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May 2016

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A New Take on Quantum Dots

Fiber Optics in Focus

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Content

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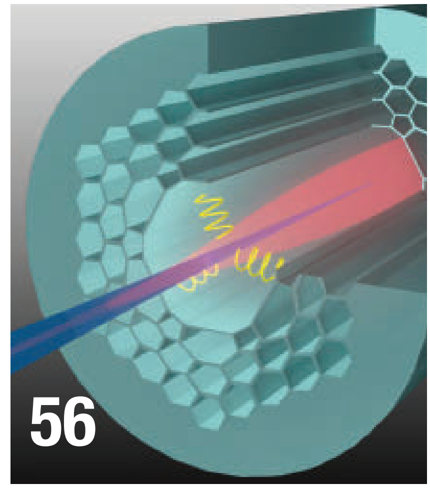
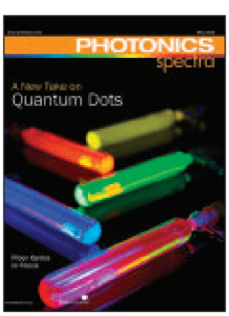


Departments & Columns

THE COVER
Nanoco Cadmium-Free Quantum Dots in solution. Courtesy of Nanoco Technologies Ltd. Cover design by Senior Art Director Lisa N. Comstock.



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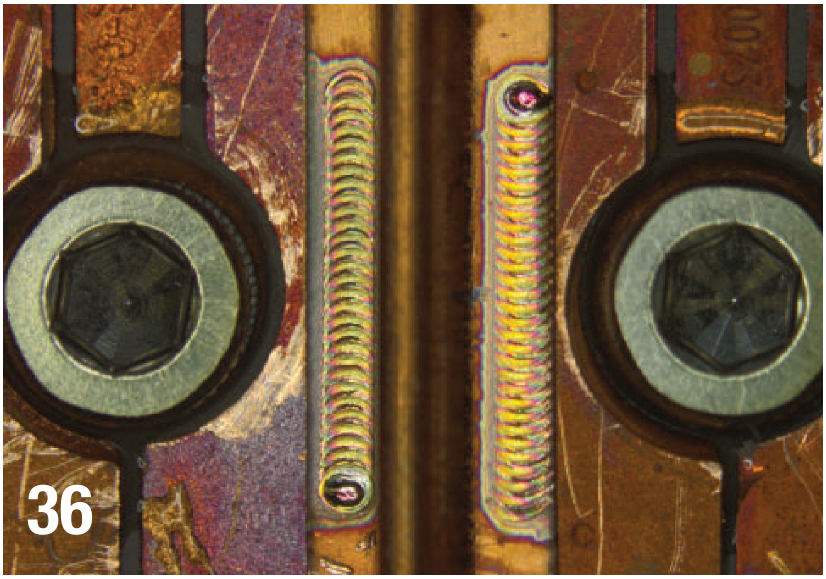
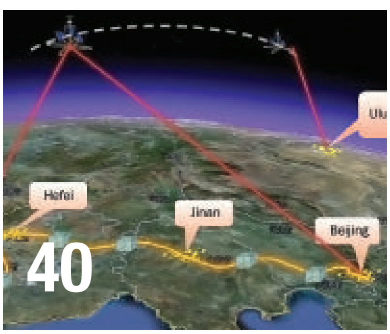
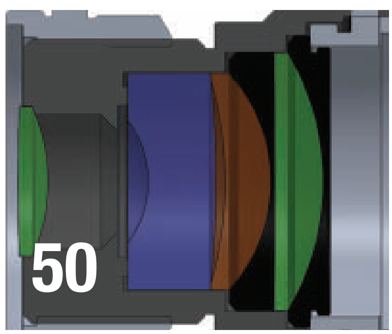
PHOTONICS: The technology of generating and harnessing light and other forms of radiant energy whose quantum unit is the photon. The range of applications of photonics extends from energy generation to detection to communications and information processing.







Features

In Memoriam
Teddi C. Laurin
Founder, Laurin Publishing Company

She was ahead of her time in developing a publishing company to galvanize this industry and help it to define itself by the word Photonics.

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editorial
COMMENT

Musings on horses and quantum leaps

The Kentucky Derby. The greatest two minutes in sports. Its very name evokes air thick with bourbon and cigar smoke, women's hats adorned with bows and feathers, sleek thoroughbreds and spectators dressed to the nines. Save, perhaps, for the Masters in April, few sporting events offer a more visually rich experience for TV viewers.

Recent advances in consumer display technology have made watching the first race of the Triple Crown even more exciting. That brings us to quantum dots — those tiny, brilliant semiconductors that offer unmatched color purity. In this month's cover story, Nanoco Technologies' Steve Reinhard examines a new heavy-metal-free version of quantum dots in "Cadmium-Free Quantum Dots Offer Vibrant Color for Liquid Crystal Displays" on page 32.

Speaking of quantum advances, Battelle's Nino Walenta and Lee Oesterling examine the singular role of the photon for ensuring data security over today's ever-expanding quantum communications networks. See "Quantum Networks: Photons Hold Key to Data Security" on page 40.

We move from all things quantum, to the shifting landscape of laser machining, where CO_2 lasers once led the field. Thanks to greater uptime, faster cutting and increasing affordability, fiber lasers are now the first choice for a wide array of industrial applications. See contributing editor Hank Hogan's "Better Lasers, Better Machining" on page 36.

While the defining attributes for lasers are their high spatial and temporal coherence, those same characteristics can have an adverse effect when it comes to optical coherence tomography (OCT). Researchers Brandon Redding, Peyman Ahmadi and Hui Cao document the development of a fiber amplified spontaneous emission (ASE) light source that delivers the brightness and low coherence required for OCT. See "An Alternative to LEDs for Full-Field Imaging" on page 46.

Zemax LLC's Cort Stinnett and Teresa Taylor examine new software capabilities to help optomechanical engineers overcome beam clipping and stray light, when building the packaging for optical lenses. See "Advances in Optical Simulation Software Bridge the Product Development Gap" on page 50.

Finally, don't miss this month's special section on fiber optics components and systems. Highlighting the section is senior editor Justine Murphy's feature, "Fiber Optics: From 'Piping Light' to All-Optical Communications" on page 56, chronicling fiber optics' origins to its present-day advancements.

Off to the races!

Michael D. Wheeler
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CONTRIBUTORS

Peyman Ahmadi
Peyman Ahmadi received a Ph.D. in physics from Oklahoma State University in 2006. In 2011, he joined Nufern Inc. as a scientist, and currently manages the industrial R&D group. Page 46.

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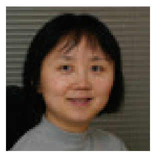
Brandon Redding received his Ph.D. from the University of Delaware in 2010. He then joined Hui Cao's lab at Yale University as a postdoctoral fellow. He currently works at the Naval Research Lab, where his research focuses on optical sensing techniques. Page 46.



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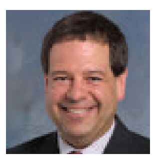
Hui Cao is a professor of Applied Physics and of Physics at Yale University. Her research interests and activities are in the areas of complex photonic materials and devices, nanophotonics and biophotonics. Page 46.

Steve Reinhard
Steve Reinhard joined Nanoco Technologies Ltd. in 2008 as vice president of business development. He has 14+ years of experience in the display and lighting industries. Reinhard earned his MBA from Binghamton University, and his B.S. in industrial engineering from Pennsylvania State University. Page 32.



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Lee Oesterling is a senior research scientist at Battelle with over 15 years' experience in the design, fabrication and test of photonics systems. He is responsible for the test and development of novel photonics technologies to support quantum information processing applications. Page 40.

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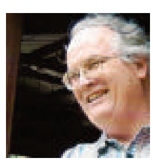

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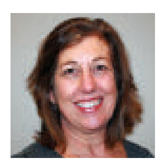
Regular contributing editor Hank Hogan holds a Bachelor of Science degree in physics from the University of Texas at Austin. He worked in the semiconductor industry and now writes about science and technology. Page 36.



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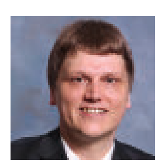

Nino Walenta
Nino Walenta, Ph.D., is a principal research scientist at Battelle and has 10 years' experience in academic research and development in the field of quantum optics, experimental quantum information processing and optical quantum communication. Page 40.


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Read more about the merger: cobolt.se and hubner-photonics.com

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OLED Display Technology Update and Forecast

In 2015, OLED displays had revenues of $13.5 billion. Forecasts indicate that by 2020, this revenue will grow to $33 billion. Barry Young, CEO of the OLED Association and an authority on the technology, presents a broad look at display applications utilizing OLEDs, including smartphones, TVs, VR systems, notebooks and tablets. He discusses the technologies used to create OLED displays, including the stacked model, the differences between backplane and frontplane technologies, thin-film encapsulation, and the materials required to create OLED displays. Young also looks at future applications for OLED displays and the challenges facing the development and application of OLED technology. Additional information and registration details for this and other webinars are available at **photonics.com/webinars**.

Available on Demand

For more information and to watch past presentations, visit **photonics.com/webinars**.

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Nexoptic, Spectrum Optix complete lens prototype study, plan merger

Canadian optics development partners Nexoptic Technology Corp. of Vancouver, British Columbia, and Spectrum Optix Inc. of Calgary, Alberta, have achieved a lens stack depth-to-aperture ratio of near 1:1 after completing the trade study phase of their proof of concept (POC) prototype development program.

"For over 400 years, general telescope design has not significantly changed," said John Daugela, president and CEO of Spectrum Optix and director of Nexoptic. "We aim to enable transformational change in lens designs with our patent-pending Blade Optics technology."

The trade study phase involved modeling and testing several lens stack design iterations in order to identify the final design for the prototype. Simulated image results obtained using Zemax ray tracing software exceeded the preliminary image quality target for the modeled lens stack design. The study was completed by optical design firm Ruda Cardinal Inc.

The next phase of prototype development has begun, and will include completion of final design adjustments to adjust performance capabilities, tolerancing, stray light analysis and fabrication drawings for the optics, the companies said.

"Having the trade study behind us is a significant milestone for the companies, as it required lengthy and creative engineering processes," said Paul McKenzie, CEO of Nexoptic and director of Spectrum Optix. "In addition to constructing a first-of-its-kind telescope, one of our main goals with our POC prototype is to demonstrate to the marketplace how our technology offers the potential to revolutionize numerous imaging applications and possibly give rise to a new breed of optical products yet to be commercialized."

Nexoptic and Spectrum Optix develop optics and lenses for cameras, telescopes, mobile devices, binoculars, computer imaging, medical imaging devices and gaming technology, among other devices. The two companies have entered into an option agreement to merge.

Deep Optics secures $4M to develop multifocal glasses, VR/AR applications

Dynamic focal glasses developer Deep Optics, headquartered in Petach Tikva, Israel, has reported closing $4 million in A-round funding.

The round includes strategic investor Essilor International SA, a French company that produces ophthalmic lenses along with ophthalmic optical equipment; Taiwan-based Atomics 14 Ventures; and several private investors, including Saar Wilf, Deep Optics's chairman and first investor.

Deep Optics said its aim is to provide alternative progressive glasses and new ophthalmic applications with electronic dynamic focal technologies based on its proprietary, patent-pending liquid crystal lenses.

Deep Optics

Omnifocals concept design.

"The human eye has a natural focusing ability that degrades with age," said Yariv Haddad, co-founder and CEO. "Current multifocal glasses compensate for this degradation, but they cannot offer adaptable correction power management. The dynamic solution we're developing is actually similar to the human focusing mechanism, and so in addition to its superior lens function, should be even easier to get used to with minimal, if any, adjustment required."

The company is also exploring additional applications for its adaptive electronic lens technology, such as virtual and augmented reality. For more information, visit www.deepoptics.com.

SSL firms Lumisyn, PhosphorTech receive SBIR Phase-II funding

Two solid-state lighting (SSL) projects were among 78 recipients of Small Business Innovation Research (SBIR)-Small Business Technology Transfer (STTR) Phase II grants announced in March by the U.S. Department of Energy's Office of Science and Basic Energy Sciences. SBIR Phase II grants — awarded to successful SBIR Phase I Release 1 recipients — are each worth about $1 million, and their duration is 24 months.

The Phase II recipients working on SSL were Lumisyn of Rochester, N.Y., selected for its advanced synthesis of compositionally novel nanocrystals that will maintain high efficiency simultaneously at high temperatures and optical flux; and PhosphorTech of Kennesaw, Ga., selected to maximize the luminous efficacy of a phosphor down-converting LED system using a combination of high-quantum-

• Singapore's Heptagon Micro Optics has announced the product shipment milestone of 2 billion units •

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yield red phosphors, surface plasmon resonance, and enhanced light-extraction efficiency, which is expected to yield more than a 42 percent improvement in efficacy while significantly reducing the amount of phosphor material.

Kopin annual revenues up 1% as expenses drop

Kopin Corp. of Westborough, Mass., a developer of wearable computing technologies and systems, has closed 2015 with an increase in revenue. The company reported 2015 revenue of $32.1 million, up from $31.8 million in 2014. R&D expenses decreased from $20.7 million in 2014 to $17.6 million for 2015. Selling, general and administrative expenses amounted to $18.1 million for 2015, compared with $19.9 million for 2014.

"In 2015, our revenues from sale of products for the wearable market doubled over 2014 to approximately $12 million," said John C.C. Fan, president and CEO of Kopin. "As more companies adopt Kopin's view that the headset is the next smartphone and voice will someday replace touch, we expect more new customers and industries to develop."

Net loss for 2015 was $14.7 million, or $0.23 per share, compared with a net loss of $28.2 million, or $0.45 per share, for 2014. Included in the 2015 results of operations was a $9.2 million gain on the sale of investments.

Kopin's technology portfolio includes ultrasmall displays, optics, speech enhancement technology, system and hands-free control software, low-power application-specific integrated circuits and ergonomically designed smart headset reference systems.

$5.18B

— value of the global robotic vision market by 2020, as projected by Marketsandmarkets

Lockheed reaches optical system milestone with fighter plane installation

Lockheed Martin Corp. of Orlando, Fla., said it has delivered its 200th electro-optical targeting system (EOTS) for the U.S. armed forces F-35 Lightning II fighter planes.

The company is delivering F-35 EOTS under low-rate initial production contracts with a total of 367 systems ordered to date. Planned production quantities for the F-35 exceed 3,000 aircraft with deliveries through 2030.

The company said its F-35 EOTS is the first sensor to combine forward-looking IR and IR search-and-track functionality to provide F-35 pilots with precise air-to-air and air-to-ground targeting capability. EOTS allows aircrews to identify areas of interest, perform reconnaissance and precisely deliver laser- and GPS-guided weapons while maintaining a stealthy profile.

The F-35 Lightning II is a fifth-generation fighter plane, combining advanced stealth with high speed and agility, fully fused sensor information, network-enabled operations and advanced sustainment.

Lockheed Martin is a global security and aerospace company engaged in the research, design, development, manufacture, integration and sustainment of advanced technology systems, products and services.

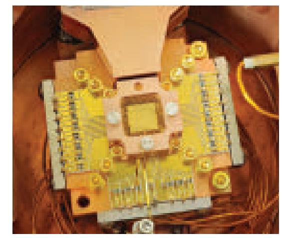
$118.9M

— value of the global shortwave-infrared market by 2022, as projected by Marketsandmarkets

This month in history

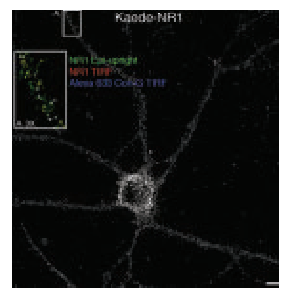
What were you working on five, 10, 20 or even 30 years ago? *Photonics Spectra* editors perused past May issues and unearthed the following:

2011



Scientists at NIST successfully facilitated the back-and-forth exchange of one quantum of energy between two beryllium ions, seeking to simplify information processing in quantum computers.

2006



To investigate molecular signaling in dendrites and the accompanying cellular modifications that help form long-term memory, University of Pittsburgh researchers used the "Bugatti of microscopes" — a combined upright and inverted research microscope made by Olympus.

1996

Laser-based systems for detecting surface contamination on silicon substrates and metals were being explored as an alternative to chlorofluorocarbon-based technologies, due to environmental concerns about the latter.

1986

Canadian cattle ranchers were using an image analysis workstation in conjunction with satellite imagery for land management by imaging the relative density of rangeland grasses over large areas.

Virus-deactivating drone wins Raytheon hack prize

Using a drone and UV light to deactivate viruses, a University of Arizona (UA) team comprising graduate students Alice Ferng and Sunglin Wang and undergraduate student Wendy Wang won the 2016 Hack Arizona's Raytheon prize for Best Drone Related Hack.

Inspired by the recent Ebola outbreak, the team created the X-Terminator Drone, which uses UV light reflected off aluminum propeller blades to irreversibly damage a virus' genetic material, making them benign and unable to replicate.

The team says that the technology would help reduce field risk for health-care workers and volunteers when faced with an epidemic, with the ultimate application being used in health-care facilities and patient clinics. High-risk areas can be sanitized by a drone prior to human contact.

Hosted at UA in Tucson, Hack Arizona brings over 800 participants together to build software and hardware projects from start to finish in under 36 hours. For more information on the first-place project, visit www.xterminatordrone.com.

A video about X-Terminator is available on the web version of this story: **www.photonics.com/A58431**

• LGS Innovations has completed a two-year lidar tech development project with DARPA •

MOVES AND EXPANSIONS

Coherent Inc., maker of lasers and laser-based technology for scientific, commercial and industrial customers, based in Santa Clara, Calif., and Plymouth, Mich.-based **Rofin-Sinar Technologies Inc.**, a developer and manufacturer of high-performance industrial laser sources and laser-based technology and components, have announced that their boards of directors have unanimously approved a definitive agreement under which Coherent will acquire Rofin for $32.50 per share in cash, in a transaction valued at approximately $942 million.

Coherent President and CEO John Ambroseo cited the company's opportunity to strengthen its materials processing capabilities through the acquisition.

The transaction is expected to be accretive to earnings per share in the first full year following the close. Coherent expects to realize approximately $30 million in annualized run rate synergies within 18 to 24 months post-closing, achieved through increased efficiencies, leveraging the scale of the combined businesses and optimizing the combined R&D portfolio.

Additional synergies are expected through accelerated growth from combining the best capabilities from both companies with a presence in over 60 global markets.

Coherent intends to finance the transaction through a combination of cash on hand and fully committed debt financing from Barclays. The transaction is expected to close within six to nine months, subject to approval by Rofin stockholders, regulatory approvals in the U.S. and other countries, as well as other customary closing conditions.

Navitar Inc., a manufacturer of precision optics and imaging system components, has signed a definitive agreement to acquire **Hyperion Development LLC**, a design firm and manufacturer of custom optical assemblies and OEM systems.

The deal will establish operations out of four engineering, design and production facilities in San Ramon, Calif., Woburn, Mass., Denville, N.J., and Rochester, N.Y.

Hyperion itself expanded in 2014 with the acquisition of AMF Optics Inc. and American Diamond Turning LLC.

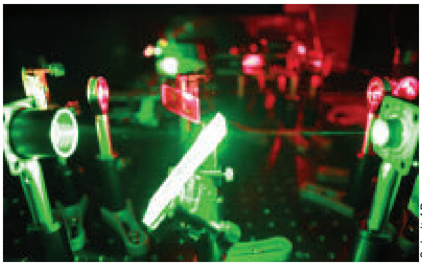
Between the two companies, sales have been made in over 45 countries around the world.

Hyperion Development provides optical technology such as deep- and extreme-ultraviolet imaging systems for lithographic printing and semiconductor process metrology. Navitar designs, develops and manufactures precision opti-

Cobolt ships 10,000th laser

Laser manufacturer Cobolt AB of Solna, Sweden, said it shipped its 10,000th laser in February. That unit, a Samba 532-nm, 300-mW single frequency laser, was delivered to the Photonic Nanomaterials Group at the University of Oxford in England, where postdoctoral student Sam Johnson, who ordered the laser, is studying nitrogen vacancy (N-V) defects in diamond lattices, which could hold the key to the future of quantum computing. The Cobolt Samba 532-nm is used in a scanning confocal microscope setup to excite the diamond, the red emission highlighting the N-V lattice defect. Johnson said Cobolt was the first choice due to the higher available output power, excellent power stability and TEM00 beam, as well as quick delivery time.

Founded in 2000 with roots in the Royal Institute of Technology in Stockholm, Cobolt, a Hubner Group Co., supplies CW and Q-switched lasers for stand-alone use in labs or OEM integration in equipment for fluorescence analysis, Raman spectroscopy, interferometric metrology, micromachining and environmental monitoring.


Cobolt AB

Sam Johnson's diamond nanophotonics experiment setup uses the Colbolt Samba 532-nm laser.

cal and electro-optical solutions for the biotechnology, medical, defense, security, industrial imaging and projection optics industries.

Avogy Inc., a power electronics startup headquartered in San Jose, Calif., and **Photonica Inc.**, a Beverly Hills, Calif.-based nanopixel technology firm, have announced plans to relocate headquarters and business operations to Rochester, N.Y., as part of the **American Institute for Manufacturing (AIM) Photonics Institute**.

AIM Photonics will focus on developing and manufacturing integrated photonics technologies under a $610 million public-private initiative awarded last July to a consortium led by the Research Foundation for SUNY (the State University of New York).

Under Phase I of the public-private partnership between Photonica, Avogy and SUNY Polytechnic Institute, the two companies will locate their advanced development, prototyping and early manufacturing operations at the Canal Ponds cleanroom facilities in Greece, N.Y., with a Phase II placement of manufacturing operations at the Eastman Business Park in Rochester, N.Y.

Combined under Phase I, Avogy and Photonica will invest more than $1.6 billion over five years, and create and support more than 1,400 high-tech jobs.

Photonica will, by itself, create and support 400 jobs in a project that involves a total investment of $700 million over the next five years, including $35 million from New York State to purchase equipment and upgrade infrastructure and cleanroom space at Canal Ponds and the Eastman park.

SUNY Poly reported that Avogy will scale up production of its current technologies with high-volume manufacturing in Rochester, and will employ nearly 400 workers with an average salary of more than $80,000 within the first five years. Its suppliers and high-tech business partners will generate more than 600 additional support jobs. The total Avogy project investment of $950 million includes $40 million from New York State for necessary tools and facility infrastructure upgrades.

Read Photonics Media's previous coverage of workforce development efforts surrounding AIM Photonics at **www.photonics.com/a58037**.

• Light Speed

Neophotonics Corp. revenues increase in 2015

Neophotonics Corp. of San Jose, Calif., has reported record revenues for 2015 of $339.4 million, an increase of 10.9 percent from $306.2 million in 2014. GAAP net income for the full year was $3.7 million, an improvement from the net loss of $19.7 million in 2014. Adjusted EBITDA was $43.2 million, up from $12 million in 2014. Neophotonics designs and manufactures advanced hybrid photonic integrated optoelectronic modules and subsystems for bandwidth-intensive, high-speed communications networks.

21.3%

— compound annual growth rate of the global terahertz spectroscopy market from 2016 to 2020, according to Marketsandmarkets, which also predicts Asia-Pacific will see the highest growth rate in that period

PEOPLE IN THE NEWS


AMS AG

Sensor and analog integrated circuit design and manufacturer AMS AG has named semiconductor industry veteran **Alexander Everke** CEO, following his appointment to the management board as CEO designate in 2015. Everke has held senior executive positions with Siemens, Infineon and NXP during his career. Prior to joining AMS, he served as executive vice president and general manager for NXP's multimarket semiconductors, high-performance mixed signal, and infrastructure and industrial business units. He holds master's degrees in electrical engineering and international business. AMS' products include sensors, sensor interfaces, power management and wireless ICs for consumer, communications, industrial, medical and automotive markets.

