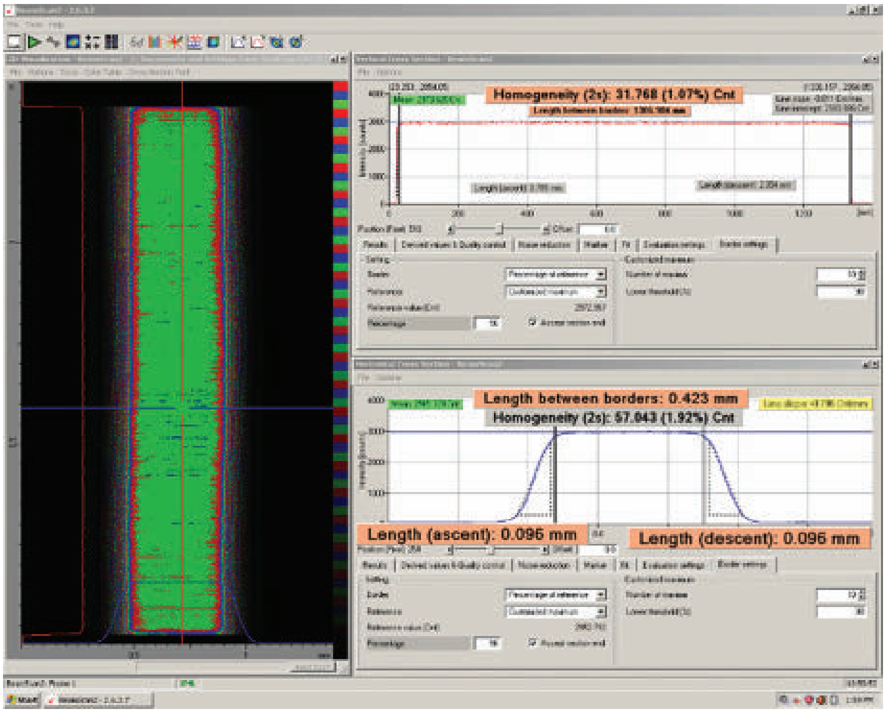
For AMLCD, the choice is a trade-off between performance and cost: The higher electron mobility of poly-Si maximizes circuit efficiency, enabling smaller area TFTs and narrower circuit traces. Reducing the size of these backplane components minimizes blocking of the backlight (which passes through this circuitry), making the display more efficient. In fact, poly-Si is key when it comes to AMLCD with a pixel density of more than 300 ppi. This holds true for most of today's smartphones, where the smaller screens and short viewing distances necessitate higher pixel densities (between 400 and 900 pixels per inch) to provide a crisp and brilliant appearance of the screen. Plus, electrical efficiency is even more critical in portable devices as it directly influences battery life.

AMOLED pixels emit light directly, so there is no backlight to block with control circuitry. However, stable, low impedance control circuitry is critical because each pixel draws current, making electron mobility and TFT current stability even more important for these displays. This makes poly-Si the only choice, and it is hence used for all small- to medium-sized AMOLED displays.

As processes evolve to support ever-larger panels, new requirements are placed on the ultrapowerful excimer systems and the associated beam delivery and beam shaping optics used in the process.

Reshaping the output beam for a narrow profile

When silicon is vapor deposited on the glass backplane, it naturally assumes the amorphous form. High-temperature annealing to create poly-Si is not viable as it would require temperature-stable panels made of expensive quartz. Therefore, the key enabler for low-cost, mass production of displays using conventional display glass was the 308-nm excimer laser for selective low-temperature polysilicon recrystallization. The excimer laser process to



Anatomy of a 1300-mm process beam measured right in front of the display substrate.

form poly-Si is commonly referred to as excimer laser annealing (ELA).

In ELA, the excimer output beam is reshaped into a long narrow line profile. The length of the line ideally matches either the half or full width of the panel; hundreds of smartphone displays are eventually diced from each panel. The panel is translated under the line beam inside an ambient controlled chamber, ideally in a single-pass or in a two-pass scan process. The panel motion is matched to the 600-Hz laser repetition rate so that every part of the panel is irradiated by about 20 pulses.

The microcrystalline structure of the polysilicon determines the electron mobility and, hence, is very important to the quality of the final display. In turn, it is controlled by the laser pulse parameters, including the pulse energy, the number of pulses per location, the line beam profile (along both the long and short axes), the temporal profile of the laser pulse, and the pulse-to-pulse energy stability. For these reasons, display manufacturers buy a line beam rather than a laser; they need a complete system that delivers the precise line beam parameters their process requires. This necessitates a high degree of beam delivery system expertise by the laser vendor, including multiple levels of internal diagnostics and system monitoring at every stage of the enabling beam path.

It is simply not practical to make the individual laser oscillator larger and longer ad infinitum. Scaling issues like cooling, discharge uniformity, control of beam quality preclude this.

Multi-oscillator = high-power excimer

Although LTPS is well-established in mass production, it is a very dynamic field. From the perspective of a laser beam supplier, the key trend is to support ever-larger panels. Specifically, the challenge is to provide a line beam profile that matches the width of these larger panels without sacrificing intensity (fluence) or any of the other system performance parameters that affect the quality of the final poly-Si.

The lasers used in ELA are the most powerful excimer lasers ever commercially developed, with pulse energies as high as 2 joules. This was a good match for creating a line beam profile up to 750 mm in length as needed for Gen 5 panels. But, soon a higher power level was needed to support the step up to Gen 6 panels measuring 1500 × 1850 mm. Moreover, a strategy was needed to scale to even larger panels in the future.

It is simply not practical to make the individual laser oscillator larger and longer ad infinitum. Scaling issues like cooling, discharge uniformity, control of beam quality, etc., preclude this. Instead, we chose a path of combining multiple lasers in a multi-oscillator concept, which resulted in VYPER, a very high-power excimer laser platform. And rather than maintaining the existing performance levels, we are doing this in a way that at the same time improves certain key performance characteristics, like pulse-to-pulse stability. It also provides a unique flexibility in terms of pulsing and temporal pulse shaping.

Excimer laser annealing system with 1300-mm line beam length

Each individual VYPER oscillator can deliver a total power of 1.2 W (2 joules) at a 6000-Hz repetition rate. The first four-oscillator system increased this to 2.4 kW in 2013, providing a line beam length of 1300 mm for large-format LTPS production on Gen 8 display glass panels. Meanwhile the latest three-laser system developed in 2016 provides up to 3.6 kW using the combined power of six oscillators.

The two oscillators of the VYPER are arranged in pairs with a master and slave configuration. Patented synchronization circuitry accurately controls the time delay between the pulses of the slave and master. An active feedback loop is employed to maintain a stable delay between the laser pulses over the running period, with a typical accuracy of 2 ns.

In this way, a two-oscillator system user can overlap the pulses to provide a high energy of 2 J per pulse at 600 Hz. Optionally, the pulse delay can be adjusted to provide longer pulses, with peak power sustained up to twice the normal laser pulse duration (24 ns). This allows exploration of the subtle effects of pulse duration on microcrystalline structure optimization. And, just as important, the concept of using multiple oscillators provides even further scalability of the line length for Gen 8+ glass panel generations.

Uncompromised line beam uniformity and pulse stability

There are two ways in which multiple excimer laser beams could be combined to make a single line profile. First, the laser beams can be combined with near 100 percent overlap and the mixed beam then shaped to the final line profile. Or, the laser beams could be shaped then stitched together end-to-end to form the final line. We chose the former as this maximizes pulse-to-pulse stability at every location along the line.

Pulse-to-pulse stability is a particularly important process parameter impacting poly-Si crystal size uniformity. Specifically, the energy stability of each individual oscillator is between 0.25 and 0.3 percent sigma, well within the LTPS process window — in spite of the inevitable variations in repetitively firing a plasma discharge at tens of kilovolts. But, by combining and mixing the pulses from two oscillators, this random pulse-to-pulse noise is reduced by a factor of $\sqrt{2}$, for a final value of about 0.2 percent sigma.

