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February 2017

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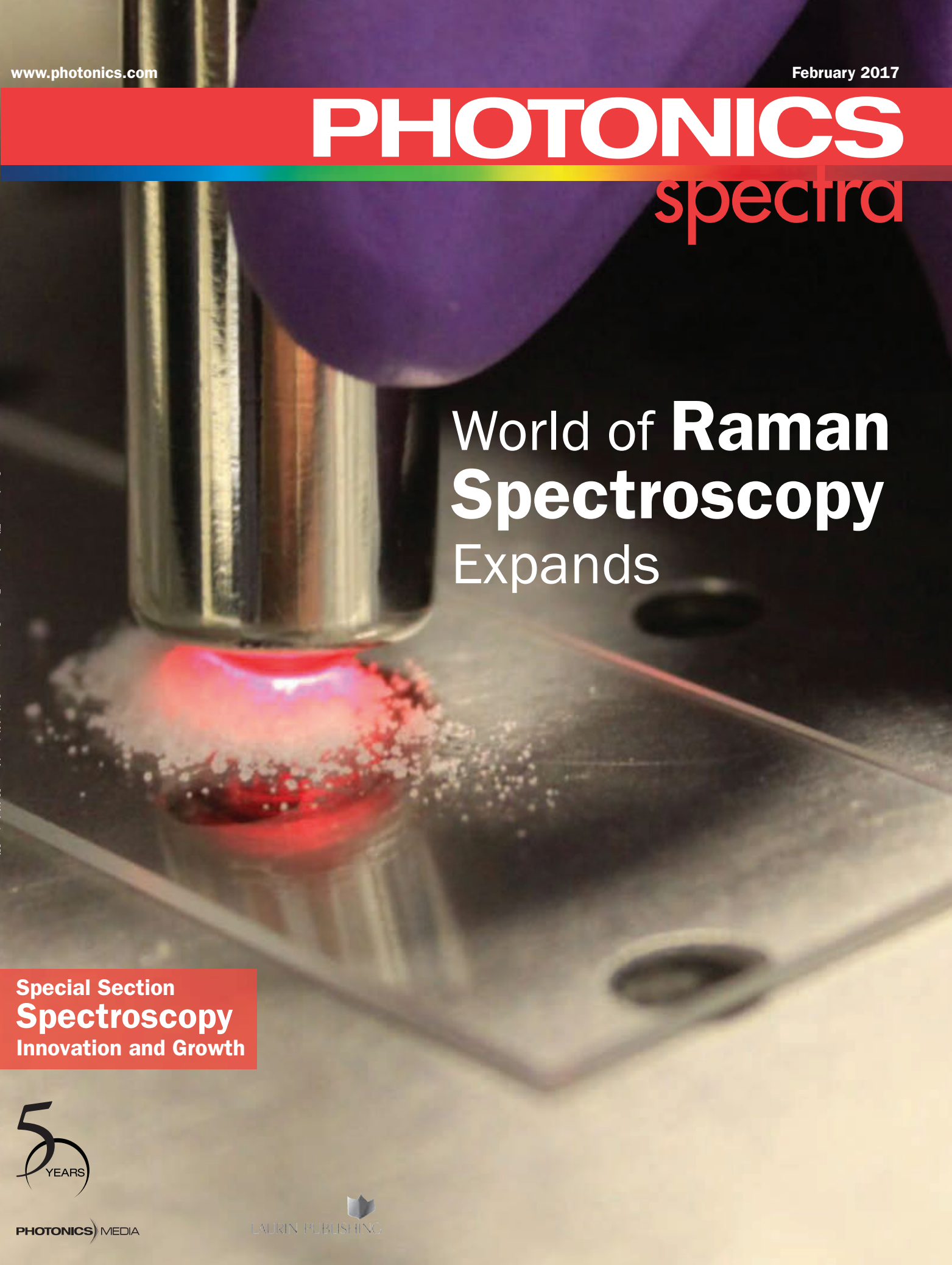

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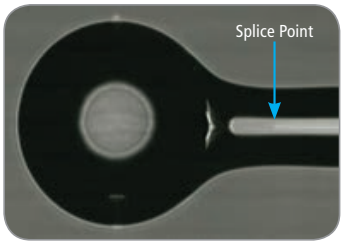
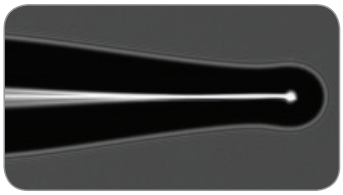
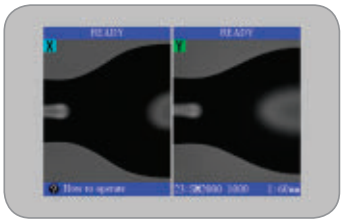


Coreless Ball Lens to
Collimate SMF Fiber Output



Tapered Probe with Small Ball End



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Departments & Columns

THE COVER
Spherical sapphire lens simplifies Raman measurement. Image courtesy of Giora Proskurowski, MarqMetrix. Cover design by Senior Art Director Lisa N. Comstock.

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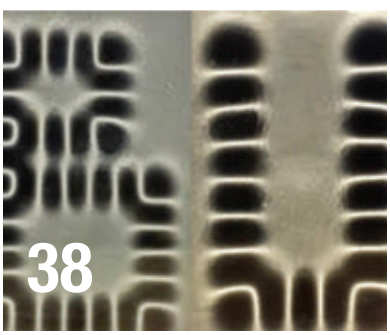
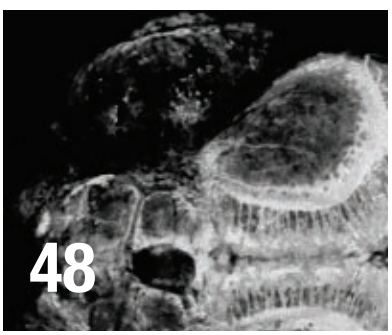
PHOTONICS: The technology of generating and harnessing light and other forms of radiant energy whose quantum unit is the photon. The range of applications of photonics extends from energy generation to detection to communications and information processing.





Features

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editorial COMMENT

Innovation at the nanoscale

Last April, Mark Zuckerberg unveiled his 10-year roadmap for Facebook. According to the plan, users of the popular social media channel can expect to see an increase in the use of high-definition video and a more prominent role for apps like Messenger and Instagram. A few years farther out, expect artificial intelligence and virtual reality to take center stage.

All of those features will call for more bandwidth. A lot more.

So it should come as no surprise that, in anticipation, the industry is aggressively pushing innovation in optical networks, including shorter and shorter links, open packet DWDM (dense wavelength division multiplexing) and an expanding role for silicon photonics. For details, don't miss Contributing Editor Hank Hogan's "Big Data Drives Optical Networking Changes," beginning on page 44.

We move from the world of big data to the world of nanomaterials in "Grapene Alignment Technique Holds Promise for Nanophotonics," on page 38. Jiming Bao and his colleagues report on a technique for aligning graphene flakes, an advance that could lead to the material's use in smart windows, solar cells and optical isolators.

Material properties are also of keen interest in laser additive manufacturing. The use of tungsten and other materials with a high thermal conductivity brings problems such as residual stress and varying mechanical strength. Jian Liu of PolarOnyx discusses the role of a femotosecond fiber laser for melting and shaping tungsten and zirconium diboride powders. See "Ultrafast Fiber Laser Opens Doors for Additive Manufacturing," on page 41.

Since its inception in 1928, Raman spectroscopy has allowed scientists to "see" a chemical fingerprint of materials. Problems often occur during sampling — which can be addressed through the use of immersion probes for testing powders, slurries and liquids. Read Brian Marquardt and Giora Proskurowski's "Spherical Lens Probes Open New Possibilities in Raman Spectroscopy," on page 34. For more on spectroscopy, don't miss this month's special section highlighted by Senior Editor Justine Murphy's "Commerce, Health and Safety Benefit From Spectroscopy," on page 54.

Finally, whether it is fluorescence microscopy for imaging living animals or label-free techniques such as anti-Stokes Raman scattering spectroscopy for imaging tumors, common among these methods is multiphoton microscopy. Researchers are calling for an increase in imaging depth and frame rate, compact femtosecond laser sources and increased resolution, to name only a few demands. See contributing editor Marie Freebody's "Optics, Tunable Lasers to Move Multiphoton Microscopy Forward" on page 48.

We hope you enjoy the issue!

Michael D. Wheeler
michael.wheeler@photonics.com

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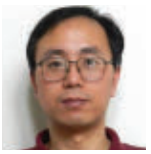
CONTRIBUTORS



Jiming Bao
Jiming Bao is with the Department of Electrical and Computer Engineering at the University of Houston, and the Institute of Fundamental and Frontier Science at the University of Electronic Science and Technology of China. Page 38.

Jian Liu
Founder and president of PolarOnyx Inc, Jian Liu pioneered and led the product development of a femtosecond laser 3D printing system. Page 41.

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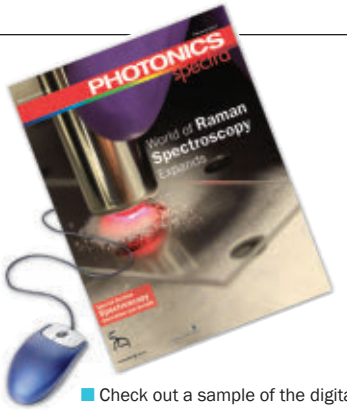

Check out a sample of the digital version of *Photonics Spectra* magazine at www.photonics.com/DigitalSample. It's a whole new world of information for people in the global photonics industry.

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What's Online:

Our free online webinars cover an impressive range of topics this month, from camera technology to high-resolution microscopy. Here's a preview:

An Introduction to Back Illuminated sCMOS Cameras

Tues., Feb. 14, at 1 p.m. EST

Scientific CMOS (sCMOS) cameras are increasingly becoming the detectors of choice for a range of quantitative imaging and spectroscopy applications. This webinar, presented by Princeton Instruments, will give you an overview of sCMOS camera technology and how it compares to CCD, EMCCD and ICCD low light imaging and spectroscopy detectors. It will cover the key improvements of "back illuminated" sCMOS technology over previous generations; performance criteria of low light detectors; and how to select the optimum detector technology based on your application requirements.

To register, visit **www.photonics.com/W117**.

Princeton Instruments

High-Speed Imaging At and Beyond the Diffraction Limit

Thurs., Feb. 16, 1 p.m. EST

Hari Shroff, Ph.D., head of the Section on High Resolution Optical Imaging at the National Institute of Biomedical Imaging and Bioengineering (NIBIB), will speak on his lab's latest work to develop high-resolution optical methods for the study of live, dynamic, 3D samples.

To register, visit **www.photonics.com/W106**.

Integrating Camera Technology Into a Successful Machine Vision Solution

Fri., March 10, at 1 p.m. EST

Imaging is a critical component of your machine vision solution, whether your field is security, manufacturing, aerospace, defense, building & construction or R&D. Rex Lee, Ph.D., CEO and president of Pyramid Imaging, Inc., is a machine vision professional with more than four decades of experience in business and academia. In this webinar he will discuss the components of a comprehensive machine vision system, including cameras, lighting, lenses, sensors and detectors, as well as how to design a system that has the components needed for optimal performance.

To register, visit **www.photonics.com/W115**.

Also coming in March

Transition Mode Reactive Sputtering Using PEM

Wed., March 15, at 1 p.m. EDT

Presented by Denton Vacuum. For more information and to register, visit **www.photonics.com/W119**.

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Osram outfits hockey players to celebrate anniversary

Light developer Osram Licht AG outfitted the Eishockeyclub Red Bull Munich professional hockey team with wearable high-tech lighting for a night event, crowning celebrations for the brand's 110th anniversary.

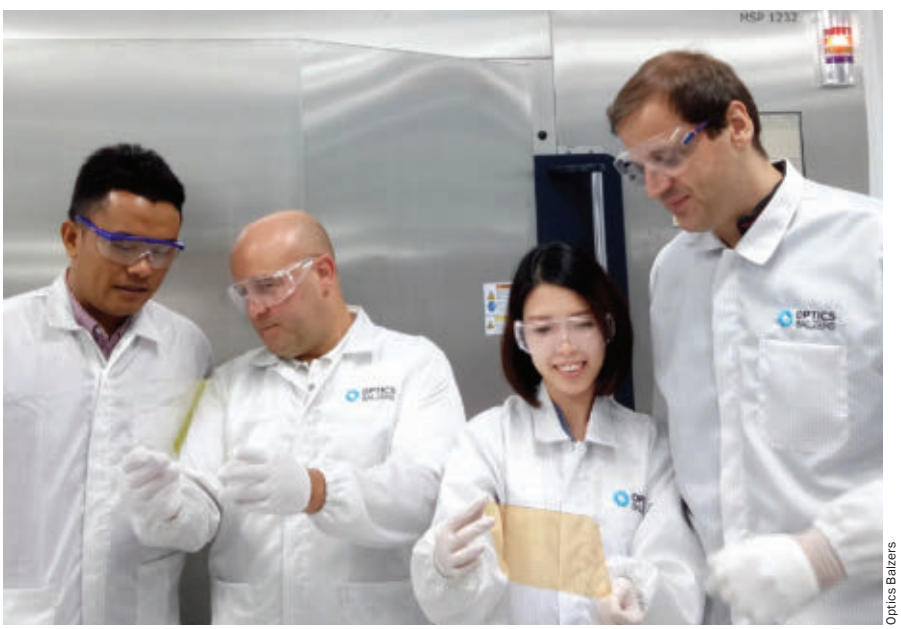
The rink and its surrounding area were illuminated by floodlights and effect lighting, with Osram unveiling its latest offering. The company will soon be introducing LED lighting integrated into fabrics. Compared with passive elements such as reflectors and signal colors, active lighting considerably improves the visibility and conspicuousness of safety clothing and sportswear. In the ice hockey game on the Zugspitze, at an altitude of just under 3000 m, this technology was exposed to extreme conditions.

The modern LEDs, integrated into the clothing, helmets and puck, are designed for tough sports and freezing temperatures. Osram has been the lighting partner of the German ice hockey champion since 2014.

Osram

Osram illuminates The Westin Excelsior Rome on occasion of the company's 110-year anniversary.

Optics Balzers opens Malaysian facility



Optics Balzers

Christian Rinner (second from left) and Matthias Warnke (far right) from Balzers are part of the transfer team. Their place of work has been relocated from Liechtenstein to Malaysia.

Optical coating and component developer Optics Balzers AG has opened a production facility in Penang, Malaysia, with 30 new employees.

"There have been various inquiries about high-quantity production projects from potential customers in Asia, and these resulted in actual orders very quickly," said Alex Vogt, CEO of Optics Balzers.

The official facility opening included a speech by the chief minister of Penang, Lim Guan Eng, who is the head of government of the Malaysian state of Penang. Vogt and his team provided guided tours of the production facilities and presented products in the showroom. A reception and traditional dragon dance concluded the festivities.

Optics Balzers is a provider of optical coatings, glass processing, patterning and bonding technologies to the manufacture of complete optical subassemblies.

• **New York State Photonics Board of Officers welcomes Samtec to AIM Photonics** •

Santa Barbara Infrared receives rights for Surrey NanoSystems' black coating

Surrey NanoSystems Ltd. has given Santa Barbara Infrared Inc. (SBIR) the exclusive rights for its ultra-black Vantablack S-VIS surface coating in blackbody calibration sources for the company's electro-optical instrumentation.

The broadband absorption of the Vantablack S-VIS makes it ideally suited to enhance the performance and utility of SBIR's precision instruments. SBIR will first use Surrey NanoSystems' U.K. facility to apply the Vantablack coating while it establishes a local facility to serve the North American defense, aerospace and electro-optical markets.

Vantablack is the world's blackest surface coating material for the UV to far-IR spectrum. It employs an innovative nanomaterial structure that absorbs virtually all incident light. Vantablack was developed for space-borne imaging applications and offers exceptional IR absorption and excellent thermal, mechanical and environmental stability.

Surrey Nanosystems is a developer of nanomaterials and, in particular, super-black coatings. Santa Barbara Infrared designs and manufactures advanced IR and electro-optical test instrumentation for military and commercial sensor systems.

GE acquires stake in Concept Laser, Arcam

General Electric Co. has announced the execution of an agreement to acquire a 75 percent stake in Concept Laser, a German manufacturer of 3D metal printing machines, allowing it to take full ownership over the next several years.

GE has also concluded its tender offer for the shares of Arcam AB, purchasing 76.15 percent of the Swedish 3D printing company. Now, with controlling shares of two important producers of additive manufacturing systems under its belt, GE has pledged to invest significant funds into the advancement of 3D printing technology, improving the portfolios of both companies.

"GE has made significant long-term commitments to both Arcam and Concept Laser to enhance their complementary technologies," said Mohammad Ehteshami, vice president for additive integration at GE Additive. "Both companies are important players in the growing additive manufacturing movement, and are foundational to GE's journey into this revolutionary manufacturing space."

AMS withdraws from NY wafer facility

Sensor manufacturer AMS AG has withdrawn from a proposed wafer fabrication facility project with the state of New York amid delays.

"We received a warm welcome from day one from the State of New York, the Utica community, Oneida County and Mohawk Valley EDGE," said Alexander Everke, CEO of AMS. "The relationship with Mohawk Valley EDGE and Empire State Development was a very positive experience, and we remain open to future opportunities for cooperation. However, this decision was taken after thorough evaluation of the wafer fabrication project and its current status."

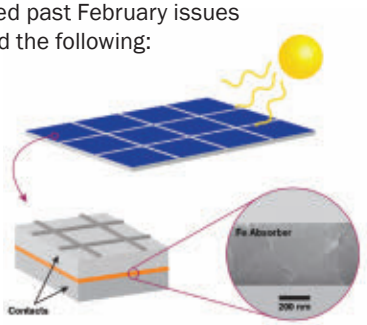
AMS develops sensors, sensor interfaces and power wireless integrated circuits for consumer, communications, industrial, medical and automotive markets.

A report by the National Academies of Sciences, Engineering and Medicine says the drop in LED prices is driving away manufacturers because of decreased profitability

This month in history

What were you working on five, 10, 20 or even 50 years ago? *Photonics Spectra* editors perused past February issues and unearthed the following:

2012



This iron germanium sulfide thin-film solar absorber could be a promising new technology for solar energy. Courtesy of Betterton Design.

2007

Conformable surfaces using novel materials (such as electrowetting display devices) are being investigated by automobile companies for dashboard and control applications. Courtesy of the University of Cincinnati.

1997

Carl Zeiss has built what it calls the world's largest ring-laser gyro. Designed for measuring the Earth's rotation, the device will be installed in a subterranean cave on the Banks Penninsula in New Zealand early this year.

1967

An external wing-mounted electronic night flash system is being produced by Chicago Aerial Industries, a subsidiary of Bourns Inc., for the Air Force. The device, which generates its own power, gives a high-intensity light for aerial reconnaissance photography in darkness.

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

CSIRO heliostats deployed to Thermal Focus

The Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia's federal government agency for scientific research, will provide its solar heliostat technology to Beijing-based Thermal Focus for concentrating solar thermal (CST) electricity generation in China.

China has announced plans to produce 1.4 GW of CST by 2018, and 5 GW by 2020, doubling the world's installed concentrated solar plants. Thermal Focus plans to manufacture, market, sell and install CSIRO's patented, low-cost heliostats, field control software and design software in China, with a shared revenue stream back to Australia to fund further climate mitigation research. CSIRO Chief Executive Larry Marshall said he was proud of CSIRO Energy's solar thermal technology team and their innovative science for the contribution it is making to support Australia's mitigation R&D.

"Australia is a leader in clean energy technology and CSIRO's partnership with China's Thermal Focus takes our climate mitigation focus to a global stage," said Marshall. "This is another great example of all four pillars of our Strategy 2020 in action: using excellent science to deliver breakthrough innovation, and through global collaboration, increasing renewable energy deliverables."

A heliostat field can represent up to 40 percent of the total plant cost. CSIRO's design features smaller than conventional heliostats and uses an advanced control system to get high performance from a cost-effective design. Its software optimizes the configuration of the heliostats prior to construction and manages each heliostat to ensure the optimum amount of reflected heat is focused on the receiver, maximizing the amount of power that can be produced.

CSIRO Australia

CSIRO's unique solar thermal heliostat technology.

$466M

— value of the global IR detector market in 2022, according to a report by Allied Market Research

Gigaphoton tests KrF excimer laser

Semiconductor lithography light source manufacturer Gigaphoton Inc. has begun testing a new krypton fluoride (KrF) excimer laser for the annealing process at large-scale liquid crystal display plants.

Testing is taking place within a mass production line at a panel manufacturer. Designed to be a high-output KrF excimer laser at 600 W, the product is expected to be an annealing light source for panel manufacturers both within Japan and abroad as demand for large-scale panels with even greater resolutions increases.

Gigaphoton is aiming to ship the first mass-produced models of the KrF excimer laser in the summer of 2017.

Gigaphoton is a developer of excimer laser, extreme UV and lithography light sources.

Gooch & Housego wins UK funding

Photonic systems developer Gooch & Housego PLC won government funding from Innovate UK and the UK National Quantum Technologies Program for its REVEAL and CASPA projects.

REVEAL aims to develop a quantum gravity sensor based on a cold atom interferometer for underground surveying in civil engineering projects. Partners include e2v Technologies Ltd., RSK Group PLC and the University of Birmingham.

The goal of CASPA (Cold Atom Space Payload) is to develop a CubeSat-compatible payload capable of producing cold atoms in space. Demonstrating this new technology in space is a vital first step toward realizing real instruments that are capable of mapping tiny changes in the strength of gravity across the surface of the earth, which could be used for resource exploration of or to monitor changes in polar ice mass, ocean currents and sea level.

"Fiber lasers are at the heart of both

projects," said Andrew Robertson, vice president of business development and head of the Systems Technology Group at Gooch & Housego. "G&H's expertise in fiber laser systems and control technology is fundamental to the effective practical deployment of cold atom technology."

Similar technology will also be used for deep space navigation and for providing higher precision timing sources for next-generation global positioning systems. Project partners include e2v, Clyde Space Ltd., XCAM Ltd., Covesion Ltd., the University of Birmingham and the University of Southampton.

Innovate UK aims to grow the U.K. economy by facilitating science and technology innovations between people, companies and partner organizations. The UK National Quantum Technologies Program translates academic work on quantum mechanics and the effects of quantum superposition and quantum entanglement into new products and services, bringing physicists and engineers together with companies and entrepreneurs who have an interest in commercializing the technology.

Teledyne Technologies to acquire e2v

Electronic component developer Teledyne Technologies Inc. will acquire technology systems developer e2v Technologies PLC.

Under the terms of the offer, e2v's shareholders will receive 275 pence in cash for each e2v share valuing the entire issued and to be issued ordinary share capital of e2v at approximately £620 million ($648 million) on a fully diluted basis. Subject to the satisfaction or waiver of all relevant conditions, the acquisition will be completed in the first half of 2017.

"Every business within e2v is highly complementary to Teledyne," said Robert Mehrabian, chairman, president and CEO of Teledyne. "As important, there is minimal product overlap. For example, we are both leaders in space and astronomy imaging, but Teledyne largely provides infrared detectors and e2v provides visible light sensors. While we both provide microwave devices, e2v's largest product and market are magnetrons for cancer radiotherapy. Teledyne supplies solid-state and vacuum microwave systems, but no magnetrons, and we primarily serve defense markets such as electronic warfare, radar and communications. However, Teledyne serves the health care market with specialized x-ray sensors."

The aggregate enterprise value for the transaction is expected to be approximately £627 million ($789 million).

$14.20B

— value of the military electro-optics and IR systems market by 2022, according to a market forecast from MarketsandMarkets Ltd.

Alpes Lasers to supply QCLs to US Air Force Intelligence project

Advanced light source developer Alpes Lasers SA has been selected as a supplier and developer of broadband quantum cascade lasers (QCLs) by several chemical sensing companies working on the Standoff Illuminator for Measuring Absorbance and Reflectance Infrared Light Signatures (SILMARILS) program.

The SILMARILS program is part of the Intelligence Advanced Research Projects Activity (IARPA) and is managed by the U.S. Air Force Research Laboratory at Wright-Patterson Air Force Base in Ohio. Alpes Lasers will develop new classes of QCLs providing high spectral power density and pulse energy in the fingerprint region of the mid-IR spectrum, which allows for specific identification of a large class of organic and nonorganic chemicals such as chemical weapons, explosives, narcotics or biological agents.

"These contracts leverage Alpes' know-how as a worldwide leader in broad gain and high power QCLs to develop new products," said Antoine Müller, CEO of Alpes Lasers. "The laser chips developed have the potential to be integrated into devices that will facilitate safety screenings in airports and can be used by law enforcement agencies worldwide."

Phase 1 of the development is expected to be completed by the end of 2017.

123,900 metric tons

— the estimated use of polycarbonate in LED lighting in 2015 according to a report by ElectroniCast Consultants

• NeoPhotonics Corp. received the 2016 Excellent Core Partner Award from FiberHome Telecommunications Technologies Co. Ltd. •

$230.6M — value of the optical time domain reflectometer market by 2021, according to forecasting firm ElectroniCast Consultants

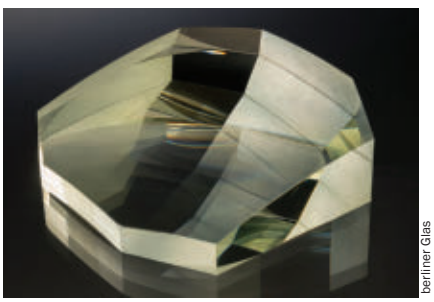
Berliner Glas used for EnMAP satellite

The Environmental Mapping and Analysis Program (EnMAP), a German Earth observation satellite mission, is using prisms from the Berliner Glas Group onboard the craft for laser communication in space.

This mission will measure sun rays reflected from the Earth's surface over a wide spectral range. The spectrometers used deliver hyperspectral data from over 240 small channels of the continuous spectrum of visible light up to NIR and create a completely new level of quality for spectroscopic observation of the Earth.

The EnMAP satellite will record data with a ground resolution of 30 × 30 m at an orbit of almost 650 km. A variable orientation of the satellite allows for comparison observations of the same location within four days. Goals of the research include the study of globally linked environmental processes and changes, the examination of the effects of human interventions into ecosystems and support for the sustainable use of natural resources.