The Optical Society (OSA) has named Chilean-born laser physicist **F.J. Duarte** as the 2016 recipient of the David Richardson Medal for his "seminal contributions to the physics and technology of multiple-prism arrays for narrow-linewidth tunable laser oscillators and laser pulse compression." Duarte founded the firm Interferometric Optics in May 2006 in Rochester, N.Y., and serves commercial and industrial clients. His R&D emphases are on dispersive miniature tunable lasers, very large N-slit laser interferometers, multiple-prism optics and secure space-to-space interferometric communications. A well-known author in the field, Duarte introduced the generalized multiple-prism grating dispersion theory, applicable to laser linewidth narrowing and pulse compression; has discovered various multiple-prism grating laser oscillator cavities; and pioneered the application of Dirac's quantum notation to N-slit interferometry and classical optics. The OSA David Richardson medal has been presented yearly since 1966, in recognition of those who have made significant contributions to optical engineering, primarily in the commercial and industrial sector.

Lumentum Holdings Inc. has promoted **Jason Reinhardt** to executive vice president of global sales and product line management, with **Vince Retort** promoted to executive vice president and chief operating officer. In his expanded role, Reinhardt's focus will be to expand partnerships with customers and map a path for marketplace success. Meanwhile, Retort will lead R&D and operations functions, focusing on synergies and efficiencies that drive faster time-to-market and time-to-volume, while aligning Lumentum's product development and manufacturing processes to meet customers' needs. Lumentum manufactures optical and photonics products for the optical networking and commercial laser fields.

Ondine JV brings photodisinfection to China

Photodisinfection technology firm Ondine Biomedical Inc. of Vancouver, British Columbia, Canada, has announced a joint venture with businessman Yanan Zhao to bring two of its nonantibiotic, photodisinfection therapies to health-care facilities in China.

The two products are Periowave, for treatment of oral infections, and MRSAid, for the prevention of surgical-site infection, which is a leading cause of hospital-acquired infections. Ondine's technology provides rapid antimicrobial efficacy to prevent and eliminate infections without encouraging the formation and spread of antibiotic resistance.

Ondine's photodisinfection therapy for hospitals debuted in the Pre-Surgical Decolonization Project in Vancouver General Hospital, Canada's largest acute care hospital, which received the 2013 Innovation Award of Excellence from the International Consortium for Prevention & Infection Control in 2013. The project reduced infection rates by 39 percent with a 12-month nonantibiotic pilot program involving more than 5,000 patients who were treated with MRSAid photodisinfection therapy prior to a major surgery.

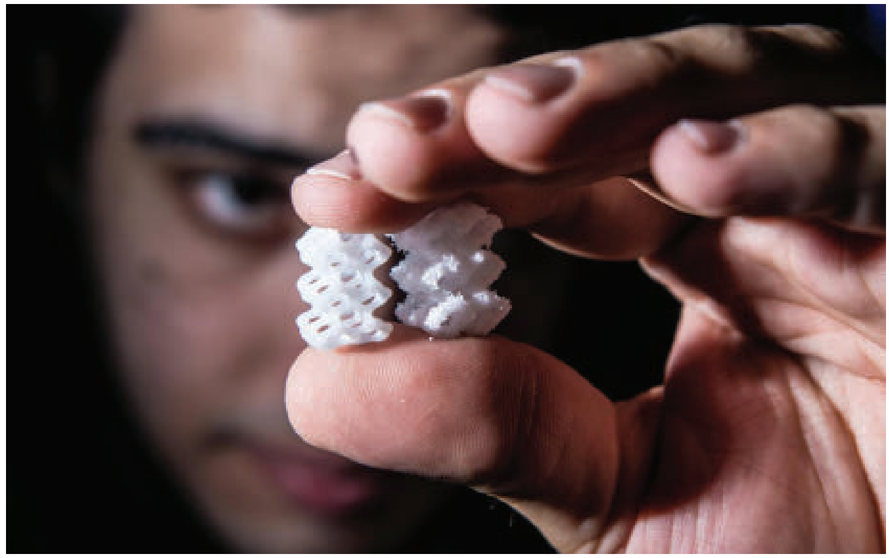
CNW Group/Ondine Biomedical

With Zhang Yanming, director of a new free-trade zone in the Henan province of China **(left)** in attendance, Carolyn Cross, chair of the board and CEO of Ondine Biomedical **(center)**, recently signed a joint venture agreement with Yanan Zhao **(far right)** to bring photodisinfection to the Chinese market.

Open-source laser sintering system 3D prints from custom powders

HOUSTON — An open-source laser sintering printer has been used to print intricate 3D objects from powdered plastics and biomaterials. The system costs a fraction of equivalent commercial systems and could give researchers a DIY technique for working with their own specialized materials.

"SLS [selective laser sintering] technology has been around for more than 20 years, and it's one of the only technologies for 3D printing that has the ability to form objects with dramatic overhangs and bifurcations," said professor Jordan Miller of Rice University, who specializes in using 3D printing for tissue engineering and regenerative medicine. "SLS technology is perfect for creating some of the complex shapes we use in our work, like the vascular networks of the liver and other organs."



Jeff Fitlow/Rice University

Ian Kinstlinger developed a method for smoothing the surfaces **(left)** of newly printed scaffolds **(right)** using vaporized solvent.

Called OpenSLS, the open-source device cost Rice bioengeering researchers less than $10,000 to build. Commercial SLS platforms typically start around $400,000 and can cost up to $1 million. However, commercial systems can't be used with custom powdered materials, which can stand in the way of researchers who want to experiment with biomaterials for regenerative medicine and other biomedical applications.

OpenSLS works differently than most traditional extrusion-based 3D printers, which create objects by squeezing melted plastic through a needle as they trace out 2D patterns, and 3D objects are then built up from successive 2D layers.

In contrast, the SLS laser shines down onto a flat bed of plastic powder. Wherever the laser touches powder, it melts or sinters the powder at the laser's focal point to form a small volume of solid material. By tracing the laser in 2D, the printer can fabricate a single layer of the final part. After each layer is finished, a new layer of powder is laid down, and the laser reactivates to trace the next layer.

The team showed that the machine could print a series of intricate objects from both nylon powder — a commonly used material for high-resolution 3D sintering — and from polycaprolactone, or PCL.

The tests using PCL, a biocompatible plastic that can be used in medical implants for humans, were particularly important, because it allowed demonstration of myriad shapes and surface textures. The increased surface area found on rough surfaces and in interconnected pore structures are preferred in some situations, while other biological applications call for smooth surfaces, said graduate student researcher Ian Kinstlinger.

The team developed an efficient way to smooth the rough surfaces of PCL objects that came out of the printer by exposing the parts to solvent vapor for about five minutes, which provided a very smooth surface due to surface-tension effects. In tests using human bone marrow stromal cells — the type of adult stem cells that can differentiate to form bone, skin, blood vessels and other tissues — the researchers found that the vapor-smoothed PCL structures worked well as templates for engineered tissues that have some of the same properties as natural bone.

"The stem cells stuck to the surface of the templates, survived, differentiated down a bone lineage and deposited calcium across the entire scaffold," Kinstlinger said.

The research was published in *Plos One* (doi: 10.1371/journal.pone.0147399).

Artificial dielectrics leveraged to control THz waves

PROVIDENCE, R.I. — Future terahertz-wave devices for communications and imaging could benefit from a lens based on artificial dielectrics.

Terahertz radiation (from about 300 to 10,000 GHz) is a relatively unexplored slice of the electromagnetic spectrum but it holds the promise of countless new imaging applications, as well as wireless communication networks with extremely high bandwidth. However, few off-the-shelf components are available for manipulating terahertz waves.

Artificial dielectrics are man-made media that mimic properties of naturally occurring dielectric media, or even manifest properties that cannot generally occur in nature. For example, the well-known dielectric property of refractive index, which usually has a value greater than unity, can have a value less than unity in an artificial dielectric.

A team of researchers led by professor Rajind Mendis of Brown University created a lens comprising an artificial-dielectric medium made up of a parallel stack of 32 metal plates, each 100 µm thick, with a 1-mm space between each plate. The plates have semicircular notches of different sizes cut out of one edge, such that when stacked horizontally, the notches form a 3D divot on one side of the device. When a terahertz beam enters the input side of the device, slices of the beam travel through the spaces between the plates. The concave output side of the device bends the beam slices to varying degrees such that the slices are all focused on a certain point.

The convergent lens had a planoconcave geometry, in contrast to conventional dielectric lenses. The team reported results demonstrating the lens is capable of focusing a 2-cm diameter beam to a spot size of 4 mm at the design frequency of 0.17 THz. The results also demonstrate that the overall power transmission of the lens was better than certain conventional dielectric lenses commonly used in the THz regime — 80 percent, about the same as Teflon lenses, but much higher than the 50 percent transmission achievable with silicon lenses.

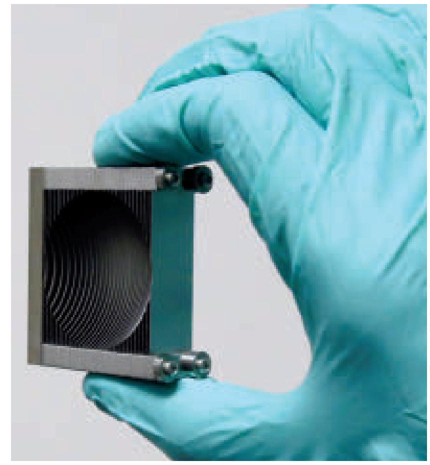
Unlike Teflon and other existing lenses, however, the new terahertz lenses offer the advantage of customization; by changing the spacing between the plates, the new device can be calibrated for specific terahertz wavelengths, the researchers said.

"That can be particularly interesting if you want to image things at one frequency and not at others," said Brown professor Dan Mittleman. "One of the important things here is that this design offers you a versatility that a simple chunk of plastic with a curved surface doesn't offer."

The team also observed that under certain conditions, the lens boundary demarcated by the discontinuous plate edges resembled a smooth continuous surface, a result they say highlights the importance of this artificial-dielectric technology for the development of future terahertz-wave devices.

"Any photonic system that uses terahertz — whether it's in imaging, wireless communications or something else — will require lenses," Mittleman said.

The researchers also said that technology used to create the lens could be used



Mittleman Lab/Brown University

Researchers have used an array of stacked plates to make a lens for terahertz radiation. The technique could set the stage for new types of components for manipulating terahertz waves.

to make a polarizing beam splitter for terahertz waves, which could be applied to elementary logic gates for terahertz photonics systems, where the binary logic states are assigned to the two polarization states. This would be an essential component of a terahertz data network.

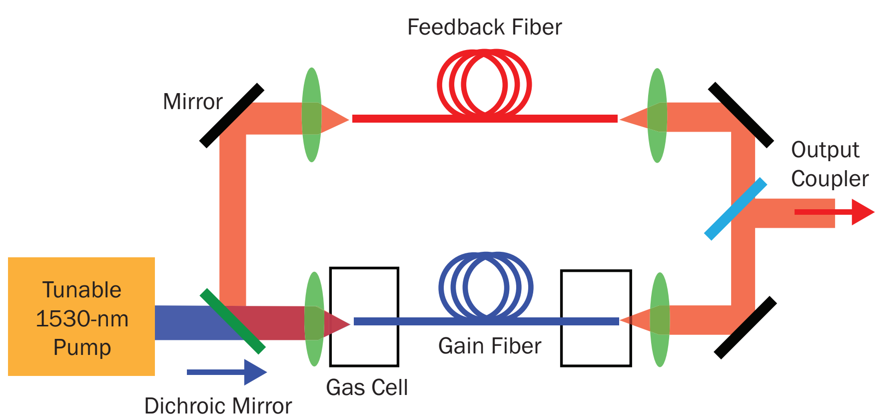
The research was published in *Nature Scientific Reports* (doi: 10.1038/srep23023).

Hybrid laser achieves stable MIR emission

BATH, England — A gas-fiber hybrid laser is capable of pulsed and continuous mid-infrared (MIR) emission between 3.1 and 3.2 µm, a spectral range that has long presented a major challenge for laser developers. The achievement could expand applications for MIR lasers, which are currently used in spectroscopy, environmental sensing and detecting explosives.

"Beyond about 2.8 µm, conventional fiber lasers start to fall off in terms of power, and the other main technology for the mid-IR, quantum cascade lasers, doesn't pick up until beyond 3.5 µm," said professor William Wadsworth of the University of Bath. "This has left a gap that has presented a great deal of difficulty."

Key to the laser's success was the team's development of silica hollow-core

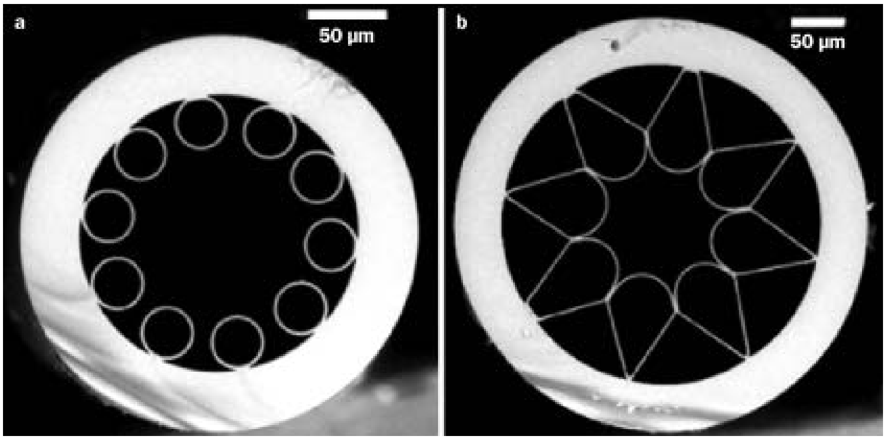


Hassan et al./The Optical Society (OSA), *Optica*

Experimental layout of the laser cavity.

fibers that perform exceptionally well in the MIR. Hollow-core fibers use internal glass structures to confine light inside hollow cores, whereas traditional optical fibers confine light in a solid core of glass.

"You can think of the structures in our



Hassan et al./The Optical Society (OSA), *Optica*

Scanning electron micrographs of the two different forms of hollow fiber used in the experiment. A gain fiber with transmission at 1.53- and 3.1-µm wavelengths **(left)**. A feedback fiber with low loss at 3.1 µm **(right)**.

fibers as very long and thin bubbles of glass," Wadsworth said. "By surrounding the region of space in the middle of the fiber with the bubbles, light that is reflected by the bubbles will be trapped inside of the hollow core."

The researchers realized the hollow-core fibers could enable a new type of fiber laser. They used acetylene gas because it emits in the MIR and can be pumped using lasers designed for the telecommunications industry. The hollow-core fibers provided a way to trap the light and the gas in the same place so that they can interact for a very long distance — 10 or 11 meters in this case.

Because light traveling inside a hollow-core fiber remains mostly in the empty core, the team said these fibers overcome the tendency of silica-based glass to absorb light at wavelengths past 2.8 µm. Silica is the preferred material for optical fibers because it is inexpensive, easy to manufacture and extremely strong.

The Bath researchers and other research groups have previously shown that gas inside a fiber can interact with light to produce MIR emission. In the new work, the researchers added a feedback fiber, the last component needed to consider the device a true laser. The feedback fiber took a small amount of light produced in the fiber containing the acetylene gas and used that light to seed another cycle of light amplification, thus reducing the pump power required to produce a laser beam.

The team said one important advantage of the design is its use of mature telecommunications diode lasers, which are practical, inexpensive and available in high powers. They plan to use a higher power pump laser to increase the fiber gas laser's power.

The researchers say that a number of

other gases should work with their fiber gas laser, allowing emission up to 5 µm.

"This laser is just one use of our hollow-core fiber," said doctoral student Muhammad Rosdi Abu Hassan. "We see it stimulating other applications of the hollow fiber and new ways of interacting different types of laser beams with gases at various wavelengths, including wavelengths that you wouldn't expect to work."

The research was published in *Optica*, a publication of The Optical Society (OSA) (doi: 10.1364/optica.3.000218).

Single-process liquid fab technique produces microlens arrays

DARMSTADT, Germany — A method for patterning large areas with highly irregular structures in a single process aims to simplify the production of microlens arrays for photovoltaic systems and patterned films for other optical technologies.

To produce material arrays, the technique combines the highly regular convection pattern that forms in thicker material layers with strong interfacial deformations possible only in much thinner liquid films.

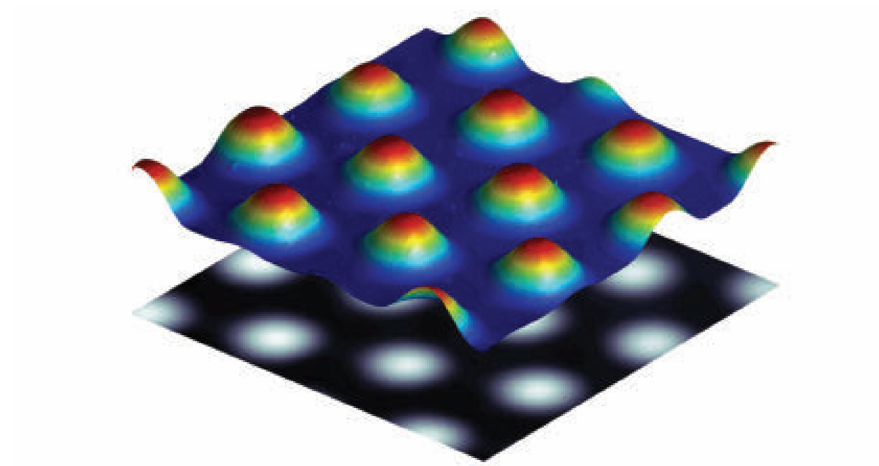
The resulting arrays locally enhance light intensity and could be used in integral imaging systems, unconventional photolithography and photovoltaic systems. For photovoltaics, an array of lenses placed atop a solar cell could serve as a light collector to enhance the efficiency of the photovoltaic system by making it less sensitive to the inclination angle of the solar light with respect to the cell surface. The method could easily be integrated into manufacturing lines, said researchers from the Technical University of Darmstadt who developed the process.

"Unlike previous work addressing systems with several interfaces, in our approach each layer has a vastly different initial thickness than the other," said doctoral candidate Iman Nejati.

The technique involved sandwiching a thin film of oil that's sensitive to irradiation with UV light between a solid planar substrate and a much thicker layer of another immiscible liquid. The system therefore contained not only a liquid-gas interface but also a liquid-liquid interface.

"Exposing this multilayer system to a surprisingly small temperature difference in the direction of the layering causes stresses at the liquid-gas interface because of a temperature-dependent surface tension," said Nejati. "These stresses drive rotating cellular flow patterns in the thicker layer, which are highly periodic in the spread direction of that layer."

Rather than using the stresses caused by the temperature-dependent surface tension directly to pattern the film, the group's approach relied on the flow pattern in the thicker layer to deform the thinner film beneath.



Iman Nejati/TU Darmstadt

Illustration of the exploitation of cellular convection in a thick liquid layer to pattern a polymer film.

The strategy enabled patterning of large areas with highly regular structures at the same time in a single process step, which saves time and reduces costs. Since the structures were generated from a liquid, without tools making mechanical contact with the working material, the resulting surface was very smooth and didn't require additional processing.

By engineering the temperature distribution along the liquid-gas interface of the thicker layer, the convection cells and deformation of the thin film can be adapted to meet the specifications of a desired structure of interest, the researchers said. Once the desired deformation is achieved, it's "frozen" in place by irradiation with UV light.

The combination of advantageous features of the technique could make it a film fabrication method superior to current methods, such as photolithography, printing and embossing.

"Given the relative simplicity of the equipment needed for our method, and how easily it adapts to specific situations, it can be used for manufacturing low-quantity products as well," Nejati said.

The researchers also said that in the future there would be no need to solidify the structures by UV light; instead the array of lenses could remain in the liquid state, which would allow modification of the periodicity of the liquid lenses if, for example, the temperature difference driving the convection cells is varied, enabling tunable lens arrays.

The research was published in *Applied Physics Letters* (doi: 10.1063/1.4940366).

Solar cell materials adapted for nanowire lasers

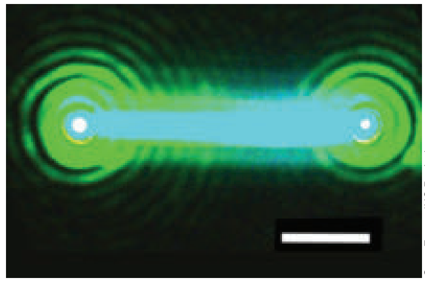
BERKELEY, Calif. — A next-generation solar cell material has been adapted into nanowire lasers as small as 200 nm that produce bright, stable laser light, which could enable optoelectronic devices.

Standard techniques that produce nanowires can require expensive equipment and exotic conditions, such as high temperatures, and can suffer from other shortcomings, such as limited tunability, low brightness or costly manufacturing processes, said researchers from the University of California, Berkeley, and the Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab).

"The whole purpose of developing nanosized lasers is to interface photonic devices with electronic devices seamlessly at scales relevant to today's computer chips," said Berkeley Lab chemist Peidong Yang. "Today, these photonic devices can be bulky."

Yang's research team pioneered the development of nanowire lasers almost 15 years ago using a different blend of materials, including zinc oxide (ZnO) and gallium nitride (GaN).

In the recent work, the research team produced nanowires by dipping a thin lead-containing film into a methanol solution containing cesium, bromine and



Sam Eaton/UC Berkeley

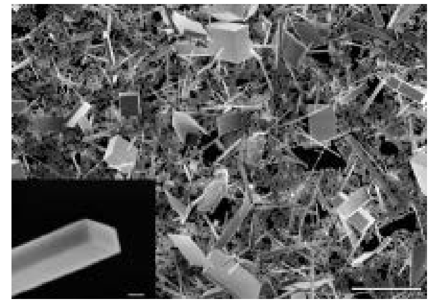
A nanowire composed of cesium, lead and bromine ($CsPbBr_3$) emits bright laser light after being hit by a pulse from another laser source. The nanowire laser proved to be very stable, emitting laser light for over an hour. It also was demonstrated to be broadly tunable across green and blue wavelengths. The white line is a scale bar that measures 2 µm.

chlorine heated to about 122 °F. A mix of cesium lead bromide ($CsPbBr_3$) crystalline structures formed, including nanowires with a diameter from 0.2 to 2.3 µm and a length ranging from 2 to 40 µm.

The same chemical blend, with a molecular architecture composed of cube-like crystal structures, has also proven effective in an emerging wave of new designs for high-efficiency solar cells. The resulting nanowires had a crystal structure resembling that of perovskite or salt, the researchers said, which makes them susceptible to damage from moisture in the air.

"That is one weakness — something we have to study and understand how to improve," Yang said. It may be possible to coat the nanowires with polymers or other material to make them more damage-resistant. There are also opportunities to test out other materials and learn whether they improve performance, he said, such as substituting tin for lead.

Select nanowires used in the experiment were placed on a quartz base and excited by another laser source that caused them to emit light. Researchers found



Sam Eaton/UC Berkeley

This scanning electron microscope image shows a collection of cesium lead bromide ($CsPgbBr_3$) nanowires and nanoplates grown from a chemical-dipping process. To produce these structures, researchers dipped a thin lead-containing film into a methanol solution containing cesium, bromine and chlorine heated to about 122 °F. The white scale bar at the lower right represents 10 µm. The image at the bottom left shows the well-formed rectangular end of a nanowire – the white scale bar associated with it represents 500 nm.

that the nanowire lasers emitted light for over 1 billion cycles after being hit by an ultrafast pulse of visible, violet light that lasted just hundredths of quadrillionths of seconds, which Yang said demonstrated remarkable stability.

The researchers said these nanowires may be the first to emit laser light using a totally inorganic blend of materials, and demonstrated that the nanowire lasers could be tuned to a range of light including visible green and blue wavelengths.

"The results indicate significant promise for perovskite nanomaterials in lasing," said Ted Sargent, a nanotechnology researcher and professor at University of Toronto who is familiar with the study. The stability of the nanolasers, which were shown to operate in air for more than an hour, was particularly impressive, he said.

The research was published in *Proceedings of the National Academy of Sciences* (doi: 10.1073/pnas.1600789113).

Pure-organic OLEDs could enable device mass production

POHANG, South Korea — Highly efficient, solution-processed fluorescence organic LEDs (OLEDs) have been fabricated using "pure-organic" emitters and could enable mass-production of the devices.

Conventional OLEDs use phosphorescent emitters that have shown high internal quantum efficiency (IQE) of nearly 100 percent. However, those emitters incorporate expensive, precious heavy metals such as iridium and platinum into phosphorescent metal complexes, which has limited their commercialization.