The way in which the discharge is equilibrated between the pair of laser oscillators is another feature contributing to the low pulse-to-pulse variations and excellent timing synchronization of the two oscillators. The two laser tubes and their solid-state pulsed power supplies are, in principle, identical. The supplies are made identical in practice using a patented hardware module called EquiSwitch. This momentarily connects then disconnects the two-power storage systems so that they are equalized, immediately prior to firing the gas discharge. By eliminating any charge deviation on the storage capacitors, the switching behavior and the cycle time of energy through the circuitry is stabilized, resulting in long-term temporally synchronous output beams of nearly identical pulse energy.

Continuing evolution of laser annealing applications

In conclusion, excimer lasers have become essential to the fabrication of all advanced mobile displays we all now encounter on a daily basis. But, the technological needs of excimer laser annealing applications continue to rapidly evolve, concurrent with market pressure to reduce production costs. Excimer laser power and line length scaling have proven capable of meeting the market requirements, and straightforward system scale-up will carry this trend on into the future.

Meet the authors

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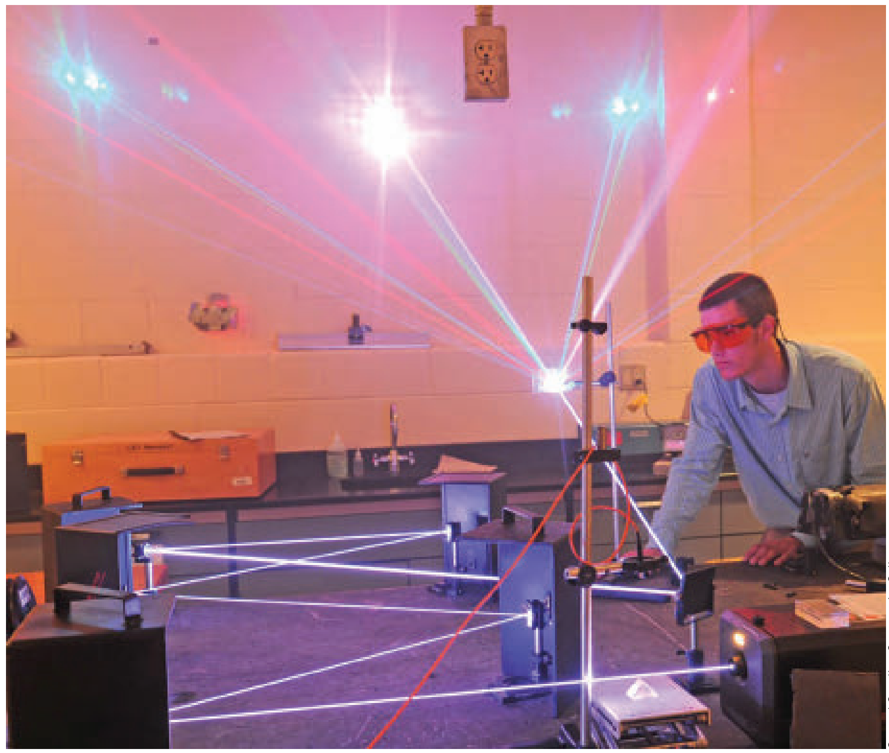
Education: Stacked for Success

The start of the 20th century marked a turning point in education, with the establishment of the first public two-year community college in 1901 — Joliet Junior College in Illinois. Such schools initially concentrated on general liberal arts studies, but with the Great Depression came a focus on job training programs, as well.

By the 1960s, the community college scene was booming, with more than 450 such schools open nationwide. Growing enrollments were fueled in part by the coming-of-age baby boomer generation. Today, there is a particular need for photonics and optics technicians and engineers; and schools like Monroe Community College in New York are preparing students for careers in the field.

Community Colleges: Preparing the Future Photonics Workforce

BY JUSTINE MURPHY
SENIOR EDITOR



Central Carolina Community College

John-Kevin Frazee demonstrates how an argon-krypton laser can be used in light shows while a student at Central Carolina Community College in 2012. Such programs are preparing students for the workforce, as well as continuing education.

World-renowned astronomer Carl Sagan once said, "Somewhere, something incredible is waiting to be known." Community college photonics and optics programs are preparing students to find it.

About 30 community colleges around the U.S. produce approximately 250 to 300 photonics graduates annually. Some go on to further their education in undergraduate degrees and beyond, while others earn their associate's degree with plans to enter the workforce. The latter group is filling a void currently felt in the photonics and engineering workforce — an estimated 800 new technicians are needed around the country each year, according to the National Science Foundation's National Center for Optics and Photonics Education (OP-TEC) in a 2012 survey of photonics and optics companies.

The number of community college graduates produced annually makes up just 15 percent of the workforce demand, the OP-TEC report states. Much more is needed for "photonics systems technicians working in applications where photonics is an enabling technology in many fields."

Resources such as the U.S. Department of Energy Office of Science Early Career Research Program are supplementing research- and workforce-ready education. SPIE offers education and training, as well, in areas such as biomedical optics and medical imaging, illumination and displays, lasers and sources, nanotechnology, optical design and engineering, and solar and alternative energy.

Photonics Spectra spoke with educators from several community college photonics and optics programs about courses and training they offer, and for their take on the importance of these programs.

- **Nicholas Massa**, a professor in the Laser Electro-Optics Technology Department at Springfield Technical Community College in Springfield, Mass., and a principal investigator for the U.S. National Science Foundation's PBL Projects: Skills for the 21st Century.
- **Jacob Longacre**, an assistant professor of Electronics Engineering Technology at Quinsigamond Community College in Worcester, Mass., who runs the school's photonics program.
- **Alexis Vogt**, an associate professor of optics and chair of the optics and photonics program at Monroe Community College in Rochester, N.Y.
- **Bob Ballard**, a Fiber Optics Association (FOA)-certified master instructor at BDI DataLynk LLC, a Lago Vista, Texas-based company he owns. BDI is partnering with SUNY Westchester Community College in Valhalla, N.Y., to provide FOA-sanctioned fiber optics network certification courses.

***Photonics Spectra*: What are the most popular areas of study within your school's optics programs — which courses do students really get excited about?**

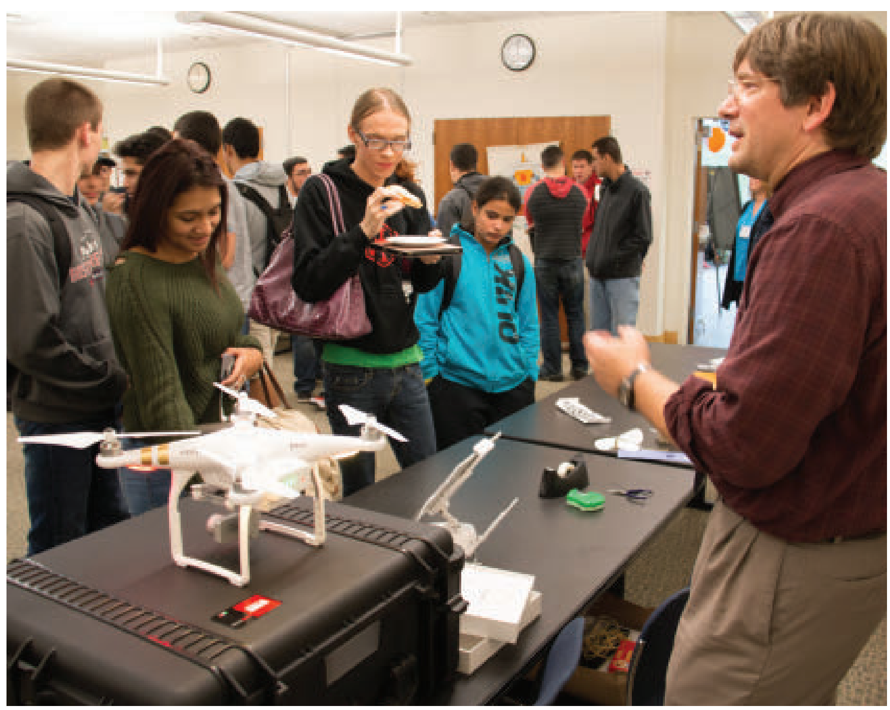
Massa: Students in my program enjoy the hands-on problem-solving courses the most. These include the Advanced Topics in Lasers course where students work in teams to solve real-world industry problems. These problem-based learning scenarios, called PBL Challenges, are presented in a multimedia format and are available through the New England Board of Higher Education's Problem-Based

Jacob Longacre, an assistant professor and leader of the photonics program at Quinsigamond Community College in Massachusetts, works with students in an electronics class on troubleshooting amplifier and power supply circuits.