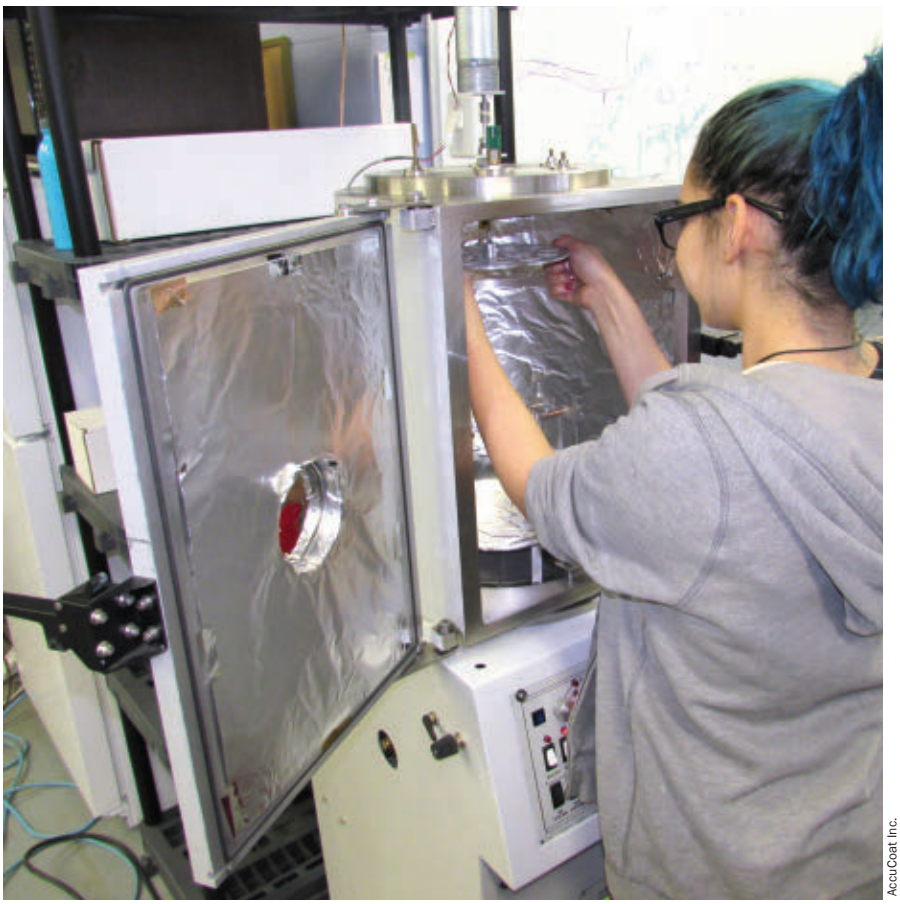
The EnMAP satellite is planned to launch in 2019.



berliner Glas

A Berliner Glas prism for EnMAP.

Coating unit, assisted by AccuCoat, installed in Rochester High School



AccuCoat Inc.

East High student loading and unloading glass from coater.

Thin-film optical coating provider AccuCoat Inc. has assisted a local high school in obtaining its own coating unit.

Sixty students per semester at East High School in Rochester, N.Y., will now reap the benefits of understanding mirror and anti-reflection coatings, as well as continuing to hone their polishing and coring skills and generating curves on optical components.

Instructor Paul Conrow, a chemist by training, was assisted by AccuCoat to source, restore, calibrate and deliver the refurbished Denton coater and fixturing to his class, with a New York State grant to fund the purchase. The restoration and installation time was donated by the AccuCoat technical team.

"AccuCoat has been phenomenally welcoming, and has gone out of its way to make their facility available to the class," Conrow said. "Keeping a diverse group of kids interested in learning this process is part of the daily challenge, and having the coater in the classroom itself is a huge help. Having a tangible, useful outcome of a coating run is key."

AccuCoat has been coating on polymer, glass, crystal and metal optics to military-grade specifications for manufacturing and R&D groups around the globe.

"One of [the] ways that Rochester will continue to succeed in the optics world is the addition of East's graduates into the mix. We are pleased to have been able to facilitate the use of this coater for the Precision Optics program," said Paul Meier-Wang, co-founder of AccuCoat. "East High currently has a precision optics manufacturing lab that no high school in the nation has. We look forward to seeing its graduates in the local optics and photonics companies."

New AIM Photonics test, assembly and packaging facility

The American Institute for Manufacturing Integrated Photonics (AIM Photonics) named Eastman Business Park, in Rochester, N.Y., as the new home of its Test, Assembly and Packaging (TAP) manufacturing facility. The site was selected in an open process organized by the state.

The selected site is known as Building 81 and is on Lake Avenue across from the Kodak Research Laboratories. ON Semiconductor owns the building and will lease excess clean room, lab and office space for the TAP facility.

Dolores Kruchten, president of Eastman Business Park, said, "We look forward to collaborating with AIM Photonics, ON Semiconductor and the Rochester area community to build a new technology ecosystem, based on our innovative past and our vision for the future."

The site's location near Kodak Research Laboratories and over 50 acres of developable industrial land provides significant expansion opportunity.

PEOPLE IN THE NEWS


Fisba AG

Optical systems developer Fisba AG has appointed former CEO **Werner Kruesi** as its U.S. managing director. Kruesi brings more than 60 years of experience in the photonics industry. He served as Fisba CEO for over 20 years at the company's headquarters in Switzerland. For his new position as U.S. managing director, Kruesi relocated to Tucson, Ariz., but remains a member of the company's board of directors. Fisba is a developer of customized optical components, systems and microsystems.


Sandia

Sandia National Laboratories technologist **Michael F. Lopez** has received the American Vacuum Society's (AVS) Thin Film Division Distinguished Technologist Award for his exceptional technical support of thin-film research and development. Lopez joined Sandia in 1994 and was promoted to distinguished technologist 10 years later. He has been a major contributor in the design, layout, fabrication, installation and check-out of high-vacuum equipment used to manufacture neutron tubes and switch tubes for generators. The New Mexico Chapter of the AVS created and endowed the national award to honor its founders and their contributions.

Peter Takacs, a physicist in the instrumentation division at the U.S. Department of Energy's (DOE) Brookhaven National Laboratory, has been named a fellow of the Optical Society (OSA). Takacs is among the 96 OSA members who the society's board of directors selected to be part of the 2017 fellow class for their significant contributions to the advancement of optics and photonics. OSA highlighted Takacs' "outstanding original contributions to grazing incidence optical metrology instrumentation, theory, practice and standards applied to x-ray optics for synchrotrons, free electron lasers and space instrumentation, setting the pace for major development over three decades." Brookhaven National Laboratory is supported by the Office of Science of the DOE. The Office of Science is the single largest supporter of basic research in the physical sciences in the United States.

Tsutomu Ogasawara has succeeded Taro Sasada as managing director of turnkey solutions manufacturer Instrument Systems GmbH. Since 2012, Ogasawara has been responsible for the launch of Instrument Systems products on the Japanese market on the part of Konica Minolta. The 47-year-old chemist brings over 25 years of experience in various sales-oriented functions at Konica Minolta in Japan and Germany. Instrument Systems develops, manufactures and markets turnkey solutions for light measurement with scanning and array spectrometers, as well as imaging photometers and colorimeters.


Trioptics GmbH

Stefan Krey

Optical measurement instrument developer Trioptics GmbH has appointed **Stefan Krey** as an additional managing director. Krey will be directing the company's development with **Eugen Dumitrescu** and Steffan Gold. He received his degree in physics and his Ph.D. from the University of Hamburg, and started off as a developer for the SpectroMaster product at Trioptics in March 2000. Since then, Krey has co-designed numerous product development projects and established the angle measurement. He was appointed the chief technology officer in 2003. Trioptics is a developer of optical measurement, inspection and manufacturing technology for development, quality control and production.


PI

Scott Jordan **(left)** and PI's vice president of Sales & Marketing, Stephane Bussa **(right)**.

Physik Instrumente GmbH & Co. KG (PI) has appointed **Scott Jordan** as head of the photonics market segment. Jordan, a PI Fellow, holds both a bachelor's and master's degree in physics from the University of California, Irvine, and an MBA in finance and new venture management from the University of Southern California. Jordan has several patents related to fast alignment techniques and was central in the development of PI's Multi-Channel Photonics Alignment System, a novel, modular, industrial-class system that automates silicon photonic alignments for packaging and test. PI is a leading manufacturer of precision motion control equipment, piezo motors, air bearing stages and hexapod parallel-kinematics.

BAE Systems provides specialized weapon sights to Army

The U.S. Army has awarded BAE Systems a seven-year contract worth up to $384 million to provide specialized weapon sights that improve soldiers' ability to quickly and accurately engage targets at extended ranges. The Family of Weapon Sights-Crew Served (FWS-CS) system uses high-resolution sensors and lightweight laser rangefinders that wirelessly transmit weapon sight imagery to a helmet-mounted display in real time.

"Supplying the Army with crew served, gunner-specific weapon sights builds on our heritage as a longtime provider of weapon sight solutions," Marc Casseres, director of Imaging and Aiming Solutions at BAE Systems, said. "Our innovative 12-µm sensor technology allows us to provide soldiers with superior clarity and range to dominate the battlefield through increased situational awareness in all operational environments and conditions."

The BAE Systems-developed FWS-CS long-range infrared sight is designed for the 0.50 caliber M2, 7.62-mm M240 machine gun, and the Mk 19 automatic grenade launcher. With an initial development order of $10.5 million, work will be performed at the company's facilities in Hudson, N.H., and Austin, Texas.

BAE Systems

BAE Systems will provide the U.S. Army with high-resolution thermal weapon sights under the Family of Weapon Sights-Crew Served program.

Sener, Thales Alenia Space sign business agreement

Engineering and technology group Sener and space systems developer Thales Alenia Space have signed an agreement to execute a joint business plan that will develop the Spanish space industry with the manufacturing of optical payloads.

The strategic agreement — signed by Thales Alena Space's CEO, Eduardo Bellido; Thales Alenia Space France's vice president for Science and Earth Observation, Hervé Hamy; and Sener's Space and Defense director, Diego Rodríguez — aims to develop the necessary capacities to lead the optical observation instruments sector in Spain, endorsing the pre-agreement signed in March 2016 by both companies.

The alliance was created with the intent of developing a national leader in Spain and a European reference in optical observation instruments, using the companies' experience in multiple scientific and Earth observation programs.

Sener

Sener and Thales Alenia Space execute joint business venture.

Sener is an engineering and technology group for the engineering, aeronautics and energy industries. Thales Alenia Space Spain is a designer, developer and marketer of advanced space systems and equipment.

Plasmonics simplify printing and imaging in color and IR

DURHAM, N.C. — A new manufacturing technique promises to bring a simplified form of multispectral imaging into daily use. Using existing materials and production approaches that are scalable and inexpensive, Duke University researchers have found a way to print and image across a range of colors extending into the infrared.

Maiken Mikkelsen, the Nortel Networks assistant professor of Electrical and Computer Engineering and Physics at Duke University, said it's a challenge to create sensors that detect both the visible spectrum and the infrared.

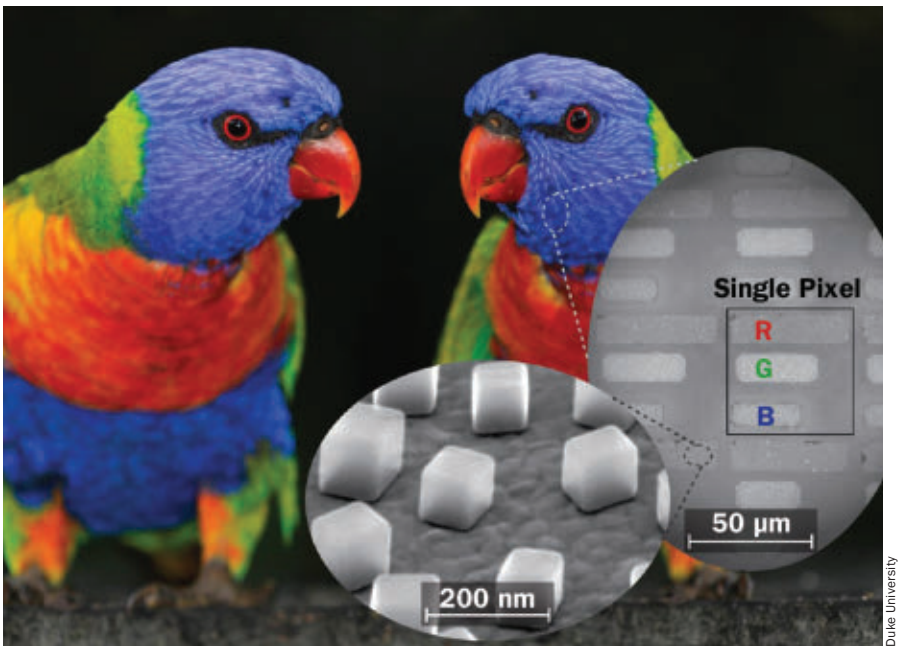
"Traditionally you need different materials that absorb different wavelengths, and that gets very expensive," Mikkelsen said. "But with our technology, the detectors' responses are based on structural properties that we design rather than a material's natural properties. What's really exciting is that we can pair this with a photodetector scheme to combine imaging in both the visible spectrum and the infrared on a single chip."

The novel technology relies on plasmonics — the use of nanoscale physical phenomena to trap certain frequencies of light. With plasmonics, engineers create silver cubes just 100 nm wide and place them only a few nanometers above a thin gold foil. When incoming light hits a nanocube, it excites the silver's electrons and traps the light's energy — but only at a certain frequency.

The size of the silver nanocubes and their distance from the base layer of gold determines that frequency, while controlling the spacing between the nanoparticles allows tuning the strength of the absorption. By tailoring these spacings, researchers can make the system respond to any specific color they want, from visible to infrared.

Current imaging technology is bulky and expensive. Duke University researchers and engineers were tasked to create a device that was not only useful, but scalable and inexpensive.

Jon Stewart, researcher and graduate student, said, "We've come up with a fabrication scheme that is scalable, doesn't need a clean room and avoids using million-dollar machines, all while achieving higher frequency sensitivities.



Duke University

Researchers tested a new technique for printing and imaging in both color and infrared with this image of a parrot. The inlay shows how a simple RGB color scheme was created by building rectangles of varying lengths for each of the colors, as well as individual nanocubes on top of a gold film that create the plasmonic element.

Maiken Mikkelsen, Duke University

A close-up of the colorful parrot picture printed on a thin gold wafer using the new nanocube-based technology. The colors appear off because of the underlying gold, as well as the difficulties that typical cameras have of imaging the new technology.

It has allowed us to do things in the field that haven't been done before."

To build a detector, Mikkelsen and Stewart used a process of light etching and adhesives to pattern the nanocubes into pixels containing different sizes of silver nanocubes. Each nanocube is sensitive to a specific wavelength of light. When incoming light strikes the array, each area responds differently depending on the wavelength to which it is sensitive. By teasing out how each part of the array responds, a computer can reconstruct the original color of the light.

The technique can be used for printing as well.

"The exciting part is being able to print in both visible and infrared on the same substrate," said Mikkelsen. "You could imagine printing an image with a hidden portion in the infrared, or even covering an entire object to tailor its spectral response."

Instead of creating pixels with six sections tuned to respond to specific colors, they created pixels with three bars that reflect three colors: blue, green and red. By controlling the relative lengths of each bar, they can dictate what combination of colors the pixel reflects.

Plasmonics help make the end product scalable, more affordable, and the color scheme will not fade over time. Researchers say images can be reproduced to create color schemes in the infrared.

The entire study appeared in *Advanced Materials* (doi: 10.1002/adma.201602971).

Multi-conjugate adaptive optics device offers widest real-time views of the sun

BIG BEAR, Calif. — A groundbreaking new optical device has been developed to correct images of the sun previously distorted by multiple layers of atmospheric turbulence.

The device developed at the New Jersey Institute of Technology's (NJIT) Big Bear Solar Observatory (BBSO) is providing scientists with the most precisely detailed, real-time pictures to date of solar activity occurring across vast stretches of the star's surface.

Philip Goode, research professor of physics at NJIT and the leader of an international team of researchers funded by the National Science Foundation (NSF) to develop this next-generation optical system, said the observatory's 1.6-m New Solar Telescope can now produce simultaneous images at approximately the same time across large structures.

"To understand the fundamental dynamics of the sun, such as the origin of solar storms, we need to collect data from as wide a field of view as possible," said Goode. "Only by seeing the comprehensive array of eruptions all at once will we be able to accurately measure the size, strength and sequencing of these magnetic events and also analyze the forces that propel the star's magnetic fields to twist around each other until they explode, spewing massive amounts of radiation and particles that, when directed earthward, can cause disruptive space weather."

The multi-conjugate adaptive optics (MCAO) device sits downstream of the aperture of the BBSO telescope, currently the world's highest-resolution solar telescope. The system is composed of three mirrors that change shape to correct the path of the incoming light waves, guided by a computer attached to ultrafast cameras that take more than 2000 frames per second to measure aberrations in the wave path. The system is called multi-conjugate because each of the three mirrors captures light from a different altitude — near the ground and at about three and six miles high — and the three corrected images together produce a distortion-free picture that eliminates the effects of turbulence up to about seven miles.

The MCAO system has tripled the size of the corrected field of view now available with the current technology, known as adaptive optics, which employs a single shape-shifting, or deformable, mirror to correct images.

"The gain of using three deformable mirrors instead of one is easily visible. The images are crisp in a much larger area," said Dirk Schmidt, a post-doctoral researcher at the National Solar Observatory (NSO) and project scientist for the international MCAO team.

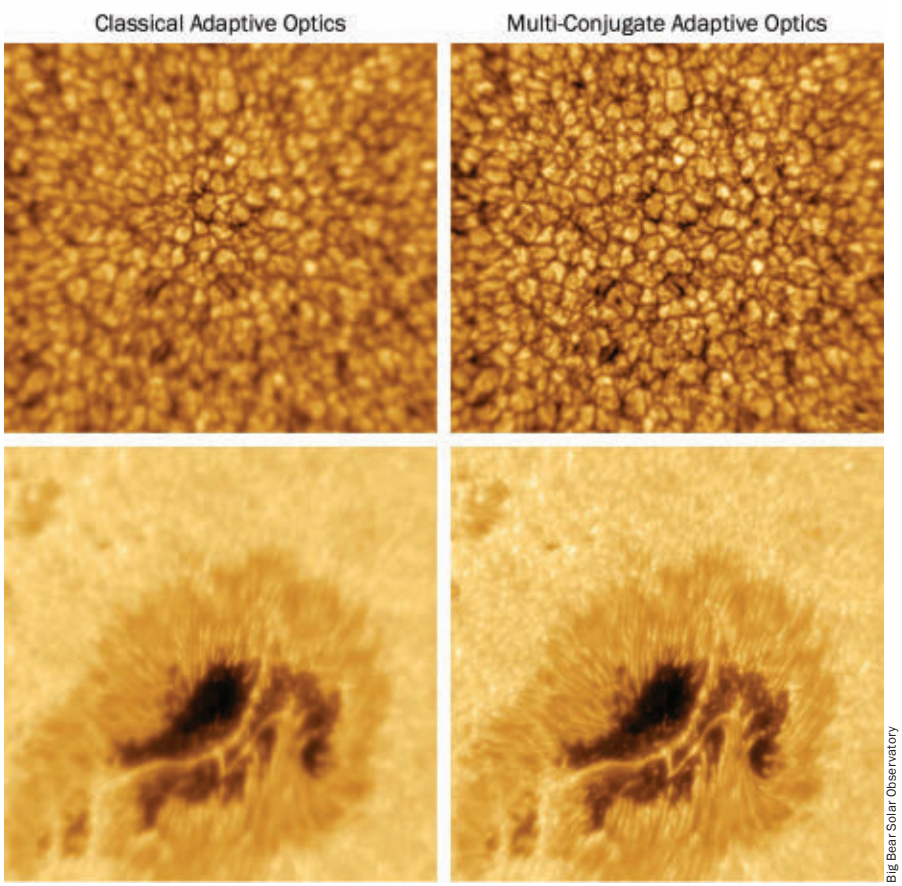
Turbulent airflows at different layers of the Earth's atmosphere — from the ground up to the jet stream — change the path of the sun's light faster than the human eye can compensate, blurring the images captured by conventional telescopes.

The MCAO team, which includes researchers from NJIT, NSO and the Kiepenheuer Institute for Solar Physics in Germany, has been working together for more than a decade on the next generation of adaptive optics to correct these distortions.

The researchers succeeded in significantly widening the field of view after several years of alternating laboratory experimentation — with an artificial light source functioning as the sun that emitted light waves purposefully distorted by the heat emanating from hot plates — with "on-sky" tests performed in real time in the BBSO's optical path.

"Finally, late last July, we saw what we had long sought — a continuous stream of sharp, wide-field corrected but essentially identical images," said Goode. "We then repeated the test several times by looking at various places on the sun to prove we had succeeded. The final trick was narrowing the field to get a deeper-focused correction with each mirror, much like you would adjust a camera to have the near and far field in focus."

The scientific gains are expected to be



Big Bear Solar Observatory

Recent images taken from Big Bear Solar Observatory of a massive section of the sun's surface — about 23,000 square miles — showcase the advances in real-time clarity over vast distances presented.

multi-level. A clearer, more comprehensive view of solar activity should provide additional clues to researchers seeking to explain mysterious dynamics, such as the means by which explosions on the sun produce magnetic explosions and radiation and accelerate particles to nearly the speed of light within seconds. Andrew Gerrard, director of NJIT's Center for Solar-Terrestrial Research, which operates the BBSO and several other solar instruments around the world and in space, noted that the more scientists understand physical processes taking place more than 90 million miles away, the better policymakers will be able to predict and prepare for solar storms with the ferocity to disrupt communications satellites, knock out GPS systems, shut down air travel and quench lights, computers and telephones in millions of homes and businesses.

The MCAO project also serves as a critical test of optical instruments that will be required by future solar telescopes.

The findings have been published in the journal *Astronomy & Astrophysics* (doi: 10.1051 /0004-6361/201629970).

Ultrastrong coupling achieved between light and matter

WATERLOO, Ontario — An ultrastrong coupling between photons and qubits 10 times larger than ever seen before may open the door to a domain of physics and applications deemed unattainable until recently.

Researchers at the University of Waterloo's Institute for Quantum Computing (IQC) are investigating light-matter interactions in quantum optics. For their research, they fabricated aluminum circuits and then cooled them in dilution refrigerators to one percent of a degree above absolute zero, making the circuits superconducting and able to carry a current without resistance or loss of energy. These superconducting circuits/qubits obey the laws of quantum mechanics and behave as artificial atoms.

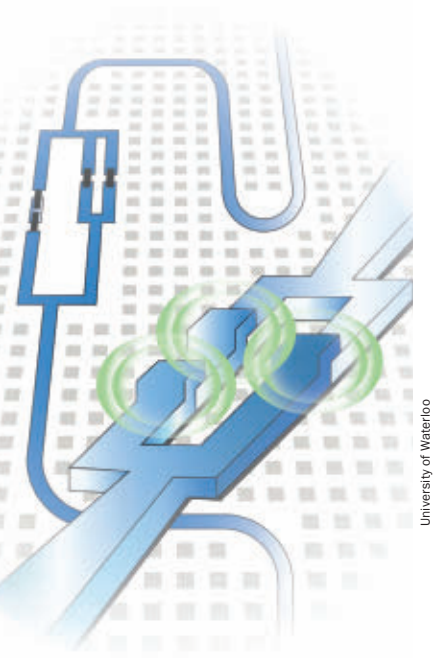
Researchers then applied a small magnetic field through a coil inside the dilution refrigerator and sent photons using microwave pulses into the superconducting circuit. By measuring photon transmissions, they were able to define the resonance of the qubit by the reflection of the photons off the qubit.

IQC researcher and postdoctoral student Pol Forn-Diaz said the team measured a range of frequencies broader than the qubit.

"This means there is a very strong interaction between the qubit and the photons," said Forn-Diaz. "It is so strong that the qubit is seeing most of the photons that propagate in the circuit, which is a distinctive signature of ultrastrong coupling in an open system."

The IQC team's research coupled with their circuit could potentially act as a quantum simulator propelling even more research and study of quantum systems in nature.

The research was published in *Nature Physics* (doi:10.1038/nphys3905).

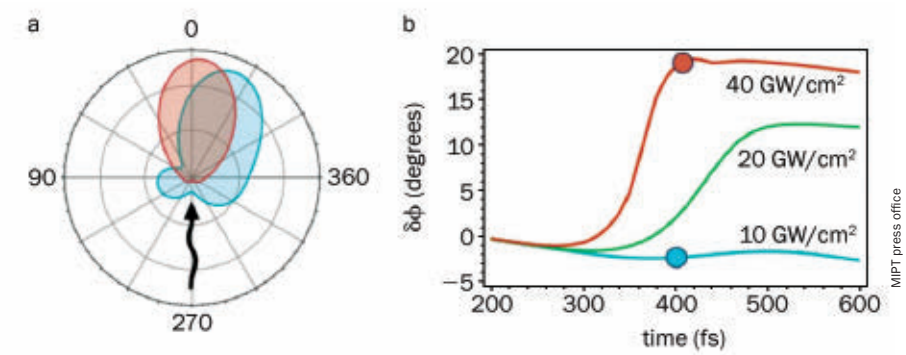


University of Waterloo

This illustration shows a qubit attached to a waveguide where light in the form of microwaves enters and exits.

Silicon nanoantennas turn light around

MOSCOW — Light is rather hard to control, as photons have neither mass nor electric charge. Devices such as nanoantennas can control the propagation of electromagnetic waves, but only to a certain degree.



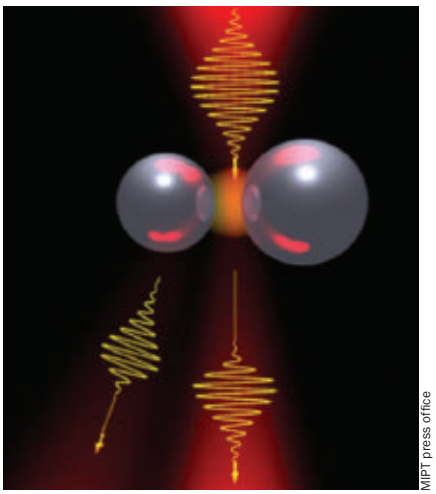
MIPT press office

The simulation results of nonlinear light scattering by a nanoantenna of two silicon particles.

A proposed nonlinear optical nanoantenna that can be manipulated will operate at 250 Gbps, shining light, so to speak, on the development of optical computers where information is carried by photons, rather than electrons, greatly increasing the speed of transmitting and processing information.

Physicists from ITMO University in Saint Petersburg, Russia; the Moscow Institute of Physics and Technology (MIPT); and the University of Texas at Austin have developed an unconventional nanoantenna of sorts that can scatter light in a particular direction depending on the intensity of incident radiation.

Using silicon nanoparticles, which gen-



MIPT press office

An artist's rendering of nonlinear light scattering by a dimer of two silicon particles with a variable radiation pattern.

erate electron plasma under harsh laser radiation, researchers demonstrated the possibilities of using these nanoparticles for nonlinear and ultrafast control of light. They were initially successful in manipulating the scattered light radiation both forward and backward. Now, they have found that by changing the intensity of incident light they can turn the scattered light beam in a desired direction.

Researcher and MIPT postgraduate student Denis Baranov said their nanoantenna is different than existing optical nanoantennas that can control light in a fairly wide range.

"This ability is usually embedded in their geometry and the materials they are made of, so it is not possible to configure these characteristics at any time," said Baranov. "The properties of our nanoantenna, however, can be dynamically modified. When we illuminate it with a weak laser impulse, we get one result, but with a strong impulse, the outcome is completely different."

With the weak laser pulse, the scientists found that the light scattered sideways. When the nanoantenna was illuminated with an intense laser pulse, leading to the production of electron plasma within the device, the scattering pattern rotated by twenty degrees.