In order to overcome these disadvantages, the research team from Pohang University of Science & Technology (Postech) has used pure-organic thermally activated delayed fluorescence (TADF) emitters that the team said show a very high IQE of nearly 100 percent without incorporating precious metals. TADF emitters also offer the advantages of easy synthesis using pure-organic molecules and versatile molecular design, reducing the cost of synthesis.

The Postech team, led by professor Tae-Woo Lee, introduced the inexpensive simple solution process to fabricate the TADF-OLEDs by solving fundamental problems that had limited the high efficiency in solution-processed TADF-OLEDs. They created a multifunctional buffer hole injection layer (HIL) that increased the hole injection capability to the emitting layer (EML) due to its high work function.

The researchers also improved the luminescence efficiency of TADF-OLEDs by preventing exciton quenching at the HIL/EML interface. They also reported that a new polar aprotic solvent improved the device efficiency by improving the solubility of pure-organic TADF emitters, reducing the surface roughness and the aggregation of dopants, and managing the exciton quenching in the emitting layer.

The improvement in solution-processed TADF-OLEDs could remedy the disadvantages of a complex and expensive vacuum-deposition process and thus lower the production cost of the devices.

"This technology is a big leap toward the development of inexpensive and solution-processed OLED displays and solid-state lightings because this method uses only low-cost, pure-organic molecules and [a] simple solution process to realize the extremely high efficiency solution-processed OLEDs," said Lee.

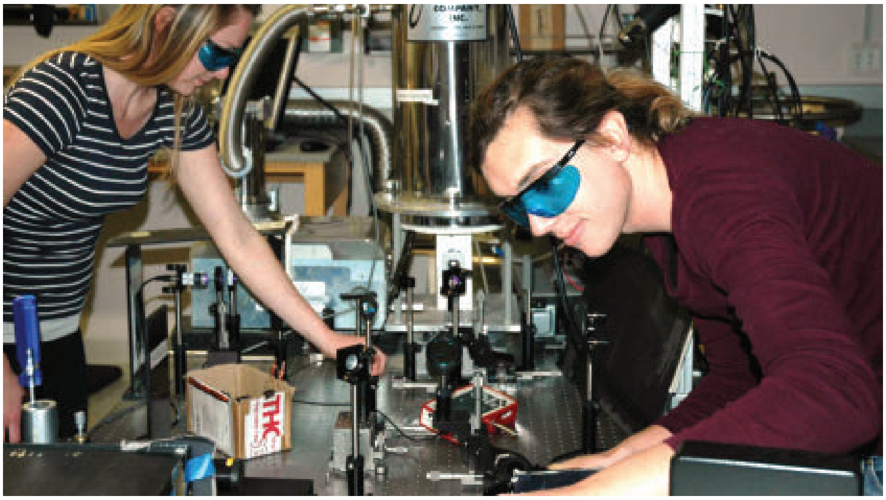
The research was published in *Advanced Materials* (doi: 10.1002/adma.201504490).

Material controls excitons at room temperature

SAN DIEGO — A material that can control excitons — bound pairs of electrons and electron holes — at room temperature could enable optoelectronic devices for commercial applications.

Excitons are created when a laser is shone onto a semiconductor device. They can transport energy without transporting net electric charge. Inside the device, excitons interact with each other and their surroundings, and then convert back into light that can be detected by sensitive CCD cameras.

Previously, researchers from the University of California, San Diego, and the University of Manchester in England



Calman

Erica Calman and Chelsey Dorow align optics required to collect measurements from a molybdenum disulfide sample.

had been working on structures based on gallium arsenide (GaAs), a material commonly used in the semiconductor industry. Unfortunately, the team said the devices they developed had a fundamental limitation: They required cryogenic temperatures (below 100 K) to operate, which ruled out commercial applications.

Now the team has reported a material change that should bring the excitonic devices up to room temperature.

"Our previous structures were built from thin layers of GaAs deposited on top of a substrate with a particular layer thickness and sequence to ensure the specific properties we wanted," said UCSD graduate student Erica Calman.

To make the new devices, the physicists turned to new structures built from a specially designed set of ultrathin layers of materials: molybdenum disulfide (MoS_2) and hexagonal boron nitride (hBN), each a single atom thick.

The structures were produced via the famous "Scotch tape" or mechanical exfoliation method developed by Andre Geim and his group. Geim is a physicist awarded a Nobel Prize in physics in 2010 for his groundbreaking work on the 2D material graphene.

"Our specially designed structures help keep excitons bound more tightly together so that they can survive at room temperature — where GaAs excitons are torn apart," Calman said.

Excitons can form a special quantum state known as a Bose-Einstein condensate, which occurs within superfluids and enables currents of particles without losses. The team discovered a similar exciton phenomenon at cold temperatures with GaAs materials.

"The results of our work suggest that we may be able to make new structures work all the way up to room temperature," Calman said. "We set out to prove that we could control the emission of neutral and charged excitations by voltage, temperature and laser power … and demonstrated just that."

The research was published in *Applied Physics Letters* (doi: 10/10.1063/1.49432).

Entangled photons could advance quantum cryptography

Faculty of Physics, University of Vienna

Long-exposure photo of laser beams with a twisted wavefront. The beams have holes in the middle due to destructive interference at the center of the twists.

VIENNA — Three photons have been experimentally entangled in a high-dimensional quantum property related to the "twist" of their wavefront structure, a milestone achievement for quantum physics.

Entanglement is a counterintuitive property of quantum physics that scientists and philosophers have long studied; entangled quanta of light seem to exert an influence on each other, irrespective of how much distance is between them.

Researchers at the Institute of Quantum Optics and Quantum Information, the University of Vienna, and the Universitat Autonoma de Barcelona achieved the twisted photons, comparing the phenomena to a metaphorical quantum ice dancer who has the uncanny ability to pirouette both clockwise and counterclockwise simultaneously. A pair of entangled ice-dancers whirling away from each other would then have perfectly correlated directions of rotation: If the first dancer twirls clockwise, then so does her partner, even if skating in ice rinks on two different continents.

"The entangled photons in our experiment can be illustrated by not two, but three such ice dancers, dancing a perfectly synchronized quantum mechanical ballet," said Vienna researcher Mehul Malik. "Their dance is also a bit more complex, with two of the dancers performing yet another correlated movement in addition to pirouetting. This type of asymmetric quantum entanglement has been predicted before on paper, but we are the first to actually create it in the lab."

The scientists created their three-photon entangled state by using another quantum mechanical trick: They combined two pairs of high-dimensionally entangled photons in such a manner that it became impossible to ascertain where a particular photon came from. Besides serving as a test bed for studying many fundamental concepts in quantum mechanics, multiphoton entangled states such as these have applications ranging from quantum computing to quantum encryption.

Along these lines, the researchers developed a new type of quantum cryptographic protocol using their state that allows different layers of information to be shared asymmetrically among multiple parties with unconditional security.

"The experiment opens the door for a future quantum Internet with more than two partners and it allows them to communicate more than one bit per photon," said Vienna researcher Anton Zeilinger.

The researchers said many technical challenges remain before such a quantum communication protocol becomes a practical reality, but given the rapid progress in quantum technologies today, it is only a matter of time before this type of entanglement finds a place in the quantum networks of the future.

The research was published in *Nature Photonics* (doi: 10.1038/nphoton.2016.12).

Graphene plasmons explored for nanoscale control of IR light

SAN SEBASTIÁN, Spain —The ability to capture IR light with graphene nanostructures could open new opportunities for ultrasmall and efficient photodetectors, sensors, and other photonic and optoelectronic nanodevices.

When light couples to charge oscillations in graphene, the result is plasmon — a mixture of light and charge oscillations — which can be squeezed into miniscule volumes that are millions of times smaller than in conventional dielectric optical cavities.

Researchers from the CIC nanoGUNE Cooperative Research Center, in collaboration with ICFO (The Institute of Photonic Sciences) in Barcelona, Spain, and Cambridge, Mass.-based graphene company Graphenea, say they have visualized, for the first time, the creation of such plasmonic systems, and have disentangled the individual plasmonic modes and separated them into two different classes.

Using a near-field microscope to put theory to praxis, the researchers identified the two classes of plasmon as sheet and edge modes, which propagate along the sheet or along the sheet edges, respectively. The edge plasmons are unique for their ability to channel electromagnetic energy in one dimension.

Sheet plasmons, the researchers said, can exist "inside" graphene nanostructures, extending over the whole area of graphene. Conversely, edge plasmons exclusively propagate along the edges of graphene nanostructures, leading to whispering gallery modes in disk-shaped nanoresonators or Fabry-Perot resonances in graphene nanorectangles, due to reflection at their corners.

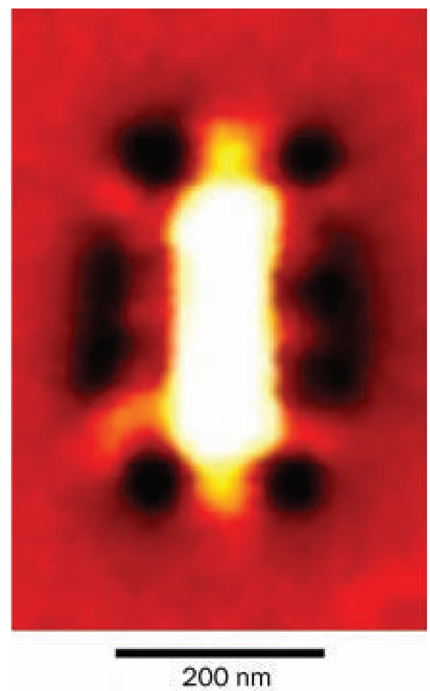
The edge plasmons were much better confined than the sheet plasmons, the researchers reported, and, most importantly, transferred energy only in one dimension. Real-space images revealed dipolar edge modes with a mode volume that was 100 million times smaller than a cube of the free-space wavelength.

The researchers also measured the dispersion of the edge plasmon based on their near-field images, highlighting the shortened wavelength of edge plasmon compared to sheet plasmon. Thanks to their unique properties, edge plasmon could be a promising platform for coupling quantum dots or single molecules in future quantum optoelectronic devices.

"Our results also provide novel insights into the physics of near-field microscopy of graphene plasmons, which could be very useful for interpreting near-field images of other light-matter interactions in two-dimensional materials," said CIC nanoGUNE professor Rainer Hillenbrand, who led the project.

The researchers said plasmonic field concentration can be further enhanced by fabricating graphene nanostructures acting as nanoresonators for the plasmons. Such a field has already been used for enhanced IR and terahertz photodetection, or IR vibrational sensing of molecules, among other applications.

The work was published in *Nature Photonics* (doi: 10.1038/nphoton.2016.44).



CIC nanoGUNE

Near-field image of a rectanglular graphene nanoresonator.

Nanoco dry Cadmium-Free Quantum Dots in vials.

Cadmium-Free Quantum Dots Offer Vibrant Color for Liquid Crystal Displays

Cadmium-free quantum dots are a safer and more sustainable option for manufacturers and consumers, featuring rich and vibrant colors without the risks associated with toxicity.

BY STEVE REINHARD
NANOCO TECHNOLOGIES LTD.

Display manufacturers are constantly striving to satisfy consumers' never-ending appetites for better and more true-to-life electronic displays. Accomplishing that has as much to do with color as it does with resolution. To do so, one technology that has been gaining increased momentum in the industry is quantum dots. While cadmium-based quantum dots have been around since the mid-1980s, more recent advancements in their chemical makeup are giving quantum dot technology new potential in the marketplace without performance trade-offs.

These microscopic nanocrystals — so tiny that 10,000 of them span the width of a human hair — emit one specific color when light passes through them. The advantage to the manufacturer is that the quantum dots can be finely tuned to a desired color as determined by their size to meet any given application requirement. For instance, the bigger dots, about 50 atoms thick, glow red, while the smallest — 30 atoms or so — glow green. Just a subtle tweak in the size of the particle can change its color across the entire spectrum.

Growing numbers of display manufacturers are incorporating these brilliant tiny semiconductors into their backlight units (BLUs), offering new levels of color purity over conventional phosphor-based light-emitting diode (LED) backlit liquid crystal displays (LCDs). Quantum dots offer the unique ability to efficiently absorb and convert light, typically that of a blue LED, into very specific reds and greens — offering more beautiful, vibrant color performance than traditional

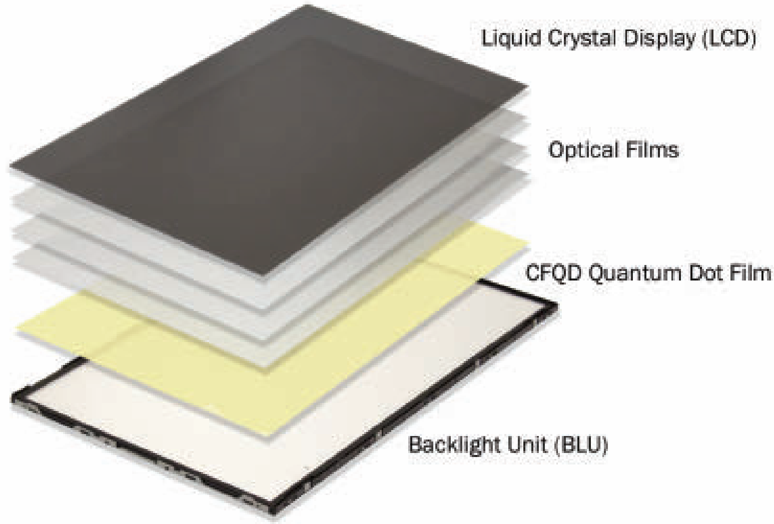
All photos courtesy of Nanoco Technologies Ltd.

LCD technology. Traditional red and green have been difficult to mimic on screen, whereas quantum dot displays deliver richer reds and more vibrant greens.

Today, when referencing color gamut — the entire range of colors available on any device — it's mostly in the range of 70 to 80 percent of the National Television System Committee (NTSC) color triangle. With quantum dots, you get 100 percent of that color range — making a sunset look all the more spectacular or the golfing green during the Masters more lifelike. Because of this bump in color performance, quantum dots allow LCD screens to finally rival OLED products, at just a fraction of the cost.

Quantum dots also present an easy solution for display manufacturers to integrate into their products. While quantum dots' chemistry is fairly complicated, the capital required to integrate them into a manufacturer's fabrication process is very minimal. Unlike OLED, which requires a complete and expensive overhaul of a production line, quantum dots leverage the existing LCD infrastructure, enabling OEMs to bring innovative new technologies to consumers without the high expense or complexity of creating new fabrication processes. Additionally, quantum dots require a tiny amount of energy to operate, making them more energy efficient.

Another benefit of quantum dots is their flexible nature. Because particles are easily tunable simply by changing their size, they can be cost-effectively customized for various display manufacturers' products and specifications.



Nanoco Cadmium-Free Quantum Dots LCD TV stack.

Scientist holding Nanoco Cadmium-Free Quantum Dots film for LCD.

Three approaches to integrating quantum dots into LCD screens

To achieve the near-perfect color quantum dots can deliver to LCD display screens, there are three different approaches to consider:

- *On-chip*, where the quantum dots are deposited directly into the LED package.
- *On-edge*, where the quantum dots are integrated within a component, such as a thin glass tube that is positioned remotely from, but in close proximity to, the LEDs.
- *On-surface*, where the configuration utilizes a remote quantum dot film that covers the surface area of the display.

Though it has the highest material consumption, the on-surface geometry offers the advantage of operating near room temperature and is more easily and cost-effectively incorporated into the encasing display architecture.

Using the on-surface method, quantum dots, incorporated into a film located in-between the LED light source and the LCD panel, are "excited" by light emitted from blue LEDs, transforming some of it into very pure green and red light. As a result, the LCD panel receives a richer white light and expands the range of color the display can reproduce. And because the quantum dot film is made by printing on a large area web, it can easily be cut down to suit a variety of display sizes from extra large HDTVs to smaller devices like monitors and tablets.

Traditional challenges with quantum dots

The majority of quantum dot products that seeded the display market initially contained II-IV compounds like cadmium selenide. Cadmium is a toxic heavy metal and its use is restricted under European and other environmental law because of its threat to both human health and the environment. For example, with its Restriction of Hazardous Substances (RoHS) Directive, the European Union limits the amount of cadmium, lead and mercury that can be included in electrical and electronic equipment placed in the European market. Cadmium is restricted to 100 ppm in homogeneous material, a figure 10

Nanoco Cadmium-Free Quantum Dots Orion light.

times less than that for mercury and lead. Anticipating further global restrictions in cadmium use, several major OEMs have stated they would launch products only using cadmium-free technology.

Other inherent challenges with quantum dots are the same as with any new material that's introduced into the market: How do you physically make enough of the material that the industry can successfully "bolt" it into products? And how can those products become affordable?

Let's address these issues.

Moving beyond cadmium

The presence of cadmium has hindered the broad adoption of quantum dots in devices, keeping display manufacturers from realizing the benefits of the technology and products out of consumers' hands. However, research into the synthesis and mass manufacture of heavy-metal-free quantum dots is of growing interest.

Cadmium-free quantum dots offer a safer and more sustainable option for manufacturers and consumers, giving them the color benefit associated with the technology without the risks associated with toxicity or potential regulatory limitations. Cadmium-free quantum dots also open up potential not just for displays, but for many more applications including lighting, solar and biomedicine.

To address the market need for safer materials, Nanoco has developed a unique quantum dot matrix of semiconductor alloy that is cadmium free. By tailoring the structure of the quantum dot and allowing the strength of the bonding interactions to be manipulated, the quantum confinement effects are reduced. The result: Nanoco has made considerable advances in narrowing the full width half maximum (FWHM) and improving the photoluminescence quantum yield of its cadmium-free quantum dots, making them perform nearly identically in a LCD display as their cadmium counterparts.

To address the issue of making enough material, the company uses a manufacturing technique called the "molecular seeding method." This process is different from traditional quantum dot synthesis because it is scalable and allows for large-batch production of high-quality cadmium-free quantum dots.

New applications: LED lighting, solar

It's rare to see a material that is a true platform technology, meaning the same material can be used across multiple applications. But eliminating toxic materials like cadmium from the makeup of quantum dots has opened up a range of new application areas, proving the value of quantum dots.

One application area is LED lighting, where cadmium-free quantum dots provide outstanding color performance without sacrificing efficiency. Applications where color quality is an absolute must include high-end retail store lighting where consumers can determine precise colors of clothing and high-value goods; surgical lights that enable accurate diagnosis and smooth operations; supermarkets that showcase the freshness and quality of meat and produce; and in agricultural uses, where LEDs provide many benefits to the grow-light and horticultural lighting industry to further enhance chlorophyll absorption peaks and ensure healthier, higher-yielding plants.

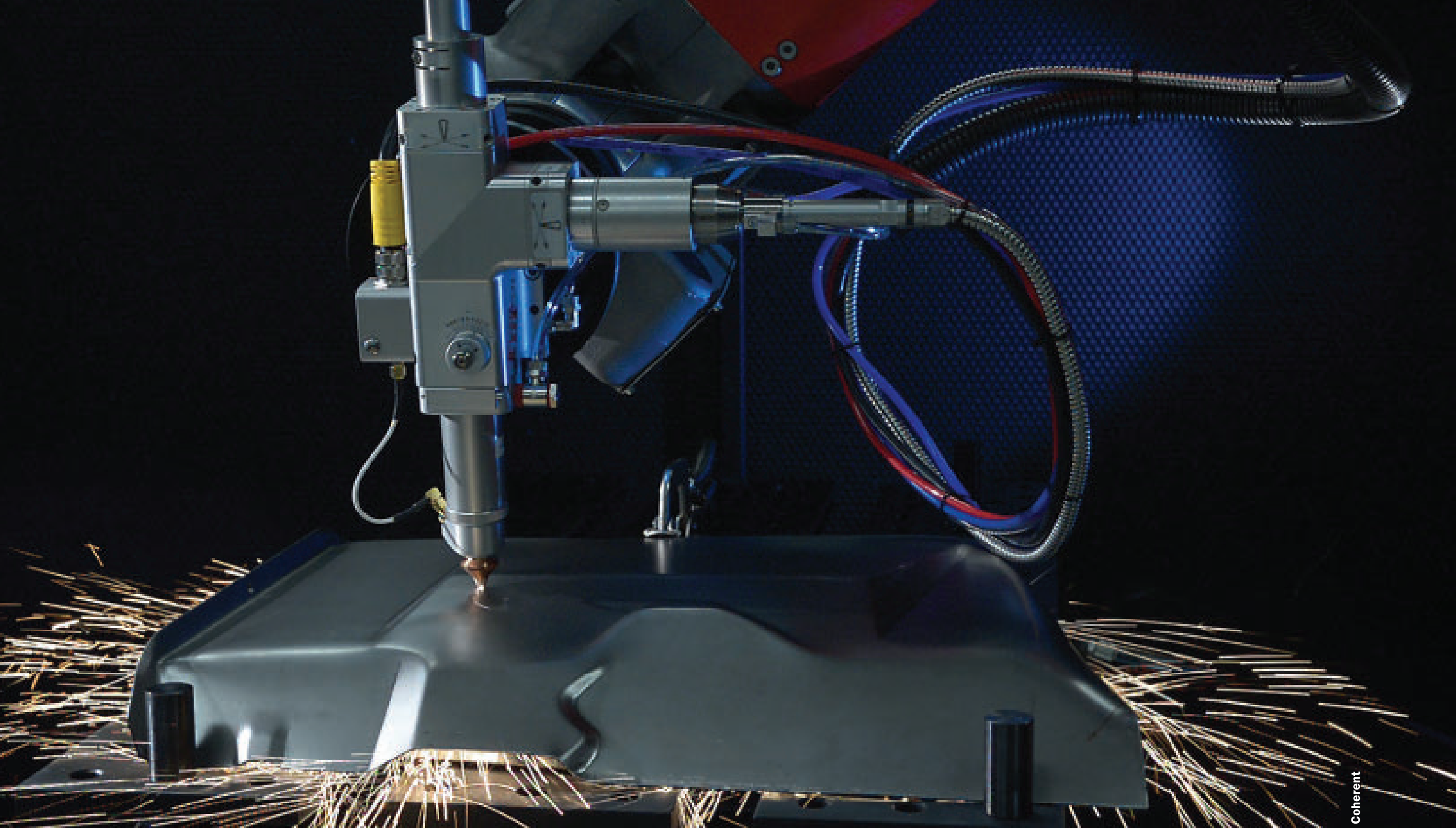
Another application is solar. Nanoco has developed a method of fabricating an efficient solar cell using a copper-indium-gallium-diselenide (CIGS) nanoparticle ink that can be deposited on thin films that are inexpensive to produce. This technology advancement results in a dollar-per-watt figure of less than 35 cents a watt on the panel. Because solar panel manufacturers can use a simple low-cost printing technology to get the nanoparticles onto the substrate, the CapEx requirements to make these panels are low. Further, large amounts of the CIGS material have been produced in an R&D setting, proving that the synthesis method is scalable.

There are also promising new applications in biomedicine, where researchers are testing quantum dots as a mechanism to colorfully illuminate tumors to improve the safety and efficacy of cancer surgery. Doctors could potentially use the quantum dots to illuminate molecules, which then bind themselves to cancer tumors, allowing the surgeon to easily distinguish the healthy from the diseased tissue. The quantum dots are more photostable than the organic dyes that surgeons use today, which means that the illuminated cells are brighter for longer periods, giving the surgeon an extended time window to perform the surgery and improve results.

As legislation restricting the use of heavy metals gets ever tighter, cadmium-free quantum dots are uniquely positioned as the future-proof quantum dot display technology on the market. Thanks to this innovative technology, the future indeed looks more colorful — and safer — for both manufacturers and consumers of LCDs, and for the range of other application areas beginning to leverage heavy-metal-free quantum dots.

Meet the author

Steve Reinhard is vice president of business development for Nanoco Technologies Ltd., with over 14 years of experience in the display and lighting industries. He has an MBA from Binghamton University and earned his B.S. in industrial engineering from Pennsylvania State University; email: sreinhard@nanocotechnologies.com.



Fiber lasers, like the one shown here cutting an automotive part, are increasingly used for cutting and other machining.

Better Lasers, Better Machining

Greater uptime, faster cutting and increasing affordability make fiber lasers the first choice where CO_2 lasers once reigned supreme.

