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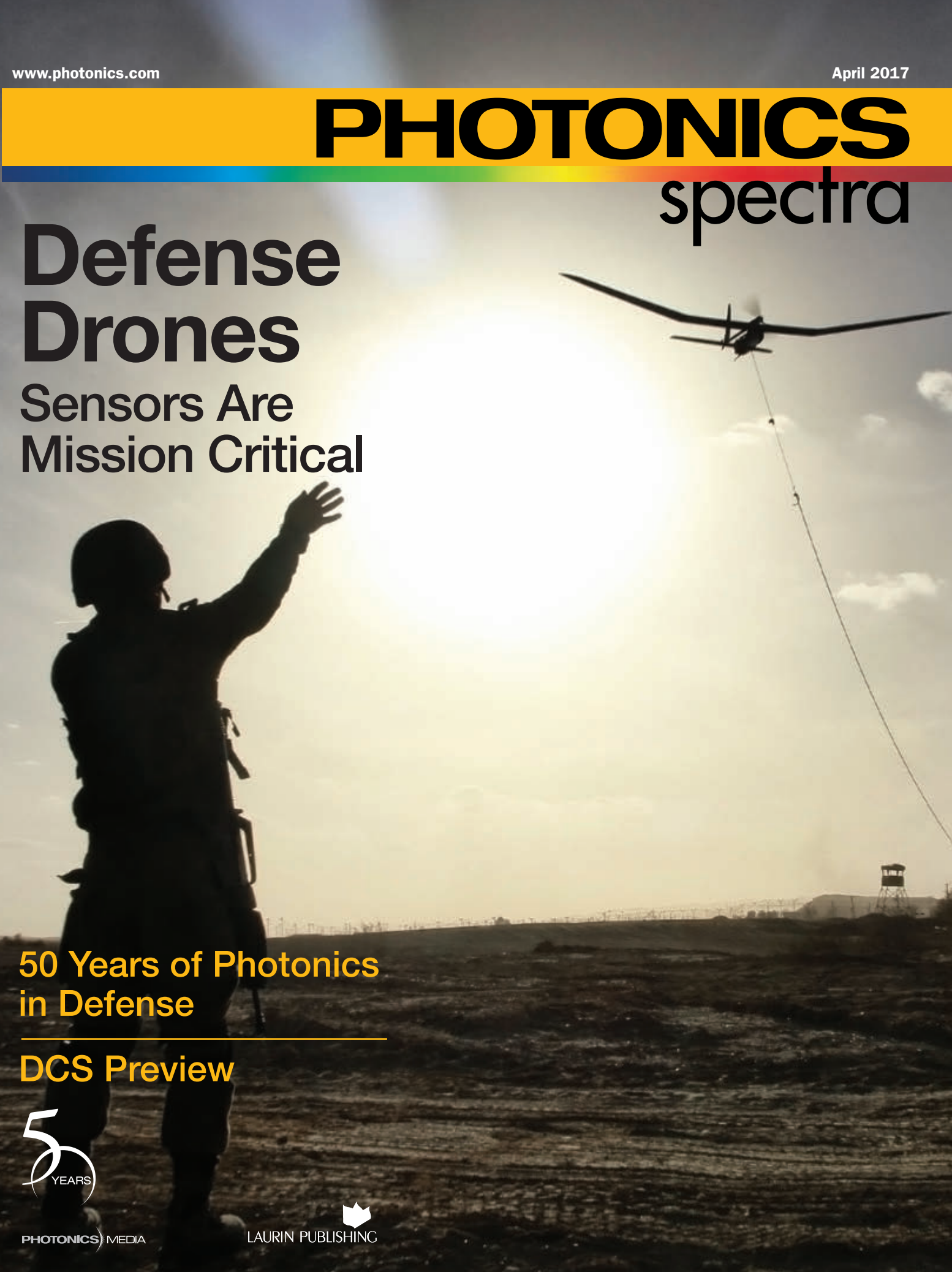
April 2017

PHOTONICS spectra

Defense Drones

Sensors Are Mission Critical



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DCS Preview

50 YEARS

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Content

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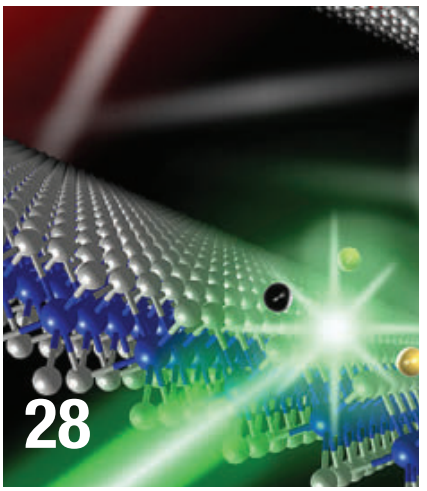

Departments & Columns

CONFERENCE PREVIEW

THE COVER
A soldier operates an Elbit Systems' Skylark UAV. Courtesy of Elbit Systems. Cover design by Senior Art Director Lisa N. Comstock.

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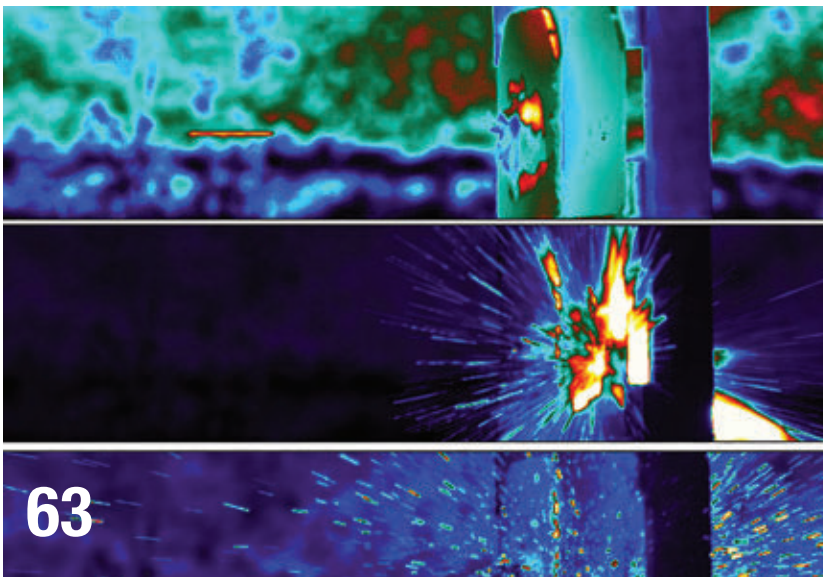
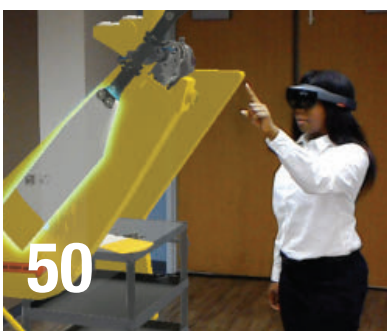
PHOTONICS: The technology of generating and harnessing light and other forms of radiant energy whose quantum unit is the photon. The range of applications of photonics extends from energy generation to detection to communications and information processing.





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ASPHERICAL	STANDARD	PRECISION
Material	All glass type	Germanium, CaF2
Diameter	10-150 mm	10-250 mm
Center thickness tolerance	+/- 0,1	+/- 0,05
Surface micro-roughness (Rq)	2 nm	>= 2Å
Surface quality (scratch - dig)	40-20	20-10
Ashphere figure error (P-V)	+/- 10 fringes	+/-3 fringes
Centration - tilt	5 arc min	2 arc min
Centering - lateral displacement	0,05 mm	0,02 mm

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editorial COMMENT

From Ruby Laser to Force Multiplier

As is the case with so many technological innovations of the 20th century, it was the defense sector that helped bring the laser to life. As recounted in *Optics and Photonics: Essential Technologies for Our Nation*, "much of the research that underpinned the laser and its predecessor, the maser, relied on federal funding." And that funding, motivated by the heightened geopolitical tensions of the Cold War, often came from the Department of Defense (DoD).

The 1950s financial backing for Charles Hard Townes' seminal research came from none other than the Joint Services Electronics Program, created to further wartime R&D of the Second World War. By 1962 — two years after Ted Maiman demonstrated the ruby laser at Hughes Aircraft — the DoD was spending about $5 million on laser-related R&D, according to "From Glow to Flow: A History of Military Research and Development."

The defense industry's fascination with the laser as a weapon has remained constant from the postwar boom to today, even becoming part of the national conversation with President Reagan's "Star Wars" initiative of the 1980s. Indeed, photonics technology in all its many forms has helped reshape the modern battle theater — from the first head-up displays on the inner windshields of jet fighters in the 1960s to the Airborne Laser project of the early 2000s. See our "50 Years of Photonics in Defense," retrospective on page 46.

While virtual reality has captured the imagination of the consumer, it's proving to be an invaluable training tool for today's military. Pilots, seagoing navigators and even maintenance and repair technicians gain on-the-job experience in the relative comfort of their barracks thanks to virtual and augmented reality systems that deliver "true-to-life" digital representations. Contributing Editor Hank Hogan examines advances made in resolution, contrast and luminance to today's systems in "As Good as the Real Thing for Military Training," beginning on page 50.

The increasing use of highly sensitive optical sensors, imagers and laser rangefinders are proving mission-critical to a new generation of UAVs, some the size a fist. Be sure to read our cover story, "Defense Drones Take Sensing to New Heights," beginning on page 56.

We round out the issue with "High-Speed IR Detectors Aid Ballistic Testing," on page 63, from Chris Bainter of Flir Systems, and Contributing Editor Marie Freebody's "From Crop Science to Space Exploration: Optical Sensing on the Rise," on page 68.

Finally, don't miss Senior Editor Justine Murphy's "DCS 2017 Brings Defense, Environment Into Focus," on page 74, where she previews plenary sessions, courses and technical program highlights for this month's annual SPIE Defense + Commercial Sensing event.

We hope you enjoy the issue!

Michael D. Wheeler

michael.wheeler@photonics.com

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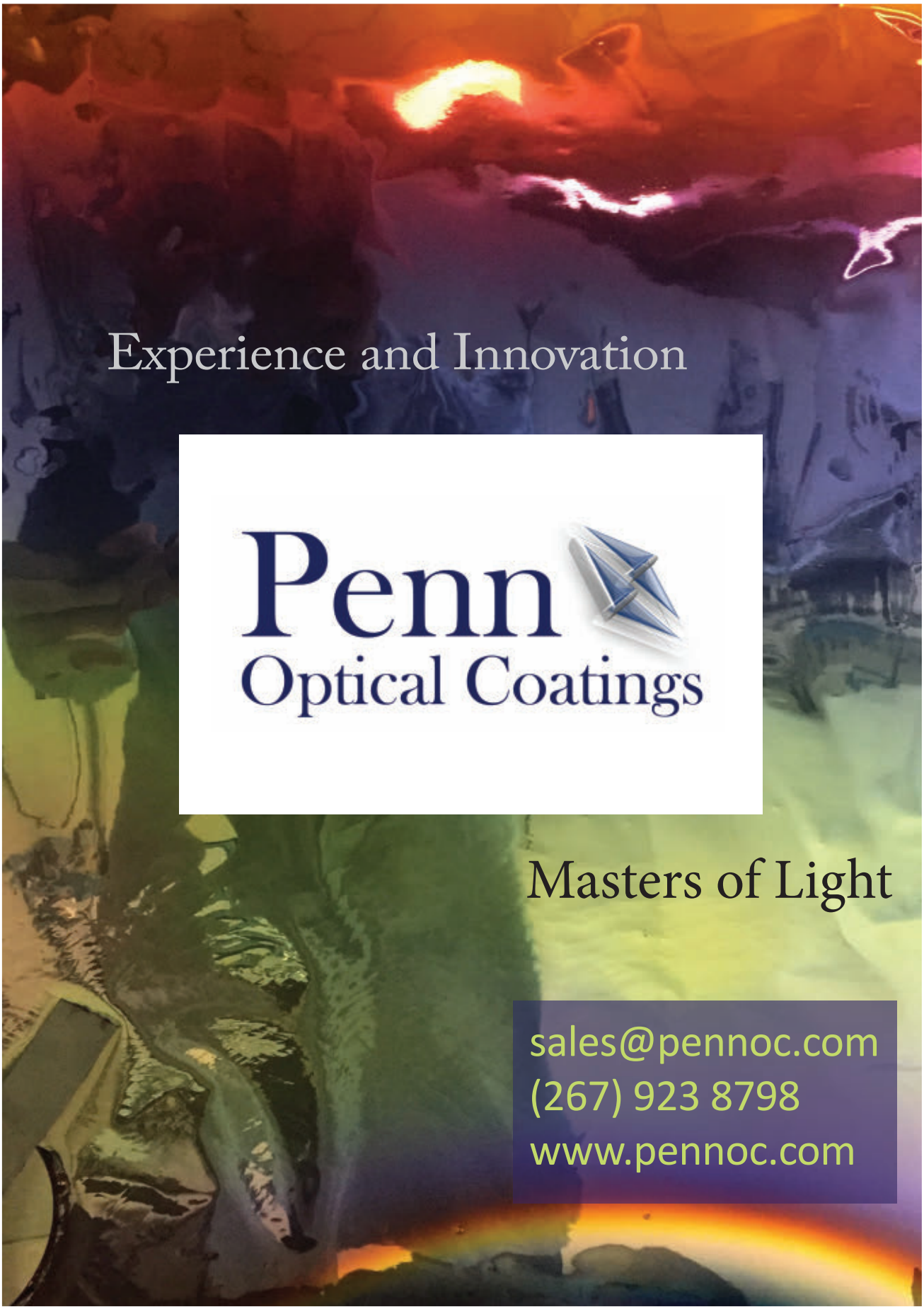

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PHOTONICS spectra

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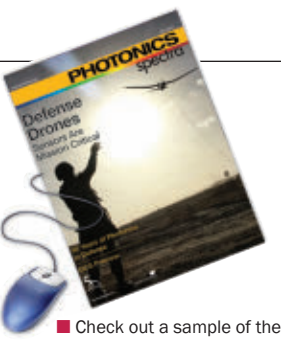
In the May issue of
Photonics Spectra...

- **Superluminescent LEDs**
- **Free-Space Laser Communication**
- **Displays and Holography**
- **Medical Sensors**

You'll also find all the news that affects your industry, from tech trends and market reports to the latest products and media.



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HOTTEST DISPLAY TRENDS TO HIT THE RED CARPET




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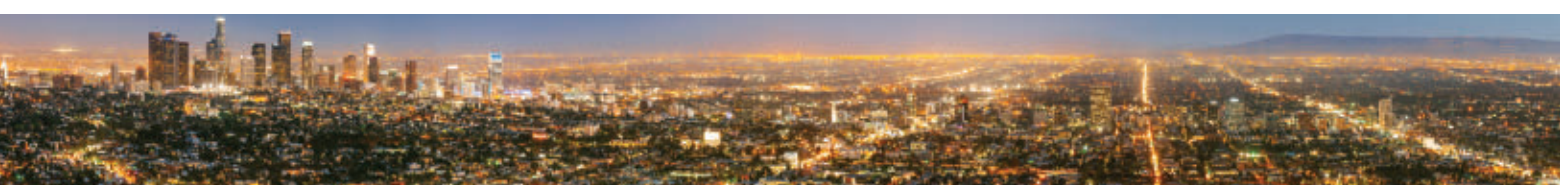

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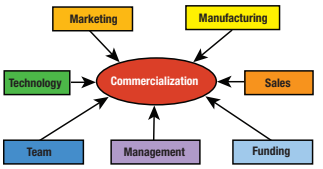
Technology Business Champions' Guide to Successful Commercialization

Thurs., April 13, at 1 p.m. EDT



This webinar — presented by David Krohn and based on his popular lecture series — is for anyone seeking potential opportunities for marketing and selling a new technology, whether a product, service or a groundbreaking idea. You will learn how to focus R&D with an eye toward commercialization; how to source funding; and how to develop and manage the resources required for successful commercialization. Please note: There is a registration fee for this webinar. For more information and to register, visit **www.photonics.com/W122**.

Free Webinars — Register Today

Table-Top Fabrication of Plasmonics-Based Ultrathin Optical Components

Thurs., April 6, at 1 p.m. EDT

Presenter: Kimani C. Toussaint Jr., Ph.D., associate professor and head of the PROBE Lab at the University of Illinois at Urbana-Champaign. To register, visit **www.photonics.com/W108**.

Large-Scale, Deep-Tissue Neuronal Imaging

Thurs., April 20, at 1 p.m. EDT

Presenter: Lingjie Kong, Ph.D., Tsinghua University. To register, visit **www.photonics.com/W104**. Sponsored by Semrock.

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Introducing the CAOS Smart Camera — Empowering Extreme Imaging

Wed., April 26, at 1 p.m. EDT

Presenter: Nabeel A. Riza, Ph.D., chair professor of electrical and electronic engineering at University College Cork. To register, visit **www.photonics.com/W109**.

Simulating Metamaterials in the Terahertz Regime

Thurs., April 27, at 2 p.m. EDT

Presenters: Ulf Olin, product specialist at COMSOL and associate professor (docent) at KTH in Stockholm, and Jiyoun Munn, technical product manager at COMSOL. To register, visit **www.photonics.com/W118**. Presented by COMSOL.

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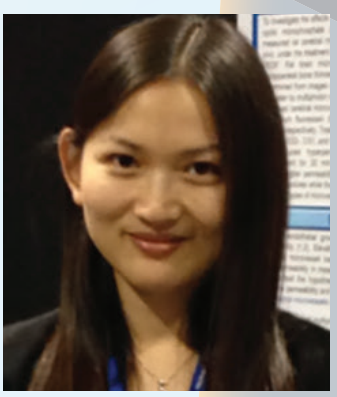
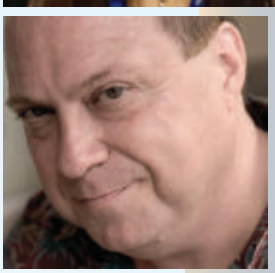
Do You Know a Beacon?

Once again, Photonics Media is honoring those who have made significant contributions to the industry in the areas of entrepreneurship, research, education, industry advocacy and leadership. If you know of someone worthy of recognition, visit **photonics.com/Beacons** for more details and to complete the short nomination form.







Nominate a Beacon by June 1.

PHOTONICS MEDIA

THE PULSE OF THE INDUSTRY

2017 Prism Award winners crowned

Known as the Oscars of the photonics industry, the Prism Awards for Photonics Innovation each year highlight the best of the best. And this year's competition was fierce — from the first femtosecond fiber laser-pumped mid-IR supercontinuum source to a drone-mounted natural gas surveillance system for indoor leakage inspection and a unique optical component technology that can sense nanovibrations of the body with very high precision.

The industry's top companies and products are chosen each year by a panel of judges who represent all fields of photonics. The awards — co-sponsored by Photonics Media and SPIE — were handed out during the annual gala event at Photonics West in San Francisco.

SPIE

2017 Prism Award winners.

The 2017 Prism Award winners are:

Additive Manufacturing/3D Printing

The Tungsten-LAM, developed by PolarOnyx Inc., employs a femtosecond fiber laser as an energy deposition source for 3D printing. It combines additive and subtractive manufacturing in a single platform via one tunable pulsed fiber laser. The company has found this significantly reduces the cost and time required for 3D metal and ceramic printing by eliminating separate post-processing. This system also enables layer-by-layer modification to create complex structures that have previously not been possible.

The company notes that this is the first femtosecond fiber laser-based 3D printing machine. It can be used with high-temperature materials, a function that differs from existing additive manufacturing technologies, which are limited to lower temperatures and require post-processing.

Biomedical Instrumentation

The TB Breathalyser, from Rapid Biosensor Systems, is the first biophotonics system available for noninvasive testing for active infectious diseases (namely tuberculosis). The novel system integrates laser, optical and engineering design with medical requirements for fast, breath-based testing. It will be effective for screening people in rural communities, the company notes, and in Europe and North America it has the potential to support screening programs at ports of entry, prisons, military establishments and schools, ultimately prompting lower health care costs.

The system has already been accepted by tuberculosis medics in India and Ethiopia as the fastest test for active infectious tuberculosis with high sensitivity and specificity >95 percent.

Detectors and Sensors

GoSpectro, developed by Alphanov, is a universal device that connects to any smartphone or tablet, turning it into a compact, easy-to-use, cost-effective light spectrometer. It makes possible the characterization of light sources (LEDs, etc.), displays, tunable lasers, optical filters or fluorescent dyes in a matter of seconds. It is a handheld tool that also measures emission and absorption peak wavelengths, cut-off wavelengths or spectral bandwidth, and enables material analysis (e.g., gemstones, crystals), or chemical analysis in liquids associated with color-based reagents for assessing water or food quality.

GoSpectro users can measure spectra, adjust acquisition parameters, display and save spectral data. Spectra are measured from 400 to 750 nm, with a resolution of <10 nm and an accuracy of <1 nm.

Imaging and Cameras

The first device to capture and process a full multi-megapixel hyperspectral data cube without the need for external processing, the new Handheld Hyperspectral Imager Model 4100 by TruTag Technologies Inc. essentially displaces existing multispectral imagers, which trade off spectral resolution for spatial resolution.

This new handheld imager allows users to dynamically select acquisition wavelengths that are not necessarily contiguous. It offers real-time processing, as well, the company notes, enabling processing for object identification and characterization. The camera can also identify and decode TruTag's optical memory microparticles, decode their spectra, and authenticate the origin of things like foods and pills.

Industrial Lasers

The Ultra-Short Pulsed Seeder for Fiber Laser, from QD Laser, features a less than 10 ps optical pulse, which, according to the company, "has been strongly needed." And its ultra-short pulsed seed laser is one of the key components for MOPA (Master Oscillator Power Amplification)-type fiber lasers.

By designing this laser chip and high-speed module, the company notes that next generations of such short optical pulse become possible. These lasers can be used for nonthermal precise microprocessing and have become a strong competitive light source to mode-locked lasers. Other advantages such as flexible tuning of repetition rate and high reliability are also possible, enabling "an

enormous impact for the progress of the precise microprocessing technology."

Materials and Coatings

Crystalline Mirror Solutions has developed the xtal mir, a "crystalline supermirror" coating that is based on substrate-transferred, single-crystal semiconductor multilayers. This novel technology exhibits a number of advantageous properties, according to the company, including a 10× reduction in Brownian noise, the highest thermal conductivity (~30 $Wm^{-1}K^{-1}$ compared to <1 $Wm^{-1}K^{-1}$ for SiO_2/Ta_2O_5).

This new technology targets ultralow-loss mid-IR optical coatings for the 3- to 5-µm wavelength range. The coatings are designed for high finesse optical cavities for power enhancement and signal recycling, enabling previously unachievable signal-to-noise ratios in the measurement of trace gases.

Metrology

Leica Geosystems has developed the Leica BLK360 Imaging Laser Scanner — "a technological leapfrog and a picture of creative expression." It provides users a unique ability to capture the reality around them in a way that was previously impossible.

The new device touts faster tablets, virtual reality goggles, ubiquitous bandwidth and awareness of laser scanning. It generates massive amounts of content for use in applications such as reality capture for virtual retailing, space mapping, and stage calibration for films and the visual arts. The laser scanner provides a degree of miniaturization that has never been seen before, allowing users to spend more time analyzing data and less time performing scans. The technology ranges up to 60 m, which can be measured with a precision of a few millimeters.

Optics and Optical Components

NuBEAM Flat-Top fiber technology, developed by Nufern, offers simplified system integration, improved efficiency, reproducibility and reliability of performances, as well as a smaller footprint and less expensive execution. According to the company, the new flat-top fiber technology offers an all-fiber solution designed as a simple drop-in replacement, compared to existing beam shaping techniques that are based mainly on free-space systems or complex optical assemblies.

The new technology employs well-established advantages of optical fiber technology — easy integration, efficient light transmission, robustness over time, small footprint, low maintenance and cost-effectiveness.

Scientific Lasers

The Mid-Infrared Supercontinuum Laser, developed by Thorlabs Inc., is a compact MIR-SC laser designed to accelerate instrument development in the mid-IR market. It is the first such femtosecond fiber-laser pumped source on the market.

Congratulations to all of this year's winners!

Magnolia Solar receives solar cell patent

Solar cell technology developer Magnolia Solar Inc. has been awarded a U.S. patent for the development and construction of a multi-junction solar cell employing extended heterojunction and step-graded antireflection structures.

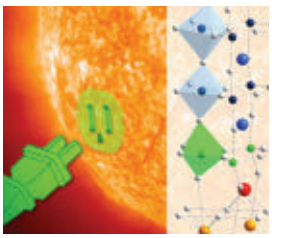
"We have been aggressively pursuing more than a dozen U.S. patent applications as a means to protect our intellectual property in the field of flexible photovoltaics and nanostructured antireflection coating technologies," said Ashok K. Sood, president of Magnolia Solar. "These patents pertain to novel device structures for increasing the efficiency of lightweight, high-performance thin-film solar cells. These novel structures employ nanostructured absorbers and leverage optical light-trapping mechanisms to increase the current output of thin-film solar cells."

Magnolia Solar is actively working on the development of flexible, lightweight, high-efficiency solar cell technologies for a wide range of portable power applications. Its portfolio includes nanostructured antireflection coatings, advanced thin-film photovoltaic absorber structures and novel, low-cost manufacturing processes.

This month in history

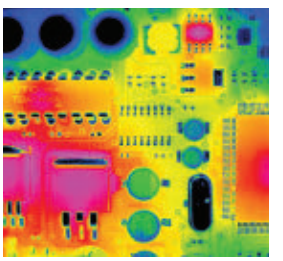
What were you working on five, 10, 20, 30 or even 50 years ago? *Photonics Spectra* editors perused past April issues and unearthed the following:

2012



Oak Ridge National Laboratory's materials scientists developed a synthesis strategy for discovering novel complex oxide thin films for stronger solar light absorption.

2007



Longwave-IR imagers that capture thermal radiation are used for printed circuit board inspection, seen here in false-color image. Anomalous hot spots could indicate problems. The recent development of higher-resolution imagers allows the detection of smaller defects.

1997

Laser radar is studying wake vortices (air disturbances around aircraft) to help determine whether planes at busy airports can safely fly closer together during bad weather — thus reducing delays.

1967

Interstellar dust grains have been identified as the solid molecular substance chlorophyll. Fred M. Johnson, chief scientist at Electro-Optical Systems Inc. announced that he was able to make the breakthrough after 13 years of research, utilizing both laser and spectroscopic techniques.

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• Light Speed

Three awarded NAS Scientific Discovery Award

The National Academy of Sciences has awarded Gabriela González, a professor of physics and astronomy at Louisiana State University (LSU), and two others with its 2017 Award for Scientific Discovery.

Born and raised in Córdoba, Argentina, González studied physics at the University of Córdoba and came to the U.S. to pursue her Ph.D. at Syracuse University. She worked as a staff scientist in the Laser Interferometer Gravitational-Wave Observatory, or LIGO, group at the Massachusetts Institute of Technology until 1997 when she joined the faculty at Penn State. In 2001, she joined the faculty at LSU.

González shares the award with David Howard Reitze, executive director of the LIGO Laboratory at California Institute of Technology and a professor of physics at the University of Florida, and Peter R. Saulson, Martin A. Pomerantz '37 Professor of Physics at Syracuse University.

The trio received the award for outstanding leadership of the large international LIGO Scientific Collaboration, bringing together all of the necessary elements — the instruments, data analysis, general relativity and astrophysics — for the first direct detection of gravitational waves.

González is currently the elected spokesperson for LIGO Scientific Collaboration, which includes the work of 90 institutions and more than 1000 researchers around the globe. The spokesperson leads the organization that carries out the scientific program of LIGO. She has served as the collaboration's spokesperson for the past six years.

NAS

Gabriela González is the elected spokesperson for LIGO Scientific Collaboration.

The National Academy of Sciences' Award for Scientific Discovery is presented every two years to recognize an accomplishment or discovery in basic research, achieved within the previous five years, that is expected to have a significant impact in the fields of astronomy, biochemistry, biophysics, chemistry, materials science or physics.

AFL receives interface, hardware patents

The test and inspection team of fiber optics manufacturer AFL has received a patent for the Health Meter interface on its WDM900 Lightwave Test Set product line, as well as two other hardware patents.

The traditional complexity of the optical spectrum analyzer is simplified by combining multiple parameters into a single diagnosis of healthy or unhealthy for all channels in a coarse or dense wavelength division multiplexing transmission system. This enables the general user to quickly and easily collect expert-level test results in the field.

In addition, the Optical Connectivity Team received two patents for subsea hardware. The first is for a full ocean pressure "tube seal" consisting of a swage and a Morrison seal. The second, "cylindrical housing with locking ring," describes a one-atmosphere pressuring housing designed to interconnect small subsea cables. Both inventions complement AFL's subsea cable product portfolio.

AFL's harsh environment team received a patent for new cable technology that enables optical fiber to be deployed as a temperature sensor in extremely high-temperature environments in hydrocarbon processing and geothermal applications.

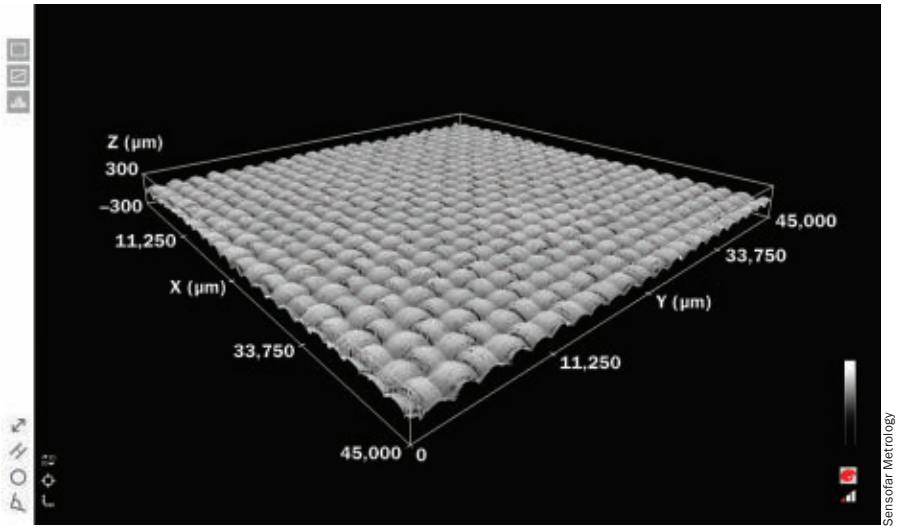
AFL is a provider of end-to-end solutions for the energy, service provider, enterprise and industrial markets.

Sensofar to supply GF Machining with metrology systems

Sensofar Metrology will supply GF Machining Solutions with its custom S neox line of surface metrology systems for the development of advanced nano-texturing methods.

The methods utilize ultrashort-pulsed laser, EDM and/or other micro- and nanomanufacturing technologies for the production of technical surfaces that exhibit precise functional characteristics or meet specific aesthetic requirements.

Sensofar's S neox system platform provides three complementary measurement techniques — confocal, interferometry and focus variation — in a single sensor head. The move to the Sensofar S line platform follows GF Machining Solutions' adoption of ultrashort-pulsed laser technology for micromachining. The new metrology systems are needed, first, to reverse engineer natural surface textures down to the nanofeature level and, second, to chart the production process of artificial surfaces manufactured with these textures.



Carbon matting surface replicated using an ultrafast laser system.

GF Machining Solutions is a provider of machines, automation solutions and services to the tool and mold making industry, as well as manufacturers of precision components. Sensofar Metrology provides high-end, noncontact, 3D surface profilers based on complementary confocal, interferometry and focus variation techniques.