To rotate the radiation pattern of the nanoantenna, the researchers used the mechanism of plasma excitation in silicon. They used two silicon nanospheres of unequal diameters; one particle is resonant at the wavelength of the laser light and the other remains nonresonant.

Sergey Makarov, a senior researcher at the Department of Nanophotonics and Metamaterials at ITMO University said their focus leans toward the development of a nanoscale optical chip measuring much less than the wavelength of a photon at less than 200 × 200 × 500 nm.

"The new device will allow us to change the direction of light propagation at a much better rate compared to electronic analogues," said Makarov. "Our device will be able to distribute a signal into two optical channels within a very short space of time, which is extremely important for modern telecommunication systems."

This type of advanced light manipulation via the proposed nanoantenna is crucial for the development of optical computers.

The research was published in *Laser & Photonics Reviews* (doi: 10.1002/lpor.201600164).

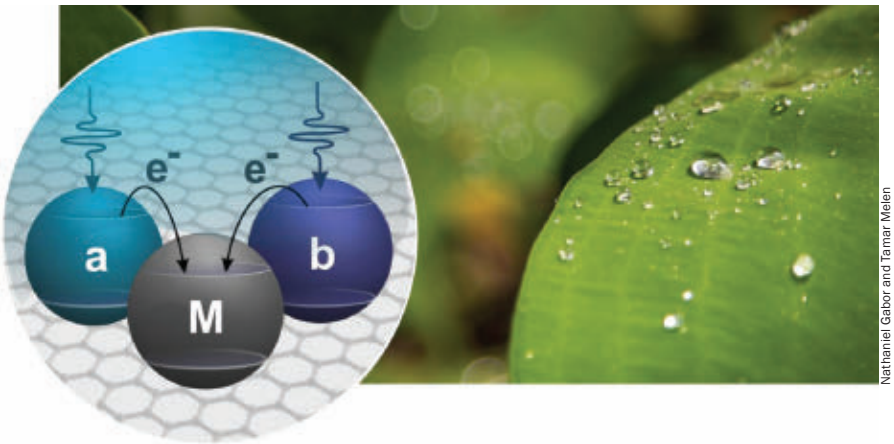
Quantum photocell could boost solar cell efficiency

RIVERSIDE, Calif. — A novel type of quantum heat engine photocell, which can help control the flow of energy in solar cells, could increase solar cell efficiency. The photocell has demonstrated the ability to regulate solar power conversion without requiring active feedback or adaptive control mechanisms. In contrast, conventional photovoltaic systems require voltage converters and feedback controllers to suppress fluctuations in solar power.

Researchers from the University of California, Riverside (UCR), set out to design a simple photocell that could match the amount of solar power generated to the average power demand, and suppress energy fluctuations to avoid the accumulation of excess energy.

"Plants have evolved to do this, but current affordable solar cells — which are at best 20 percent efficient — do not control these sudden changes in solar power," said primary researcher Nathaniel Gabor. "That results in a lot of wasted energy and helps prevent widescale adoption of solar cells as an energy source."

The researchers compared the theoretical minimum energy fluctuations in nanoscale quantum heat engine photocells: one in which the photocell absorbed one color of light, and the other in which the photocell absorbed two colors. They found that fluctuations were naturally suppressed in the two-channel photocell. Essentially, one channel absorbed at a wavelength at which the average input power was high, while the other channel absorbed at a wavelength at which the average input power was low. The photocell switched between high and low power to convert varying levels of solar energy into a steady-state output.



Nathaniel Gabor and Tamar Melen

In a light harvesting quantum photocell, particles of light can efficiently generate electrons. When two absorbing channels are used, solar power entering the system through the two absorbers **(a and b)** efficiently generates power in the machine **(M)**.

When the team applied its models to the measured solar spectrum on Earth's surface, it discovered that the absorption of green light, the most radiant portion of the solar power spectrum per unit wavelength, provided no inherent regulatory benefit, a finding that led them to reject green light for use in a photocell whose primary role would be the regulation of energy flow.

The team optimized the photocell parameters to reduce solar energy fluctuations and found that the absorption spectrum was nearly identical to that observed in photosynthetic green plants. This discovery led the researchers to propose that the natural regulation of energy found in the quantum heat engine photocell could play a role in photosynthesis, possibly accounting for the predominance of green as a plant color.

Unrelated research has shown that some molecular structures in plants, including chlorophyll a and b molecules, could be important in preventing plants from accumulating excess energy. The molecular structure of the quantum heat engine photocell was found to be similar to the structure of photosynthetic molecules that incorporate pairs of chlorophyll.

Gabor and his team are potentially the first to connect quantum mechanical structure to the greenness of plants. Their work provides a set of tests for researchers aiming to verify natural regulation of solar energy. Additionally, their design allows regulation without active input, a process made possible by the photocell's quantum mechanical structure.

The research was published in *Nano Letters* (doi: 10.1021/acs.nanolett.6b03136).

Max Grossnickle and QMO Lab

Nathaniel Gabor's Laboratory of Quantum Materials Optoelectronics utilizes infrared laser spectroscopy techniques to explore natural regulation in quantum photocells composed of two-dimensional semiconductors.

Solar cells processed at room temperature could cut costs of wearable devices

Christopher Moore, Georgia Tech

Ph.D. researcher Vladimir Kolesov holding an electrically doped polymer film.

ATLANTA — A simple solution-based electrical doping technique could help reduce the cost of polymer solar cells and organic electronic devices, and help move organic photovoltaics into a new generation of wearable devices.

Researchers at the Georgia Institute of Technology (Georgia Tech), the University of California at Santa Barbara, Kyushu University in Japan, and the Eindhoven University of Technology in the Netherlands developed the technique that provides a new way of inducing p-type electrical doping in organic semiconductor films. Their process involves briefly immersing the films in a solution at room temperature; this could replace more complex techniques that require vacuum processing.

Bernard Kippelen, director of Georgia Tech's Center for Organic Photonics and Electronics, said, "Our hope is that this will be a game-changer for organic photovoltaics by further simplifying the process for fabricating [a] polymer-based solar cell."

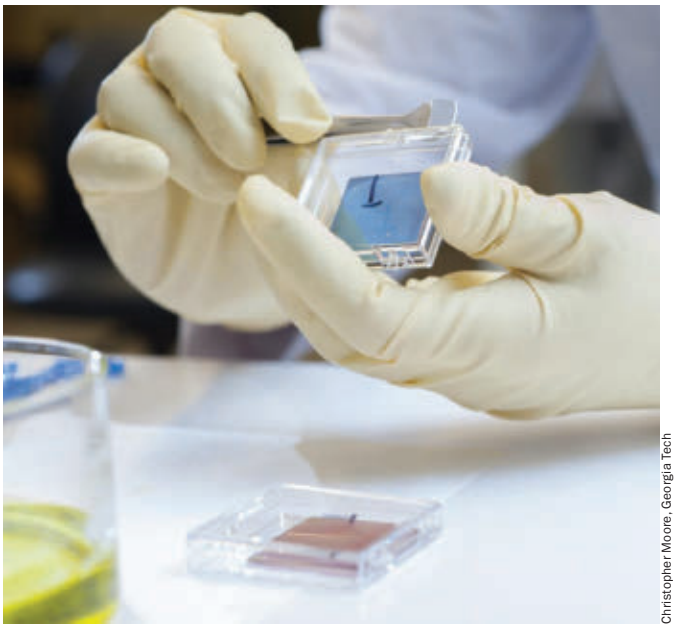
Kippelen and his colleagues believe this new technique could impact other device platforms in areas such as organic printed electronics, sensors, photodetectors and LEDs.

The technique consists of immersing thin films of organic semiconductors and their blends in polyoxometalate (PMA and PTA) solutions in nitromethane for a few minutes. The diffusion of the dopant molecules into the films during immersion leads to efficient p-type electrical doping over a limited depth of 10 to 20 nm from the surface of the film. The p-doped regions show increased electrical conductivity and high work function, reduced solubility in the processing solvent, and improved photo-oxidation stability in air.

For the first time, single-layer polymer solar cells were demonstrated by combining this new method with spontaneous vertical phase separation of amine-containing polymers that leads to efficient

Christopher Moore, Georgia Tech

Close-up of a polymer film on a glass substrate before immersion in a polyoxometalate solution to electrically dope the film over a limited depth.



Christopher Moore, Georgia Tech

Polymer films used in polymeric solar cells doped by the new solution-based electrical doping technique.

electron collection at the opposing electrode.

Senior research scientist Canek Fuentes-Hernandez said the geometry of these new devices is unique, as the functions of hole and electron collection are actually built into the light-absorbing active layer, resulting in the simplest single-layer geometry with few interfaces.

"The realization of single-layer photovoltaics with our approach enables both electrodes in the device to be made out of low-cost conductive materials," said Fuentes-Hernandez. "This offers a dramatic simplification of a device geometry, and it improves the photo-oxidation stability of the donor polymer."

Ph.D. student Felipe Larrain hopes the new technique will allow fabrication of solar cells in areas that lack capital-intensive manufacturing capabilities.

"Our goal is to further simplify the fabrication of organic solar cells to the point at which every material required to fabricate them may be included in a single kit that is offered to the public," Larrain said. "The solar cell product may be different if you are able to provide people with a solution that would allow them to make their own solar cells. It could one day enable people to power themselves and be independent off the grid."

The research done between these universities is different from others in that they are processing the films at room temperature.

"Being able to process solar cells entirely at room temperature using this simple solution-based technique could pave the way for a scalable and vacuum-

free method of device fabrication, while significantly reducing the time and cost associated with it," said Vladimir Kolesov, a Ph.D. researcher.

Lifetime and cost analysis studies are still needed to assess the full impact of these innovations.

The research was sponsored by the Office of Naval Research and appeared in the journal *Nature Materials* (doi:10.1038/nmat4818).

Single device can function as both a laser and anti-laser

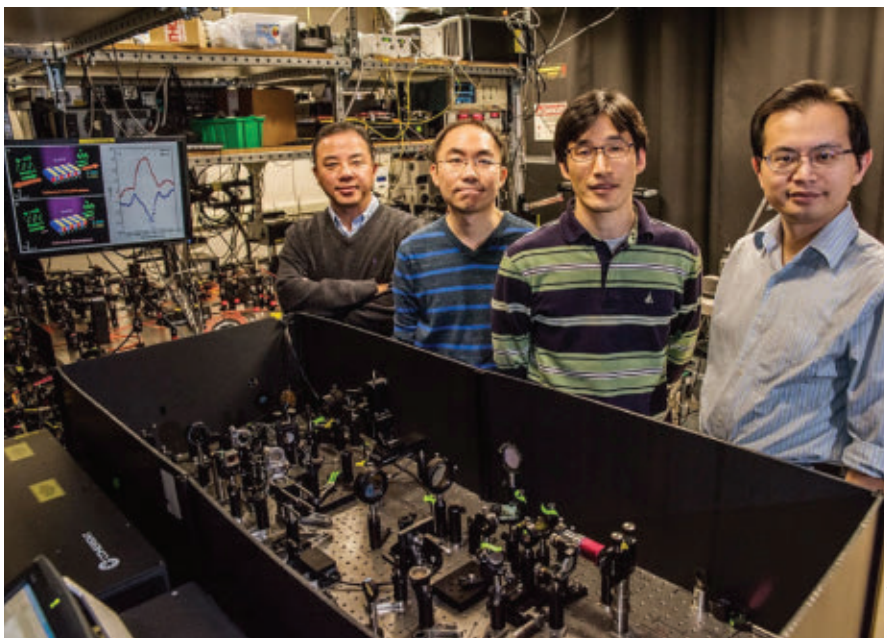
BERKELEY, Calif. — An integrated device that demonstrates lasing and anti-lasing at the same frequency in a single cavity has been developed using parity-time symmetry. The lasing and anti-lasing resonances that were demonstrated share common resonant features such as identical frequency dependence, coherent in-phase response and fine spectral resolution. Lasing and anti-lasing in a single device could offer a novel path for enabling light modulation with high contrast approaching the ultimate limit.

To form the device, which measures 200 µm long and 1.5 µm wide, a research team at Lawrence Berkeley National Laboratory built 824 repeating pairs of gain and loss materials using nanofabrication technology. The gain medium was made out of indium gallium arsenide phosphide (InGaAsP), a material commonly used as an amplifier in optical communications. The loss medium was formed by pairing chromium (Cr) with germanium (Ge). The team repeated this pattern to create a resonant system in which light bounces back and forth throughout the device to build up the magnitude of amplification (or absorption).

"In a single optical cavity we achieved both coherent light amplification and absorption at the same frequency, a counter-intuitive phenomenon because these two states fundamentally contradict each other," said senior faculty scientist Xiang Zhang. "This is important for high-speed modulation of light pulses in optical communication."

In experiments, researchers directed two light beams of equal intensity into opposite ends of the device. They found that by tweaking the phase of one light source, they were able to control whether the light waves spent more time amplifying or absorbing materials.

Speeding up the phase of one light source resulted in an interference pattern favoring the gain medium and the emission of amplified coherent light, or a lasing mode. Conversely, slowing down the phase of one light source resulted in more time spent in the loss medium and the coherent absorption of the beams of light, or an anti-lasing mode.



Marilyn Chung/Berkeley Lab

(From left) Berkeley researchers Xiang Zhang, Zi Jing Wong, Jeongmin Kim and Yuan Wang stand next to the optical setup they designed to demonstrate both lasing and anti-lasing in a single device.

If the phase of the two wavelengths was equal and the wavelengths entered the device at the same time, neither amplification nor absorption occurred, because the light occupied each region for an equal amount of time.

The magnitude of the gain and loss, the size of the building blocks, and the wavelength of the light moving through the device combine to create conditions of parity-time symmetry.

When the system is balanced and the gain and loss are equal, there is no net amplification or absorption of the light. But if conditions are perturbed such that the symmetry is broken, coherent amplification and absorption can be observed.

"This work is the first demonstration of balanced gain and loss that strictly satisfies conditions of parity-time symmetry, leading to the realization of simultaneous lasing and anti-lasing," said professor Liang Feng at the University of Buffalo. "The successful attainment of both lasing and anti-lasing within a single integrated device is a significant step toward the ultimate light control limit."

The researchers targeted a wavelength of about 1556 nm, which is within the band used for optical telecommunications. The device has the flexibility to operate as a laser, an amplifier, a modulator, and an absorber or detector.

"On-demand control of light from coherent absorption to coherent amplification was never imagined before, and it remains highly sought after in the scientific community," said researcher Zi Jing Wong. "This device can potentially enable a very large contrast in modulation with no theoretical limits."

The research was published in *Nature Photonics* (doi: 10.1038/nphoton.2016.216).

1.3-nm photodetector can generate more current than thicker devices

DAEJEON, South Korea — A photodetector that is ten times smaller than current standard silicon diodes has been developed using molybdenum disulfide (MoS_2) sandwiched between two graphene sheets. The 2D device, which has just one layer of MoS_2, demonstrated the ability to produce more photocurrent than comparable multilayered devices, even though it absorbed less light.

To discover the reason for this surprising result, researchers from the Institute of Basic Science (IBS) compared photovoltaic devices with one layer of MoS_2 with devices with seven layers of MoS_2, and tested how well the devices were able to convert light into an electric current. Researchers found that although the device with one layer of MoS_2 absorbed less light than the one with seven layers, it had higher photoresponsivity.

"Usually the photocurrent is proportional to the photoabsorbance; that is, if the device absorbs more light, it should generate more electricity, but in this case, even if the one-layer MoS_2 device has smaller absorbance than the seven-layer MoS_2, it produces seven times more photocurrent," said researcher Yu Woo Jong.

The results could not be explained through classical electromagnetism; but an explanation could be found in quantum physics. The thinner device could generate more current because it had more electrons flowing in the same direction. When light hit the devices, some electrons from the MoS_2 layer entered an excited state and flowed through them, producing an electric current. In order to pass through the boundary between MoS_2 and graphene, the electrons needed to overcome an energy barrier. This was done through quantum tunneling.

Theoretical modeling showed that asymmetric potential barriers in the top and bottom interfaces of the graphene/one-layer MoS_2/graphene heterojunction enabled asymmetric carrier tunneling, causing high photoresponsivity in the one-layer MoS_2 device.

The bottom SiO_2 layer of the devices increased the energy barrier, while the air on top reduced the barrier. This gave the electrons in the monolayer device a higher probability of being able to tunnel from the MoS2 layer to the top layer of graphene (GrT). In the monolayer device, the energy barrier at the GrT-MoS_2 junction was lower than the barrier at the junction of the bottom graphene layer (GrB) and MoS_2; so the excited electrons transferred preferentially to the GrT layer and created an electric current.

In contrast, in the multilayer MoS_2 device, the energy barriers between the GrT-MoS_2 and the GrB-MoS_2 junctions were symmetric. Therefore, the electrons in the multilayer device had the same probability of going to either side, which had the effect of reducing the probability of generating current.

Another reason why the thicker device could not generate more current is that electrons and the "holes" they create when they enter an excited state move

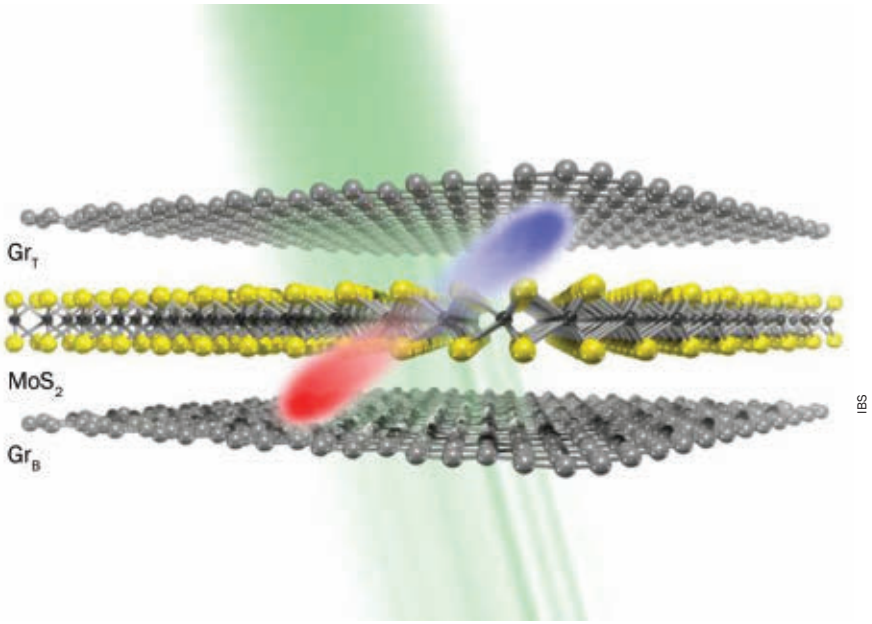
slowly through the junctions between graphene and MoS_2, leading them to recombine within the MoS_2 layer in an undesirable way.

Spectral-dependent studies further showed that the internal quantum efficiency in one-layer MoS_2 could reach a maximum of 65 percent, compared to seven percent in seven-layer MoS_2.

"This device is transparent, flexible and requires less power than the current 3D silicon semiconductors. If future research is successful, it will accelerate the development of 2D photoelectric devices," said Yu.

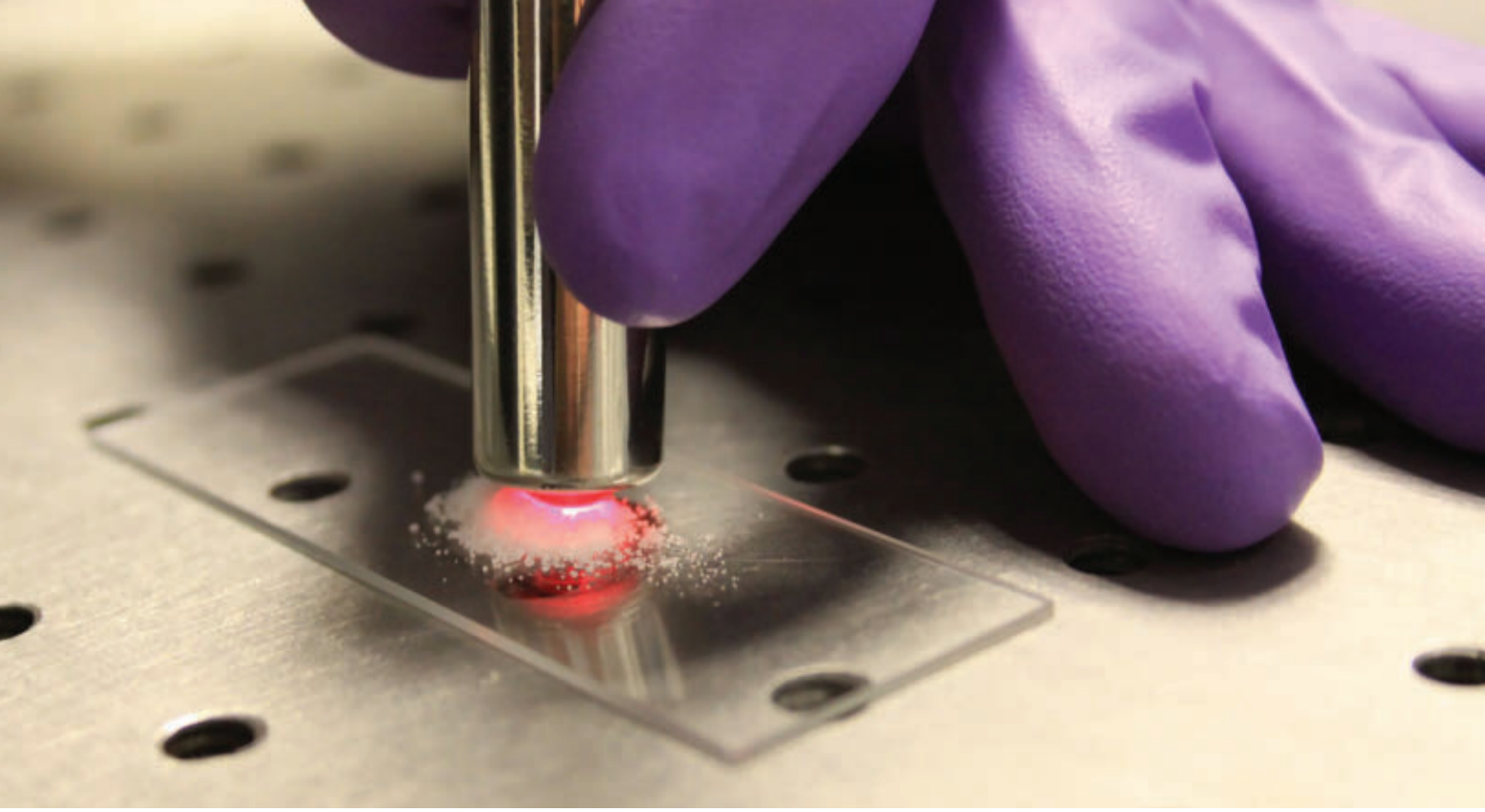
The novel device could be used in applications such as the Internet of Things, smart devices, wearables and optoelectronics.

The research was published in *Nature Communications* (doi:10.1038/ncomms13278).



IBS

Illustration of the device with the molybdenum disulfide (MoS_2) semiconductor layer sandwiched between top (GrT) and bottom (GrB) graphene layers. Light **(green ray)** is absorbed and converted into an electric current. When light is absorbed by the device, electrons **(blue)** jump into a higher energy state and holes **(red)** are generated in the MoS_2 layer. The movement of holes and electrons created by the difference in electronic potential between the GrT-MoS_2 and the GrB-MoS_2 junctions generates the electric current.



A powder measurement, as shown here, can be traditionally challenging for Raman measurement as the particle size can impact the measurement setup. With a spherical sapphire lens, there is no need to change accessories for different substrates, yet the user will achieve equal performance.

Spherical Lens Probes Open New Possibilities in **Raman Spectroscopy**

Immersion probes offer advantages for testing powders, solids, slurries and liquids.

BY BRIAN MARQUARDT AND
GIORA PROSKUROWSKI, MARQMETRIX INC.

Since its inception in 1928, Raman spectroscopy has allowed scientists to see a chemical "fingerprint" of material. Using light, substances are identified by the way specific wavelengths interface with a sample and are scattered. Pioneered by Sir C.V. Raman 90 years ago using simple sunlight with a series of filters to read a sample, Raman spectroscopy has evolved to become an information-rich measurement technique.

The advent of the laser in the 1960s significantly boosted the effectiveness and sensitivity of Raman spectroscopy, however not without challenges still present. Raman is a weak effect and the challenge has been separating the inelastically scattered light from the intense Rayleigh-scattered laser light. To overcome this, modern instrumentation utilizes high-performance edge filters and notch filters for laser rejection. Additionally, because of the weak effect, Raman features can be masked by photoluminescence; however, scientists have found that utilizing multiple laser excitation systems to switch between excitation wavelengths optimizes Raman features when fluorescence may be present.

Other challenges with Raman spectroscopy are due mainly to optical sampling. In some cases the sampling container or slide will interfere with the measurement, returning spectra for the container as opposed to the intended sample. When utilizing higher-power lasers to increase the Raman signal, the sample can be damaged. All types of samples have a laser power density threshold, and operating below that threshold will protect the sample integrity and the resulting measurements. While Raman measurements can be made with any excitation source, standard wavelengths for Raman are 532, 633, 785, 993 and 1064 nm, primarily determined by the common availability of stable lasers at those wavelengths.

Even with the aforementioned challenges, Raman remains a robust measurement technique for accurate identification and quantification. Unlike most spectroscopic methods, Raman can be a quantitative technique, as the amount of inelastically scattered light is directly related to the concentration of the analyte causing the scattering. Another powerful aspect of Raman spectroscopy is that water is a relatively low Raman scatterer, meaning that the signal from water has minimal effect on the analyte signal. With the right sample interface, the Raman technique is largely insensitive to sample type, so no sample handling or preparation is required. Lastly, Raman is nondestructive; the sample is not consumed during the measurement process.

Traditional Raman measurements require the user to gauge and adjust the focal distance, which can lead to variation in the measurement results. For example, a scientist would move the sample up and down, much like a microscope platform, until the signal was maximized. Even with proper training and equipment, this focusing sequence can be a subjective process requiring active decisions leading to unavoidable sampling reproducibility errors.