Learning Resource Center. Above all, however, students enjoy the Senior Projects in Lasers course the most. In this yearlong capstone course, the majority of students work on real-world industry-sponsored projects under the guidance of an industry mentor. Many of these projects are conducted on-site at the company and some are actually paid internships that lead to employment upon graduation. Through this course, students get to experience what it is like to actually work as a laser technician alongside engineers and scientists before graduating, which has a tremendous impact on their motivation and learning. Some of the innovative projects students have engaged in include building a commercial-quality scanning fiber laser marking/etching system, a frequency-doubled green fiber laser, a hybrid solar/compressed air engine vehicle, and many others — all industry-sponsored.

Longacre: Our program is very new, so our data-set is limited, but 3D imaging is an area that generates a great deal of excitement. The students recognize the impact that 3D imaging will have on applications they are familiar with, such as movies and video games. The students can also identify some of the issues with these technologies, and see how they cross into multiple areas, including optics, electronics, mechanics, psychology, etc.

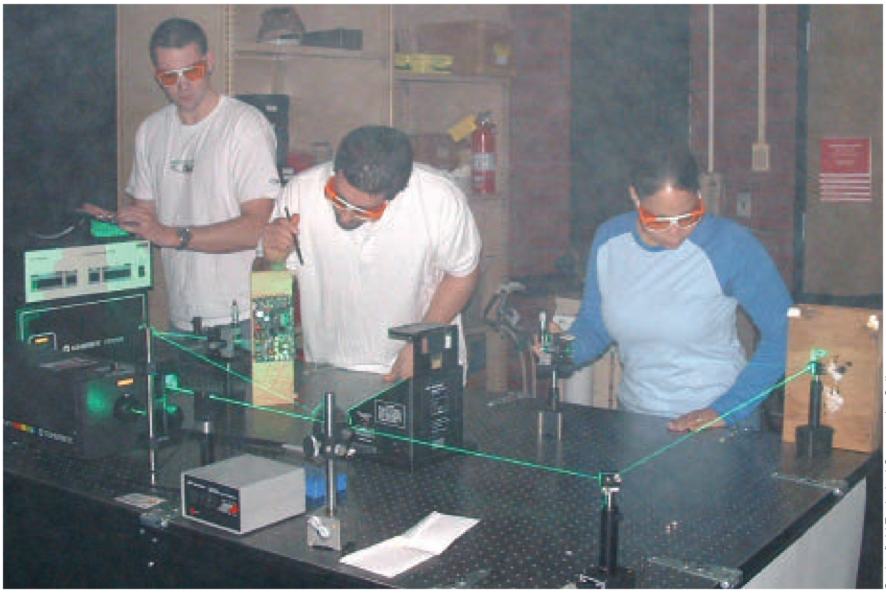
Vogt: The Optical Systems Technology program at Monroe Community College (MCC) was established in 1963 as the first school in the nation to train technicians to work in the optics industry. Our program remains the only community college in the country awarding associate degrees in optics. In 2015, close to $1 billion was awarded to the optics, photonics and imaging sectors in the Rochester, N.Y., region, and our optics program has seen enrollment numbers rise as a result. Students are interested in pursuing a course of study where employment opportunities are abundant, and in Rochester we currently have more job openings for skilled optics technicians than we have graduates to fill the jobs. Enrollment in our Introduction to Optics course, for example, has doubled from last fall. Over 50 percent of a student's time in our program is spent in a laboratory environment. Students leave our program with hands-on skills that prepare them for the optics and photonics workforce. The MCC Optics & Photonics program is designed for both career placement,



A Manufacturing Day presentation last year at Quinsigamond Community College in Massachusetts allowed Jacob Longacre, an assistant engineering professor at the school and leader of its photonics program, a chance to talk with students about the integration of optical, electronic and aerodynamic technologies exemplified by drones.

as well as 2+2 transfer opportunities. We provide a two-year Associate of Applied Science (AAS) degree, with a track in traditional optics and a second track in photonics, a one-year certificate and a 2+2 program where a student spends two years at MCC and then transfers to a four-year college to complete a bachelor's degree in optics at the University of Rochester or Imaging Science at Rochester Institute of Technology. We have students excited about and enrolled in all three paths.

Ballard: A well-trained fiber optics technician is in demand in today's vast telecommunications job market. A fiber optics technician maintains fiber optic cable systems that carry both analog and digital transmissions. Fiber optics technicians are responsible for installing, testing, troubleshooting and maintaining optical fiber cables that are used in sending and receiving communications data. These trained technicians splice and fuse fibers, and install cables beneath the ground and in conduit, and in the various areas of building structures. The Westchester [Community College] Certified Fiber Optics Training program prepares the student to take the certification exams, which are offered immediately after each course. Each exam is sanctioned by the Fiber Optic Association (FOA). The FOA is an international, nonprofit organization that certifies fiber optic



Springfield Technical Community College

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

New Photonics Program Aims to Fill Northeast Region's Workforce Gap

SUNY Westchester Community College is currently developing a new photonics program within its Electrical Technology discipline to address the Northeast region's increasing demand for technicians in the workforce.

It's widely known that the optics and photonics workforce is struggling to find quality technicians. A 2012 industry survey by the National Science Foundation's National Center for Optics and Photonics Education (OP-TEC) found that an estimated 1,500 new technicians have been needed nationwide each year. Initiatives to address this challenge are popping up across the country, giving optics and photonics companies new hope for future workforces.

Among such initiatives is a new photonics program currently in development at Westchester Community College (WCC) in New York, part of the State University of New York system. This new program aims to educate and train students for roles that should ultimately help fill the technician gap.

Surveying the field

WCC recently conducted its own survey — similar to OP-TEC's 2012 study — of optics and photonics companies in the Northeast region. The goal was to obtain a better understanding of the industry's needs, and in turn use this information, along with direct industry outreach, "to develop the in-class and out-of-class experiences our students need to be industry-ready," according to Kyriakos Ioannou, curriculum chair of Electrical Technology at WCC, and the Joseph and Sophia Abeles Endowed Chair for Alternative Energy Technology. "We are developing our program to adequately train technicians to work in this field for the Northeast."

Ioannou is joined in this new photonics program venture by Stephen J. Leone, program administrator at WCC, and Laurie Miller McNeill, the school's director of Institutional Advancement.

The WCC survey also gauged companies' interest in partnering with the school to create such a program. A number of the survey respondents noted they will be hiring photonics technicians within the next five years. And several other companies said they would consider assisting local education efforts in optics and photonics technology at the middle school, high school or community college level. WCC offers programs in various engineering technologies, with strong industry partnerships in those areas; the new photonics program will be an extension of that, Ioannou said, into the growing photonics field.

Program planning

The new photonics program will begin with the option for Electrical Technology students to concentrate specifically in photonics. WCC does not currently offer any photonics or optics classes, per se. But there are some components of these fields included in several Electrical Technology classes. Existing courses in this discipline will be modified to introduce the new photonics component, according to Ioannou, and will also prepare technicians, approves fiber optic technician training courses and participates in the development of standards for the industry. Available courses [in this program include] Certified Fiber Optic Technician (CFOT) Basic Course, Certified Fiber Optic Specialist/Testing & Maintenance (CFOS/T), and Certified Fiber Optic Splicing Specialist Course (CFOS/S).