Light Speed

mPower signs licensing agreement with Sandia

A licensing agreement between solar start-up company mPower Technology Inc. and Sandia National Laboratories has been signed for "home-grown" solar collection technology using microsystem-enabled photovoltaics (MEPV).

"This is an important milestone," said Murat Okandan, founder and CEO of mPower, as well as a former Sandia scientist. "It is an extremely exciting time in the solar industry with the upcoming critical, rapid change in the worldwide energy infrastructure. A lot of things are coming together and we're excited to be part of it."

MEPV uses micro-design and micro-fabrication techniques to make miniature solar cells, also known as "solar glitter." mPower is commercializing MEPV as Dragon SCALEs — small, lightweight, flexible solar cells that fit into and power devices or sensors of any shape or size, including wearable ones. The high-efficiency cells can be integrated into satellites and drones, biomedical and consumer electronics, and can be folded like paper for easy transport.

"There is other MEPV intellectual property useful for other applications and using other materials," said Bob

PEOPLE IN THE NEWS

Limo

Guido Bonati has been appointed the new CEO of optics manufacturer Limo Lissotschenko Mikrooptik GmbH. Bonati has more than 20 years of experience in the laser industry. He has a doctorate in engineering and, in addition to over 16 years of management experience in the fields of product and corporate development, is also a recognized technology expert and proven authority on international markets for lasers and optics. Limo is a developer, manufacturer and supplier of micro-optics and laser systems.

LED developer Lumileds has named **Mark Adams** as its CEO. Adams most recently served as president of Micron Technology Inc., a manufacturer of advanced memory solutions, from 2012 to 2016. He currently sits on the board of directors at Cadence Design Systems Inc. and Seagate Technology PLC. He received his bachelor's degree in economics from Boston College and his MBA from Harvard University. Lumileds is a wholly owned subsidiary of Royal Philips, developing LEDS and automotive lighting products.

Multilayer optics supplier Rigaku Innovative Technologies Inc. has appointed **Alex Sedlacek** as its sales engineer. Sedlacek will work closely with OEM and custom orders in North America and around the globe. He has experience in commercial business-to-business sales and is a certified electro-finisher through the National Association for Surface Finishing. Sedlacek holds a degree in mechanical engineering technology and industrial technology from Northern Michigan University. Rigaku Innovative Technologies is a supplier of high-performance multilayer optics used in commercial and academic institutions and government research facilities.

Thomas Research Products

LED manufacturer Thomas Research Products has appointed **Tony Raso** as its regional sales manager for the Midwestern U.S. Raso works with lighting OEMs, energy service companies, retrofitters, engineers and designers throughout the Midwest, with this role expanding his ability to support customers with complete component solutions for solid-state lighting and custom design services. Raso has more than 30 years of experience in the electronics and lighting industry, with extensive working knowledge of LEDs for OEMs. He earned his degree in electrical engineering from the University of Illinois. Thomas Research Products provides component solutions for OEMS that use LEDs.

Professor **Nathan Cahill** at the Rochester Institute of Technology (RIT) has been named a Rising Researcher by SPIE, the interna-

Westervelt, Sandia licensing specialist. "That is still available for licensing."

mPower used an exclusive license option on the MEPV technology in its initial product development and decided in October to convert it to a full commercial license that lets the company move to the next stage of its commercialization plan. The mPower license applies to a portion of Sandia's MEPV intellectual property portfolio associated with silicon solar cells.

Mary Monson, Sandia's senior manager of industry partnerships, said companies like mPower take the laboratory's technology and further develop it so it can be manufactured for widespread use in the energy and defense sectors.

"Sandia's partnerships with industry play an integral role in our mission success," she said.

A federally funded research and development center, Sandia National Laboratories is a contractor for the U.S. Department of Energy's National Nuclear Security Administration, supporting numerous federal, state and local government agencies and organizations.

$1.2B

— value of the global Free Space Optics (FSO) market by 2022, as reported by MarketsandMarkets

tional society for optics and photonics, for his contributions to defense and security research. Cahill is the associate dean for industrial partnerships in the College of Science and an associate professor in RIT's School of Mathematical Sciences. He directs the Image Computing and Analysis Lab at RIT, which focuses on the development of mathematical models and computational algorithms for the analysis of color, hyperspectral and medical imagery. Cahill is one of 10 early career professionals selected to receive the new award. The first cohort of SPIE Rising Researchers was chosen for their work in defense, commercial and scientific sensing, imaging and optics, or in product development.

Spin-on glasses and materials provider Desert Silicon Inc. has made **Philip C.S. Yin** its new executive vice president, general manager and board director. Appointed by the board of directors, Yin has a distinguished career in the compound semiconductor and semiconductor industries. He most recently served as vice president and general manager of China operations for ARC Energy Inc., a manufacturer of equipment for the growth of sapphire crystals and aluminum oxide used in LED bulbs and displays. He received his bachelor's degree in physics from Villanova University and his Ph.D. in materials science from Brooklyn Polytechnic Institute.

Sener to provide mirrors for the European Extremely Large Telescope

Private engineering and technology group Sener has signed a contract with the European Southern Observatory (ESO) for the design and production of cells for the M2 and M3 secondary and tertiary mirrors of the European Extremely Large Telescope (E-ELT).

The contract, signed by professor Tim de Zeeuw, director general of the ESO, and Diego Rodríguez, the director of Sener's space department, involves the design, construction and verification of the cells for the mirrors, as well as their control systems and auxiliary equipment.

The largest optical/infrared telescope ever to be built, the E-ELT will be 39 meters and use a complex optical system of five mirrors with sophisticated technology. The cells' mechanisms guarantee the alignment of the telescope during observation while correcting optics deformations, which have a diameter of >4 meters and weight of approximately 3.5 tons.

The E-ELT is intended to advance astrophysical knowledge by enabling detailed studies of planets around other stars, the first galaxies in the universe, super-massive black holes and the nature of the dark sector, as well as detecting water and organic molecules in protoplanetary disks around other stars. It is located on the top of Cerro Armazones in the Atacama Desert of northern Chile.

Sener

Sener has signed a contract with the European Southern Observatory.

Hexagon Manufacturing Intelligence, Wichita State enter research partnership

Metrology solutions developer Hexagon Manufacturing Intelligence has formed a technology partnership with Wichita State University (WSU) for research and development.

The company will lease 3000 sq ft of space near the university's 3DExperience Center in the Experiential Engineering Building on WSU's Innovation Campus. Educators and students will have access to Hexagon software and precision metrology systems for the collection, analysis and active use of measurement data in industrial sectors such as aerospace, automotive, power generation and medical.

The new commitment to WSU is an extension of a five-year partnership with its National Institute for Aviation Research (NIAR). NIAR and Hexagon have cooperatively developed an automated scanning solution for customer applications and hosted technology workshops and training events.

"Using Hexagon equipment, we are able to demonstrate to the aerospace industry how fast parts can be inspected and measured to a very high degree of accuracy," said Brian Brown, director of robotics and automation at NIAR.

"This strategic partnership with NIAR gives Hexagon another research platform to take on complex manufacturing issues and pioneer tech-enabled breakthroughs in the aviation industry," said Angus Taylor, president and CEO of Hexagon Manufacturing Intelligence North America. "The massive product backlog of the aerospace market is driving engineering creativity and the search for more productivity. We intend to remain at the forefront of that trend by forging alliances with dedicated innovators like NIAR, who can push the envelope with our extensive portfolio of manufacturing intelligence solutions."

Hexagon will employ full-time staff at the campus to facilitate research and development and support their local customer base. The company will also introduce an internship program for the midwestern U.S. Students will have access to state-of-the-art industrial metrology software and systems, which will help lead to job placement opportunities in manufacturing. Hexagon is the third global partner to join the Wichita State's Innovation Campus, following Airbus and Dassault Systemes.

Hexagon Manufacturing Intelligence is a developer of metrology and manufacturing solutions.

$19.2B

— value of the global market for sensors and detectors by 2021, according to BCC Research

SPI Lasers sells lamp-pumped business to TJS

Fiber laser manufacturer SPI Lasers UK Ltd. has sold its lamp-pumped Nd:YAG service and support business to laser system manufacturer TJS Inc.

The sale is part of SPI's plan to remain focused on the fiber laser market.

"Our challenge at SPI Lasers is to continue to increase both the power and peak performance of our fiber lasers," said Thomas Fehn, CEO of SPI. "The service and support of lamp-pumped solid-state lasers no longer fits with this vision. In order to remain focused on our long-term goals and ensure we remain committed to offering the very best levels of customer service and support, we felt the time was right to sell the lamp-pumped service and support business. In TJS, I strongly believe we have found the ideal business partner to offer outstanding levels of service and support, ensuring customers can rest easy in the knowledge that their lasers will be efficiently maintained and supported for many years to come."

Headquartered in Denville, N.J., TJS will continue to provide technical support, consumable components, service and repairs for the lamp-pumped lasers from their manufacturing and technical facility in Sanford, Fla.

"Our customers are our top priority. We are confident that we will offer all JK/SPI lamp-pumped solid-state laser customers the very best levels of global after-sales support," said Anthony Molee, CEO of TJS. "We very much look forward to building effective relationships with our latest customers."

SPI is a designer and manufacturer of fiber lasers for use in materials processing applications. TJS is a manufacturer and supplier of laser systems, laser flash lamps, components, service and repair for the laser market.

Gooch & Housego acquires StingRay Optics

Photonic component and systems manufacturer Gooch & Housego PLC has acquired lens developer StingRay Optics LLC.

Gooch & Housego says potential synergies include leveraging the company's greater reach through global sales teams and expertise in manufacturing infrared precision optics and specialist coatings.

"The acquisition of StingRay meets our strategic aims of moving up the value chain and diversifying the business through increasing our footprint in the aerospace & defense sector," said Mark Webster, CEO of Gooch & Housego. "It is a profitable and growing business in its own right, which has established an excellent reputation in the U.S. defense industry for the high quality of its custom optical assemblies. As part of the bigger G&H family, we believe it will be able to fulfill its true potential by leveraging our greater reach and our complementary

manufacturing and technical capabilities. We are very much looking forward to working with StingRay's talented management and workforce."

Osram acquires Maneri-Agraz

Light manufacturer Osram GmbH has acquired the business operations of Houston-based Maneri-Agraz Enterprises Ltd., a national provider of energy-efficient lighting solutions.

Maneri-Agraz will be part of Osram's Sylvania Lighting Solutions (SLS) service division, which is a segment of Osram's Lighting Solutions business unit. Its client base includes food and beverage manufacturing and distribution facilities, technology companies, and aerospace facilities, among others.

"Maneri-Agraz has taken great pride in delivering the highest-quality service to our customers for more than 20 years, and we are proud to become part of the Sylvania Lighting Solutions team," said John Maneri, founder of Maneri-Agraz, who will serve as a consultant. Maneri's business partner, Frank Agraz Jr., will join SLS as a business development manager.

The deal allows Osram's service business to increase its reach in the southern U.S. commercial and industrial business sector. The company's North American operation is Osram Sylvania, headquartered in Wilmington, Mass.

"The acquisition demonstrates Osram's commitment to pursuing opportunities that fit our strategic growth plans, and to expanding our service-oriented business," said Eladia Pulido, CEO of Osram Lighting Solutions.

Osram is a developer of lighting solutions for diverse applications ranging from virtual reality, autonomous driving or mobile phones to smart and connected lighting solutions in buildings and cities.

$60.23B

— value of the global photonic crystal market by 2022, as reported by Allied Market Research

Gooch & Housego researches, designs, engineers and manufactures advanced photonic systems, components and instrumentation for applications in the aerospace and defense, industrial, life sciences, and scientific research fields.

$8.09B

— value of the global atomic spectroscopy market by 2024, as reported in a new market report by Data Bridge Market Research

Photonics Solutions signs distribution agreement with Bristol Instruments

Optical interferometer-based instrumentation developer Bristol Instruments Inc. has announced a distribution agreement with U.K. supplier Photonics Solutions.

"We are very pleased to have Photonics Solutions as a distributor for our wavelength meter and spectrum analyzer products," said Brian Samoriski, vice president of sales and marketing at Bristol Instruments. "Their extensive experience, coupled with world class customer service, will allow us to better reach and support our customers in the U.K."

Scott Sandruck, European sales manager for Bristol Instruments, will manage the partnership with Photonics Solutions.

Bristol Instruments designs, manufactures and markets precision instruments based on optical interferometry.

Lawrence Livermore Petawatt Laser System reaches continuous operation

The High-Repetition-Rate Advanced Petawatt Laser System (HAPLS) at the Lawrence Livermore National Laboratory (LLNL) has demonstrated continuous operation of an all-diode-pumped, high-energy femtosecond petawatt laser system.

With completion of this milestone, the system is ready for delivery and integration at the European Extreme Light Infrastructure (ELI) Beamlines facility project in the Czech Republic. HAPLS set a world record for diode-pumped petawatt lasers, with energy reaching 16 J and a 28-fs pulse duration at a 3.3-Hz repetition rate. In three years, HAPLS went from concept to a fully integrated and record-breaking product, representing a new generation of application-enabling diode-pumped, high-energy and high-peak-power laser systems with innovative technologies originating from the Department of Energy's fusion laser research and development.

"Lawrence Livermore takes pride in pushing science and technology to regimes never achieved before," said Bill Goldstein, director of LLNL. "Twenty years ago, LLNL pioneered the first petawatt laser, the NOVA Petawatt, representing a quantum leap forward in peak power. Today, HAPLS leads a new generation of petawatt lasers, with capabilities not seen before."

LLNL is a multi-program national security laboratory focused on strengthening U.S. security through the development and application of science and technology to enhance defense and reduce threats.

Sale of Source Photonics to equity consortium completed

Optical component and module provider Source Photonics Inc. has announced that Francisco Partners has completed the sale of the company to a private equity consortium led by Redview Capital and Asia-IO, with participation from investors including TR Capital, Axiom Asia and Aberdeen Asset Management.

"It has been a pleasure to work with Doug and the talented management team at Source Photonics," said Andrew Kowal, partner at Francisco Partners.

"The Source Photonics team made tremendous strides in transforming the company into a leader in its served markets, while delivering best-in-class operational performance. We believe they are very well-positioned for the future and wish them continued success."

Source Photonics is a provider of optical communications technology that enables communications and connectivity in datacenters and metro and access networks.

Holographix receives BAE Systems' Product Innovation Award

Optics developer Holographix LLC has been chosen by defense company BAE Systems PLC as the 2016 Product Innovation Award winner at its Electronics Systems Supplier Conference.

The award recognizes Holographix's innovative solutions over the last 10 years while supporting the development and manufacture of BAE Systems' custom see-through optical waveguides for their LiteHUD Head-Up Display products, as well as their Q-Sight/Q-Warrior Helmet-Mounted Display products.

"Holographix's corporate mission since inception in 2003 has been to provide products and services that meet or exceed our customers' expectations," the company said in a release. "In most cases, however, due to the sensitive nature of our customers' projects, they often request that Holographix refrain from disclosing our working relationship. Therefore, it is with great honor and appreciation that we accept this award from BAE Systems, to recognize the innovative ideas and solutions that Holographix is able to offer our customers."

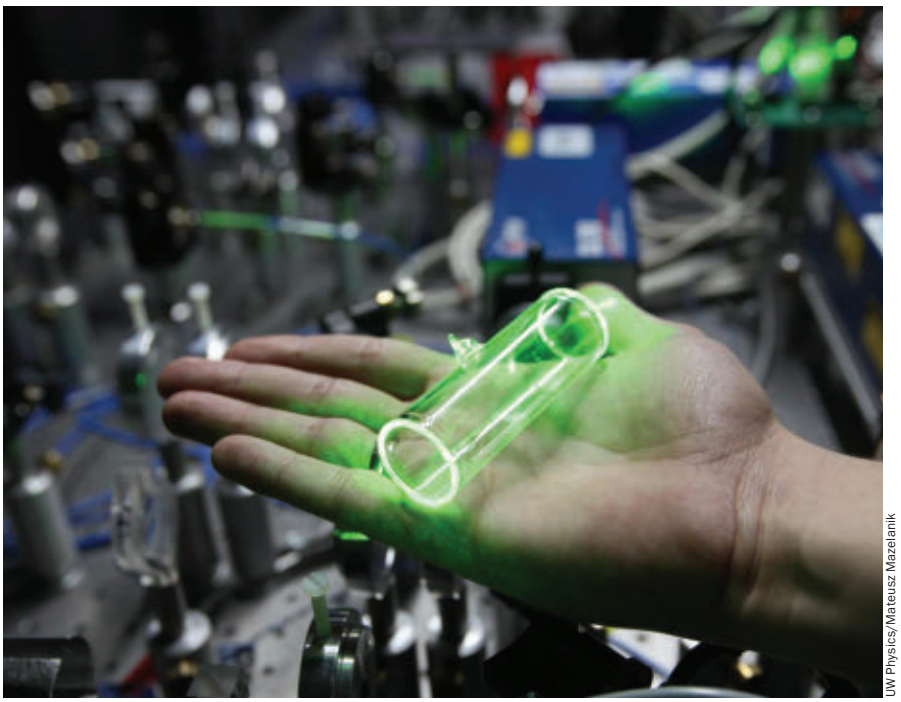
Holographix is a manufacturer of custom replicated optics such as diffraction gratings, microlens arrays, optical diffusers and wafer-level optics. BAE Systems is a defense, security and aerospace company.

Holographix

Product Innovation Award presented to Holographix by BAE Systems.

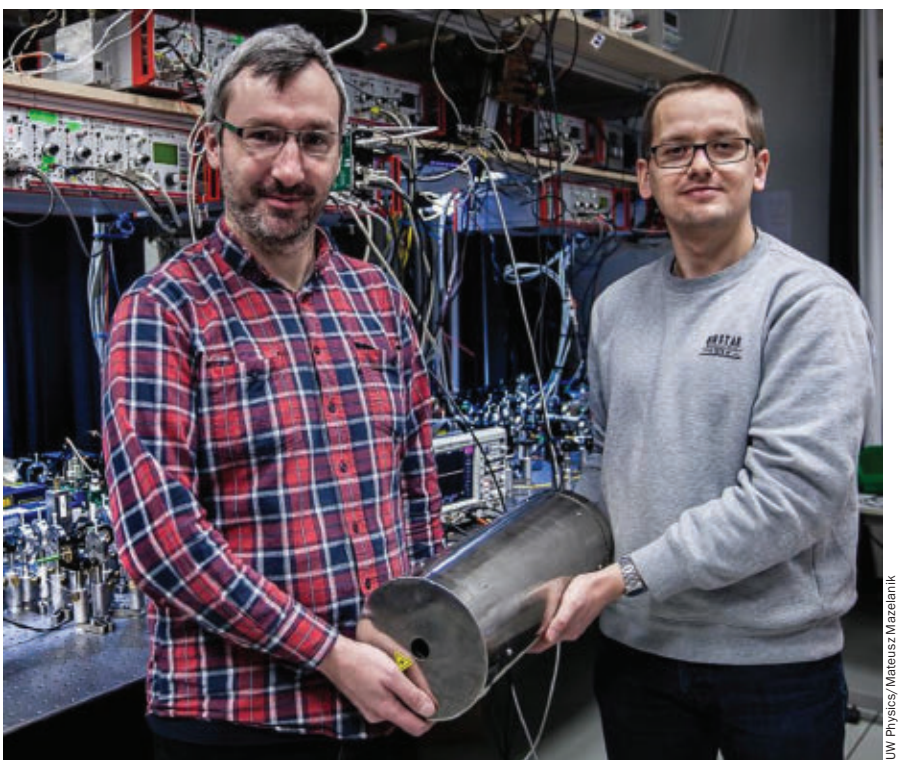
$42.6B — value of the global use of fiber optic cleavers and strippers by 2021, according to a research report released by ElectroniCast Consultants

Holographic atomic memory produces photons on demand



UW Physics/Mateusz Mazelanik

The heart of the system to generate groups of photons is a glass cell filled with hot gas vapor. Illuminating the cell with a laser results in the emission of photons with a wavelength in the infrared spectrum range.



UW Physics/Mateusz Mazelanik

Wojciech Wasilewski **(left)** and Michal Dabrowski from the Faculty of Physics at the University of Warsaw demonstrate the single-photon generator based on holographic quantum memory. Here, the gas-filled glass cell is located inside the magnetic shield used to eliminate external disturbances.

WARSAW, Poland — A device that is able to generate single photons on demand in groups of several dozen or more could help scientists overcome one of the fundamental obstacles facing the construction of quantum computers.

Physicists from the Faculty of Physics at the University of Warsaw (UW) have invented holographic atomic memory. Wojciech Wasilewski, physicist and professor at UW Physics, said their device enables the production of a precisely controlled group of photons, as opposed to just a single photon.

"Compared to existing solutions and ideas, our device is much more efficient and allows for integration on a larger scale," said Wasilewski. "In the functional sense, one can even think of it as a first equivalent of a small 'integrated circuit' operating on single photons."

Single photons can be successfully used in quantum communication protocols that guarantee full confidentiality. However, to be able to perform complex quantum computations, entire groups of photons are needed.

The simplest method of generating groups of photons is to use a sufficiently large number of sources. The devices in widespread use today utilize the phenomenon of spontaneous parametric down-conversion (SPDC). Under certain conditions, a photon generated by a laser can split into two new ones, each with half the amount of energy, and with all other properties linked by the principles of conserving energy and momentum. When information is recorded on one of the photons from the pair the researchers discover the existence and properties of the other photon, which remains undisturbed by observation and therefore perfectly suitable for quantum operations. The problem with this is that every SPDC source generates single photons rather slowly and quite randomly. As a result, for a simultaneous emission from even as few as 10 sources, it could take several years.

In 2013, a team of physicists from the Universities of Oxford and London proposed a much more efficient protocol for generating groups of photons. The idea was to place a quantum memory at each source, which would be capable of storing emitted photons. The photons stored in

the memories could be released at the same moment. This reduced emission time from years down to microseconds.

The source from the University of Warsaw physicists represents the first implementation of this concept, and one that's more integrated. The photons are created immediately within the quantum memory as a result of the laser pulse, which lasts only microseconds. External sources of single photons are no longer needed at all, and the necessary number of quantum memories has dwindled to just one.

"Our entire experimental setup takes up about two-square-meters of our optical table surface. But the most important events take place in the memory itself, in a glass cylinder measuring approximately 10 cm in length and with a diameter of 2.5 cm," said Michal Dabrowski, a Ph.D. student at UW Physics.

The new memory, which was built with the support of PRELUDIUM and SONATA grants from Poland's National Science Centre and the resources of the PhoQuS@UW project, is a spatially multimode memory where individual photons can be placed, stored, processed and read in different areas inside the cylinder, acting as separate memory drawers. The write operation, performed with a laser beam, works by preserving a certain spatial model, a hologram, in the form of atomic excitations. Illuminating the system with the laser allows the physicists to reconstruct the hologram and read the memory's content.

In the conducted experiments, the new source generated a group of 60 photons. Calculations show that in realistic conditions, the use of higher-power lasers would help to increase this number even up to several thousand.

Theoretically, the new quantum memory will be able to perform several hundred operations on a single photon, which is sufficient for quantum communication and information processing.

The research has been published in the journal *Physical Review Letters* (doi: 10.1103/PhysRevLett.118.063603).

Adhesive material controlled remotely using light

KIEL, Germany — An intelligent adhesive composite material, similar to the adhesive mechanisms that allow geckos and other animals to walk upside down or cling to a wall, has been developed, and it can be controlled using light.

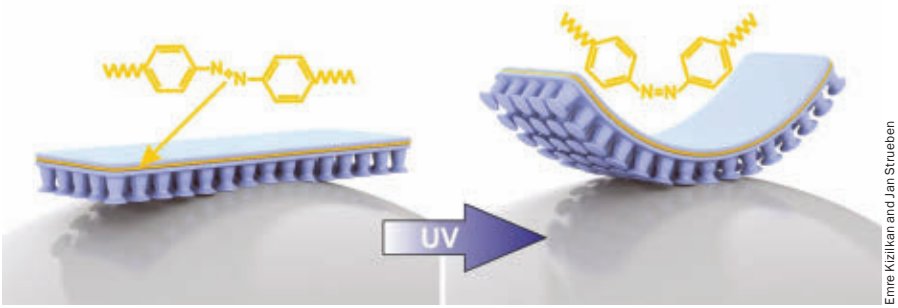
Scientists at Kiel University created the artificial, microstructured transport device that can be remotely controlled using UV light, making it possible to precisely transport objects in a micro-range.

"The advantage of light is that it can be used very precisely. It is reversible, so it can be switched on and off again, and that can be done very quickly," said researcher Emre Kizilkan.

The scientists first developed an elastic porous material — liquid crystal elastomer (LCE) — which bends when illuminated with UV light for its special molecular structure. Then they noticed that the more porous the material, the more it bent. Kizilkan and fellow researchers made use of this fact.

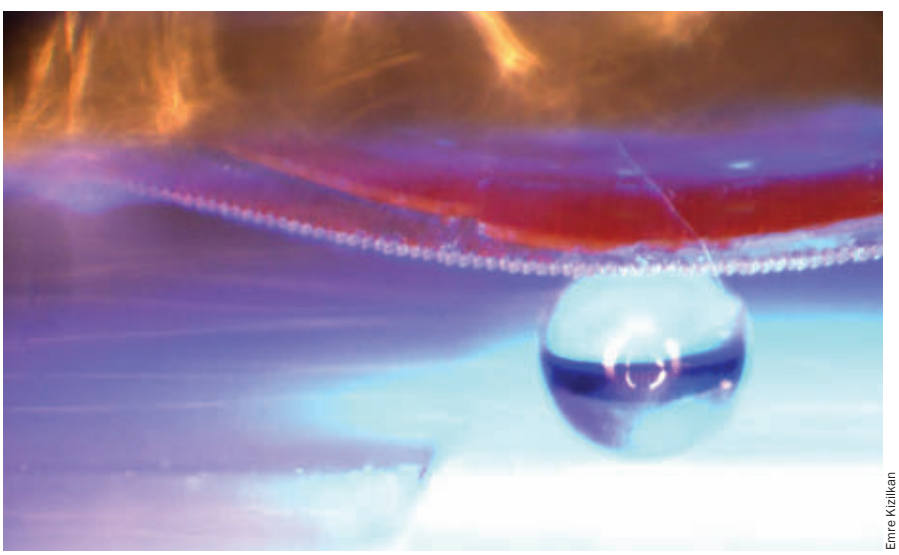
"Due to their structures, porous materials can be very easily incorporated to other materials," said Kizilkan. "So we tested what happens when we combined the elastic material, which reacts well to light, with a bio-inspired material that has good adhesive properties."

The surface of the new material consists of mushroom-shaped adhesive microstructures, similar to those found on the feet of some species of beetle. Flat or three-dimensional small elements such as



Emre Kizilkan and Jan Strueben

The new composite material consists of two substances: an adhesive material **(blue)** and an elastic LCE (liquid crystal elastomer) plastic **(yellow)**. LCE is made up of azobenzene molecules that bend — thus bending the whole material — when they are irradiated with UV light. The curvature causes the adhesive elements to detach from the object.



Emre Kizilkan

When illuminated with UV light, the intelligent material with the adhesive surface bends. This way it can lift, transport and put down flat and three-dimensional objects like this 1-mm-diameter glass sphere.

microscope slides or glass spheres can attach and be picked up. When the composite material is illuminated with UV light, it bends. Because of the bending of the surface, more and more adhesive elements detach from the object, until it can finally be dropped down again.

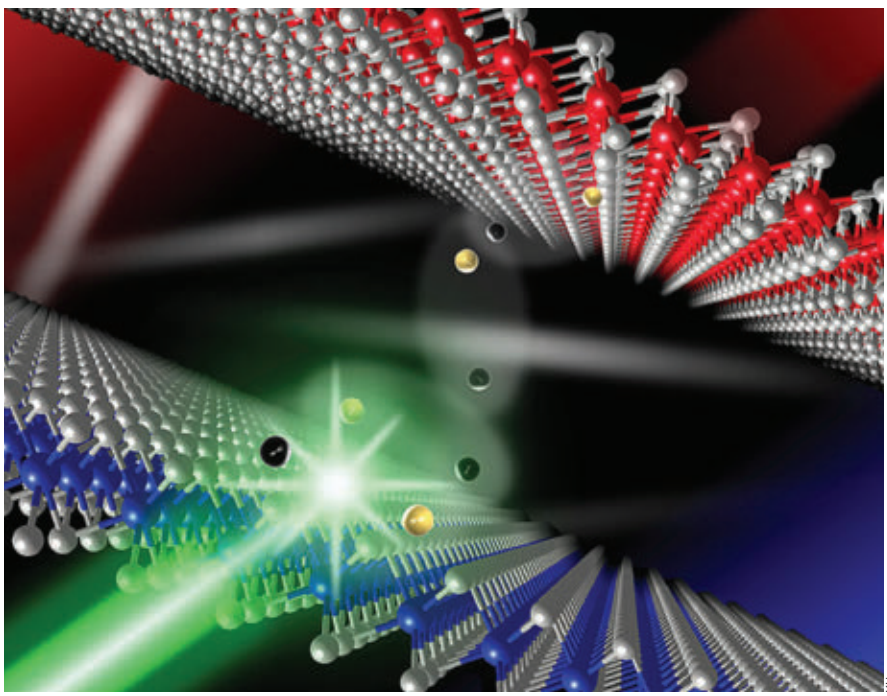
"We were able to show that our new material can be used to transport objects," said Kizilkan. "Moreover, we demonstrated that the transport can be controlled very precisely with light, on a micro-level."

Through tunable ultraviolet light illumination, the adhesive ability of this bio-inspired transport device was reduced up to a factor of 2.7 in terms of adhesive forces and was quickly recovered when the light stimulus ceased.

The findings could be used for future applications in the fields of robotics, industry and medical technology. It also has possible uses in building sensitive sensors and micro-computer chips.

The Kiel-based research team's results were published in the scientific journal *Science Robotics* (doi: 10.1126/scirobotics.aak9454).

New bilayer material could improve LED technology



KU

Using the 'Scotch tape' method made famous by creating graphene and laser beams, researchers craft new material that could improve LED screens.

LAWRENCE, Kansas — A new bilayer material measuring less than one nanometer in thickness per layer could lead to more efficient and versatile light emission.

Researchers working at the Ultrafast Laser Lab at the University of Kansas (KU) successfully created the material by combining atomically thin layers of molybdenum disulfide and rhenium disulfide.

Hui Zhao, associate professor of physics and astronomy at KU, said molybdenum disulfide (MoS_2) and rhenium disulfide (ReS_2) both absorb light as semiconductors, are flexible and can be stretched and compressed.

"The goal of this whole direction of research is to produce light-emitting devices, such as LEDs, that are ultrathin — just a few nanometers thick — and flexible enough that you can bend it. We showed through this bilayer material [that] can be achieved," said Zhao.

The KU researcher compared the behavior of the electrons in the new material to that of a classroom.

"One can think of a material as a classroom full of students — which are the electrons — one on each seat," he said. "Sitting on a seat, a student — or electron — can't move freely to conduct electricity. Light can provide enough energy to stand up some of the students, who can now move freely and, as electrons, to conduct electricity. This process is the foundation for photovoltaic devices, where the energy of sunlight is captured and converted to electricity."

Zhao said that emission of light involves the inverse process, in which a standing electron sits down in a seat, releasing its kinetic energy in the form of light.

"To make a good material for light emission devices, one needs not only the electrons that carry energy, but also the 'seats' — called holes — for the electrons to sit down," he said.