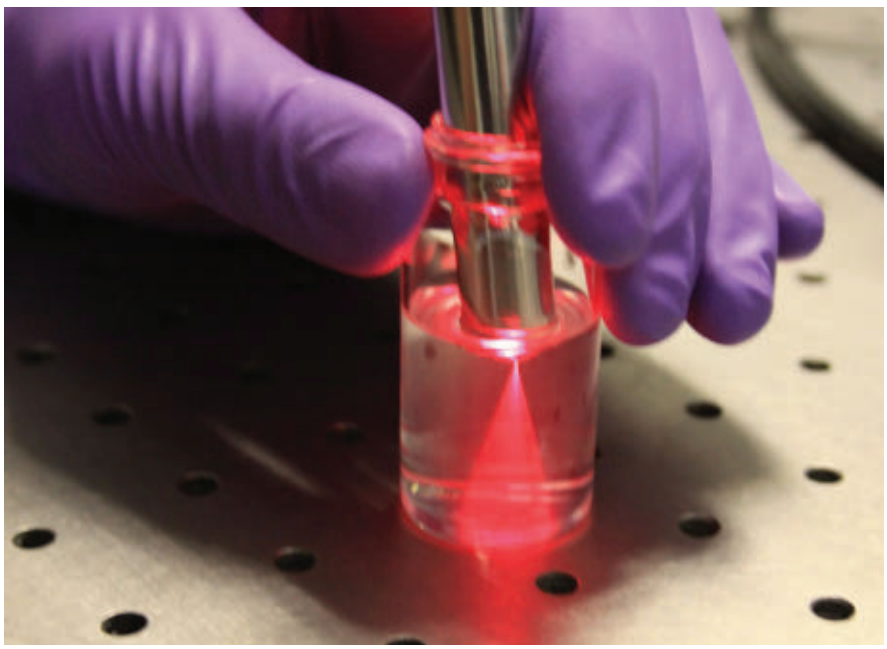
Another focusing technique involves using a visual imaging camera with the probe. With this technique there is a camera imaging the object or sample while the user adjusts the sample position into focus visually. Once focus has been achieved in the camera image, a Raman measurement is performed. The challenge with this method is that many times the focal distance of the camera is not the same as the focal point of the Raman laser. In effect, this technique still requires the operator to manually focus before each measurement.

Eliminating sampling error

Recent advancements in Raman instrumentation include probes that feature a spherical lens. With any data measurement process, reliability and repeatability are paramount and something scientists are always keen to improve. Reliability of Raman measurements is dependent upon the laser power density; adding curvature to the instrument lens focuses the laser into a tighter area after it is fired. Originally, when developing the spherical lens Raman probe, the goal was to concentrate the laser for tight focus. During development, it became apparent that sampling errors due to the variable focal distance could be eliminated by touching the lens directly to the sample. And because of the curvature, the "touch" takes place at the tangent of the sphere, exactly where the optical focus is located.

The lens material also needed to be durable and resistant to scratching for the probe to work in "touch" mode. Therefore, sapphire spherical optics were employed because sapphire is one of the hardest optical materials, second only to diamond. The challenge was finding optically pure sapphire free of impurities that can have intense Raman signals that can interfere with sample measurement. UV-grade sapphire offers the lowest levels of chromium and titanium impurities on the market.

With the combination of a spherical lens and sapphire material, the measurement-to-measurement reproducibility has been demonstrated to less than 0.1 percent relative standard deviation when measur-



Today's Raman instrumentation provides accuracy, versatility and flexibility for capturing qualitative and quantitative data and can be used in many different environments.

A recent advancement in Raman instrumentation is the MarqMetrix TouchRaman BallProbe, which features a spherical lens, shown above. The lens is made with UV-grade sapphire for its rugged interface and purity.

Images courtesy of Giora Proskurowski, MarqMetrix.

ing titanium dioxide concentration in a latex paint application. These results were considerably less than the sampling error, ~2 percent, calculated when focal adjustments were performed manually.

The optical train, including the lens, fixes the focal length at the tangent of the sphere, regardless of the sample type or sample form. This leads to a Raman measurement device where the user simply has to touch the sample to take the measurement.

Testing powders, slurries and liquids

Raman spectroscopy has had historical challenges with efficiency and accuracy across different sample types partially because samples had to be pure or in a single state to mitigate interference and produce repeatable measurements. Immersion probe technology was designed to address these issues, broadening the value of use across different sample mediums, such as powders, solids, slurries, liquids and gasses, specifically to mitigate error and improve reliability of the measurement.

Looking at liquids specifically, Raman BallProbe technology is valuable for analyzing heterogeneous solutions. As long as the mixture is touching the spherical lens, the user will obtain accurate and precise sample data. In the case of small volume samples, the spherical lens probe is effective at measuring the sample contents without interference from the container — for example, well plates and low-volume vials. Granular materials and powders can be especially challenging for traditional standoff Raman measurements as particle size can impact the measurement setup. The common approach is to require the user to fill a glass vial with the powder and measure through the glass.

With the spherical sapphire lens, there is no need to change accessories for different substrates, and the user will achieve equal performance. Additionally, the touch interface allows the laser to lead directly into the sample, mitigating scatter. The sphere generates the focus right at the tangent of the optic. So while a flat window probe would work well in immersion, the measurement result would vary quite dramatically when measuring a powder due to light scattering in different directions. Traditional flat-lensed Raman probes typically include several accessories that must be used to accommodate measurements of various sample types, such as a vial holder for powders, a fixed focal spacer for solids and a sealed optic for immersion.

With the advancements of the spherical sapphire lens in probes, measurement is simplified to "if a user can see and touch the sample, they can measure it," without having to adjust the probe type or the focal distance. The probe separates the scientist from the measurement, improving sampling and measurement reproducibility.

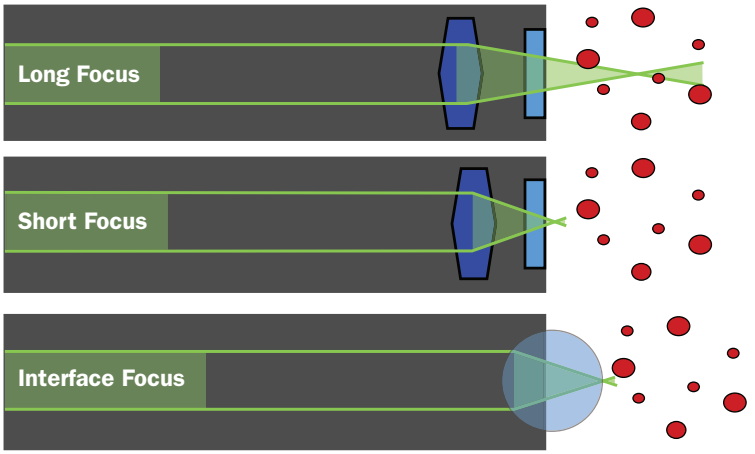
No fouling of the device

The spherical interface of this technology minimizes fouling or sample buildup. Unlike flat optics where fouling begins at the edge of the optic and grows into the center, the spherical lens on the probe is self-cleaning at the tangent of the sphere — right where the measurement occurs. This technology has made Raman more accessible for process sampling and in situ measurements.

Spherical probes have been installed in process environments that are challenging with respect to flow and fouling, including wet granular materials and fluidized beds. In one case, the device ran continuously for 18 months without maintenance after replacing a traditional probe that fouled within two weeks of initial installation.

Taking it to the field

Not all measurements can take place in a laboratory or controlled setting and the benefits of Raman spectroscopy should not be limited to the lab. Challenges with suboptimal measurements — even when using optical spacers or adapters to control focal distance — have discouraged the use of the technology. Raman was often shelved or not used in these applications because it was too time-consuming to ensure the best measurements. A recent user of a quality control application in cosmetics nearly abandoned using Raman because the technique did not meet the needs of the company when implemented outside the R&D laboratory. When the BallProbe was installed as the sample interface, the production line results began



Particulates/Bubbles
- Reduces throughput.
- Decreases signal/noise.

Partial Solution
- Optically move working distance and depth of field.
- Still problems with solids and slurries.

Solution
- Ball lens allows sampling directly on face (tangent) of optic.
- Distance, depth of field and phase boundary are well controlled.

to match the expectations developed by the R&D team.

Another challenge in the field can be extreme conditions, especially when considering the petrochemical and oil and gas industries. Developing a high-pressure probe that can withstand 20,000 psi and 500 degrees Celsius was a logical evolution once it was realized that the sapphire lens could withstand and operate effectively in extreme conditions. Probes are available for use in high-pressure (up to 25,000 psi) and temperature applications.

Greater flexibility, broader applications

Raman spectroscopy is a superior measurement technology because of the flexible sampling interface, high sampling rate and high spectral specificity. Today's Raman instrumentation provides accuracy, versatility and flexibility for capturing qualitative and quantitative data. It can be used in many different environments as an analytical tool for the study of solids, powders, slurries, liquids and gases. A Raman instrument interfaced with a fiber-coupled probe has the versatility and flexibility for measurements to be made in situ for the monitoring of processes.

An instrument with a sapphire sphere as the measurement interface is a recent technological advancement that further improves the usability and accessibility for Raman measurement. New applications for the technology because of the rugged interface and reliability include measuring hydrothermal vents at the bottom of the ocean to high-temperature, high-pressure environments in the oil and gas industry. When working with high-value materials and small sample sizes, such as in pharmaceuticals, the anti-fouling properties and ability to measure in-situ mitigate waste of raw materials, providing a more valuable measurement option. New applications are being developed and technologies continue to advance in the world of Raman.

A Raman instrument interfaced with a fiber-coupled probe, as shown here, gives it the versatility and flexibility for measurements to be made in situ for the monitoring of processes. Unlike flat optics, where fouling is a challenge, the spherical interface minimizes sample buildup.

Meet the authors

Brian J. Marquardt, Ph.D., is the co-founder of MarqMetrix, an optical sensor and instrumentation company focused on industrial process measurement and control. He is also the director of the Center for Process Analysis and Control and senior principal engineer at the Applied Physics Laboratory at the University of Washington. Research interests include the development and application of spectroscopic instrumentation, primarily Raman and LIBS, for continuous real-time chemical, biological and environmental analysis.

Giora Proskurowski, Ph.D., is the director of MarqMetrix Raman Applications and Probes, which includes applications development and management of the BallProbe product line. Before joining MarqMetrix in 2014, he spent a decade working on oceanographic instrument development, production and deployment. His research focused on the biogeochemistry of deep-sea hydrothermal vent volatiles and the distribution and chemistry of plastic marine debris.

Graphene Alignment Technique Holds Promise for **Nanophotonics**

New method controls the orientation of individual nanomaterials, which may soon lead to advances in LEDs, solar cells, smart windows and optical isolators.

BY JIMING BAO AND FENG LIN,
UNIVERSITY OF HOUSTON, AND
JONATHAN HU, BAYLOR UNIVERSITY

Nanomaterials, such as nanowires and nanotubes, are designed to have quantum confinement in one or two dimensions so that their properties in other dimensions can be engineered, differing from that of their corresponding bulk material. As such, the unique and superior properties of nanomaterials are always associated with their shape and symmetry.

Consider graphene. A single layer of graphene absorbs about 2.3 percent of incident light, but this is only valid for incident light normal to the graphene plane; the absorption becomes zero when the electrical field of light is perpendicular to the plane. Understanding the anisotropic properties of nanomaterials is important for device applications with composite materials or functional devices that involve hundreds of thousands of individual nanomaterials.

Equation.

$$\tau = M \times B, \tau = m\ \chi\ B \sin(\theta)\ B \cos(\theta) = \tfrac{1}{2}\ m\ \chi\ B2 \sin(2\theta).$$

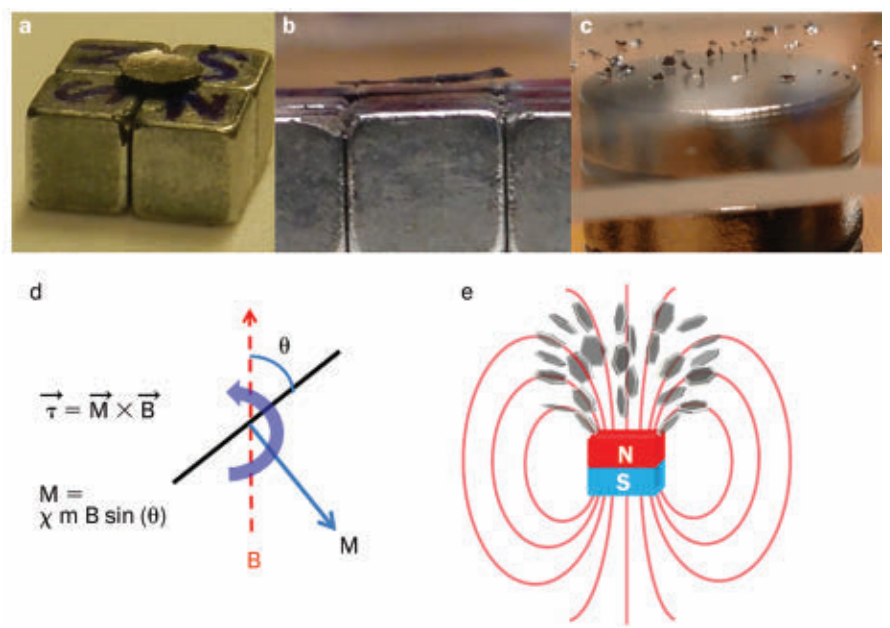


Figure 1. Levitation and rotation of graphite or graphene flakes by magnetic field. Magnetic levitation of a piece of highly ordered pyrolytic graphite (HOPG) on neodymium magnets with alternating up-facing poles **(a)**. Magnetic levitation of a disk made of multilayer graphene flakes **(b)**. Alignment of multilayer graphene flakes with a vertical magnetic field on the surface of a neodymium magnet **(c)**. Torque experienced by a graphene flake under a uniform magnetic field **(d)**. Schematic of graphene flakes aligned with magnetic field of a magnet **(e)**.

A case in point: If suspended graphene flakes in a solvent are randomly oriented, they appear isotropic macroscopically, and unique properties of graphene disappear. Only when they are aligned can their unique properties be utilized and transferred to large-scale devices.

The orientational control and assembly of nanomaterials is an integral part of nanotechnology that has led to recent research on the structured assembly of nanowires and nanotubes. The alignment of graphene and related device applications has also been reported recently by several groups, but it was achieved by using either shear stress or magnetic nanoparticles. The alignment of graphene by magnetic field has been theoretically studied, but a large magnetic field of 9 Tesla was required.

In contrast, the authors recently demonstrated magnetic alignment of graphene using a weak field from commercial neodymium magnets[1] — results made possible by large micro-sized flakes and their excellent diamagnetic susceptibility.

Magnetic response

Graphene and graphite are typically considered nonmagnetic materials, but they exhibit the highest diamagnetic susceptibility, second only to superconductors. Such large diamagnetism is a result of the magnetic response of in-plane orbital electrons, which circle around the

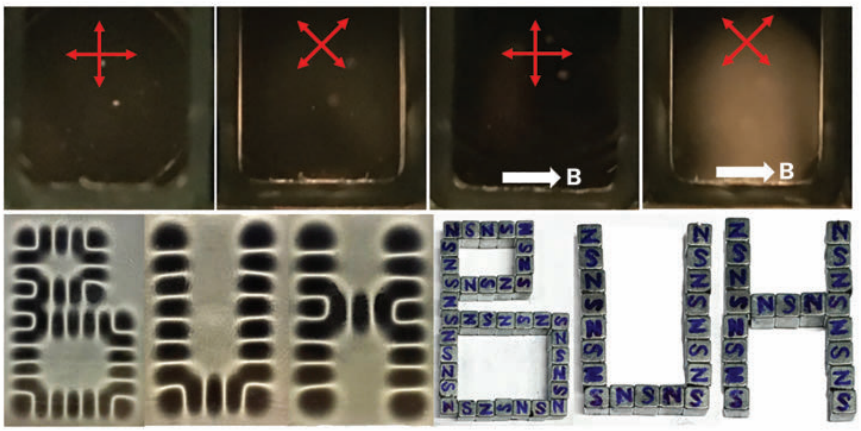


Figure 2. Birefringence and magnetic field sensing/display of aligned graphene flakes. Optical transmission of suspended few-layer graphene through two cross-polarized filters without and with a magnetic field **(top)**. Red arrows indicate direction of polarization. Letters "B", "U" and "H" of magnets displayed by a suspension of multilayer graphene flakes **(bottom)**.

When graphene flakes are aligned parallel to the substrate, they are highly reflective. These properties enable them to find wide photonic applications such as optical isolators, lasers, light-emitting devices, solar cells, smart windows and smart screens.

external field due to the so-called Lorentz force, and subsequently induce a magnetic field in an opposite direction to the applied field, resulting in a repelling force between a magnet and graphene.

A convenient and interesting demonstration of a strong diamagnetism is magnetic levitation (Figure 1a). Such levitation is made possible by another unique property: very low density of graphite. Graphene's magnetic susceptibility can be tested in the same way. Figure 1b shows the levitation of a graphene disk made of multilayer graphene flakes by drying of graphene suspension. The levitation indicates that the sample is dominated by the intrinsic diamagnetism as opposed to potential ferromagnetic impurities. Note that a stable levitation cannot be achieved by a single magnet. When a graphene flake is placed on a magnet, it will either lay flat on the surface, or stand on its edge (Figure 1c). Such response is a consequence of anisotropic diamagnetism (Figure 1d). A vertical magnetic field induces a magnetic moment M, which is normal to graphene surface and points opposite to B. $M = m \chi B \sin(\theta)$, where m is the mass of graphene flake, χ is the diamagnetic susceptibility. The torque experienced by the flake is given by the equation on the facing page. Based on this equation, the torque always makes θ smaller; in other words, it turns the flake aligned with the magnetic field. The torque is zero when θ is zero and 90°, and it reaches the maximum at 45°. Note the repulsive force is zero in such a uniform magnetic field, and the orientation is not stable when the flake is perpendicular to the field. Figure 1e illustrates the alignment of graphene flakes with the magnetic field of a magnet. It is important to point out that the total control of flake orientation in a three-dimensional arrangement requires another perpendicular magnetic field.

The macroscopic alignment of suspended graphene flakes can be confirmed using birefringence imaging. This is because a flake is optically anisotropic like a liquid crystal rod molecule. The top panels in Figure 2 show the appearance of birefringence after the application of a lateral magnetic field. The flakes are randomly oriented and the suspension is optically isotropic without magnetic field so that optical transmission through two cross-polarized filters is very weak.

Graphene flakes as reflective mirrors

Maximum transmission when two polarizers are rotated 45° relative to the magnetic field confirms the alignment of flakes with the field. The magnetic alignment can be most easily observed where no special light illumination and polarizers are needed (Figure 2). The bright and dark features correspond to the region where the magnetic field between two magnets

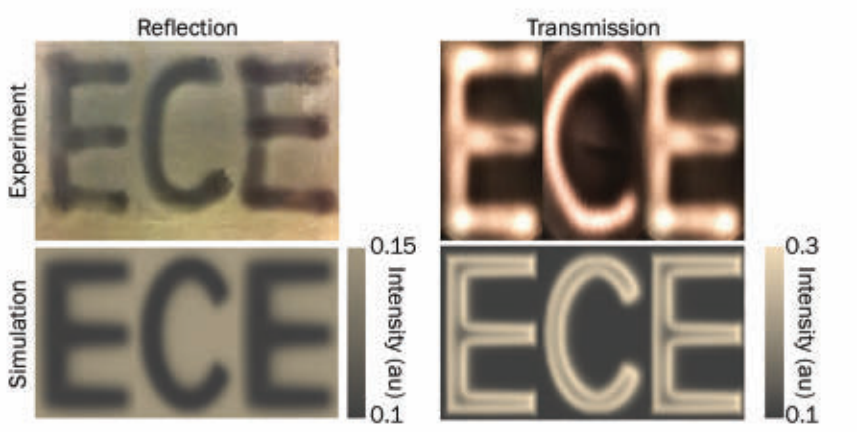


Figure 3. Reflective and transmissive displays of "ECE" written by a magnet rod made of stacked cubic neodymium magnets seen in Figures 1 and 2. Optical pictures **(top)**, simulations.**(bottom)**.

Images courtesy of **Jiming Bao, University of Houston.**

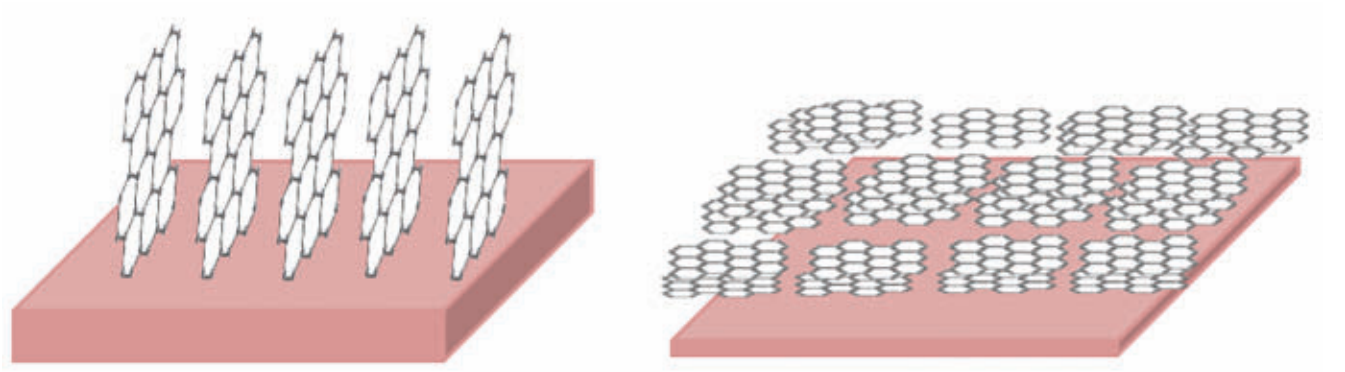


Figure 4. Two alignment configurations for device applications. Flakes perpendicular to the substrate **(left)**. Flakes parallel with the substrate **(right)**.

is parallel with the surface and the region where the field on the surface of magnets is perpendicular to the surface, respectively. The bright and dark contrast is due to anisotropic optical property of graphene flakes. Here a flake, especially a multilayer flake, can be treated as a reflective mirror. When its surface faces the viewer, it appears bright, but it appears dark when its edge is toward the viewer. Such magnetic field sensing and display remind us of iron filings, but graphene clearly has advantages such as faster response, no aggregation and higher spatial resolution.

The strong orientational response to magnetic field and orientation-dependent optical reflectance and transmission allow us to design a graphene magnetic writing board by simply enclosing graphene suspension between two glass windows. The letters "ECE" (Figure 3) are written with a magnet bar made of stacked magnets. Letters are very visible in reflection and transmission; the results agree with simulation on the bottom image. Note that both bright pattern and dark pattern with strong transmission and low reflection originate from the same causes: low reflection and absorption when a graphene flake is facing perpendicular to the incident light. Similar optical anisotropy and display applications have also been observed in graphene oxide[2].

The strong and distinctive optical reflection and transmission have demonstrated the power of aligned graphene. Such macroscopic properties are expected in all other properties of graphene such as electrical, thermal and mechanical properties. Figure 4 shows two alignment configurations of graphene flakes with respect to the supporting substrate. Vertically aligned graphene flakes exhibit weak optical reflection and strong transmission. When flakes are aligned parallel to the substrate, they are highly reflective. These properties enable them to find wide photonic applications such as optical isolators, lasers, light-emitting devices, solar cells, smart windows and smart screens. In an energy-efficient building, smart windows will block more light in summer when additional light or heat should be minimized. Smart windows will transmit more light in winter, when more light and heat is preferred from the sun. In addition, graphene-based screens can block the view from unwanted personnel in a meeting with proprietary information; the same screen should be converted to transparent in a normal business environment. Because other properties such as thermal and electrical conductivity are also strongly dependent on flake orientation, aligned flakes can be used for electromagnetic shielding, transparent conductive windows and thermal interface materials. Composite with aligned graphene as nanofillers will show very anisotropic mechanical and elastic properties in addition to other above mentioned properties.

Uniform size required

Certainly the quality of constituent graphene flakes will affect the overall performance and functionality of graphene assembly. For most applications discussed above, we need graphene flakes with uniform size, thickness and high magnetic susceptibility. Wet exfoliation remains as a viable technique to produce graphene flakes in a large quantity, but such produced flakes are not uniform and are often mixed with graphite particles and aggregates. More controlled exfoliation and post-purification techniques are needed to produce pure and uniform flakes, which are more important for a wide range of photonics applications such as graphene liquid crystals, magneto-optic switch, nonlinear and polarizing optical devices[3]. The orientation control of graphene by magnetic field also opens up applications in other fields where graphene flakes can be used as mechanical actuators, material mixing or transport.

Meet the authors

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Ultrafast Fiber Laser Opens Doors for **Additive Manufacturing**

By taking advantage of instantaneous high-temperature plasma generation, high-temperature metals such as tungsten can be transformed.

BY JIAN LIU
POLARONYX INC.

Femtosecond (fs) lasers have long been a workhorse in subtractive manufacturing, prized for their unique ability to athermally ablate materials. They are commonly used in surface structuring, drilling and thin-film scribing. However, few thought that an fs laser could be used in additive manufacturing (AM). By taking advantage of instantaneous high-temperature plasma generation, a recently developed fs fiber laser can melt high-temperature metals such as tungsten. Employing the fs fiber laser, parts created using tungsten achieved 99 percent density. Moreover, researchers have shown that the fs laser can deposit metals on glass substrate.

Overcoming limitations

Laser additive manufacturing centers on selective laser melting, using material powders to build three-dimensional parts with complicated structures. It's an efficient, robust and cost-effective technique for the next generation of manufacturing.

AM processes for many industrial metals such as titanium (Ti), with ~1668 °C melting temperature, and aluminum (Al), with ~650 °C melting temperature, are well-established. Melting these metals requires the use of a CW or long-pulsed laser.

However, when it comes to using current AM lasers and tungsten as the material of choice, challenges emerge, including residual stresses, density, uniformity and variation in mechanical strengths.

Notably, CW or long-pulsed lasers can only process materials with low- to medium-thermal conductivity and melting temperature, due to low peak intensity. Processing high-temperature and high-thermal conductivity materials such as tungsten — with a melting temperature of 3422 °C and thermal conductivity of 173 W/(m·K) — needs a much higher power laser to deposit high energy in a short period of time against fast thermal drain.

Table. 1
Comparison of Iron and Glass

	Iron	Glass
Melting Temperature (C)	1400	1500
Thermal Conductivity W/(m·K)	17	0.9
Thermal Expansion Coefficient (µm/m·K)	15.9	5.9
Thermal Diffusivity (mm^2/s)	3.3	0.34

Another problem is that simply increasing the power of a CW or long-pulsed laser induces thermal diffusion outside the focal volume — often referred to as HAZ — as well as residual stress. That can cause cracks and fatigue of the joint part. Furthermore, the formation of unstable intermetallic phases can further degrade the quality of joining and reduce hardness and strength. Separate post-processes are also required to polish, cut, trim and structure the AM components, leading to extra labor and cost.

Finally, current CW laser additive manufacturing systems use material absorption to bond powders — but for bonding to occur, the materials can only absorb at a specific laser wavelength.