***PS*: What is some of the innovative work these students and their instructors are doing?**

Longacre: The most innovative work has been coming from the courses … that have students apply what they learn to design and build things. Students internalize the information more effectively, but they also learn how things work in reality, where the structure, sensors, actuators and electronics all have to work together. A great concept can fail for some simple reason like binding hinges. This also introduces students to concepts like testing designs or subsystems quickly and cheaply, then learning from failures to iteratively improve the overall design.

Vogt: Optics and photonics continue to be innovative fields with new advancements daily. At MCC we bring these innovations into our classrooms and labs through curriculum, state-of-the-art equipment and visits to area optics companies. All of our students visit multiple optics companies before graduating to see the innovation ... in Rochester. Most of our students participate in paid summer internships to learn about this innovation first-hand.

Ballard: All of our courses provide comprehensive lecture sessions followed by detailed hands-on sessions including installation, testing and troubleshooting techniques, not only utilized throughout the fiber optics networking industry, but also approved and sanctioned by the FOA. Hands-on sessions represent real-life scenarios offering challenging scenarios, which enable all students to practice repair and troubleshooting techniques learned during class.

Massa: In our program, we try to emphasize practical hands-on applications of optics and photonics. While we provide the theoretical underpinnings of the science and technology of lasers, optics and electronics, everything we do is intended to provide graduates with solid technical skills, as well as problem-solving, critical-thinking and teamwork skills. We are very lab-intensive and have state-of-the-art facilities that give students hands-on experience with the latest technology. Students receive extensive hands-on training [in] lasers, optics, fiber optics, holography, interferometry, electronics, 3D design using SolidWorks, LabView and much more. In fact, just this past spring we were awarded a $500K grant from the Commonwealth of Massachusetts to develop a new laser materials processing lab with several high-powered fiber and CO_2 laser cutting and welding systems, as well as the latest optical test and measurement equipment.

students for more advanced photonics classes that will eventually be available.

"Once we have the classes running, we will be working toward establishing a certificate program in photonics and eventually an associate's degree," Ioannou said. "We are currently modifying the syllabus for Introduction to Technology to include a photonics component, and reviewing the syllabus for Technical Physics 2 to assure that the students will have the basis in light, optics and photonics to continue with the photonics classes."

In addition, WCC is working with OP-TEC to develop a Fundamentals of Light and Lasers course that will be followed by a Laser Systems and Applications class.

To get the new program going, the school has already received a Mentor-Connect grant — supported by funds from the National Science Foundation (NSF) that assist community colleges around the country to "develop programs to meet critical needs in technician education." WCC also plans to apply for another NSF grant, for Advanced Technological Education, in the fall. According to Ioannou, the new program will be the first of its kind among community colleges in the region.

"At this time, there are no two-year colleges in the Northeast providing training for photonics technicians," he said. "We look forward to helping close that gap for industry."


Kyriakos Ioannou/WCC

(left to right) Westchester Community College's Laurie Miller McNeill, Kyriakos Ioannou and Stephen J. Leone are now working to develop a photonics program at the school to assist in growing the industry's workforce. It will be the first such program among two-year colleges in the Northeast region.

NIF

A group of technicians, engineers and scientists validate the performance of the High Contrast ARC Front End (HCAFE) AFECT (ARC Front End Compressor Table) system at the National Ignition Facility at Lawrence Livermore National Laboratory in California.

***PS*: What advice would you give a new student entering the school's optics programs, about the work ahead of them and their career options?**

Massa: You don't have to be a mathematical wizard to be successful in the laser field. If you like science and technology, have a willingness to learn and think outside the box, and like to build things, you will be successful in the laser field. Intellectual curiosity and an entrepreneurial spirit are the only prerequisites.

Longacre: The field of photonics covers a wide area. Find your area of interest and apply what you learn to it. Courses and jobs that do not fall exactly into that area will still provide applicable knowledge. Recognize that the world does not operate cleanly within specific majors or fields of study. Develop a framework for yourself to understand how disciplines relate and complement each other. Then you can use all the tools available, not just those traditionally associated with your interests.

Ballard: Prerequisites for our basic, three-day CFOT course, as well as all of our courses, require that the attending student be able to read and write the English language fluently and be able to see and identify small tools. Because of the bandwidth demand throughout the data/telecommunications industry, many employment opportunities exist. From opportunities in the fiber to the home market with companies such as Google, Time Warner, and Verizon, to employment opportunities in the Local Area Network (LAN) infrastructure industry, fiber optic technician employment opportunities are growing around the world.

Vogt: At MCC we prepare students to enter the workforce as skilled optics technicians and we also prepare students for advanced education. The opportunities for students upon graduation are numerous. We currently have more job openings than we have graduating students. We are here to help students succeed and to grow the optics workforce. The optics and photonics fields are at the forefront of future technological advancements and we welcome other students to join our program.

justine.murphy@photonics.com

Community College Listing

Community colleges worldwide are educating and training the workforce of tomorrow in such fields as photonics, optics, fiber optics, lasers, electro-optics and more. Below is a partial listing of these schools.

Baker College

Photonics and Laser Technology Program
Flint, Mich.
www.baker.edu/baker-college-of-flint/programs-degrees/photonics-and-laser-technology
The Photonics and Laser Technology associate's degree program is designed to meet real-world needs. Classroom studies are combined with hands-on training in a state-of-the-art lab, where students learn to build, test, modify, install, operate, calibrate, maintain and repair laser and electro-optic devices. Graduates are fully prepared to work as photonics technicians in any one of a number of industries, including aerospace, agriculture, chemical, communications, lighting, construction, medicine and manufacturing.

Camden County College

Photonics Department/Lasers, Electro-Optics and Fiber Optics Technology
Blackwood, N.J.
www.camdencc.edu/academics/departments/photonics-laser-electro-optic-tech
The school's programs provide state-of-the-art training in laser/electro-optics and fiber optics technology. These programs offer students career opportunities in electro-optics, laser and telecommunications areas. The laser/electro-optic technology program offers technical theory, expert knowledge of different laser systems and safety regulations, and hands-on experience to prepare students for careers in research, manufacturing and testing of laser/optic equipment, among others. The fiber optics program provides hands-on training, and technical theory covering aspects of optical waveguides, fiber optic sensors, and accompanying measurement and other equipment.

Central Carolina Community College

Engineering Department/Laser and Photonics Technology
Lillington, N.C.
www.cccc.edu/curriculum/majors/lasers-photonics
Central Carolina offers an associate's degree in applied science, focusing on laser and photonics technology. This program includes instruction on understanding the application of electronic, fiber optic, photonic and laser principles. And an emphasis on hands-on learning prepares students for real-world projects and practical applications.

Cincinnati State Technical and Community College

Electro-Mechanical Engineering Technology: Laser Major (EMETL)
Cincinnati
www.cincinnatistate.edu
The EMETL program prepares graduates to successfully begin careers and advance professionally in local and national industries that utilize lasers and electro-optic systems. Students work with laser materials processing systems, and operate and troubleshoot optical systems such as lasers, lens systems and fiber optics. Graduates can support industrial equipment in automated manufacturing and research environments, and are also prepared to pursue a bachelor's degree in electro-mechanical engineering or related fields.

College of Lake County

Laser, Photonics and Optics Program
Grayslake, Ill.
www.clcillinois.edu/programs/lpo
This program offers associate's degrees in applied science, as well as three certificate options, all to prepare students for positions as photonics technicians installing and troubleshooting lasers, optical systems, fiber optic devices, telecommunications equipment, photonics manufacturing equipment, simple control systems and more. Courses cover the fundamentals of light, lasers, photonics and laser applications, among others.