BY HANK HOGAN
CONTRIBUTING EDITOR

When it's time to cut, weld, ablate, mark or otherwise machine materials, manufacturers are increasingly turning to lasers. Falling system costs and better resulting product quality are two reasons why. Still, the need exists to further lower the cost of laser machining while expanding the range of materials that can be handled. For that, there's progress in fiber and other laser technologies from greater power, more precise processing and new wavelengths.

An illustration of these trends can be found at Mazak Optonics Corp. The company, which has its North American headquarters in Elgin, Ill., does not make laser engines but does incorporate those supplied by well-known vendors to make laser-cutting equipment used at large companies and independent job shops.

Mazak Optonics has seen a significant change in laser machining technology over the past few years, according to Marc Lobit, general manager of sales support operations. "Laser-cutting technology is still shifting to fiber [lasers], with about 75 percent of our machines sold in 2015 being fiber," he said.

Lobit noted that five or so years ago a majority of the company's products used CO_2 lasers. Fiber's higher reliability and uptime, along with its associated decrease in maintenance costs as compared to CO_2 lasers, have driven the change.

A big reason for this is the beam delivery system, which is straightforward for fiber lasers. In contrast, CO_2 lasers employ mirrors to get the beam to the business end of the cutting machine, which leads to relatively high upkeep.

"[CO_2 lasers] were very labor-intensive and expensive to maintain." Lobit said. "Mirrors would become damaged. They would wear out over time from the heat that's reflecting off of [them]."

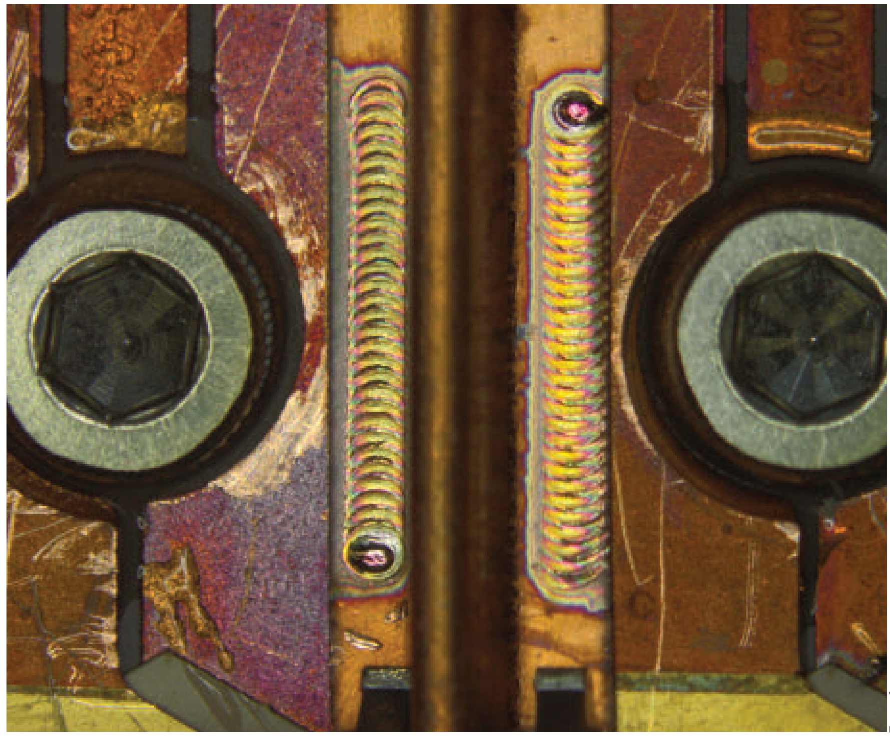
The transition to fiber laser technology brought about other advantages, he added. The ytterbium fiber lasers output a beam at 1070-nm wavelength, about a 10th of that of a CO_2 laser. The result of this difference, the greater uptime, and other differences was faster cutting using a fiber laser, and better results, particularly when it came to edge quality. Consequently, a single fiber laser cutting machine can replace two to three of the older systems.

Laser machining does not completely replace and often is complementary to the traditional, mechanical approach, Lobit noted. Mazak Optonics is part of Japan's Yamazaki Mazak Corp., a manufacturer of laser and mechanical machine tools and systems. The company's customers may use lasers to cut but may go the traditional route for machining shapes or adding fine detailing.

As for the future of laser machining, more power is on its way. Today, Mazak Optonics has products ranging up to 6 kW. "Higher power is starting to hit the market. This enables thicker cutting, but probably the most important benefit will be faster cutting for 1/4- to 1/2-in. thicknesses," Lobit said.

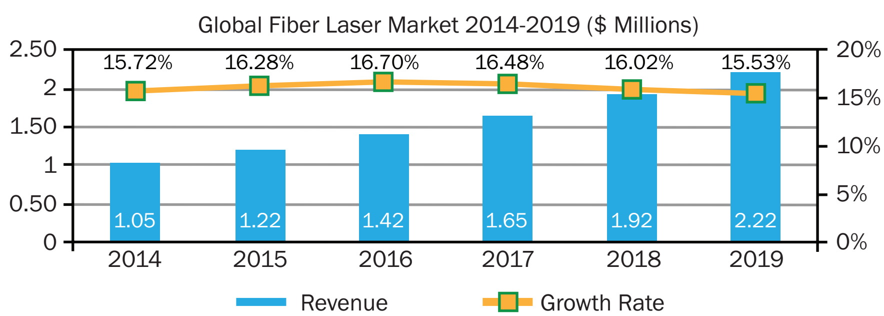
Laser manufacturers are also coming out with new wavelengths. This is important because not all materials react the same way to a given wavelength, pointed out Tracey Ryba, product manager for laser systems and OEM lasers at Trumpf Inc. The laser manufacturer has its U.S. headquarters in Farmington, Conn.

For instance, CO_2 lasers are good for producing perforated holes for easy separation of food packaging plastic bags. As for metals, a wavelength around 1000 nm generally works well. However, copper is highly reflective at that wavelength. So, Trumpf developed a frequency doubled, pulsed green disk laser for welding copper, Ryba said.



Trumpf

By doubling frequency to the green portion of the spectrum, lasers can weld copper, even thin layers, without damage to ceramic material lying below.



Technavio

The global fiber laser market was valued at $1.05 billion in 2014 and is expected to reach $2.22 billion in 2019, growing at a compound annual growth rate of 16.20% during the forecast period, according to Technavio.

High precision = less processing

As for the future of laser machining, it's instructive to look at the past. According to Ryba, fiber and disk lasers have largely replaced CO_2 lasers because they are more reliable and easier to maintain.

Both fiber and disk lasers depend upon a diode to pump the lasing material. Today, the beam quality or power (or both) of a diode laser makes it unsuitable for many machining applications, but Trumpf expects continued progress will change that. The push will be to simplify the laser system and go the direct diode laser approach, Ryba said.

This is because when it comes to laser versus traditional machining, ongoing cost cutting changes the balance and favors the laser approach, he added. Over the past seven or eight years laser systems have come down about threefold in cost per delivered watt. That drop in price cannot continue — unless the system can be further simplified. Going to a diode laser instead of a diode-pumped laser could do that.

It also could be that even without additional cost cutting that laser machining is more cost-effective than other approaches, due to the elimination of manufacturing steps.

"Part of the advantage of laser welding is you don't have to do so much post processing typically," Ryba said. "Compared to traditional machining, the laser is high precision."

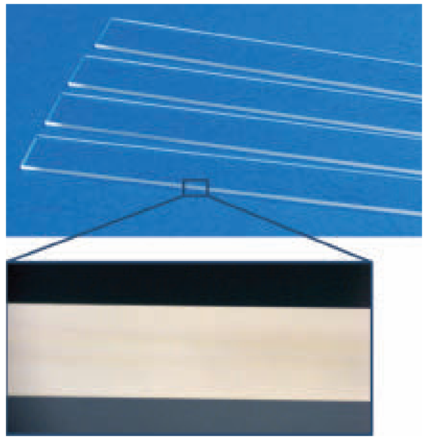
For another example illustrating trends and developments in laser machining, consider Boeing. The Chicago-based aerospace giant has been laser cutting materials for over a quarter-century, said William Schell, Boeing associate technical fellow. Today, the company uses laser machining to fabricate the ducting system for its airplanes, replacing conventional milling, band saw and shear/nibbling equipment.

"The lasers offer exceptional speed and accuracy over other cutting processes, particularly on nickel-cobalt alloy materials, which are difficult to cut," Schell said.

He added that the company's technology research organization designed, implemented and patented a laser trim machine for trimming duct details. With it, a mechanic scribes a mark, puts it in the field of view of a camera, and then a laser rotates around the stationary part, cutting off the excess to the scribe mark.

Boeing's laser trim machine addresses process limitations with conventional cutting methods and the safety issues brought about by trying to manually handle duct trimming. Schell noted that the use of a laser was particularly beneficial when an increase in the thickness of the duct walls was needed to meet design requirements. The thicker walls began to damage the conventional cutting equipment.

Asked about issues associated with laser machining, Schell mentioned one that impacts all manufacturing operations. "While lasers offer unique advantages over traditional methods, they also come with their own set of safety challenges. Being able to cost-effectively and safely implement the use of lasers in a factory environment — a production work cell — can be challenging," he said.


Laser Zentrum Hannover eV

CO laser separation after laser surface scribe of a borosilicate glass.

When looking at the future of laser machining, Frank Gaebler, director of marketing at Coherent Inc. of Santa Clara, Calif., points to several trends. One is the emergence of increasingly powerful fiber lasers. Due to their nature they are inherently more reliable and cost less to operate than the old laser machining workhorse, the CO_2 laser.

However, the old standby is still best when working with very thick materials. "The shipyard business and these places where you have to cut plates instead of sheets, then the CO_2 laser might still be the best choice," Gaebler said.

Another important development is the advent of affordable ultrafast lasers. With pulse widths in the femto- and picoseconds, such lasers enable machining on a microscopic scale, something that can't be easily done, if at all, using traditional methods. Because the pulse widths are so short, the heat-affected zone in the material is negligible, and that gives laser processing an advantage.

For instance, ultrafast lasers are used to precisely drill holes of differing shapes and sizes in fuel injector nozzles. This buys better combustion of fuel, leading to greater efficiency, more power, or some combination of both.

Another example are stents and other medical devices that go into the body. These are made of biocompatible polymers and other materials that have to be finely machined, presenting challenges to manufacturing methods not based on ultrafast lasers.

A third trend is the development of new wavelengths. Coherent, for instance, has come up with a CO laser that produces a 5-µm wavelength output. Because it is half the wavelength of a 10-µm CO_2 laser beam, it can be focused to half the spot size, which ups the intensity fourfold.

As to why a new wavelength might be needed, Gaebler noted that some materials do not work well with current lasers. Pigment-free polyethylene films, for example, have in the past not been processed well with lasers due to limited material absorption, too low a beam intensity, or both.

"But at 5 µm it works pretty well. They can cut it with high reliability and very little heat-affected zone," Gaebler said.

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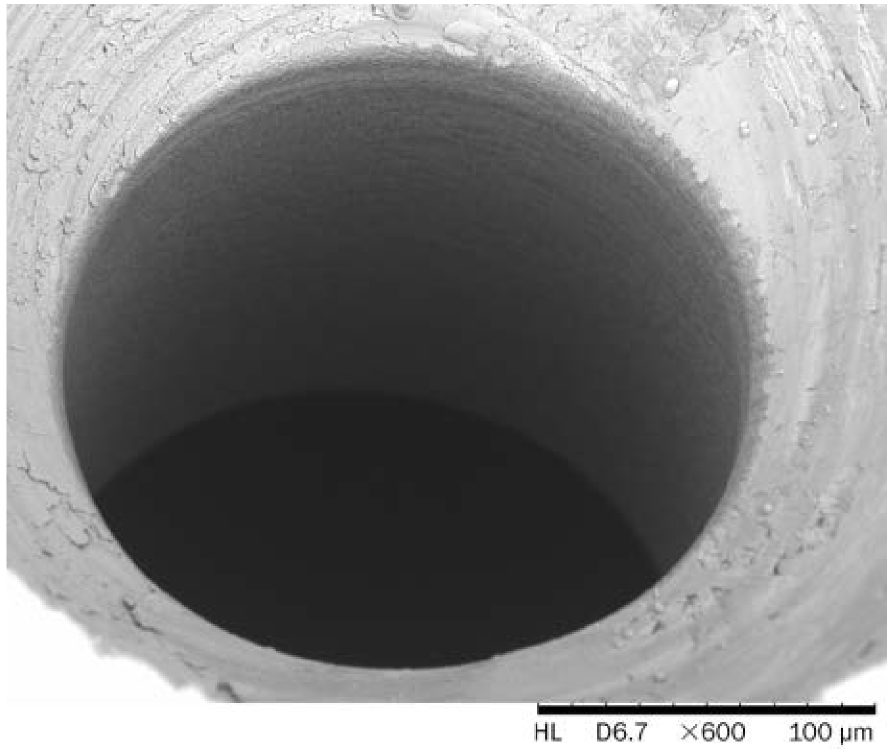
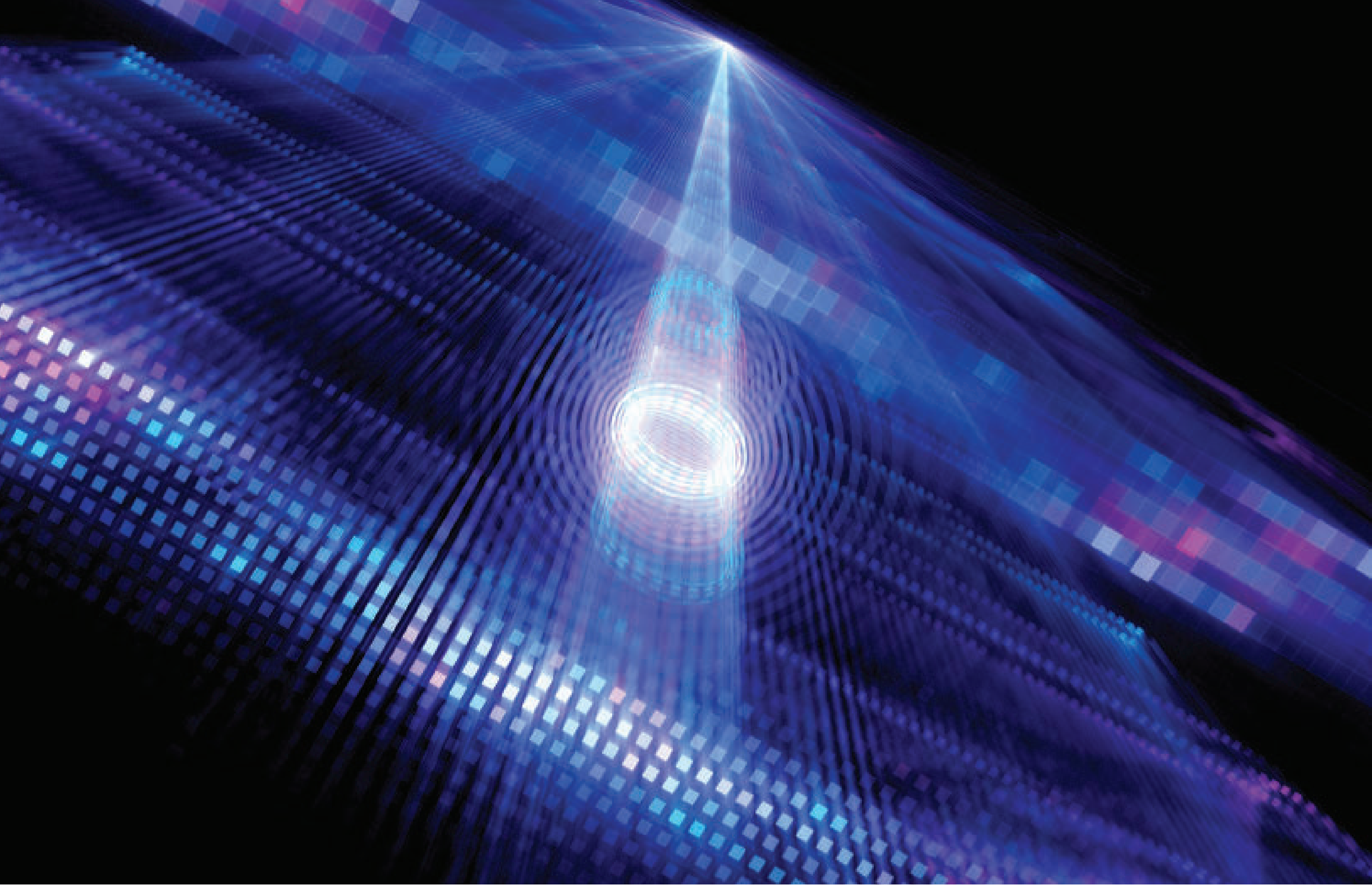


A gasoline injector nozzle drilled by a Coherent Monaco Laser through 250-µm-thick stainless steel.



Quantum Networks:
Photons Hold Key to Data Security

Photonics enables quantum key distribution to secure the world's data.

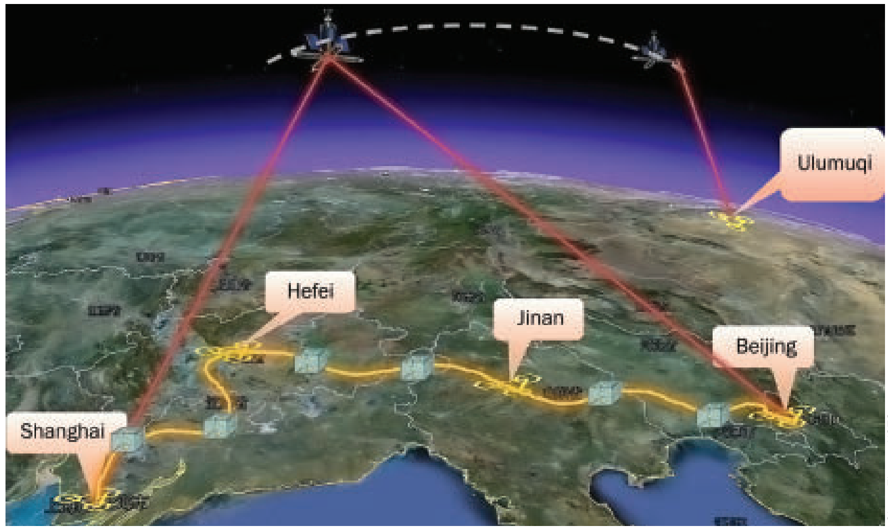
BY NINO WALENTA AND LEE OESTERLING
BATTELLE

Quantum technology is no longer science fiction. Election results, health data, mobile phone communications, sensitive business information, banking transactions and user IDs — more and more applications are secured with quantum key distribution (QKD) in quantum telecommunication networks. The longest-running quantum network has been in operation for more than seven years, while the largest quantum network features more than 50 nodes. Today, quantum links have been established with satellites, planes and balloons.

Underlying the expansion of quantum networks is photonics technology. To comply with the compactness, robustness, reliability and costs of modern telecom infrastructures, implemented systems rely on well-established standard components such as electro-optical modulators, semiconductor detectors and integrated photonics circuits. At the same time, they push their limits toward maximum modulation ratio, low-noise single-photon sensitivity and ultra-low coupling and propagation losses, respectively.

As data transfers skyrocket in both size and frequency, more and more countries and companies are investing in large-scale quantum communication networks. To date, about 2.9 exabytes of data—16 million Blu-ray discs—are transmitted through the Internet every day. The security of this data relies heavily on cryptographic keys that must be securely distributed and shared between parties. Once these keys are established, they are used to encrypt transmitted data to protect secrecy, or for authentication to prevent forging against eavesdroppers. However, protecting data becomes more and more vulnerable as the security of the mathematical algorithms that are used to distribute the keys is increasingly threatened by improving computer power, new attack algorithms and, in particular, the emergence of quantum computers.

Using special quantum algorithms, a quantum computer is able to perform integer factorization and brute-force searching much faster than conventional computers. Consequently, widely used cryptosystems that base their security on the premise that certain computational problems are difficult to solve are threatened. Currently, multiple technological approaches toward scalable quantum computers are being developed, including quantum processors based on integrated photonic chips. Some experts expect that in 10 to 15 years quantum computers will be powerful enough to break the key distribution schemes that are currently used. Hence, already today data that is supposed to remain secure for more than 10 to 15 years has to be considered vulnerable since an eavesdropper can simply record the transmitted data and decipher it once a quantum computer is available.



Qiang Zhang, USTC

Illustration of the Chinese nationwide quantum key distribution (QKD) network, which includes a planned satellite QKD link.

Encoding keys in photons

While quantum physics poses a major threat to the security of our data, it luckily offers an elegant solution to the security problem: quantum key distribution. Instead of using mathematically difficult problems, QKD protects the distribution of cryptographic keys by encoding information in quantum states of —for example — the polarization, phase or quadratures of photons. Using quantum states allows security to be based on fundamental physical and quantum-information theoretical principles, expressed by the no-cloning theorem, which states that it is physically impossible to produce perfect copies of unknown quantum states; the Heisenberg uncertainty principle, which puts forth that measuring unknown quantum states inevitably introduces detectable errors; or properties of quantum entanglement, which set a fundamental limit on the information leaked to unauthorized third parties. Because of these principles, any eavesdropping attempt inevitably introduces detectable errors. The number of errors directly quantifies how much information about the key could have been gained, even with the most powerful future strategy and hardware, including quantum computers. After the quantum exchange, a number of post-processing steps, known as key distillation, correct the introduced errors and amplify the security of the key by removing any leaked

Nicolas Gisin

Projected QKD network rollout in South Korea.

information. In short, QKD allows precise quantification of security of the keys before they are used, and there would be no way for an eavesdropper to wait for future progress in technology to obtain secrets. By continuously providing such highly secure keys, QKD is especially beneficial for symmetric cryptographic algorithms like AES (Advanced Encryption Standard).

Most QKD systems are built around standard telecom components like modulators, semiconductor and superconductor detectors, and photonic lightwave circuits, but push their limits to meet the high requirements of QKD. This includes maximizing the extinction ratio of modulators and the signal-to-noise ratio of single-photon detectors, and minimizing the coupling and propagation losses in photonic circuits and other optical components. Eventually, these improvements might bring benefits to standard telecom systems, too.

Protecting financial transactions, election results

For more than a decade, QKD has been used in commercial applications. In 2004, QKD helped to protect a financial transaction between the Vienna City Hall and the headquarters of Bank Austria Creditanstalt. Since 2007, commercial QKD systems have been used regularly by the government of Geneva, Switzerland, to protect the transmission of election results against corruption during transmission. Since then, several businesses have used QKD to protect their data links to backup sites and disaster recovery centers.

Since QKD is a point-to-point technology and its maximum transmission distance is ultimately limited by fiber losses to a few hundred kilometers, these applications are well-suited. In order to overcome these limits and extend QKD to larger networks with many users and over greater distances, experts have proposed connecting multiple QKD links in a nodal network of trusted relays. Within these networks, keys are established between any two nodes protected by QKD, but intermediate nodes must be protected against tampering.

On the road toward today's large-scale

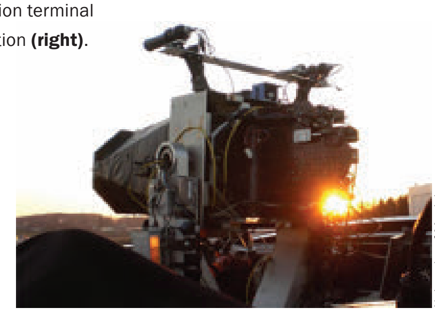
QKD networks, several field tests demonstrated their compatibility with photonic telecom networks and the interoperability of different QKD systems in a common network. They protected several applications, including phone and video teleconferences, the distribution of data collected at the CERN laboratory, and the remote security surveillance of a soccer stadium during the FIFA World Cup 2010. Along with continuous improvements in performance and costs of optical components that facilitated better reliability, integration, mass production and ease of use, today's QKD network systems reliably protect sensitive information of numerous adopters every day.

To find today's most ambitious QKD networks, one must look to the Asian "Quantum Triangle" between Japan, South Korea and China. In 2016, the first stage of a South Korean nationwide QKD network began operation between Seoul, Bundang and Suwon. Over the next five years, the consortium led by SK Telecom envisions its expansion to a national administrative QKD network with several thousand nodes for public administration, police and postal services.