In Zhao's new material, all the electrons and their seats will be in one layer, enabling light emission to be much stronger.

Zhao and fellow researchers Matthew Bellus, Samuel Lane, Frank Ceballos and Qiannan Cui, all KU physics graduate students, and Ming Li and Xiao Cheng Zeng, of the University of Nebraska-Lincoln, created the new material using the same low-tech "Scotch tape" method pioneered in creating graphene.

"There's a trick," Zhao said. "You use Scotch tape to peel off a layer from the crystal and then you fold the tape a few times, so when you push the tape against a substrate and quickly peel it off, some of the material will be left on the substrate. Under a microscope, single-atom layer sections will have a different color because of their thickness, very much like a thin film of oil on water."

The researchers at KU's Ultrafast Laser Lab were then able to stack the MoS_2 layer on top of ReS_2, with a precision better than one micrometer. The atomically thin sheets were connected by the so-called van der Waals force, the same force that allows a gecko to scale a smooth window pane.

"The van der Waals force isn't very sensitive to the atomic arrangement," said Zhao. "So, one can use these atomic sheets to form multilayer materials, in a fashion like atomic Legos."

After the samples were made, team members used ultrafast lasers to observe motion of electrons and seats between the two atomic layers, and they saw clear evidence that both electrons and the seats can move from MoS_2 to ReS_2, but not along the opposite direction.

In doing so, the team confirmed theoretical calculations performed by Li and Zeng, who previously had analyzed related properties of about a dozen atomic sheets, and predicted that bilayers formed by MoS_2 and ReS_2 would have promise as the basis for LED technology.

According to Zhao, the ultimate goal is to develop a method that allows precise control of the location of electrons and seats among different atomic layers so that the electronic and optical properties of the material can be controlled and optimized.

"We'd someday like to see LEDs that are thinner, more energy efficient and bendable," he said. "Think about a computer or phone screen if you could fold it a few times and put it in your pocket."

The research has been published in the peer-reviewed journal *Nanoscale Horizons* (doi: 10.1039/C6NH00144K).

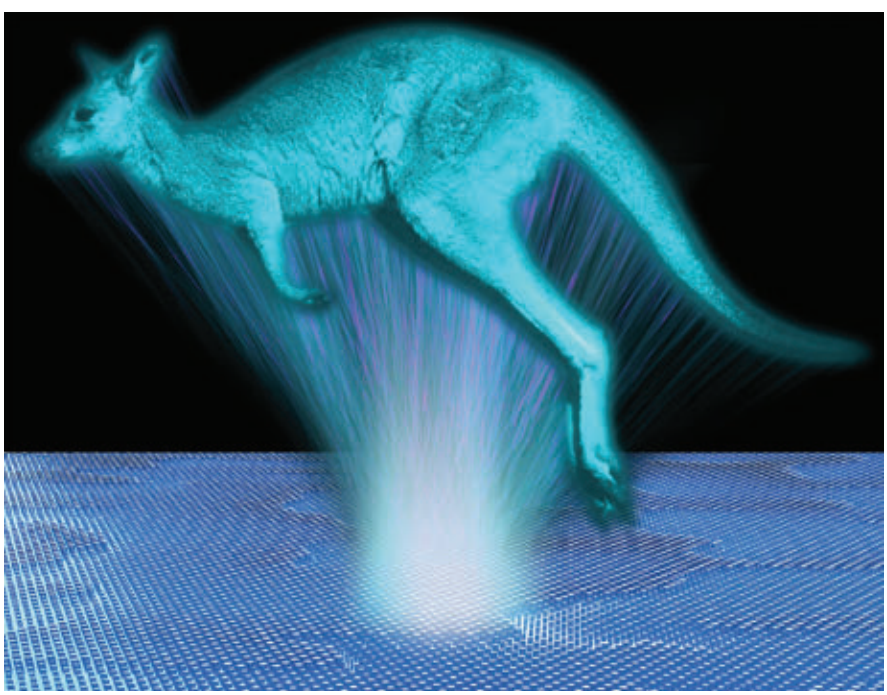
Infrared hologram device achieves new optical properties

CANBERRA, Australia — Australian National University (ANU) physicists have invented a tiny device that creates high holographic images, opening the door to imaging technologies often seen in science fiction movies.

"As a child, I learned about the concept of holographic imaging from the 'Star Wars' movies. It's really cool to be working on an invention that uses the principles of holography depicted in those movies," said Lei Wang, a Ph.D. student and lead researcher at the ANU Research School of Physics and Engineering.

Holograms perform the most complex manipulations of light. They enable the storing and reproduction of all information carried by light in 3D. In contrast, standard photographs and computer monitors capture and display only a portion of 2D information.

Wang said, "While research in holography plays an important role in the development of futuristic displays and augmented reality devices, today we



ANU

Australian researchers have made a breakthrough in holographic technology.

are working on many other applications such as ultrathin and light-weight optical devices for cameras and satellites."

The device consists of millions of tiny silicon pillars, each up to 500 times thinner than a human hair, that project complex holographic images in infrared.

Sergey Kruk, a researcher from the ANU Research School of Physics and Engineering, said the material used is transparent, loses minimal energy from the light and does complex manipulations with light.

"Our ability to structure materials at the nanoscale allows the device to achieve new optical properties that go beyond the properties of natural materials," said Kruk. "The holograms that we made demonstrate the strong potential of this technology to be used in a range of applications."

The device could replace bulky components to miniaturize cameras and save costs in astronomical missions by reducing the size and weight of optical systems on space craft.

The research has been published in the journal *Optica* as a Memorandum, a special announcement of scientific breakthroughs (doi: 10.1364/OPTICA.3.001504).

Novel BIC laser holds promise for optical communications

SAN DIEGO — Lasers based on an unconventional wave physics phenomenon known as bound states in the continuum — BIC — have the potential to be used as high-power lasers for industrial and defense applications. The technology developed by researchers at the University of California, San Diego, could also revolutionize the development of surface lasers for communications and computing applications.

Bound states in the continuum are waves that stay confined in an open system. Conventionally, waves would escape from an open system, but BICs remain localized. Since they are unconventional, BIC lasers possess unique properties that have not yet been found in existing lasers.

One key characteristic of the BIC laser is its capability to be readily tuned to emit different wavelengths of laser beams.

"They are also capable of producing vector beams, which are essentially engineered shapes of the emission beam," said Boubacar Kanté, an electrical engineering professor who led the research at UC San Diego's Jacobs School of Engineering. This is possible with BICs because "the lasing wavelength is tunable in the near-infrared range by controlling the dimension of the cylindrical nanoresonators."

These properties could be conducive in creating increasingly powerful computers and optical communication systems that can store even more information than current ones.

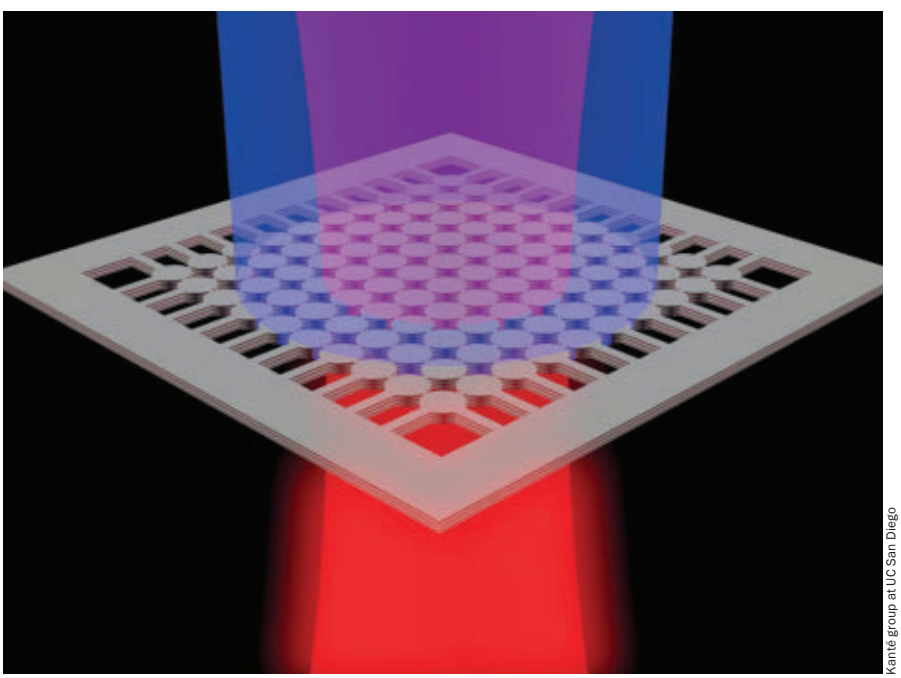
The BIC system created by Kanté's group is powered with a high-frequency laser beam that induced its own laser beam with a lower frequency. "Ideally, this BIC laser would be powered by a physical battery instead of being powered by another laser," said Kanté.

Kanté told Photonics Media that this would be the next step in the research of BIC lasers. The system built for the research "is constructed out of epitaxially grown InGaAsP semiconductor material with quantum wells," he said. "This material is unique in the sense that it comes with different energy levels or bands of energy — mainly two bands called conduction and valence bands."

Unique to the BIC laser is the capability of achieving surface lasing without compromising its compact form. "We demonstrate lasing in the telecommunication band [~1.55 μm] with laser arrays as small as 8 × 8 [~8 × 8 μm]," Kanté said. Other common surface lasers called VCELs (vertical-cavity surface-emitting lasers) need arrays about 100 times larger to achieve lasing. The smaller array consumes less power, thus is more energy efficient than other surface lasers.

The researcher speculated that one day VCSELs may be replaced by BICSELs — bound state in the continuum surface-emitting lasers — which could lead to smaller devices that consume less energy.

The next step for this versatile technology is to create a BIC laser that is electrically powered. This would be a huge advancement toward achieving integration of BIC lasers into modern technology.



Kanté group at UC San Diego

Schematic of the BIC laser: a high-frequency laser beam **(blue)** powers the membrane to emit a laser beam at telecommunication frequency **(red)**.

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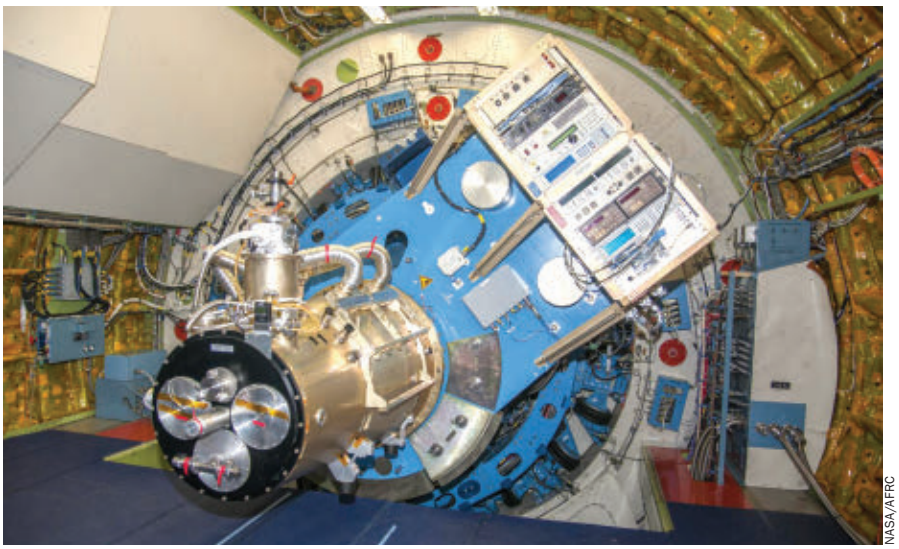
Moth's eye inspires design and applications of NASA camera

GREENBELT, Md. — A moth's eye is the inspiration behind the technology that allows a new NASA-developed camera to create images of astronomical objects with far greater sensitivity than was previously possible.

When magnified, a moth's eye contains a very fine array of small tapered cylindrical protuberances whose job is to reduce reflection. This allows the moth to absorb light, making night navigation possible.

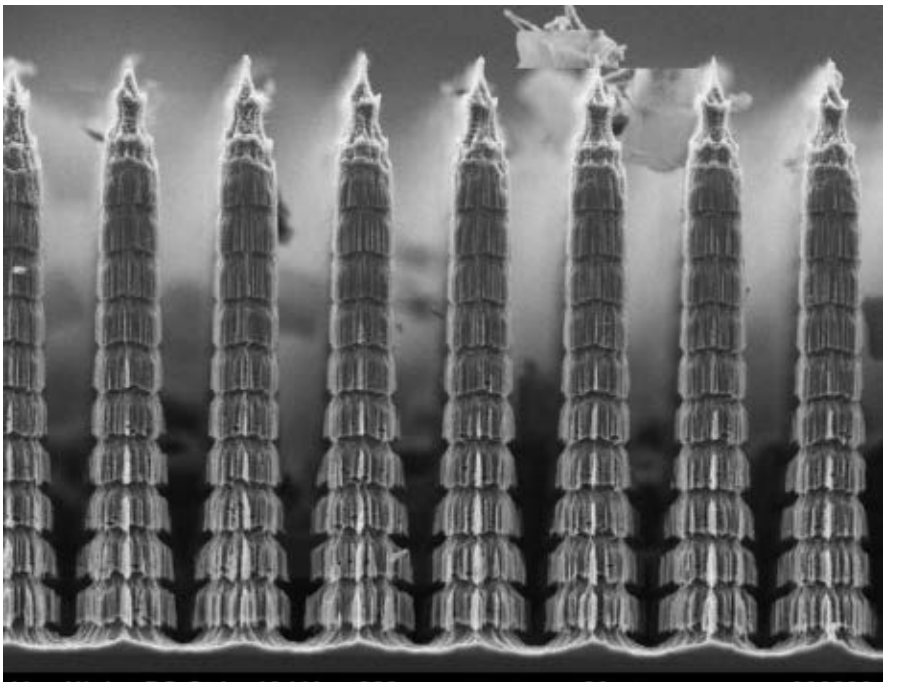
The same absorber technology concept, when applied to a far-infrared absorber, results in a silicon structure containing thousands of tightly packed, micromachined spikes or cylindrical protuberances no taller than a grain of sand. It is a critical component of the four 1280-pixel bolometer detector arrays that a team of scientists and technologists at NASA's Goddard Space Flight Center in Greenbelt, Md., created for the High-Resolution Airborne Wideband Camera-plus, or HAWC+.

NASA just completed the commissioning of HAWC+ onboard the Stratospheric Observatory for Infrared Astronomy, or SOFIA, a joint venture involving NASA and the German Aerospace Center (DLR). This heavily modified 747SP aircraft carries with it an eight-foot telescope and six instruments to altitudes high enough to



NASA/AFRC

NASA recently completed the commissioning of a new airborne camera on NASA's SOFIA aircraft. This image shows HAWC+ on SOFIA's telescope.



NASA

These images, taken with a scanning electron microscope, show details of a new absorber that is enabling observations by the High-Resolution Airborne Wideband Camera-plus, or HAWC+, a new SOFIA instrument. The "spikes" were inspired by the structure of a moth's eye.

not be obscured by water in Earth's atmosphere, which blocks most of the infrared radiation from celestial sources.

The upgraded camera measures polarized light from the emission of dust in our galaxy and makes images. With this instrument, scientists will be able to study the early stages of star and planet formation, and, with HAWC+'s polarimeter, map the magnetic fields in the environment around the supermassive black hole at the center of the Milky Way.

Goddard scientist Ed Wollack said the system can measure minute variations in the light's frequency and direction.

"This enables the detector to be used over a wider bandwidth. It makes the detector far more sensitive — especially in the far infrared," said Wollack.

Wollack worked alongside Goddard detector expert Christine Jhabvala to devise and build the micro-machined absorbers critical to the Goddard-developed bolometer detectors.

Bolometers are commonly used to measure infrared or heat radiation. When radiation is focused and strikes an absorptive element, typically a material with a resistive coating, the element is heated. A superconducting sensor then measures the resulting change in temperature, revealing the intensity of the incident infrared light.

This particular bolometer is a variation of a detector technology called the backshort under-grid sensor, or BUGS, used now on a number of other infrared-sensitive instruments. In this particular application, the reflective optical structures — the so-called backshorts — are replaced with the micro-machined absorbers that stop and absorb the light.

The team had experimented with carbon nanotubes as a potential absorber. However, the cylindrically shaped tubes now used for a variety of spaceflight applications proved ineffective at absorbing far-infrared wavelengths. In the end, Wollack looked to the moth as a possible solution.

"You can be inspired by something in nature, but you need to use the tools at hand to create it," Wollack said. "It really was the coming together of people, machines and materials. Now we have a new capability that we didn't have before. This is what innovation is all about."

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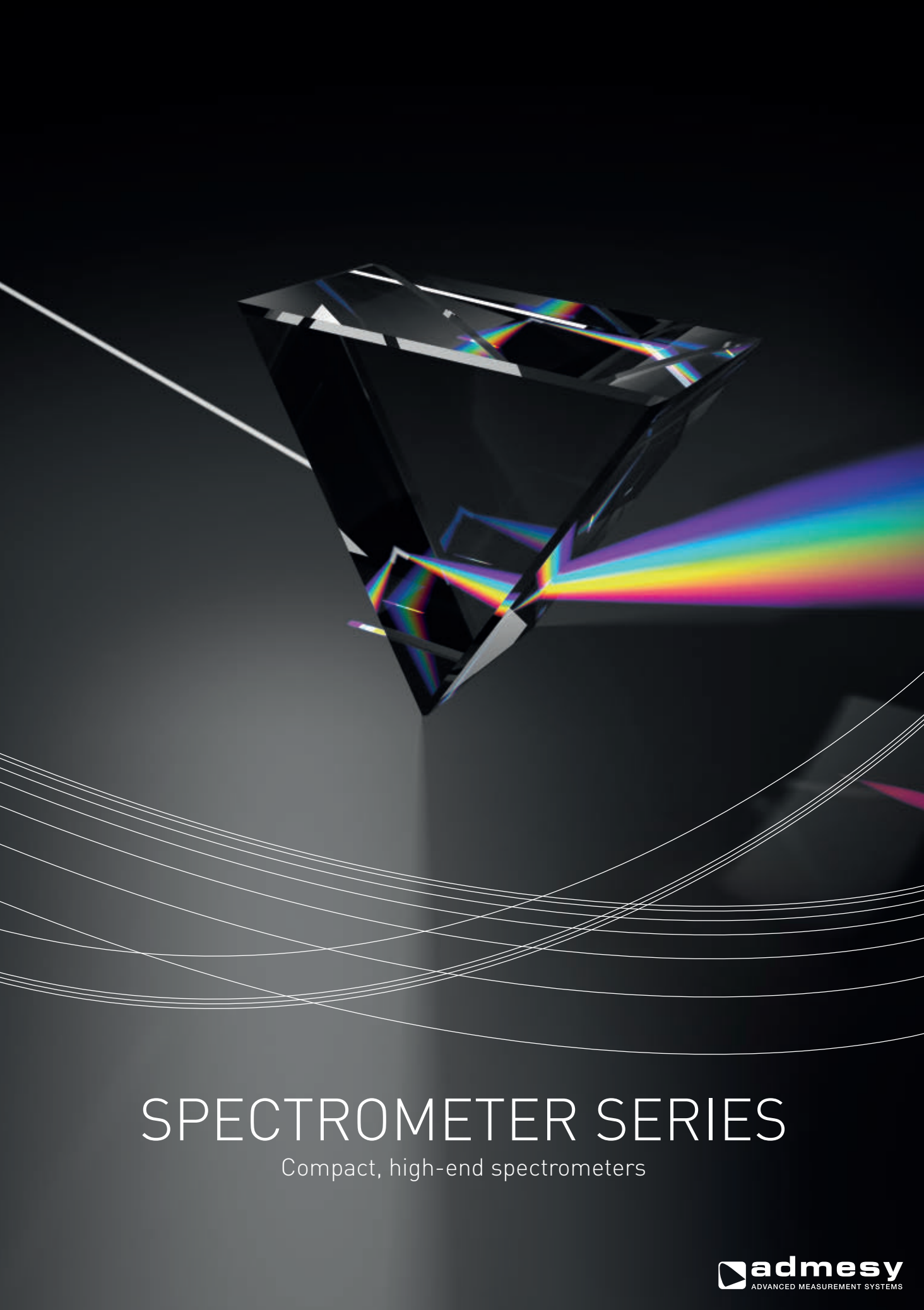

SPECTROMETER SERIES

Compact, high-end spectrometers

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ADVANCED MEASUREMENT SYSTEMS

RHEA SERIES

The Rhea series spectrometer offers a unique combination of ease of use and accurate measurement capabilities packed in a robust jacket. The Rhea utilizes a high-end ultra-sensitive cooled CCD detector enabling low noise at long integration times. An integrated neutral density filter wheel extends this dynamic range and also adds a shutter function.

Admesy's Rhea is the new flexible platform in custom spectral measurement demands within the 200 and 1100nm range. Various choices in slit sizes, gratings and sensors allows to define the perfect spectral measurement solution for specific high-end spectral measurement applications or OEM integration. The Rhea series is available in a variety of optical systems: 5, 10 or 20mm collimating lenses, cosine corrector and fiber connectors. This flexibility makes the Rhea the ultimate high-end spectrometer for OEM integration, display, lighting and generic spectral measurements in both laboratory and production settings.

HIGHLIGHTS

- Customizable slit, grating and sensor for custom wavelength ranges
- High-end cooled CCD sensor
- Extreme sensitivity
- ND filter wheel for large dynamic range
- Built-in shutter function
- Internal calculations for most common parameters
- Excellent linearity
- Dark current compensated, virtually zero over entire integration range
- USB, RS 232, Ethernet, trigger in & out interfaces
- Various wavelength ranges between 200-1100nm
- Standard UV, VIS and UV-NIR versions available

ADMESY SPECTROMETER LINE-UP

HERA SERIES

The Hera series spectrometer offers highly accurate measurements with auto range function and excellent linearity in a robust and compact housing. An ideal measurement solution when ease of use, stability, performance and price are key factors. The Hera series is available in various spectral ranges, from UV up to NIR. Besides enabling spectral analysis in these spectral ranges, it measures colour in XYZ, Yxy and luminance for display measurements as well as colour rendering index (CRI), correlated colour temperature (CCT), irradiance, illuminance and PAR for lighting applications.

To suit all measurement needs all Hera ranges are available in various optical configurations: lens based systems for spot measurements of displays and diffuse luminous surfaces; cosine corrector systems for diffuse measurements of light sources or optical fiber connections to connect the Hera to various optics such as lenses, integrating spheres or sampling probes. This wide range of possibilities and options makes the Hera series the perfect solution for common display and lighting applications and colour appearance measurements varying from R&D to continuous use in production lines.

HIGHLIGHTS

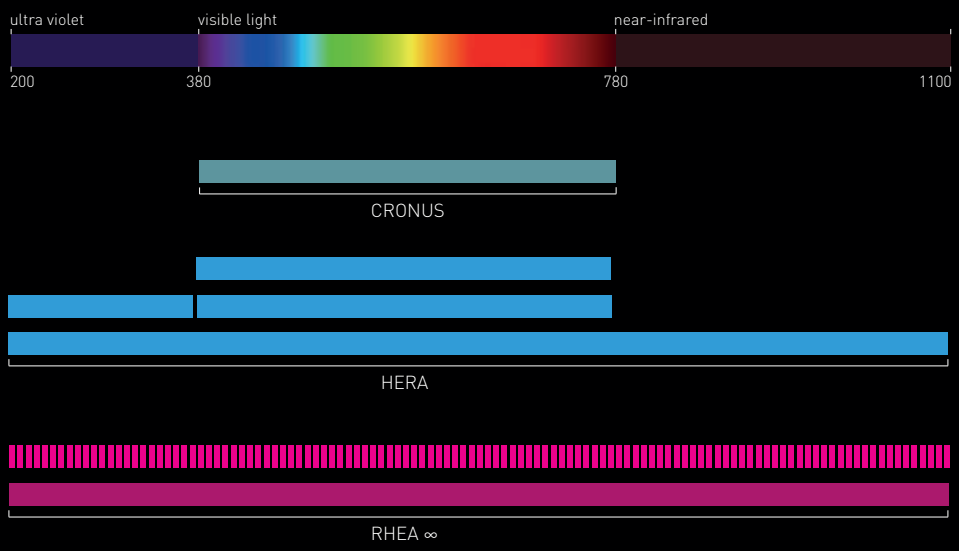
- Internal calculations for most common parameters
- Excellent linearity
- Dark current compensated
- Holographic grating for low stray light
- USB, RS 232, Ethernet, trigger in & out interfaces
- UV, VIS and UV-NIR ranges available

HYBRID DEVICE: CRONUS SERIES SPECTRO-COLORIMETER

The Cronus series offers the unique combination of accuracy and speed: a VIS spectrometer and high speed tri-stimulus colorimeter which results in a complete measurement solution for display and lighting applications.

- The XYZ sensor provides additional high speed colour and flicker measurements for display standards including JEITA and VESA methods.
- For lighting applications the Cronus supports flicker index, flicker percentage and IEEE 1789 recommendation.

WAVELENGTH RANGES



Admesy: Colour and Light Measurement for R&D and Production

PROFILE

Founded in 2006, Admesy provides our customers with innovative Test & Measurement solutions tailored for color and light measurement in production processes. Our products are innovative, compact, fast, user-friendly and robust.

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Admesy offers a broad range of test and measurement instruments focused on colour and light measurements for R&D and inline production process environments.

All products are developed and produced in-house based on a long history of inline testing. Admesy measurement devices are developed for R&D and industrial use and combine high speed accurate measurements with a robust device and low maintenance needs. Our product range includes spectrometers, colorimeters, light meters, 2D spectral vision systems and numerous accessories.

Our wide product range offers solutions for various measurement questions in display, lighting, analysis and OEM integration ranging from optical characteristics such as brightness, spectral power distribution, whitepoint adjustment and colour and flicker behaviour to OEM integration of spectrometers for analysis purposes.

Admesy was founded in 2006 in the Netherlands and has quickly grown into an international company serving customers all over the world from its headquarters near Maastricht, The Netherlands. Besides our office in the Netherlands we have a support office near Seoul in South Korea and near Shengzhen in China allowing us to quickly assist and support our numerous Asian customers.

admesy
ADVANCED MEASUREMENT SYSTEMS

Physicists optically manipulate Abrikosov vortices

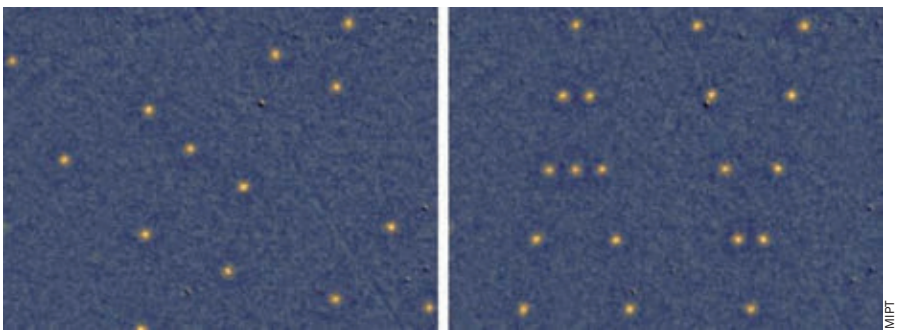
BORDEAUX, France and MOSCOW — Scientists from the University of Bordeaux and the Moscow Institute of Physics and Technology (MIPT) have performed a unique experiment involving the optical manipulation of individual Abrikosov vortices in a superconductor. Their results could help design new logic units based on quantum principles for use in supercomputers.

Superconductivity — zero electrical resistance — occurs in certain materials in the temperature range from −273 to −70 °C. When a material transitions into this state, the magnetic flux fields are expelled. A superconductor either has all magnetic field lines ejected from its interior or allows partial penetration of the magnetic field.

The phenomenon of partial penetration was explained in 1957 by Alexei Abrikosov, for which he was awarded the 2003 Nobel Prize in Physics. Abrikosov demonstrated that type-II superconductors — materials that do not exhibit complete magnetic field expulsion — can only be penetrated by discrete magnetic flux units. As the field within a superconductor grows stronger, this gives rise to the cylindrical current loops known as Abrikosov vortices.

"Type-II superconductors are used everywhere: from medicine to energetics and other industries. Their properties are determined by the 'vortex matter,' which makes research into vortices and finding ways to manipulate them very important for modern physics," said Ivan Veshchunov, a researcher at the Laboratory of Topological Quantum Phenomena in Superconducting Systems at MIPT.

To manipulate the vortices, the scientists used a focused laser beam, as the vortices are attracted to higher temperatures in a superconductor.



MIPT

The randomly distributed vortices in the superconducting sample **(left)** have been repositioned into a pattern forming the letters "AV," which stands for Abrikosov vortices **(right)**.

Because the vortices act as magnetic flux quanta, they can be used to shape the overall magnetic flux profile, enabling physicists to perform various experiments with superconductors. While a triangular vortex lattice occurs naturally in certain magnetic fields, other types of lattices and devices like vortex lenses can be created by moving vortices around.

Professor Brahim Lounis from the University of Bordeax told Photonics Media that this technology is the most promising in terms of the design of superfast memory for quantum computers.

"The interplay between photons and single flux quanta should open up novel research directions in quantum computation based on braiding and entanglement of vortices; Josephson switches of electric current; or optically controlled elements of rapid single flux quantum logics (RSFQ)," said Lounis.

RSFQ-based logic elements are already used in digital-to-analog and analog-to-digital converters, high-precision magnetometers and memory cells. A number of prototype computers based on this technology have been developed, including the FLUX-1 designed by a team of U.S. engineers. However, the RSFQ logic elements in these computers are mostly controlled by electrical impulses. Optically controlled logic is one of the emerging trends in superconducting systems.

Professor Lounis said optical manipulation of individual vortices is challenging and prior to their experiment was only achieved with scanning local probe techniques. These techniques are intrinsically slow and difficult to implement.

"With our simple far-field optical method, single vortices can be manipulated over large distances; they are only limited by the field of view of the microscope objective — ~1 mm — and at high driving speeds only limited by the ratio of the hotspot size — ~1 µm — to the thermal response time," said Lounis. "Our method opens the way to fast optical operations."

The experiments performed by the scientists serve as a proof of concept for an approach that could be used in future research into Abrikosov vortices.

The research has been published in the journal *Nature Communications* (doi: 10.1038/ncomms12801).

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Vacuum impurities could impact OLED lifetime

FUKUOKA, Japan — While issues affecting the efficiency of OLEDs are well understood, the reasons why some OLEDs degrade and lose brightness over time have not been as easy to identify. Devices fabricated with seemingly the same procedures and conditions but by different research groups often degrade at vastly different rates, even when the initial performances are the same. One possible explanation for discrepancies in OLED lifetimes could be miniscule impurities present in the vacuum chamber during fabrication.

Researchers from Kyushu University investigated the influence of impurities in a vacuum chamber used for the fabrication of OLEDs. Their analysis revealed that tiny amounts of impurities present in the vacuum chamber during OLED fabrication were potentially being incorporated into OLEDs, leading to variations in lifetime. They also found a correlation between lifetime of the OLED and device fabrication time.

Using liquid chromatography-mass spectrometry on silicon wafers stored in the vacuum chamber before device fabrication, the researchers detected a variety of materials and found that many of the impurities could be traced to previously deposited materials and plasticizers from the vacuum chamber components.

The researchers found that, because of impurities in the deposition chamber, lifetime sharply increased for OLEDs that spent a shorter time in the deposition chamber during fabrication. This trend remained even after considering changes in residual water and source material purity,

indicating that controlling and minimizing the device fabrication time could lead to longer lifetime for OLEDs.

