www.photonics.com

November 2024

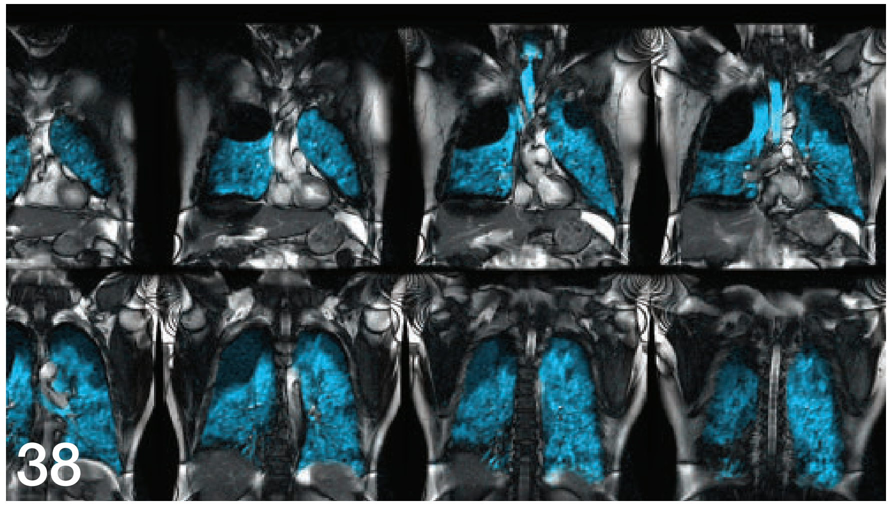
PHOTONICS spectra®

The Ultimate Planar Optics

PHOTONICS MEDIA

LAURIN PUBLISHING

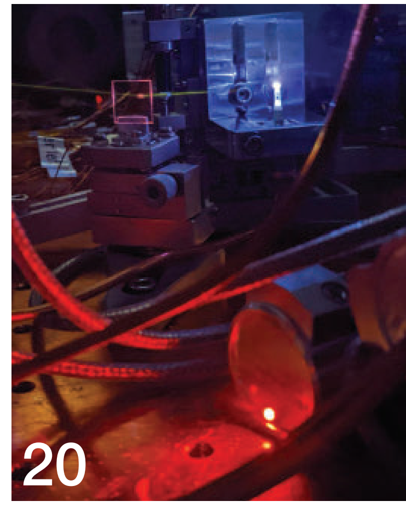
Features



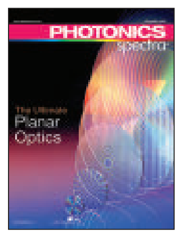
PHOTONICS SPECTRA ISSN-0731-1230, (USPS 448870) IS PUBLISHED MONTHLY BY Laurin Publishing Co. Inc., 100 West Street, PO Box 4949, Pittsfield, MA 01202, +1 413-499-0514; fax: +1 413-442-3180; email: photonics@photonics.com. TITLE reg. in U.S. Library of Congress. Copyright ® 2024 by Laurin Publishing Co. Inc. All rights reserved. Copies of *Photonics Spectra* on microfilm are available from University Microfilm, 300 North Zeeb Road, Ann Arbor, MI 48103. *Photonics Spectra* articles are indexed in the Engineering Index. **POSTMASTER:** Send form 3579 to *Photonics Spectra*,100 West Street, PO Box 4949, Pittsfield, MA 01202. Periodicals postage paid at Pittsfield, MA, and at additional mailing offices. **CIRCULATION POLICY:** *Photonics Spectra* is distributed without charge to qualified scientists, engineers, technicians, and management personnel. Eligibility requests must be returned with your business card or organization's letterhead. Rates for others as follows: $122 per year, prepaid. Overseas postage: $28 surface mail, $108 airmail per year. Inquire for multiyear subscription rates. Publisher reserves the right to refuse nonqualified subscriptions. **ARTICLES FOR PUBLICATION:** Scientists, engineers, educators, technical executives, and technical writers are invited to contribute articles on optical, laser, fiber optic, electro-optical, imaging, optoelectronics, and related fields. Communications regarding the editorial content of *Photonics Spectra* should be addressed to the senior editor. Contributed statements and opinions expressed in *Photonics Spectra* are those of the contributors — the publisher assumes no responsibility for them.

Departments

Columns



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.



The Cover

A micron-thin film, coated over a flat glass substrate, can deflect a light beam in the same way as a prism. Today, an optic as clear and efficient as glass shaped into these flat prisms and lenses, yet not as heavy or thick, and capable of overcoming efficiency limitations, is finally in sight. Courtesy of BEAM Co. Cover design by Senior Art Director Lisa N. Comstock.

PHOTONICS spectra®

***Photonics Spectra* Editor** Jake E. Saltzman

Editorial Staff

Editor-in-Chief Michael D. Wheeler
Senior Editors Douglas J. Farmer
Jake E. Saltzman
Joseph T. Kuczynski
News Editor Joel P. Williams
Departments Editor Dominic V. Acquista
Conference Coordinator Jacob H. Mendel
Copy Editors Carolyn G. Kenney
Michael P. Bleau
Kate Lavallee
Contributing Editors Andreas Thoss
Marie Freebody
Hank Hogan
James Schlett
Michael Eisenstein

Creative Staff

Senior Art Director Lisa N. Comstock
***BioPhotonics* Art Director** Suzanne L. Schmidt
Digital Designer Brian W. Healey
Creative Designer Devon A. Unwin

Corporate Staff

President/CEO Thomas F. Laurin
Vice President Kristina A. Laurin
Vice President Erik W. Laurin
Vice President of Sales Matthew M. Beebe
Internal Audit Officer Mollie M. Armstrong
Controller Liusha Hua
Accounts Receivable Manager Kathleen G. Paczosa
Business Manager Elaine M. Filiault

Business Staff

Director of Audience Development Heidi L. Miller
Director of Sales Operations Rebecca L. Pontier
Circulation Production Manager Kimberly M. LaFleur
Circulation Assistants Alice M. White
Theresa A. Horn
Traffic Manager Daniel P. Weslowski

Buyers' Guide & Digital Media Staff

Director of Publishing Operations Kathleen A. Alibozek

Managing Editor Jeanne L. Kelly
Assistant Editor & Digital Support Tracy J. Nye
Assistant Editor & Print Ad Production Patricia M. Mongeon
Digital Ad Production Jordan R. Young
Digital Project Manager Alan W. Shepherd
Digital Developer & IT Support Brian A. Bilodeau
Computer Specialist & Digital Support Angel L. Martinez

Editorial Offices

100 West Street, PO Box 4949
Pittsfield, MA 01202-4949
+1 413-499-0514; fax: +1 413-442-3180
www.photonics.com

News releases should be directed to our main office. If you would like an editor to contact you, please notify us at the main office, and we will put you in touch with the editorial office nearest you.

Editorial email: editorial@photonics.com
Advertising email: advertising@photonics.com
Press releases: pr@photonics.com
Event listings: events@photonics.com

Advertising Offices

Main Office 100 West Street, PO Box 4949
Pittsfield, MA 01202-4949
+1 413-499-0514
Fax: +1 413-443-0472
advertising@photonics.com

Japan Sakae Shibasaki
The Optronics Co. Ltd.
Sanken Bldg., 5-5 Shin Ogawamachi
Shinjuku-ku, Tokyo 162-0814, Japan
+81 3-3269-3550
Fax: +81 3-5229-7253
s_shiba@optronics.co.jp

For individual advertising contacts' information, view listings next to advertiser index.

Circulation Offices

100 West Street, PO Box 4949
Pittsfield, MA 01202-4949
+1 413-499-0514
Fax: +1 413-445-4829
circulation@photonics.com

More Than 100,000 Distributed Internationally

Alliance for Audited Media

www.photonics.com

Editor's Note

In lieu of a banner year, a watershed moment

On Wednesday, Oct. 3, 2023, the clock started ticking on what would become a seismic 24-hour period. For those of us in North America, it began when we woke up to the news that Pierre Agostini, Ferenc Krausz, and Anne L'Huillier had been announced as winners of the Nobel Prize in physics. The trio's award, in recognition of their advancements in attosecond pulse generation, established consecutive years in which a photonics (or photonics-enabled) achievement was celebrated with the ultimate honor.