Recently, a team of researchers developed an fs laser for AM for melting and shaping tungsten powders, hafnium diboride (HfB_2) and zirconium diboride

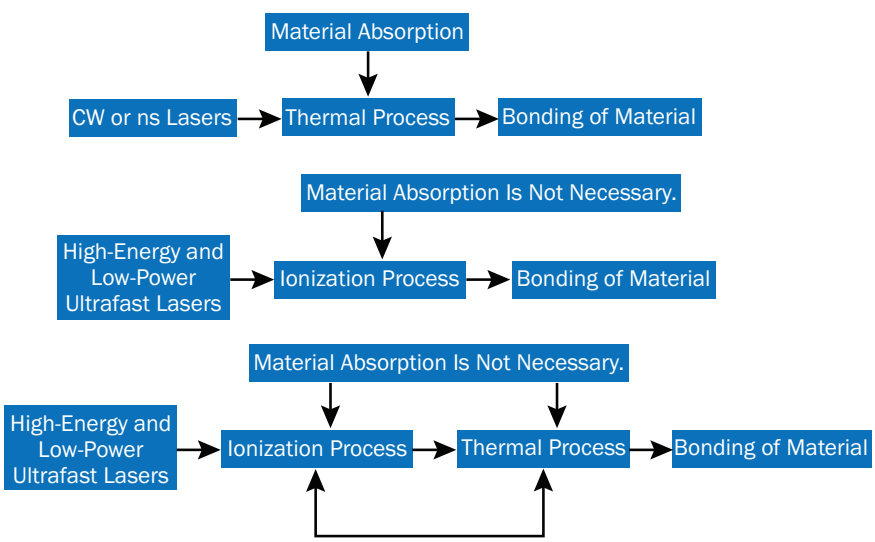

Figure 1. Comparison of femtosecond laser additive manufacturing process versus CW or ns laser process.

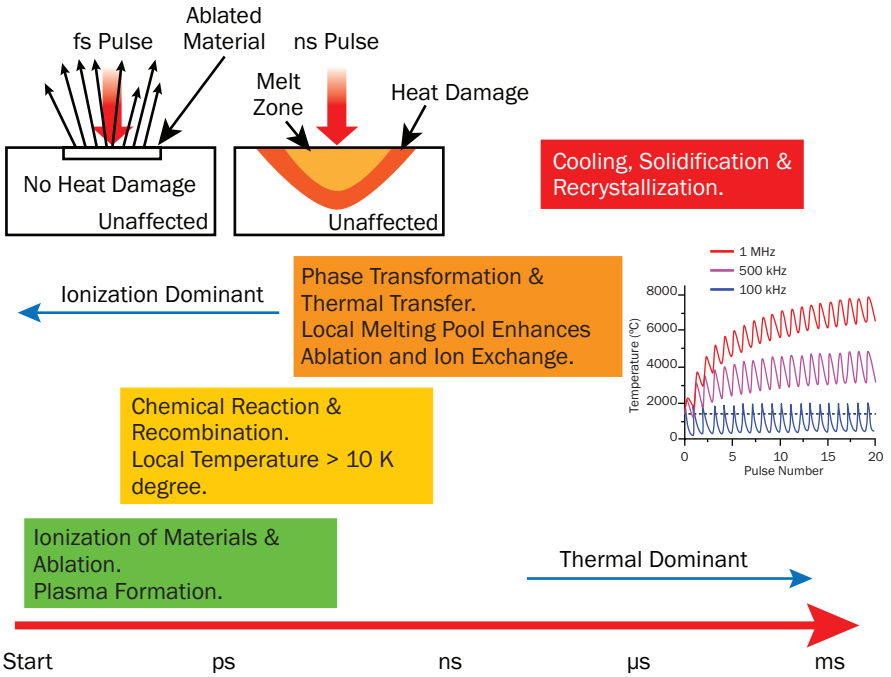

Figure 2. Temporal evolution of fs laser additive manufacturing process.

(ZrB_2), providing an unprecedented way to modify material functions and mechanical properties[1,2,3,4].

Rapid delivery of energy

The main characteristic of the ultrashort laser pulse is the high-peak intensity that results in rapid (ps) delivery of energy into the material, independent of material absorption characteristics, to cause ionization, which is much faster than the plasma expansion (ns to µs), therefore the local temperature is rapidly increased to over 6000 °C (controllable through energy and pulse number) and the thermal damages to surroundings are reduced or eliminated.

Compared with CW laser additive manufacturing, the fs laser approach creates instantaneous high temperatures to melt high-temperature and high-thermal-conductivity metals, forming much stronger microscale welding/bonding between similar or dissimilar refractory metal powders in various shapes and sizes. This multifunctionality could significantly reduce building time and cost, which is not achievable for CW laser additive manufacturing. A comparison of the mechanism using CW, high-energy low-pulse repetition rate and high-energy high-pulse repetition rate highlights the benefit of balance of ionization and thermal process (Figure 1).

Many parameters can have an impact on fs laser additive manufacturing quality. The process is very complicated, involving variables related to material properties, laser parameters, as well as human operation and intervention. In terms of laser parameters, there are energy, pulse width, average power, pulse repetition rate, peak power, beam quality, focal spot size, hatch, scanning speed and contour, and mode of operation. In terms of powder quality — size, shape and residual stress all play critical roles.

As to the dynamics of powder welding — heat flow, chemical reaction, metal evaporation, thermal diffusion and transfer, stress and fatigue are important. Melting, solidification and cooling, grain/microstructure formation, phase transformation, cracking, and femtochemistry are important parameters, too.

Closer look at the AM process

A simplified look at the mechanisms of the AM process (Figure 2) shows that the ablation of the fs fiber laser incurs ionization and recombination of materials in the ps regime to form new grains and microstructures during supercooling and solidification from a few ps to a few ms.

By varying process parameters such as fs fiber laser parameters (energy, power, pulse repetition rate), scanning speed and pattern, any type of sample can be made with controllable porosity, microstructure, density (up to 99 percent), shapes and structures.

Tungsten powders can be used to make various components, including thin walls and gears, on Tungsten substrates (Figure 3). It is also important to note that the microstructure can be varied by changing the pulse width (Figure 4) to tailor the mechanical properties of AM parts[3].

Fabricating dissimilar materials

Moreover, femtosecond laser additive manufacturing shows unprecedented advantages in dissimilar material parts fabrication. As an example, iron was chosen as the main material for investigation; it has a melting temperature of ~1400 °C and its heat conductivity at room temperature is 17 $W/(m \cdot K)^{-1}$. The iron powders have a size distribution of 1 to 5 µm. Three-mm-thick glass slides were used as the substrates.

Iron and glass feature starkly different melting temperatures and thermal con-

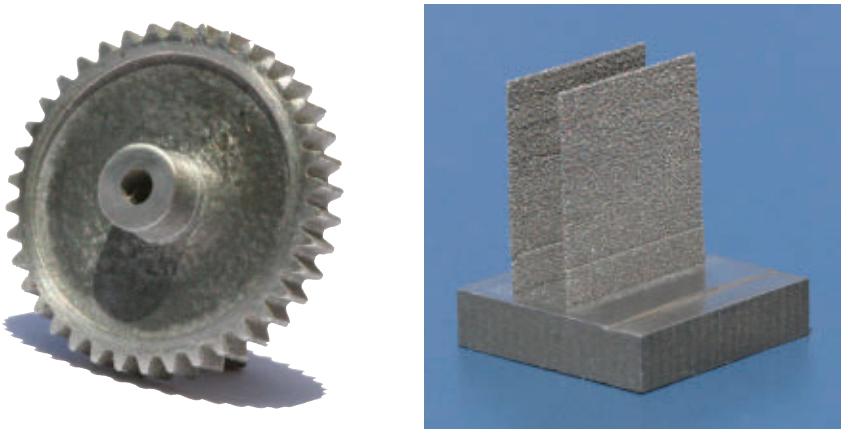

Figure 3. Samples of tungsten parts on tungsten substrates with various shapes and density. The gear has a 1/2-in. diameter **(left)**, while the thin wall **(right)** has a thickness of 100 µm.

Images courtesy of PolarOnyx.

ductivity (Table 1). In addition to those differences, glass is very brittle and easily cracked during the laser process.

A side coating of a fused silica glass window was created to reduce stray light for laser remote sensing. Three layers of iron powder were spread and melted for all four sides of the glass window (Figure 5). The reflectance (<1 percent) improvement is significant over uncoated surfaces of the window. After three layers of iron powder coating, the surface of the glass was completely covered with melted iron powder (Figure 5a), which completely blocked the stray light when a red light from a laser pointer passed through the glass windows (Figure 5b).

Applications in developing new medical devices

Femtosecond fiber laser AM shows unprecedented capability in melting refractory materials, making multimaterial components, and manipulating microstructures to tune mechanical properties. By integrating the ablation feature of a femtosecond laser, the 3D printing system can make devices with more complex structure. These features enable many applications in aerospace, medical devices and defense.

Meet the author

Jian Liu is the founder and president of PolarOnyx Inc. He has pioneered and led the product development of a femtosecond laser 3D printing system (Tungsten-LAM, 2016 R&D 100 Award winner); email: jianliu@polaronyx.com.

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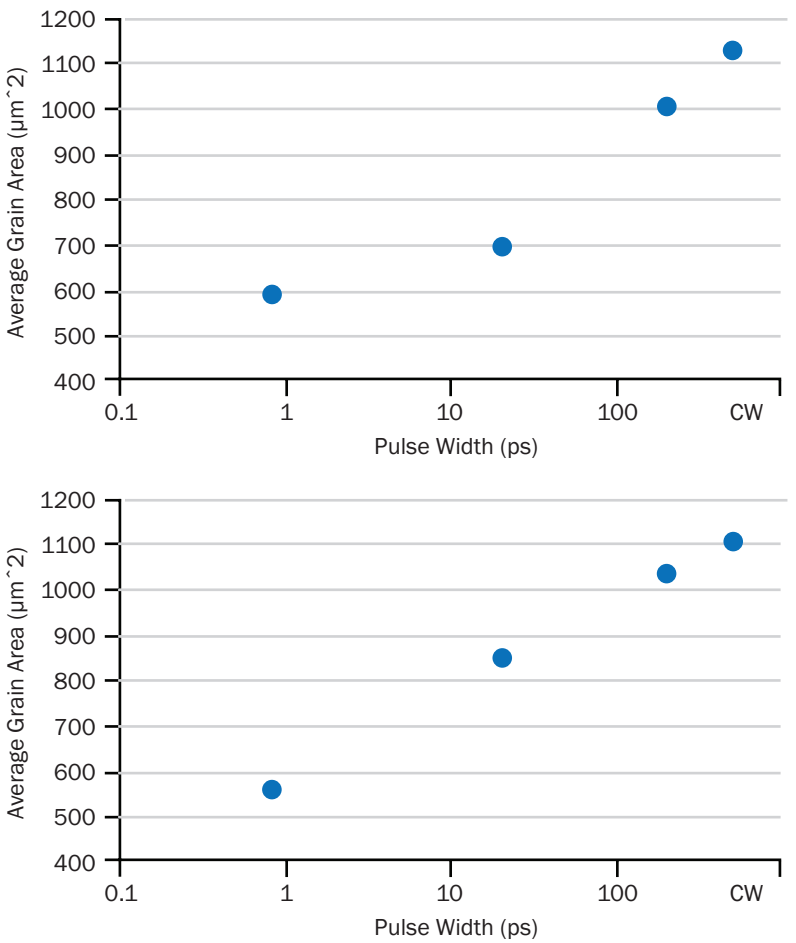


Figure 4. Average grain size as a function of pulse width. Top surface **(top)**; cross section **(bottom)**.

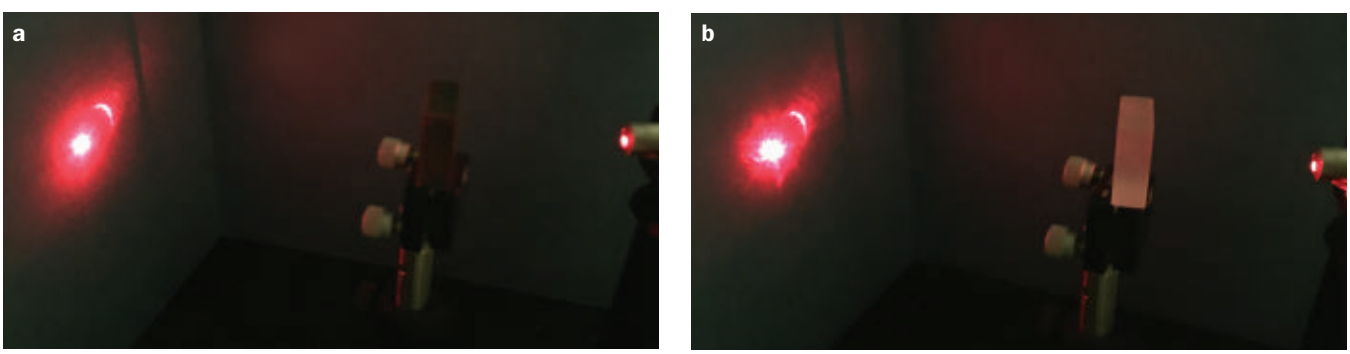


Figure 5. Laser light passes through an optical glass window. An iron powder coating is applied to four sides of a fused glass window, helping minimize stray light **(a)**, compared to laser light passing through an uncoated optical glass window **(b)**.

Massive data centers, like Facebook's 290,000-sq-ft one on the edge of the Arctic Circle in Luleå, Sweden, are being built in response to growing demand, which is leading to changes in optical networking.

Big Data Drives **Optical Networking** Changes

Facebook, Google, Microsoft and others' unquenchable demand for bandwidth is driving innovations such as the combining of packet and dense wavelength division multiplexing technologies.

BY HANK HOGAN
CONTRIBUTING EDITOR

Long driven by telecom, optical networks are now being pushed by large data centers operated by Facebook, Amazon, Google, Microsoft and others. Here, runs are shorter and the emphasis is not on utility-grade reliability, a change from the telecom world. Instead, lowering the cost per bit and boosting bandwidth are of paramount importance. Suppliers have come up with new solutions, with users not waiting for standards to be finalized.

Consider Facebook. Host to 1.8 billion monthly active users, the Menlo Park, Calif.-based company sees a future of higher bandwidth demands than what's needed for text and still images. Analysts predict 75 percent of the world's mobile data traffic will consist of video and virtual reality by 2020, noted Katharine

Schmidtke, the company's source manager for optical technology strategy.

"With the onset of these new services, we need to make sure our global infrastructure is designed to handle richer content at faster speeds. To meet these current requirements and any future bandwidth demands, we're deploying the 100G (gigabits per second or Gbps bandwidth) data center, which puts increasing pressure on the optical network," she said.

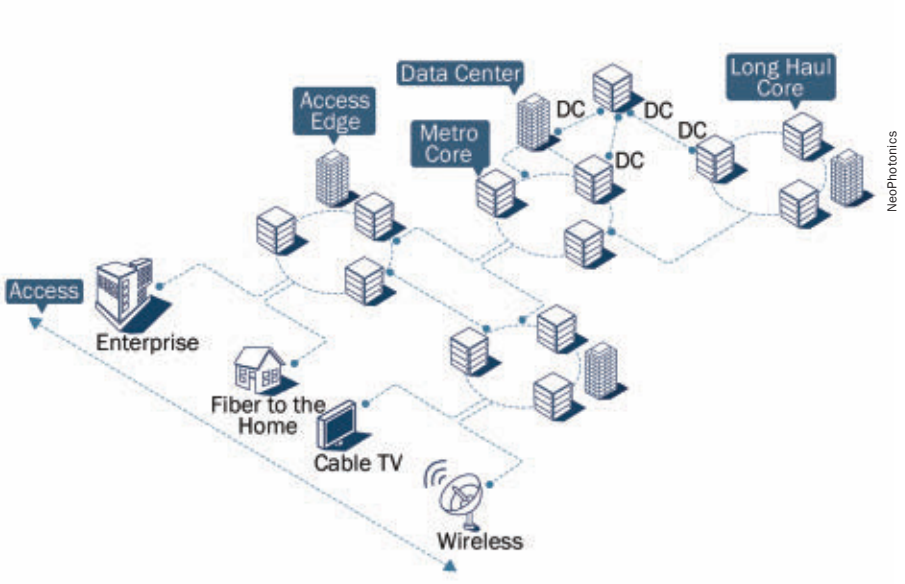
Facebook is actively working to bring about solutions that combine packet and dense wavelength division multiplexing technologies. Dubbed "Open Packet DWDM," an advantage of this approach is that it cleanly separates software and hardware, Schmidtke said.

That enables each to independently advance. Because it is based on open specifications, anyone can contribute systems, components or software. Facebook has done this and intends to continue this work, driven, in part, by self-interest.

"There needs to be a cost-effective solution that's optimized for the specific requirements of a data center," Schmidtke said.

As director of packet optical architectures at Cisco Systems Inc., Russ Esmacher has seen the impact of large data centers. Headquartered in San Jose, Calif., Cisco has optical networking products in both the telecom and data center markets.

Telecom, also known as transport, has its roots in telephone voice traffic. Such networks have traditionally been built to utility-grade specifications, with reliability of 99.999 percent while moving information over thousands of kilometers. In contrast, data centers use runs of, at most, a few tens of kilometers. They also utilize packet-based networks, a technology developed for the internet. Due to architectures that have been designed for network and not nodal redundancy, reliability of individual components can be lower than five 9s without impacting data delivery.



NeoPhotonics

Access, metro and long-haul fiber optic networks.


Facebook

Traffic from millions of users flows into and out of data centers, requiring large amounts of storage and network capacity.

Pressure to cut costs

Traditionally, the transport and packet worlds were built and existed independently. However, the influence of large data centers has started to change this, to the benefit of transport operators. They face flat rates and demands for more bandwidth, so they're looking for ways to reduce expenses. "Can you deliver an optimized network that cuts the cost to deliver a bit to the subscriber by 50 percent?" Esmacher said.

The answer, he added, is yes. By using the spine-and-leaf network architecture and other optical technologies employed in the data center as well as with packet-optical transport solutions, metro transport networks can see their costs slashed by half or more. Such solutions, along with other approaches that achieve the same savings by making routers more intelligent and sophisticated, are now being deployed, Esmacher said.

Going forward, achieving optical cost reductions will be increasingly critical because networks are a mix of electronic and optical components. Hence, data is translated from electrons to photons and back again repeatedly.

At one time, most of network expend-

itures went to the electronic side, which accounted for perhaps 85 percent of capital costs a decade ago, Esmacher said. Thanks to Moore's Law, the cost of electronics has fallen more rapidly than it has for optical elements. Today, about half the capital cost is optical transport and associated optics, which has changed the industry's focus.

"Now we're seeing the market, probably over the last year and a half, starting to look at the optical industry and say what can be done here. Silicon photonics, using CMOS technology, certainly feels like a right move," Esmacher said.

NeoPhotonics

Some optical networking components are fabricated in a clean room, such as this facility in NeoPhotonics headquarters in San Jose, Calif.

Broadcom Ltd.

High-speed fiber optic connections for a data center.

By taking advantage of the large silicon manufacturing base to build modulators and other components, silicon photonics promises cost reductions and performance improvements. The rapidly growing volume of such devices used in data centers could also help achieve cost goals.

However, Esmacher noted that the current inability of a silicon platform to lase via electrical pumping means that a pure silicon solution is not in the cards. Instead, lasing sources will be constructed out of a material like indium phosphide or gallium arsenide.

Shorter links on the horizon

Esmacher predicted that in the future optical technology will find itself in shorter and shorter links. Today it is being looked at for runs between routers and servers. Soon it will be used within the boxes themselves. That is one reason to go with silicon photonics and photonic integrated circuits. The number of connections is going up as this push to shorter links proceeds. Only with increasing integration can the necessary density be realized.

San Jose, Calif.-based NeoPhotonics Corp. designs and manufactures hybrid photonic integrated circuits for bandwidth-intensive, high-speed communications networks using silicon, indium phosphide and gallium arsenide wafers and components. Its products are found in telecom and data centers, where speeds today max out at 100 Gbps and distances run up to 10 kilometers. Between data centers, distances run from a few kilometers to several thousand, with rates running up to 600 Gbps on a single wavelength, said Winston Way, chief system architect.

Way said the company's strength lies in getting higher bandwidth out of modulators and receivers, as well as clean laser sources. The requirement for more bandwidth is driven, in part, by the increasing speed of electronics — performance the optical components need to match. Historically, electronics data rates double every six to seven years.

In 2000, electronic components were rated at 10 Gbps. By 2010, they were up to 25, and the bandwidth was 100, achieved

by ganging up four channels. Today, electronics are up to 50 Gbps and so the industry is looking at 400-Gbps connections. That points to future directions for optical networks, Way noted.

If the cost can be reduced to the degree that seems possible, silicon photonics will enable more parallel connections and, therefore, greater bandwidth. "They can integrate a lot of channels in one silicon IC [integrated circuit]. But they have to face all the challenges of packaging and the limited optical power," Way said.

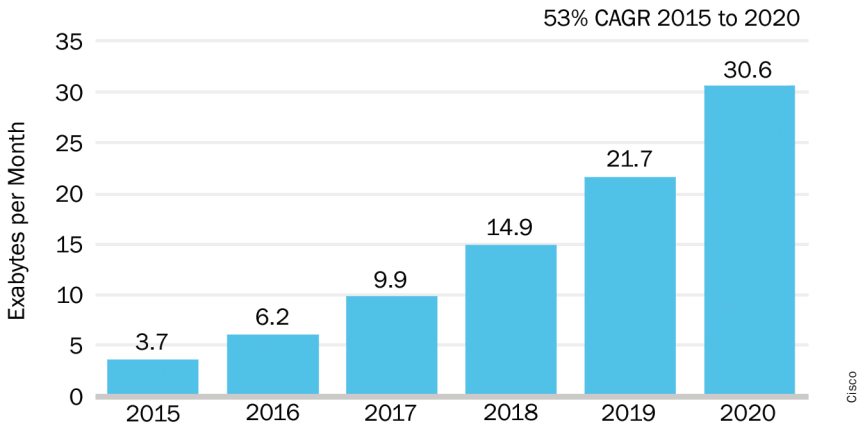
The multiple channels on such chips can be utilized by having one wavelength per fiber and then putting as many fibers in a bundle as needed. Alternatively, there can be multiple wavelengths traveling down a single fiber. The first is better suited for short runs because the expense per unit length of multifiber cable tends to be higher than for a single fiber one. The second approach makes more demands on the photonic components, such as requiring multiple uncooled lasers, low loss multiplexing/demultiplexing, and minimization of channel cross-talk.

The big data center operators are taking their own approaches to optical networking, Way said. Thus, it may be some time before a consensus and a standard emerge.

Way also noted that data centers get attention, in part, because they are a rapidly growing market. Another reason is interconnecting data centers are having an impact on the transport side of optical networking. However, long haul and metro still make up the bulk of the transport market, accounting for perhaps five out of every six dollars spent outside the data center.

The long-reach optical transport and short-range data center domains use different sources, fibers, receivers and modulators. Somewhere around 40 to 120 km, however, there is a crossover between the two; Way noted both technologies need to demonstrate a lower cost of ownership to win over that range. That also happens to be about the distance of a typical data center interconnect, or runs that tie two separated sites together with a high-bandwidth, high-capacity link. These tend to be 100 kilometers or less and are a very hot application area, Way said.

The march up in optical networking bandwidth presents challenges, said



Cisco

Mobile data traffic is expected to surge, leading to changes in data centers and optical networking.


Broadcom Ltd.

High-speed fiber optic connections for a data center.

Mitchell Fields, vice president and general manager of the fiber optic products division at Broadcom Ltd. Headquartered in Singapore and San Jose, Calif., the company is a supplier of sources, detectors and chips, including vertical-cavity surface-emitting lasers and lasers for use in silicon photonics.

One challenge is that data center optical networking can require speeds that are hard to achieve. Another is that when the switch is made to a new higher speed, the surge in demand for components can be difficult to satisfy. It may be possible, for instance, to build the necessary components but not at the desired price.

Working out those kinks can take time and such problems have in the past delayed the widespread adoption of a new bandwidth threshold. Today 100 Gbps is being deployed but the next step up, to 400 Gbps, is some time off, Fields noted.

"There will always be these niche applications where people use 400 gig as the early demonstrations of it," he said. "But what I always look for is when you start to see that knee in the ramp curve."

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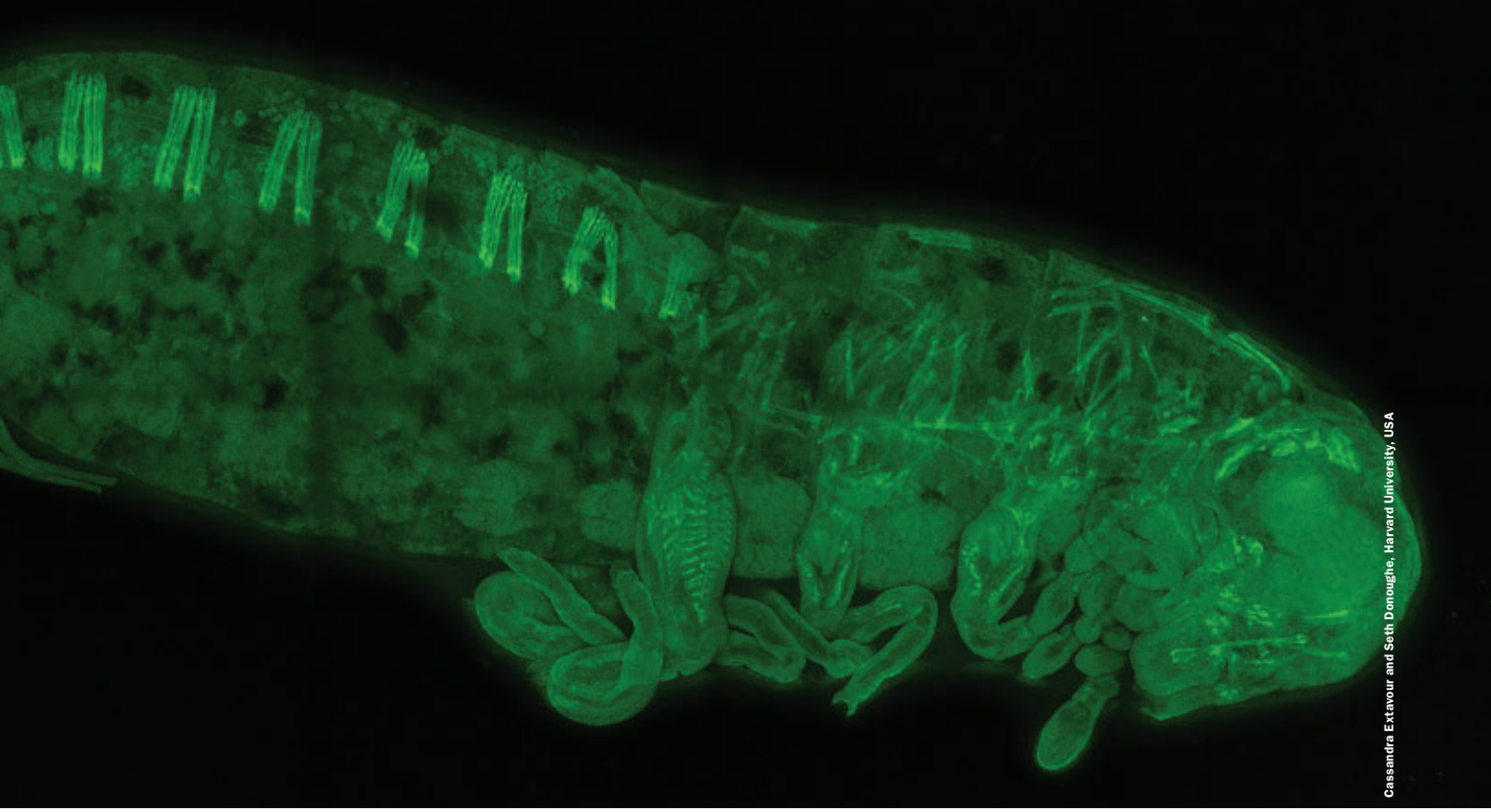


This is an egg-stage 22 *Gryllus bimaculatus* (cricket) embryo, stained with phalloidin coupled to Alexa488. The image was acquired using multiphoton excitation at 900 nm and LSM 880 with Airyscan in Fast mode as the detection device (www.extavourlab.com).