University of Munich

The plane with QKD hardware in an optical communication terminal **(inset)** that created the first QKD link with a ground station **(right)**.

Tokyo's impressive quantum network began operating in 2010 and connects four QKD hubs across the city with systems developed by NEC, Toshiba, NTT and others. The QKD keys are supplied to government agencies, network operators, NICT research facilities and Tokyo University. These keys protect sensitive data and teleconferences. Recently, a link that transfers genome data between an analysis center and genome database center was included. Its QKD ensures that the genomic data remain secret.



University of Munich

In 2015, the Tokyo network demonstrated smartphone applications made by NEC and Mitsubishi that were topped up with highly secure keys from QKD to use for end-to-end encryption of phone calls. Demonstrations also showed how a hospital visit might look in the future, in which patients use their QKD-enhanced smartphones to authenticate and protect the transfer of their personal medical records using quantum keys.

The largest — and ever-growing — quantum network to date was deployed between/in metropolitan areas in China. It started in 2007 with a QKD network in Beijing's commercial telecomm infrastructure and, since 2010, a much larger quantum network has operated in Hefei. This network of over 45 nodes connects city government agencies, military units, financial institutions and health-care offices.

Another large QKD network consisting of 50 nodes began operating in Jinan in 2014. This network provides QKD keys to 90 users at 28 institutions and commercial customers, including the China Industrial and Commercial Bank, Xinhua News Agency, the China Banking Regulatory Commission and various government offices. Within the next few months, China plans to complete the world's longest quantum communication link, a 2000-km QKD backbone between Shanghai, Hefei, Jinan and Beijing. Evolving technology — more compact, robust and reliable components — is helping make these longer networks possible.

Intercontinental QKD network

The next frontier for QKD technology is space. China's aerospace engineers are developing QKD links using satellites that serve as mobile nodes that would extend a network to remote locations or even globally. By 2020, China envisions an intercontinental network between Asia and Europe.

Although these ideas may sound far-fetched, recent advances are raising hopes. In 2007, a team of European researchers realized a 144-km QKD link between two ground observatories on the Canary Islands of La Palma and Tenerife. The link saw atmospheric losses and turbulence equivalent to low-orbit satellite links. In 2010, a QKD link to a hot-air balloon floating at an altitude of 20 km was successfully achieved, simulating the vibration, motion and velocity of low-orbit satellites. In 2013, scientists created a fully functional QKD link between a ground station and an airplane moving at 290 km/h at a distance of 20 km at the same radial velocity as a satellite. And more recently, a research team at the Italian Space Agency and the University of Padova used satellites equipped with a corner cube retroreflector to transmit QKD signals from a transmitter in low and medium orbits over 7,000 km to a ground receiver. These results indicate that taking QKD into space is more than just a promising idea.

While the examples above focus on long-range QKD network systems, researchers are also looking to put QKD into highly integrated low-cost handheld devices. Eventually, these miniaturized portable QKD devices could be topped-up with keys from quantum terminals and carried in the pocket to protect day-to-day routine and business. Researchers have even proposed putting such miniaturized systems on drones. These devices might establish links with ground stations to protect control communications against spoofing or between drones to transport keys to access remote locations.

As QKD systems advance, the need has arisen for a set of recommended standards and practices. While specific QKD standards are still under development by entities such as the ETSI QKD Industry Specification Group and the Cloud Security Alliance, a recent project by Battelle strives to be the first commercial QKD system that complies with the government's FIPS 140-2 information security standard. This could help drive the deployment of QKD in environments that strictly require certified devices. Battelle plans to add these systems to its QKD network in Columbus, Ohio, the first commercially funded QKD network in the United States. This network has operated since 2013 and will eventually connect Battelle facilities throughout the country.

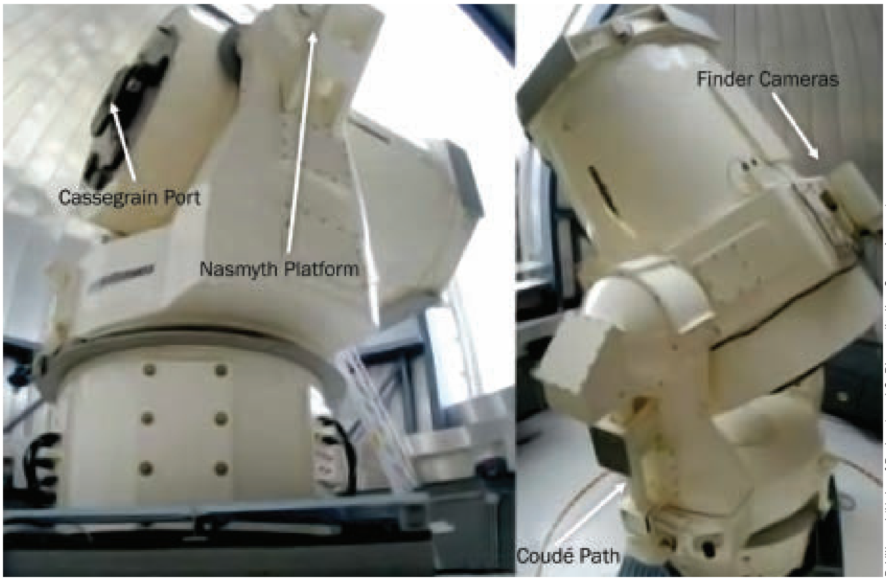
Meanwhile, the UK National Quantum Technologies Programme plans to foster the development of specific QKD standards and to apply them to a QKD network that will enable secure transactions across government agencies, industrial and commercial companies, and the wider public.

Quantum repeater networks

Today's networks are based on the trusted node architecture and require a certain level of trust in the intermediate nodes. Ultimately, the goal is to replace this architecture with quantum repeater networks that would enable quantum states to be distributed over long distances. This would avoid the need for anti-tamper technology at intermediate nodes.

The obstacle with quantum repeaters is that, until recently, all proposed architecture relied on two critical technologies: efficient sources of entangled photons and cryogenically cooled quantum memories that are able to store the quantum states for a sufficiently long period of time.

Although efficient entangled photon sources are commercially available and significant progress has been made toward quantum memories that support high data rates in multiplexed networks, quantum repeaters are still several years away. Recently, however, new quantum repeater architectures have been proposed that, although relying heavily on entanglement,



P. Villoresi (Univ. of Padova) and G. Bianco (Italian Space Agency)

The telescopes at the Matera Laser Ranging Observatory in Mater, Italy, that demonstrated the feasibility of QKD from a satellite equipped with a corner cube retroreflector.

completely avoid the need for quantum memories. This approach may well accelerate the emergence of quantum repeater networks.

In a world of growing cyber threats, QKD applications promise a new era of secure data transmissions. The technology has been proven; it's now a question of scale.

Perhaps in the not-too-distant future an everyday user will visit a quantum terminal as casually as an ATM today. The user might load quantum keys onto a pocket-size smart quantum device. As he or she accesses financial and medical data — and as that information traverses the globe — the user would know it is truly secure, confident that even a quantum computer could do no harm.

Meet the authors

Nino Walenta, Ph.D., a principal research scientist at Battelle, recently joined the company to work on an internally funded quantum key distribution network project. He has 10 years' experience in academic research and development of quantum technologies; email: walenta@battelle.org. Lee Oesterling, Ph.D., is a senior research scientist at Battelle and has over 15 years' experience with the design, fabrication and test of photonics systems and components. He is responsible for the test and development of novel photonics technologies to support quantum information processing applications; email: oesterlingl@battelle.org.

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Ray Kurzweil

Inventor, Author, Futurist

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Business and Society in the Age of Accelerating Returns

The 21st century is an era in which the very nature of what it means to be human will be both enriched and challenged, as our species breaks the shackles of its genetic legacy, and achieves inconceivable heights of intelligence, material progress, and longevity. While the social and philosophical ramifications of these changes will be profound, and the threats they pose considerable, celebrated futurist Ray Kurzweil presents an inspiring vision of our ultimate destiny in which we will merge with our machines, can radically extend our lives, and are vastly more intelligent.

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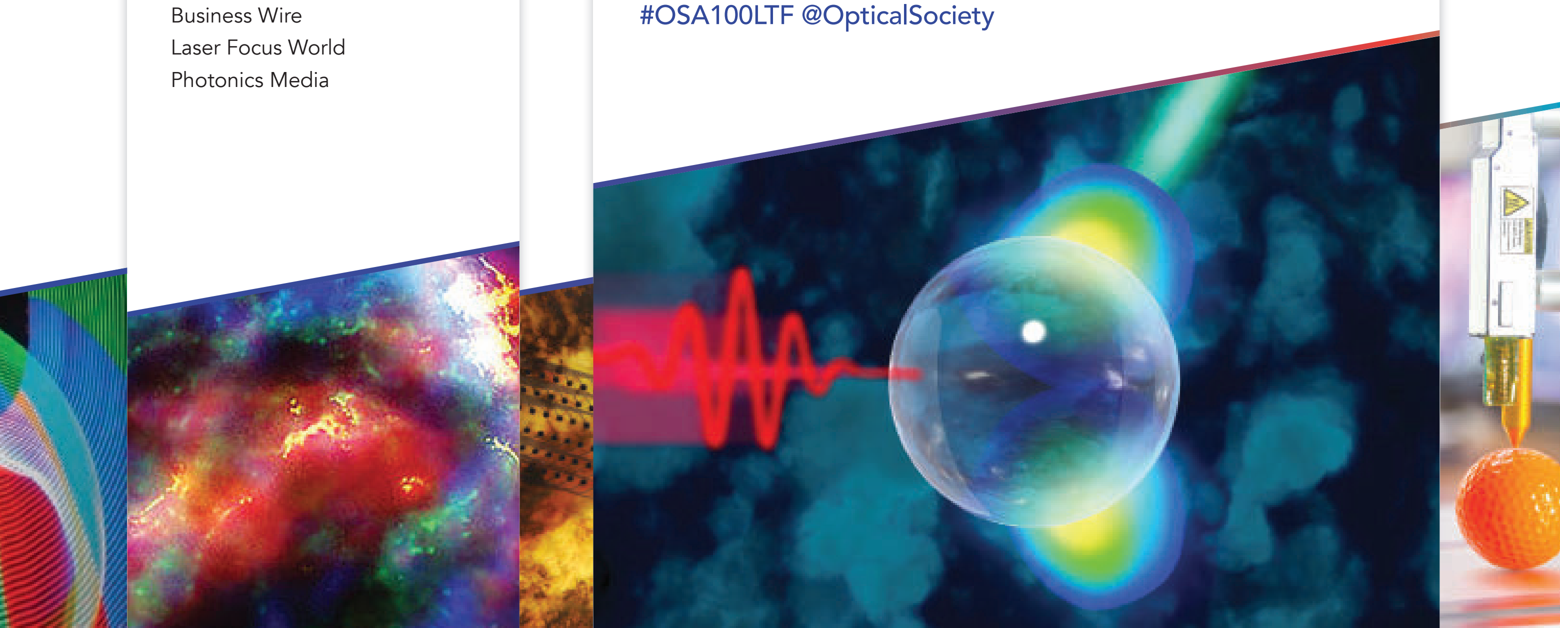

An **Alternative to LEDs** for Full-Field Imaging

A broadband fiber amplified spontaneous emission light source delivers the brightness and low spatial and temporal coherence required for optical coherence tomography and ranging applications.

BY BRANDON REDDING, U.S. NAVAL RESEARCH LAB; PEYMAN AHMADI, NUFERN INC.; and HUI CAO, YALE UNIVERSITY

For some applications, the defining attributes of traditional lasers — high spatial and temporal coherence — can have an adverse effect. High spatial coherence introduces artifacts such as speckle in imaging, which degrades the image. As a result, low-spatial coherence sources such as thermal sources or LEDs are still used in most full-field imaging systems, despite their limited brightness. Low temporal coherence is also desirable in optical coherence tomography (OCT) or frequency resolved lidar, since it provides depth information or ranging.

While thermal sources and LEDs have both the low spatial and low temporal coherence required for applications, they do not provide the laser-level brightness needed for high-speed parallel imaging systems or imaging with the intense optical scattering common for biomedical imaging.

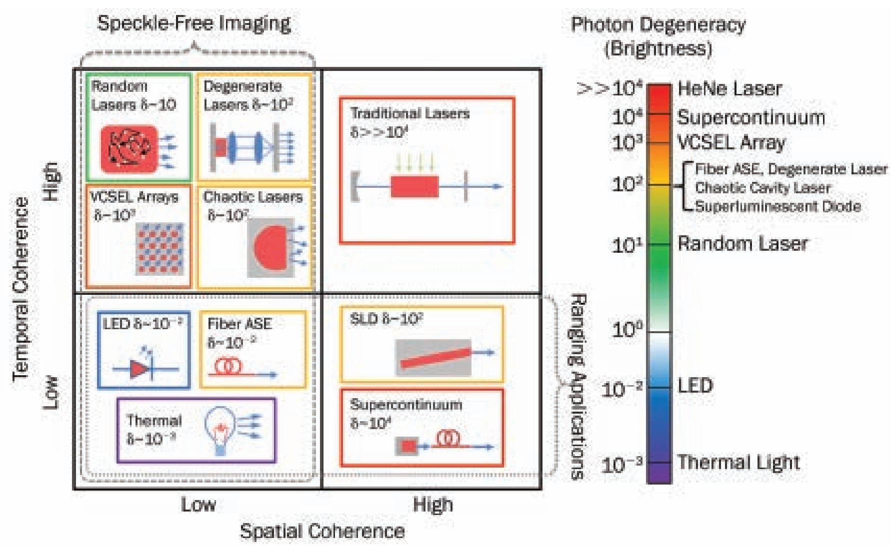

Figure 1. Light sources are categorized in terms of their spatial coherence, temporal coherence and power per mode. Low spatial coherence sources enable speckle-free imaging while low temporal coherence sources enable ranging applications. The recently developed fiber ASE (amplified spontaneous emission) source uniquely combines low spatial and low temporal coherence while maintaining high photon degeneracy.

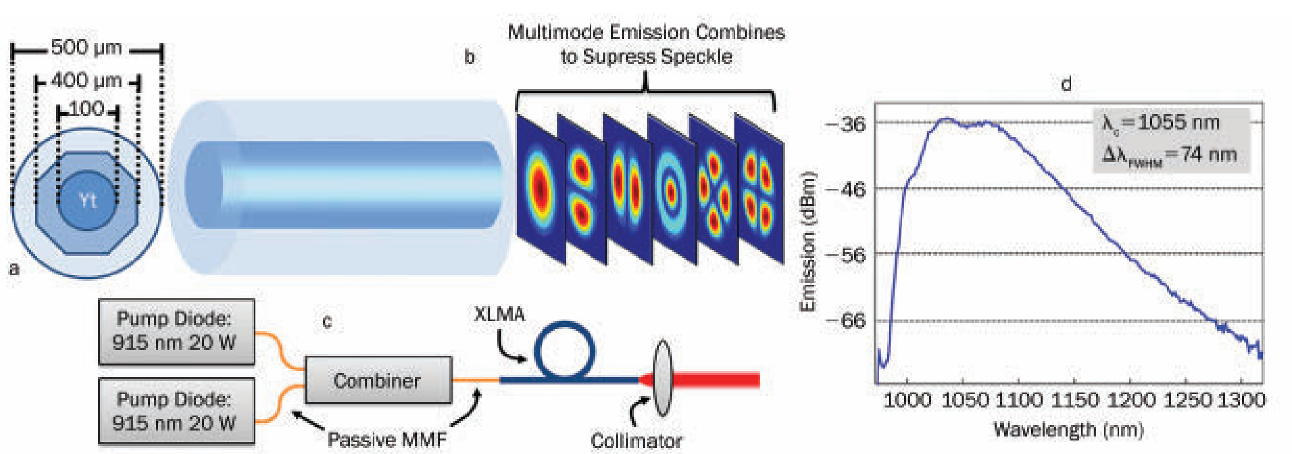

Figure 2. Cross section of the Yb-doped XLMA fiber **(a)**. The fiber consists of a 100-µm-diameter, Yb-doped gain core with NA=0.1 surrounded by an octagonal 400-µm pump core and a 480-µm outer cladding. The multimode gain core provides amplified spontaneous emission (ASE) in many spatial modes simultaneously **(b)**. Schematic of the fiber ASE source **(c)**. The emission spectrum from the fiber ASE source is centered at 1055 nm with a 3-dB bandwidth of 74 nm **(d)**.

All images courtesy of Nufern.

Brightness can be quantified by a parameter called photon degeneracy, which is defined as the number of photons per coherence volume and is equivalent to the spectral radiance or power per mode of a light source. In a laser, the photon degeneracy is usually much greater than unity; for example, a typical HeNe laser has a photon degeneracy of about 10^9. In contrast, traditional low coherence sources such as thermal sources and LEDs have a degeneracy of less than 1. In recent years a number of light sources have been developed that maintain high photon degeneracy, while providing either low spatial coherence or low temporal coherence — but not both.

A research team from Yale University and Nufern Inc. recently categorized different light sources in terms of their spatial coherence, temporal coherence and photon degeneracy (δ) (Figure 1). Traditional lasers combine both high spatial and high temporal coherence along with high photon degeneracy (which is color-coded in the figure). While this combination has made lasers a powerful tool for a wide variety of applications, the high spatial coherence has limited the adoption of lasers in parallel imaging and projection applications. The high temporal coherence limits use in ranging applications, including OCT or frequency resolved lidar. Superluminescent diodes (SLDs) and supercontinuum light sources have low temporal coherence, enabling ranging applications, while maintaining high spatial coherence and high brightness. These sources have been widely used in OCT, but are poorly suited for full-field imaging due to their high spatial coherence.

Recently, several multimode lasers that combine low spatial coherence with high brightness required for speckle-free imaging have been developed, including dye-based random lasers[1], powder-based random Raman lasers[2], solid-state degenerate lasers[3], semiconductor-based chaotic cavity lasers[4], and semiconductor-based large-area vertical-cavity surface-emitting lasers (VCSELs)[5] and VCSEL arrays[6]. While these light sources enable speckle-free imaging with a high brightness source, they maintain relatively high temporal coherence and are not suitable for ranging applications.

The Yale/Nufern team recently developed a fiber amplified spontaneous emission (ASE) source that combines low spatial coherence with low temporal coherence, while maintaining high power per mode[7]. Although thermal sources and LEDs also combine these characteristics, the fiber ASE sources provide orders of magnitude higher brightness. It is also the first demonstration of a high-brightness, speckle-free fiber-based light source that provides many of the same advantages inherent to traditional fiber lasers, such as excellent beam quality, emission directionality and robustness.

To achieve low spatial and low temporal coherence, the researchers needed a fiber source that provided emission in a large number of spatial modes over a wide spectral band. To accomplish this, they

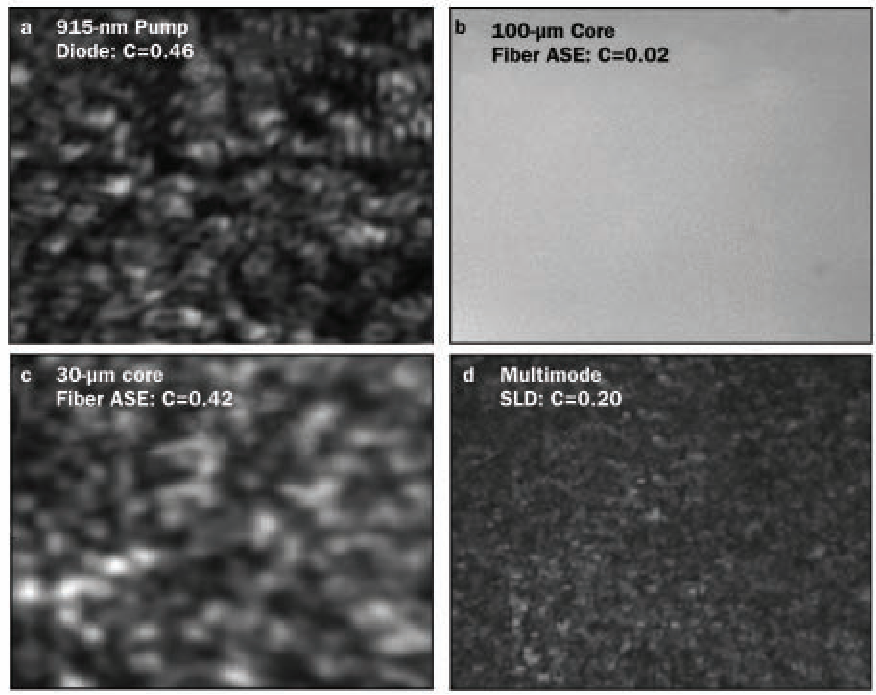

Figure 3. Emission from the pump diode **(a)** and the 100-μm core fiber ASE source **(b)** is collimated onto a ground glass diffuser and the transmitted light is recorded on a camera. The spatially coherent laser light from the pump diode produces a speckle pattern with contrast of about 0.46, whereas the low spatial coherence fiber ASE source efficiently suppresses speckle, resulting in uniform illumination on the camera with a contrast of about 0.02. A 30-μm core fiber ASE source **(c)** and a multimode SLD **(d)** were also tested; however, neither source supported enough modes to effectively suppress speckle formation.

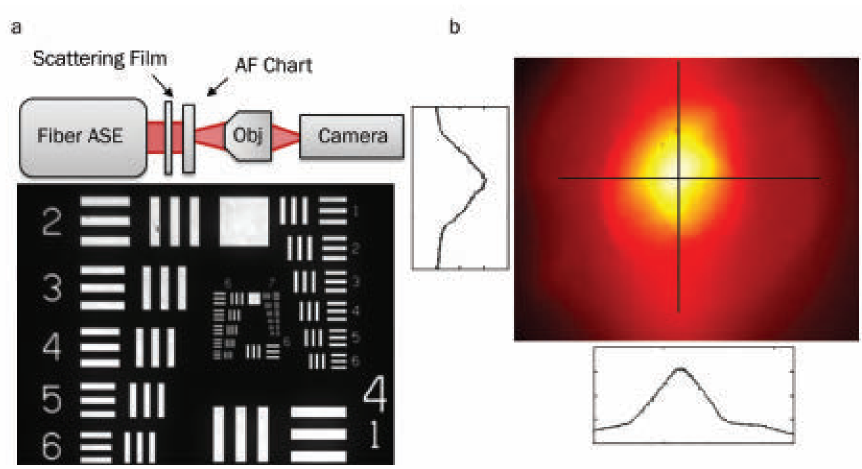

Figure 4. A speckle-free image of a resolution chart illuminated in transmission through a scattering film with the fiber ASE source **(a)**. The spatial profile of the collimated fiber ASE output beam **(b)**.

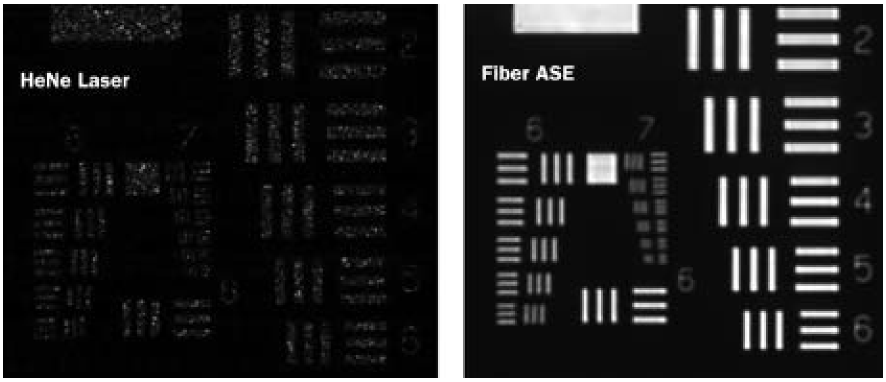

Figure 5. A resolution chart was imaged under illumination from a standard HeNe laser and the fiber ASE source. The fiber ASE source suppresses the formation of speckle, which has historically precluded imaging with laser and ASE-based light sources.

used a recently developed fiber with an extra-large mode area (XLMA) gain core. The XLMA fiber used in the initial demonstration had a 100-µm-diameter, Yb-doped gain core surrounded by a 400-µm diameter pump core, and a 480-µm diameter outer cladding (Nufern XLMA-YTF-95/400/480) (Figure 2a). The large gain core supported about 360 spatial modes providing the potential for low spatial coherence. To achieve broadband emission with low temporal coherence, the spontaneous emission is amplified in the fiber and lasing is avoided by minimizing feedback from the end facet of the fiber with an angled cleave.