In the optical sciences community, the 2023 winners represented something more. Though the accomplishments of Agostini, Krausz, and L'Huillier made it six of the last 10 Nobel Prizes in physics to have a photonics connection, it also marked the first Nobel Prize in five years to be awarded to an individual or group whose seminal work was in laser physics. In Nobel Prize time, five years can feel more like 50.

The award of the Nobel Prize in chemistry on the morning of Oct. 4 intensified the focus that the previous day's news had already placed on the optical sciences. Moungi Bawendi, Louis Brus, and Alexei Ekimov took the prize for the discovery and development of quantum dots. As far as innovations in chemistry go, few tie as tightly to photonics as quantum dots, given their utility in optical communications, displays, solar cells, and optical imaging.

Put simply, it was a good day for photonics. And after scientists at the National Ignition Facility achieved fusion ignition on Dec. 5, 2022 — a bona fide historical milestone that will live in the annals of more than any singular scientific discipline — the 24 hours bridging Oct. 3 and Oct. 4 last year sent a strong signal that 2023, too, was to be considered a banner year for photonics.

This year's Nobel Prize in physics signals something else. Awarded to John Hopfield and Geoffrey Hinton, "for foundational discoveries and inventions that enable machine learning with artificial neural networks," there is no need to go back and check how many times AI has featured in the celebrated achievements of previous Nobel Laureates.

But could six of the next 10 Nobel Prizes in physics — or in chemistry, physiology, or economic sciences — recognize AI-related, or even AI-aided innovations?

That we might ask such a question indicates that we've reached a turning point.

More certain than the future of AI is that, in terms of impact and potential, we are due if not overdue to include foundational AI in any conversation about the present and future of the sciences. Questions about the ethics of AI in a context such as the awarding of the Nobel Prizes will endure. And many will balk at favoring accomplishments routed in computational methods compared with more traditional achievements. But this topic is not one to ignore any longer.

For that, you can thank the 2024 Nobel Prize in physics winners. You can also thank society. Unlike the Royal Swedish Academy, its stance on AI is hardly just now beginning to take shape.

jake.saltzman@photonics.com

PHOTONICS spectra®

Contributors

Ken Barat
Ken Barat is a certified laser safety officer with 30 years of experience addressing laser safety for end users internationally. He has written 11 texts on the subject and espouses the motto “safety through cooperation.” Page 52.

Nelson Tabiryan
Nelson Tabiryan is a pioneer in liquid crystal photonics developments, an Optica Fellow, and CEO and president of BEAM Engineering for Advanced Measurements Co., founded in 1996. Page 30.

Michael Eisenstein
Michael Eisenstein studied biology at Brown University and Rockefeller University. He has worked as a freelance science journalist and as an editor for the past 10 years. Page 47.

Andreas Thoss
Andreas Thoss, Ph.D., is a laser physicist, founder of THOSS Media, and a contributing editor to *Photonics Spectra*. He has been writing and editing technical texts, with a focus on the field of photonics, for two decades. Page 42.

Robert Kohlhaas
Robert Kohlhaas has served as head of the Terahertz Group at Fraunhofer HHI since 2022, researching photonic terahertz devices and systems. He studied physics at the Technische Universität Berlin, where he also completed his Ph.D. Page 42.

Jeffrey Ungar
Jeffrey Ungar is the founder of QPC Lasers and was formerly director of advanced R&D at Ortel, which was later acquired by Lucent Technologies. He has been involved in the development of high-power laser diodes for 40 years. Page 38.

Lars Liebermeister
Lars Liebermeister has worked in the Terahertz Sensors and Systems Group at the Fraunhofer Heinrich Hertz Institute since 2016, becoming deputy group leader in 2019. He holds a Ph.D. in photonics from the Ludwig-Maximilians-Universität. Page 42.

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

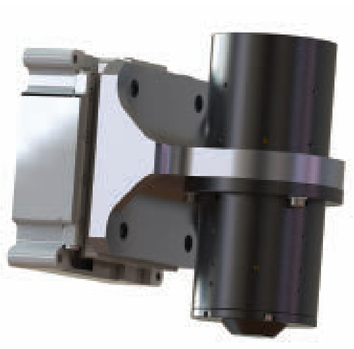
Follow Photonics Media on Facebook, X, Instagram, LinkedIn, and YouTube.

Photonics Spectra Webinars

View Webinars on Demand

On-demand webinars are free to Photonics.com registered members. Watch informative seminars presented by experts in the field, at a time that is convenient for you! To view webinars on demand and to see the Photonics Media upcoming webinar listings, visit **www.photonics.com/webinars**.

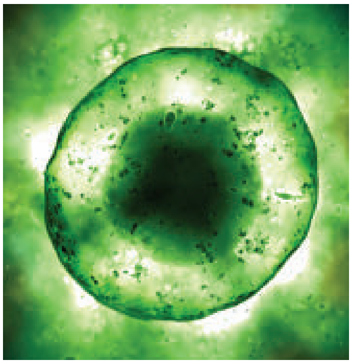
Accelerating Life Sciences Imaging Instrument Development with Unrivaled Performance and Speed



Developing a high-performance fluorescence microscope is a challenging task in which all subsystems must work in harmony. In this webinar, Joseph Mulley and James Feeks of IDEX Health & Science introduce key system architecture decision points and discuss their pros and cons. By considering the effect of each decision on the system, it is possible to design a more cohesive microscope that achieves a desired performance. The Melles Griot XPLAN CCG Lens Series and Dover Motion DOF-5 precision z-stage are introduced with an explanation of how the components can enable a high-performance breadboard microscope under an accelerated timeline. Presented by IDEX Health & Science. To view, visit **www.photonics.com/w1102.**

IDEX HEALTH & SCIENCE

Multiplex Imaging: Camera, Lights, Optics, Action!



Multiplex imaging, either multicolor fluorescence or multispectral absorption and reflection imaging, is rapidly gaining popularity in the life sciences and medical arenas. Imaging samples at a variety of wavelengths, in live or fixed samples, provides a depth of information that was never possible to attain using conventional microscopy. This webinar discusses the options and requirements for performing multiplex imaging, from the illumination to the detection and the optics in between to navigate the light to and from the sample. Presented by Excelitas.
To view, visit **www.photonics.com/w1092.**

EXCELITAS TECHNOLOGIES

PHOTONICS spectra SUMMIT

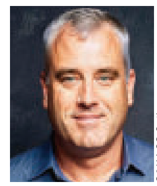
Polymer Optics Summit


FlexEnable
Paul Cain.


Greenlight Optics
Mike O'Keefe.


Apollo Optical Systems
Dale Buralli.


Jenoptik
Jan Heller.


G&H | GS Optics
David Boyd.

The editors of *Photonics Spectra* magazine invite you to the Polymer Optics Summit, a one-day virtual event premiering on Dec. 4, 2024. This event explores the latest applications and innovations in polymer optics. All presentations remain accessible on demand following the event.

Attendees will discover the role that polymer optics play in advancing optical designs, solving complex manufacturing challenges, and enhancing performance in cutting-edge technologies, such as augmented reality. Experts from FlexEnable, Apollo Optical Systems, Greenlight Optics, Jenoptik, and G&H | GS Optics will present actionable insights into improving optical communication and overcoming design obstacles.

Registration is free and provides access to practical knowledge that can enhance the understanding and application of polymer optics in your projects. Join the conversation with industry leaders and discover new ways to leverage polymer optics in your field.

Website

For more information and to register, visit **www.photonics.com/PO2024**.

Bioplastic 3D Tunable-Focus Lenses and Dimmers for Enhancing Optical Performance in AR Glasses
Paul Cain, FlexEnable

Solving Complex Design and Manufacturing Challenges with Polymer Optics
Mike O'Keefe, Greenlight Optics

Polymer Optics in Optical Design: Keys to Effective Communication
Dale Buralli, Apollo Optical Systems

High-Precision Polymer Optics and Optoelectronics: Solutions to the Physical Limit
Jan Heller, Jenoptik

Injection-Molded Optics for Medical and Diagnostic Instruments
David Boyd, G&H | GS Optics

Upcoming Summits

Hyperspectral Imaging — *January 15, 2025*

Integrated Photonics — *February 12, 2025*

Spectroscopy — *March 12, 2025*

Infrared Imaging — *April 16, 2025*

Microscopy — *May 14, 2025*

Register today at www.photonics.com/PO2024.