Idaho State University

Pocatello, Idaho
www2.isu.edu/ctech/robotics
Students in robotics and communication systems engineering technology programs are educated and trained for careers as electronic systems technicians; such positions could include conducting research and making repairs, as well as software development, semiconductor testing, lasers and optics, national defense and telecommunications. Degree options and certificate programs include Robotics and Communication Systems Engineering and Laser/Electro-Optics Technology Advanced Technical Certificate.

Indian Hills Community College

Advanced Technology Center
Ottumwa, Iowa
www.indianhills.edu/courses/tech/laser
The laser and optics technology program features electronic technician courses and training, offering the skills necessary to begin a career in the lasers field. Students spend nearly half of their time in these programs in the lab, working with industrial laser systems. Upon graduating, they are prepared for careers in engineering support, technical sales, manufacturing and maintenance.

Indian River State College

Fort Pierce, Fla.
www.irsc.edu
Photonics-related programs here offer degrees in Electronics Engineering Technology (with specialization in lasers and fiber optics). Several certificate programs are available, as well as, in lasers and photonics, and solar energy.

Irvine Valley College

School of Physical Sciences and Technologies
Tustin, Calif.
http://academics.ivc.edu/physci/photonics/Pages
New courses developed and taught at Irvine Valley College are based on the industry-guided photonics curricula written by the National Center for Optics and Photonics Education (OP-TEC). Programs provide hands-on, laboratory-driven classes utilizing state-of-the-art industrial equipment. And now,

the school's Photonics Initiative Team is collaborating with regional companies that manufacture advanced photonics devices or use photonics in engineering applications that range from laser surgery to homeland security. This initiative is designed to create a career path to employment via internships and industry-guided coursework.

Lake Washington Institute of Technology

Kirkland, Wash.
www.lwtech.edu/academics/electronics-technology
The school offers programs in electronics technology through advanced electronics principles and applications. Graduates are able to utilize the skills learned in these programs to enter into either the electronics manufacturing industry as assemblers, inspectors, managers and testers, or into any high-tech industry.

Minnesota State College Southeast

Winona, Minn.
www.southeastmn.edu
The Minnesota State College Southeast offers programs in electronics technology, which provide students with a broad spectrum of career opportunities; 50 percent of the classwork is hands-on. All instructors stay up-to-date in the electronics field and current technology is implemented in the curriculum.

Monroe Community College

Rochester, N.Y.
www.monroecc.edu/academics/majors-programs/stem/optical-systems-technology-associate-degree
The optical systems technology associate's degree provides a direct path to employment in the high-tech optics industry. This program is offered in collaboration with the Corning Incorporated Foundation, which supports STEM education programs. MCC's optical systems degree provides the advanced training for the optical systems workforce. In these programs, students gain practical, hands-on experience with state-of-the-art optical systems used in the industry.

Niagara College

Welland, Ontario, Canada
www.niagaracollege.ca/technology-studies/programs/photonics-engineering-technology
The Niagara College photonics engineering technology program touts the largest photonics training labs in Canada, in addition to dedicated photonic and microelectronic labs, and a teaching clean-room facility. Students learn skills in laser, optical, electro-optical and vacuum technologies.

North Central State College

Mansfield, Ohio
www.ncstatecollege.edu/cms/degrees/integrated-engineering
The Industrial Technology Integrated Engineering program readies students to diagnose and repair industrial equipment problems using proper technical assessment skills, as well as core mechanical and electrical skills. The program provides students with a base knowledge in advanced skills such as programmable logic controllers (PLC), mechanical drive systems, hydraulic/pneumatic systems, electronics and digital applications, robotics and process control.

Northwestern Michigan College

Traverse City, Mich.
www.nmc.edu/programs/academic-programs/engineering-technology/catalog-photonics
Northwestern Michigan College offers an engineering technology degree, which features a broad-based curriculum across all areas of technical education. This prepares graduates for emerging job markets and highly technical fields. The degree program is designed for students to focus on areas of interest or specialize in one of seven technical concentrations — automation and robotics, computers, electronics, marine, photonics, unmanned aerial systems, and unmanned ground vehicles.

Pima Community College

Tucson, Ariz.
www.pima.edu/programs-courses/credit-programs-degrees/science/engineering
The engineering program at the school offers an associate's degree, with an optical engineering concentration.

Puerto Rico Photonics Institute

Universidad Metropolitana School of Environmental Affairs
San Juan, Puerto Rico
http://prpi.suagm.edu
Puerto Rico Photonics Institute prepares students for work in optics and lasers in industries of high demand such as aerospace, medical devices, nanotechnology, manufacturing, communications and biotechnology.

Quinsigamond Community College

Worcester, Mass.
www.qcc.edu/academics/engineering-and-engineering-technology/electronics-engineering-technology-photonics-option
The Photonics Option in Electronics Engineering Technology program prepares students for careers as photonics technicians and/

or electronics technicians with photonics experience. Photonics technicians build, test, troubleshoot and maintain systems involving lasers, fiber optics and other electro-optical components. The program also helps students build a foundation of knowledge that forms the basis for further study in electronics and photonics.

San Jose City College

Laser Technology Department
San Jose, Calif.
www.sjcc.edu/academics/departments-divisions/laser-technology
The laser technology program at San Jose City College ensures that students learn what employers need. Upon graduation, they are prepared for careers in labs and manufacturing firms in a variety of industries.

Springfield Technical Community College

Laser Electro-Optics Technology Department (LEOT)
Springfield, Mass.
http://catalog.stcc.edu/preview_program.php?catoid=17&poid=4014&returnto=3440
The LEOT program is designed to provide students with a solid working knowledge in a broad range of photonics areas including laser systems, electronics, optics, electro-optics and fiber optics. Classroom lectures are supplemented with extensive hands-on laboratory experience and real-world activities designed to develop and enhance students' problem-solving and critical thinking skills. Graduates of this program work in a wide variety of companies involved in making lasers, integrating lasers into other products and systems, and conducting research and development on next-generation laser-based applications.

State Technical College of Missouri

Electronics Engineering Technology Department
Linn, Mo.
www.statetechmo.edu/programs/industrialtech/eet
The Electronics Engineering Technology program prepares graduates to fill diverse roles
in building and maintaining the electronic circuits that drive our modern-day existence. This hands-on program includes projects such as engineering and building computers. Its broad curriculum teaches the principles of electricity, digital communications and industrial electronics. Students can also earn industry-recognized certifications from the Society of Manufacturing Engineers.

Texas State Technical College

Waco, Texas
www.waco.tstc.edu/programs/LaserElectroOpticsTechnology
In the college's state-of-the-art cleanroom and equipment facility, students receive hands-on training on vacuum systems, electronic support systems, lasers and optics, semiconductors and more. They leave the school prepared for careers in industries such as manufacturing, biomedicine and health care, communications, engineering, information technology, semiconductor manufacturing and fiber optics, and at agencies including NASA and the U.S. Department of Defense.

Three Rivers Community College

Norwich, Conn.
www.threerivers.edu/Div_academics/Technologies/technologies.shtml
The school offers associate's degree and certificate programs in lasers and fiber optics technology, and students receive practical, hands-on training.

University of Hawaii Maui College

Electronic & Computer Engineering Technology (ECET)
Kahului, Hawaii
www.maui.hawaii.edu/ecet
The ECET program prepares students for careers in such high-technology industries as electronics/electro-optics, renewable energy, telecom and network systems. Students also have the option of extending their time in the Engineering Technology (ENGT) four-year program to earn a bachelor of applied science degree.

Valencia College

Architecture, Engineering and Technology Department
Orlando, Fla.
http://net1.valenciacollege.edu/future-students/degree-options/associates/electronics-engineering-technology
An Electronics Engineering Technology associate's degree prepares students for specialized careers in electronics. The program transforms students into highly skilled technicians capable of assisting in the design, production, operation and servicing of electronics, lasers and photonics; robotics and mechatronics; and telecommunication and wireless systems.