Optics, Tunable Lasers to Move **Multiphoton Microscopy** Forward

Scientists call for deeper imaging at a higher frame rate with a wider field of view, but can the top microscope makers rise to the challenge?

BY MARIE FREEBODY
CONTRIBUTING EDITOR

Of the numerous far-field imaging techniques, multiphoton microscopy has proved particularly valuable in many biological studies, providing multimodal images from deep within tissue, as well as label-free images of complex biological structures and inorganic probes.

From fluorescence microscopy for imaging living animals and label-free techniques such as second-harmonic generation and coherent anti-Stokes Raman scattering spectroscopy for imaging tumors in intact tissues together with the increasing use of next-generation femtosecond laser platforms to further advance neuro-imaging and in vivo brain studies, there are numerous multiphoton methods that have been developed since the concept was demonstrated over two decades ago.

Common to all of these methods is the mechanism in which two or more photons combine to generate a contrast difference within the sample resulting in optically sectioned images with high resolution. Another commonality is that multiphoton microscopy users would like to see some developments that could improve the quality and impact of their research and even help bring the technique into the clinical setting.

At King's College London, professor Klaus Suhling and colleague Simon Ameer-Beg are finding innovative ways to speed up multiphoton imaging for beam-scanning applications. In a paper published in *Biomedical Optics Express* (https://doi.org/10.1364/BOE.6.000277), the team, led by Ameer-Beg, demonstrated that multifocal multiphoton imag-

ing with a 2D single-photon avalanche diode array offers significant speed advantages compared with single-beam laser scanning or wide-field fluorescence lifetime imaging (FLIM) microscopes.

"We have recently used multibeam-scanning multiphoton microscopy for rapid acquisition of FLIM data based on time-correlated single-photon counting," Suhling said. "The use of multiple beams and multiple detectors has allowed us to speed up data acquisition significantly, by more than an order of magnitude, whilst retaining single photon sensitivity."

But to routinely make FLIM movies and study dynamic processes quantitatively, Suhling says the team would need compact femtosecond laser sources, tunable over a large wavelength range, as well as better detectors.

Echoing the call for smaller sources is professor Stanley Botchway at the Science and Technology Facilities Council and Oxford Brookes University in Oxford, England. Through his research, he also highlights that the need for a multidisciplinary approach is now more important than ever.

Within the Science and Technology Facilities Council, Botchway and his team are using multiphoton microscopes to investigate drugs such as combretastatins used for age-related macular degeneration, phototherapy and brain cells imaging using multiphoton processes. Their research is now at the stage of deep tissue imaging of live mice[1].

For real-time disease detection and treatment, starting with animal models, Botchway says that very long working distance objectives — beyond 10 cm — would be needed as well as multiple outputs from the laser platform. This would enable selective multicomponent imaging with significant excitation of the different fluorescent probes under investigation.

"Multiphoton microscopy hasn't changed much in the last 10 years. But lasers for multiphoton microscopy have improved significantly with ease of use and tunability," he said. "Although small footprint femtosecond lasers would allow them to enter clinical settings."

Microscope manufacturers are keen to respond. Some of the leading microscopy specialists are already working to overcome the top challenges set forth by modern day science.

Increasing imaging depth

Increasing the penetration depth in vivo remains one of the primary challenges for neuroscientists. Researchers hope to study neuronal activity deep in the cortex and the hippocampus of mice, in some cases do away with implanted cranial windows in favor of imaging through the intact skull, and image the brain of larger rodents and possibly small primates.

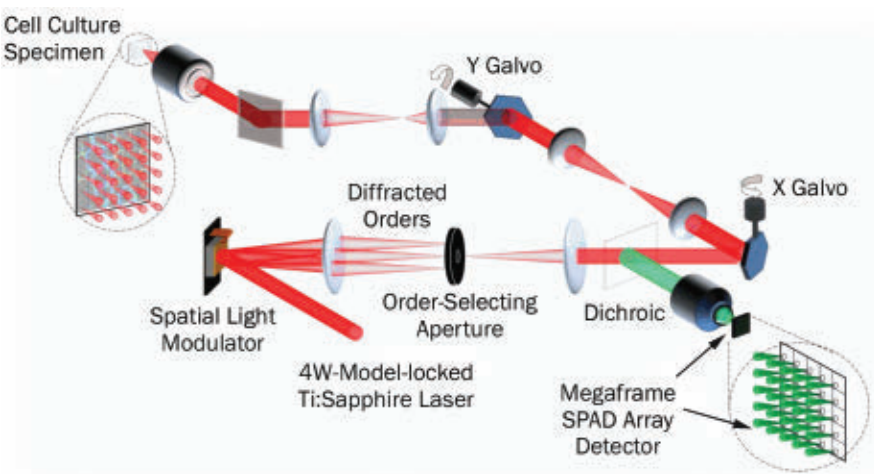
The difficulty is combining the use of lasers emitting at longer wavelengths, where water absorption does not affect the sample, delivering larger amounts of energy per pulse and the use of adaptive optics for removing the detrimental effects caused by aberrations due to the sample structure.

In this case, concepts applied in astronomy to measure atmospheric turbulence have been brought into microscopy successfully[2] to measure and correct for the aberrations inside the sample by using the nonlinear guide star concept. Third-harmonic generation has also been used to perform long-term time-lapse recordings of more than five hours in living samples[3].

Some of today's leading biophotonics and neuro-imaging laboratories are turning to three-photon excited fluorescence (3PEF) microscopy and third-harmonic generation microscopy, using longer IR excited wavelengths, typically 1.3 µm for

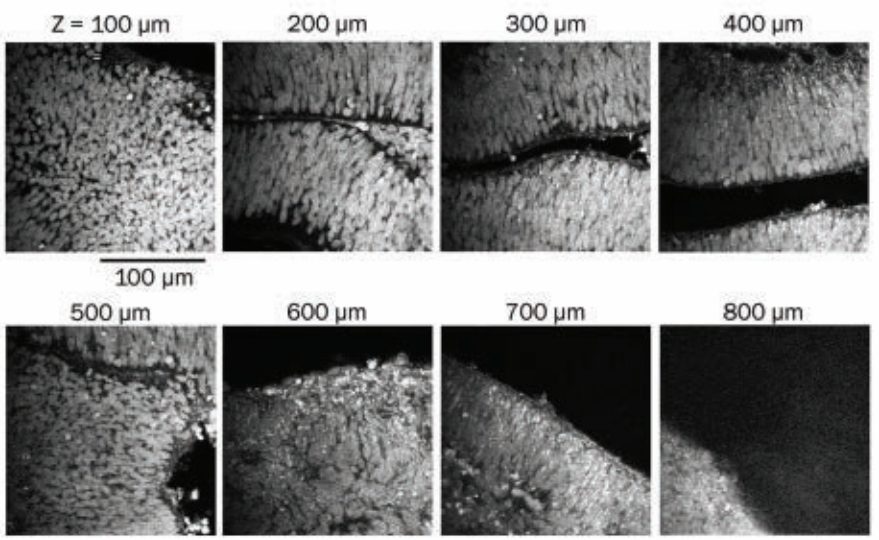
Multiphoton Microscope: A User's Wish List

- **Increase the imaging depth.** Requires the use of lasers emitting in the absorption window for excitation of biological tissue. In this region, water absorption does not affect the sample and optical scattering is lower.
- **Increase the frame rate.** To allow for the following of real-time processes.
- **Extend the field of view employing customized optical paths and large-scale optics.** To allow wider fields to be visualized to a few millimeters.
- **Develop compact femtosecond laser sources.** Mass clinical uptake is hampered by bulky femtosecond lasers operating between 680 to 930 nm. The clinical setting would need small footprint, simple turnkey femtosecond lasers at this wavelength and below (600 to 640 nm) for the excitation of UV-absorbing photodynamic drugs.
- **Include multiple tunable sources for multimodality.** Single box tunability from 500 to 1300 nm would be excellent as currently an optical parametric oscillator (and ring cavity) is needed to cover below 680 nm.
- **Increase resolution.** To enhance the quality of research as well as open the door to new imaging applications.



Dr. Simon Ameer-Beg, King's College London

Operational schematic of the multifocal multiphoton system.

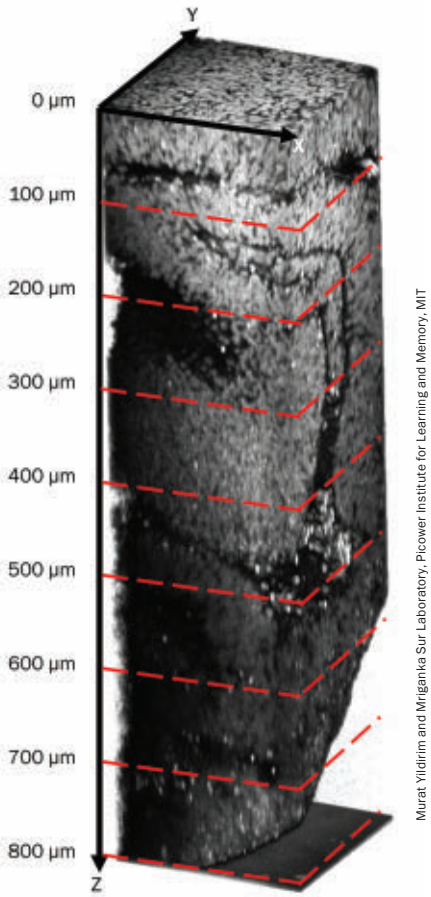


Murat Yildirim and Mriganka Sur Laboratory, Picower Institute for Learning and Memory, MIT

Combined three-photon excited fluorescence and third-harmonic generation imaging of DAPI-stained mutant cerebral organoid, imaged with Spirit 1040-16 and Spirit-NOPA-IR.

green markers and 1.7 µm for IR markers.

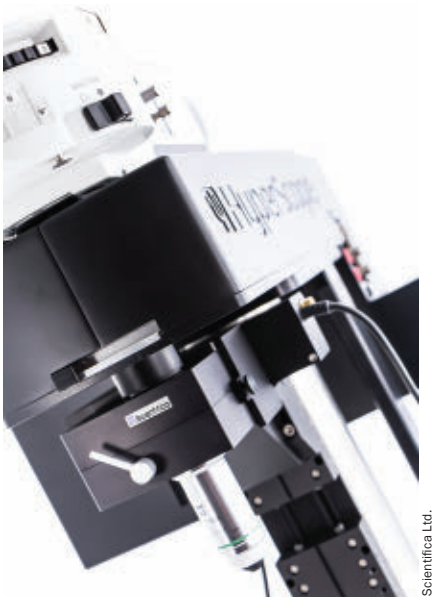
"These techniques typically require high peak powers (greater than megawatt level), moderate average powers (tens or hundreds of milliwatts) at megahertz repetition rate," explained Julien Klein, senior manager of Product Marketing at Spectra-Physics Inc., in Santa Clara, Calif. "The first practical use of 3PEF for in vivo calcium imaging in live mice was recently demonstrated using a Spectra-Physics ytterbium-based femtosecond amplifier and a noncollinear optical parametric amplifier with high peak power output in the infrared tunable from 1.2 to 2.5 µm."



Murat Yildirim and Mriganka Sur Laboratory, Picower Institute for Learning and Memory, MIT

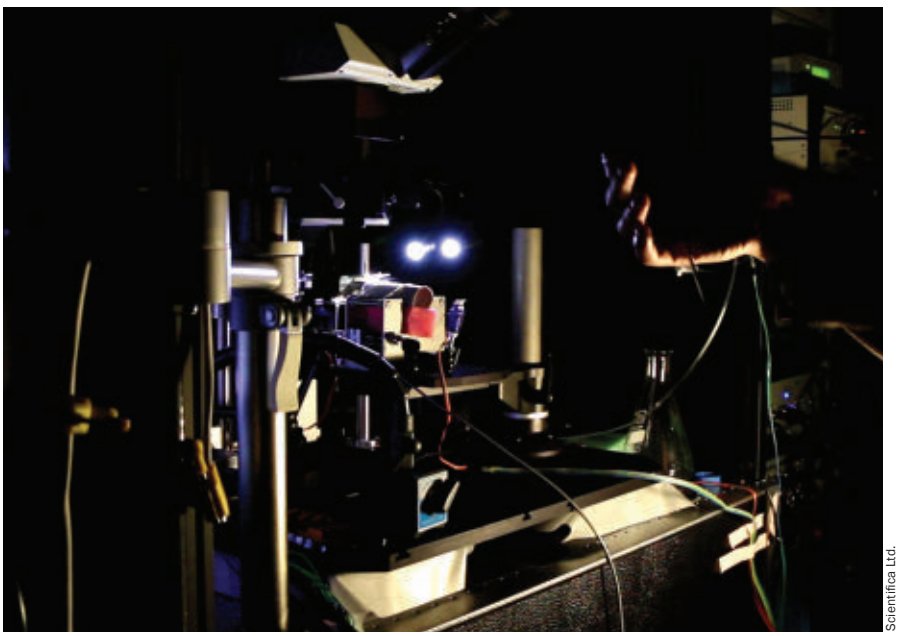
At Uckfield, England-based multiphoton imaging specialist Scientifica Ltd., Christian Wilms, an applications scientist, points out that of all the long-term goals, deeper imaging remains the most elusive since the depth obtainable with two-photon imaging is limited by a number of factors.

"Scattering and absorption of excitation light are an unchangeable constraint. In addition, aberrations due to structures in the tissue and refractive index mismatch lead to a degradation of the focal volume[2]," he said. "Over the past 10 years several biophotonics labs have tried applying different adaptive optics strategies to this problem. So far there does not appear to be a consensus approach and we anticipate further developments in the future."



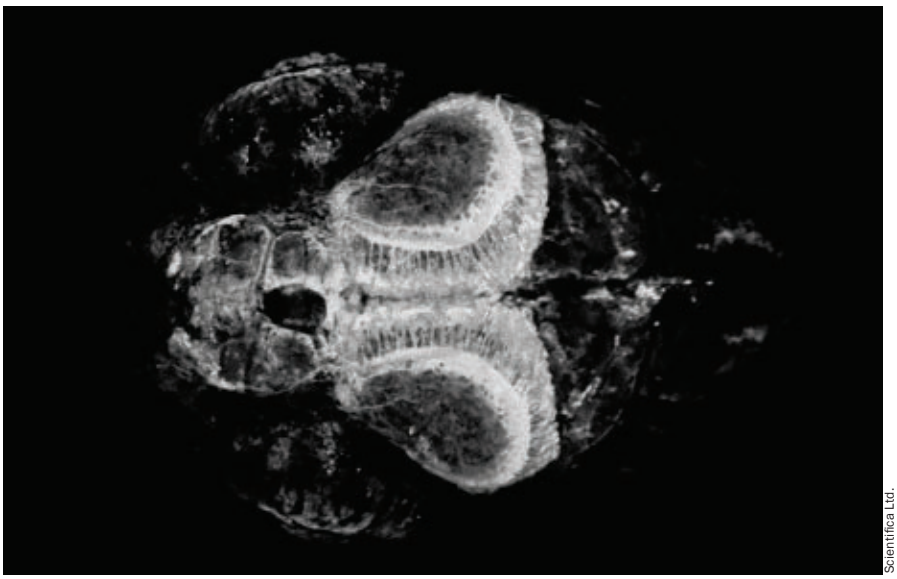
Scientifica Ltd.

A dual scan-head multiphoton microscope.



Scientifica Ltd.

Researchers prepare a multiphoton microscope for in vivo imaging in mice.



Scientifica Ltd.

In vivo 6DPF zebrafish larvae expressing GCamp6 imaged using the Scientifica HyperScope.

Faster frame rate

Increasing the frame rate to allow researchers to follow real-time processes such as the propagation of electrical activity within the brain is now being addressed by commercial instruments. For example, the wide commercial availability of resonance-scanning-based multiphoton microscopes has made high frame rate imaging available to all researchers in the past four to five years.

What is more, there is growing interest in acousto-optic deflector (AOD)-based microscopes, to allow for even higher data acquisition rates.

"These advances have been made possible by adding electro-optical devices that allow light to be deflected using a radio frequency signal and a medium that responds to such emission by experiencing a change in refractive index or by using techniques that allow whole volume imaging such as wavefront coding[4]," explained Rodrigo Aviles, Electro-Mechanical development manager at Scientifica Ltd.

Wider field of view

Increasing the field of view size while maintaining subcellular resolution is particularly important for neuroscientists, enabling them to investigate how different regions of the brain communicate with each other. First commercial systems allowing fields of view up to 5 mm were introduced in November 2016.

Compact femtosecond laser sources

According to Eva Simbürger, product manager of Light Microscopy at Carl Zeiss Microscopy GmbH based in Jena, Germany, there has been good progress in providing compact femtosecond laser sources thanks to the development of laser technologies already used in telecommunications.

"Compact fiber lasers will be a (near) future option if not already used," she said. One drawback, however, is that they are not tunable. But on the other hand they have a very small footprint and already provide reasonable output power.

The use of alternative ultrafast laser technologies has already been demonstrated in the past, such as a semiconductor disk laser emitting at 965 nm used for simultaneous two-photon excited fluorescence and second-harmonic generation in both fixed and living samples[5] and chip-sized devices based on quantum dot technology emitting around 1260 nm

used to demonstrate its use for two-photon excited fluorescence imaging[6].

Multiple tunable sources for multimodality

The use of more laser lines in parallel is becoming more and more prominent. As researchers look into the use of even higher wavelengths, manufacturers are triggered into developing optics that provide a reasonable transmission — particularly in the range of 1100 to 1500 nm or above.

"With the extended tuning range of ultrafast lasers and microscopes that are now able to efficiently transmit further IR-shifted excitation light, this is definitely an avenue that we expect to grow quickly in the coming years," Scientifica's Wilms said.

For example, a 30-fs laser system tunable around 1 micron has been demonstrated for use on living samples[7]. The system uses a microstructure fiber to broaden the spectrum of a Yb:tungstate, solid-state laser.

In fact, today's multimodal microscopes now contain input ports for ultrashort pulsed lasers to allow for the combination of multiple techniques such as two-photon-excited fluorescence, second-harmonic generation, third-harmonic generation and coherent anti-Stokes Raman scattering.

Higher resolution

According to Carl Zeiss Microscopy's Simbürger, there are ideas to achieve higher resolution and sensitivity for intravital imaging, and the combination of multiphoton imaging with new Airyscan technology has provided a rather good starting point to achieve this.

"Intravital imaging on awake animals using optogenetic approaches now will trigger much more imaging with direct feedback on behavior," she said. "This will definitely expand, although those experiments are very demanding."

Taking a different approach is materials scientist and professor Jeff Squier, who heads up the Department of Physics at the Colorado School of Mines. Squier is working with professors Randy Bartels and Jeff Field from Colorado State University to develop a new enhanced resolution imaging method that works across multiple imaging modalities and requires only single-element detection.

Their work was reported in *PNAS* (PNAS, doi: 10.1073/pnas.1602811113) in May 2016 and details a method based on spatial-frequency-modulated imaging for multiphoton superresolved imaging that allows for simultaneous imaging of both coherent and incoherent signal light.

"We have developed a general method for enhanced resolution that is applicable across multiple imaging modalities, second-harmonic generation imaging, two-photon excitation fluorescence, etc.," explained Squier. "The really exciting concept is that it is easy to deploy — existing multiphoton microscopes can be readily adapted to use this method."

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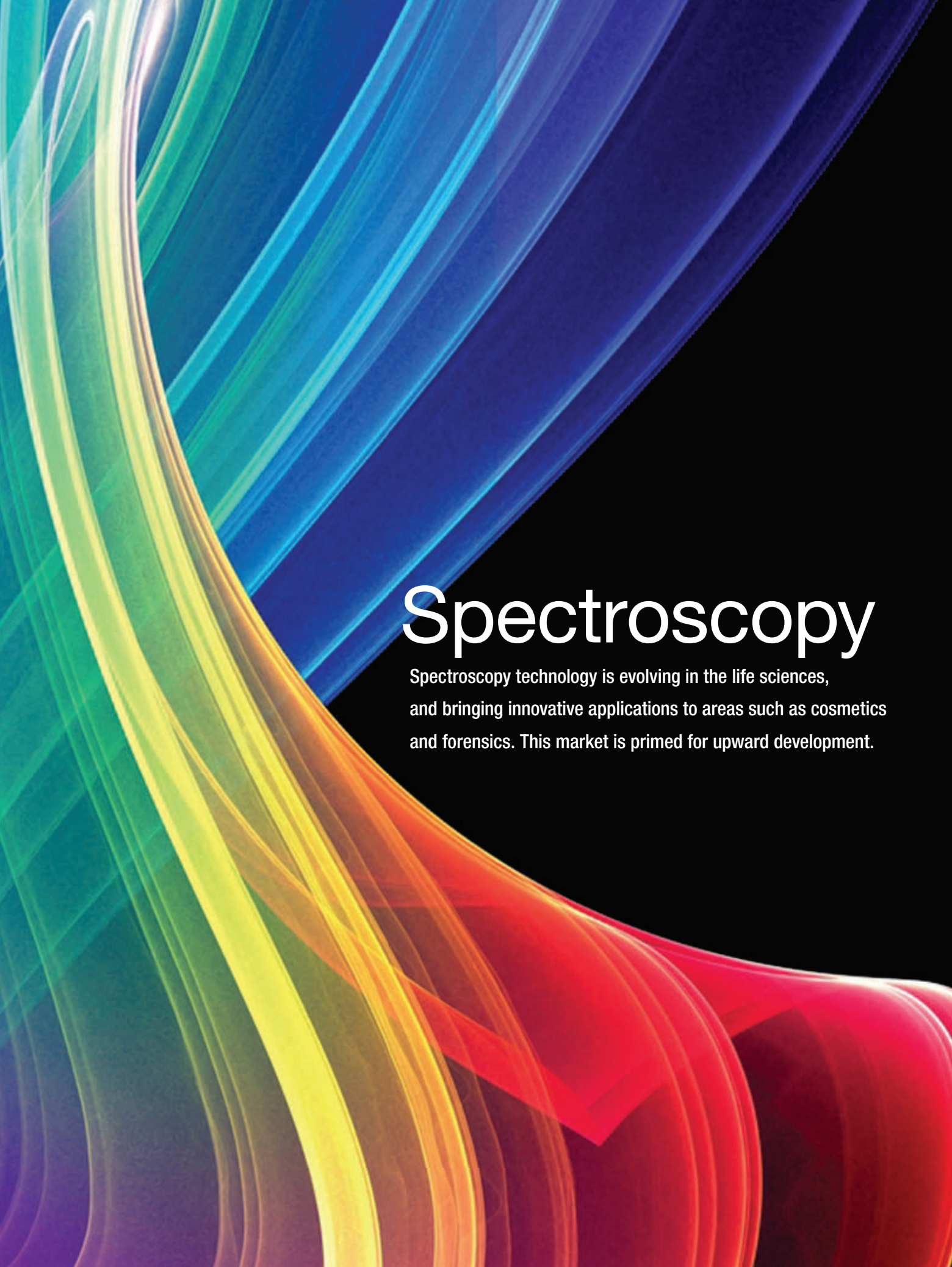


Spectroscopy

Spectroscopy technology is evolving in the life sciences, and bringing innovative applications to areas such as cosmetics and forensics. This market is primed for upward development.

Commerce, Health and Safety Benefitting From **Spectroscopy**

Recent research reveals spectroscopy's potential impact in commercial food production facilities and in the surgical suite.

BY JUSTINE MURPHY
SENIOR EDITOR

For decades, spectroscopy has been used in the life sciences, pharmaceuticals, and even cosmetics and forensics applications. Now, researchers are finding new applications for this noninvasive technique in a broad and growing market.

Optical spectroscopy is providing poultry hatcheries with a noninvasive, nondestructive way to accurately determine the sex of a chick before it hatches.

New technique allows pre-hatch chicken gender reveal

Optical spectroscopy is proving that it just might be okay to count your chickens before they hatch. This method is providing hatcheries with a noninvasive, nondestructive way to accurately determine the sex of a chick within four days of an egg being laid.

A team from the Technical University Dresden in Germany and Vilnius University in Lithuania found that optical spectroscopy essentially picks up on differences in the fluids contained in an egg from which a cockerel will develop, compared to one from which a hen will hatch.

Using a laser that emitted at a wavelength of 785 nm, the researchers investigated 27 eggs for up to 11 days after being laid. Within just a few days after incubation, sex-related differences were already evident in the near-IR fluorescence spectrum. According to the researchers, further analysis showed that the blood of male eggs demonstrates a specific fluorescence band located at ~910 nm. The researchers then looked at whether these fluorescence characteristics could be used to classify if a hen or a cockerel will develop, when coupled with changes in the wavelength of light. Tested on nearly 400 eggs, the technique was accurate in 93 percent of cases.

"In ovo sexing based on spectral analysis is noninvasive, does not require extraction of egg material and does not use consumables," said Roberta Galli of TU Dresden, a lead author on the study that was published in *Analytical and Bioanalytical Chemistry* (doi: 10.1007/s00216-016-0116-6). "The method is applicable during the fourth day of incubation, before onset of embryo sensitivity at day seven, and is therefore in agreement with animal welfare."

This optical spectroscopy technique could lead to more ethical practices in the poultry industry. Specifically, it could prevent the annual culling of billions of day-old cockerels worldwide, which have much less economic value than hens, the researchers said, noting that the current global demand for eggs totals about 68.3 million tons per year.

NIR spectroscopy: A developing food science innovation

NIR spectroscopy was first used to monitor food quality in the 1970s when Canada began to replace the very targeted "chemical-requiring and cumbersome Kjeldahl analysis" method to evaluate the protein content in cereals. Kjeldahl specifically measures protein content in food; nitrogen content is also measured with this method and then equated with the protein content.

"We have known and developed [spectroscopy] methods … and they have become better and cheaper over time," said Soren Balling Engelsen, a professor at the University of Copenhagen's Department of Food Science (FOOD), and a co-author on a study published in the journal *Current Opinion in Food Science* (doi: 10.1016/j.cofs.2016.08.001).

NIR spectroscopy is the future of food testing, according to the Copenhagen researchers, but it must be used more broadly in order to be widely effective.

"Even though [NIR spectroscopy] is widely used in the food industry, it can be used far more," said Klavs Martin Sorensen, a postdoctoral researcher at Copenhagen, and co-author of the study. "It will become more attractive to use [NIR spectroscopy] at production sites, where you previously wouldn't have been using advanced measuring equipment."

Nontargeted methods of analysis could

better detect food fraud — defined by the U.S. National Center for Food Protection and Defense as "the deliberate and intentional substitution, addition, tampering or misrepresentation of food, food ingredients or food packaging; or false or misleading statements made about a product for economic gain" — than those currently employed.