SPIE elects Cather Simpson into presidential chain

SPIE elected Cather Simpson, a professor of physics and chemical sciences at the University of Auckland to serve as the society's 2025 vice president. With her election, Simpson joins the SPIE presidential chain and will serve as president-elect in 2026 and as the society's president in 2027.

Simpson also serves as founder, CEO, and director of Orbis Diagnostics, a microfluidic blood test platform. Since 2022, she has served on Fisher & Paykel Healthcare's board of directors. She has received multiple professional recognitions, including the Australian and New Zealand Optical Society's W.H. (Beattie) Steel Medal; the Pickering Medal from the Royal Society Te Apārangi in New Zealand, a society of which she is a Fellow; and an Ako Aotearoa Award for Sustained Excellence in Tertiary Teaching. Simpson is also an inventor on more than 10 patent families.

Simpson was named an SPIE fellow member last year and is an SPIE lifetime member. She served on the SPIE board of directors between 2021 and 2023.

Zygo Corporation's Peter de Groot will serve as the 2025 SPIE president while University of Rochester professor Julie Bentley will serve as president-elect.

Along with Simpson, Jim McNally, CEO of StratTHNK Associates, was elected to serve as the 2025 SPIE secretary/treasurer. The following newly elected society directors will serve three-year terms between 2025 and 2027: Alexis Vogt, endowed chair and professor of optics at Monroe Community College and AmeriCOM's executive director of workforce and higher education; Debbie Gustafson, CEO of Energetiq Technology; Brian Pogue, Robert Turell University of Wisconsin Medical Foundation (UWMF) Professor of Medical Physics at the University of Wisconsin-Madison and editor-in-chief of SPIE's *Journal of Biomedical Optics*; and Kishan Dholakia, a professor and the director of the Centre of Light for Life at the University of Adelaide.


SPIE

(Top row, from left) Cather Simpson, Jim McNally, and Alexis Vogt. **(Bottom row, from left)** Debbie Gustafson, Brian Pogue, and Kishan Dholakia.

IPG Photonics sells Russian operations

IPG Photonics sold its interest in its Russian subsidiary, IRE-Polus, in a sale that marks the finalization of the laser maker's exit from all facilities in Russia following imposed sanctions on trade after the start of the war with Ukraine. IPG completed the sale to a group led by Softline Projects LLC and current management of IRE-Polus. Proceeds of the transaction stand at $51 million before fees.

"Our team executed flawlessly to transition our manufacturing operations after the war's outbreak without any impact to our customers," said Mark Gitin, who was named CEO of IPG Photonics in April and assumed the position from company cofounder Eugene Scherbakov in June.

"Our ability to respond to adverse events out of our control highlights the resilience of the company as we were able to lean on our global manufacturing capabilities to increase production in Germany, the U.S., and Italy and start production in Poland," Gitin said.

IPG was founded in Russia by physicist and laser expert Valentin Gapontsev in 1990, and the company suspended capital investment there following the start of the war in Ukraine. In addition to working to increase capacity and inventories of critical components outside Russia, IPG, in 2022, said it had started qualifying third-party components suppliers in order to reduce its reliance on its Russian operations.

IPG's Russian operations had supplied components for its major facilities in Germany and the U.S. as well as finished products for the Chinese market.

The company said that it expected the sale to reduce its third quarter revenue as compared with its previously provided guidance by approximately $5 million. IRE-Polus revenue accounted for <5% of IPG's full-year revenue at the time of the sale.

In a separate development, IPG announced this summer that it plans to build a 37,300-sq-ft production facility in eastern Canada. The facility will create 20 jobs.

Optica to implement changes following Huawei funding inquiry

Following the departures of former CEO Elizabeth Rogan and head of the Optica Foundation Chad Stark, Optica said that it plans to enact changes to processes and procedures related to the Optica Foundation Challenge.

Optica's change in leadership followed an inquiry from the House of Representative's Committee on Science, Space, and Technology (CSST) into ties between Optica and blacklisted Chinese tech firm Huawei. The inquiry found that the Optica Foundation Challenge had accepted funds from Huawei.

An independent review undertaken by Optica's board of directors found that not all of the agreed controls associated with the Optica Foundation Challenge were followed and that there was a lack of transparency with the Optica Foundation Board.

"We regard these as serious issues, and we determined that a change in leadership is in the best interest of the organization,"

This month in history

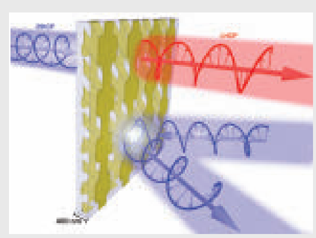
What were you working on five, 10, 20, or even 30 years ago? *Photonics Spectra* editors have perused past November issues and unearthed the following:

1994

Engineers from Northwestern University and the University of California at San Diego put together a 5-µm diameter double-disk laser that emitted light in a single direction. The laser operated at 1.5 µm and had a potential application in fiber optic network interconnects.

2004

A team from the University of California, Berkley and Lawrence Berkley National Laboratory demonstrated that crystalline oxide nanoribbon waveguides can be used with other nanowire optical components to create rudimentary systems that suggest the feasibility of nanowire-based photonic integrated circuitry. They focused on SnO_2 and ZnO nanoribbons.

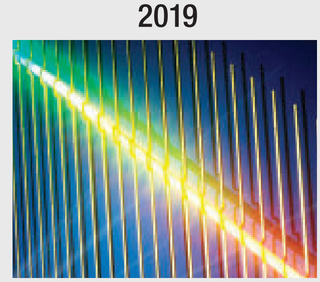


2014

Researchers from the University of Michigan's Lurie Nanofabrication Facility created an ultrathin metasurface that could alter light polarization with 50% efficiency. It measured 250 × 250 µm and was 400 nm thick. It comprised three 28-nm patterned gold sheets fabricated using electron-beam lithography and separated at subwavelength intervals by dielectric substrates.

2019

Scientists at the University of Cambridge developed a microspectrometer based on a single, compositionally engineered nanowire that operates independently of complex optical components or cavities. The spectrometer was the smallest designed at the time.



Optica president Gerd Leuchs said, in a statement issued Sept. 3.

Speaking with Photonics Media, Leuchs said that the organization would discuss changes to its procedures and controls, along with plans to appoint a new CEO.

As of press time, Leuchs told Photonics Media, there is not yet an expected timeline to determine Rogan's replacement. The organization named deputy executive director Elizabeth Nolan interim CEO.

The CSST began investigating ties between Optica and Huawei following a Bloomberg report in May alleging that Huawei had been secretly funding U.S. research through Optica. The report stated that Huawei had been the sole source of funding for the 2022 and 2023 Optica Foundation Challenge.

Optica notified the CSST on June 6 of its decision to return the entirety of Huawei's funding for the Optica Foundation Challenge, including funds from previous years. The CSST subsequently issued another letter to Rogan, on July 29, following another report from Bloomberg that called into question the way in which Optica had characterized its relationship with Huawei.

Joel Williams, News Editor
joel.williams@photonics.com

Mynaric makes leadership position changes, cites production struggles

Laser communications company Mynaric terminated Mustafa Veziroglu as CEO and member of the company's management board. The move comes after the producer of optical communications terminals for air, space, and mobile applications resolved an update to its full-year revenue guidance. The update included a drop-off in expected revenue from the originally published range of between €50 million and €70 million ($56 million and $78 million) to a revised range of between €16 million and €24 million. The company attributed the decrease in guidance to production delays of its CONDOR Mk3 optical communications terminal.

Mynaric additionally revised its forecast for its annual operating loss. The company now expects its full-year 2024 operating loss to range between €55 million to €50 million, compared with previous guidance of a range between a loss of €40 million to €30 million.

The company attributed the guidance decrease to the lower-than-expected revenue and higher-than-expected production costs to lower yields. "With the lower than previously expected revenue and cash-in from customers for fiscal year 2024, we will need to pursue additional capital sources to secure our ongoing operations and production ramp," the company said.

Mynaric said in a press release that it is evaluating different strategic options to address its near-term capital needs.

Mynaric simultaneously announced the departure of its CFO, Stefan Berndt von-Bülow, and appointed Andreas Reif chief restructuring officer and a member of the management board, also with immediate effect.