Research partners at Sumika Chemical Analysis Service Ltd. (SCAS) confirmed an increase of accumulated impurities with time by analyzing the materials that deposited on extremely clean silicon wafers that were stored in the deposition chamber when OLED materials were not being evaporated.

Results suggest that the impurities floating in a vacuum chamber could significantly impact OLED lifetime values and reproducibility, even if they amount to less than even a single molecular layer.

"Although we often idealize vacuums as being clean environments, we detected many impurities floating in the vacuum even when the deposition chamber is at room temperature," said professor Hiroshi Fujimoto.

"Really small amounts of these impurities get incorporated into the fabricated devices and are causing large changes in the lifetime," professor Chihaya Adachi said.

To improve lifetime reproducibility, a practice often adopted in industry is the use of dedicated deposition chambers for specific materials, but this can be difficult in academic labs, where often only a limited number of deposition systems are available for testing a wide variety of new materials. In these cases, deposition chamber design and cleaning, in addition to control of the deposition time, are especially important.

"This is an excellent reminder of just how careful we need to be to do good, reproducible science," said Adachi.

The research was published in *Scientific Reports* (doi:10.1038/srep38482).

CU Boulder team tracks methane leaks with lasers

BOULDER, Colo. — With a $1.3 million grant from the Department of Energy's Office of Fossil Energy, researchers from the University of Colorado Boulder, the University of California Davis, the National Institute of Standards and Technology (NIST), and aircraft operator Scientific Aviation will field a ground-based laser system to take a closer look at emissions from natural gas storage facilities across the U.S.

Greg Rieker, assistant professor of mechanical engineering at CU Boulder and the principal investigator of the study, said their efforts will represent the first field-based campaign of its kind.

"This is an incredible opportunity to bring together cutting-edge technologies and researchers to answer an important, practical question. We aim to produce results that will enable sound policy decisions and business practices that keep everyone safe, and keep natural gas in the ground until we're ready to use it," said Rieker.

The laser system, which sends invisible, eye-safe laser beams through the atmosphere to distances well over one mile, was developed under a recent grant from the DOE's Advanced Research Project Agency-Energy (ARPA-E). It is able to measure changes in methane concentrations in the air down to one part-per-billion. The data received will be used to gain a better understanding of how emissions of methane come out of the ground, equipment and abandoned well heads around storage facilities, and whether these emissions are steady through time or vary.

The UC-Davis and Scientific Aviation teams will mount light aircraft flights around the storage facility where the ground system is deployed. They will also monitor a large number of other facilities throughout the country. The aircraft is equipped with methane detection technology that will provide estimates of total emissions arising from storage facilities.

Natural gas for power generation and heating is typically extracted and processed in remote areas before being transported closer to cities for storage. The gas is stored at high pressures in underground reservoirs and caverns. The location of storage sites near cities offers rapid on-

demand delivery, but poses significant environmental, health and safety risks in the event of a mishap.

The team believes the monitoring technology may serve a longer-term purpose as a continuous monitoring system for storage facilities.

"Any time we find a home for our technologies in the private sector is a big win for us and for the agencies that fund our research. We genuinely hope that will be the case here," said Rieker.

The team will share results of the study with the EPA for inclusion in its greenhouse gas emissions inventory for the U.S.

Material offers broadband, selective light absorption for use in energy, defense

LA JOLLA, Calif. — A novel class of particle absorbers, called transferable hyperbolic metamaterial particles (THMMP), has shown selective, omnidirectional, tunable, broadband absorption when closely packed. The novel material, which absorbs more than 87 percent of near-IR light at 1200- to over 2200-nm wavelengths, with a maximum absorption of 98 percent at 1550 nm, could be used for energy, automotive and stealth applications.

The thin, flexible, light-absorbing material, a near-perfect broadband absorber, can absorb light from every angle. According to researchers, it could be customized to absorb certain wavelengths of light while letting others pass through. Materials that "perfectly" absorb light already exist, but they are bulky and can break when bent. Also, they cannot be controlled to absorb only a selected range of wavelengths.

The tunability of the novel material relies on surface plasmon resonances, which occur on the surface of metal nanoparticles upon interaction with certain wavelengths of light. Because they can carry high amounts of free electrons, metal nanoparticles exhibit strong surface plasmon resonance in visible light but not in IR.

Researchers at the University of California, San Diego, surmised that if they could change the number of free electron carriers in the metal nanoparticles on the surface of the material, they could tune the material's surface plasmon resonance to different wavelengths of light.

"Make this number lower, and we can push the plasmon resonance to the infrared. Make the number higher, with more electrons, and we can push the plasmon resonance to the ultraviolet region," said professor Donald Sirbuly.

In order to control the number of free electron carriers on the metal surface, the researchers built an absorber from zinc oxide and combined it with its metallic version, aluminum-doped zinc oxide, which can hold a high enough amount of free electrons to give it plasmonic properties in the IR.

The materials were combined and structured using nanofabrication technologies, then deposited one atomic layer at a time on a silicon substrate to create an array of standing nanotubes, each made of alternating concentric rings of zinc oxide and aluminum-doped zinc oxide. The hyperbolic nanotube array was then transferred from the silicon substrate to a thin, elastic polymer. The material exhibited mechanical flexibility and visible transparency while maintaining near-perfect absorption at telecommunication wavelengths, even after being transferred to the polymer.

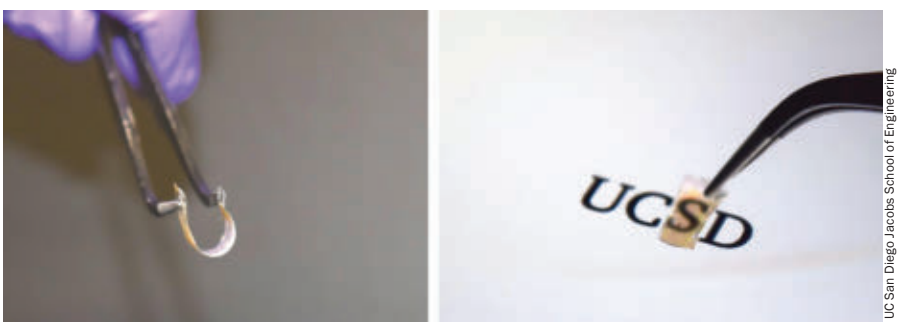
"This material offers broadband, yet selective absorption that could be tuned to distinct parts of the electromagnetic spectrum," said professor Zhaowei Liu.

"There are different parameters that we can alter in this design to tailor the material's absorption band: the gap size between tubes, the ratio of the materials, the types of materials and the electron carrier concentration. Our simulations show that this is possible," said researcher Conor Riley.

The nanoparticle-based design is potentially transferrable to any type of substrate and could be scaled up to make large surface area devices, such as broadband absorbers for large windows.

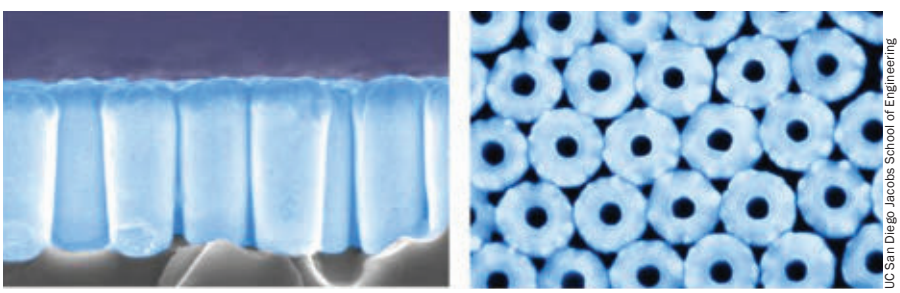
Potential applications for the near-perfect broadband absorber include transparent window coatings for buildings and cars, devices for improving solar cell efficiencies, and shields for blocking thermal detection. The researchers continue to explore different materials, geometries and designs to develop absorbers that work at different wavelengths of light for various applications.

The research was published in Proceedings of the *National Academy of Sciences* (doi: 10.1073/pnas.1613081114).



UC San Diego Jacobs School of Engineering

A near-perfect broadband absorber that's thin, flexible and transparent in visible light.



UC San Diego Jacobs School of Engineering

Scanning electron miscroscope images of a nanotube array: side view **(left)** and top view **(right)**.

Spectroscopy technique could detect chemicals in minuscule amounts

LEXINGTON, Mass. — A microscope that can chemically identify micrometer-sized particles could one day be used in high-security venues to rapidly screen people for microscopic amounts of potentially dangerous materials.

The technique, which was developed by researchers at the Massachusetts Institute of Technology's Lincoln Laboratory, uses photothermal modulation of Mie scattering (PMMS) to enable concurrent spatial and spectral discrimination of individual micrometer-sized particles, and uses an imaging configuration to detect multiple species of particles.

"We're actually imaging the area that we're interrogating," said researcher Alexander Stolyarov. "This means we can simultaneously probe multiple particles on the surface at the same time."

The researchers measured the IR absorption spectra of individual 3-µm acrylic and silica spheres. Trace quantities of material were deposited onto an IR-transparent substrate and simultaneously illuminated by a wavelength-tunable, intensity-modulated quantum cascade pump laser and a CW 532-nm probe laser. Absorption of the pump laser by the particles resulted in direct modulation of the scatter field of the probe laser.

The probe light scattered from the interrogated region was imaged onto a visible-wavelength camera, enabling simultaneous probing of spatially separated individual particles. Physical changes of the individual particles could be tracked using the microscope's lens.

By tuning the wavelength of the pump laser, the researchers were able to obtain the IR absorption spectrum and use the instrument to identify the material composition of individual particles. The slight heating of the particles did not cause any permanent changes, making the technique suitable for nondestructive analysis.

The microscope's use of visible wavelengths for imaging gives it a spatial resolution of around 1 µm, compared to the roughly 10-µm resolution of traditional IR spectroscopy methods. The increased resolution makes it possible to distinguish and identify individual particles that are extremely small and close together.

"If there are two very different particles in the field of view, we're able to identify each of them," said Stolyarov.

"This would never be possible with a conventional infrared technique because the image would be indistinguishable."

The microscope combines a quantum cascade laser with a very stable visible laser source and a commercially available scientific-grade camera.

"We are hoping to see an improvement in high-power wavelength-tunable quantum cascade lasers," said researcher Ryan Sullenberger. "A more powerful infrared laser enables us to interrogate larger areas in the same amount of time, allowing more particles to be probed simultaneously."

The instrument employs a simple optical setup consisting of compact components that would allow it to be miniaturized into a portable device about the size

of a shoebox. It uses IR spectroscopy to detect the IR fingerprint of unknown materials without the use of bulky IR detectors.

"The most important advantage of our new technique is its highly sensitive, yet remarkably simple design," said Sullenberger. "It provides new opportunities for nondestructive chemical analysis while paving the way toward ultrasensitive and more compact instrumentation."

The researchers plan to test their microscope on additional materials, including particles that are not spherical in shape. They also want to test their setup in more realistic environments that might contain interferents in the form of particles that aren't from the chemical of interest.

"The presence of interferents is perhaps the biggest challenge I anticipate we will need to overcome," said Stolyarov. "Although contamination is a problem for any technique measuring absorption from small amounts of materials, I think our technique can solve that problem because of its ability to probe one particle at a time."

The microscope's ability to identify individual particles could make it useful for fast detection of chemical threats or controlled substances. Its high sensitivity is also ideal for scientific analysis of very small samples or for measuring the optical properties of materials.

The research was published in *Optics Letters*, a journal of the Optical Society of America (doi: 10.1364/OL.42.000203).

Infrared links could replace wires in data centers

UNIVERSITY PARK, Pa. — A team of engineers is proposing to eliminate most of the wires in data centers and instead use infrared free-space optics for communications.

The free-space optical inter-rack network with high-flexibility (Firefly) architecture is a joint project of Penn State, Stony Brook University and Carnegie Mellon University.

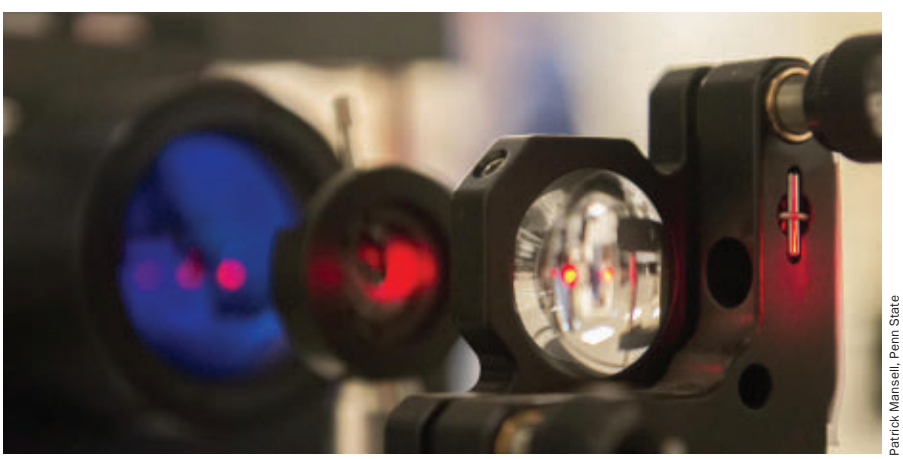
Firefly uses infrared lasers and receivers mounted on top of data center racks to transmit information. The laser modules are rapidly reconfigurable to acquire a target on any rack.

Mohsen Kavehrad, W. L. Weiss Chair Professor of Electrical Engineering at Penn State, said human interference is minimal because the racks are more than 6.5 feet high and most workers can walk between the rows of racks without breaking the laser beams.

"It uses a very inexpensive lens, we get a very narrow infrared beam with zero interference and no limit to the number of connections with high throughput," said Kavehrad.

While fiber-optic cabling and energy expenditure for idle servers are problems, throughput is more critical. When hundreds of cables merge into a few, the data transfer bottlenecks that result reduce the speed at which the data center can deliver information. A flexible, configurable system could be the fix, reducing bottlenecks and decreasing the number of servers needed.

The engineers have created a simplified, proof-of-concept system to show that their infrared laser can carry the signal and target the receiver. They are transmitting wavelength division multiplexed, bidirectional data streams each carrying data at a transmission rate of 10 Gbps from a bit error rate (BER) test set. BER testing determines the number of errors in a signal caused by interference, noise, distortion or synchronization problems.



Patrick Mansell, Penn State

An infrared laser beam is going into the receiver of the signaling system.

The proof of concept setup has the bidirectional signal wavelength division multiplexed with a one-way cable television signal. The total data stream goes from fiber-optic cable to the infrared laser, across the room to the receiver and shows the results on a TV and the BER test set. A hand breaking the laser beam shuts off the system, but when the hand is removed, the signal is rapidly reacquired.

The system uses microelectromechanical systems (MEMS) with tiny mirrors for rapid targeting and reconfiguring. These MEMS use tiny amounts of electricity from four directions to reposition the mirror that targets the receiver. The movement of the mirrors is so small it is undetectable, but the computer program quickly locates the receiver and then narrows the target to pinpoint accuracy. The laser beam can also be rapidly moved to target a different receiver. Accurately targeting and sending a signal via infrared laser are only two of the hurdles the researchers need to pass before Firefly is operational. Once the signal arrives at the target it must seamlessly enter the fiber-optic cable. Controlling and managing the data distribution system in an unwired environment is also important.

"We are trying to come up with something reconfigurable using light instead of millimeter waves (radio frequency)," said Kavehrad. "We need to avoid overprovisioning and supply sufficient capacity to do the interconnect with minimal switches. We would like to get rid of the fiber optics altogether."

The National Science Foundation supported the Firefly project.

New design tools produce higher-quality, lower-cost large-area LEDs

OULU, Finland — A novel LED light source based on large, flexible and transparent substrates has been developed with help from an easy-to-customize LED foil. The light source, developed at the VTT Technical Research Centre of Finland, can be mass produced and used in applications such as vehicles, greenhouses, shopping centers and architectural lighting.

VTT is working with Finnish companies Flexbright and Lighting Design Collective on a three-year European project called Delphi4LED. Their main objective is to develop a standardized method to create multi-domain (thermal-optical-electrical) LED-based design and simulation tools for the solid-state lighting industry.

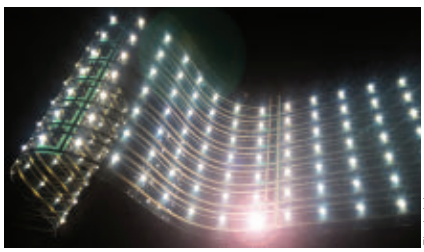
Heat management is a key factor dictating the performance and reliability of LED lighting solutions. The operation of LED components is also affected by their electrical and optical characteristics. Combining all of these properties is difficult using the existing design tools.

Researchers in the Delphi4LED project have developed new simulation models to consider these factors in simplified form, ultimately saving computing capacity and enabling a more comprehensive design than is currently possible.

Researchers hope to make the design process more efficient and reduce the number of design errors. This will allow faster production and faster introduction of the products on the market, with higher quality and a lower cost.

A Finnish consortium coordinated by VTT Technical Research Centre of Finland is applying the results of the Delphi4LED project to the development of LED luminaires based on transparent large-area foil. These kinds of novel structures enable the implementation of a thin, flexible light source for lighting and display applications.

The project is being coordinated by Philips Lighting from the Netherlands. Other partners in the consortium are Technische Universiteit Eindhoven from the Netherlands; Havells Sylvania Lighting Belgium from Belgium; Magillem Design Services SAS, Ingélux, PISEO, Philips France and Ecce'Lectro from France; Budapest University of Technology & Economics and Mentor Graphics Hungary from Hungary; Mentor Graphics UK from the United Kingdom; and Pi Lighting SARL from Switzerland.



Flexbright

The Delphi4LED project has developed a tool that enables mass production of high-quality large-area LEDs that cost less.

50 Years of **Photonics in Defense**

From state-of-the-art aerial imaging systems of the ’60s to Boeing’s Airborne Laser project in the the 21st century, photonics technology has played a vital role in the modern military. In honor of *Photonics Spectra*’s 50th anniversary, the editors compiled a retrospective on major advances by era.

The Airborne Laser and Advances in Airborne Optics

(2006-Present)

In the early 2000s, Boeing and other contractors developed the Airborne Laser (ABL), consisting of lasers aboard a plane that would effectively target and destroy ballistic missiles during the boost phase of flight. This same era saw advances in airborne optical systems and larger detectors capable of operating in expanded spectral ranges.

Optics-based systems have to be protected in flight, which may be done through a clear enclosure or via a retractable system.

Thales Group, *EuroPhotonics*, Winter 2016

Thales Group, *EuroPhotonics*, Winter 2016

Mounted in structural assemblies, optics help ensure airborne sensors produce the clearest possible image.

Photonics Spectra, June 2014

For additional images, visit www.photonics.com/A61773.

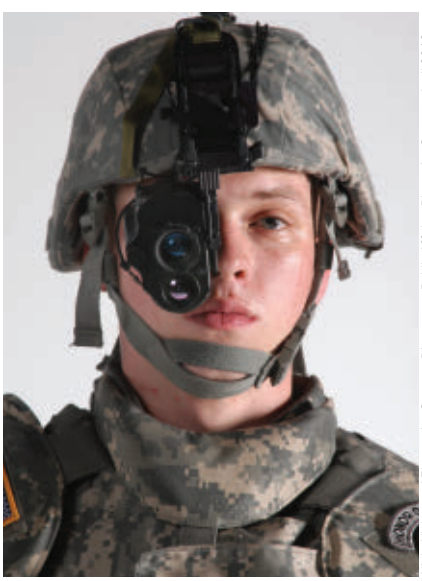
Spectrometers Detect Chemical and Biological Agents

(1991-2006)

By the early '90s, chemical and biological warfare was becoming a more evident threat. Miniature spectrometers that incorporated UV lasers could identify agents by their reflective properties.

ICx Technologies, *Photonics Spectra*, December 2009

A National Guardsman samples a spill using a handheld device and Raman spectroscopy to identify the liquid.

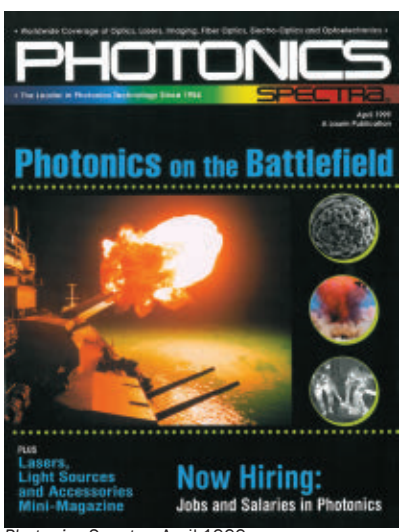


Night Vision and Electronics Sensors Directorate Public Affairs, *Photonics Spectra*, April 2013

Enhanced night-vision goggles like these, developed for the U.S. Army's Night Vision and Electronic Sensors Directorate, fuse IR-based thermal imaging with visible image intensification.

Quintessence Photonics Corp. *Photonics Spectra*, December 2005

Mid-infrared diode lasers enable early warning systems against chemical warfare agents



Photonics Spectra, April 1999

IR Imaging Evolves

(2000-Present)

The 21st century has seen key advances in IR imaging, allowing for cheaper, lighter and less power-hungry equipment. Materials such as strained superlattice gallium arsenide allowed for greater sensitivity and higher operating temperature.

U.S. Air Force photo by Tech. Sgt. Steve Faulisi, Balad Air Base, *Photonics Spectra*, April 2010

U.S. Army photo by Spec. Olanrewaju Akinwunmi, *Photonics Spectra*, April 2010

A close-up night-vision view of a U.S. Army soldier, 1st Battalion, 30th Infantry Regiment, wearing a Kevlar helmet with night-vision goggles attached **(right)**. Night-vision light-enhanced photography showing U.S. Army Sgt. 1st Class Arnold Stone, 2nd Battalion, 108th New York Army National Guard, wearing his AN/PSV-7D night-vision goggles while using a handheld radio to call for a situation report **(above)**.

Aerial Imaging

(1966-1976)

During the late '60s and early '70s, the military called for more advanced imaging systems to produce sharp, high-resolution images taken from planes, as seen in "Improving the Photogrammetric Characteristics of Aerial Cameras," in the Jan./Feb. 1968 issue of *Optical Spectra*.

Optical Spectra, January/February 1968

The 6-in. f/5 Geocon IV lens designed by James G. Baker.

Optical Spectra, January/February 1968

This photograph of Phoenix, Ariz., was recorded by the Fairchild-designed KC-6A camera installed in an RC-135A aircraft from an altitude of 25,000 feet. Sky Harbor Airport is near the center of the photo.

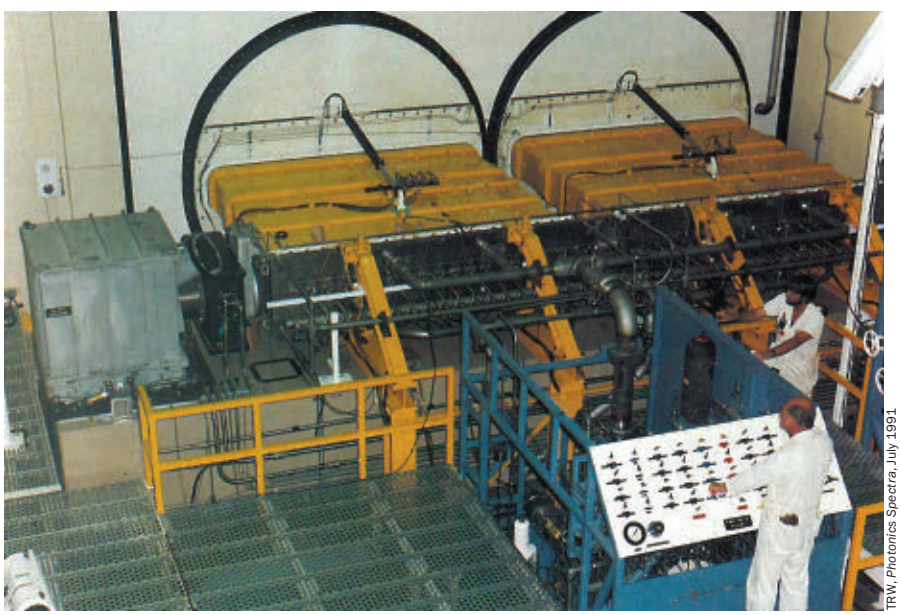
Directed Energy Weapons

(1991-2006)

Directed Energy Weapons (DEWs) may not have been integrated into the military as much as speculated, but the research influenced the development of other directed energy applications. Industrial photonic equipment (welding, machining, etc.) benefited from the research done for DEWs and continually impacts manufacturing.

TWR Inc., *Photonics Spectra*, June 1994

An artist's rendition of the general area defense integrated anti-missile (GARDIAN) laser system proposed by TRW of Redondo Beach, Calif., to the U.S. Army for use against cruise missiles.



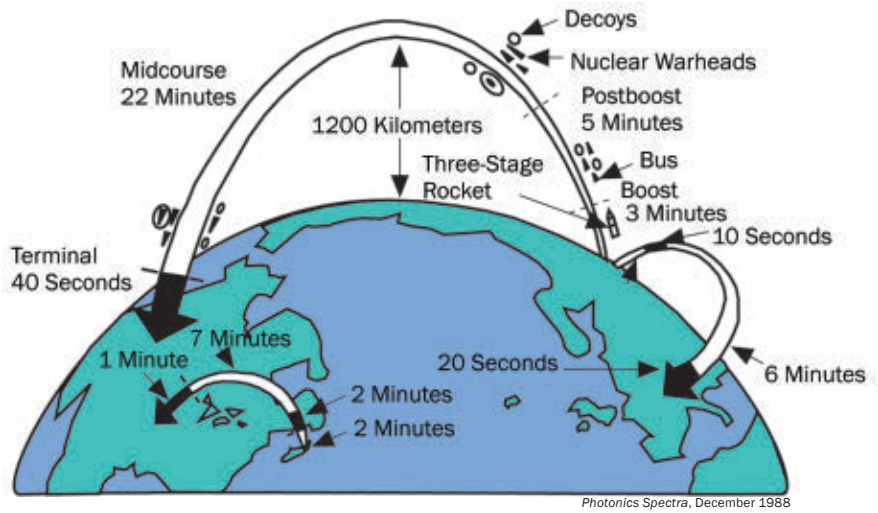
TRW, *Photonics Spectra*, July 1991

MIRACL laser in test configuration.

Star Wars

(1984-1991)

The Strategic Defense Initiative epitomized the Reagan era. The program aimed to protect the U.S. from ballistic nuclear attacks using space-based lasers. Investigations involved x-ray and chemical lasers and spurred advances in IR imaging.



Photonics Spectra, December 1988

The missile thread that the Strategic Defense Initiative was charged with defending against.

Photonics Spectra, August 1989

Stampede to "Star Wars"

It was just two and one-half years ago that President Reagan, in an emotional finale to an otherwise forgettable speech, called for the development of a space-based antimissile defense system that would make nuclear weapons "impotent and obsolete." Today it would be difficult to find a first-rate scientist who considers that a realistic, attainable goal. Yet the "Star Wars" program that it hatched is on its way to becoming a gigantic new industry — potentially "the first trillion-dollar weapons project." ... A recent Wall Street Journal *article describes "Star Wars" as the "business opportunity of a generation," and speaks of military suppliers engaging in a veritable "feeding frenzy" to get a share of the $26 billion allocated for the program's first five years. The photonics industry is among the big potential beneficiaries.*

— Teddi C. Laurin, *Photonics Spectra*, July 1985

Dawn of Fiber Optic Communications

(1976-1984)

During the late '70s, the military began integrating optical technology with radar and testing whether the technology could withstand the stress of the battlefield. This laid the groundwork for advances in communications that would pave the way for faster transmission of information.

Optical Spectra, March 1979

Personnel at Sembach Air Base in West Germany are shown here dropping a kilometer-long optical fiber cable that was used to connect a control center at the base with a remote radar installation. The fiber optic radar link was tested by the U.S. Air Force Electronics Systems Division and the Mitre Corporation, which designed and manufactured the link.

Head-Up Displays for Aviation

(1966-1976)

Extensive research was done to develop a pilot visual aid system to improve flight safety. Head-up displays (HUD) superimpose flight information on the inner windshield of the cockpit of a jet fighter in vivid color.

Electric Picture Display Systems

As Good as the Real Thing for **Military Training**

Better resolution, contrast and luminance have improved head-mounted virtual and augmented reality systems, giving airborne pilots and seagoing navigators a 'true-to-life' representation of the battle theater.

BY HANK HOGAN
CONTRIBUTING EDITOR

"Fight like you train and train like you fight" is a military maxim. To better do that, the military is turning to virtual, augmented and mixed reality. In virtual reality (VR), digital representations replace the real world, with a high-end example being immersive simulators with realistic sights, sounds and motion. In augmented reality (AR), projected data overlays what trainees see. Mixed reality (MR) combines the real and synthetic.

Substituting representations for actual friend, foe, equipment and hazards enables less costly, safer and more frequent training of airborne pilots, seagoing navigators, maintenance and repair technicians, and others. In this, VR/AR/MR benefit from ongoing display improvements.

"As technology advances, more capabilities are possible, and therefore it's possible to provide higher-fidelity solutions," said Benito Graniela, visual systems engineer at the Naval Air Warfare Center Training Systems Division in Orlando, Fla.

Gains in resolution, luminance

In general, costs are down and performance up. Consumer industry demand has cut the cost of computing platforms, graphics cards, memory and disk drives. Also, display aspects such as resolution, contrast, luminance, refresh rate and geometric distortion have gotten better. That makes critical visual cues appear more lifelike.

"The economies of scale generated by these markets and the shift from custom build to COTS (commercial off-the-shelf technology) have allowed for higher-fidelity virtual environments at the same cost of systems of five or 10 years ago," Graniela said.

The recent development of inexpensive yet capable head-mounted units promises

(Above) When there are multiple projectors in a virtual reality simulation, they must have their output blended and warped to avoid artifacts where outputs overlap. Here is the result of a camera-based blending and warping.

MetaVR, Close Air Solutions and Battlespace Simulations

continued future improvement. However, more needs to be done, such as in deploying higher resolution and faster refresh devices. The result could eventually be a low-footprint yet highly immersive experience.

At the same time, though, as important as the display are the seamless integration of the virtual environment, the simulation models and the human-computer interface. Furthermore, simulation or motion sickness has been the primary reason why such applications have not advanced further, although work has been done to solve some of the basic problems, Graniela said.

In a large system, the scenes displayed are constructed via multiple projected images, which present challenges. The different individual segments, for example, must be seamlessly blended together. In military applications, this can be difficult because training may involve simulating operations at night. Hence, not only must the display be bright enough but the contrast must also be high. It may perhaps have to be as much as two million to one for simulating the nighttime landing of Navy planes on aircraft carriers.

Image generators for flight training must compute a scene 60 times a second. With today's projector displays, this can mean doing so for four million pixels.

While system resolution is important, color and other visuals are as well, said R.P. Higgins, president of Melbourne, Fla.-based Electric Picture Display Systems, which makes large simulation systems for military and civilian clients and has experienced the consumer-driven display technology push. Years ago, projector illumination was done by lamps, which tended to dim, so that after a few hundred hours a red buoy might appear yellow. The advent of LEDs fixed that problem, but at the cost of a decrease in brightness. Now laser phosphor illumination is being deployed.

"It gives a steady light but probably at five or six times the brightness levels, and maybe more, of an LED," Higgins said.