The fiber ASE source provided emission in many spatial modes simultaneously (Figure 2b); additionally the source emission was quite broadband, indicative of low temporal coherence (Figure 2d).

The light source produced 270 mW of CW emission with a center wavelength of 1055 nm and a 3-dB bandwidth of 74 nm. While higher output power can be expected in the future, this first-generation fiber ASE source already provides about 4 mW/nm, comparable to commercially available supercontinuum sources[8].

Suppressing speckle formation

The researchers then assessed the fiber ASE source's ability to suppress speckle formation. To do this, they collimated the emission onto a ground glass diffuser and recorded images of the transmitted light with a camera. As a reference, they first measured the intensity pattern formed by laser light from one of the 915-nm pump diodes, which produced a high-contrast speckle pattern (Figure 3a). Repeating the experiment with the fiber ASE source produced a uniform image (Figure 3b).

To quantify the speckle suppression, they calculated the speckle contrast of the two images. The pump diodes produced a contrast of about 0.46 (less than unity due to the use of multiple pump diodes), whereas the fiber ASE source produced a speckle contrast of only about 0.02.

The researchers also compared the speckle formation using two additional ASE sources: a fiber ASE source based on a 30-µm diameter gain core and a commercially available semiconductor-based multimode super luminescent diode (Superlum M-381) (Figure 3c, d). The 30-µm diameter fiber ASE source produced relatively broadband emission with a 3-dB bandwidth of about 20 nm centered at about 1055 nm; however, the emission still produced speckle with a contrast of about 0.42. The multimode SLD (which also operates based on ASE) provided about 150 mW of power at λ=800 nm with a 3-dB bandwidth of 40 nm. Nonetheless, the SLD also produced speckle with contrast of about 0.2. Thus, the XLMA fiber ASE source was the only ASE source that suppressed speckle to acceptable levels for full-field imaging applications.

Initially, it was surprising to find that the multimode fiber ASE source supported such a large number of spatial modes, whereas the ASE produced by a semiconductor-based multimode SLD maintained relatively high spatial coherence and produced high-contrast speckle. In addition, previous studies found that mode competition in multimode Fabry-Perot lasers limited lasing to only a few modes, even in waveguides supporting several hundred transverse spatial modes[9].

The researchers suggested two factors that could enable the fiber ASE source to support a large number of modes. First, the SLD and the multimode Fabry-Perot laser both used semiconductor quantum wells as gain materials, which allow for efficient carrier diffusion. This has the effect of increasing the mode competition[10]. In contrast to a quantum well, the Yb dopants in the XLMA fiber are spatially localized, leading to spatial hole burning, which can reduce the effects of mode competition. Second, the fiber bending and imperfections in the XLMA fiber can introduce mode coupling such that a mode that initially experiences strong gain may couple into a mode with lower gain, thereby equalizing the gain experienced by different modes over the length of the fiber. The reduction of mode-dependent gain in the multimode fiber favors multimode operation[11]. Thus, the fiber medium may be particularly well-suited to the development of highly multimode ASE appropriate for speckle-free imaging.

The researchers then used the fiber ASE source to illuminate a U.S. Air Force resolution test chart, which was imaged in transmission mode. A speckle-free, full-field image was obtained (Figure 4a). In addition to providing the low spatial coherence needed for imaging, the low temporal coherence (broad emission spectrum) makes the fiber ASE source a good candidate for ranging applications such as OCT. For example, the 74-nm emission bandwidth would provide an axial resolution of 6.6 µm in OCT. The fiber ASE source also exhibits high directionality, with a divergence angle of less than 6°. Despite the presence of many spatial modes, the spatial profile of the output beam from the fiber ASE source is smooth and stable — ideal for illumination in imaging applications, as confirmed by the image of the collimated beam (Figure 4b).

In addition to producing speckle-free illumination like a thermal source or LED, the fiber ASE source also provides much higher brightness, useful for high-speed imaging or imaging through scattering samples. As a quantitative comparison, the team estimated the photon degeneracy of the fiber ASE source to be about 10^2, as compared with LEDs and thermal sources, which are limited to a photon degeneracy well below unity. The fiber ASE source also provides a comparable level of photon degeneracy to recently developed low-spatial coherence lasers, as shown in Figure 1.

The fiber ASE source uniquely combines high power per mode with both low spatial and low temporal coherence. The ASE source produces 270 mW of CW emission with a 74-nm 3-dB bandwidth centered at λ = 1055 nm. Highly multimode emission, combined with spectral compounding, enables speckle-free imaging while the broad emission spectrum also makes it an attractive light source for ranging applications. The researchers expect that increasing the size of the gain core could enable emission in more spatial modes while also providing the potential for higher power. As such, the XLMA-based fiber ASE source could enable new applications in high-speed parallel imaging, projection and ranging.

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Advances in **Optical Simulation Software** Bridge the Product Development Gap

New software addresses the overlooked needs of optomechanical engineers by helping them package, analyze and validate new designs, simplifying the transition between optics design and packaging.

BY CORT STINNETT and TERESA TAYLOR
ZEMAX LLC

From cellphone cameras to space telescopes, driverless cars to the laser interferometer at LIGO (Laser Interferometer Gravitational-Wave Observatory), optics are transforming our lives. Optical system design and the optical engineer's toolbox have evolved over the last two decades accordingly. What used to take optical engineers months to create can now be designed in a matter of hours or days. Using optical simulation software, optical engineers can design optical systems that weren't possible two decades ago.

Although the toolbox for optical engineers has expanded to drive innovation and meet today's challenges, optomechanical engineers have been left far behind, without the tools to address even basic problems. Further, optical engineers and optomechanical engineers address different challenges. Optical engineers use simulation software to lay out a lens system, essentially creating lenses and components in "free space." They design the shapes and determine the positions of the lenses, mirrors, prisms, gratings and other optical components to achieve a given performance goal and to meet design specifications.

In contrast, optomechanical engineers design and build the packaging for the lens design. They are concerned with the materials, finishes, thermal design, stress, vibration, tolerancing, manufacturability, cost to manufacture and other considerations that may affect the optical performance or the success of the product. They must also design for brand consistency and user experience, such as the industrial design, weight, look and feel, and durability.

Inefficient workflow

In addition to addressing different challenges, optical and optomechanical engineers work in different design environments and speak in different languages; the process workflow between them is inefficient and cumbersome. In most cases, optomechanical engineers receive an exported STEP or IGES file in a computer-aided design (CAD) program from an optical simulation package. These “data blobs” do not include optics design files or data about the components or clear aperture location.

Optomechanical engineers must manually rebuild the optical system within the CAD package, which is time-consuming and can introduce errors. For a complex optical system such as a telescope with many lenses, rebuilding the optical components in a CAD program can take days or weeks.

After importing and rebuilding the optical components, optomechanical engineers can start building the mechanical geometry and analyzing their design. However, there are no tools to help them assess the impact of their design on the optical system. They must either export the design back to the optical engineer to validate the design or build physical prototypes to assess the product’s performance.

The cycle of prototype and redesign can be repeated many times before the optomechanical design is finalized. These repeated design iterations increase costs, create stress within the design team and delay time to market. They also negatively impact the optical engineer, who typically works with several optomechanical engineers at one time. Validating each optomechanical engineer’s designs (often multiple times) creates a bottleneck in the workflow and a high opportunity cost for the organization by reducing the amount of time the

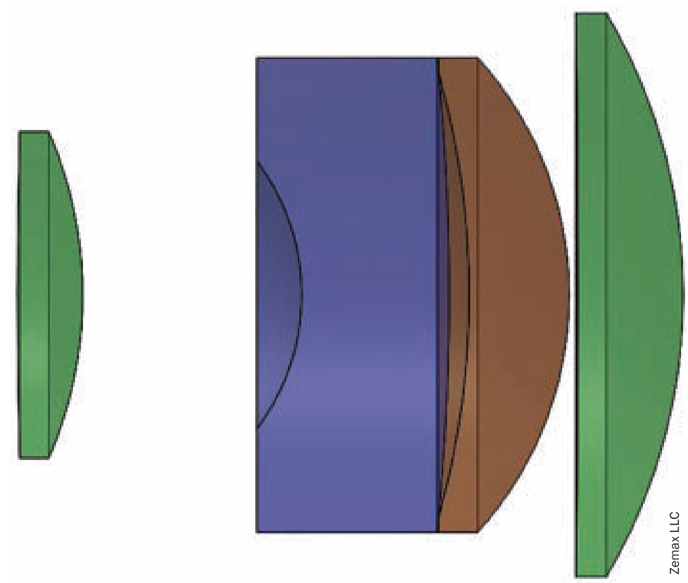


Figure 1. A 25-mm lens design in free space.

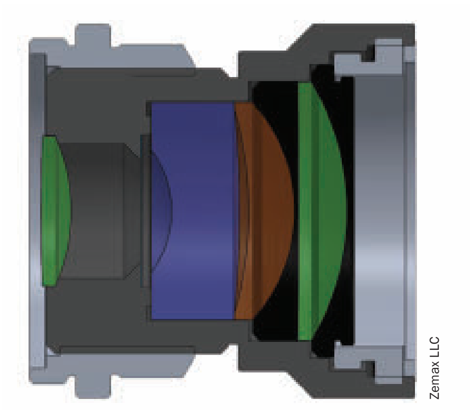


Figure 2. The same 25-mm lens design fully packaged.

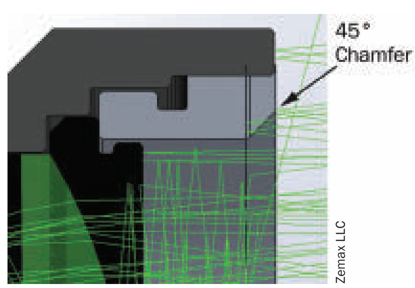


Figure 3. The 45° angle of the chamfer introduces stray light.

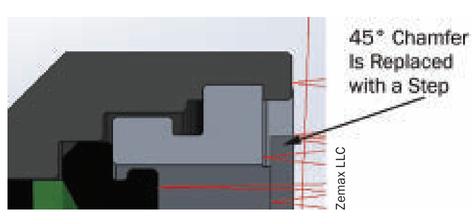
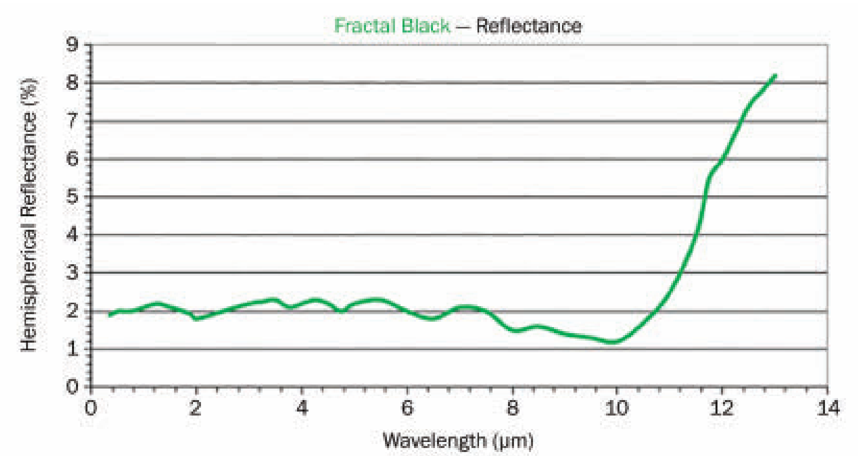


Figure 4. The stray light is corrected by changing the chamfer angle to a step.

optical engineer could spend developing new optical systems for the market.

Improving optomechanical product development

To equip optomechanical engineers with the tools they need to package, analyze and validate optomechanical designs, Zemax LLC has developed LensMechanix, a plug-in for the 3D CAD design software SOLIDWORKS from Dassault Systemes that enables optomechanical engineers to analyze and validate their designs using full multithreaded ray tracing. Data associated with the optical components is preserved, such as materials, coatings, surface radii, edges, wavelengths and clear aperture location.



Acktar Ltd.

Figure 5. Reflectance vs. wavelength for Acktar's Fractal Black coating.

LensMechanix also loads sources and detectors, and automatically creates the optical component parts with actual lens dimensions, eliminating the need for STEP and IGES files. Within minutes, optomechanical engineers can start building mechanical geometry from the dimensionally accurate optical components, and then run ray traces and perform surface power analysis to compare the optical performance in SOLIDWORKS with the original output.

Ray tracing capabilities make it easy for optomechanical engineers to discover and correct stray light contamination, beam clipping, image focus issues or other potential problems caused by the mechanical geometry — before they build a prototype or send the design to the optical engineer to review. A simple chart indicates "pass/fail" for image quality and stray light metrics. Detailed results data is also stored so that optomechanical engineers can troubleshoot the design or gather additional insights.

Stray light and beam clipping present challenges

Mechanical product development can degrade optical performance in many ways. Two common problems are stray light and beam clipping. To demonstrate stray light and a possible solution, take a 25-mm single Gauss lens as an example. Stray light can be introduced into an optical system in many ways; even subtle changes to the mechanical geometry have a potentially major impact on optical performance. As shown in Figure 3, the 45° chamfer on the front retaining ring directs light onto the interior mechanical and optical surfaces. The reflected light propagates through the system, degrading the image quality. Changing the angle on the front retaining ring from a 45° chamfer to a small step or series of steps greatly reduces the amount of stray light entering the optical system (Figure 4).

Applying an absorptive coating such as Acktar's Fractal Black can help mitigate stray light. Absorptive coatings are optimized for specific wavelength ranges and must be matched to the optical system requirements. Acktar's Fractal Black coating minimizes reflectance through a portion of the spectrum in optomechanical designs (Figure 5).

The best method of reducing stray light highly depends on the product under de-

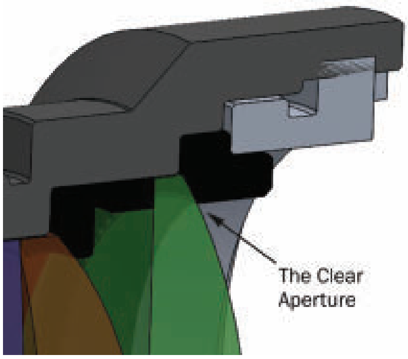


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Figure 6. The location of the clear aperture on lens surface 1.

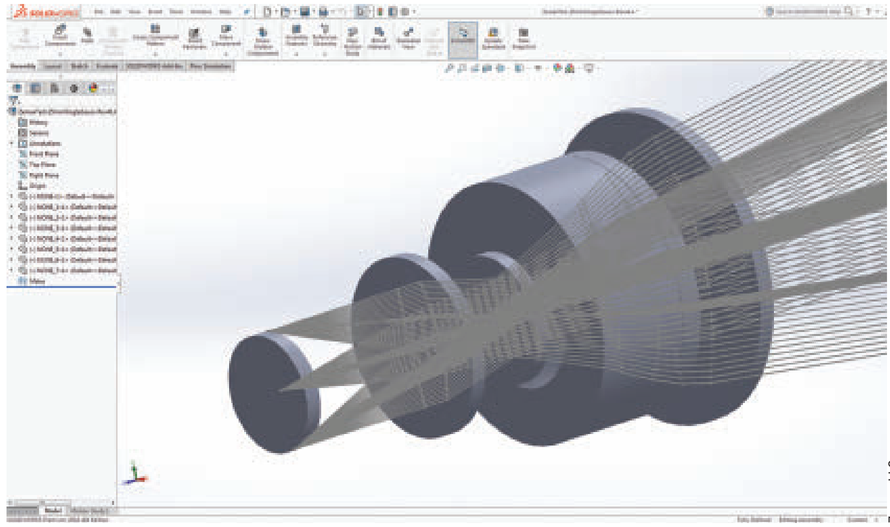

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Figure 7. A STEP file imported with a static ray bundle.

velopment. The optomechanical engineer must consider the manufacturing and assembly processes in addition to materials, finishes and cost.

Another common problem is beam clipping, which occurs when mechanical geometry interferes with light entering an aperture. The lens boundary that is intended for light to pass through is called the clear aperture (Figure 6).

Any mechanical geometry that extends into the clear aperture will cause beam clipping. To evaluate beam clipping, today an optical engineer provides a ray bundle to the optomechanical engineer. A ray bundle file is the static ray trace output from the optical simulation package. Figure 7 shows an optical system imported with a static ray bundle.

As the mechanical packaging takes shape, the optomechanical engineer manually overlays the ray bundle onto the design to check that the rays do not hit the mechanical geometry. The static ray bundle, however, may not account for all of the mechanical geometry. When the mechanical packaging is large compared to the optical system, the optomechanical engineer must manually extend rays to account for all of the mechanical geometry. If the optomechanical engineer uses a fold mirror to change the direction of the light, it renders the new static ray bundle useless, and he or she must start over with a new design from the optical engineer.

New software can trace rays through an optomechanical system that has been modified with a fold mirror. It streamlines the workflow between optical and optomechanical engineers, who can collaborate efficiently while working in their preferred environments and formats. With the tools to validate their own designs, optomechanical engineers can eliminate repeated prototypes and extra development iterations, dramatically saving time for themselves and for optical engineers, improving collaboration, and speeding delivery to manufacturing.

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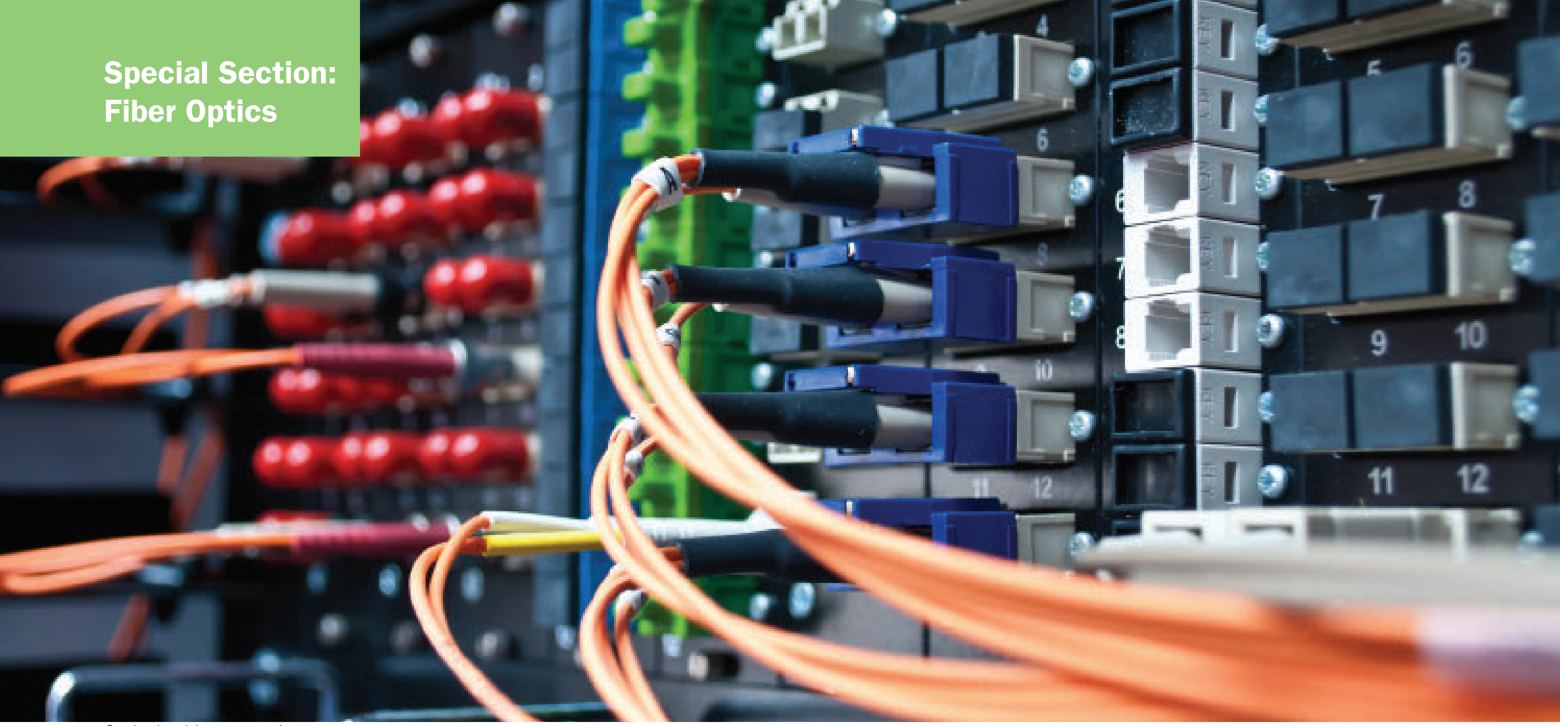
Fiber Optics

The world is in the midst of an expanding fiber optics revolution. While its foundational concept has been around for more than a century, this technology is seeing application in an increasing number of technologies — from media displays and data communications to phone systems and the Internet.


Optical cable connections.

Fiber Optics: From 'Piping Light' to All-Optical Communications

Fiber optics components and systems are seeing application in an increasing number of technologies, products and research initiatives. From its modest beginnings to present-day advancements, the field of fiber optics is poised to further revolutionize communication networks, optical devices and more.

BY JUSTINE MURPHY
SENIOR EDITOR

The basis of optical communications systems, fiber optics uses thin, flexible glass or plastic fibers as wave guides, or "light pipes," to channel light from one location to another. This concept has been around since the late 19th century, when scientist William Wheeling patented the "piping light" method of light transfer. Alexander Graham Bell later developed the photophone, an optical voice transmission system that used free-space light to carry the human voice from one location another about 200 meters away.

These inventions kick-started the field of fiber optics, but it wasn't until the mid-20th century that it began to take its modern shape. Today, such systems are finding strength in military, industrial, commercial and data applications, among others.

A communications revolution

From the first generation systems to the most current, fiber optics has revolutionized the way people communicate in today's world, from telephone systems to the Internet to media displays. And while it is still evolving, fiber optics has helped to advance research in various areas of the photonics industry, in products including lasers.

IPG Photonics Corp., headquartered in Oxford, Mass., recently developed an innovative fiber optics-based laser system, which was honored in 2015 with a Prism Award for Photonics Innovation in the industrial lasers category. The 500-W, quasi-CW, green, single-mode fiber laser (GLPN-500-R) is suited for industrial applications ranging from copper welding to solar cell manufacturing, in addition to applications in defense and security, materials processing and laser light shows.

"The laser provides pulse energies similar to [its] predecessor, 100-W green laser, a few microjoules, but at a higher repetition rate," said Alexei Markevitch, market development manager at IPG. "Therefore, it can be used in all applications where the earlier lower power laser has been qualified, but at a five times higher throughput."

He added that the laser's combination of single-mode beam quality, short wavelength, short pulse duration and higher power allows exploration of new applications. A year after the product's Prism Award win, IPG has continued to enhance its GLPN-500-R. The laser's architecture and components underwent continued optimization, according to the company, resulting in a significant reduction in form factor.

"The end-user rack-mounted version has been reduced in size by more than 30 percent, and a super compact OEM laser module has been released," Markevitch said. "The laser heads in operation have acquired many thousands of hours, proving robust operation of the doubling crystals and optics at unprecedented high powers."

Now, IPG's R&D team is working on customized versions of the laser, with features specific to applications and customers, i.e., linewidth, modulation capabilities, control features, etc.