People in the News


Jenoptik
Stefan Traeger.

Jenoptik extended the contract of company CEO **Stefan Traeger**. The extension will come into effect in July 2025 and will run through June 2028. Traeger has acted as Jenoptik's president and CEO since 2017 and serves as nonexecutive director of Aixtron SE.

MKS Instruments appointed **Ram Mayampurath** executive vice president, CFO, and treasurer. Mayampurath most recently served as senior vice president, CFO, and treasurer of Rogers Corporation and previously served in divisional financial leadership roles at Royal Philips Electronics.

Photonic quantum computing hardware developer QuiX Quantum added **Basil Garabet** to its supervisory board. Garabet has held the role of president and CEO of NKT Photonics since 2015 and serves on the board of the Danish Quantum Community, is president and board member of the European Photonics Industry Consortium, and is a board member of Bifrost Communications.


QuiX Quantum
Basil Garabet.

Infrared imaging company Emberion appointed **Sami Kyllönen** CEO. Kyllönen previously served as the company's COO and director of production. He succeeds company founder **Tapani Ryhänen** in the CEO position. Prior to Emberion, Kyllönen led manufacturing operations at GE Healthcare Finland. He has more than 15 years of experience in leadership positions in operations, program management, and design management.

Lightwave Logic Inc., a developer of electro-optic polymers for data communications, appointed **Thomas M. Connelly Jr.** to its board of directors. Connelly previously served as CEO of the American Chemical Society and as chief innovation officer at DuPont. His addition is expected to aid Lightwave in expanding its initial business focus from data centers and AI clusters connectivity to include other markets, such as materials, organics, quantum/optical computing, aerospace, defense, and storage.

New Scale Technologies, a micro motion and automation systems company, promoted **Stefan Friedrich** to vice president of sales and marketing. Additionally, the company announced that **Qin Xu** will transition from vice president of engineering to CTO, and **Michael DiRisio** from program manager to engineering manager.

TiniFiber, a manufacturer of optical cabling solutions, named **Tom Artinian** CEO. **Christian Peterson**, TiniFiber's founder and outgoing CEO, will transition to chairman of the board. **Tom**

PsiQuantum to open quantum computing lab at Griffith University

Quantum computing company PsiQuantum partnered with Griffith University to open a Test & Characterization lab at the university's campus in Nathan, Australia. This expansion builds on a recent memorandum of understanding signed by PsiQuantum, Griffith, and four other Queensland, Australia, universities on various educational programs and research projects relating to quantum computing.

In the Test & Characterization lab, workers will perform characterization and calibration methods for subsystems essential for PsiQuantum's utility-scale system in Brisbane, Australia. The lab, operated exclusively by PsiQuantum, will focus on both cryogenic and room temperature photonic quantum computing subsystems and integrate the operation of combined subsystems at high performance. Results will be incorporated into existing production pathways, and the lab will initially collaborate with other PsiQuantum facilities worldwide, evolving as the quantum computer site becomes fully operational.

The lab space is slated for operation in early 2025.


Griffith University

PsiQuantum's Test & Characterization lab at Griffith University will focus on cryogenic and room temperature photonic quantum computing subsystems.

Brown, who served as the interim president since May, will be promoted to senior vice president of business development and sales. Artinian has 30 years of experience within the fiber optics and cabling industries, most recently serving as COO and president at Hitachi Metals' Wire and Cable division.

Photodiode and infrared sensor developer Phlux Technology appointed **Christian Rookes** vice president of marketing, **Brian Williams** vice president of operations, and **John Fuller** director of engineering. Rookes has more than 25 years of experience in semiconductor and technology sectors, most recently as vice president of marketing and business development at HiLight Semiconductor. Williams is currently CEO of Ultraleap Manufacturing with more than 35 years of semiconductor sector experience. Fuller previously served as engineering director at Gas Sensing Solutions.

Fujitsu to open European all-photonics network lab

Fujitsu Limited plans to establish an open all-photonics network (APN) lab in Düsseldorf, Germany, the company said. The lab aims to further the adoption of APNs and promote the expansion of the Innovative Optical and Wireless Network (IOWN) initiative.

The open APN lab comes as part of a contract gained from the Japanese Ministry of Internal Affairs and Communications to conduct field trials toward the overseas deployment of APNs in Europe.

Open APNs facilitate the connection of multivendor products and solutions while providing high capacity, low latency, and low power consumption. A new IOWN service is planned to be introduced in Japan at the start of the 2025 fiscal year.

Network carriers, data center operators, and vendors will be able to use the lab to verify APN functionality and multivendor connectivity beginning in November, and until the lab closes in March 2025. Following the lab's close, Fujitsu plans to conduct field trials and further expand its APN labs globally, including in North America.

Soitec-led project targets high-frequency semiconductors

Move2THz, a European research and industry consortium led by Soitec, has commenced work to develop a generation of high-frequency semiconductors based on indium phosphide (InP). The 27-member consortium plans to lay the groundwork for a European supply and manufacturing ecosystem for InP semiconductors. It further plans to address barriers to their wider adoption, including the cost and availability of InP-based advanced substrates.

InP devices can operate at frequencies approaching or exceeding 1 THz, offering superior speeds and increased energy efficiency compared with silicon technologies. These devices are set to address applications ranging from photonics for mega data centers and AI to integrated antennas critical for 6G mobile communication, sub-terahertz radar sensing, and beyond.

One of the principal goals of the project is to establish an InP-on-silicon global

Briefs

Lockheed Martin signed a definitive agreement to acquire **Terran Orbital**, a satellite-based aerospace and defense solutions company and member of the Lockheed Martin Ventures investment fund portfolio. The transaction, which is valued at approximately $450 million, is expected to close in the fourth quarter of 2024.

IPG Photonics is investing more than CAD 21 million ($15.4 million) to build a production facility in Kingston, Ontario. The 37,300-sq-ft facility will expand production, meet growing demand of the automotive and consumer electronics industries, and create 20 jobs, according to the company.

TRUMPF Maschinen Austria opened an extension to its Smart Factory at its Pasching site in Austria. TRUMPF has invested approximately €40 million ($44 million) in the expansion of the site over the past two years, building two production halls with an area of 7000 sq m, and 850 sq m of office space. The site is equipped with a laser hybrid welding system for large parts, such as machine frames, which the Pasching plant supplies to other TRUMPF locations. The site also contains a milling center to quickly process large parts with high precision.

ams OSRAM launched a China Development Center aimed at driving business growth and technological innovation. The center will bridge R&D teams and combine experts on product marketing, system solution engineering, application engineering, and supply chain innovation. The organization is set to open offices in Shanghai and Shenzhen, China.

Quantum Brilliance (**QB**), a developer of diamond-based quantum technology, announced a strategic collaboration with **Oak Ridge National Laboratory** (**ORNL**) to build a joint platform that enables collaborative development of quantum computing with high-performance computing. The collaborators plan to codevelop computational methods that exploit parallel and hybrid computing and new software tools that will enable users to implement those methods and develop their own.

Synthetic diamond material solutions provider **Element Six** is leading a program under the Ultra-Wide BandGap Semiconductors (UWBGS) initiative established by the U.S. Defense Advanced Research Projects Agency (DARPA). Element Six will contribute its expertise to large-area chemical vapor deposition polycrystalline diamond and high-quality single crystal diamond synthesis, to realize 4-in. device-grade single crystal diamond substrates. Element Six has partnered with **Orbray**, **Raytheon**, **Hiqute Diamond**, **Stanford University**, and **Princeton University** to further develop the technology toward the realization of ultrawide bandgap semiconductors.

Boeing scheduled the 2026 launch of a satellite — Q4S — which is designed to demonstrate quantum entanglement swapping capabilities on orbit. The year-long Q4S demonstration involves two entangled photon pair sources housed within a space vehicle. Boeing's payload and technology partner, **HRL Laboratories**, a joint venture between Boeing and **General Motors**, has made significant advancements in benchtop exercises as the joint team finalizes technical designs of a space-hardened payload that is ready for launch.

Exosens, a detection and imaging technology company, acquired **LR Tech**, a specialist developer and manufacturer of Fourier transform infrared devices. The acquisition will enable Exosens to complete its instrument offerings for detectors and imagers, targeting science and environmental standard, which will facilitate upscaling of the wafer size and volume compatible with CMOS manufacturing capacities, while minimizing the use of rare InP resources. Consortium members include CEA-Leti, Eindhoven University of Technology, Smart Photonics, Chalmers University of Technology, ETH Zürich, the Ferdinand-Braun-Institut, and Microwave Photonics.