The future is 8K

Looking forward, resolution will continue to increase, he added. Today, the state-of-the-art for projection is 4K, or roughly 4000 pixels in the horizontal

(Above) An image generator is running in four displays — three that can be seen and a fourth within the JTAC's (joint terminal attack controller's) Ranger 47 binoculars/laser designator on the tripod. This shows training using a 4-meter 220-degree cylindrical display featuring a seamless high-fidelity image surface.

Merged reality, which combines the real and synthetic, is being used for maintenance training, in part because it allows collaborative training.

and 2000 vertical. On the horizon is 8K resolution, which has about four times as many pixels.

The Oculus Rift, the HTC Vive and other head-mounted devices (HMDs) are a promising display trend but they have a drawback: Users cannot see what's around them. Rockwell Collins, a Cedar Rapids, Iowa-based avionics and IT supplier, has a solution, said Craig Langhauser, product line manager in the simulations and training solutions group.

The company mounts live action cameras on the goggle-like device, using these to capture surroundings. This is then blended with the virtual environment, creating a mixed reality display.

"Most importantly, the trainee sees themselves. They see their hands, their own feet, their own gear," Langhauser said. "It gives a truer sense of immersion and connection to the training. Therefore, you get better training."

The visual representation does not have to be perfect, but it, along with everything else, must be good enough to convince users. Typically, this means that a combination of visuals, sounds and motion must be employed, with the fidelity of each varying by application, Langhauser said.

Looking to the future, he cited the past. More than a decade ago, Rockwell Collins produced a custom system for the U.S. Army because consumer technology lacked the necessary performance. When that was no longer true, the cost fell from tens of thousands to a few hundred dollars. Something similar is happening to VR, AR and MR applications, according to Langhauser.

For another use case, consider efforts by the DiSTI Corp. of Orlando, Fla. It has been investigating the use of see-through self-contained units, like Microsoft's HoloLens, for mixed reality maintenance training. An important advantage of this approach is that it allows a collaborative work environment.

Quantum3D

A Navy Seahawk helicopter full-mission simulator. Such virtual reality applications include sight, sound and motion to create a realistic-seeming situation suitable for training.

Rockwell Collins

Using cameras to capture nearby surroundings enables merged reality, allows trainees to see their own hands and body, and can improve training.

Current displays need to have higher resolution, a wider field of view, a faster refresh rate, be brighter and have an improved battery life.

Electric Picture Display Systems

Nine projectors installed 32 in. above the floor create a 360-degree image, used in virtual reality simulations for military and other training.

"Maintenance is done in teams, and so should be the training," said Scott Ariotti, director of global marketing.

With mixed reality, trainees can be presented with a synthetic environment that can contain real mockups that must be physically manipulated. What's more, each trainee can get an individual view. However, current HMDs need to have higher resolution, a wider field of view, a faster refresh rate, be brighter and have an improved battery life, Ariotti said.

Over time, these issues may be resolved. For that to happen, though, it will be because the fix aligns with a mass market use, like gaming or entertainment. Then the military will be able to take advantage of the advances, leading to changes in the training ecosystem.

MetaVR Inc. of Brookline, Mass., has been making PC-based image generators, which transform a database into a virtual scene, for 20 years, said Philip Winston, lead software engineer. Traditionally these have run the multiple channels found in a large, domed simulator. The arrival of HMDs of adequate resolution could change that.

"Instead of one guy training, you have 50 guys and they all have HMDs," Winston said, in discussing an expansion of the image generator audience and target.

He added that MetaVR invests heavily in its software. Much of this involves tailoring the image generator so that it can take advantage of hardware improvements, such as the move from one to many processor cores.

An example of this application expansion can be seen in a system developed by Quantum3D, a Milpitas, Calif.-based training and simulation provider. Jan Bjernfalk, vice president of products, recalled a request to add a medic to a helicopter evacuation trainer. The medic didn't need the same degree of visual fidelity as a pilot, but what was presented to the medic did have to sync up with what others saw. Current head-mounted displays provided a good-enough representation, for much less than a separate domed display.

"They're virtually inside the helicopter. They can be looking at a virtual patient,"

U.S. Navy

An engineer with the Naval Air Warfare Center Training Systems Division tests a commercial off-the-shelf (COTS) virtual reality headset. Such headsets could help in virtual reality based training, particularly after further development and improvement.

Bjernfalk said. "They need to be able to communicate with the rest of the crew and do their job."

Even if head-mounted and other simulation displays improve, the advances won't be entirely without cost to the military. As resolution moves up, so too does the file size, boosting bandwidth and processing demands.

When "good enough" is OK

There also is greater data density to consider, said Vlad Argintaru, project engineering manager at Aero Simulation Inc. of Tampa, Fla. At one time the imagery resolution in a database was between one and 16 meters. Now synthetic environments are built from imagery resolution of as much as 30 centimeters and terrain elevation posts eight or less meters apart.

Image generators for flight training must compute a scene 60 times a second. With today's projector displays, this can mean doing so for four million pixels, Argintaru said. The quality of the rendering by the display is critical.

"What is more important than a high pixel count is to have smear reduction techniques that render better-quality pixels," Argintaru said.

If HMDs can replace more expensive displays, then the cost savings can be substantial, said Dan Brockway, vice president of marketing at VT MÄK, a Cambridge, Mass.-based company that makes image generator software.

Although options exist when constructing a VR, AR or MR representation, there is a downside when leveraging consumer technology. Military users will be familiar with game and entertainment imagery and may expect to get the same level of visual detail. But games are built on a business model where large sums can be spent optimizing the virtual world, something not practical — and often not required — for military projects, Brockway said.

He noted that a simulator only needs to have good-enough fidelity to make it effective. Hence, there may be no need for game-like visual content.

"It's a challenge to build all that content, but the technology is there to do it," Brockway said.

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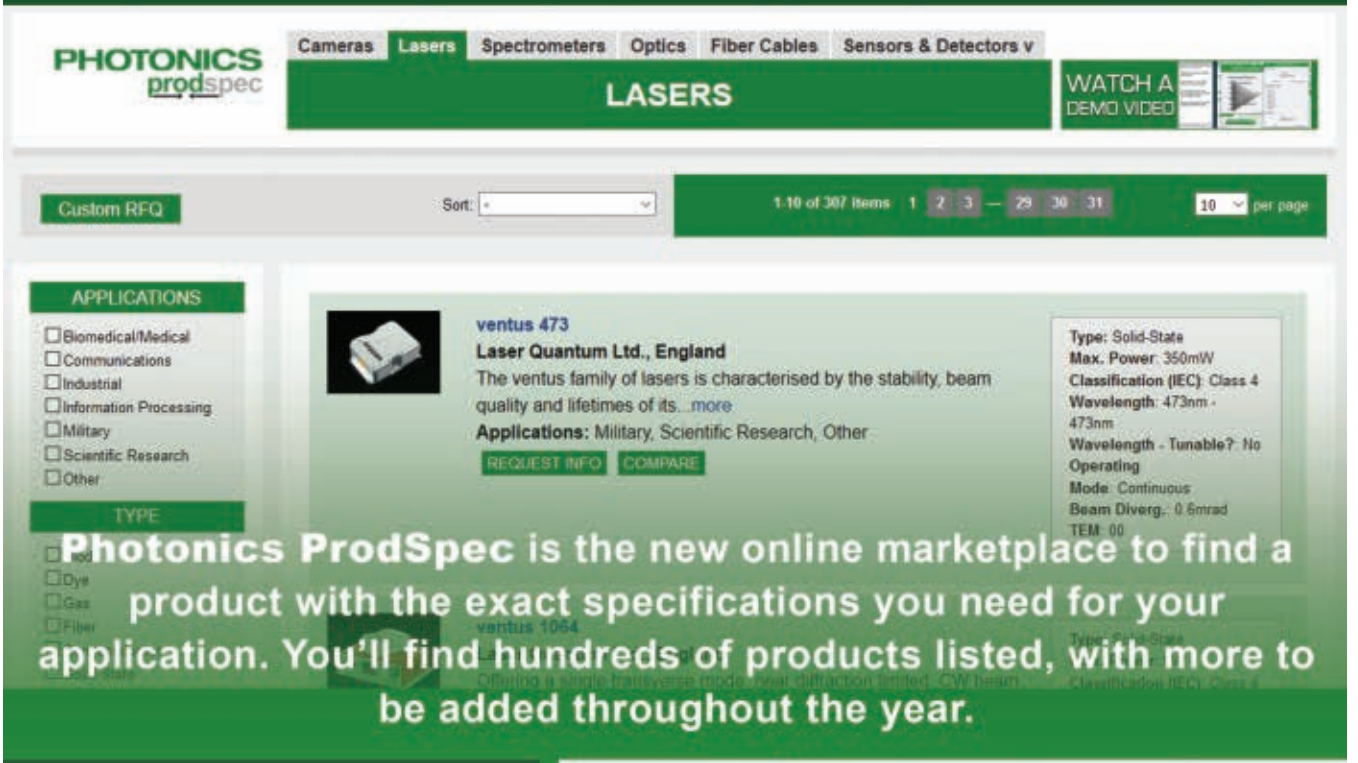

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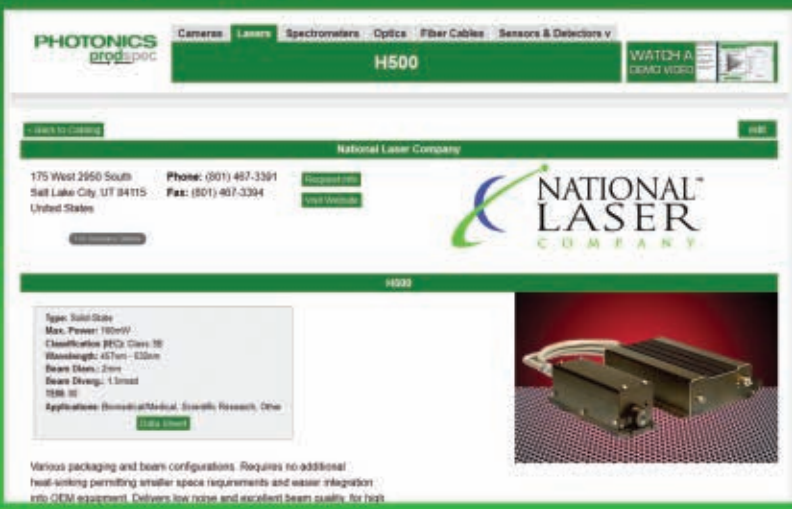

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PHOTONICS MEDIA

Defense Drones Take **Sensing** to New Heights

Ever-smaller UAVs — along with larger ones built for high-altitude flight — are equipped with an impressive array of sensitive optical sensors, laser rangefinders and thermal cameras for tasks ranging from intelligence gathering to hunting down terrorists.

BY MICHAEL D. WHEELER
MANAGING EDITOR

They're lurking in the air in the trouble spots around the world, from the mountains of Afghanistan to the deserts of Iraq and Syria, to the disputed waters of the South China Sea. Unmanned aerial vehicles (UAVs), or drones, are acting as the eyes in the sky, playing an increasingly prominent role in spying, search and rescue operations, border security and combat operations.

Today, the big players in the drone market — Boeing, Lockheed Martin, Northrop Grumman, AeroVironment, and Thales — have significantly stepped up their game, offering unmanned aerial systems (UAS) in different domains and classes. As the type and nature of drone missions has expanded, so too has the assortment of imagers, sensors and rangefinders found on them.

Advantage to the hawk-sighted

Some of the most interesting advances have come in the fast-expanding "micro UAV" class. Consider the palm-sized Black Hornet Nano drone from Prox Dynamics AS of Norway. In use by the Norwegian and British armies, the 10 × 2.5-cm system is small enough to fit in a soldier's pocket and is deployed by throwing it in the air. Its main mission is to provide troops with situational awareness — scouting for obstacles, hidden enemy shooters and explosive traps in the war zone.

Despite its size — it weighs less than an ounce — it can fly for up to 25 minutes at line-of-sight distances for up to a mile. Billed as an aerial sensor and hand controller, the pocket-sized system offers unique advantages for situational awareness and mission planning.

"Calling the Black Hornet a drone

doesn't do it justice," said Kevin Tucker, Flir's Surveillance GM. "The Black Hornet is a flying sensor, rather than a drone, as it is a highly optimized airborne vehicle that is designed to carry specific electro-optical sensors."

The Black Hornet features three cameras in all, including Flir Systems' Lepton microthermal camera and a visible spectrum camera, as well as a low-power rotor and software for flight control, stabilization and communications.

"Prox Dynamics was actually one of our first customers for Lepton on their Black Hornet," said Jeff Frank, senior vice president at Flir, which acquired Prox Dynamics in November. "Through Flir's unique, commercially developed, military-qualified (CDMQ) business model, we invest in our own research and development, which enables us to build products and bring them to market faster. We're continuing to invest to reduce the size, weight and costs of our sensors."

Smaller than a dime and less expensive than a traditional IR camera, the Lepton was first introduced to bring thermal imaging to smartphones. It captures highly accurate, calibrated temperature from a distance, and features a radiometric thermal camera core, meaning it measures the absolute temperature in a scene.

While the company didn't disclose the specific use cases of the Lepton in a military setting, Frank noted that Flir also offers a commercially available radiometric IR camera — the Vue Pro R series. Knowing the absolute temperature of, say, an insulator in a power grid can be a strong indicator of the likelihood of a pending failure, Frank said.

For thermal cameras like the Lepton, there have been notable gains in heat dissipation. Ultra-light cryocoolers help reduce the sensor temperature to cryogenic temperatures, which boosts target detection and surveillance capabilities.

"The increasing concern over developing cost-effective cooling technologies is widening the opportunities for the cooled thermal imaging camera providers," said Moutushi Saha, lead analyst at Technavio, a market research firm that recently published the report "Global UAV Payload and Subsystems Market 2017-2021."

Size, weight and power

With the proliferation of mini drones comes a greater emphasis on sensor components that are smaller and more rugged — and often times available off the shelf.

In pint-sized UAVs, "the size, weight, power and cost (SWaP-c) parameters can be very critical and require the embedded systems to meet strict design and weight constraints," Saha said.

Those factors are often part of the conversation, confirmed Eric Desfonds, product line manager of sensors for the defense and aerospace division of Excelitas Technologies, which supplies photodiodes and lasers used in optical systems aboard defense UAVs, notably in laser rangefinders and laser spot trackers.

"In line with the desire to continue to optimize SWaP-c, we make small but high-performance components that are the building blocks for more complex systems," said Desfonds. "There is a desire in the market to use smaller packaging, even SMD [surface-mount device], not necessarily for UAVs, but in general for military systems. The commoditization of avalanche photodiodes and pulsed laser diodes certainly explains this."

The level of customization for components required in UAV payloads can vary considerably, but the assessment usually begins with what's already available on the market.

"Commercial off-the-shelf (COTS) products are often considered by designers. We sample first our COTS offerings and provide customizations and/or qualification to meet the customer's unique

Flir Systems

Flir Systems

The Black Hornet drone from Prox Dynamics AS carries three cameras — including the Lepton thermal imager from Flir Systems — to help scout for obstactles and hidden combatants.

Photographer Alan Radecki. Northrop Grumman

Photographer Alan Radecki. Northrop Grumman

Photographer Alan Radecki. Northrop Grumman

Scenes from the recent sensor installation of the Global Hawk

needs," Desfonds said. "Component design can be optimized to meet specific standards for the UAV design."

After that, components may be optimized for the respective UAV design.

"The rapid designing and innovations in COTS-based technologies have enhanced the computing capability and enabled compact designing," Technavio's Saha said. The "reduction of complete system development costs and reduced long-term maintenance costs have also driven the employment of COTS components."

A UAV equipped with an inbuilt camera and sensor processing unit, for example, has elements for imaging processing, image stabilization, video compression, analysis and tracking.

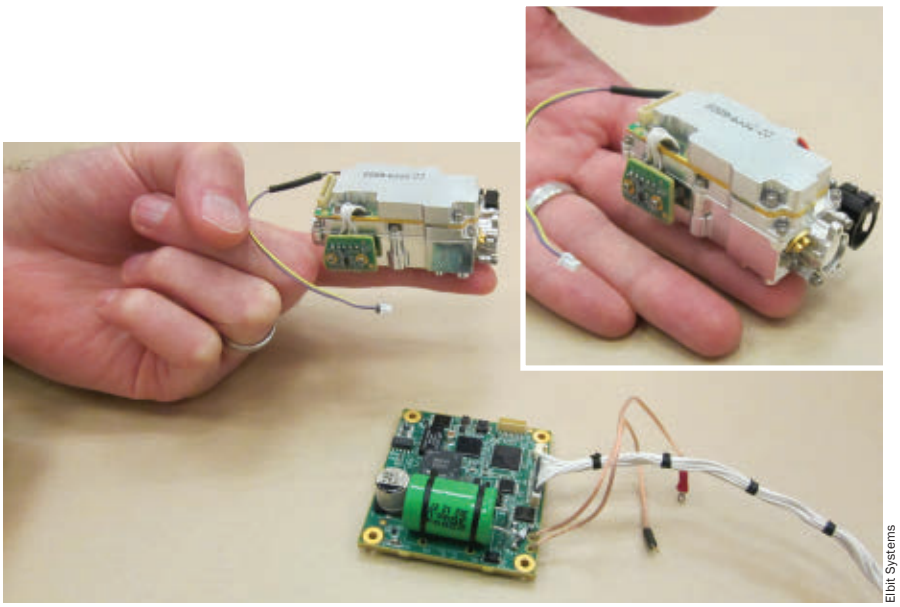
"All of these functions can be achieved just by employing an advanced COTS module, which is as compact as an SD memory card and can be used in the smallest sensor platforms," Saha said.

Another good example of the miniaturization trend can be found in an innovation from Haifa, Israel-based Elbit Systems. The company developed a new type of miniature designator marker (MDM) for its small-class UAVs. Laser designators allow users to rapidly home in on hostile targets.

"The operational need to designate from small UAVs, particularly below cloud cover, has become an ever-growing requirement to enable significantly shortening the sensor-to-shooter duration," said Dalia Rosen, Elbit's VP of corporate communications.

Elbit's high-performance MDM weighs only 100 g and is assembled using automated robotic techniques; it's too small to be manufactured using standard methods, according to Rosen.

It fits within the 4-in.-diameter optical turret aboard Elbit's Skylark mini-UAV that weighs only 7.5 kg. The Skylark can be used in conjunction with a fighter



Elbit Systems

A close look at micro designator marker (MDM), the miniature designator from Elbit Systems.

aircraft capable of deploying laser-guided weapons.

UAVs flying higher

On the other end of the spectrum from the hand-launched Skylark and micro-sized Black Hornet is the granddaddy of unmanned combat aircraft, Northrop Grumman's Global Hawk. With its 130.9-ft wingspan, bulging front and elegant looks, it dwarfs other entries in the UAV defense sector.

In operation with the U.S. Air Force since 2001, Global Hawk has amassed more than 200,000 flight hours with missions flown in support of U.S. military operations in Iraq, Afghanistan, North Africa and the greater Asia-Pacific region. It flies at very high altitudes — up to 60,000 ft — and for up to 30 hours at a time.

Its multiple sensor payloads gather near-real-time, high-resolution imagery of large areas day or night, not only "finding" targets using broad area searchers, but also fixing, tracking and assessing targets through its multiple sensor modalities.

Currently, it's undergoing an upgrade to the MS-177 seven-band multispectral sensor developed by UTC Aerospace Systems. The enhancements include a gimbaled optical design, a wide-area search mode and a motion imagery mode, according to Northrop Grumman. This upgrade essentially gives Global Hawk the ability to collect more than six times the area coverage in an hour than the current SYERS-2B operating on the U2 platform. The MS-177 can continuously track a target without having to change the UAV's flight path.

The MS-177, according to the research firm MarketsandMarkets, now "has the ability to provide the longest-range combat identification imaging capability in the U.S. military's inventory."

Flight tests with the new seven-band multispectral sensors began earlier this year, a Northrop Grumman spokesperson said.

In October of last year, the company tested a second sensor designed specifically for the requirements of high-altitude long-endurance missions. An optical bar camera synoptic sensor was fitted to the turret of a RQ-4 Global Hawk UAV.

"The high-altitude optical bar camera is the world's highest-resolution broad-area synoptic sensor," said Sachin Garg, an associate director at MarketsandMarkets and co-author of a recent report on the UAV defense market, "Drones Market by Type, Payload, Application, Component and Geography — Global Forecast to 2022."

The Global Hawk also tested the SYERS-2 intelligence-gathering system last February. The SYERS-2 features shortwave- and midwave-IR capabilities

continued on page 61

Unmanned Black Hawk Relies on Single-Photon Lidar for Navigation

Last year, Sikorsky, a subsidiary of Lockheed Martin, in partnership with Carnegie Mellon University and United Technologies, conducted a joint autonomy demonstration involving both an unmanned ground vehicle and a UH-60MU Black Hawk.

The Black Hawk was equipped with Sikorsky's Matrix technology — a set of hardware and software capabilities for autonomous flight — and was used to transport an autonomous unmanned ground vehicle to its mission area 12 miles away. The proof-of-concept demonstration was intended to showcase how autonomous technology can prevent exposing warfighters to hazardous conditions.

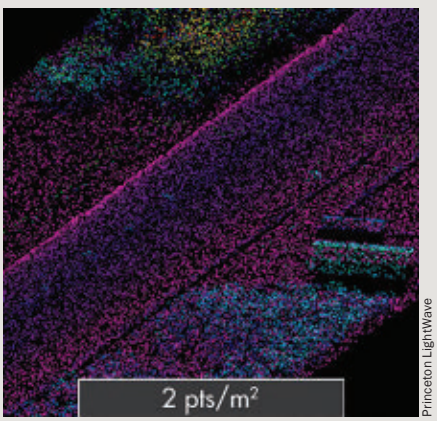
Aboard the Black Hawk was a single-photon lidar system featuring unprecedented sensitivity.

"Our 'secret sauce' is a single-photon technique called Geiger-mode lidar," said Princeton Lightwave's Jay Liebowitz, whose company developed the free-running camera.

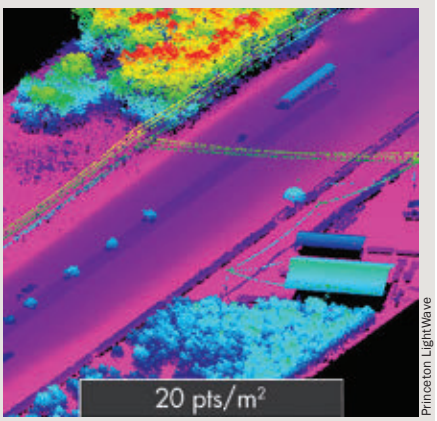
Single-photon or Geiger-mode lidar differs from conventional lidar in the very high rate of eye-safe laser pulses emitted (usually at 1.5 or 1.06 µm from YAG lasers). A Geiger-mode camera can count the small percentage of photons that bypass water droplets in the air, to get a true picture of what's in the flight path.

"The value in what we do is seeing through obscurants such as rain, fog and snow," Liebowitz said, a capability that's also prized in the advance of driverless cars.

Princeton's Geiger-mode camera features a 32 × 32-pixel focal plane array. It also features a "free-running" capability, allowing the camera to detect and read out events simultaneously — critical for applications such as coherent lidar and ultra-sensitive lidar situational awareness.



Princeton LightWave



Princeton LightWave

Geiger-mode lidar offers 10 times the resolution at four times the altitude compared with linear-mode lidar.

for low light operation and is capable of penetrating haze and smoke, making it particularly useful in detecting counter-insurgency operations.

Operating in low light conditions was a key attribute behind the development of the Mantis i45 gimbal, designed to deliver lightweight, compact and powerful visual awareness to the Puma AE unmanned aircraft from AeroVironment.

The gimbal features a suite of sensors for daylight, low light and thermal imaging including ultra-high-resolution electro-optical and IR imagers. The thermal IR imagers feature resolution of 640 × 512 pixels and a field of view at 32°. Dual 15 megapixel color cameras are designed to offer wide and narrow views.

Fully waterproof, the gimbal provides full lower hemisphere coverage, continuous pan and is packaged to withstand extreme environments.

"The combination of sensors and how they're packaged is unique to us," said Steve Gitlin, vice president of corporate strategy for AeroVironment, a supplier of UAVs to virtually every branch of the U.S. military and to 35 allied countries. "The fact the Puma can land on the ocean is a unique breakthrough in the space," he said.

The Puma was used last year aboard the U.S. Coast Guard Cutter *Polar Star* as part of an expedition to open up sea lanes in Antarctica. That mission involved streaming real-time footage from the i45 gimbal high-resolution and IR cameras to better understand ice thickness and other conditions.

Vidar: a new technology for maritime monitoring

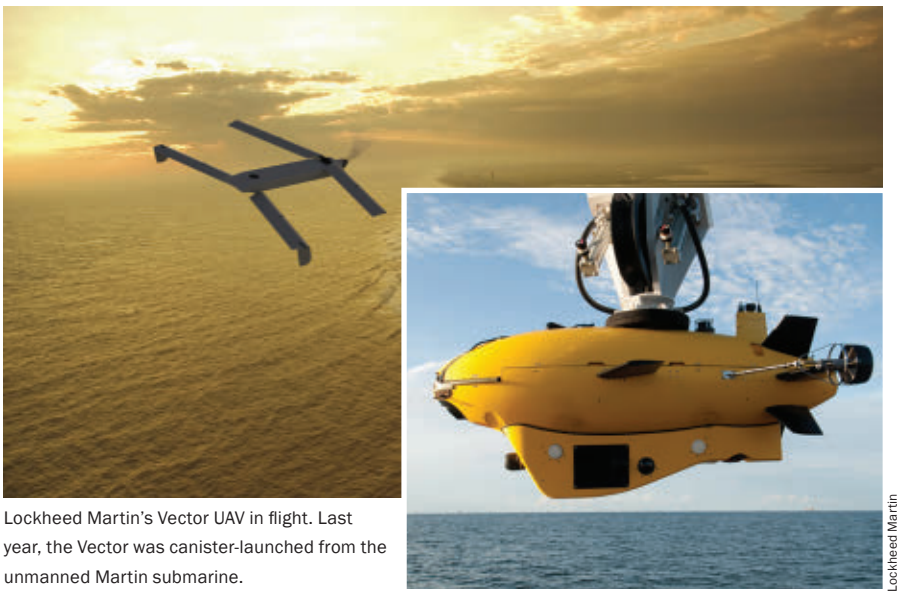
Another major player in the UAV field is Boeing, which, along with its subsidiary Insitu, offers UAVs of varying sizes and payloads for customers throughout the global defense markets.

"Our defense customers are increasingly employing us to provide them with high-resolution video imagery correlated with other types of sensors to achieve situational awareness and clarity," said Dave Anderson, director of defense payloads for Insitu.

Those sensors include an electro-optical imager, a midwave-IR imager and laser rangefinder, all housed aboard Insitu's RQ-21A Blackjack, an unmanned

Northrop Grumman

The Global Hawk in flight.



Lockheed Martin

Lockheed Martin's Vector UAV in flight. Last year, the Vector was canister-launched from the unmanned Martin submarine.

UAV Payload Market Set to Eclipse $10.5 Billion

The U.S., Russia, China and the U.K. have all made significant investments in developing next-generation UAV platforms for strengthening their security and surveillance offerings. The increasing need for surveillance and security operations, along with growing territorial disputes in maritime regions, has pushed military agencies to invest more in enhancing their target acquisition capabilities and acquiring more advanced UAVs with associated payloads and subsystems, according to Technavio, which recently released its "Global UAV Payload and Subsystems Market 2017-2021" report.

The firm estimates that the global UAV payload and subsystems market will reach a compound annual growth rate (CAGR) of 7.72 percent over a five-year period, reaching $10.05 billion in 2021 from $6.93 billion in 2016. In terms of regional segmentation, North and South America held a 49.21 percent market share in 2016, followed by APAC at 30.16 percent and EMEA at 20.63 percent.

The cameras and sensors segment constituted the highest share of the UAV component market at 39.97 percent in 2016, followed by the weaponry segment, which had a share of 27.27 percent.

system used extensively by the U.S. Marine Corp.

The Blackjack has two siblings: the slightly smaller ScanEagle, and the 135-lb Integrator. Featuring a 16-ft wingspan, the Integrator's payload includes a laser rangefinder, IR marker and high-definition electro-optical imager.

"Both the ScanEagle and Integrator are built in modular fashion, so we have the ability to change between payloads in the field," said Anderson. "This allows us to swap between our high-resolution EO900 turret to our EO/MWIR/laser pointer 'dual imager.'"

The increasing need to monitor the world's oceans from above prompted Insitu to unveil vidar (visual detection and ranging) technology aboard the ScanEagle in 2016. A wide-area autonomous detection system for electro-optic imagery, the vidar system includes a large backplane digital video camera that continuously scans the ocean in a 180° arc in front of the vehicle. Software then autonomously detects any object on the surface of the ocean, and it's so sensitive, it could detect the spout of a whale at 1.5 nm from the air.

"The original mission for our UAS was to search the ocean, initially for tuna, but not that much later for objects of more military interest," Anderson said. "As we evolved our full-motion video capability, we were stretched by two competing objectives — wide-area search and discovery and high-resolution imagery of objects in the water."

Working with the software company Sentient Vision Systems (SVS), Insitu employed a proprietary processing capability to find objects in the incoming video. The success of pixel-based search is directly related to the number of pixels available.

"The dual turret capability of vidar is the answer," he said. "While the multi-megapixel camera in the aft turret step-stares across a 180-degree swath, providing food for the SVS algorithms, our EO zoom camera up front allows us to interrogate the objects that the aft turret finds."

That combination proved highly effective for improving situational awareness in trials in the Pacific Ocean, off Cape Cod in the Atlantic, and during the Unmanned Warrior exercise in Scotland last year, he said.

Lockheed Martin also has its eyes on the high seas. Last summer it deployed a canister-launched small drone from an autonomous underwater vehicle in naval exercises held in Narragansett Bay, R.I.

Following instructions from a ground station via underwater communications, the underwater vehicle successfully launched the 4-lb Vector Hawk, which in turn transmitted continuous video during its flight from its Perceptor dual-sensor gimbal, a payload that included both electro-optical and IR imagers, as well as a laser illuminator.

The Perceptor is integrated into Procerus Technologies' vision processing unit, for target tracking, target geolocalization and net landing capabilities.