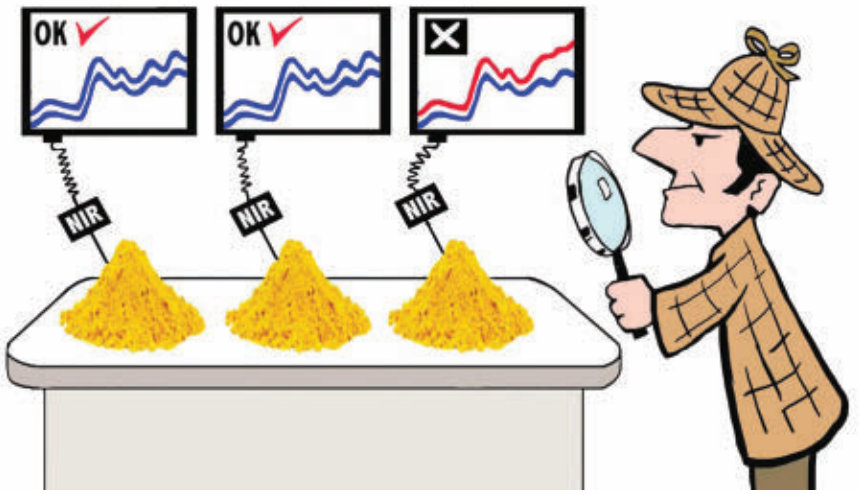
"The problem is that the food analyses which are predominantly used today are only spot checks and they are typically targeted toward a single kind of food fraud," Engelsen said. "When you want to detect food fraud and food adulteration, you are not looking for a single substance. [You] have to look broadly."

The Copenhagen study cited a 2008 case in which the targeted Kjeldahl method unwittingly allowed manufacturers in China to add melamine — an industrial synthetic substance containing 66 percent nitrogen — to milk powder for infant formula. They falsely claimed to consumers that this provided more protein; instead, adding melamine resulted in six deaths and illness in an estimated 300,000 children. This contamination was able to essentially trick the Kjeldahl method, according to the researchers, as it detected more of the protein. Engelsen said NIR spectroscopy, with its broader, nontargeted analysis, cannot be fooled.

With NIR spectroscopy, light is sent into the food and measured when it comes back, taking a nontargeted physicochemical fingerprint of the food. This offers higher, more comprehensive accuracy than Kjeldahl and other techniques. According to the researchers, the fingerprint obtained will often contain "1000+ spectral variables that each relate to the physicochemical composition of the food in their own unique way."

NIR spectroscopy can also be used to examine large quantities of raw materials, detecting fluctuations in many different ingredients at once. Such monitoring allows inspection of close to 100 percent of the ingredients and raw materials that go into food production, subsequently reducing manufacturing errors and potential low product quality.

Engelsen said increased use of nontargeted NIR spectroscopy "will definitely be able to save us from many forms of food modification that could be of more or less serious kinds — from receiving lower-quality products to becoming seriously ill."



Sorensen et al./University of Copenhagen

Near-IR spectroscopy is proving a key tool in detecting food fraud.

Light-reflectance spectroscopy evaluates surgical margins

Emerging as a formidable tool in the life sciences, light-reflectance spectroscopy could enable real-time tissue analysis during prostate cancer surgery, as well as more accurate distinction between malignant and benign tissue.

A team from the University of Texas Southwestern Medical Center, in a study of patients with intermediate- to high-risk disease requiring radical prostatectomy, employed a novel light-reflectance spectroscopy probe to evaluate surgical margins on radical prostatectomy tissue specimens and correlate the findings with pathological examination. Light-reflectance spectroscopy analysis was performed on 17 prostate gland specimens, of which a total of 11 histologically positive and 22 negative surgical margins were measured. The optical probe predicted positive surgical margins with 85 percent sensitivity, 86 percent specificity and 86 percent accuracy.

Light-reflectance spectroscopy measures light intensity backscattered from tissues. In prostate cancer patients, a radical prostatectomy — a procedure that entails removal of the prostate gland and some of the surrounding tissue — is often recommended. But due to the amount of time involved with traditional techniques and the lack of proven clinical usefulness, analysis to determine removal of all cancer surrounding the visible tumor's edges is not routinely performed during surgery.

"When you want to detect food fraud and food adulteration, you are not looking for a single substance. [You] have to look broadly."
Soren Balling Engelsen

The benefits of the light-reflectance spectroscopy procedure, once fully qualified, could include highly accurate surgical removal of all cancerous tissue, the researchers said, as well as the ability to spare more healthy tissue, thus minimizing the likelihood of cancer recurrence or need for additional treatment. Further study is required, however, according to UT Southwestern professor Dr. Jeffrey Cadeddu, "to determine whether such analysis may be used in real time to improve surgical decision-making and decrease the amount of tissue surgeons need to remove."

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Global **Spectroscopy Market** Set to Expand

Optical biopsy spectroscopy techniques, along with Resonance Raman and near- and short-wave IR techniques, are poised to enter clinical and consumer markets.

BY JUSTINE MURPHY
SENIOR EDITOR

The global spectroscopy market continues on its rise toward the billion dollar zone. With increasing applications in pharmaceuticals and the life sciences, as well as some in industrial settings and food safety, the market is witnessing steady growth in several areas.

"The market size is huge," said Robert R. Alfano, a professor of science and engineering at the City College of New York and director of its Institute for Ultrafast Spectroscopy and Lasers. He noted that the 2PEF (two-photon excitation fluorescence) spectroscopy microscope market alone has grown to about $7 billion since 2005.

Growth in the spectroscopy market is occurring in the bio- and health care-related fields, in particular, he said. "The supercontinuum microscope, a more advanced version of the NLO (nonlinear optical) microscope, offers more applications and similar markets [to 2PEF spectroscopy] from resonant effects."

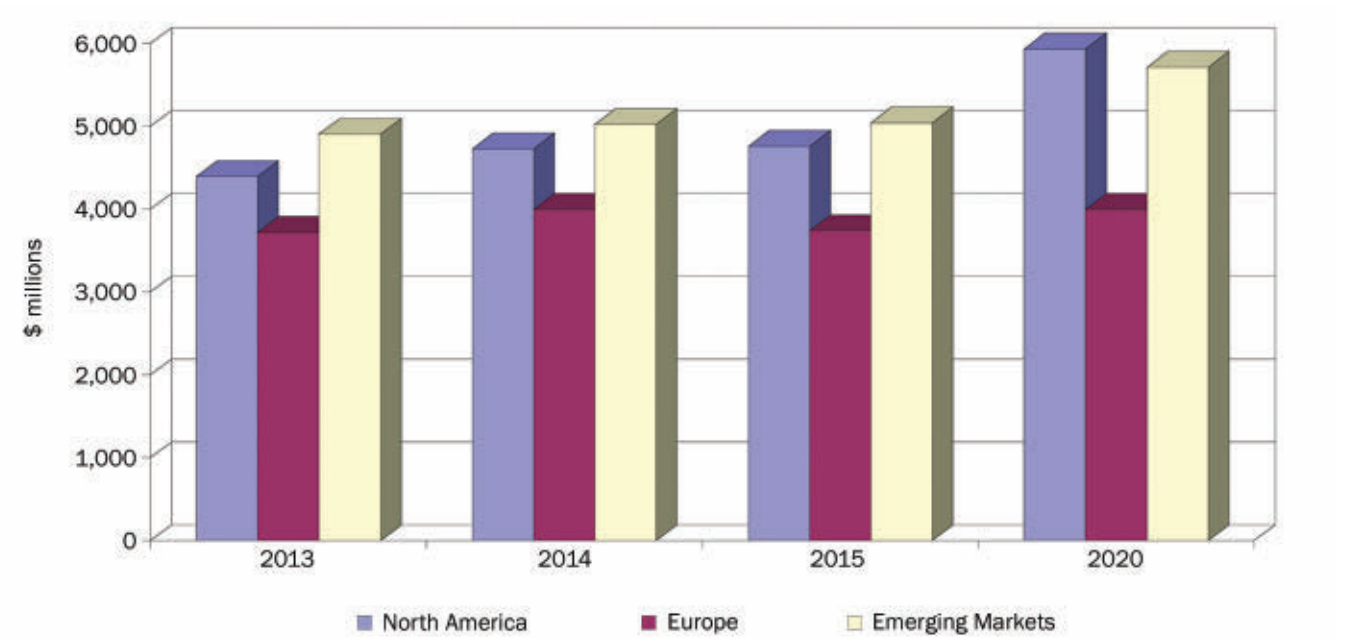
Alfano envisions optical biopsy spectroscopy technologies such as 1PEF, 2PEF, SHG (second-harmonic generation spectroscopy), resonance Raman, and near-IR and short-wave IR imaging to grow and ultimately enter the clinical area and commercial marketplace in items such as smart refrigerators and food optical detectors for home use.

Swiftly evolving submarkets

Several different segments within the spectroscopy market are primed for growth, according to many market experts.

IR spectroscopy — categorized into near-, mid- and far-IR — is employed in biological, pharmaceutical, chemical, food and beverage, environmental and semiconductor applications, and is a market that North America is expected to lead through the next several years. In 2015, this region held the largest IR spectroscopy market share. Overall, this sector of the spectroscopy market should top $1.26 billion by 2022, at a CAGR of 6.5 percent.

Raman spectroscopy joins the aforementioned submarkets in significant growth over the next several years. In a 2016 study from ReportLinker, this sector is expected to grow nearly 10 percent an-



BCC Research

The global spectroscopy market is swiftly expanding, thanks, in part, to technological advances and demand in emerging regions and industries.

nually through 2021 to reach $1.8 billion. It topped out at $1.1 billion in 2016. The life sciences is the largest application area for Raman spectroscopy; this area alone is on target to reach $658 million by 2021. Semiconductor applications in Raman spectroscopy should grow to $271 million by 2021.

"Probe-based Raman spectroscopy accounts for the largest share of the market in terms of instrument sales, and this product segment is expected to continue to lead the market throughout the forecast period," said BCC Research analyst Sinha Gaurav. "In terms of sampling techniques, surface-enhanced Raman scattering (SERS) accounted for the largest market share, with 40.9 percent of the global market in 2015."

Another area set for growth is the process spectroscopy market; process spectroscopy is any use of spectroscopy to obtain real-time data to monitor and optimize a manufacturing process. This market "reflects the rising awareness for quality throughput among end-use industries such as oil and gas, pharmaceuticals, and food and agriculture," according to information from Radiant Insights Inc., a market research and consulting company.

Experts there believe the process spectroscopy market will hit $1.27 billion by 2022, at a CAGR of nearly 9 percent.

The expansion of the Raman spectroscopy market is driven by technological advancements namely in health care and research, as well as diagnostics, materials science and mining.

MarketsandMarkets, an international market research company, cites the pharmaceutical industry as a key end-use segment for such market growth; specifically, an increased focus on drug safety regulations, "where process spectroscopy techniques enable the detection of metals in drug samples."

Market growth drivers

Continually developing spectroscopy technologies are pushing market growth in numerous sectors, including the aforementioned mass, process, IR and Raman spectroscopy.

The expansion of the Raman spectroscopy market is driven by technological advancements namely in health care and research, as well as diagnostics, materials science and mining. Other growth factors include "rising demand for R&D and increasing applications in homeland security, medical diagnosis, food processing, carbon materials and semiconductors."

Also, "increasing demand for real-time analysis of samples in the harshest condi-

tions is expected to propel the demand for SERS during the [market] forecast period [2016-2021],” said BCC’s Gaurav.

The growth of IR spectroscopy, and all of its subcategories, can be attributed to anticipated increases in government funding for R&D in North America, as well as potential changes in drug development regulations, according to MarketsandMarkets in a 2016 report. Advancements in and the rise of bio-related research sectors such as proteomics could also contribute, offering “a platform for key players to showcase new products and technologies.”

Similar forces are driving the process spectroscopy market — technological advancements and prices that experts anticipate will be critical parameters affecting the industry. The popularity of portable or handheld spectroscopy instruments should drive the market growth, as well, over the forecast period. Additionally, the focus on reducing operational expenditure should further drive the global adoption of process spectroscopy.

Growth of this submarket globally will also be “fueled by the [U.S.] Food and Drug Administration’s move to implement process analytical technologies in the pharmaceutical industry,” according to a Transparency Market report.

Looking to the future

In addition to global growth, the spectroscopy market continues to expand “largely due to the technological developments and demand from pharmaceutical and biotechnology, environmental, and food and beverage industries,” BCC told Photonics Media. From $13.5 billion in 2015, this market is expected to hit $15.6 billion by 2020. North America alone will account for nearly $6 billion.

The spectroscopy market evolution can be attributed to a rising interest in eco-friendly technologies and increased environmental concerns, for which spectroscopic instruments can play a key role. BCC added that “R&D spending, increasing competition, patent expiries and new technologies are giving a direction to the [spectroscopy] market.” The advancements, new product launches and changing lifestyles have influenced the spectroscopy market to grow into the future.

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Read more about spectroscopy…

In this issue…

- Don’t miss “**Spherical Lens Probes Open New Possibilities in Raman Spectroscopy**,” by Brian Marquardt and Giora Proskurowski of MarqMetrix Inc., on page 34.

Online at Photonics.com…

- “**Smartphones Poised to Shake Up Spectroscopy**,” by James Schlett, Contributing Editor, from the January 2017 issue of *BioPhotonics*
- “**Spectroscopy: Mastering the Techniques**” and “**Spectroscopy: Tools of the Trade**,” both by Dr. John R. Gilchrist, Gilden Photonics, for the *Photonics Handbook*

Spectroscopy Directory

A select list of companies from around the world that manufacture or supply spectroscopy products. The list was compiled using data submitted for the *Photonics Buyers' Guide*. For more information, visit PhotonicsBuyersGuide.com.

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SpectrEcology LLC
Wesley Chapel, Fla.
www.spectrecology.com

tec5USA Inc.
Plainview, N.Y.
www.tec5usa.com

Zolix Instruments Co. Ltd.
Beijing
www.zolix.com.cn

Spectrometers, Visible

Admesy BV
Ittervoort, Netherlands
www.admesy.nl

Agilent Technologies Inc., Chemical Analysis
Santa Clara, Calif.
www.agilent.com

B&W Tek
Newark, Del.
www.bwtek.com

Bristol Instruments Inc.
Victor, N.Y.
www.bristol-inst.com

Data Optics Inc.
Ypsilanti, Mich.
www.dataoptics.com

En'Urga Inc.
West Lafayette, Ind.
www.enurga.com

GratingWorks USA
Acton, Mass.
www.gratingworks.com

Hamamatsu Corporation
Bridgewater, N.J.
www.hamamatsu.com

HORIBA Jobin Yvon, HORIBA Scientific
Longjumeau, France
www.horiba.com/scientific

International Light Technologies, Gilway & International Light Divs.
Peabody, Mass.
www.intl-lighttech.com

McPherson
Chelmsford, Mass.
www.mcphersoninc.com

Newport – Corion Filters & Mirrors
Franklin, Mass.
www.corion.com

PhotonTec Berlin GmbH
Berlin
www.photontec-berlin.com

Princeton Instruments
Trenton, N.J.
www.princetoninstruments.com

Resolution Spectra Systems
Meylan, France
www.resolutionspectra.com

Spectral Products
Putnam, Conn.
www.spectralproducts.com

SpectrEcology LLC
Wesley Chapel, Fla.
www.spectrecology.com

Spectrometers, VUV

BaySpec Inc.
San Jose, Calif.
www.bayspec.com

GratingWorks USA
Acton, Mass.
www.gratingworks.com

McPherson
Chelmsford, Mass.
www.mcphersoninc.com

Photon Control Inc.
Burnaby, British Columbia, Canada
www.photon-control.com

Spectrometers, X-Ray

Allied Scientific Pro
Gatineau, Quebec, Canada
www.alliedscientificpro.com

HORIBA Jobin Yvon, HORIBA Scientific
Longjumeau, France
www.horiba.com/scientific

McPherson
Chelmsford, Mass.
www.mcphersoninc.com

Shimadzu Europa GmbH
Duisburg, Germany
www.shimadzu.eu

Spectrophotometers, Fluorescence

Agilent Technologies Inc., Chemical Analysis
Santa Clara, Calif.
www.agilent.com

Optical Building Blocks
Edison, N.J.
www.obbcorp.com

Spectrophotometers, Infrared

Spectraline Inc.
West Lafayette, Ind.
www.spectraline.com

Spectrophotometers, Near-Infrared

Admesy BV
Ittervoort, Netherlands
www.admesy.nl

Agilent Technologies Inc., Chemical Analysis
Santa Clara, Calif.
www.agilent.com

Spectrophotometers, Ultraviolet

Admesy BV
Ittervoort, Netherlands
www.admesy.nl

Quantum Northwest Inc.
Liberty Lake, Wash.
www.qnw.com

TechnoSpex Pte. Ltd.
Singapore
www.technospex.com

Spectrophotometers, Visible

Admesy BV
Ittervoort, Netherlands
www.admesy.nl

Data Optics Inc.
Ypsilanti, Mich.
www.dataoptics.com

Gigahertz-Optik Inc.
Newburyport, Mass.
www.gigahertz-optik.com

Instrument Systems GmbH
Munich
www.instrumentsystems.com

Ocean Optics Inc.
Dunedin, Fla.
www.oceanoptics.com

Photon Control Inc.
Burnaby, British Columbia, Canada
www.photon-control.com

Quantum Northwest Inc.
Liberty Lake, Wash.
www.qnw.com

TechnoSpex Pte. Ltd.
Singapore
www.technospex.com

Zolix Instruments Co. Ltd.
Beijing
www.zolix.com.cn

Spectroradiometers

CI Systems Inc.
Simi Valley, Calif.
www.ci-systems.com

Data Optics Inc.
Ypsilanti, Mich.
www.dataoptics.com

Electro Optical Industries LLC
Santa Barbara, Calif.
www.electro-optical.com

Gigahertz-Optik Inc.
Newburyport, Mass.
www.gigahertz-optik.com

Gooch & Housego Orlando
Orlando, Fla.
www.GHinstruments.com

Infrared Systems Development Corp.
Winter Park, Fla.
www.infraredsystems.com

Instrument Systems GmbH
Munich
www.instrumentsystems.com

International Light Technologies, Gilway & International Light Divs.
Peabody, Mass.
www.intl-lighttech.com

Labsphere Inc., Photonics
North Sutton, N.H.
www.labsphere.com

Spectroradiometers, Field Portable

Data Optics Inc.
Ypsilanti, Mich.
www.dataoptics.com

Gooch & Housego Orlando
Orlando, Fla.
www.GHinstruments.com

Infrared Systems Development Corp.
Winter Park, Fla.
www.infraredsystems.com

International Light Technologies, Gilway & International Light Divs.
Peabody, Mass.
www.intl-lighttech.com

Ocean Optics Inc.
Dunedin, Fla.
www.oceanoptics.com

Spectroscopic Accessories and Supplies

art photonics GmbH
Berlin
www.artphotonics.com

Newport – Oriel Instruments
Bozeman, Mont.
www.newport.com/oriel

Ocean Optics Inc.
Dunedin, Fla.
www.oceanoptics.com

Photon Control Inc.
Burnaby, British, Columbia Canada
www.photon-control.com

PhotonTec Berlin GmbH
Berlin
www.photontec-berlin.com

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

Quantum Northwest Inc.
Liberty Lake, Wash.
www.qnw.com

Sacher Lasertechnik GmbH
Marburg, Germany
www.sacher-laser.com

Spectrum Measuring Instruments, Infrared

BaySpec Inc.
San Jose, Calif.
www.bayspec.com

Bristol Instruments Inc.
Victor, N.Y.
www.bristol-inst.com

Gooch & Housego Orlando
Orlando, Fla.
www.GHinstruments.com

Instrument Systems GmbH
Munich
www.instrumentsystems.com

J.A. Woollam Co. Inc.
Lincoln, Neb.
www.jawoollam.com

Newport – Oriel Instruments
Bozeman, Mont.
www.newport.com/oriel

Resolution Spectra Systems
Meylan, France
www.resolutionspectra.com

Spectrum Measuring Instruments, Ultraviolet

Gooch & Housego Orlando
Orlando, Fla.
www.GHinstruments.com

Instrument Systems GmbH
Munich
www.instrumentsystems.com

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Lincoln, Neb.
www.jawoollam.com

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Bozeman, Mont.
www.newport.com/oriel

tec5USA Inc.
Plainview, N.Y.
www.tec5usa.com

Spectrum Measuring Instruments, Visible

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Instrument Systems GmbH
Munich
www.instrumentsystems.com

J.A. Woollam Co. Inc.
Lincoln, Neb.
www.jawoollam.com

Mightex Systems
Toronto
www.mightex.com

Newport – Oriel Instruments
Bozeman, Mont.
www.newport.com/oriel

Ophir – Spiricon LLC, Photonics
North Logan, Utah
www.ophiropt.com/photonics

Resolution Spectra Systems
Meylan, France
www.resolutionspectra.com

TechnoSpex Pte. Ltd.
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www.technospex.com

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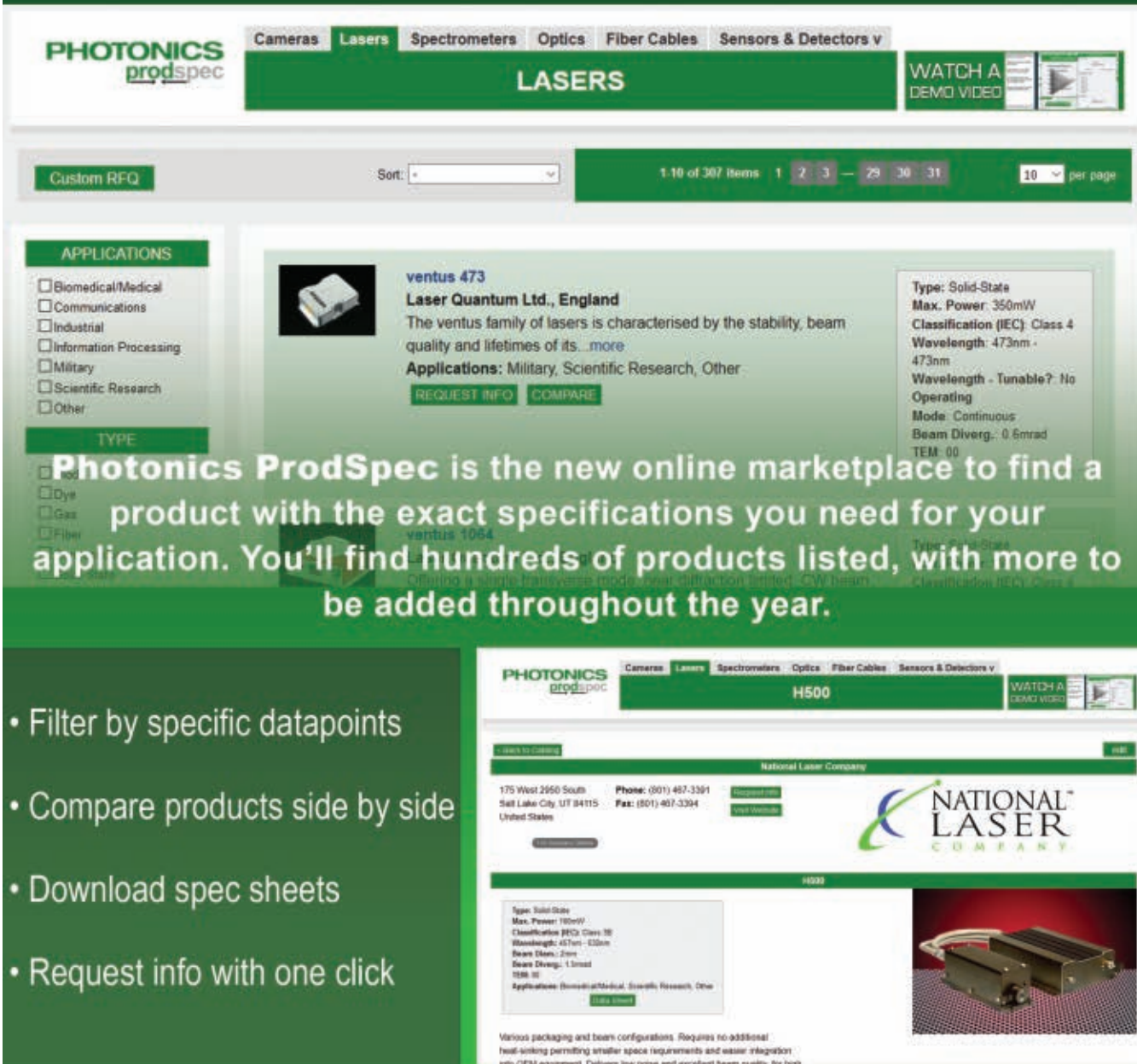

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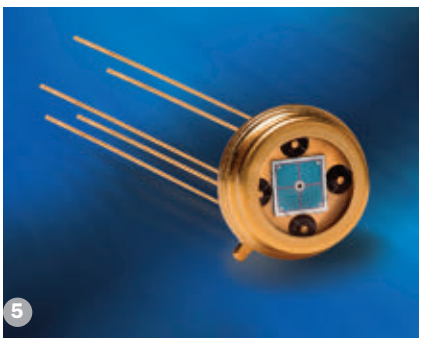


1 Stereo Vision Building Kit

The new stereo vision building kit from **AutoVimation GmbH** is extended by an electronics box, calculating the stereo image from two USB cameras with FPGA support. The output delivers a depth of field image or point cloud that is transmitted to a PC via Ethernet and processed there. The system works with ambient light, but light sources or pattern projectors can be added if required. Compared with common stereo sensors, users benefit from having full control over the system. The optical base camera resolution, lens and working distance may be configured by the customer.
sales@autovimation.com

2 CO_2 Optics

A line of field-replacement CO_2 optics is available from **Laser Research Optics** for lasers that cut composites for precision gaskets where smooth-edge definition is required. The optics include ZnSe lenses and mirrors, which are direct field replacements for popular lasers used in manufacturing gaskets. Optimized for use at 10.6 µm, lenses are offered in 1- to 1.5-in. O.D. sizes with 1- to 12-in. focal lengths and available with dual-band anti-reflective coatings to aid in system alignment.
sales@laserresearch.net

3 Diffuse Reflectance Probe

The Diffuse Reflectance (DR) Probe from **Ocean Optics Inc.** measures 45° diffuse reflectance, enhancing UV-VIS and NIR spectroscopy results. The sampling tool removes localized variance in reflectance measurements. It is ideal for applications such as color analysis, material identification and quality monitoring of foods. The DR Probe integrates a light source and collection optics into one unit to measure 45° diffuse reflectance. With the probe's collection optics fixed in place relative to the light source, the measurement geometry is constant. An included standoff accessory ensures a consistent, 40-mm focal length between the probe and the sample.
www.oceanoptics.com

4 Multi-Focus Optics

The foXXus and twoXX multi-focus optics from **AdlOptica GmbH** are designed for multi-kW lasers. Focusing a laser beam in separate foci perpendicular to or along the optical axis allows optimizing energy distribution for higher productivity and improved quality of materials processing. Optical design provides theoretically lossless focusing in a variable number of foci, and refractive optical components guarantee high resistance to radiation of multi-kW continuous wave or pulsed lasers. The multi-focus optics operate with both TEM00 and multimode lasers at various wavelengths and various beam sizes.
info@adloptica.com