By 2027, Move2THz expects to provide competitive elements for the terahertz technology sector. The project is ultimately targeting the year 2030 for a mature InP ecosystem, coinciding with the expected ramp-up of 6G-associated technologies.

The three-year project is a recipient of European Union funding as well as top-up financing from the governments of France, Switzerland, Germany, Sweden, the Netherlands, and Belgium.

$344.3M — projected size of the global freeform optics market by 2030, according to Research and Markets

markets. This acquisition follows Exosens' recent acquisition of radiation detection solutions company Centronic, completed in August.

The **Open XR Optics Forum** made its Open XR Signal Specifications document available, providing a full line-side signal specification for Open XR Optics transceivers and enabling implementation of line-side compatible transceivers.

Nirrin Technologies, a developer of analytical tools for bioprocess analysis, was awarded a $2 million Small Business Innovation Research (SBIR) Direct Phase II grant from the National Institutes of Health. The grant will fund further development of Nirrin's proprietary high-precision tunable laser spectroscopy (HPTLS) platform for biomanufacturing applications. HPTLS combines NIR spectroscopy with a tunable laser source to provide a quantitative method for the analysis of bioprocess components. Nirrin will apply SBIR funds to ramp up development on upstream bioprocessing applications for bioreactor automation and control.

Morphotonics, a provider of large-area nanoimprint technology, launched a series B funding round, with a first closing of more than $10 million, and a second closing expected by the end of the year. The funding will allow the company to scale its operations and supply chain, expand its global customer base — particularly in Asia — and help it to position fully automated, large-area nanoimprinting as a standard in display optics production through product innovations.

Quanta Computer Inc., a provider of solutions for cloud computing, made a $20 million three-tranche investment in **Vuzix Corporation**, a supplier of smart glasses and AR technology, to support and expand Vuzix's waveguide production capabilities and for the joint development of new AR/AI smart glasses technologies. The first investment tranche will consist of $10 million of Vuzix common stock. The second and third tranches of the total planned investment are $5 million each, tied to specific milestones, and will consist of the purchase of Vuzix series B preferred stock.

Quantum sensing company **Mesa Quantum** closed an oversubscribed seed funding round of $3.7 million. Among other areas, the company's technology has applications in defense, energy, space, and telecommunications.

Quantum Optics Jena lands $9.4M in funding

Quantum technology startup Quantum Optics Jena (QOJ) closed an €8.5 million (approximately $9.4 million) series A funding round. The funds will be used to fuel QOJ's expansion and accelerate the commercialization of its quantum key distribution technology.

QOJ's approach uses entangled photon pairs for tap-proof communication. The photons generate a "key" which is used to encrypt and decrypt data — a method known as entanglement-based key distribution (EKD). With this approach, multiple users can securely communicate at the same time by using the generated quantum keys.

QOJ also develops hardware, software, and services for data exchange for customers with high security requirements, such as government networks and financial institutions. The company is now working to build a communication system with partners in the rural area surrounding Jena to securely send information and patient data to the Jena University Hospital.

Also, QOJ is involved in the construction of a European Quantum Communication Infrastructure, expected to be operational across all of Europe by 2027. The company is active in Singapore, Spain, Austria, and Slovakia, and has a sales office in the U.S.

The funding round, led by venture capital firm Join Capital, was joined by early investors ELAS Technologies GmbH, Fraunhofer Technologies-Transfer Fonds, and beteiligungsmanagement Thüringen as well as angel investor Malte Pollmann.

Mobileye to shutter lidar development

Mobileye, a developer of autonomous driving and driver-assistance technology, will end the internal development of next-generation frequency-modulated continuous-wave (FMCW) lidars for use in autonomous and highly automated driving systems. The company said the decision was based on factors including progress on its EyeQ6-based computer vision perception, increased clarity on the performance of its internally developed imaging radar, and continued better-than-expected cost reductions in third-party time-of-flight lidar units.

"As part of our regular review of the long-term technology road map, we now believe that the availability of next-generation FMCW lidar is less essential to our road map for eyes-off systems," the company said in a statement.

Mobileye's lidar R&D unit will wind down by the end of 2024, and the move will affect about 100 employees. Operating expenses for the unit are expected to total around $60 million in 2024, including approximately $5 million related to share-based compensation expenses, according to the company.

Though the move is not expected to have a material effect on the company's results in 2024, it will result in the avoidance of lidar development spending in the future, the company said.

Announcing the move, Mobileye named imaging radar as a strategic priority. The company called imaging radar a core building-block technology that is expected to drive competitive advantage for Mobileye-based eyes-off systems in terms of scalability and cost and performance optimization.

LIS Technologies closes $12M seed round

Laser technology startup LIS Technologies closed an expanded, oversubscribed $11.9 million seed funding round. The company plans to use the funds to advance the construction of a new facility in Oak Ridge, Tenn., for physical test work and demonstrations, and to expand its staff of scientists and engineers.

The company, which claims to be the only patented laser uranium enrichment company originating from the U.S., said that it will use the capital to fuel the revitalization and rebirth of its proprietary laser enrichment technology.

Potential applications for the technology, called Condensation Repression Isotope Separation by Laser Activation (CRISLA), span uranium enrichment for nuclear fuel, the synthesis of stable isotopes critical for medical and other scientific research, and quantum computing, particularly in semiconductor manufacturing. For the laser enrichment of uranium, this method has sufficient selectivity that will enable the production of low-enriched uranium in a single-stage and high-assay LEU in two stages, according to the New York-based company.

VividQ secures $7.5M to commercialize holographic display tech

VividQ, a developer of computational holography display technology, completed an additional $7.5 million in series A funding, bringing the company's total funding to more than $30 million. The funding supports the company's planned expansion into the U.S. as well as its product development road map.

VividQ's software generates interference patterns based on input data from game engines and other 3D content sources. The content is then rendered to a spatial light modulator (SLM), which supports display types, such as digital micromirror displays, phase light modulators, and liquid crystal on silicon (LCoS). The interference pattern is then illuminated with a coherent or partially coherent light source, such as lasers or LEDs, forming holographic, full-color images in front of the SLM.

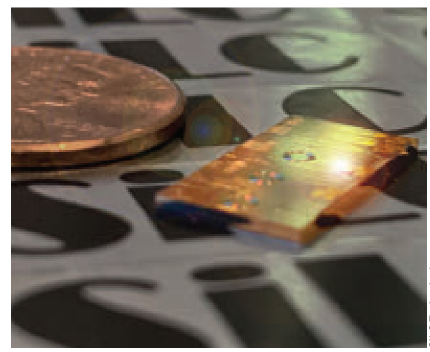
VividQ said it has already secured multiyear partnerships with JVCKenwood and U.S.-based leaders in display and automotive technology, in addition to Fortune Global 500 brands developing consumer electronics displays and VR/AR headsets.

$38.4B — predicted size of the global photonic integrated circuits market by 2029, according to Mordor Intelligence

SiLC receives Honda investment for AI vision development

SiLC Technologies, a developer of integrated, single-chip frequency-modulated continuous wave (FMCW) lidar solutions, received an investment from Honda to develop next-generation solutions for mobility applications. SiLC's technology focuses on enabling advanced AI-based machine vision.

The investment was made through Honda's startup-focused global innovation program Honda Xcelerator Ventures, led by Honda Innovations. The latest funding comes one year after SiLC introduced four versions of its FMCW lidar-based Eyeonic Vision System, and after the company secured $25 million to expand production to support designs for its Eyeonic solutions.