Future tradeoffs

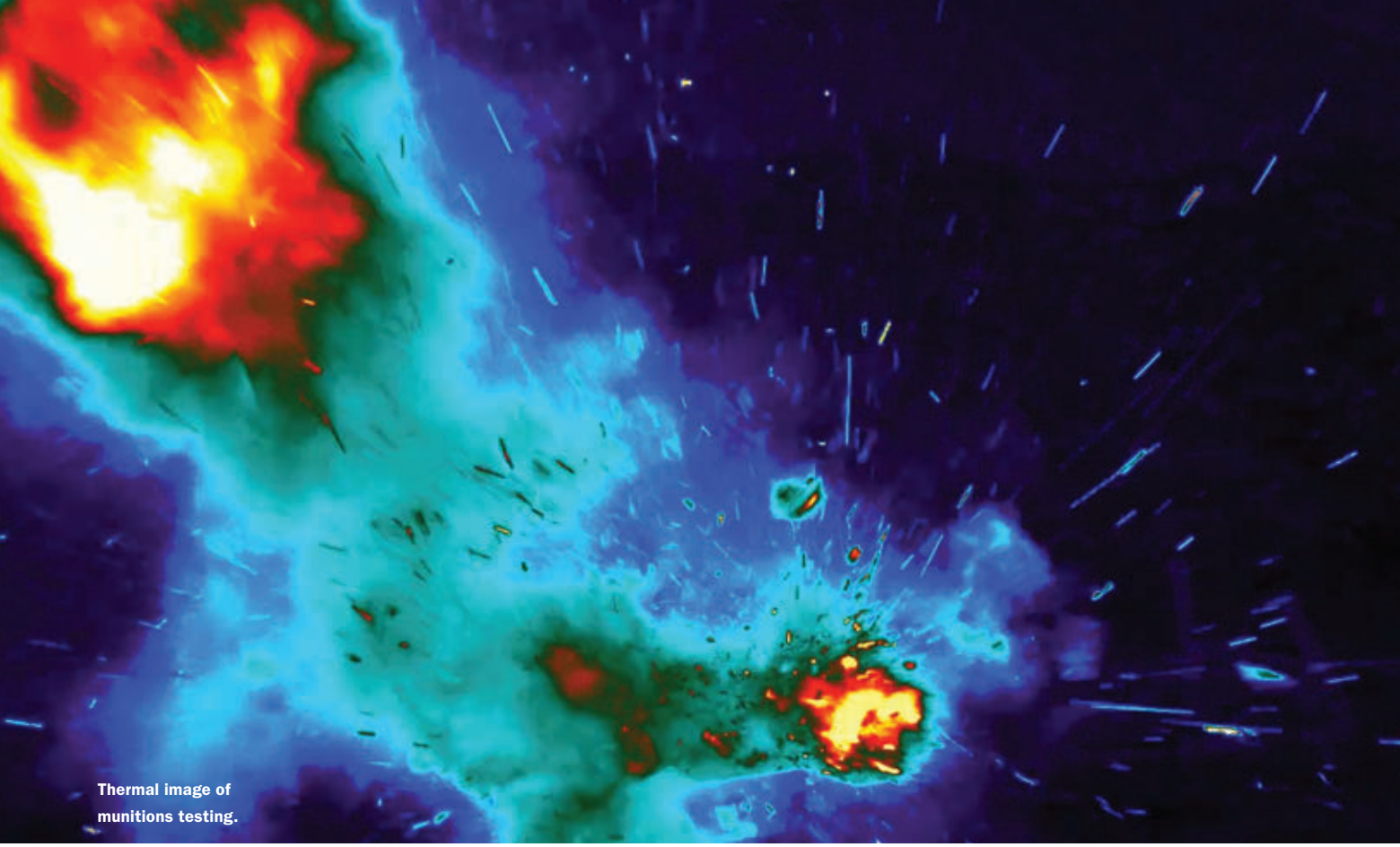
One of the biggest challenges right now is addressing customers' demand for higher resolution and increased endurance — even as UAVs become smaller.

"There are always trade-offs in the space in which we operate," said AeroVironment's Gitlin. "Any increase in battery size means we're carrying a heavier payload, which can adversely affect other system attributes such as flight time. At the same time, we're seeing innovations occur at the nanoscale."

michael.wheeler@photonics.com

AeroVironment

AeroVironment's Puma AE is equipped for land and maritime operations. Its gimbaled payload **(inset)** includes a stabilized IR camera and IR illuminator in one modular payload.



Thermal image of munitions testing.

High-Speed IR Detectors Aid Ballistic Testing

Next-generation high-speed IR readouts and new detector materials give IR cameras the needed speed and dynamic range for high-speed thermal testing on the range.

BY CHRIS BAINTER
FLIR SYSTEMS

For many years, high-speed visible cameras offered the ability to stop motion on fast-moving objects and provided unique insight through slow-motion playback for high-speed applications such as ballistics, munitions and tracking applications. Unfortunately, their thermal IR camera counterparts didn't offer the snapshot speeds, high frame rates, and wide temperature measurement ranges necessary to be useful for these same testing applications. But with next-generation high-speed infrared readout integrating circuits (ROICs) and new strain layer superlattice (SLS) detector materials, there are finally commercial off-the-shelf (COTS) infrared cameras that can provide the much-needed speed and dynamic range to meet the challenges of high-speed thermal testing applications on the range. The following will discuss the benefits of these next-generation ROIC and detector material technologies and how they are pushing the boundaries on high-speed thermal testing capabilities.

Legacy thermal cameras: slow frame rates

There are two key challenges to recording high-speed events with legacy thermal cameras. The first is that ROICs don't offer short-enough snapshot speeds to stop motion on high-speed objects, leading to blurring in the imagery and subsequently inaccurate temperature measurements. The second is that older ROICs simply don't have fast enough frame rates. If sampling isn't done fast enough, aliasing in the data can occur and critical temperature spikes could be missed during tests.

Over just the past two years, there have been significant gains in ROIC design and detector material, leading to significant breakthroughs in infrared camera technologies for high-speed thermal applications. New ROIC designs

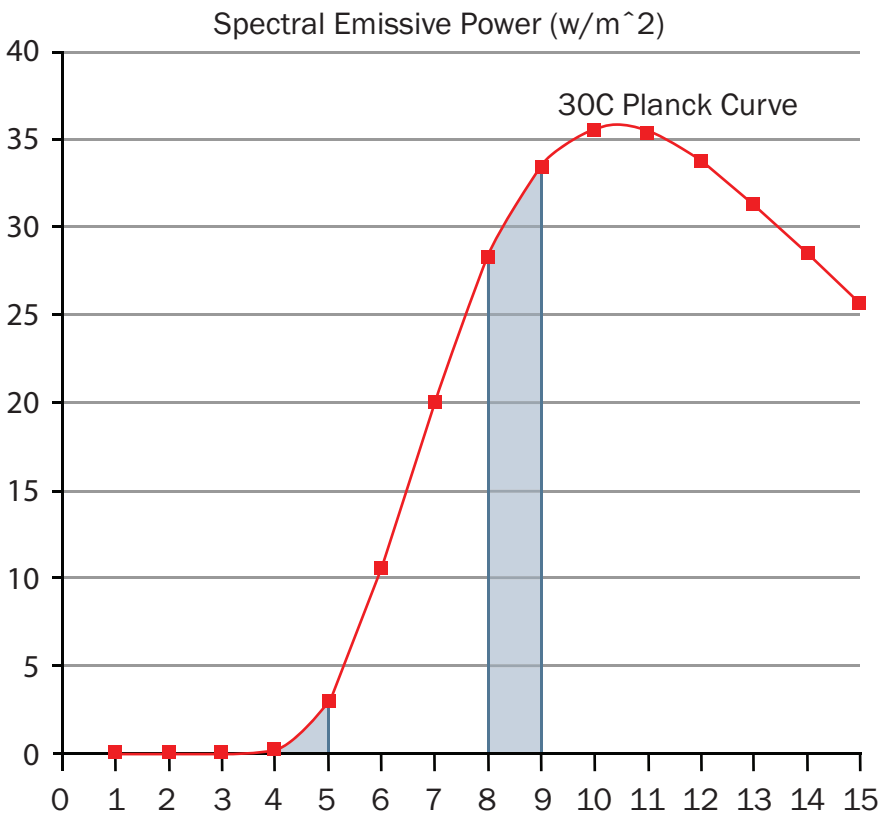
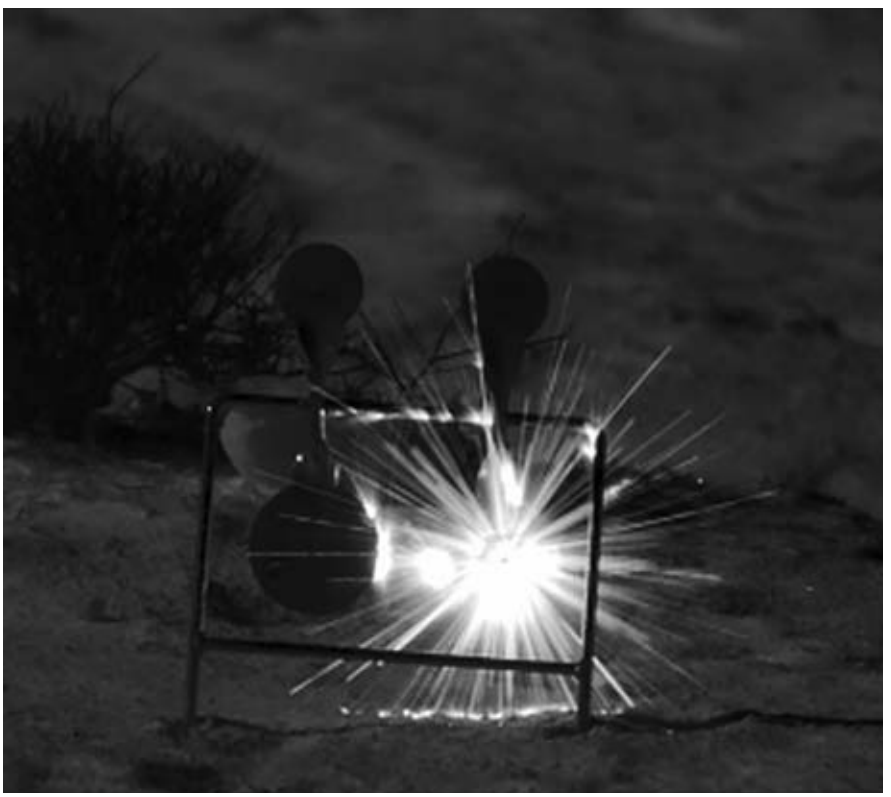


Figure 1. Spectral emissive power of a 30 °C ideal blackbody.



High-speed thermal camera image of .45 bullet hitting a steel plate.

now allow for integration times below 270 ns — sufficient to stop motion on many high-speed range applications, such as ballistics testing on a .223 round from an AR-15, impact and scoring applications, munitions testing on high explosives or muzzle flash measurements. The new design also allows for frame rates of thousands — or even tens of thousands — of frames per second, depending on the number of pixels per frame selected by the user. At those speeds, IR cameras are still only working at about 1/10th of the speed of that of a visible camera; even so, this is a giant leap forward and makes IR cameras now useful for high-speed range and lab testing applications.

Along with faster frame rates and higher speeds, newer ROICs are more linear across their entire dynamic range. This means that for a given increase in radiant energy, there's a corresponding linear increase in count values for the camera. Older ROICs have a roll-off at the low end and high end of the dynamic range. The response looks like an "S" curve. This is critical because, for many high-speed targets, the detector needs to be set at a short integration time to stop motion and allow for fast frame rates, but if the target is not hot enough, it won't supply enough photons for the detector to push into the mid well-fill range. These lower-temperature targets require operation at the very bottom of the well-fill. The older-generation ROICs, being nonlinear at low well-fill, meant the nonuniformity and calibrations would not calculate correctly and measurements on that data were nearly useless. Newer ROICs are linear all the way to near zero well-fill. This remedies the problem and allows for crisp imagery and accurate temperature measurements in this shorter well-fill range.

Long-wave SLS detectors

In recent years, there've been significant readout and camera electronic advances that push the limits of resolution, speed and sensitivity; however, it wasn't until recently, with the introduction of type II SLS, that the industry saw a new detector material enter the market that offers equally significant advances in overall thermal camera performance in line with their ROIC and camera electronic counterparts. With the integration

Images courtesy of Flir Systems

For many high-speed targets, the detector needs to be set at a short integration time to stop motion and allow for fast frame rates, but if the target is not hot enough, it won't supply enough photons for the detector to push into the mid well-fill range.

of SLS into commercially available thermal camera solutions, a new longwave-IR (LWIR) solution offers significant improvements in speed, temperature range, uniformity and stability over current detector material incumbents.

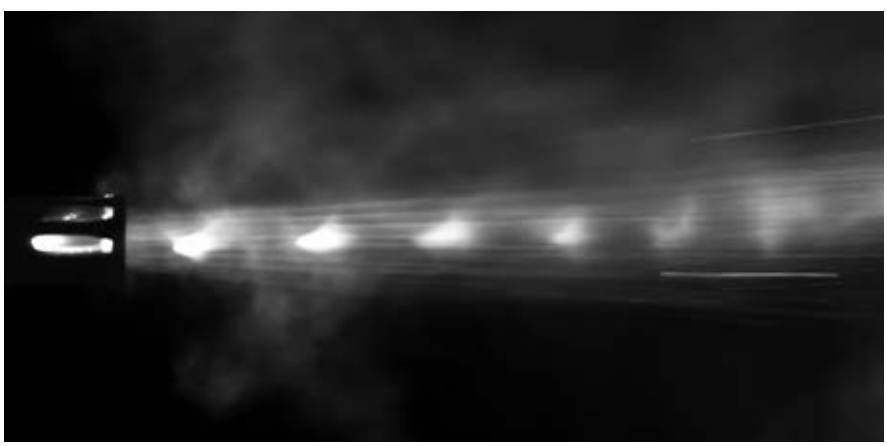
While SLS works in both the LWIR and midwave-IR (MWIR) bands, the biggest performance benefits come when SLS is filtered to the LWIR bands exclusively. In fact, one of the key benefits of SLS is its short integration times, or snapshot speeds, over other infrared camera materials. In comparison to similar MWIR indium antimonide (InSb) detectors, SLS has 12.6× faster snapshot speeds than InSb detectors when imaging the same temperature range.

As discussed previously, sometimes there is a scene that is changing fast, but is not sufficiently hot to achieve the well-fill needed for short snapshot speeds and high frame rates. For example, if a MWIR camera images at 640 × 512 at 1000 frames per second but requires an integration time of 1.2 ms due to the bandpass in which the camera operates, that would prevent achieving the camera's full frame rate potential. In comparison, an LWIR SLS detector will get more photons in the LWIR, which allow for shorter snapshot speeds and faster frame rates.

A second benefit of LWIR SLS thermal cameras is their wider temperature bands.

Table 1.
Camera Performance Metrics

LWIR SLS Camera, f/2.5, 7.5 to 10.5 µm		
Int T (ms)	**Temp Range (°C)**	**Filter**
0.1600 ms	−20 to 150 °C	None
0.0410 ms	55 to 350 °C	None
0.0146 ms	150 to 650 °C	None
0.0718 ms	250 to 1000 °C	ND1
0.0280 ms	400 to 2000 °C	ND1
MWIR InSb Camera, f/2.5, 3 to 5 µm		
Int T (ms)	**Temp Range (°C)**	**Filter**
2.0205 ms	−20 to 55 °C	None
0.8442 ms	10 to 90 °C	None
0.2403 ms	35 to 150 °C	None
0.1040 ms	80 to 200 °C	None
0.0179 ms	150 to 350 °C	None
0.3218 ms	250 to 600 °C	ND2
0.0535 ms	500 to 1200 °C	ND2
0.0191 ms	850 to 2000 °C	ND2
LWIR MCT Camera, f/3, 7.7 to 9.3 µm		
Int T (ms)	**Temp Range (°C)**	**Filter**
0.175 ms	5 to 150 °C	None
0.050 ms	125 to 300 °C	None
0.025 ms	200 to 375 °C	None
0.010 ms	300 to 475 °C	None



Mach diamonds exiting a barrel.

The LWIR SLS camera has a starting temperature range from −20 °C to 150 °C with one integration time (Table 1). To achieve the same temperature band with MWIR InSb, you'd need to cycle through (superframe) three integration times, each representing a different temperature range. Having to cycle through three temperature ranges means three times more work when calibrating the camera as well as one-third slower overall frame rate. Cycling through three temperature ranges to superframe them into one complete −20 °C to 150 °C temperature range

Watch the Video
View slow motion videos of a bullet being fired on a test range (FLIR Armor Focus) at **photonics.com/VideoGallery.aspx**.

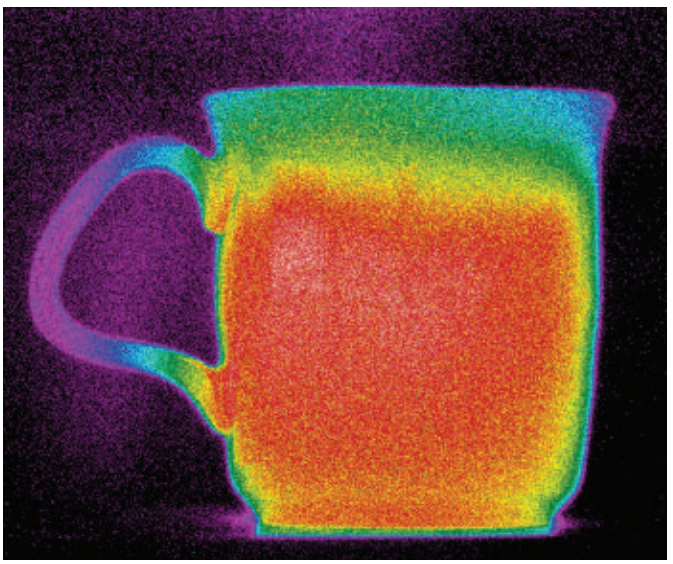


Figure 2. Mercury Cadmuim Telluride (MCT) image at start up.

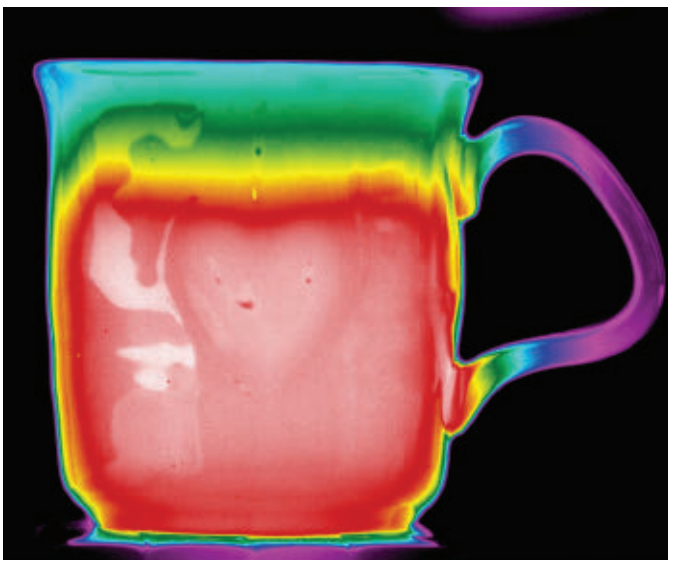


Figure 3. Strain layer superlattice (SLS) image at start up.

results in one superframe image per three frames captured from the camera.

One can also measure higher temperature ranges before needing a neutral density (ND) filter with LWIR SLS thermal cameras. The SLS camera evaluated allowed for measurements up to 650 °C before requiring an ND filter, whereas an MWIR InSb camera only measures up to 350 °C before it requires an ND filter.

This is partly a function of the SLS operating in the LWIR band vs. the InSb operating in the MWIR. Notice the spectral emissive power of a 30 °C ideal blackbody (Figure 1). The area under the curve represents the power within that waveband, which shows a much larger area for the LWIR than the MWIR. As objects heat up, this curve's peak shifts to the left and tails off to the right. The change in power in the LWIR band is less dramatic over a range of temperatures than the more dramatic change that happens in the MWIR band. This is how the SLS LWIR is able to avoid over- or underexposure for a given integration time in comparison to the MWIR InSb detector. In comparison, the change in power in the MWIR band is substantial and saturation soon occurs for a single integration time. The SLS allows users to tackle challenging applications where the target heats up across a wide temperature range quickly, such as a combustion research application.

However, operating in the LWIR is not the only factor. LWIR mercury cadmium telluride (MCT) detectors, for instance, also are limited in their ranges, similar to MWIR InSb detectors. Notice that the LWIR MCT cameras also have both shorter individual ranges per integration time as well as limitations on how high they can measure before needing an ND filter to cut down the signal.

When looking at high-speed range-testing applications, one of the biggest advances offered by LWIR SLS cameras in comparison to incumbent LWIR-cooled

detector options is the dramatically improved uniformity and stability through cooldowns. A main drawback to LWIR MCT cameras is the poor uniformity and stability. When the user turns on an LWIR MCT camera, the last uniformity correction performed needs updating (Figures 1 and 2).

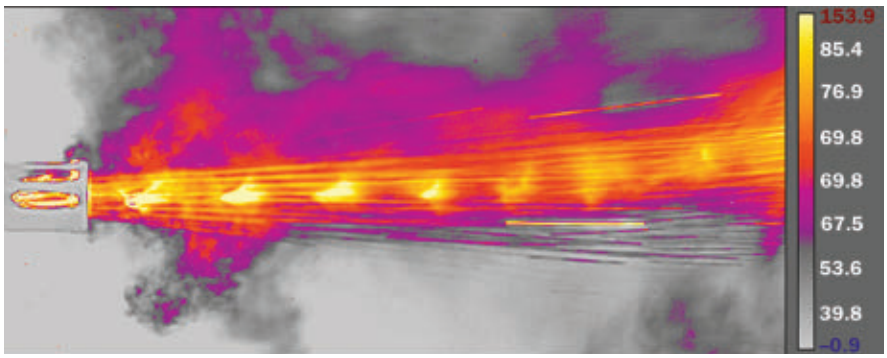
This presents problems for field-based test-range applications that are simply not conducive to updating gain, offset and bad pixel maps due to environmental conditions; for example, if the camera is in a test chamber, in a blast zone or another location that's not easily accessible. LWIR SLS, on the other hand, operates much like MWIR InSb: Simply turn it on and start testing. The uniformity correction done previously in the lab works just as well in the field with no extra image uniformity updates, beyond possibly a one-point-offset update using the internal nonuniformity correction (NUC) flag inside the camera. The NUC also holds well through multiple cooldowns over a long duration. The camera tested for this article has not required a new NUC since initial fielding of the camera more than a year ago.

Shorter integration times, faster frame rates

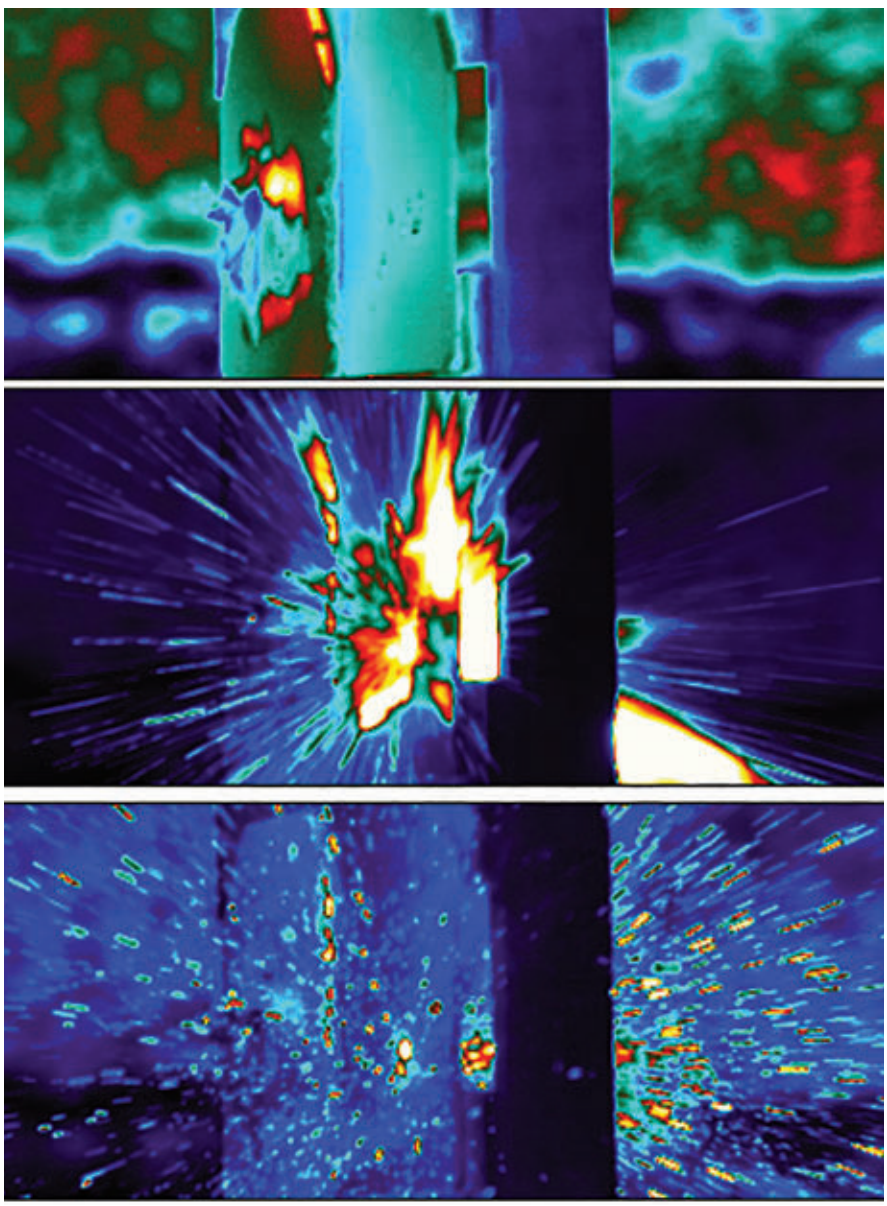
The advances in ROIC design allowing for shorter integration times, faster frame rates and better linearity at low well-fill, coupled with the advances in new detector materials such as LWIR SLS, high-speed thermal cameras, are finally becoming the standard for high-speed thermal measurement on the government test range. The SLS detectors fill a niche in the performance spectrum by offering shorter integration times, wider temperature bands and better uniformity than MWIR InSb or LWIR MCT materials.

Meet the author

Chris Bainter is the global business development director for Flir Systems, a world leader in the design, manufacture and marketing of sensor systems. Chris has a bachelor's degree in computer engineering from Kansas State University and an MBA from the University of Southern California; email: chris.bainter@flir.com.



Thermal Image of AR-15 muzzle exhaust.



One of the advantages of thermal over high-speed visible imaging is that shrapnel is much easier to see due to the high thermal contrast against the background. Here, an AR15 55-grain, .233-caliber round penetrates plated body armor.

From Crop Science to Space Exploration, **Optical Sensing** on the Rise

Technologies that were once recognized only by niche professionals and the military have reached a price point that has the commercial sector excited.

Lockheed Martin

IRIS is a small satellite with a powerful payload that takes high-resolution images of the sun's interface region — the birthplace of solar storms.

BY MARIE FREEBODY
CONTRIBUTING EDITOR

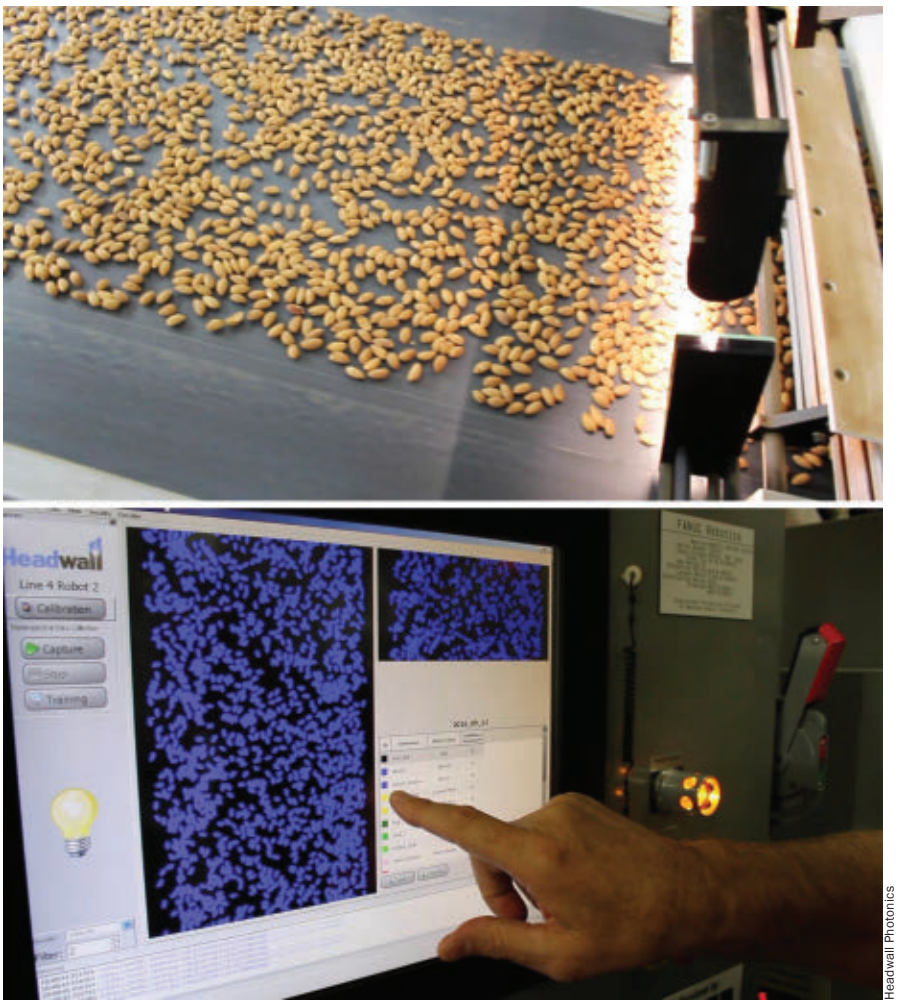
From smartphones, smart homes and autonomous vehicles to crop science, food inspection and space observations, optical sensors are finding increasing use in the commercial sector.

Image sensing evolved from the military arena to commercial applications such as remote sensing, advanced machine vision, the medical/biotechnology world, and even into artwork and antiquities. Once size, weight and cost were driven down, there was an immediate upturn in the market; and this growth has been exponential.

"There aren't too many takers for a $20 million hyperspectral sensor, which does exist, but at less than five percent of that with performance attributes nearly equal, you start seeing interest from a range of commercial uses," said Christopher Van Veen of hyperspectral imaging specialists Headwall Photonics in Bolton, Mass. "The multimillion-dollar hyperspectral instruments aboard defense aircraft and satellites represented a springboard for companies like Headwall to take the optical/mechanical technologies and refine them for commercial pursuits while driving cost out."

At thermal imaging specialists Flir Systems Inc., based in Wilsonville, Ore., an increasing awareness of the technology has led to a vast number of new users in commercial industries, including for home repairs, heating and ventilation contractors, plumbers, and electricians, to name a few.

"While the value of the technology was known by many professional users and



Headwall Photonics

Headwall Photonics' hyperspectral imaging sensors are used at one of the world's largest almond growers and distributors, Travaille & Phippen in Manteca, Calif. The company inspects the almonds along conveyor lines using Micro-Hyperspec hyperspectral sensors paired with hyperspectral software and robotics. The sensor uses algorithms to discern 'good' from 'bad' with very high spectral and spatial resolution. The software communicates to robotic arms, which then know exactly where offending items are.

those with military experience, lack of awareness, the acquisition cost, or both, prevented the vast majority of users from using it," said Bill Terre, general manager and vice president of the OEM and Emerging segment at Flir.

In 2014, uncooled thermal imaging cameras came down from over $1,000 to $399 and many found the new value proposition made sense. Today prices continue to drop, with the latest models priced at less than $200. For many professionals, the more modest capital expenditure was what they needed to give it a go.

"Many have started with entry-level thermal imagers like the Flir ONE, but over time have migrated to more capable equipment. Even though this upgrade may come with a higher cost, we believe this trend will only increase over time," said Terre.

Smartphones get smarter

Today's cellphones take great pictures, but tomorrow they'll assist doctors in diagnosing patient health. With sensor technology finally maturing to a mass-production level, tasks that were typically handled by people are increasingly being taken on by optical sensors.

With over 1.4 billion smartphones purchased in 2016, according to research

Excelitas Technologies

Excelitas Technologies launched its 1 × 4 Pulsed Laser Diode Array for lidar applications at Photonics West 2017. The company believes the future will see more and more intelligence being integrated into the sensor module.

firms International Data Corporation and Statista, a massive economy of scale has led to meaningful technology advances and cost reductions in many areas, including visible sensing and — on a lesser scale — thermal sensing.