Teddi C. Laurin Scholarship

Established to Promote Industry Leadership

University of Arizona Student Kaitlyn Williams Named First Recipient

The first recipient of the Teddi C. Laurin Scholarship is Kaitlyn Williams, a recent graduate of the University of Arizona's Optical Engineering undergraduate program. She will continue her education with a master's degree in optical engineering, where she'll focus on lens design with applications in telescopic camera systems.

The scholarship is named in honor of Teddi C. Laurin, founder of Laurin Publishing Co.

Williams has a special interest in "optics involved in space satellites — particularly those within the small space market," she said. During her studies, she will also work as an optical systems engineer in Raytheon's Small Space Satellite Division in Tucson, Ariz.

During her undergraduate years, Williams was named to the College of Engineering Dean's List every semester. Involved in the local community, she served as coordinator for the "Laser Fun Day Spring 2016," one of the largest optics outreach events for school-age children in the country.

Co-funded by Photonics Media and SPIE, the scholarship was created to raise awareness of optics and photonics, and to foster growth and success in the photonics industry by supporting students involved in the field. To be considered, applicants must be in their second year of an optics/photonics program, with preference given to those working on industry-leading photonics research projects.

Formal presentation of the award was on Monday, Aug. 29, by Ryan Laurin, vice president of Photonics Media, a unit of Laurin Publishing Co., at a luncheon at SPIE's Optics and Photonics Conference in San Diego.

"Teddi had a long-standing desire to see the photonics industry expand and gain worldwide recognition," said Tom Laurin, president and CEO of Laurin Publishing. "The scholarship that bears her name is a fitting tribute to the time and effort she invested in making that happen. We wish our first recipient, Kaitlyn Williams, the best of luck as she pursues her graduate degree in optical engineering."

Kaitlyn Williams

Teddi C. Laurin, who passed away in November 2015, entered the worlds of optics and publishing in the early 1960s, working alongside former Eastman Kodak physicist Dr. Clifton M. Tuttle on a one-volume annual optical industry directory. When Dr. Tuttle retired, Teddi took over management of the *Optical Industry Directory*, expanding it over the years into a four-volume compendium that included the *Photonics Handbook* and *Photonics Dictionary*.

In 1967, responding to a need she saw for a trade magazine to serve the optical industry, Teddi established *Optical Spectra* to publish relevant business and technical news. In 1982, she changed the magazine's name to *Photonics Spectra*, declaring in an editorial that "in the coming decades, we will see photons — the elementary particles of light — put to work to do most of the things electrons do now — and do it better and faster."

Teddi C. Laurin

Teddi's devotion to that mission was widely recognized in the industry. In 1991, she received the SPIE President's Award in recognition of her "distinguished leadership and service in support of the optics industry and optical engineering." She was instrumental in the development of the Circle of Excellence Awards — given annually by vote of *Photonics Spectra*'s Board of Editorial Advisors to the 25 most innovative new products of the previous year — the spirit of which is alive in the Prism Awards for Photonics Innovation, presented annually by SPIE and Laurin Publishing Co./Photonics Media.

The Teddi C. Laurin Scholarship will be granted annually in August.

For an application and additional information, visit SPIE's website: **www.spie.org/membership/student-members/scholarships/named-spie-scholarships**.

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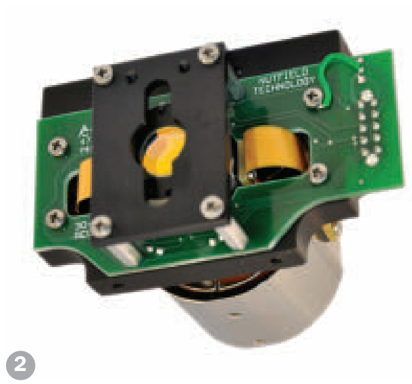

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1 Fluorometer

Applied NanoFluorescence LLC offers the NS MiniTracer fluorometer for the rapid trace detection of single-walled carbon nanotubes. The fluorometer is optimized for sensitive quantification of single-walled carbon nanotubes through their shortwave-infrared (SWIR) emission. The device is designed for environmental and biomedical researchers needing rapid trace detection, as well as the study of quantum dots that emit at SWIR wavelengths.

info@appliednano.com

2 High-Speed Focuser

Nutfield Technology Inc. has announced the BLINK High-Speed Focuser with an ultrastiff air bearing design enabling a friction-free bearing. The device offers servo bandwidths in excess of 500 Hz with 13-mm clear aperture and stroke. When used as the focusing element of a post-objective scanning system, BLINK dynamically maps a focal correction onto the laser beam as a function of its XY position, allowing high-speed processing of large planar samples with very small spot sizes.

sales@nutfieldtech.com

3 Power Meter

The LTK-1 benchtop power meter from **Exfo Inc.** combines the FTB-1750 power meter module with the new LTB-1 platform. The optical power meter delivers high-performance power measurements. An 85-dB range and fast stabilization enables simultaneous measurement of high and low signals on up to four channels. The kit includes a web-based user interface and remote control capabilities via built-in Ethernet port and instrument drivers.

www.exfo.com/contact-us

4 Gimbal Mount

Optimal Engineering Systems Inc. offers the AU300-XZ motorized three-axis gimbal mount, featuring 360° rotation of each axis. The rigid black anodized aluminum alloy frame of the gimbal mount handles loads up to 10 kg and has the clearance necessary for mounting lasers, cameras, optics and instrumentation for pointing, scanning, tracking, positioning and other applications. The azimuth, elevation and roll stages feature bidirectional stepper motors capable of microstepping, and each axis features low backlash worm gear drives and precision V groove and cross roller bearings for resolution of 3.6 arcsec, and repeatability and positional accuracy to 18 arcsec. Travel speed of each axis is 10°/s.

sales@oesincorp.com

5 Beam Expanders

The TECHSPEC series of variable beam expanders from **Edmund Optics** now includes models available in the 355-nm wavelength with 2× to 8× magnification range. The expanders are designed for UV laser machining and feature diffraction-limited performance with a ¼λ transmitted wavefront. High laser damage threshold antireflective coatings ensure maximum transmittance, while minimizing ghost reflections.

mdeal@edmundoptics.com

6 Miniaturized Laser

Coherent Inc. has announced the OBIS CORE LS miniaturized laser, offering optically pumped semiconductor laser technology in a scaled-down package optimized for analytical instrumentation. The device measures 52 × 27 × 12 mm, and delivers power and beam quality at wavelengths ranging from 488 to 594 nm. The laser can be used for ultracompact, laser-based optical subsystems due to its size, reduced heat load and integrated smart electronics.

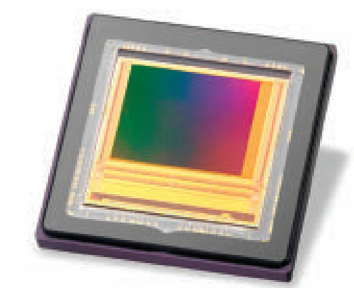
tech.sales@coherent.com

ISTAR System

The SupervisIR from **Elbit Systems Ltd.** is an IR wide-area persistent ISTAR (information, surveillance, target acquisition and reconnaissance) system with night capabilities. The system detects, tracks and displays visual motion imagery of moving air, ground and sea targets, and is designed for border patrol, perimeter security, surveillance and countersurveillance operations. System capabilities can be augmented with additional sensors, such as monitoring radars, and an advanced investigating sensor, the LVCR, which is a multispectral long-range observation and target acquisition system.

sales@elbitsystems.com

CMOS Sensor



The Onyx EV76C664 1.3-MP CMOS image sensor from **e2v Technologies Ltd.** is designed for low-light applications. The sensor's pixel design offers high sensitivity and performance in the near-infrared spectrum, allowing the device to be used in all light environments where wide dynamic range is needed. It features an embedded active imaging system that synchronizes external illumination and internal electronic shuttering, allowing discernible color images to be produced at extremely low light levels and through diffusing environments, such as fog or smoke, by range-gating.