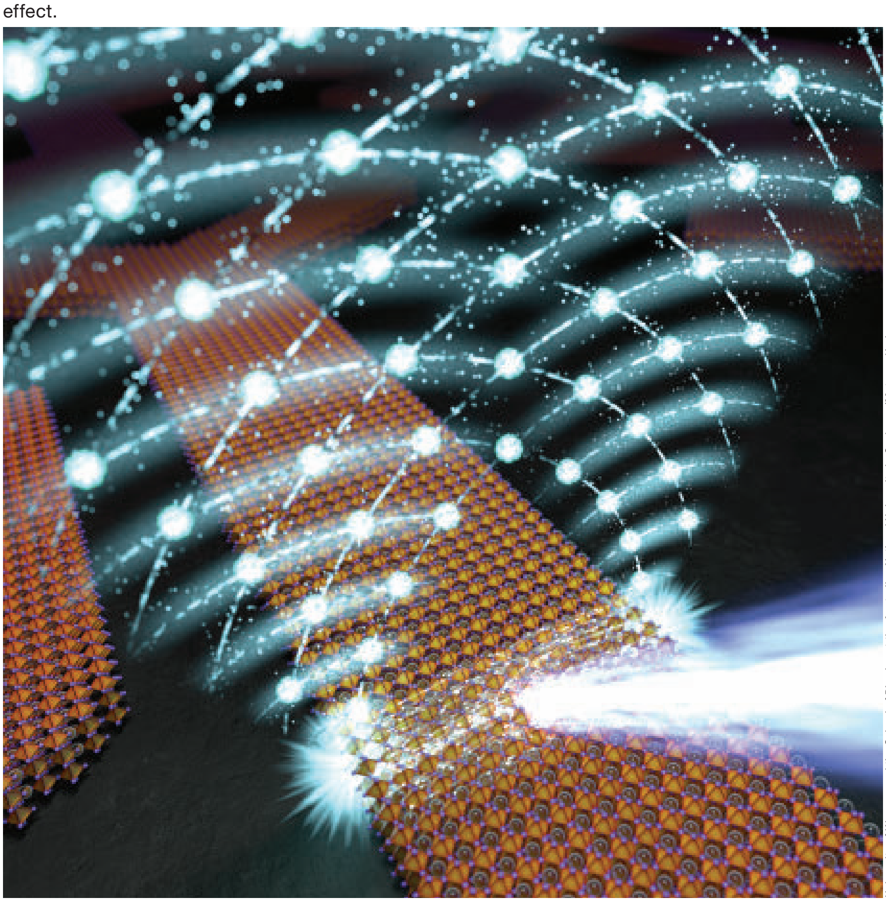
SiLC Technologies

SiLC's integrated single-chip frequency-modulated continuous-wave (FMCW) lidar technology. The company has received investment from Honda, Dell, and Sony, among others.

Perovskite waveguides offer quantum, integrated device capabilities

WARSAW, Poland — A research team from the University of Warsaw, in collaboration with institutions in Europe and Australia, developed a way to efficiently fabricate large-scale waveguiding perovskite crystals in predefined shapes, such as couplers, splitters, and microwires. The work charts a course to use perovskite materials to streamline the fabrication of chip-scale devices harnessing the capabilities of integrated nanolasers, waveguides, and other elements. The optical, lasing, and waveguiding capabilities of perovskite make this material a promising platform for integrated photonic circuits for classical and quantum signal processing.

Researchers led by a team at the University of Warsaw developed a method to create perovskite waveguides with an edge lasing effect.



University of Warsaw and the School of Physics at the Australian National University in Canberra/Matęusz Krol

Along with repeatable, scalable synthesis techniques, the researchers used nearly atomically smooth gallium arsenide (GaAs) templates, which they made with electron-beam lithography and plasma etching, to create the crystals. This approach resulted in high-quality single crystals with precisely defined dimensions and shapes, for possible use in nonlinear optics.

"These crystals, due to their high quality, form Fabry-Pérot-type resonators on their walls, allowing strong nonlinear effects to be observed without the need for external Bragg mirrors," researcher Matęusz Kedziora said.

Additionally, the researchers grew the perovskite crystals from solution in narrow polymer molds using a microfluidics approach.

The team used cesium-lead-bromide ($CsPbBr_3$) as its perovskite material. $CsPbBr_3$ perovskites make good semiconductors for optical applications, because of their high exciton binding energy and oscillator strength.

The predesigned perovskites displayed an edge lasing effect, which is associated with the formation of the condensate of exciton-polaritons — quasiparticles that behave partly like light and partly like matter.

"The wavelength of the emitted light is modified by the effects of strong light-matter interactions, indicating that the emission is due to the formation of a non-equilibrium Bose-Einstein condensate of exciton-polaritons," said professor Barbara Piętka, researcher and one of the project's initiators. "This is therefore not conventional lasing due to the Purcell effect (weak coupling), but emission from a condensate in the strong light-matter coupling regime."

When the researchers nonresonantly stimulated a condensate of waveguided exciton-polaritons, the transverse interfaces and corners of the perovskite microstructures exhibited bright polariton lasing. The team used far-field photoluminescence and angle-resolved spectroscopy to confirm the high coherence between different signals of the emitted light from the edges and corners.

The team detected large blueshifts with excitation power and high mutual coherence between the different edge and corner lasing signals in the far-field photoluminescence, indicating that spatially extended condensates of coherent polaritons had formed. Due to interactions within the condensate, the researchers observed an increase in energy with increasing population of a given blueshift, which further confirmed the presence of nonlinear effects.

The condensate polaritons were found to propagate over long distances in the wires from the excitation spot and were able to couple to neighboring wires through large air gaps, indicating that they could potentially be used for integrated polaritonic circuitry and on-chip optical devices with strong nonlinearities.

The predesigned perovskite waveguides with edge lasing could help advance the use of perovskite crystals in nonlinear photonics that operate at room temperature. Moreover, the perovskite structures could be compatible with silicon technology, which would increase their commercialization potential. The structures can be fabricated on any substrate, enhancing their compatibility with existing photonic devices. Integrated photonic circuits operating at room temperature, combined with optical nonlinear effects, could be transformational to the ability of classical and quantum devices to optically manipulate and analyze signals.

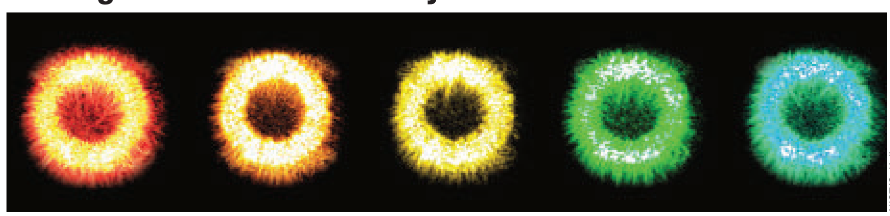
The research was published in *Nature Materials* (www.doi.org/10.1038/s41563-024-01980-3).

Micro-rings make green gap wavelengths accessible for tiny lasers

GAITHERSBURG, Md. — Compact, high-quality lasers that generate red and blue light have been available for years, but lasers that emit light at yellow and green wavelengths and are small enough to fit on a chip have been more difficult to build. Wavelengths between 532 and 633 nm, commonly referred to as the green gap, are especially challenging to produce with conventional laser gain. Green laser pointers, for example, produce light only in a narrow spectrum of green. Because these lasers/devices are not integrated in chips, they cannot work with other devices.

The fabrication of stable, miniature lasers in the yellow and green regions of the visible light spectrum could create opportunities in many application areas, from undersea communications and quantum computing to medical treatments and displays. A miniature source of green laser light could be useful in underwater communications, for example, because water is nearly transparent to blue-green wavelengths in most aquatic environments.

At the National Institute of Standards and Technology (NIST), scientists used a ring-shaped microresonator small enough to fit on a chip to close the so-called green gap. By changing the dimensions of the microresonator, the researchers extended its range to wavelengths as short as 532 nm.



NIST/S. Kelley

A series of visible light colors generated by a micro-ring resonator developed by National Institute of Standards and Technology (NIST) researchers.

The researchers' solution is based on earlier work by NIST Fellow Kartik Srinivasan and his team. In previous studies, the researchers used microresonators composed of silicon nitride (SiN) to convert IR laser light into other colors.

The researchers pumped IR light into a ring-shaped resonator, where it circled thousands of times until it reached intensities high enough to interact strongly with the SiN. The interaction created an optical parametric oscillation (OPO) that produced two new wavelengths, called the signal and the idler. The signal had a wavelength in the visible range. The idler had an IR wavelength that was longer than that of the pump laser.

Though the researchers generated several visible colors by altering the microresonator dimensions, they were unable to generate the full complement of yellow and green colors to fill the green gap.