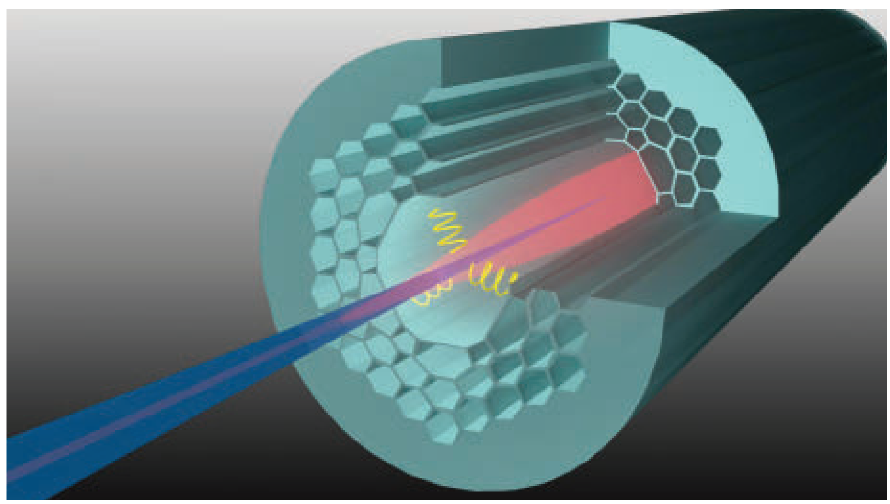
Fiber optics is seeing innovation in other research, as well, including at the Max Planck Institute for the Science of Light (MPL) in Erlangen, Germany. There, researchers have demonstrated that laser light can be used to manipulate a glass optical fiber that is tapered to a sharp point called a nanospike, which is smaller than a speck of dust, in the middle of an optical fiber with a hollow core. In a paper published in OSA's *Optica*, they reported that optical forces cause the nanospike to self-align at the center of the hollow core, trapping it stronger at the core center as the laser power increases.

To create the nanospike, an ordinary single-mode glass optical fiber about 100 µm in diameter was heated so that it could be stretched to form a tapered portion, and then the fiber's tip was etched with hydrochloric acid to create a nanospike around 100 nm in diameter, and less than 1 mm long. In their work, the researchers inserted the nanospike into the hollow-core fiber. A high-power 1064-nm laser beam was then launched into the single-mode fiber to create the optical trap. When the laser light entered the tapered portion of the fiber, the researchers said it began to spread out beyond the nanospike into the empty space inside the hollow core fiber. As the taper got smaller, the light began to sense the boundary of the larger fiber core, causing the light to reflect inward toward the tapered fiber. This reflected light exerted a mechanical force on the nanospike, forming an optical trap.

"Launching very high power laser light into an optical fiber, especially a hollow-core fiber, can be very difficult and usually requires extensive electronics and optics to maintain alignment," said Philip Russell, director at MPL, and leader of the research team.

This system offers a completely new method of coupling light into hollow-core fibers with the unique features of self-stabilization and self-alignment, without the need for extensive electronics and optics, said Shangran Xie, a postdoctoral fellow in the Russell Division at MPL, and first author of the *Optica* paper.

"The optical trapping mechanism in our system is also different from conventional optical tweezers, as it arises from



Philip Russell/Max Planck Institute for the Science of Light

A simple, self-aligning method traps tiny tapered glass fiber inside hollow-core optical fiber, with potential applications in laser cutting and basic physics research.

Guiding light: An early history of fiber optics

Fiber optics' roots can be traced back to the late 1800s. In 1870, Irish physicist John Tyndall demonstrated that light could be guided to follow a specific path. In a stream of water that flowed downward from one container to another, he directed a beam of sunlight to the same path as the water. Tyndall's experiments demonstrated total internal reflection, which means optical rays are unable to break from the material in which they are traveling.

Experiments several years later by scientist William Wheeling expanded on Tyndall's work. He patented a method of light transfer called "piping light." Using several mirrored pipes that extended from a single light source, the light could be sent to different rooms in a way similar to water plumbing in a building. These findings, along with Tyndall's, formed the basis of modern fiber optics communications networks.

1870 Scientist John Tyndall's experiments with water and beams of light mark the first research of the guided transmission of light.

1880 Scientist William Wheeling patents a method of light transfer called "piping light."

Alexander Graham Bell develops the photophone, an optical voice transmission system.

The Optical Society (OSA), *Optica*

Robotics has benefited from advances in lasers, optical fiber, image sensors and optical sensors.

the optomechanical interaction between the nanospike and HC-PCF [hollow-core photonic crystal fiber]," he said. "The measured optical trapping force acting on the nanospike is one order of magnitude stronger than conventional optical tweezers. This new trapping mechanism may find future applications on stably optical trapping of complex shaped objects, [such as] biological cells and DNA."

Xie added that, at this point, the work is progressing well. He and fellow researchers hope to further apply this nanospike technique to other hollow-core fiber systems, including gas- or liquid-filled HC-PCF. This could lead to applications such as UV light generation and biological cell trapping.

Looking to the future

Many envision a communication network that is "completely in the optical domain, giving rise to an all-optical communication network," according to the paper by Idachaba et al., which also predicts that all signals could be processed in the optical domain, without any form of electrical manipulation. The researchers note a cost-saving benefit of all-optical networks: There would be no need to replace related electronics when the data rate increases, "since all signal processing and routing occurs in the optical domain."

Improvements in laser technology are also possible, including the extension of existing semiconductor lasers to a wider variety of lasing wavelengths; shorter wavelength lasers with very high output powers are of interest in some high density optical applications, the paper states. Also cited for future growth are technologies such as optical amplification and optical transmitters/receivers.

As such technologies and applications expand, so, too, should the workforce. Programs like Tukwila, Wash.-based The Light Brigade, a fiber optics training subsidiary of infrastructure specialist AFL, are emerging to help build the staff. The Light Brigade is working with the NeST Institute of Fiber Optic Technology Pvt. Ltd. of Kerala, India, to introduce the Amal Jyothi NeST Center for Fiber Optic Technology training program. It aims to provide leading fiber optics training solutions to meet the high demand for skilled

A brief modern fiber optics timeline

1957 Basil Hirschowitz, Larry Curtis and C. Wilbur Peters, all members of the medical school faculty at the University of Michigan, create the first fiber optics endoscope.

1961 American Optical Co. employees Elias Snitzer and Will Hicks created and demonstrated the first optical glass fiber laser. The National Academy of Engineering (NAE) affirms that the fiber's core was small enough for the light to follow a single path. Snitzer later developed the first optical fiber amplifier, and was also involved in the development of the first fiber optics laser amplifier.

1970 Donald Keck, Peter Schultz and Robert Maurer, all scientists at Corning Glass Works, created the first glass optical fibers that were touted as "the purest glass ever made," according to NAE. It was composed of fused silica from the vapor phase, and exhibited light loss of less than 20 dB/km (1 percent of light remains after traveling 1 km). This and other similar developments helped bring fiber optics components and systems toward commercialization.

1977 A 1.5-mile underground fiber optics transmission system links Illinois Bell central offices and customers across three buildings.

1980 AT&T announces that it will install fiber optics cable linking major cities between Boston and Washington, D.C.

1997 The Fiber Optic Link Around the Globe becomes the longest single-cable network in the world at 17,500 miles long.

2000 360Networks of Seattle completes the first fiber optics cable between the U.S. and Venezuela.

2012 Elias Snitzer, hailed the father of fiber lasers and fiber amplifiers, is honored posthumously by the Institute of Electrical and Electronics Engineers for his contributions to fiber optics technology and other photonics research.

To learn more about fiber optics technology, read "**Fiber Optics: Understanding the Basics**," a Photonics Handbook article by OFS, Specialty Photonics Div., at **Photonics.com/EDU/Handbook**.

fiber optics technicians in India. Students who complete the training can earn an ETA (Electronic Technicians Association International) Fiber Optic Installer certification, and course graduates receive job placement assistance across India and the Middle East.

"This collaboration with the [Amal Jyothi] engineering college will provide more opportunities for people to be trained, and ultimately employed, as fiber optic field technicians," said Larry Johnson, founder and director of The Light Brigade.

Also evolving is the fiber optics market. Production is expected to reach record levels within the next few years, namely in the Asia-Pacific region, Europe and North America, according to a 2014 report, "Fiber Optics Market Worth $3 Billion by 2019," by MarketsandMarkets. The Asia-Pacific fiber optics market is growing with "government directives intended to increase and encourage national broadband applications," and is expected to see the fastest growth rate by 2019.

Telecom and broadband take the top positions in the fiber optics market, as

Institute of Engineering and Technology Archives

Murray Ramsay demonstrates video transmission over optical fibers to Queen Elizabeth II during a physics exhibition in London in 1971. It showed the technology's potential to revolutionize telecommunications.

stated in the report, with an approximately 55 percent share by value in 2013. These applications, in addition to private data networks, and use in the oil and gas industries, are expected to see the fastest growth rate in this market by 2019.

justine.murphy@photonics.com

Light Brigade, NeST introduce India fiber optics training program

KERALA, India — The Light Brigade Inc., the fiber optics training subsidiary of infrastructure specialist AFL that is headquartered in Tukwila, Wash., is joining forces with the NeST Institute of Fiber Optic Technology Pvt. Ltd. (NIFOT) of Kerala, India, to open the Amal Jyothi-NeST Center for Fiber Optic Technology.

Aiming to provide leading fiber optics training solutions to meet the high demand for skilled fiber optics technicians in India, the curriculum for the program was developed by The Light Brigade and has been approved by the Electronic Technicians Association (ETA) International. Students who complete the training can earn an ETA Fiber Optic Installer certification. In addition, the program offers course graduates job placement assistance across India and the Middle East.

"[The] Light Brigade is excited to be a part of the expansion plans for providing more fiber optic training opportunities in India," said Larry Johnson, founder and director of The Light Brigade. "This collaboration with the [Amal Jyothi] engineering college will provide more opportunities for people to be trained, and ultimately employed, as fiber optic field technicians."

The Light Brigade

Larry Johnson, founder and director of The Light Brigade, cuts the ribbon at the inauguration ceremony of the new fiber optics training center at Amal Jyothi College of Engineering in Kerala, India.

The Light Brigade provides instructor-led public and custom classes on fiber optics design, maintenance and testing including advanced topics such as fiber to the x (FTTX), dense wavelength division multiplexing, polarization mode dispersion and chromatic dispersion. NIFOT is a developer of computer and communication technology, including fiber optics, networking, microwave and software.

Fiberguide to license Motheye AR nanostructures from Telaztec

Fiberguide Industries

Motheye antireflective nanostructures were originally discovered by the observation of nocturnal insects, such as moths.

STIRLING, N.J. — Fiberguide Industries Inc., a Halma company, said it has been granted an exclusive license from TelAztec LLC optics of Burlington, Mass., to develop Motheye antireflective (AR) nanostructures for use in fiber optic cable, specifically for high-power delivery applications.

These nanostructures were originally discovered by the observation of nocturnal insects, such as moths. The compound eyes of these insects were found to reflect little or no light, regardless of the light's angle of incidence. TelAztec used this observation to develop effective, randomized, AR nanostructures for use on glass substrates, which Fiberguide Industries will market under the trade name RARe Motheye.

RARe Motheye coatings have damage

thresholds that are far greater than AR coatings, according to Fiberguide, close to that of silica fiber and three to seven times higher than standard AR coatings. The random AR surfaces have broad antireflection properties and operate over a large (about 400-nm) wavelength range compared to the narrow (about 50-nm) operating range for conventional AR coatings.

Potential applications include medical systems, industrial lasers, directed energy, digital cinema projects and data array transmission.

Lightwave Logic shows single-mode laser light via polymer waveguides

LONGMONT, Colo. — Photonic device and optical polymer material systems developer Lightwave Logic Inc. has successfully guided laser light through 16 of its passive, single-mode ridge waveguides made entirely out of advanced organic polymer systems.

To achieve high modulator performance, the guided light must remain single-mode throughout the length of its on-chip propagation.

"This is an important step in our device development program, and we can now move forward to demonstrate the ability of these first all-polymer devices to modulate light," said Tom Zelibor, chairman and CEO of Lightwave Logic.

To achieve high modulator performance, the guided light must remain single-mode throughout the length of its on-chip propagation. These results are a milestone in the company's development process as it demonstrates the ability to design and fabricate single-mode waveguides, which are a building block of waveguide modulators.

"Our ability to successfully modulate light for longer distance applications in the market can fulfill a tremendous commercial need that we intend to pursue," Zelibor said. "The end result of this capability will be more ubiquitous 100- and 400-Gbps solutions that the market is demanding."

Unlike multimode fiber, single-mode fiber allows light to travel with less distortion over longer distances and is less expensive. Datacenter and telecommunications applications often require data to be moved at distances greater than 500 m with single-mode light.

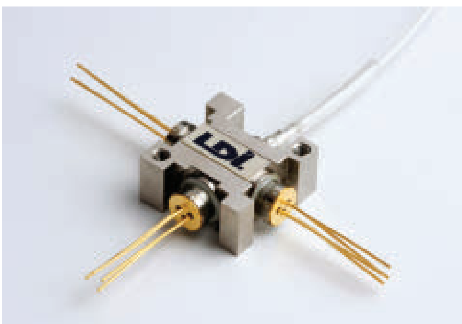
"The photonics industry is rapidly becoming aware of polymer photonics as a viable replacement technology that can provide cost-effective solutions that can alleviate many technology pain points that threaten the ability to meet the almost endless demand for data at faster speeds, especially for datacenter applications," Zelibor said.

Lightwave Logic said it will now enter the commercialization process, beginning with passive-waveguide loss measurements, followed by the development and active testing of electro-optic modulators. Utilizing CW input laser light, electro-optic modulators convert digital electrical data into output pulses of light that can be transported across fiber optical communication networks. Active testing is accomplished by applying an electrical signal to a modulator and evaluating the resulting output optical signal.

Lightwave Logic is a development-stage company that produces prototype electro-optic demonstration devices, moving toward commercialization of its high-activity, high-stability organic polymers for applications in high speed fiber optic telecommunications, data communications and electro-optical device markets.

new products

1



2

1 Fiber Cable

OFS Fitel LLC has announced the MiDia 2GX cable, which increases fiber density and enhances performance for metro networks. The microcable enables tight, low-loss bends without risking fiber strength or long-term reliability. The cable occupies 36 percent less area than conventional 250-µm coated fibers, enabling smaller diameter cables with a greater number of fibers per tube to minimize cabled diameters in congested duct networks. The MiDia 2GX microcable is designed for seamless installation into existing microduct networks.

shsalyer@ofsoptics.com

2 Fiber-Coupled Laser

OSI Laser Diode Inc., an OSI Systems Co., has announced the TCW TriBiner-series fiber-coupled laser, the TCW RGBM-105R. The triple-wavelength device is a red, green and blue (RGB) laser diode module designed to meet strict efficiency footprint requirements of the visible laser display market. The module couples all three wavelengths – 450, 520, and 638 nm – into a single output fiber pigtail. Typical optical power is 35 mW at 25 °C, and spectral width (FWHM) is 2 nm for all three wavelengths. The CW threshold current is 30 mA for the 450-nm wavelength, 40 mA for the 520-nm wavelength and 50 mA for the 638-nm wavelength. The operating temperature range at rated drive conditions is from −20 to 50 °C. Applications include RGB displays, RGB projectors and optical sensors.

pscarillo@osilaserdiode.com

Polishing Lapping Film

The ÅngströmLap Ultimas-Pro Final Polishing Lapping Film from **Fiber Optic Center Inc.** is a cost-effective protrusion-producing film, meeting Telcordia specifications. The films offer high performance at low manufacturing cost, with positive protrusion, a positive fiber height, a translucent white color and 75-µm-PET base. The film is available in a 5-in. disk.

sales@focenter.com

Fiber Optics
Fibers and Connectors Directory

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

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50 Victor Heights Parkway
Victor, N.Y. 14564-8909
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Fax: (585) 924-2623
info@bristol-inst.com
www.bristol-inst.com
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Edmund Optics Inc.
101 E. Gloucester Pike
Barrington, N.J. 08007
Tel: (856) 547-3488
Fax: (856) 573-6295
sales@edmundoptics.com
www.edmundoptics.com
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Fermionics Opto-Technology
4555 Runway St.
Simi Valley, Calif. 93063
Tel: (805) 582-0155
Fax: (805) 582-1623
L.Perillo@fermionics.com
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Fax: (908) 231-1539
usa@hamamatsu.com
www.hamamatsu.com
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Innovation Photonics
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Verona, N.J. 07044
Tel: (973) 857-8380
Fax: (973) 857-8381
info@innpho.com
www.innpho.com
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154 Hobart St.
Hackensack, N.J. 07601
Tel: (201) 343-8983
Fax: (201) 343-2132
main@masterbond.com
www.masterbond.com
See our ad on page 34

MOXTEK Inc.
452 W. 1260 N.
Orem, Utah 84057
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Fax: (801) 221-1121
info@moxtek.com
www.moxtek.com
See our ad on page 62

Newport Corporation
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www.newport.com
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Photonics
3050 North 300 West
North Logan, Utah 84341
Tel: (435) 753-3729
Fax: (435) 753-5231
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www.ophiropt.com/photonics
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115 Route 46 West, Bldg. A-2
Mountain Lakes, N.J. 07046
Tel: (973) 331-1191
Fax: (973) 331-1373
sales.us@spectrogon.com
www.spectrogon.com
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Fiber Optic Connectors, Multimode, Multifiber

Adamant America Inc.
Rochelle Park, N.J.
www.adamant.jp/en

Aurora Optics Inc.
Broad Axe, Pa.
www.aurora-optics.com

CMG Technologies
Woodbridge, England
www.cmgtechnologies.co.uk

Control Cable Inc.
Baltimore
www.controlcable.com

Diamond Advanced Components Inc.
Norwood, Mass.
www.diamond-ac.com

FiberTech Optica Inc.
Kitchener, Ontario, Canada
www.fibertech-optica.com

Fiberwe Technologies Co., Ltd.
Shanghai
www.fiberwe.com

GSR Global
Bedford, Mass.
www.gsrusa.net

InnovaQuartz LLC
Phoenix
www.innovaquartz.com

LEMO SA
Ecublens, Switzerland
www.lemo.com

LEONI Fiber Optics GmbH
Neuhaus-Schierschnitz, Germany
www.leoni-fiber-optics.com

LighTech srl
Capriate S.G., Italy
www.lightech-fo.com

Molex Inc., Optical Solutions Group
Downers Grove, Ill.
www.molex.com/fiber

Nissin Kasei USA Corp.
San Jose, Calif.
www.nissinkasei.co.jp

Optoscribe Ltd.
Livingston, Scotland
www.optoscribe.com

Petcom
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Polymicro Technologies
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www.responsemicrowave.com

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Bend, Ore.
www.tratechfiber.com

Fiber Optic Connectors, Multimode, Single-Fiber

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www.cablelan.com

CMG Technologies
Woodbridge, England
www.cmgtechnologies.co.uk

DPM Photonics LLC
Vernon, Conn.
www.dpmphotonics.com

Emit Technology Co. Ltd.
New Taipei City, Taiwan
www.emit.com.tw

Fiberoptic.com, The Fiber Optic Marketplace
Breinigsville, Pa.
www.fiberoptic.com

Fiberstore Inc.
Tukwila, Wash.
www.fiberstore.com

FiberTech Optica Inc.
Kitchener, Ontario, Canada
www.fibertech-optica.com

Fiberwe Technologies Co. Ltd.
Shanghai
www.fiberwe.com

Kientec Systems Inc.
Stuart, Fla.
www.kientec.com

LEMO SA
Ecublens, Switzerland
www.lemo.com

LEONI Fiber Optics GmbH
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www.leoni-fiber-optics.com

LEONI Fiber Optics Inc., High Power Fiber Optics & Connectors
Williamsburg, Va.
www.leoni-northamerica.com

Nissin Kasei USA Corp.
San Jose, Calif.
www.nissinkasei.co.jp

Norca Corp., Precision Div.
Lake Success, N.Y.

OFS
Norcross, Ga.
www.ofsoptics.com

Optocomponents GmbH
Emmendingen, Germany
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Optoscribe Ltd.
Livingston, Scotland
www.optoscribe.com

Optosun Technology Ltd.
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www.optosun.eu

Polymicro Technologies
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www.molex.com/polymicro

Precipart
Farmingdale, N.Y.
www.precipart.com

PT Fiberoptics
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www.PTF.us

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www.adamant.jp/en

Blue Helix Ltd.
Crawley, England
www.bluehelix.co.uk

Coastal Connections
Ventura, Calif.
www.coastalcon.com

Diamond Advanced Components Inc.
Norwood, Mass.
www.diamond-ac.com

Fiberoptic.com, The Fiber Optic Marketplace
Breinigsville, Pa.
www.fiberoptic.com

Fiberwe Technologies Co. Ltd.
Shanghai
www.fiberwe.com

Haphit Ltd.
Shanghai
www.haphit.com

Intepon Co.
Shenzhen, China
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Kientec Systems Inc.
Stuart, Fla.
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Emit Technology Co. Ltd.
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Fiber Optic Fibers, Erbium-Doped

Acreo Swedish ICTAB
Kista, Sweden
www.acreo.se

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

Fibercore
Southampton, England
www.fibercore.com

FiberElectronics LLC
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IDIL Fibres Optiques
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Infrared Fiber Systems
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www.irflex.com

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www.leoni-fiber-optics.com

Sumita Optical Glass Inc.
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www.sumita-opt.co.jp

US Fiberoptec Technology Inc.
San Jose, Calif.
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Fiber Optic Fibers, Plastic

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GP Fiber Optics GmbH
Moerfelden, Germany
www.gp-fiberoptics.com

Incom Inc.
Charlton, Mass.
www.incomusa.com

Industrial Fiber Optics
Tempe, Ariz.
www.i-fiberoptics.com

LEONI Fiber Optics GmbH
Neuhaus-Schierschnitz, Germany
www.leoni-fiber-optics.com

Optocomponents GmbH
Emmendingen, Germany
www.optocomponents.de

Paradigm Optics Inc.
Vancouver, Wash.
www.paradigmoptics.com

Saint-Gobain Crystals
Hiram, Ohio
www.crystals.saint-gobain.com

South Coast Fiber Optics Inc.
Old Town, Fla.
www.southcoastfiberopticsinc.com

Fiber Optic Fibers, Plastic-Clad Silica

Fiberguide Industries Inc.
Stirling, N.J.
www.fiberguide.com

Fiberoptic Engineering Corp.
Panama City, Fla.
www.fiberopticengineeringcorp.com

Fused Fiberoptics LLC
Southbridge, Mass.
www.fusedfiberoptics.com

heracle GmbH
Jena, Germany
www.heracle.de

j-fiber GmbH
Jena, Germany
www.j-fiber.com

LEONI Fiber Optics GmbH
Neuhaus-Schierschnitz, Germany
www.leoni-fiber-optics.com

OFS
Norcross, Ga.
www.ofsoptics.com

Polymicro Technologies
Phoenix
www.molex.com/polymicro

SOMTA Ltd.
Riga, Latvia
www.somta.lv

US Fiberoptec Technology Inc.
San Jose, Calif.
www.usfiberoptec.com

Fiber Optic Fibers, Polarization-Maintaining

Chiral Photonics Inc.
Pine Brook, N.J.
www.chiralphotonics.com

Coastal Connections
Ventura, Calif.
www.coastalcon.com

CorActive High-Tech Inc.
Quebec City
www.coractive.com

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

Fibercore
Southampton, England
www.fibercore.com

Fiberstore Inc.
Tukwila, Wash.
www.fiberstore.com

iXBlue Photonics
Saint-Germain-en-Laye, France
www.photonics.ixblue.com

KVH Industries Inc.
Middletown, R.I.
www.kvh.com

LEONI Fiber Optics GmbH
Neuhaus-Schierschnitz, Germany
www.leoni-fiber-optics.com

Neolight Technologies LLC
Chicago
www.neolighttechnologies.com

OFS
Norcross, Ga.
www.ofsoptics.com

PDSmfg LLC
Bend, Ore.
www.pdsmfg.com

Photonstream Ltd.
Shenzhen, China
www.photonstream.com

Verrillon Inc.
North Grafton, Mass.
www.verrillon.com

Fiber Optic Fibers, Silica, Multimode

Acreo Swedish ICTAB
Kista, Sweden
www.acreo.se

CorActive High-Tech Inc.
Quebec City
www.coractive.com

Fiberguide Industries Inc.
Stirling, N.J.
www.fiberguide.com

Fiberoptic Engineering Corp.
Panama City, Fla.
www.fiberopticengineeringcorp.com

Fiberoptic Systems Inc.
Simi Valley, Calif.
www.fiberopticsystems.com

FiberTech Optica Inc.
Kitchener, Ontario, Canada
www.fibertech-optica.com

heracle GmbH
Jena, Germany
www.heracle.de

j-fiber GmbH
Jena, Germany
www.j-fiber.com

LightGuideOptics Germany GmbH
Rheinbach, Germany
www.lgoptics.de

LightGuideOptics USA LLC
San Jose, Calif.
www.lgoptics.com

M2 Optics Inc.
Raleigh, N.C.
www.m2optics.com

Molex Inc., Optical Solutions Group
Downers Grove, Ill.
www.molex.com/fiber

Multimode Fiber Optics Inc.
Chester, N.J.
www.multimodefo.com

Neolight Technologies LLC
Chicago
www.neolighttechnologies.com

Nufern
East Granby, Conn.
www.nufern.com

Oplatek Group Oy
Leppavirta, Finland
www.oplatek.com

PDSmfg LLC
Bend, Ore.
www.pdsmfg.com

Photonstream Ltd.
Shenzhen, China
www.photonstream.com

Polymicro Technologies
Phoenix
www.molex.com/polymicro

SCHOTT AG, SCHOTT Lighting and Imaging
Mainz, Germany
www.schott.com/lightingimaging