www.e2v.com/contact-us

Energy Detector

Gentec Electro-Optics Inc.'s next generation of all-in-one INTEGRA Detectors features a redesigned format that enables optical-table mounting, and a choice of USB, external trigger or RS-232 connector options. The detectors are adapted for embedded laboratory applications and can also be used by field service technicians due to an integrated moni-

tor, requiring fewer instruments. The combined detector and meter system measures energy from pW to kW, and from fJ to J.
info@gentec-eo.com

Framing Camera

Specialised Imaging Ltd. has announced the SIM-D ultrafast framing camera for academic teaching and research groups. Intuitive design allows students and researchers to achieve top-quality results with scanning capability up to 1 billion fps. A novel optical periscope for focus adjustment enables rapid and simple experimental setup and optimization. Full remote operation through Ethernet connectivity comes as standard, enabling the SIM-D to be integrated into almost any environment.
info@specialised-imaging.com

Linear Stages

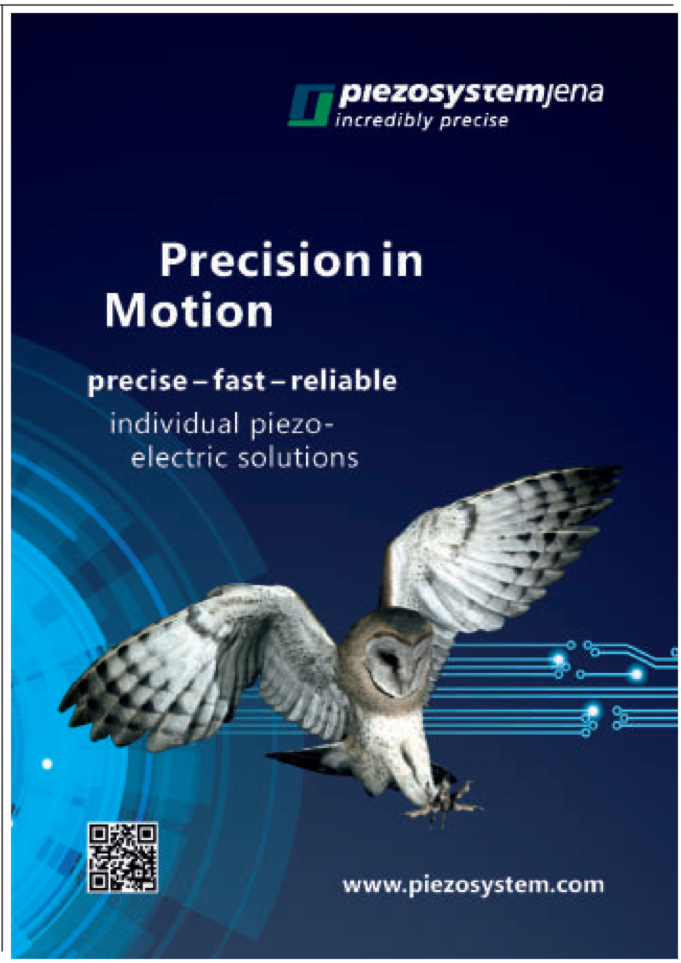
Physik Instrumente LP has announced the N-565 linear stages with a width of 65 mm and length of 80 mm. The low-profile stages feature a fully integrated linear piezo motor. An integrated interferometric linear encoder can resolve to 20 pm and allows incremental motion below 1 nm. Due to the short signal period of 0.5 µm, the linearity error of PIOne encoders is less than 1 percent. PiezoWalk technology combines the technological advantages of piezo class resolution with long travel ranges.
info@pi-usa.us

Video/Imaging Platform

Microsemi Corp. has announced an imaging and video platform for the development of low-power and reliable video processing applications. The platform comprises a field-programmable gate array (FPGA) mezzanine card, a comprehensive intellectual property suite and graphical user interface, as well as a flexible image sensor interface connector and GUI-based software, enabling users to configure sensor display demonstrations in real time. The system is designed for applications including drones, machine vision, robotics, IR cameras, head-up display, target acquisition systems, medical imaging, surveillance and automotive imaging.
www.microsemi.com/salescontacts

Forkless Mounts

Newport Corp. offers the PX series of forkless pedestals and posts, a space-saving option for the stable mounting of optical components. The devices have an internal slotted base, allowing them to be directly mounted to optical tables or breadboards without a clamping fork. This patent-pending feature can provide up to 66 percent space savings compared to standard pedestals, while still providing positional flexibility and excellent long-term stability. They are are available in stainless steel and aluminum versions, with flanged pedestals or straight posts.
rick.sebastian@newport.com



new **products**

Thermal Imaging Camera

Flir Systems Inc. has released the T1030sc thermal imaging camera, featuring hardware, software and optics tailored for its sensitive 1024 × 768 HD-IR detector. OSX Precision HDIR optics feature a precision ultrasonic autofocus capability. The combination of the high-resolution detector and the variety of OSX lenses allows users to view problems from longer distances and with greater accuracy. The T1030sc offers thermal sensitivity <20 mK and temperature operating ranges with calibrations up to 2000 °C. The optical system features an ultrasonic drive, ambient temperature drift compensation and parasitic radiation protection.

flir@flir.com

Thin-Film Coating

Intevac Inc. has announced the optical Diamond-Like Carbon (oDLC) thin-film coating for applications in the mobile electronics market. The optically transparent and mechanically hard protective coating provides improvements in the scratch resistance of display cover panels for all types of mobile electronic devices, as well as point-of-sale and automotive infotainment systems. Compared with uncoated display cover glass, the coating provides a 20× increase in scratch resistance, >91 percent light transmission, >10× increase in haze resistance and a 20 percent increase in breakage resistance.

www.intevac.com/contact-us

Image Sensor

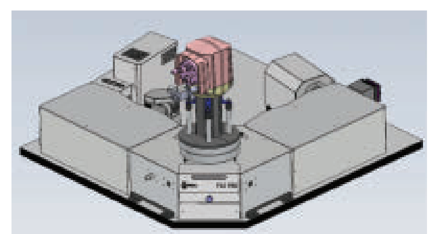
ON Semiconductor offers the 8-MP KAI-08052 image sensor, providing twice the sensitivity in near-infrared (NIR) wavelengths as the company's standard Interline Transfer CCD pixel design. The pixel design improves detection of NIR wavelengths by up to a factor of two, depending on the specific wavelength studied, without any reduction in image sharpness. This device is designed for scientific and medical imaging where samples emit or fluoresce in NIR wavelengths, or in machine vision and intelligent transportation systems.

www.onsemi.com

Injection Molding Material

Shin Etsu Silicones of America Inc. has announced the KE-2062 series of 70-Shore A, optically clear, silicone liquid injection molding (LIMS) materials featuring a wide operating temperature range, transparency and flexibility. The KE-2062-70 LIMS material was utilized to mold an entire magnifying glass including two key surfaces: the textured, embossed handle and bezel, and the diamond polished lens. The material was designed to meet the increasing thermal requirements for high-brightness LED optical lenses.

ebishop@shinetsusilicones.com



Fluorescent Spectrometer

Edinburgh Instruments Ltd.'s upgraded FLS980 Fluorescence Spectrometer measures over a temperature range of <3 to 300 K without the need for cryogenic liquids. The device uses the Optistat Dry, which utilizes a Gifford-McMahon cooler with a helium gas closed circuit. New software allows the cryostat operation to be controlled directly from within the F980 operating software of the spectrometer.

sales@edinst.com

Detection Software

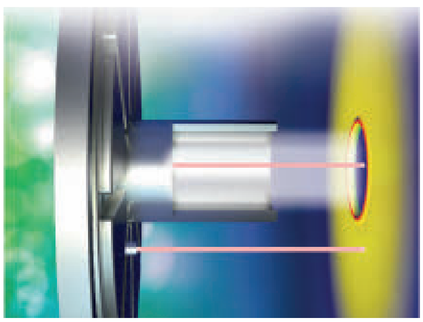
Sentient Vision Systems has announced Kestrel 4.0 land and maritime automated object detection software. Processing requirements are improved, providing reductions of 50 percent measured in prerelease deployments. The software is now able to easily process high-definition imagery on a processor. Ground-based customers can operate Kestrel on smaller, more mobile ground processing systems. In the air, small-form-factor processing chips are possible instead of heavy boxes.