5 Silicon Photodiodes

Annular quadrant silicon photodiodes from **OSI Optoelectronics Inc.** operate between 350 and 1100 nm for backscatter reflectivity measurements. The new silicon quadrant detector features an annular package design and includes a 200-µm laser-cut hole on the chip. The header enables a fiber to be coupled from the back of the detector, ensuring that the detector sensing area is always normal to the direction of the light, reducing the need for angular compensation during backscatter measurements. Available in TO-5 and TO-8 metal packages, the active area on each element is 1.6 and 19.6 mm^2, respectively.
www.osioptoelectronics.com

6 Standalone High-Speed Camera

The PhotoCam SpeederV2 portable, standalone, high-speed camera systems from **Photron Inc.** is designed for production fault-finding. The camera system allows workers to quickly view and identify production errors on the integrated 7-in. LCD remote touchscreen without the need for a computer or network infrastructure. One or two miniature remote camera heads are tethered to the compact camera control unit. The production line imaging system provides up to 2000 fps at full-pixel resolution and higher frame rates at reduced resolutions. Speed priority mode produces high-frame rate, full-resolution video capture to the on-board internal memory. Time priority mode provides extended duration video capture for streaming to an integrated solid-state drive.
image@photron.com

sCMOS Camera System

Princeton Instruments Inc. has announced the KURO:1200B, an sCMOS camera system to implement back-illuminated sensor technology. The device delivers both fast frame rates and high sensitivity needed for applications such as hyperspectral imaging, astronomy, cold-atom imaging, quantum imaging, fluorescence spectroscopy and high-speed spectroscopy. With back-illuminated sCMOS sensor architecture, the KURO provides >95 percent quantum efficiency and 100 percent fill factor, significantly reducing the fixed-pattern noise seen in front-illuminated sCMOS cameras and eliminating the need for the performance-limiting microlenses. Designed for operation within the LightField software ecosystem, the KURO camera is easy to control and can be integrated quickly in many imaging and spectroscopy experiments.
info@princetoninstruments.com

Detection and Surveillance System

The 550CZ-18 long-range target detection and surveillance system from **Sierra-Olympic Technologies Inc.** is designed for all-weather security applications. The MWIR imaging system features long-range target detection with recognition capabilities. The 18× continuous zoom lens provides 18° horizontal field of view at a wide angle and 1° horizontal field of view at a narrow angle. The thermal camera system can reliably detect human-sized targets at 18 km in good conditions. The 640 × 512-pixel resolution, indium antimonide detector with a 15-µm pitch is optimized to operate in the MWIR spectrum for imaging in marine and high-humidity environments. Other all-weather applications include border protection, vessel traffic monitoring, critical infrastructure protection and airport perimeter surveillance.
sales@sierraolympic.com

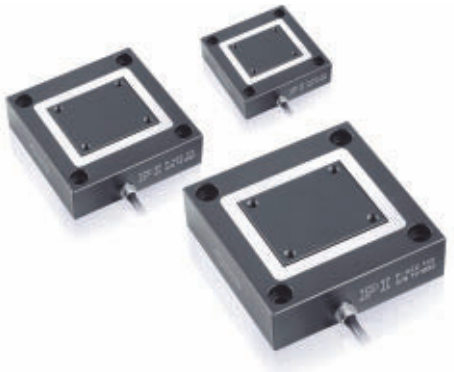
Isolation Source

The Surface Solution Isolation Source from **4D Technology Corp.** is designed for the AccuFiz

Fizeau laser interferometers. The fiber-coupled source excludes all but the surface of interest, making it simple to measure flat, transparent optics with physical thickness as thin as 200 µm. In a single setup, both the front and back surfaces of an optic can be measured without repositioning. Transmitted wavefront error, homogeneity and optical thickness can then be obtained from a combination of measurements. Its compact, lightweight design is extremely rigid for maximum stability in any orientation or environment. Wavelengths from 355 nm through 1.064 µm, apertures from 33 to 800 mm, and horizontal and vertical mounting configurations provide the right options for a wide range of applications and budgets.
www.4dtechnology.com

Sapphire Waveplates

Meller Optics Inc. has announced Sapphire Waveplates that extend polarization control into the IR, beyond fused silica optical waveplates. The devices feature Moh 9 hardness, making them highly resistant to chemicals, scratching, shock and temperature fluctuations. Designed to change the polarization state of a laser beam from linear to circular and vice versa in high-power IR and visible lasers, accuracy is assured by ultra-precise, in-house goniometric validation of their crystallographic orientation and location. Offered in custom sizes from 10 to 30 mm in A or M plane configurations, the Sapphire Waveplates can be made as thin as 0.4 mm and <25 mm in diameter with transmitted wavefront of >λ/10 at 6.32.8 nm. They are antireflection coated on both sides and provide λ/4 and λ/2 retardation with tolerances of > λ/300 at 632 µm, > λ/400 1.06 µm and > λ/1000 at 2.94 µm.
sales@melleroptics.com



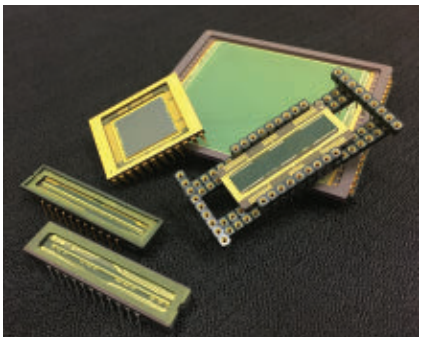
Linear Stages

PIHera Piezo Flexure linear stages from **Physik Instrumente LP** are featured from P-620.1 to P-629.1, consisting of 60 stages available in a wide variety of travel ranges. Flexure-guided piezo positioning stages deliver vibrationless motion, with virtually unlimited resolution, and fast response in comparison to mechanical bearing-guided motorized systems. The lack of rolling elements means there is no bearing rumble to affect the uniformity or straightness of the linear motion. PIHera precision closed-loop single stages are equipped with absolute-measuring direct-metrology capacitance sensors and provide resolution down to 0.1 nm in a compact, FEA-optimized package for high stiffness and long lifetime. A cost-effective positioning accuracy of 0.02 percent make the compact stages ideal for applications that require frictionless, vibration-free positioning with high linearity.
info@pi-usa.us

Laser Beam Profiling Training Tool

Ophir Photonics has released the "Understanding BeamGage: The BeamGage Training DVD" training tool for the BeamGage laser beam profiling system. Presented in 14 video chapters, the training covers the features and power of the system. Topics include Ultracal, the baseline correction algorithm that helped establish the ISO 11146-3 standard for beam measurement accuracy; camera controls; integrating Ophir power meter measurements; displaying 2D and 3D profiles; charting and graphing and statistical measurements. BeamGage is a state-of-the-art beam profiling system that performs extensive data acquisition and analysis of beam parameters, such as beam size, shape, uniformity, divergence, mode content, and expected power distribution. The system can analyze different light sources — from lasers to LEDs to optical fibers — as well as compare key statistics and provide 3D viewing in real time.
kenneth.ferree@us.ophiropt.com

new products



UV-Conversion Coatings

Acton Optics & Coatings has announced its UV-conversion coatings, Metachrome and Unichrome. The composite phosphor coatings provide scientists and engineers with a cost-effective way to improve the UV detection capabilities of CCDs, CIDs and CMOS sensors. Both proprietary coatings extend performance in the UV down to 120 nm. Peak photonic emission of Metachrome occurs in the green-visible region; Unichrome's peak emission is in the blue-visible range. Utilization of the coatings with front- and back-illuminated devices also renders a much cleaner signal response. Due to its anti-etaloning effect, Metachrome typically yields a signal that is 7.5× smoother than that of an uncoated back-illuminated sensor. Unichrome typically yields a signal that is 1.5× smoother. Applications include emission spectroscopy, inductively coupled plasma and laser-induced breakdown spectroscopy equipment.
info@actonoptics.com

Magnifier Luminaire

Featuring the fully rotational OMNIVUE magnifier lens, the OMNIVUE LED Magnifier Luminaire from **Waldmann Lighting** is now equipped with new LED technology. The 3 diopter (1.75×) magnifying lens, made from optical quality glass, tilts independently of the light source for optimum positioning. Three 3.5-W LED modules provide the choice of two light levels with the touch of a switch. The OMNIVUE LED also features precise positioning and now even longer-lasting maintenance-free operation. Two optional Add-x lenses are available for additional magnification up to 15 diopters. For longer reach applications, OMNIVUEMAX LED is available with a 43-in. extended reach arm, ideal for production benches and workstations. An optional pin mount for production workstations is also available.
waldmann@waldmannlighting.com

Beam Shapers

A new family of axicon array beam shapers from **PowerPhotonic Ltd.** is designed for use with multimode lasers. Capable of handling high peak and pulsed power of <20 kW continuous wave with a high efficiency of >98 percent, the arrays can be used to generate ring-shaped spots, a typical requirement for materials processing applications. By precisely controlling the angle of the axicon and the tip radius, ring diameter, the level of extinction in the center of the ring and the width of the ring can be adjusted. The new family consists of a small number of readily available standard products, with low-cost options to customize key parameters of the design. Typical applications for the axicon arrays include materials processing such as additive manufacturing, welding, laser diagnostics and research applications requiring a ring-shaped laser output.
sales@powerphotonic.com

Embedder Software

The VisualApplets Embedder from **Silicon Software GmbH** is a hardware solution that is easily integrated into image processing devices such as cameras and vision sensors. Using VisualApplets, the graphical development environment, the devices' field-programmable gate arrays are rendered freely programmable to realize individual image processing applications as often as desired and to port them onto other devices. Manufacturers of image processing devices, following the one-time implementation, can develop as many applications as desired, transfer them to further devices, and open up development for customers of their own applications. Programming the FPGA directly in the device enables it to execute portions of the image preprocessing, reducing data load and system costs. The system addresses applications in the industry 4.0 sectors.
info@silicon.software

Camera Link Translator

The CLT-371 Camera Link Translator from **Vivid Engineering** converts Camera Link to HD-SDI, enabling the use of Camera Link cameras with HD-SDI monitors. Camera Link to HDMI and Camera Link to DVI are also supported via an inexpensive external adapter. The CLT-371 works with most color and monochrome base-configuration cameras. Output format is available in 1920 × 1080 or 1280 × 720. System features include automatic frame rate adaptation, Bayer white balance correction, camera synchronization support and an RS-232 port for camera control. Configuration is available through rear-panel switch settings.
sales@vividengineering.com

Fiber Laser

The SBM1200FL flatbed, multipurpose, fiber laser, cutting and engraving system from **Laser Photonics LLC** is built with customizable fiber laser power

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www.laserphotonics.com

Lidar Solution

Renewable NRG Systems has announced WINDCUBE, an advanced lidar solution that offers meteorology experts real-time, high-resolution vertical and spatial profiling of the planetary boundary layer. The lidar technology, which delivers volumetric lower atmospheric observations unavailable via other methodologies, sets the stage for next-generation weather prediction models, providing meteorological professionals with powerful new capabilities to analyze and mitigate atmospheric risks such as storm formations and severe pollution events. WINDCUBE lidar enables real-time, 3D detection capabilities for parameters including spatial wind variance, vertical velocity distribution, low-level jet maxima, surface heat flux and mixing ratios in micro-, meso-, and macro-scale regimes. It provides atmospheric scientists and operational meteorologists with real-time assessments of mesoscale outflow boundaries, gust fronts, dry lines and other air mass interactions critical to valuable severe weather forecasts and alerts.
sales@renewablenrgsystems.com

Conveyor System

The WIDECURE conveyor system from **Dymax Corp.** is designed to offer consistent, fast and safe curing. Equipped with a 25-in.-wide belt, this system is ideal for curing light-curable materials on larger parts or larger quantities of smaller parts. The conveyor can be outfitted with a long-wave or short-wave bulb, delivering over 4 J/cm^2 of curing energy at 5 ft/min. Users can easily control various curing parameters through a touch screen control panel, achieving greater curing flexibility tailored to their specific application. In addition, the system's tightly

controlled belt speed and minimal bulb degradation further allow better control over cure.
www.dymax.com

Tunable Lasers

The Continuously Tunable Lasers (CTL) platform from **Toptica Photonics AG** can now provide continuous, mode-hop-free wavelength tuning up to 110 nm around the wavelengths of 1050, 1320 and 1470 nm. They can achieve scans with high absolute accuracy, sub-pm resolution and output powers up to 80 mW. Piezo tuning allows even higher resolutions down to 5 kHz. It reaches low drift values and a linewidth <10 kHz. The new wavelengths of the CTL platform support a variety of applications like spectroscopy, waveguide characterization, studying microresonators, seeding ytterbium amplifiers, as well as testing of ytterbium fiber components. In addition, the CTL at the 1470-nm central wavelength lends itself for specific applications in the

telecommunication range, where high resolution and low noise are required.
sales@toptica.com

Tension Cleaver

The Fujikura CT-104 tension cleaver from **AFL** is designed for fibers with a cladding diameter of 80 to 600 µm. Developed to address the medical and fiber laser markets, the CT-104 fiber cleavers offer superior tension cleaving performance beyond other conventional cleavers. The cleavers incorporate a manual clamping system that allows for a quicker cleaving process than what is typical with automated clamping systems. The CT-104 tension cleaver is equipped with a new motorized diamond blade assembly. The tension is easily adjusted to meet the precise requirements for all fiber diameters in this range. Additionally, the CT-104 features a large screen as well as the same user interface as the CT-105 and CT-106 cleavers.
sales@aflglobal.com

Fume Hoods

The UniFlow AireStream Fume Hoods from **Hemco Corp.** are constructed entirely of chemical-resistant, flame-retardant, nonmetallic composite resin materials. An exclusive unitized construction does not require screws, bolts, rivets or metallic hardware for assembly. The fume chamber is

molded in one piece, seamless with all corners coved for easy cleaning and light reflectivity. The hoods come in 48-, 60-, 72- and 96-in. models with either constant air volume or restricted bypass features. The hood is equipped with a 36-in.-high extended view height, exclusive vector slotted rear VaraFlow baffle system, aerodynamic sash lift with perforated air-sweep feature and molded-in belled outlet collar for reduced airflow resistance.
info@hemcocorp.com

Mineral Spectrometer

Spectral Evolution Inc.'s oreXpress spectrometer with EZ-ID software can provide critical real-time mineral identification in limestone exploration where it is important to distinguish between calcite, dolomite and clays. The oreXpress field NIR spectrometer with EZ-ID delivers two spectral libraries of over 500 minerals and 1500 spectra that include known samples for calcite, dolomite and clays like kaolinite. By matching the spectra of an unknown field sample against those in the two libraries, EZ-ID can provide a fast and easy initial identification to help distinguish minerals. Quick and accurate mineral identification can provide geologists with a rapid way to see if deposits have the proper mineral mix.
sales@spectralevolution.com

Intermodulation Tracker

The PIM Hunter from **Anritsu Co.** is a passive intermodulation test probe that helps field technicians quickly discover the precise location of external passive intermodulation sources at cell sites. Designed for use with Anritsu's PIM Master, Spectrum Master and BTS Master handheld analyzers, the PIM Hunter complements the patented Distance-to-PIM technology that determines the distance between the antenna and external PIM. A technician can walk along the arc of that distance with PIM Hunter to detect the exact source of the external PIM. PIM Hunter has been custom designed to support external PIM identification over the 600- to 2700-MHz frequency range.
www.anritsu.com

Happenings

FEBRUARY

● **Laser Additive Manufacturing workshop (LAM) (Feb. 21-22)** Houston. Contact Laser Institute of America, +1 (407) 380-1553; www.lia.org/conferences/lam.

Printed and Flexible Electronics Congress (Feb. 21-22) London. Contact Steve Hambrook, +44 186 584 9841, steve@globalengage.co.uk; www.globalengage.co.uk.

SPIE Advanced Lithography (Feb. 26-March 2) San Jose, Calif. Contact SPIE, +1 360-676-3290, customerservice@spie.org; www.spie.org/x10942.xml.

39th International Activated Carbon Conference (Feb. 23-24) Orlando, Fla. Contact Barbara Sherman, +1 724-457-6576, barb@pacslabs.com; http://pacslab.com.

PHOTOPTICS 2017 (Feb. 27-March 1) Porto, Portugal. 5th International Conference on Photonics, Optics and Laser Technology. Contact PHOTOPTICS Secretariat, +351 265-520-185, photoptics.secretariat@insticc.org; www.photoptics.org.

● **Photonics World of Lasers and Optics 2017 (Feb. 28-March 3)** Moscow. Contact Ms. Margarita Semyakina, +7 499-795-29-06, ms@expocentr.ru; www.photonics-expo.ru.

MARCH

● **Pittcon 2017 (March 5-9)** Chicago. The Pittsburgh Conference on Analytical and Applied Spectroscopy. Contact The Pittsburgh Conference, +1 412-825-3220, info@pittcon.org; www.pittcon.org.

● **AeroDef Manufacturing Conference and Exhibition (March 6-8)** Fort Worth, Texas. Contact SME, +1 866-635-4692, service@sme.org; www.aerodefevent.com.

PIC International Conference (March 7-8) Brussels. The Photonics Integrated Circuits Conference is colocated with the Seventh CS International Conference focusing on the compound semiconductor industry. Contact Angel Business Communications, +44 0-2476-718-970, info@picinternational.net; www.picinternational.net.

● **LASER World of PHOTONICS CHINA (March 14-16)** Shanghai. Contact Katrin Hirl, +49 89-949-20324, katrin.hirl@messe-muenchen.de; www.world-of-photonics-china.com.

● **Image Sensors Europe 2017 (March 14-16)** London. Contact Smithers Apex, +44 1372-802000, info@smithersapex.com; www.image-sensors.com.

Lamdamap 12th International Conference & Exhibition 2017 (March 15-16) Wotton-Under Edge, England. Lamdamap 12th International Conference & Exhibition on Laser Metrology, Coordinade Measuring Machine & Machine Tool Performance. Contact euspen, +44 1234 754023; www.euspen.eu.

PAPERS

OSA Applied Industrial Optics: Spectroscopy, Imaging, and Metrology 2017 (June 26-29) San Francisco
Deadline: Abstracts, by Feb 15
Selected topics include: LED/laser lighting, autonomous/automated systems, flexible photonics, organic optics, nano/micro-photonics, non-destructive evaluation/non-invasive testing, biophotonics, wearable technology, and fabrication and manufacturing. Contact OSA, +1 202-223-8130, cstech@osa.org; www.osa.org/en-us/meetings/osa_meetings/imaging_and_applied_optics_congress/applied_industrial_optics_spectroscopy_imaging.

Quantum 2017 (May 7-13) Turin, Piedmont, Italy
Deadline: Abstracts, by Feb 15
Topics to include: quantum technologies, foundations of quantum mechanics, quantum metrology, imaging and sensing quantum information. Contact Marco Genovese, +39 011 3919 253, quantum2017@unito.it; www.quantum2017.unito.it.

Microscopy & Microanalysis 2017 (Aug. 6-10) St. Louis
Deadline: Papers, by Feb. 15
Contact Microscopy Society of America, +1 800-538-3672, associationmanagement@microscopy.org; www.microscopy.org/MandM/2017/program/submit.cfm.

● **OFC 2017 (March 19-23)** Los Angeles. The Optical Fiber Communication Conference and Exhibition. Contact OSA, +1 (202) 416-1907, custserv@osa.org; www.ofcconference.org.

● **International Laser Safety Conference (ILSC) (March 20-23)** Atlanta. Contact Laser Institute of America, +1 (407) 380-1553; www.lia.org/conferences/ilsc.

FCMN 2017 (March 21-23) Monterey, Calif. 2017 International Conference on Frontiers of Characterization and Metrology for Nanoelectrics (FCMN). Contact Della Miller, +1 530-896-0477, della@avs.org; http://www2.avs.org.

● **SPIE Smart Structures NDE 2017 (March 25-29)** Portland, Ore. Contact SPIE, +1 360-676-3290, customerservice@spie.org; www.spie.org/x88673.xml.

APRIL

● **OSA Biophotonics Congress: Optics in the Life Sciences (April 2-5)** San Diego. Contact The Optical Society, +1 202-223-8130, info@osa.org; www.osa.org/en-us/meetings/osa_meetings/optics_in_the_life_sciences/.

● **AUTOMATE 2017 (April 3-6)** Chicago. A3 Association for Advancing Automation. Contact +1 734-994-6088, info@automateshow.com; www.automateshow.com.

● **WCX17: SAE World Congress Experience (Apr. 4-6)** Detroit. SAE World Congress and Exhibition is now WCX17: Sae World Congress Experience. Contact SAE International, +1 877-606-7323 (U.S. & Canada), +1 724-776-4970 (Outside U.S. and Canada), customerservice@sae.org; www.wcx17.org.

● **ASLMS 2017 (April 5-9)** San Diego. 37th Annual Conference of the American Society for Laser Medicine and Surgery. Contact ASLMS, +1 (715) 845-9283, information@aslms.org; www.aslms.org/annual-conference.

● **SPIE Defense + Commercial Sensing (April 9-13)** Anaheim, Calif. Contact SPIE, +1 360-676-3290, customerservice@spie.org; www.spie.org/conferences-and-exhibitions/defense--commercial-sensing.

● **SPIE Technologies and Applications of Structured Light (April 18-21)** Yokohama, Japan. Part of Optics & Photonics International Congress 2017. Contact SPIE, +1 360-676-3290, customerservice@spie.org; www.spie.org/conferences-and-exhibitions/structured-light.

● **OPIE 2017 (April 19-21)** Yokohama, Japan. Optics & Photonics International Exhibition. Contact OPIC; www.opie.jp/en/index.php.

● **SPIE Optics & Optoelectronics (Apr. 24-27)** Prague. Contact SPIE, +1 360-676-3290 or +1 888-504-8171, customerservice@spie.org; www.spie.org/conferences-and-exhibitions/optics-and-optoelectronics.

● **IS Auto 2017 (April 24-26)** Dusseldorf, Germany. Image Sensors Automotive 2017. Contact Smithers Apex, +44 1372 802000, info@smithersapex.com; www.image-sensors.com.

Ukiva Machine Vision Conference & Exhibition 2017 (April 27) Milton Keynes, England. UK Industrial Vision Association. Contact Chris Valdes, +44 020 8773 5517, chris.valdes@ppma.co.uk; http://ukiva.org/mvc.

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LED-powered tiles a potential boon for home decor?

Imagine changing the color of a bedroom or bathroom with the touch of a button. Envision transforming a living room into the inside of an art gallery or a ceiling into a movie theater.

Italian scientists are using pioneering photonics technology to make these possibilities reality with the Luminous Electronic Tile — LUMENTILE— project, combining the simplicity of a plain ceramic tile with the sophistication of today's touchscreen technology.

Guido Giuliani, associate professor of optoelectronics at the University of Pavia, told Photonics Media this is the first time anyone has tried to embed electronics into ceramics or glass for a large-scale application, and that photonics and electronics are key to this product and future smart applications.

"LUMENTILE exploits state-of-the-art commercial high-brightness, high-power RGB LEDs for making the tiles luminous and bright, and obviously color-changing," said Giuliani. "In addition, we are developing a proprietary technology for the so-called 'light management,' that is, making the light emitted by single LEDs diffuse uniformly throughout the entire tile surface while keeping a high optical efficiency and a low-cost production process."

A combination of ceramic, glass and organic electronics, the tile is made up of structural materials, solid-state light sources and electronic chips that can be controlled with a central computer, smartphone or tablet.

The thinking behind this is that it will be an option to consumers as part of the initial architect and design process in a house. Specifications will be set by the users and not by the electrical engineers.

"You are instantly in control of your own environment. If you like flowery wallpaper, ducks or Christmas trees, now you can change it with one tap," Guiliani said.

Decorating is not the only use scientists see for the Luminous Electronic Tile. Potentially, the tiles could be used for advertising outside of a building, camouflaging military vehicles at the flick of a switch and as smart floor panels to, for example, recognize when an elderly user is no longer standing or has perhaps fallen.

The LUMENTILE product will be enhanced to include flexible, bendable and possibly wearable structures, while improving the ruggedness and applicability to smart-city environments. Giuliani said the possibilities are endless.

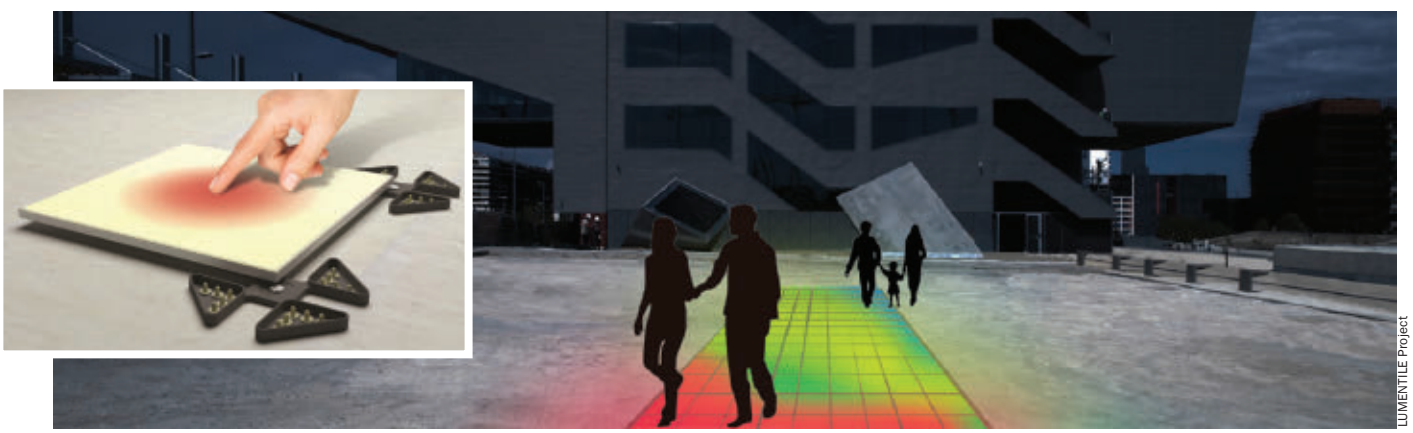
"We believe that LUMENTILE products will go on the market by 2020 with large-scale production and installations in shopping malls, airport terminals, public spaces, new building covers and private houses," he said.

By the end of this year, Giuliani and his fellow LUMENTILE partners from Italy, Finland, Switzerland and Spain expect to go live with two or three installations in public places aimed at customers who want to be the first to have this technology.

The tiles will have the capability of being switched off to a default color setting of basic silver, black or white. Just as easily as they are turned off, they can be turned on to transform a dining room into, let's say, the Taj Mahal. One could literally redecorate the inside of a house every single day.

Now, imagine this technology on the outside as well. Local homeowner's associations wouldn't be too happy.

Autum C. Pylant
autum.pylant@photonics.com



A walkable, sensorized floor of LUMENTILE. This will be installed in a public place, like a square or a shopping mall, and will be made of luminous tiles equipped with pressure sensors capable to detect a person walking onto the tile. Smart tiles for the future (inset).

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