SEDI-ATI Fibres Optiques
Courcouronnes, France
www.sedi-fibres.com

SOMTA Ltd.
Riga, Latvia
www.somta.lv

Spectraconn Inc.
Rockaway, N.J.
www.spectraconn.com

US Fiberoptec Technology Inc.
San Jose, Calif.
www.usfiberoptec.com

Fiber Optic Fibers, Silica, Single-Mode

Acreo Swedish ICTAB
Kista, Sweden
www.acreo.se

CorActive High-Tech Inc.
Quebec City
www.coractive.com

CT Fiberoptics Inc.
Somers, Conn.
www.ctfiberoptics.com

Fibercore
Southampton, England
www.fibercore.com

Fiberguide Industries Inc.
Stirling, N.J.
www.fiberguide.com

j-fiber GmbH
Jena, Germany
www.j-fiber.com

LEONI Fiber Optics GmbH
Neuhaus-Schierschnitz, Germany
www.leoni-fiber-optics.com

Lightwavestore.com
Ottawa, Ontario, Canada
www.lightwavestore.com

M2 Optics Inc.
Raleigh, N.C.
www.m2optics.com

Neolight Technologies LLC
Chicago
www.neolighttechnologies.com

OFS
Norcross, Ga.
www.ofsoptics.com

Verrillon Inc.
North Grafton, Mass.
www.verrillon.com

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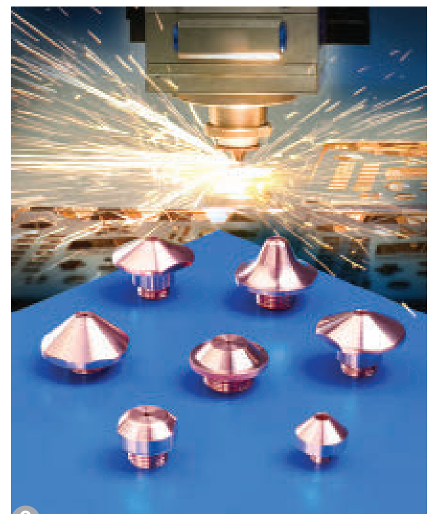


6

1 LVDS Cameras

Basler Inc. now offers its dart board-level cameras with BCON interface based on the low-voltage differential signaling (LVDS) standard. Designed for embedded applications based on LVDS, such as field-programmable gate array boards and system on chip, the camera offers reliable image-data transfer at high speed. BCON also enables the developer of an embedded system to switch from one dart camera to another without additional integration costs or effort.
sales.usa@baslerweb.com

2 Delay Line Kits

Newport Corp. has announced its DL series of delay line kits, providing scientists and researchers with the necessary components to build a complete optical delay line. The DL100 and DL200 kits are designed for experiments requiring delays up to 1333 ps. Both kits come fully equipped with a broadband retroreflector from 450 to 10,000 nm to ensure a parallel reflected beam with no need for adjustments. The DL300 and DL600 kits are designed for advanced experiments requiring up to 8000-ps delays and fast delay variations.
sales@newport.com

3 Wavelength Meters

Bristol Instruments Inc.'s 871 Series of laser wavelength meters measures the absolute wavelength of pulsed and CW lasers. A measurement rate of 1 kHz enables the wavelength characterization of individual laser pulses, with the resulting time resolution of 1 ms providing detailed wavelength analysis of tunable lasers. The device uses a Fizeau etalon design to measure to an accuracy of ±1 ppm (±300 MHz at 1000 nm). The series is available for operation from 350 to 1700 nm.
info@bristol-inst.com

4 Sapphire, Ruby Balls

Meller Optics Inc. has announced sapphire and ruby balls for short-focal-length lenses for microair vehicles or fly-sized insect drones used in military surveillance. They feature 9 Moh hardness, with 42-in. and metric sizes from 0.1-mm to 0.5-in. diameters with 0.000025-in. sphericity and ±0.0001-in. basic diameter tolerance. The balls can be precision ground into planoconvex lenses with surface finishes to 80-20 scratch-dig. Applications include bearings, check valves, stylus tips and fiber optic lens systems.
steve@melleroptics.com

5 Colorimeter/Polarimeter

Gooch & Housego Instruments, Life Sciences Division, offers the Mantis Imaging Colorimeter/Photometer. The device delivers ultrafast, high-resolution, spatially resolved measurements of luminance, chromaticity and color temperature. Its compact size and ruggedness make it ideal for full-field measurements of automotive and aerospace lighting and displays in high-speed production test environments.
orlandosales@goochandhousego.com

6 CO_2 Laser Nozzles

Copper CO_2 laser nozzles from **Laser Research Optics** are designed to optimize cutting accuracy in Mitsubishi and Trumpf lasers. The devices feature 10-µm orifice accuracy to direct the laser beam and optimize cutting performance. Compatible with mechanical or sensor heads, the field-replacement nozzles are offered in 1.5- and 2-mm orifice sizes. They are also available with straight and tapered tips from 0.375- to 0.96-in. long. Cylindrical configurations are available for low-pressure cutting with oxygen, while the conical types are recommended for high-pressure nitrogen or argon cutting.
scott@laserresearch.net

new products

Carbon/Sulfur Analyzers

Horiba Scientific, a division of Horiba Instruments Inc., offers the EMIA-Pro and EMIA-Expert carbon/sulfur analyzers with nondispersive infrared measurement capabilities. Measurement, display of results and cleaning takes about 70 seconds. The devices have an optimized range from 1.6 ppm to 6 percent for carbon, and 2 ppm to 1 percent for sulfur. Equipped with a unique CO detector, they can be used for a variety of inorganic materials such as steel, cokes, and catalyst; nonferrous alloys such as aluminium; and lithium-ion battery materials.
info-sci@horiba.com

3D Imager for Android

Vayyar Imaging Ltd. has introduced the Walabot 3D imaging system for Android devices. Walabot's sensor technology is able to look through walls to detect structural foundations, track a person's location and vital signs as they move through a Smart Home, measure the speed of a fast-moving ball, and help drones and cars avoid collisions. The system turns a smartphone into a 3D imaging system, helping alert homeowners to activity in their home or other environments.
info@vayyar.com

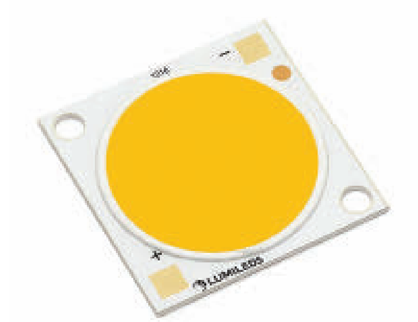
Data Processing Unit

Headwall Photonics Inc. offers the HyperCore data processing unit, serving as the central connection point for remote sensing instruments such as multiple hyperspectral sensors, lidar, thermal cameras, RGB instruments and global positioning

systems, among others. A small size and weight, powerful data processing, and 500-GB storage connections allow users to fuse hyperspectral sensing data with other aircraft sensor payloads. The device utilizes Hyperspec III spectral imaging application software, and is designed for use aboard small and light unmanned aerial vehicles.
information@headwallphotonics.com

Wide-Angle Adapter

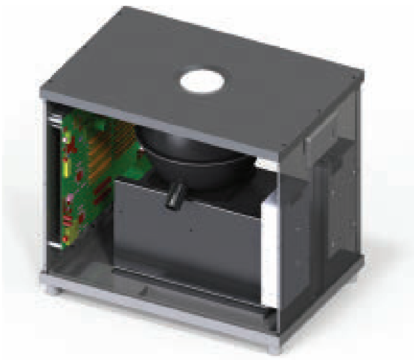
Resolve Optics Ltd. offers the model 387 0.7X wide-angle adapter for optimized use with the Fujinon TF4XA-1 4-mm HD lens for 3-CCD cameras. The adapter mounts onto the TF4XA-1 via the 30.5-mm external thread on the front of the lens and has an M60 × 0.5 thread on the front to facilitate the mounting of filters, and converts the 4-mm focal length TF4XA-1 HD lens to a 2.8-mm focal length, while maintaining its HD 200 cycle performance across all sesnors. It increases the horizontal field-of-view from 71° to a minimum of 95°.
sales@resolveoptics.com



CoB Arrays

The third generation of **Lumileds'** Luxeon Core Range of chip-on-board (CoB) arrays feature 10 percent higher efficacy at constant flux compared to previous generations. Reaching more than 160 lm/W, the upgrade spans the company's full

range of products, from the smallest light-emitting surfaces of 6.5 mm for cost-effective spotlights, to a light-emitting surface of 23 mm for efficient replacement of 100- to 150-W high-intensity discharge devices in indoor or outdoor applications. The series is offered over a range of color temperatures from 2200 to 5700 K, and color rendering indexes of 70, 80 and 90.
info@lumileds.com



Tunable Light Source

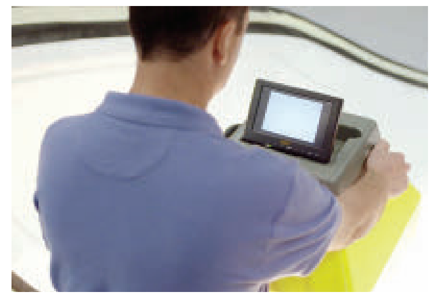
Gamma Scientific has announced the SpectralLED tunable light source for camera and image sensor calibration. The device combines 30 discrete LEDs, each with a different center wavelength, enabling the device to be programmed on-demand to product output that matches any illuminant source or the spectrum of any illuminant reflected by a target. Applications include smartphones, tablets, DSLR cameras, cinematography camcorders, diagnostic medical imaging, technical and industrial photography, or any OEM camera/sensor/detector application.
contact@gamma-sci.com

OTN Processor

Microsemi Corp. has announced the DIGI-G4 optical transport network (OTN) processor. The device enables the transition to 400-G switching solutions available in mass production. Users can double the 100-G OTN port density on optical transport systems while achieving a 50 percent reduction in power per 100-G port. The DIGI-G4 allows metro networks to manage traffic growth throughout their systems.
sales.support@microsemi.com

UVC LEDs

Crystal IS Inc. has augmented its Optan SMD (surface mount device) product line for instrumentation with the addition of higher light output and wavelength-specific bins to meet increased demand for UVC LEDs in fluorescence spectroscopy, imaging and biofouling control. The company's UVC LED uses lattice-matched native aluminum nitride substrates and offers high light output at wavelengths from 250 to 280 nm. Applications include flow cytometry for bioanalytics and medical diagnosis, cell counting, cell sorting, and biomarker detection. It can also be used as a light source for catalyzing persulfate oxidation in total organic carbon measurement.
sales@cisuvc.com



Nondestructive Test System

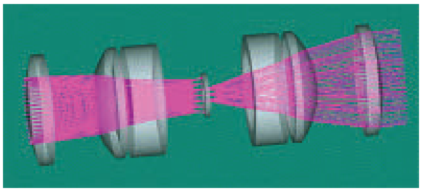
The NDTherm nondestructive testing system from **Opgal Optronic Industries Ltd.** is based on thermal imaging. Using active thermography and unique algorithms, NDTherm enables fast, contact-free, real-time inspection of parts. It detects deep

flaws in various composite materials and structures such as carbon-fiber-reinforced polymer, sandwich structures, hybrids and porous materials. The system can be used on small or large surfaces including cases where access is only possible from one side of the structure.
info@opgal.com

LWIR Zoom Lens

The SupIR 40- to 300-mm, *f*/1.5, continuous zoom lens from **Ophir Optics** is an uncooled, motorized LWIR (longwave-infrared) device featuring a 17-µm detector for the detection of objects in border patrol, surveillance, policing, high-end maritime and airport applications. The lens can detect a 2.3 × 2.3-m vehicle at 18 km. It also delivers the ability

to recognize the vehicle at 9 km and the ability to identify it at 3 km. A 7.5× zoom ratio provides a wide field of view. The lens is designed to interface with all known 17-μ focal plane array providers.
sales@us.ophiropt.com



Undesired Order Blocker

The UDOB (undesired order blocker) from **Holo/Or Ltd.** enables maintenance of high-power laser yield without damaging surrounding areas. The optomechanical module blocks up to 99 percent of undesired orders, including the zero order, and can be adjusted to meet custom specifications. The UDOBs are designed for sensitive applications such as materials processing and metrology, and for other diffractive optical elements users.
sales@holoor.co.il

Imaging Platform

Pleora Technologies Inc. has announced the NBASE-T interface platform for high-performance imaging. The devices transmit uncompressed, high-bandwidth, GigE Vision-compliant images at speeds up to 5 Gbps over low-cost Cat 5e cabling. NBASE-T is an extension of the IEEE 802.3 Ethernet standard and was initially developed to support higher bandwidth data transmission over the installed base of Cat 5e twisted pair copper cable. Manufacturers are able to meet increasing speed requirements while taking advantage of Ethernet's less expensive, long-distance, field-terminated cabling, point-to-multipoint multicasting and lower-cost networking components.
info@pleora.com

Micro-SWIR Cameras

UTC Aerospace Systems, a unit of United Technologies Corp., distributes the Micro-SWIR 640CSX camera from Sensors Unlimited Inc. Suited for integration into commercial systems and industrial process monitoring applications, the low-light to daytime imager offers a digital output of 30 or 60 fps full frame rate, and is available with optional near-infrared/shortwave-infrared (SWIR) wavelength response to end the sensitivity of the 640CSX. An industry standard C-mount lens interface allows customers to select numerous commercial off-the-shelf lens options. The camera is available without ITAR (International Traffic in Arms Regulations) restrictions.
daniel.coulom@utas.utc.com

Satellite Window Film

Deposition Sciences Inc. offers Sunshade material, a thermally insulating, broadband electromagnetic window for satellite systems. The electromag-

netic thin film is manufactured with nonmetallic coatings and has no laser ablation or patterning. The film is designed to protect satellites from solar radiation, providing radio-frequency transparency at all frequencies below 18 GHz, allowing 99.4 percent of the energy to pass through. It reflects up to −25 dB at all frequencies below 18 GHz and up to −30 dB at all frequencies below 8 GHz. The material is available in large format, covering areas up to 2.5 × 10 ft. It controls temperatures passively, can transmit high-speed data and also allows static charge to bleed off.
solutions@depsci.com

Pulse Energy Controller

Spectra-Physics offers the E-Track dynamic pulse energy control for its Explorer One series of ultracompact UV and green, actively Q-switched, diode-pumped solid-state (DPSS) lasers. E-Track actively measures and controls the laser for continual energy and power stabilization under rapidly changing operating set points or environments. This feature enables quick adjustments in pulse energy levels and rapid gating for precision micromachining applications including scribing, marking and drilling of tiny features, holes and thin layers in a wide range of materials and devices. E-Track can operate at high pulse-repetition frequencies and can be controlled either via serial commands or by supplying an analog signal to the laser.
herman.chui@spectra-physics.com

Aluminum Mirrors

Präzisions Glas & Optik GmbH offers the SEA-VIS series of aluminum front surface mirrors at sizes up to 1250 × 800 mm. The mirrors feature a dielectric overcoating that enhances the visible reflectivity compared to bare aluminum or protected aluminum metallic mirrors. Device properties include high optical performance, the absence of ghost images in reflection, broadband and color-neutral coating and high imaging performance. Applications include 45° deflection mirrors, large-format front surface mirrors, redirecting mirrors, sensor optics, barcode scanner mirrors and more.
info@pgo-online.com

Portable Laser Scanner

Hexagon Manufacturing Intelligence Inc. has announced the Leica Absolute Scanner LAS-20-8, a portable laser scanner for large-volume inspection applications such as automotive sheet metal, aerospace mold tools and large industrial castings, among others. The handheld 3D scanner allows shop floor operators to easily and quickly capture complex point-cloud data. Autoadjust laser intensity for different surface types minimizes training requirements. The LAS-20-8 is optimized for portable metrology applications requiring effective measurement volumes up to 196.85 ft.
bridget.benedetti@hexagonmetrology.com

Microassembly Platform

Finetech USA's FINEPLACER femto 2 die-bonding platform is designed for advanced packaging and bonding in automated precision manufacturing, with a focus on high yield. With a placement accuracy of ± 0.5 µm at three sigma and maximum process flexibility, the machine supports a range of applications at chip and wafer level. The platform accommodates optoelectronics, semiconductors, silicon photonics, medical engineering, sensor production and R&D. High-quality dispensing options allow lines, dots and patterns, as well as micro dipping solutions for smallest components and contact areas.
adg@finetechusa.com

Liquid-Lens Camera

PixeLink has announced the PL-D755 USB3 camera with an autofocus liquid lens that incorporates Sony's Pregius IMX250 sensor. The camera uses the Varioptic Caspian electronically focus-controllable C-mount lens, able to reconfigure in tens of milliseconds for fast focus changes. The 9.6-, 16- and 25-mm focal length Varioptic lenses provide autofocus capabilities in enclosed and board-level PixeLink cameras. The global shutter 5-MP camera provides low power consumption, high shock resistance and fast focus adjustment, and is available in both monochrome and color.
info@pixelink.com

Dual-Band Photoreceiver

The LPRV2300 dual-band photoreceiver for test

and measurement instrumentation from **Finisar Corp.** is designed to offer direct-current-coupled response. The device provides a highly linear transimpedance amplifier, guaranteeing a flat frequency response and signal implementation with low-noise performance. The frequency ranges from direct current to 35 GHz with dual-band responsivity in the 1310- and 1550-nm wavelengths. Applications include test and measurement, microwave photonics, instrumentation and laboratory research.
sales@finisar.com

Visible Laser Sources

Visible laser light sources from **SoraaLaser** feature unique performance properties such as collimated output and waveguide delivery, providing advantages over LED, OLED and legacy sources in specialty lighting. Based on patented semipolar GaN laser diodes, the sources also use advanced phosphor technology, providing minimal power consumption and a long lifetime with highly directional output. Safe, highly collimated white light output is created by focusing the laser light on a small spot on the phosphor and then converting the beam to white light. The sources are designed for specialty lighting applications in the architectural, hospitality, retail, security, entertainment and automotive fields.
info@soraalaser.com

LED Emitter

LED Engin Inc. has announced the LZ4-04MDPB emitter, a 4-die, high-current, RGBW flat lens LED device for stage, entertainment and architectural lighting. Each individually addressable green, blue and white die can be driven at up to 3 amps, with the red die up to 2.5 A. The output ranges from tungsten-effect white lighting to a full spectrum of brilliant colors. With a 7 × 7-mm footprint, the emitter rapidly and effectively dissipates up to 40 W of power due to its four-channel, multilayer ceramic substrate, cutting thermal resistance to 0.9 °C/W.
sales@ledengin.com

OLED Fingerprint Imager

Sonavation Inc. offers fingerprint imaging technology through smartphone organic LED (OLED) displays. The technology will allow smart device manufacturers to increase the usable size of their displays by 10 to 20 percent by eliminating the need for a separate inactive area for a fingerprint sensor. Applications include displays for smartphones, tablets, wearables and devices.
info@sonavation.com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DEDICATED TO THE ADVANCEMENT OF MANUFACTURING R&D. IMTS FEEDS OUR CURIOSITY, PUSHING US TO IMPROVE WELL BEYOND OUR 65 BOLD YEARS IN BUSINESS.
WE ARE

● Happenings

MAY

SPIE Translational Biophotonics (May 16-17) Houston. Contact +1 360-676-3290, customerservice@spie.org; spie.org/x103861.xml.

Display Week (May 22-27) San Francisco. Presented by The Society for Information Display. Contact conference coordinator Mark Goldfarb, +1 212-460-8090, Ext. 202, mgoldfarb@pcm411.com; www.displayweek.org.

IEC 60825-1 Seminar (May 24-25) Munich. Seminar on the new edition of IEC Laser Product Safety Standard produced by Laser 2000 GmbH. Contact Mandy Germann, head of marketing, +49 0-8153-405-39, m.germann@laser2000.de; www.laser2000.de.

● **LASYS (May 31-June 2)** Stuttgart, Germany. Contact +49 711-18560-0, info@messe-stuttgart.de; www.messe-stuttgart.de/en/lasys.

JUNE

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

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

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

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

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

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

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

JULY

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

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

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

PAPERS

Hyperspectral Imaging and Applications Conference (Oct. 12-13) Coventry, England
Deadline: Abstracts, June 13
HSI, colocated with Photonex, welcomes original contributions on all aspects of hyperspectral imaging, particularly in the following areas: biology, food technology, GIS, medicine, microscopy, surveillance, remote sensing, pollution monitoring, industrial inspection, defense, antiquity analysis and chemical analysis. Contact Brenda Hargreaves, conference administrator, Xmark Media Ltd., +44 0-1372-750555; brenda@xmarkmedia.com; www.hsi2016.com/area-for-speakers.

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

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

AUGUST

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

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

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

SEPTEMBER

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

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

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

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

OCTOBER

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

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

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

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

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

NOVEMBER

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

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

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

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So long washing machine, hello sunshine

Imagine hanging your clothes on the line for laundering instead of drying.

As futuristic as it sounds, that may one day be a reality thanks to recent findings from a research team at RMIT University in Melbourne, Australia. The work could lead to nano-enhanced textiles that can clean themselves when put under light or worn in the sun.

Led by Rajesh Ramanathan, Ph.D., the team developed a cheap and efficient way to grow special nanostructures based on copper and silver, which absorb visible light.

"When the nanostructures are exposed to light, they receive an energy boost that creates 'hot electrons,'" Ramanathan told *Photonics Spectra*. "These energetic 'hot electrons' release a burst of energy that enables the nanostructures to degrade organic matter."

This burst of energy effectively eliminated organic compounds in a matter of minutes.

"Some of the basic dyes we tested were degraded within six to 10 minutes under a common LED light," Ramanathan said. "We are currently in contact with several industries and are doing testing more rigorously on other common stains such as wine, ink and sauce."

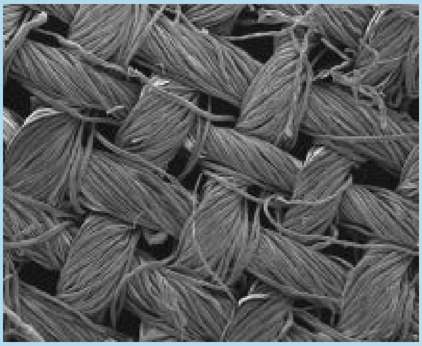
Heretofore, the challenge for researchers had been figuring out how to build the structures outside of a lab and in such a way to easily scale up for commercial applications. To do this, the researchers employed a novel technique that involved dipping the textiles into several different solutions. The result was the development of stable nanostructures within 30 minutes.

Ramanathan noted that the process itself is fairly simple and he envisions it would be easy for industries to incorporate the approach into current manufacturing processes. The first commercial products incorporating the nanostructures may come within three to five years.

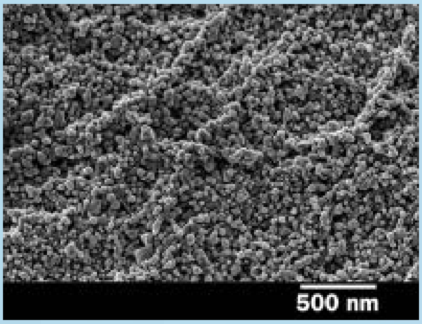
Until then, hold on to your Whirlpool.

Michael D. Wheeler
michael.wheeler@photonics.com

The red color indicates the presence of silver nanoparticles. Image magnified 200×.



Cotton textile covered with nanostructures invisible to the naked eye. Image magnified 200×.



Close-up of the nanostructures grown on cotton textiles by RMIT University researchers. Image magnified 150,000×.

All images courtesy of RMIT University.