sales@sentientvision.com

Request info about these products at **Photonics.com/rsps**

Diode Laser Driver

The D200 diode laser driver from **Highland Technology Inc.** is a compact precision device. A direct current-coupled trigger signal produces fact, 2-ns transitions. Up to 4 amps of regulated drive current supports lasers with forward voltages of up to 9 V. A built-in edge-triggered pulse generator provides up to 1-µs pulse widths. A pulse-follower mode is also provided, accommodating externally defined trigger widths up to 100 percent duty CW. Power, pulse width, drive current and differential triggering functions are accessible through a ribbon cable header for embedded OEM applications.
sales@highlandtechnology.com



DIP System

Horiba Scientific introduced a differential interferometry profiling (DIP) system for glow discharge optical emission spectrometry (GD-OES) — a technique for fast, multielemental depth profiling of conductive and nonconductive materials. GD-OES relies on plasma for the sputtering of a representative area of the investigated specimen and on a high-resolution spectrometer for the simultaneous measurement of all elements of interest. DIP provides real-time layer thickness, crater depth and sputter rate without calibration.
info.sci@horiba.com

Piezo Stage

Attocube Systems AG offers the ECSz5050 piezo stage for vertical positioning. Its drive system offers an orientation independent force of 8 N over a travel range of 8 mm, without adding to the small footprint of the ECS5050 series (50 × 50 mm). The stage is designed for lateral motion setups, and can be combined with the whole range of rotators, goniometers and linear positioners from Attocube's Industrial Line portfolio.
info@attocube.com

Optical Encoders

Micromo offers IER3 and IERS3 optical encoders, which are an optoreflective system on a single chip. The LED, photodetectors, analysis unit and interpolation levels are installed in one chip, so the encoders take up very little space. A Faulhaber DC micro motor or brushless DC servo motor can be positioned with a typical accuracy of 0.1 to 0.3° with the IER3 and IERS3, enabling a range of high-precision positioning applications.
www.micromo.com/contactus

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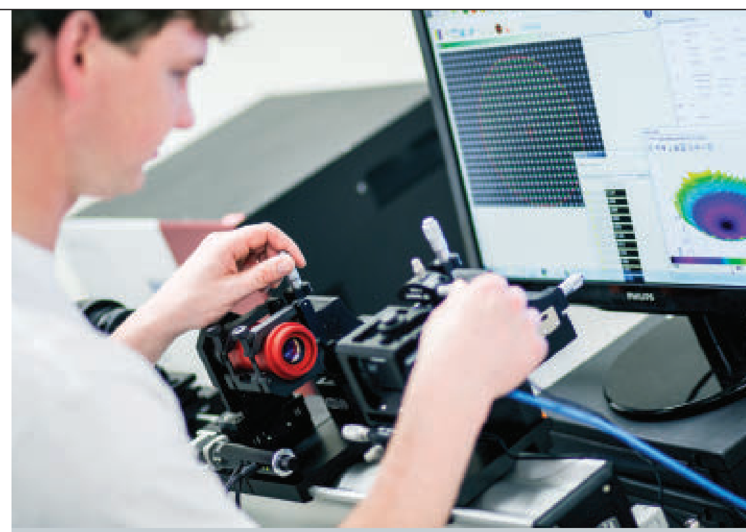

Happenings

SEPTEMBER

IMTS (Sept. 12-17) Chicago. The International Manufacturing Technology Show. Contact +1 508-743-8535, IMTS2016@xpressreg.net; www.imts.com.

ENOVA Paris (Sept. 14-15) Paris. Technology exhibition focusing on electronics, embedded measurement, vision, optics and IoT. 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 Luisa Margione, +44 0-1732-752125, luisa.margione@nexusmediaevents.com; www.ecoc2016.de.

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

AutoSens (Sept. 20-22) Brussels. The Automotive Sensor and Perception Conference. Contact +44 (0)208 133 5116, enquiries@auto-sens.com; www.auto-sens.com.

OCTOBER

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

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

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

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

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

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

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

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

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

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

NOVEMBER

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

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

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

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

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

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

DECEMBER

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

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

PAPERS

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.

SPIE Smart Structures NDE (March 25-29, 2017) Portland, Ore.
Deadline: Abstracts, Sept. 12
Smart Structures NDE is a multidisciplinary conference devoted to smart sensors, nondestructive examination, bioinspired and robotics systems, electroactive polymers, civil infrastructures, and automotive and aerospace applications. Submissions are solicited in 10 technical areas, including Bioinspiration, Biomimetics and Bioreplication; Active and Passive Smart Structures and Integrated Systems; and Nondestructive Characterization for Composite Materials, Aerospace Engineering, Civil Infrastructure and Homeland Security. Contact SPIE, +1 360-676-3290, customerservice@spie.org; www.spie.org/x88673.xml.

SPIE Defense + Commercial Sensing (April 9-13, 2017) Anaheim, Calif.
Deadline: Abstracts, Sept. 26
Defense + Commercial Sensing comprises technical conferences, courses and exhibitions on sensing, imaging and photonics technologies for defense, security, industry and the environment. Focused topical tracks are agricultural applications, fiber optic sensors, pharmaceutical applications and unmanned autonomous systems. Contact SPIE, +1 360-676-3290, customerservice@spie.org; www.spie.org/conferences-and-exhibitions/defense--commercial-sensing.

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Champion golfer, renowned stargazer

It's a rare event when the worlds of professional sports and optics converge.

But that was the case last month when PGA golf pro Jimmy Walker fended off World No. 1 Jason Day in a thrilling finish to win his first-ever major — the 2016 U.S. PGA Championship.

Not long after Walker hoisted the Wanamaker Trophy, word quickly spread of the elite golfer's off-course passion: astrophotography.

It turns out that Walker, who happens to have telescope maker Celestron as one of his primary sponsors on tour, spends his spare time taking celestial images. His photographs regularly appear on NASA's "Astronomy Picture of the Day" website and include the Crescent Nebula, a cosmic bubble, the Pinwheel Galaxy, Bode's Galaxy and the Soap Bubble Nebula. His work also appears on www.darkskywalker.com.

Walker's equipment includes a 16-inch reflecting Celestron EdgeHD Pro 1400 telescope, and a CCD camera from Apogee Imaging in California. (Apogee's parent company, Andor Technology, posted very public Facebook kudos to the golfer after his PGA win.)

Telescope country club

Several years ago, Walker set up his gear at a high-altitude site in New Mexico called New Mexico Skies. In a 2014 profile posted on pga.com, Walker likened the site to a "telescope country club," home to dozens of telescopes at any given time. Organizations with instruments on the premises read like a "who's who" among the scientific and university ranks, including NASA, CalTech, Yale University and University of St. Andrews.

The observatory sits some 7,000 ft above sea level and is equipped with rain and cloud sensors that can help identify the perfect conditions for celestial viewing.

Walker can access his telescope and camera remotely via the internet to conduct imaging sessions. Images are captured in black and white, but a wheel of seven different filters helps add color back to the night sky.

Creating a single image is a lengthy process. Gathering color data can take up to four hours and another three to nine for luminance, according to information from pga.com.

"So once you add it all up, it's quite a bit of time invested in one image," Walker said. "The longer you do on an image, the cleaner it looks. It just fills in all the noise gaps and the background where there's not much signal."

Walker says the trick to creating memorable images involves practice and knowing how to get the most out of his equipment.

That advice holds true for a stellar round of golf, too.

Michael D. Wheeler
michael.wheeler@photonics.com

Astrophoto images courtesy of Jimmy Walker/Celestron.
Additional image courtesy of Celestron.


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