The researchers next increased the thickness of the microresonator, optimizing the micro-ring geometries for green gap emission and enabling the light generated by the resonator to penetrate deeper into the green gap. Using dispersion engineering, they exposed the microresonator to more air by etching away some of the silicon dioxide layer underneath it to create an undercut. This step made the output colors less sensitive to the micro-ring dimensions and the IR pump wavelength, giving the researchers more control over the slightly different green, yellow, orange, and red wavelengths that they could generate from their devices.

The researchers eventually accessed the entire green gap with the OPO in the SiN micro-rings pumped near 780 nm. Then, using only four devices, they created more than 150 distinct wavelengths evenly distributed across the gap. They further established the utility of OPO to coherent applications, demonstrating continuous frequency tuning of >50 GHz and narrow optical linewidths of <1 MHz.

"Previously, we could make big changes — red to orange to yellow to green — in the laser colors we could generate with OPO, but it was hard to make small adjustments within each of those color bands," Srinivasan said.

Because the output power is only a few percentage points of that of the input laser, the team is investigating how to produce the green gap laser colors more efficiently. Improving the coupling between the input laser and the waveguide that channels the light into the microresonator, along with developing better methods of extracting the generated light, could improve the efficiency significantly.

Additional potential applications for wavelengths in the green gap include full-color laser projection displays and laser treatments for diabetic retinopathy and other medical conditions. Compact lasers that encompass the green gap wavelength range could also potentially be used in quantum computing and communications to store data in qubits. Access to the green gap wavelengths could further help to bring nonlinear nanophotonics and its many advantages to the visible spectrum.

The research was published in *Light: Science & Applications* (www.doi.org/10.1038/s41377-024-01534-x).

Swiss team raises EUV lithography resolution to 5 nm

WÜRENLINGEN, Switzerland — Researchers at the Paul Scherrer Institute (PSI) developed a photolithography technique that offers significantly improved resolution and that can be used to create denser circuit patterns. The current state-of-the-art microchips have conductive tracks separated by 12 nm. In the current work, the PSI team's method enabled tracks with a separation of only 5 nm.

In photolithography, a silicon wafer is coated with a light-sensitive layer called a photoresist. It is then exposed to a pattern of light corresponding with the blueprint for a microchip, which alters the chemical properties of the photoresist, making it either soluble or insoluble to certain chemical solutions. Subsequent treatment removes the exposed (positive process) or unexposed (negative process) regions. In the end, conductive tracks are left behind on the wafer forming the desired wiring pattern.

Since 2019, manufacturers have been using extreme-ultraviolet (EUV) light with a wavelength of 13.5 nm in mass production, printing structures as small as 10 nm and under. In experiments led by PSI researchers Iason Giannopoulos, Yasin Ekinci, and Dimitrios Kazazis from the Laboratory of X-ray Nanoscience and Technologies, the team used radiation from the Swiss Light Source (SLS) for their investigations, tuned to 13.5 nm in accordance with the industry standard.

However, the PSI researchers extended conventional EUV lithography by exposing the sample indirectly rather than directly. In EUV mirror interference lithography, two mutually coherent beams are reflected onto the wafer by two identical mirrors. The beams then create an interference pattern, the period of which depends on the angle of incidence and the wavelength of the light. The group achieved resolutions — or track separations — of 5 nm, in a single exposure. Viewed under a microscope, the conductive tracks were found to have high contrast and sharp edges.

Paul Scherrer Institute/Mahir Dzambegovic

Researcher Iason Giannopoulos of the Paul Scherrer Institute (PSI) holds part of the apparatus used to carry out experiments with extreme-ultraviolet (EUV) lithography at the Swiss Light Source (SLS).

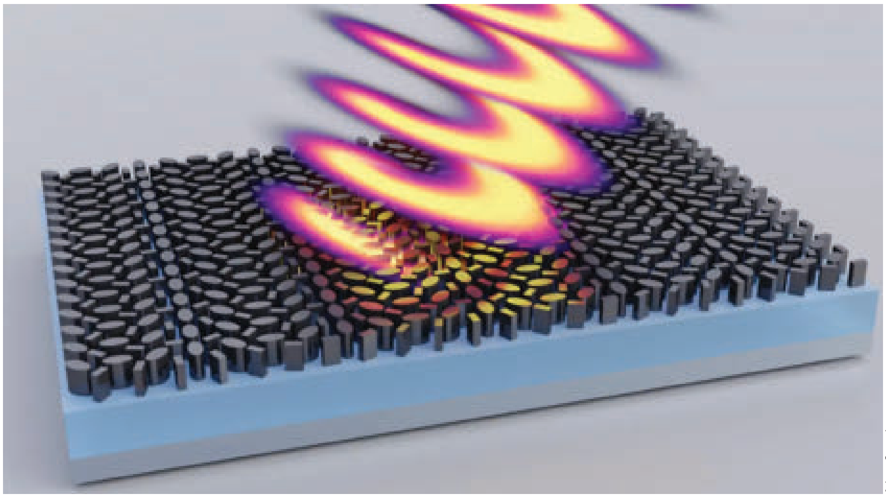
Despite the possibilities demonstrated by the work, the method is not attractive to industrial chip production due to its slow speed. Additionally, the method can only produce simple and periodic structures, rather than a designed chip.

However, the method does provide a route for the early development of photoresists needed for future chip production with a resolution that is not yet possible in the industry. "This is really exciting since it extends the horizon of what we deem as possible and can also open up new avenues for research in the field of EUV lithography and photoresist materials," Kazazis said.

The team plans to continue its research, which is poised to be bolstered by a new EUV tool at the SLS expected by the end of 2025. The tool, coupled with the updated SLS 2.0, currently undergoing an upgrade, is expected to provide greatly improved performance and capabilities.

The research was published in *Nanoscale* (www.doi.org/10.1039/D4NR01332H).

Thermal metasurface controls and creates a light source



Adam Overvig

A thermal metasurface is made of a single layer of nanostructured silicon **(gray)** on top of glass **(blue)** and a metal mirror **(gold)**. The nanostructured surface is specifically tailored so that it thermally emits circularly polarized light to a desired direction.

NEW YORK — Optical metasurfaces offer the potential to shape and customize light for specific applications, but existing metasurfaces can only control laser light sources and require bulky, expensive excitation setups to do so.

Researchers at The City University of New York (CUNY) engineered a metasurface that can both produce and control its own thermal radiation. This advancement in 2D materials development could be used to create custom, compact, portable light sources for space, field research, and defense applications.

In previous work, the researchers theoretically showed that metasurfaces can be designed to shape the thermal radiation they generate, and that desirable features, such as defined frequencies, custom polarization, and specific wavefront shapes, can be introduced into the radiation.

The team experimentally validated this theory in its current research. It demonstrated polarization-selective, unidirectional, narrowband thermal emission generated within single-layer metasurfaces and showed that metasurfaces can precisely control the optical properties of thermal radiation generated within the metasurface itself.

To enable the control of thermal emission, the researchers designed the metasurface to allow asymmetric emission of circularly polarized light toward a single direction. They implemented polarization gradients across the surface of the material to spread the photonic Rashba effect from circular polarizations to any pair of orthogonal polarizations, and they applied this to thermal emission. They created a thermal geometric phase through pointwise specification of elliptical polarization, confirming that chiral emission is possible without breaking reciprocity.

The researchers simplified the architecture previously envisioned for the device, making the metasurface a single structured layer with a 2D pattern. With this streamlined design, the metasurface is easier to fabricate and more practical to implement.

Unlike laser light, which exhibits a well-defined frequency, polarization, and propagation direction, thermal emission has an incoherent, unpolarized nature, making it challenging to control. Advancements in materials that interact with light have shown that patterned surfaces can transform thermal emission into partially coherent beams with tailored directionality and frequency selectivity.

"Our ultimate aim is enabling metasurface technology that does not require external laser sources, but can provide precise control over the way its own thermal radiation is emitted and propagates," said professor Adam Overvig, now at Stevens Institute of Technology. "Our work is an important step in this quest, providing the foundation for a new class of metasurfaces that do not require external laser sources, but are fed by internal incoherent oscillations of matter driven by heat."

The team said that its approach to developing optical metasurfaces that do not rely on external light sources can be used to enhance LED light sources, which are inexpensive and ubiquitous but difficult to control. The team aims to create more complex thermal emission patterns in the metasurfaces, such as a pattern that focuses thermal emission to a specific point above the device, and a pattern that can be used to build a thermal hologram. Such advancements could improve the design and functionality of custom light sources.