"Thermal sensors have found application in mainstream smartphones via two avenues: aftermarket attachments like the Flir ONE and direct integration in smartphones such as the CAT S-60 handset," Terre said. "These two vehicles account for hundreds of thousands of new users of thermal technology in 2016 alone. This significant increase in adoption has facilitated new awareness of the capabilities of thermal imaging. As a result, the industry has seen a strong increase in demand."

Shrinking optics and silicon elements

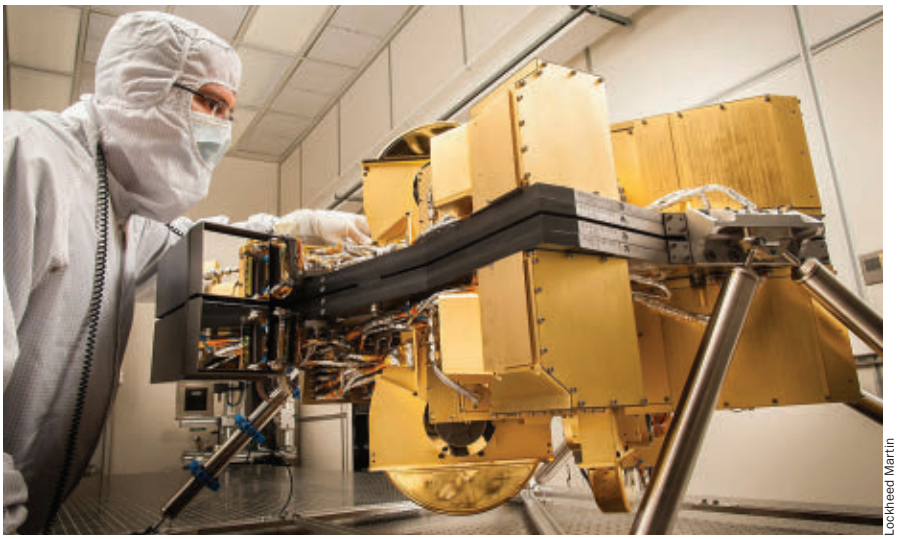
One of the most daunting challenges Flir faced was conforming to the total volume requirement in smartphones of less than 250 mm^2. The development of wafer scale vacuum packaging for the focal plane arrays (FPAs) was necessary to meet cost and Z-height maximums.

"Optics, constructed using only silicon elements and manufactured purely at the wafer level, were necessary to address both cost and volume limitations," Terre said.

An image resolution significantly less

than quarter video graphics array 320 × 240 became fundamental in tackling the unprecedented cost constraints. Unfortunately, the image appearance of an 80 × 60 or even a 160 × 120 FPA is far too little resolution for consumers accustomed to viewing the abundance of high-definition imagery seen today.

Ultimately, very sophisticated signal processing algorithms were necessary to increase the perceived image appearance, which is carried out by the general processing unit and image signal processor in modern handsets.



Lockheed Martin

The Near Infrared Camera (NIRCam) is the primary optical instrument aboard NASA's next deep space observer, the James Webb Space Telescope.

Flir also combined a thermal image with the high spatial frequency content of the visible image, known as multispectral imaging, or MSX, to increase the apparent resolution beyond that of the native focal plane array size.

"All of the advancements required for compatibility with the high-volume handset market have been realized with Flir's Lepton family," Terre said. "With two resolutions and pixel pitches — 80 × 60-17 µm and 160 × 120-12 µm — the Lepton sensors have been directly integrated into mobile handsets, mobile accessories, self-contained breathing apparatus, micro UAVs, personal vision systems and test/measurement equipment, to cite just a few examples."

Smart home

Sensing applications using cameras and IR sensors, mostly on battery operated devices, are a critical component to many of the products in the smart home market.

Wolfgang Schmidt, senior product

manager of IR Sensing at Excelitas Technologies in Waltham, Mass., expects this trend to continue as the market grows — driving size and power requirements down, and calling for enhanced performance and function.

"Some of our latest breakthroughs focus on digital sensors. After the first digital sensor was introduced in 2010, we provided a low-power digital infrared sensor with only 5 µA /1.8 V power consumption in 2016," said Schmidt. "Additionally, our new CaliPile Multi-Function Infrared Sensor represents a bridge between motion and temperature measurement applications."

CaliPile intelligent IR sensors combine motion sensing, presence detection and temperature measurement in a single digital thermal infrared package. It features selectable frequency filters and levels that allow users to set the product into one of the three major operation modes.

Crop and food inspection

Remote sensing is perhaps the biggest market for optical sensors, with applica-

Sensing Spacecraft

Global security company Lockheed Martin has a long history not only in the defense and security arena, but also in space sciences and specifically NASA programs. In its latest mission into space, Lockheed Martin is helping NASA begin the hunt for dark energy, a mysterious force powering the universe's accelerating expansion.

The company is comleting a study to build an important part of the primary optical instrument aboard the Wide Field Infrared Survey Telescope (WFIRST), whose mission aims to uncover hundreds of millions more galaxies and reveal the physics that shapes them.

"From solar observing satellites to NIRCam — the near-infrared camera for the James Webb Space Telescope — Lockheed Martin has been at the forefront of space sensing," said Jeff Vanden Beukel, Lockheed Martin program director for the Wide-Field Optical-Mechanical Assembly (WOMA). "Our Advanced Technology Center is focused on developing next-gen and gen-after-next technologies. We see customers looking to explore larger telescopes and longer wavelengths, as well as ways to reduce payload size and cost for future missions."

Innovative telescope and back-end relay optical designs have allowed for more compact systems with wider fields of view. Imaging focal plane arrays have also continued to progress with increased pixel count and improved sensitivity.

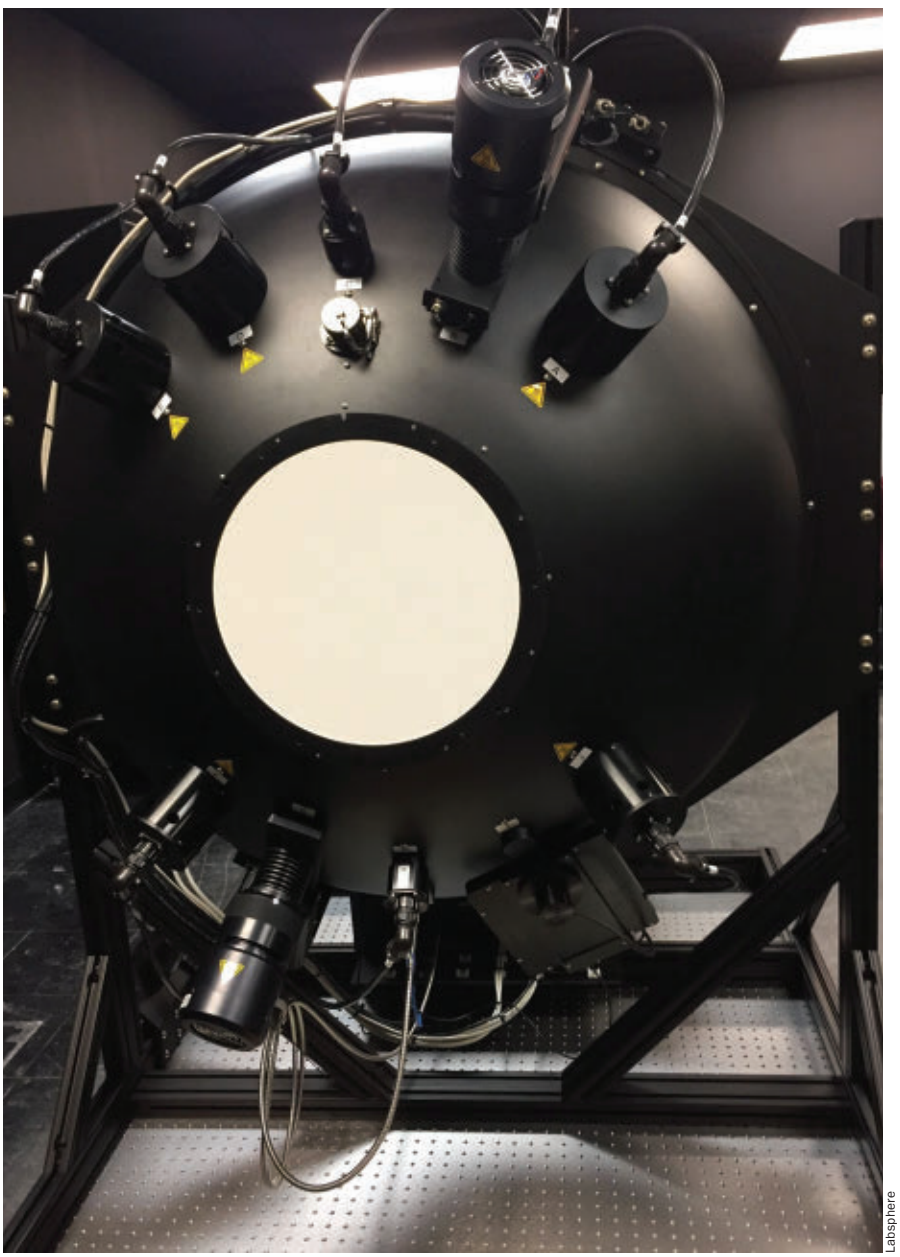
"Spacecraft isolation, alignment integration and test, sensor technologies, telescope design — these are all areas that will help shape the next generation of sensing spacecraft," said Vanden Beukel.

tions ranging from crop science to greenhouse gas emissions and plant phenotyping to geological analysis.

In crop science you can "see" the telltale signs of crop diseases, which left unchecked and unseen can lead to entire economies collapsing. For example, the value of being able to detect disease very early in coffee beans in South America, in citrus fruit in Florida or wine grapes in Napa is incalculable.

"By making sensors smaller and more affordable, two things happen: more scientists can afford them, and more UAVs [unmanned aerial vehicles] can carry them," said Headwall's Van Veen. "And we find at Headwall that the remote sensing platform of choice is the UAV. They are nimble, tactical, easily deployed and affordable. It's important that the payload be matched to the craft, which is why size and weight are both key metrics. Too heavy or too big, the UAV's capable of lifting them are fewer."

The advanced machine vision market is also seeing the benefits of hyperspectral imaging. This industry has lived with rudimentary RGB camera systems for a long time, but governmental oversight within the food inspection industry is causing many leaders to look at new sensing technology that gives a crisper view of their product under inspection.



Labsphere

Low-uncertainty uniform source for testing European Earth-observation satellites.

Headwall's sensors are today in place in central California at a leading almond producer. There, the hyperspectral sensors sit, like silent sentinels above the high-speed production line, examining every single almond and determining whether it passes the grade. Finely crafted algorithms are used to grade the nuts and once the sensor detects an out-of-spec nut or berry, software immediately communicates its spatial position on the line to downstream robotics for ejection.

"The Headwall sensors inspecting almonds all use a diffractive approach based on gratings and mirrors. The diffraction gratings are all 'originals' rather than replicates," said Van Veen. "That means each instrument is an exact duplicate of its neighbor, which is crucial when multiple inspection lines are all looking at the same thing. Instrument repeatability and consistency matter from one sensor to the next."

Lidar

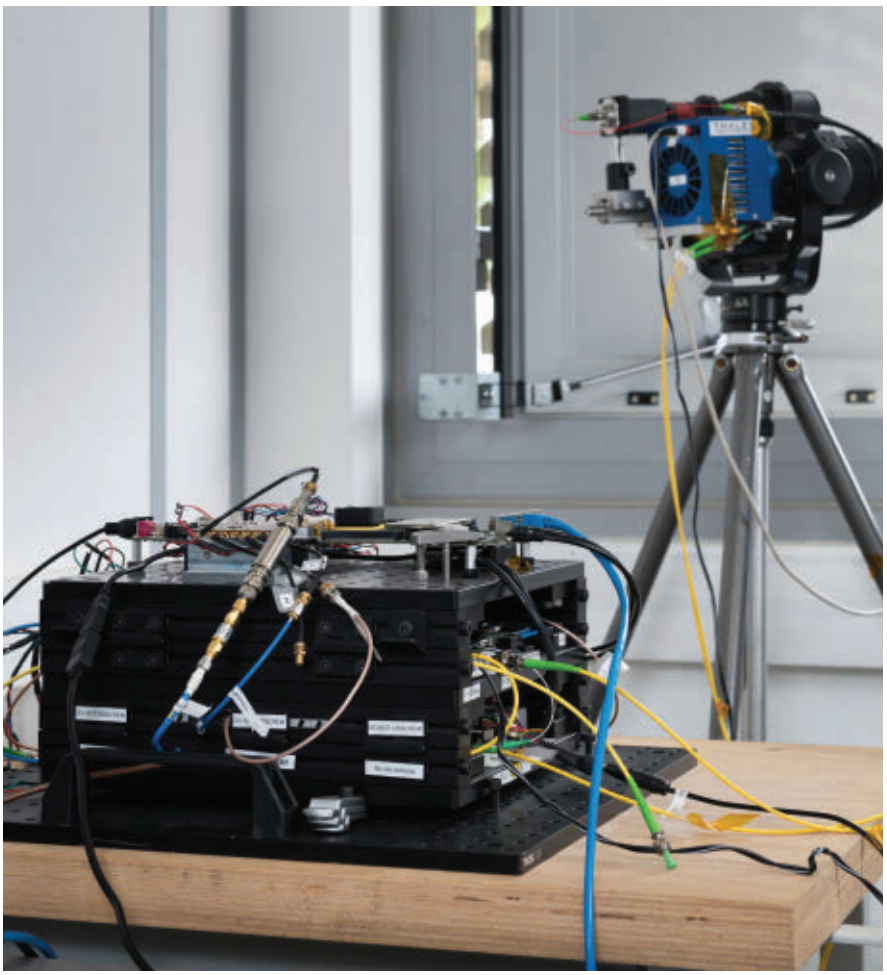
The automotive lidar market is exploding and pushing the boundaries of what is and will be available on the sensor front, according to experts. Thales is involved in active optical sensing, mainly for lidar and active imaging systems, where technology advances are helping to expand the market.

"There is a diffusion of coherent lidar technology for both defense- and civilian-oriented purposes. For active imaging, main progresses come from additional contrasts provided by polarimetric imaging and multispectral imaging," said Daniel Dofli, director of research for physics applications at Thales Group of France. "Fiber-based technologies developed originally for the telecom markets are now largely used in lidar systems, with a clear impact on cost, size and, [to] some extent, on performance."

Dofli predicts that the emergence of photonic integrated circuits will trigger a second revolution in terms of increased compactness and reliability on one hand,

Labsphere

Multispectral color-tunable source for wide angle lens commercial camera calibration.



ecliptique Laurent Thion

The lidar market is exploding, with technology advances helping to expand it.

and of tremendous cost reduction on the other.

Excelitas Technologies launched its latest 1 × 4 pulsed laser diode array for lidar applications at Photonics West 2017. It combines high-efficiency multi-cavity laser chip technology with a small form-factor surface mount device.

Its 1 × 4 linear configuration minimizes space requirements in the assembly to enable smaller, less costly optical components for applications requiring high reliability such as autonomous vehicles and drones.

"Innovative products like these are just the beginning. In the future, we will see more and more intelligence being integrated into the sensor module," Schmidt said.

Software must keep up with data

Software not only manages the sensor, for example, instructing it when to collect data based on geographical coordinates, but also handles the key post-processing tasks once you've collected several gigabytes of hyperspectral data. What do you do with all that data? How do you go from raw image data to actionable solutions and answers to your questions? That aspect of 'software' is every bit as important as anything else.

When it comes to handling the huge amounts of data from optical imaging, there can be fewer disciplines that generate more than satellite-based sensors for earth observation. In order to enable climate change prediction and a better understanding of the complex chaotic system driving these phenomena, data on the order of greater than two percent uncertainty needs to be gathered for 25 years on orbit.

"The sensing technology will only go as far as the data will allow it to go," said Chris Durell, director of Marketing, Imaging Products, at Labsphere in New Hampshire. "We can now take a massive amount of information, but if we cannot extract the needed data to make decisions, this is just wasted information. Better data extraction is needed to enable the next level of growth in optical sensing."

marie.freebody@photonics.com

"Fiber-based technologies developed originally for the telecom markets are now largely used in lidar systems, with a clear impact on cost, size and [to] some extent on performance."

Daniel Dofli, director of research for physics applications at Thales Group of France.

DCS 2017 Brings Defense, Environment Into Focus

SPIE 2017 Fellows

The society has announced the Fellows of 2017 — 71 in total — who join more than 1200 others chosen since the SPIE's inception in 1955. They are chosen based on their significant scientific and technical contributions in the multidisciplinary fields of optics, photonics and imaging, as well as service to SPIE and the greater optics and photonics community.

"[In 2017] they represent 16 countries on three continents, and 13 of the 71 are women, which represents an all-time high for a single year," said Majid Rabbani, 2016 chair of the SPIE Fellows Committee, and a professor at Rochester Institute of Technology's Kate Gleason College of Engineering. "Their affiliations encompass the full range of academia, industry and government labs and institutes, with expertise spanning all aspects of the photonics community, including strong representation from the medical imaging community."

Rabbani noted that the new fellows are recognized at SPIE meetings of their choice throughout the year. Several are expected to be acknowledged at DCS.

BY JUSTINE MURPHY
SENIOR EDITOR

Changes in the nature of warfare in today's high-tech world demand the most advanced tools for soldiers and others in the defense and security sectors. Environmental and health care segments are evolving, too, as an onset of innovative technologies is improving medical care and environmental monitoring. SPIE's annual Defense + Commercial Sensing (DCS) event — to be held this year in Anaheim, Calif., from April 9 to 13 — brings such advancement into focus.

"In recent years the imaging and sensing market has exploded as consumer applications have emerged, leveraging technologies traditionally developed for the industrial, defense and security markets," said Andrew Brown, senior director at SPIE. "Future growth will be fueled by applications in new areas such as lidar for autonomous vehicles, wearable sensors, the internet of things, agriculture, and food safety and water quality assurance. SPIE Defense and Commercial Sensing, with its focus on real-world applications, attracts leaders from industry, government and the research community to explore the latest developments in sensing and imaging and to promote the transition of technologies from the research lab to end markets."

The DCS annual conference and exhibition — touted as a leading global event in the photonics industry — takes innovative sensing, imaging and other photonics technologies and products to new heights for applications in defense, security, health care and the environment. Through focused topical tracks, technical programs, plenary sessions, courses and research presentations, DCS highlights technical advances in sensors, infrared technology, laser systems, spectral imaging, radar, lidar and more. A job fair and exhibition will feature companies from around the world.

"The 380-company exhibition will feature some of the world's leading companies showcasing their products and services. This is the largest showcase for infrared cameras at every price point, spectroscopic sensing, and fiber optics for lightguides, inspection, and sensing systems," Brown said.

Technical programs

Defense + Security is one of two technical programs at DCS. It focuses specifically on sensors, imaging and optical technologies for security, law enforcement, avionics and aerospace, defense and military applications.

Another DCS technical program is Commercial + Scientific Sensing and Imaging. This offers sessions on sensors, imaging and image processing, and photonics technology innovations for agriculture, manufacturing, health care, pharmaceutical, transportation, information systems and environmental applications.

Plenaries, courses & tracks

Three focused topical tracks will cover much ground in unmanned autonomous systems (UAS), agriculture and fiber optic sensors.

The UAS segment offers a look at the latest research for enhancing air, ground and underwater UAS such as lidar, infrared, and multispectral and hyperspectral imaging. Several industry sessions will be held, as well, within this track. Among them:

- **Lidar for Autonomous Vehicles:** The Future of 3D Sensing and Perception
- **Technological Breakthrough in Lidar Technology:** Taking Fully Autonomous Driving to the Masses
- **The Industrial Impacts** of Thermal Imaging Drones
- **High-Speed Imaging:** Today's Possibilities and Future Directions

A number of conferences held within the Defense + Security technical program relate to UAS, including Unmanned Systems Technology, Laser Radar Technology, Sensors and Systems for Space Applications, and Next Generation Analysts. In the Commercial + Scientific Sensing and Imaging technical program, subconferences include Thermosense: Thermal Infrared Applications, and Autonomous Air and Ground Sensing Systems for Agricultural Optimization and Phenotyping.

The agriculture track allows attendees to explore sensing, imaging and related photonics technologies for agricultural and food safety and quality applications, such as unmanned aerial vehicles (UAVs), hyperspectral imaging, phenotyping and infrared thermography. Such applications will be the focus of several sessions, as well — Photonics and Food: Optical Tools Tackle Food Safety Challenges; Miniaturized and Mobile Spectroscopy and Optical Sensor Applications; and Infrared Applications: ThermoSense XXXIX.

Fiber optic sensors are the emphasis of the third track. Experts in this field will discuss the different aspects of fiber optic sensor technology based on conventional and specialty optical fibers, including photonic crystal fibers and metalized fibers, for aerospace, civil structures, defense, medical and environmental applications. A related subconference — Fiber Optic Sensors and Applications XIV — offers sessions that concentrate in these and other related areas.

DCS will host two top industry players in 2017 for plenary presentations —

Rising Researchers

DCS features presentations by Rising Researchers, a series that recognizes "early career professionals who are conducting outstanding work in product development or research in the defense, commercial and scientific sensing, imaging, optics or related fields." According to SPIE, Rising Researchers provides personal recognition, while enriching further professional growth and networking opportunities.

These researchers work in various disciplines such as defense and security, nanotechnology, electronic imaging and signal processing, optical design and engineering, remote sensing, and biomedical optics. Also, medical imaging will be recognized this year.

Defense & Security
Nathan Cahill, Rochester Institute of Technology
Daniel LeMaster, Air Force Research Laboratory

Nanotechnology
Matt Graham, Oregon State University
John Hennessy, NASA Jet Propulsion Laboratory
Yongmin Liu, Northeastern University

Electronic Imaging & Signal Processing
Daniela Moody, Descartes Labs
Shuo Pang, University of Central Florida

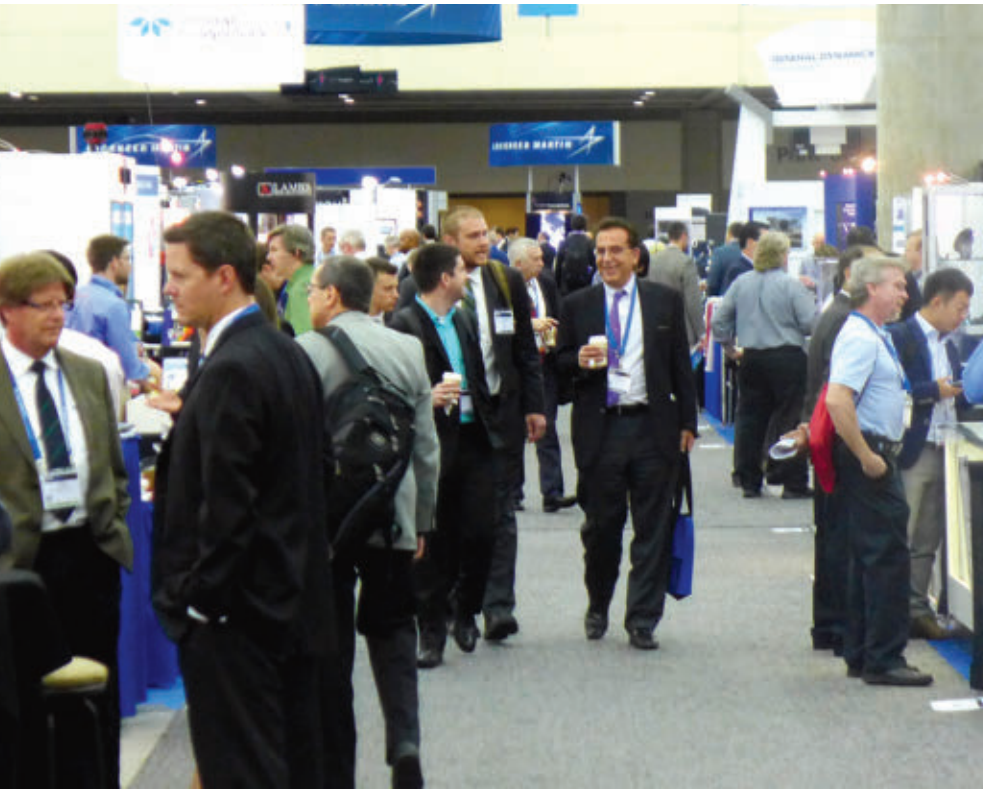
Optical Design & Engineering
Junsuk Rho, Pohang University of Science and Technology

Remote Sensing
Adrian Tang, UCLA and NASA Jet Propulsion Laboratory

Biomedical Optics & Medical Imaging
Fei Tian, Stevens Institute of Technology

The Rising Researchers are chosen based on their potential long-term contribution to sensing, imaging, optics, photonics and related fields, as well as their work's role in the scientific, educational or economic impact of optics and photonics.

Images are courtesy of SPIE.

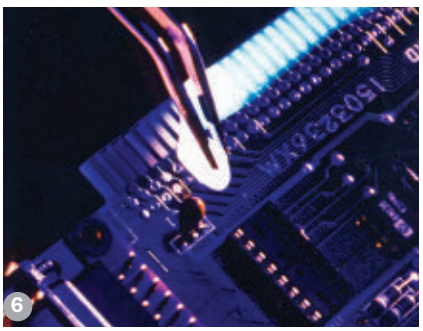


Thomas J. Burns, director of the Strategic Technology Office at the Defense Advanced Research Projects Agency, and Parker Abercrombie, Immersive Visualization Project lead for NASA's Jet Propulsion Laboratory. The plenary presentations will cover much ground, focusing on "game-changing technology and valuable insights" for the defense, security and environmental sectors.

In addition, an extensive series of courses will cover IR sensors and systems, optics and optomechanics, imaging and sensing, quantum radiometry, lasers and more.

"SPIE Defense + Commercial Sensing will provide a valuable experience for those already working in the field or who want to gain an understanding of the technology and markets driving this rapidly advancing sector," Brown said.

justine.murphy@photonics.com



1 Thermal Imaging Camera

The T1030sc thermal imaging camera from **Flir Systems GmbH** is designed for conservation and research efforts. The camera records full 1024 × 768-resolution images at 30 fps. The T1030sc lets users capture lossless HD radiometric imagery at up to 120 Hz, which can be viewed, acquired, analyzed and shared in FLIR ResearchIR Max or MathWorks MATLAB. The portable, high-speed, HD thermal imaging and measurement camera gives researchers and scientists high resolution and sensitivity in a flexible, battery-powered, handheld package.
research@flir.com

2 Conoscope Lens

A conoscope lens for the ProMetric series of imaging photometers and colorimeters has been announced by **Radiant Vision Systems LLC** to measure the color, luminance and contrast of multiple angular distributions of light at once. By mounting a conoscope lens directly to a ProMetric imaging photometer or colorimeter, angle performance measurement is possible for a wide range of display types, including those based on LCD and OLED technologies, as well as backlights. The conoscope lens solution simultaneously acquires viewing angle measurements to ±60°.
info@radiantvs.com

3 Fiber-Based Green Laser

The Monaco 517 fiber-based laser from **Coherent Inc.** delivers visible green output, producing 20 W at 517 nm and combines a short pulsewidth of <400 fs with a high pulse energy of 20 µJ to generate high-peak intensity. Designed for the precision micromachining of tough materials like polymers, the device's MHz pulse repetition rate supports fast throughput. The Monaco 517 is also simple to integrate into any OEM system because its self-contained compact laser head measures 635 × 340 × 167 mm.
tech.sales@coherent.com

4 Large-Aperture Polygon Scanners

Standard model polygon scanners from **Precision Laser Scanning LLC** feature apertures of >20 mm with short lead times and low prices. The Wood Pecker family of polygon scanners is targeted toward the material processing market with speeds of 400 to 4000 rpm. The Eagle Eye family of polygon scanners is targeted toward the imaging market with speeds of 1000 to 10,000 rpm. Both models have a 21-mm aperture.
info@precisionlaserscanning.com

5 SIMS Analyzers

Secondary ion mass spectrometry (SIMS) analyzers for surface characterization from **Hiden Analytical** are workstations that incorporate instruments for fundamental research through automated quality control applications. The systems feature integrated load lock, sample manipulation and multispecimen sample carriers. All elements are ultrahigh-vacuum compatible and feature the Hiden dual-mode MAXIM mass spectrometer operating in the secondary ion detection mode for positive/negative ion detection and in the secondary neutral (SNMS) detection mode for positive data quantification. The MASsoft Professional SIMS PC data system enables full control of the mass spectrometer, the ion gun operating parameters and the ion beam raster area and scan rate, with acquired data presented in real time. The ESM LabVIEW SIMS Imaging program acquires, stores and displays the data for presentation in the form of elemental surface maps with both 2D and 3D view capabilities.
info@hiden.co.uk

6 Light Cure Masking Agent

The DYMAX Speedmask 9-20479-B-Rev-A UV/light cure temporary masking agent from **Intertronics** is specifically designed to meet the needs of the electronics industry. Its fast cure and simple removal will improve productivity in printed circuit board assembly. It is formulated for the protection of PCB connectors and other components, either during the soldering process or during conformal coating. It features a tight viscosity tolerance, which aids in maintaining good process control during application. Speedmask 9-20479-B-Rev-A maximizes production speed as it cures in seconds under UV/visible light and is solvent and silicone free. It is benign to gold or copper finishes on connector pins or other components.
info@intertronics.co.uk

Picosecond Laser

The Genki-10 XP picosecond laser from **Onefive GmbH** features 100-W output power in a compact package for workstation integration. The system is based on the Genki seed laser and provides clean pulses shorter than 10 ps, an optimal pulse duration for many micromachining applications. To satisfy the increasing demand of picosecond laser workstations, the Genki-10 XP has been optimized to provide up to 100 W of average power and 300-µJ pulse energy at the industry-standard wavelength of 1064 nm. Wavelength conversion options are available, and pulse repetition rates up to 80 MHz can be achieved.
contactus@onefive.com

IR Viewer

The HI POWER IR VIEWER from **Precision Laser Scanning LLC** is a versatile visualization tool for assembling, aligning, testing and monitoring high-power near-IR laser systems. The glass has invisible nanocrystals that convert 900 to 1070 nm to green visible light. 3D visualization allows users to observe beam mode, size and shape. The laser damage threshold is >100 W/mm^2 continuous wave, and it passes >80 percent of the beam so it can be left in place while running a system. The viewing glass size is 20 × 20 × 2.5 mm overall. The handle allows the user to safely insert the viewing glass at any accessible beam location.
info@precisionlaserscanning.com

600-mm Aspheric Lenses

Optical Surfaces Ltd. has announced the fabrication of high-performance aspheric lenses up to 600 mm in diameter with a range of high-quality optical glasses with low *f*-numbers to optimize light-gathering and focusing performance. A range of high-power laser coatings is available to maintain high transmission and enable the aspheric lenses to operate at the ultrahigh-energy thresholds demanded by the Terawatt lasers used to investigate fundamental plasma physics. All aspheric lenses are provided with a complete quality test assurance report.
sales@optisurf.com

Fume Hood

The UniFlow CE AireStream from **Hemco Corp.** is a full-duty fume hood in a compact size, offering 50 percent energy savings over conventional hoods. The hood is equipped with the exclusive vector-slotted rear VaraFlow baffle system. Hoods are offered in 30-, 36-, 48- and 72-in. widths and can be equipped with a wide selection of accessories to meet specific process needs. The device is constructed of composite resin for superior chemical resistance and no rusting. It can be supplied with or without an exhaust blower in standard or explosion-proof models.
info@hemcocorp.com

Digital Multispectral Sensor-On-Chip

AMS AG has announced the AS7262 visible range sensor and the AS7263 NIR sensor, each providing six calibrated spectral channels. The multispectral sensors employ a new fabrication technique that enables nano-optical interference filters to be deposited directly on the CMOS silicon die with extreme precision. This interference filter technology offers precise and reproducible filter characteristics that are stable over both time and temperature. They are also much smaller and more cost-effective than the components typically used in today's spectral analysis instruments. The AS7262 six-channel visible light sensor with integrated intelligence provides a calibrated digital output over an I2C or UART interface. It measures light intensity at 450, 500, 550, 570, 600 and 650 nm. The AS7263 detects 610- , 680-, 730-, 760-, 810- and 860-nm IR signatures. Both devices include an electronic shutter with LED drive circuitry, which means that device designers can accurately control the light source and the spectral sensing functions with a single chip.
www.ams.com

UV-LED Illuminators

The LumiBright 3300B UV-LED Illuminators from **Innovations in Optics Inc.** are high-power, highly uniform UV-LED solutions for UV digital light

processing (DLP) applications such as 3D printing, computer-to-screen and computer-to-plate printing and maskless lithography. Available wavelengths for the UV-LED array include 365-, 385-, 395- and 405-nm-in. single- or multiwavelength configurations. Water-cooling allows the UV-LED array to be operated at a very high current density. The 20-W illuminator is designed for the DLP7000 chipset and the 30-W illuminator design supports the DLP9500 chipset.
info@innovationsinoptics.com

Broadband Spectral Equalizer

The Lambda Equalizer from **Santec Corp.** is an ultra-broadband spectral equalizer at a wavelength of 900 to 1750 nm based on liquid crystal on silicon (LCOS). The device achieves a wavelength resolution of 2 nm with an optical attenuation range of 100 to 1 percent. Optical single mode fibers are available for the optical input and output ports. The equalizer was developed using wavelength-selective switch technology in fiber optics and the LCOS-based spatial light modulator technology. The "no moving parts" feature provides high reliability in field and precision wavelength managements compared with a conventional 2D micromirror device.
info@santec.com

Linear Perforation Software Feature

The LinPerf linear perforation feature of the LASERDYNE S94P software from **Prima Power Laserdyne LLC** provides an easy way to create programs that produce linear patterns of laser-processed features on flat surfaces. The flat surfaces may be oriented in any plane accessible by the laser beam based on the number of axes and configuration of a laser processing system. Users provide information about the pattern such as hole spacing, orientation of the pattern, number of passes required to produce the holes, laser conditions, type of assist gas, and hole diameter or feature shape in the S94P graphical interface.
lds.sales@primapower.com

Multimode Diode Laser

nLight Corp. has announced a bright, multimode diode laser, extending the Element portfolio of diode lasers. The diode laser emits 200 W from a 105-µm fiber at 0.15 NA. The device features innovative developments in both chip and packaging technology, with the brightness of Element revolutionizing the architecture of high-power fiber laser and direct diode systems. Based on cascaded single-emitter laser diodes, high-power fiber coupling and simplified packaging, the Element platform offers the highest brightness diodes in the industry today. Available at wavelengths from 793 to 976 nm and power levels up to 220 W, the lasers are designed for next-generation fiber and solid-state laser pumping.
www.nlight.net

new products

Polygon Scanner Mirrors

Precision Polygon Scanner Mirrors from **II-VI Inc.** address facet geometry, flatness and roughness requirements for next-generation fast scanning systems. Designs include prismatic, pyramidal and irregular polygons. The mirrors are available in a full range of sizes, shapes and substrate materials, with dimensions up to 300 mm and facet angle tolerances up to 2 arc seconds.
info@iiviinfrared.com

Balanced Photodiodes

The DSC705 high-power, balanced photodiodes from **Discovery Semiconductors Inc.** provide 5-GHz bandwidth. They are balanced InGaAs photodiodes in a push-pull configuration with each photodiode capable of handling high optical power up to 17 dBm (50 mW). As a pair, they will handle 20 dBm (100 mW).The photodiodes are ideal for quantum key distribution detection schemes, as they are shot-noise limited. The broad wavelength response of 1060 to 1650 nm allows for one device for multiple wavelengths and reduces operational and inventory cost. Additionally, they are well-suited for applications using high local oscillator powers up to 20 dBm, such as lidar with high dynamic range.
www.discoverysemi.com

High-Speed Imaging Photometer

The Fast Imaging Photometer from **Gooch & Housego PLC** is an ultrahigh-speed imaging photometer that is ideal for aerospace, defense, automotive and lighting applications. The device is National Institute for Standards and Technology (NIST)-traceable, compact, rugged, affordable and an upgrade from spot photometry systems. The intuitive application software allows for fast image capture in either single shot or burst mode, with capture rates greater than 350 full fps. The 640 × 480 CMOS sensor is photometrically calibrated to enable accurate, full-scene luminance measurements.
orlandosales@goochandhousego.com

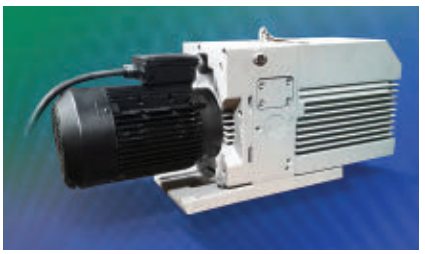
Laser Diode Modules

BEA Lasers Inc. has announced two low-profile additions to its rugged MIL series of laser diode modules. The MIL RA features a right angle, and the MIL Compact features straight housing. Both laser modules are ideally suited for applications with limited space and tight positioning requirements.

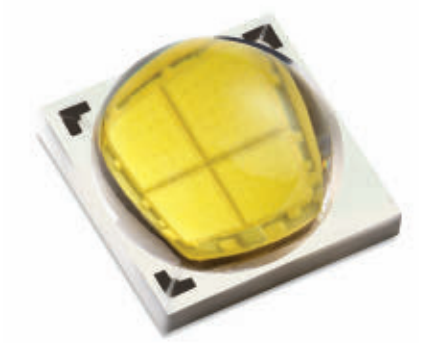
Both models utilize a 3/8-in. rugged laser housing fitted with a M12 connector, 2-m long PVC jacketed cable and integrated power supply. The optional sensor-style bracket or multi-adjustable LB bracket completes the laser system. The laser diode modules are offered with standard 515- or 635-nm wavelengths with 1 or 5 mW. Other outputs are available on request.
info@bea-eo.com

Vacuum-Pump Rebuilding Services

Vacuum-pump rebuilding services and remanufactured pumps have been announced by **Grauling Research Inc.** for thin-film coating, semiconductor and industrial equipment manufacturers. Warrantied pump rebuild services are offered for a wide variety of vacuum pumps including rotary vane pumps, rotary piston pumps, dry pumps, scroll pumps and blowers. Grauling will disassemble, decontaminate and chemically clean each vacuum pump and perform a full inspection



before reassembly and final testing. Warranties for workmanship and defects last for 12 months, consistent with industry standards. The vacuum-pump rebuilding service is ideal for all industries that utilize vacuum-pumping systems including aerospace, medical, lighting, defense, national labs, government agencies, solar, automotive, food packaging, imaging and agricultural applications.
www.graulingresearch.com



Multi-Die Emitter

The LUXEON MX multi-die emitter from **Lumileds** delivers high efficiency and flux for outdoor fixtures and high bay lighting applications. Lighting fixtures benefit from the emitter's 1200-lumen, 150-lm/W efficacy at 85 °C, which enables a system efficiency of 120 lm/W when driven at 700 mA. The LUXEON MX makes it possible for luminaire makers to meet the efficiency and quality requirements of the DesignLights Consortium Premium V4.1 at 700 mA at 85 °C. The emitter will be offered in a range of color temperatures from 3000 to 6500 K and color rendering indexes of 70, 80 and 90 in 3-, 6- and 12-V configurations. Applications include roadway lighting, street lighting, stadium lighting and high bay fixtures.
info@lumileds.com

Spectral Sensing System-On-Chip

Espros Photonics Corp. and Viavi Solutions Inc. have announced a miniaturized spectral sensing system-on-chip. The spectral sensor combines Viavi Solution's 64-channel, micro-patterned bandpass filter array and the high-performance Espros hybrid CCD-CMOS imager for a miniature spectral sensor that is less than 2.7 × 2.7 × 1.1 mm in size. One sensor version is offered for the visible range of 385 to 900 nm and another for the NIR range of 775 to 1065 nm. Applications include the analysis of food, beverage and medication compositions.
info@espros.com

InGaAs Photodetector

The ET-3600 InGaAs photodetector from **Electro-Optics Technology Inc.** is designed for ultrafast pulse resolution and frequency response measurement. With a 22-GHz minimum bandwidth, the ET-3600 provides an easy-to-use, fast solution for 900- to 1650-nm applications. It is available as a free space device or with FC/UPC input, making it suitable for the monitoring of laser output.
sales@eotech.com

Compact Linear Lights

The LM45 and LM75 series of compact linear lights from **Smart Vision Lights** features MultiDrive and OverDrive Strobe technologies for high-pulse operation. The built-in MultiDrive feature allows users to employ either series in continuous operation or OverDrive depending on wiring method. The industry-standard 5-pin M12 quick-disconnect cable provides simple wiring. Each series also features overcurrent protection, PNP and NPN strobe input and continuous operation. Its housing is 51-mm long, providing a small footprint. Standard wavelength colors are white, 470-nm blue, 530-nm green, 625-nm red, and 850-nm IR. Additional wavelengths are available upon request. Multiple lens options provide a broad spectrum of illumination area. Zero to 10-V analog control offers total command over intensity.
www.smartvisionlights.com

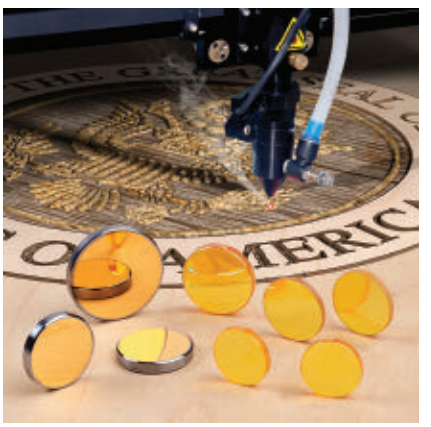
Laser Diodes for Raman Spectroscopy

Electro Optical Components Inc. has announced laser diode modules from Beijing RealLight Technology Co. Ltd. designed for Raman spectroscopy. The 785-, 830- and 1064-nm lasers are narrow bandwidth for precision in the spectroscopy process. Package options are available in various laser combinations for specific application needs.
info@eoc-inc.com

LED Test and Bin Measurement

The TPI21-TH LED production test and bin measurement system from **Gigahertz-Optik Inc.** is designed for accurate testing of LEDs in both pulsed and constant-current modes under temperature control. The system's design conforms to the latest norms and regulations, incorporating a high-quality, thermoelectrically cooled CCD spectroradiometer with an integrating sphere to ensure accurate measurement of luminous flux, spectrum, color and color rendering. A key feature of the system is its electronic zero setting, which permits precise, transitory measurements within a light pulse. The system's 250-W thermoelectric stage enables

quick measurements of SMD and onboard LEDs with junction temperatures controlled within the range of 25 to 85 °C. An optional light-tight housing eliminates the need of a dark room. A range of easy-to-use LED adapters provide reliable electrical and thermal connection.
info-us@gigahertz-optik.com



CO_2 Optics

A line of field-replacement CO_2 optics that feature lenses in a wide range of focal lengths for low-power lasers where depth-of-field is critical is available from **Laser Research Optics**. The CO_2 Laser Lenses and Mirrors meet OEM and ISO-10110 specifications and are optimized for 10.6-µm wood-cutting and engraving laser systems where depth-of-field is critical. Suitable for direct field replacement, they come in 1/2- to 1-1/2-in. diameter sizes with focal lengths from 1 to 25 in., 1/2-in. increments. They are offered with coatings to meet specific phase and polarization requirements. Especially effective for plywood, the lenses have 40-20 scratch-dig surface quality, <1/40th wave sphericity and provide <0.2 percent total absorption values. The lenses and mirrors are available for Camtech, Emission Technologies, Epilog, Ferba, Kern, Laser Pro Engravers, LST Lasers, Pinnacle, Synrad, Trotec, Universal and Vytek engraving and marking lasers.
sales@laserresearch.net

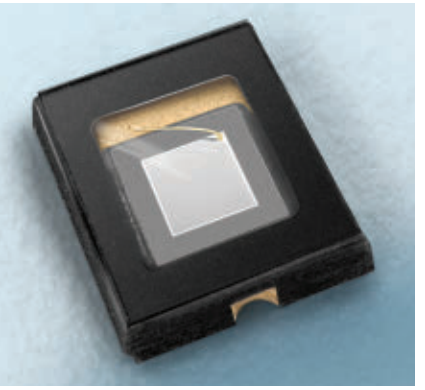
Pulsed Laser Wavelength Meter

The 871 Series Pulsed Laser Wavelength Meter from **Bristol Instruments Inc.** features an unsurpassed measurement rate of 1 kHz and a wave-

length accuracy of 0.75 parts per million. The meter uses a unique Fizeau etalon design to measure laser wavelength of both pulsed and continuous wave lasers. This performance is guaranteed by automatically calibrating with a built-in wavelength standard. The system is available for operation from 375 to 1700 nm. Pre-aligned fiber-optic input ensures optimum alignment, resulting in uncompromised accuracy. Automatic pulse detection triggers data collection for asynchronous operation. An integrated proportional-integral-derivative controller benefits researchers who need active regulation of their laser's frequency.
info@bristol-inst.com

Surface-Mount Device Photodiode

The NXIR-RF100C, a red and NIR-enhanced, reduced-footprint, surface-mount device photodiode from **Opto Diode Corp.** has a spectral response from 320 to 1100 nm. The rugged package is designed specifically for environments requiring an extended temperature range from −40 to 125 °C and has an anti-reflective-coated window



that provides 98 percent transmission. The device expands the company's high-performance, through-hole photodiode packages, allowing designers to reduce space and cost. The NXIR-RF100C has an active area of 1 mm^2 in a small 3 × 3.5-mm surface-mount package. The new device has high responsivity of 0.62 A/W at 850 nm and 0.35 A/W at 1064 nm. The detectors are available in high volume on tape and reel. The device can be used for laser-monitoring and rain- and sun-sensor applications.
sales@optodiode.com

Compact Hexapods

The H-850KML, 500-kg high-load hexapod and the H-825KLL, 35-kg load compact hexapod

from **Physik Instrumente LP** are six-axis parallel positioning systems. Available in a variety of sizes with bases ranging from 100 mm to 1 m and different stiffness configurations in addition to the load range capabilities, hexapods are an easy solution to complex multi-axis precision motion applications. The hexapods come with state-of-the-art controllers and software tools, resulting in fast solution implementation to each customer's needs. The center of rotation can be changed on the fly with a software command. Other advantages are the absence of friction caused by moving cables.
info@pi-usa.us

APRIL

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

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

● **Experimental Biology 2017 (April 22-26)** San Francisco. Contact American Society for Investigative Pathology (ASIP); http://10times.com/asip-san-francisco.

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

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

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

MAY

● **Design & Manufacturing New England 2017 (May 3-4)** Boston. Contact UBM Canon, +1 310-445-4200, UBMCanonConferences@ubm.com; www.design-manufacturing-new-england.designnews.com.

● **LIGHTFAIR International 2017 (May 7-11)** Philadelphia. Contact LIGHTFAIR International, +1 877-437-4352, info@lightfair.com; www.light fair.com/lightfair/V40/index.cvn?id=10000.

Quantum 2017 (May 7-13) Turin, Italy. From Foundations of Quantum Mechanics to Quantum Information and Quantum Metrology & Sensing. Contact Marco Genovese, +39 011-3919-253, quantum2017@unito.it; www.quantum2017.unito.it.

● **RAPID + TCT 2017 (May 8-11)** Pittsburgh. Contact SME, +1 800-733-4763 (U.S. and Canada), +1 313-425-3000 (outside U.S. and Canada), service@sme.org; www.rapid3devent.com/.

● **Control Stuttgart (May 9-12)** Stuttgart, Germany. Contact Messe Sinsheim GmbH, +49 726-16-890, info@messe-sinsheim.de; www.tradefairdates.com/Control-M129/Stuttgart.html.

● **CLEO 2017 (May 14-19)** San Jose, Calif. Conference on Lasers and Electro-Optics. Contact The Optical Society, +1 202-416-1907, info@cleoconference.org; www.cleoconference.org/home.

PAPERS

SPIE Photomask Technology (Sept. 12-14) Monterey, Calif.
Deadline: Abstracts, April 24
Contact SPIE, +1 360-676-3290, customerservice@spie.org; http://spie.org/conferences-and-exhibitions/photomask-technology--extreme-ultraviolet-lithography-2017.

ECOC 2017 (Sept. 17-21) Gothenburg, Sweden
Deadline: Abstracts, April 28
ECOC welcomes and encourages the submission of original, unpublished, clear and relevant papers in any of the following topic areas: fibers; fiber devices and fiber amplifiers; integrated optoelectronic devices and optical processors; digital techniques for optical communication systems; transmission subsystems and optical network elements; datacom and computercom hardware; point-to-point transmission links; core, metro, and data center networks; and access, local area and indoor networks. Contact Sweden MEETX, +46 31-708-86-90, ecoc2017@meetx.se; http://ecoc2017.org/authors.

Photonics Roadshow Scotland 2017 (June 14) Glasgow, Scotland
Deadline: Abstracts, May 12
Authors should submit a 35-word summary immediately and 2-page abstract nearer the deadline. Contact Brenda Hargreaves, +44 1372 750555, brenda@xmarkmedia.com; www.photonex.org.

Nanophotonics and Micro/Nano Optics International Conference 2017 (Sept. 13-15) Barcelona, Spain
Deadline: Papers, June 28
Topics include: photonic and plasmonic nanomaterials, optical properties of nanostructures, nonlinear nano-optics, quantum dots and color centers, strong light-matter interactions at the nanoscale, metamaterials, enhanced spectroscopy and sensing, nano-optomechanics, quantum nano-optics, nanoscale photothermal effects, and nanomedicine. Contact Organizing Committee, +337 81-20-1182, nanop2017@premc.org; www.premc.org/conferences.

● **EASTEC (May 16-18)** West Springfield, Mass. Contact SME, service@sme.org; www.easteconline.com.

● **Display Week 2017 (May. 21-26)** Los Angeles. Contact Society for Information Display, mhardcastle@mcapr.com; www.displayweek.org.

Bio-IT World Conference & Expo '17 (May 23-25) Boston. Co-located with Medical Informatics World Conference. Contact Cambridge Healthtech Institute, +1 781-972.5400, chi@healthtech.com; www.bio-itworldexpo.com/.

ETOP-2017 (May 29-31) Hangzhou, China. 14th International Conference on Education and Training in Optics and Photonics. Contact IEEE Photonics Society; http://opt.zju.edu.cn/ETOP2017.

● **SENSOR +TEST 2017 (May 30-June 1)** Nuremberg, Germany. Contact AMA Service GmbH, +49 503-39-6390, info@sensorfairs.com; www.sensor-test.de/welcome-to-the-measurement-fair-sensor-test-2017.

JUNE

● **SiIM 2017 Annual Meeting (June 1-3)** Pittsburgh. The Society for Imaging Informatics in Medicine (SIIM). Contact SIIM, +1 703-723-0432, info@siim.org; www.siim.org/page/SIIM2017.

LPM2017 The 18th International Symposium on Laser Precision Microfabrication (June 5-8) Toyama, Japan. Contact JLPS - Japan Laser Processing Society, +81-6-6879-8642, lpm2017@jlps.gr.jp; www.jlps.gr.jp/lpm/lpm2017.

● **WMTS 2017 (June 6-8)** Edmonton, Alberta, Canada. Western Manufacturing Technology Show. Contact SME, +1 888-322-7333 ext 4444, bkiller@sme.org; www.wmts.ca.

CYTO 2017 (June 10-14) Boston. 32nd Congress of the International Society for Advancement of Cytometry. Contact Roya Jaseb, +1 301-634-7017, info@cytoconference.org; www.cytoconference.org.

9th World Congress on Materials Science and Engineering (June 12-14) Rome. Contact Richard Green, +1 650-268-9744, materialscongress@conferenceseries.com; http://materialsscience.conferenceseries.com/europe.

Vacuum Roadshow Scotland 2017 (June 14) Glasgow, Scotland. Colocated with Photonics Scotland. Contact Laurence Devereaux, +44 1372-750555; http://vacuumroadshow.com.

Photonics Scotland 2017 (June 14) Photonics Technology Roadshow. Colocated with Vacuum Roadshow. Glasgow, Scotland. Contact Laurence

● Indicates shows **Photonics Media** will be attending.
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Devereaux, +44 1372 750555, id@xmarkmedia.com; www.photonex.org.

BIO International Convention (June 19-22) San Diego. Biotechnology Innovation Organization (BIO). Contact Biotechnology Innovation Organization, +1 202-962-6655, convention@bio.org; www.convention.bio.org.

CARS 2017 (June 20-24) Barcelona, Spain. Computer Assisted Radiology and Surgery. Contact Mrs. Franziska Schweikert, +49-7742-922 434, office@cars-int.org; www.cars-int.org.

European Conference on Biomedical Optics (ECBO) (June 25-29) Munich. Contact Ellen Richter-Maierhofer, +49 899-49-2037, info@photonics-congress.com; www.osa.org/en-us/meetings/topical_meetings/european_conferences_on_biomedical_optics.

CLEO/Europe-EQEC 2017 (June 25-29) Munich. Conference on Lasers and Electro-Optics/Europe and the European Quantum Electronics Conference. Contact European Physical Society, conferences@eps.org; www.cleoeurope.org.

OSA Applied Industrial Optics: Spectroscopy, Imaging, and Metrology 2017 (June 25-30) San Francisco. Contact OSA, info@osa.org; www.osa.org/en-us/meetings/osa_meetings/imaging_and_applied_optics_congress/applied_industrial_optics_spectroscopy_imaging.

Laser World of Photonics (June 26-29) Munich. Contact Messe Munchen GmbH, +49 89-949-20720, info@world-of-photonics.com; www.world-of-photonics.com.

Sensors Expo & Conference 2017 (June 27-29) San Jose, Calif. Contact Questex LLC, +1 617-219-8300; www.sensorsexpo.com.

JULY

OSA Congress: Optical Design and Fabrication (July 9-13) Denver. Contact OSA, +1 202-223-8130, info@osa.org; www.osa.org/en-us/meetings/osa_meetings/optical_design_and_fabrication.

SEMICON West 2017 (July 10-13) San Francisco. Contact SEMICON West, +1 408-943-6986, lgeary@semi.org; www.semiconwest.org.

International Conference on Additive Manufacturing & 3D Printing (July 11-13) Nottingham, England. Contact Additive Manufacturing & 3D Printing Research Group (3DPRG), donna@am-conference.com; https://www.am-conference.com.

ALD 2017 (July 15-18) Denver. 17th International Conference on Atomic Layer Deposition. Contact Della Miller, +1 530-896-0477, della@avs.org; https://aldconference.avs.org.

OSA Nonlinear Optics (July 17-21) Waikoloa, Hawaii. Contact The Optical Society (OSA), +1 202-416-1907; http://www.osa.org/.

OSA Optical Sensors (July 24-27) New Orleans. Contact OSA, +1 202-223-8130, info@osa.org; www.osa.org.

IRCSEEME 2017 (July 26-28) Newcastle upon Tyne, England. International Research Conference on Sustainable Energy, Engineering, Materials and Environment (SEEME). Contact Monica Martins, info@ircseeme.com; www.ircseeme.com.

CLEO Pacific Rim Conference (July 31-Aug. 4) Singapore. Contact CLEO, cleopacrim@osa.org; www.photonics2017.org/index.php.

6th International Conference on Photonics (July 31-August 2) Milan. Contact Elisa Walker, +1 888-843-8169, photonics@conferenceseries.net; www.photonics.conferenceseries.com.

AUGUST

Microscopy & Microanalysis 2017 (Aug. 6-10) St. Louis. Contact Jay Potts, +1 703-964-1240 x14, mm2017ProgramChair@microscopy.org; www.microscopy.org/MandM/2017.

SPIE Optics + Photonics 2017 (Aug. 6-10) San Diego. Contact SPIE, +1 360-676-3290, customerservice@spie.org; http://spie.org.

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Futuristic Foldable, Printable OLEDs

Laptops and tablets are hard and breakable; many can't handle harsh conditions. And bending or stretching them is out of the question. But what if you could fold up that tablet and stick it in your pocket? Or imagine an ultrathin smart tablet that can easily be stretched from small to extra large. This is a potential application of stretchable smart fabric that has been developed in a lab at Michigan State University.

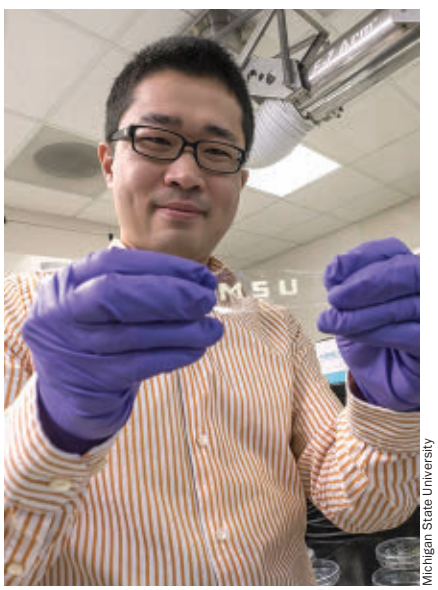
Michigan State University

The smart fabric created by Michigan State University engineers, shown here in its stretched state, could one day lead to an ultrathin smart tablet that could be manually stretched to a larger size.

Chuan Wang, assistant professor of electrical and computer engineering, said the material can be produced on a standard printer — promising major cost advantages over current technologies.

"We can conceivably make the costs of producing flexible electronics comparable to the costs of printing newspapers," said Wang. "Our work could soon lead to printed displays that can be stretched to larger sizes, as well as wearable electronics and soft robotic applications."

Professor Wang and his team have developed the first stretchable integrated circuit that is made entirely using an inkjet printer. The smart fabric is made from nanomaterials and organic compounds that are dissolved in a solution to produce different electronic inks. The inks are run through the printer to make the devices.



Michigan State University

Chuan Wang, a Michigan State University engineering researcher, displays the stretchable electronic material he and colleagues developed in his lab.

Researcher Le Cai told Photonics Media that, from the ink, they have successfully created the elastic material, the circuit and the organic light-emitting diode (OLED) needed for such a technology.

"The electronic parts, like transistors and logic gates, can work as the control circuits of the displays, while OLEDs will be used as the light-emitting elements," said Cai. "Our devices are soft and conformal while conventional devices are rigid and brittle. Being stretchable or bendable is essential for the future direction electronics are going."

This new technology is suitable for low-cost and large-area manufacturing without using expensive cleanroom facilities, which complies with the idea of green manufacturing.

Their next step is combining the circuit and OLED into a single pixel, which they estimate will take one to two years, as there are generally millions of pixels just underneath the screen of a smart tablet or a large display. Once this is accomplished, the smart fabric can be commercialized.

The stretchable electronic fabric can be folded and then put in one's pocket without breaking. But, there are other potential applications.

"Ultimately, we are shooting for large-area, conformal and interactive systems composed of electronic circuits, display and lighting elements, sensors, actuators and energy harvesting components," said Cai.

Ink-fabricated stretchable circuitry smart fabric — say that three times fast — could change the look and feel of tomorrow's electronics.

Autum C. Pylant
autum.pylant@photonics.com

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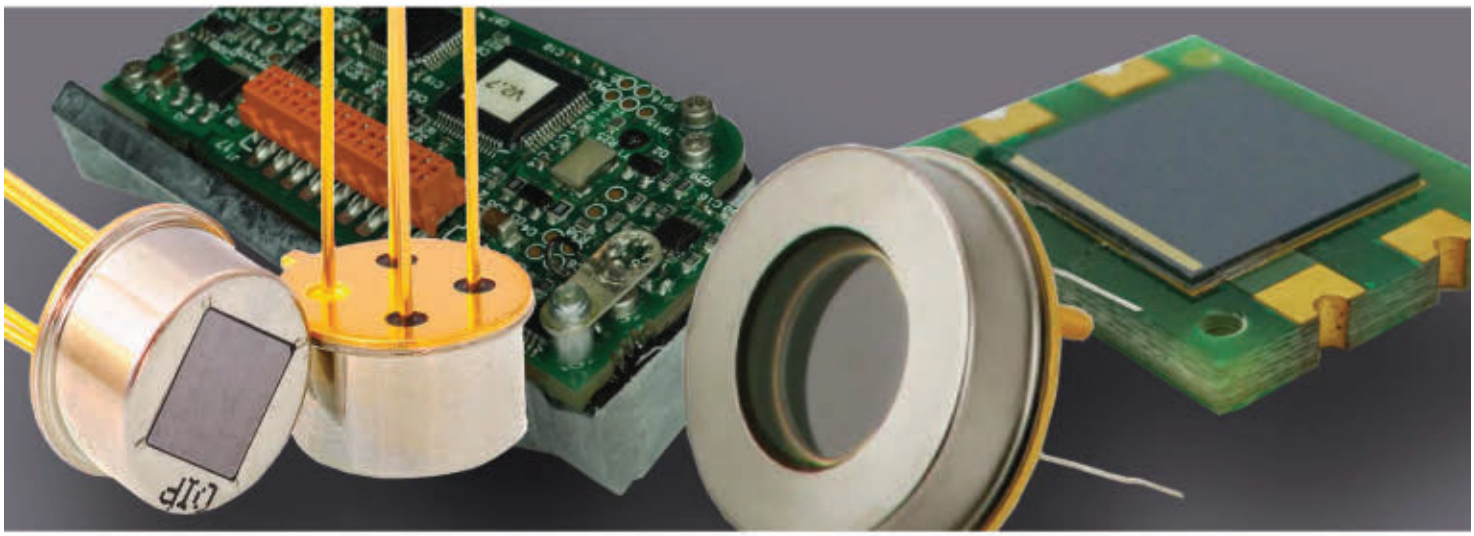

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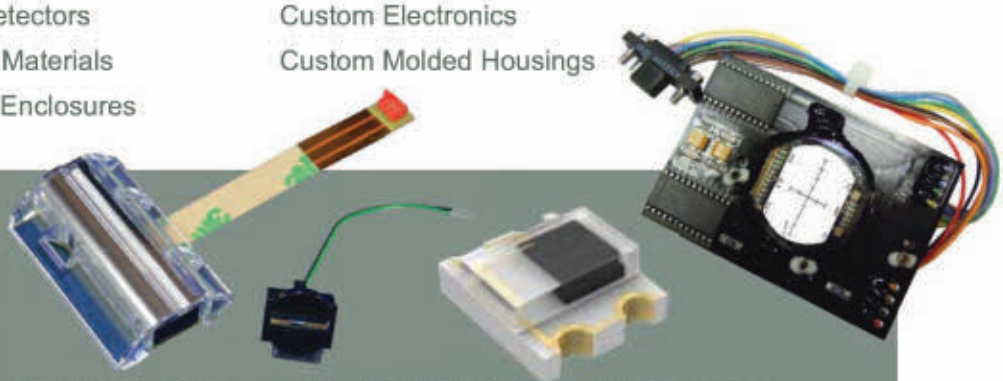

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