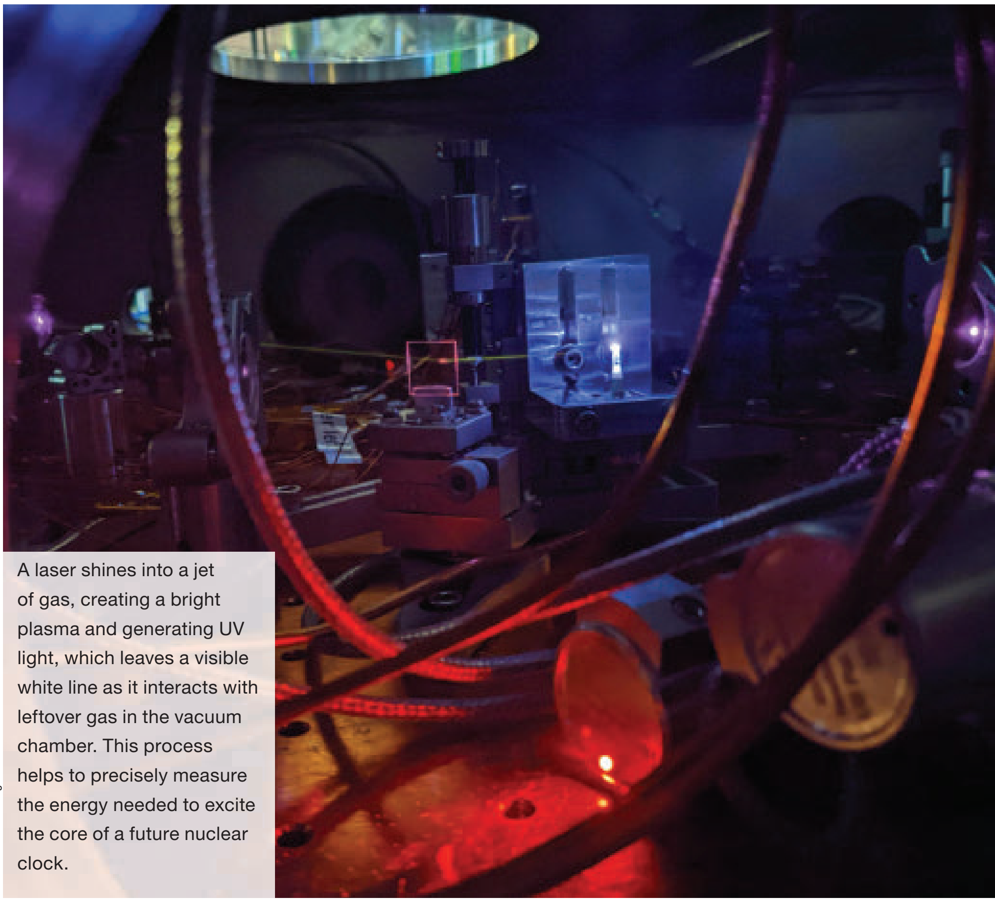
According to CUNY professor Andrea Alù, the work supports additional applications, including those outside controlled laboratory settings. "The ability to create compact, lightweight sources with desired spectral, polarization, and spatial features is particularly compelling for applications requiring portability, such as space-based technology, field research in geology and biology, and military operations," Alù said.

The research was published in *Nature Nanotechnology* (www.doi.org/10.1038/s41565-024-01763-6).

UV lasers, combs provide high-frequency light for nuclear clock

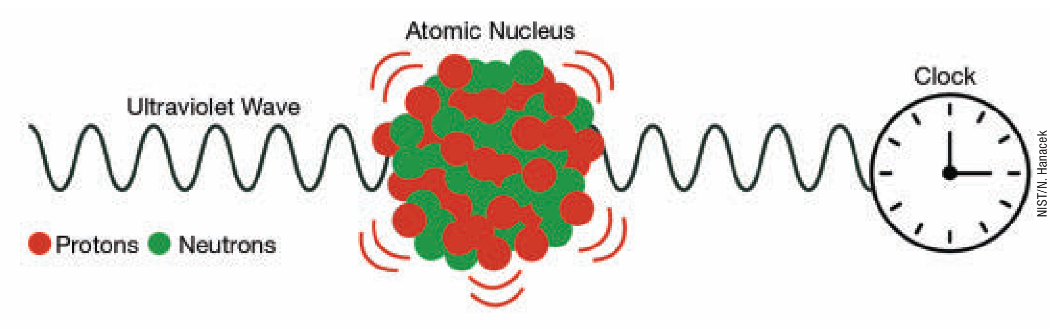
BOULDER, Colo. — An international team of JILA (formerly known as the Joint Institute for Laboratory Astrophysics)-led scientists at the University of Colorado Boulder demonstrated the key components of a nuclear clock, including the precise frequency measurements of an energy jump in the nucleus of a thorium-229 (Th-229) atom. While the team's laboratory demonstration is not a fully developed nuclear clock, it contains all the key technology for such a device, which uses the energy that jumps within an atom's nucleus to measure time.

Nuclear clocks offer the potential to be more accurate than their atomic counterparts and are less sensitive to external disturbances, such as stray magnetic fields. Atomic clocks currently provide the primary time standard used to regulate clocks internationally. They are used in GPS navigation and internet synchronization and provide timestamping for financial transactions. The development of nuclear clocks could lead to more precise navigation systems, faster internet speeds, more reliable network connections, and more secure digital communications.



JILA/Chuankun Zhang

A laser shines into a jet of gas, creating a bright plasma and generating UV light, which leaves a visible white line as it interacts with leftover gas in the vacuum chamber. This process helps to precisely measure the energy needed to excite the core of a future nuclear clock.



NIST/N. Hanacek

A nuclear clock uses UV light to excite the nucleus of an atom. When light hits the nucleus at just the right frequency, it causes the nucleus to change its energy state. This process initiates a complete sequence that is necessary to develop a nuclear timekeeping device.

A much higher frequency of light is needed to cause energy jumps in nuclei than what is needed to induce energy jumps in atomic clocks. Most atomic nuclei must be hit by coherent x-rays, a high-frequency form of light with energies greater than what current technologies can produce, to make energy jumps. To measure time in a nuclear clock, the researchers used Th-229, an atom whose nucleus has a smaller energy jump than any other known atom. Th-229 nuclei exhibit a low-energy nuclear transition that is within reach of vacuum ultraviolet (VUV) laser light sources.

The researchers built a VUV laser to create precise energy jumps between the individual quantum states of Th-229 nuclei and precisely measure the frequency of an energy jump in the nuclei, which they embedded in a solid crystal. They used an optical frequency comb to count the number of VUV wave cycles that were executed to create the energy jump.

Using the comb, the researchers excited a Th-229 nuclear clock transition in the solid-state host material and determined the absolute transition frequency. They stabilized the fundamental frequency comb to the JILA strontium (Sr) atomic clock and coherently upconverted the fundamental to its seventh harmonic in the VUV range by using a femtosecond enhancement cavity. The VUV comb established a frequency link between the nuclear and electronic energy levels and allowed the researchers to measure the frequency ratio of the Th-229 nuclear clock transition and compare it to the Sr atomic clock.

By comparing the frequency of the nuclear clock transition to the optical frequency used in the JILA Sr atomic clock — one of the most accurate atomic clocks in the world — the researchers established a direct frequency link between a nuclear transition and an atomic clock.

To the best of the team's knowledge, it is the first to establish a direct frequency connection between Th-229 nuclei and an existing atomic clock. In the work, the team achieved a level of precision 1 million times higher than the previous wavelength-based measurement. The direct frequency link and increase in precision are critical to developing a nuclear clock and integrating it with existing timekeeping systems.

Although a functioning nuclear clock is still in the future, the JILA-led team has made valuable progress toward creating a portable, highly stable nuclear clock device. The research has already yielded results, including the ability to observe details in the shape of the Th nucleus that had never before been observed. The use of Th-229 embedded in a solid crystal, combined with the Th-229 nucleus' resilience to external disturbances, makes compact, robust nuclear timekeeping devices a possibility.

"Imagine a wristwatch that wouldn't lose a second even if you left it running for billions of years," said Jun Ye, a physicist at JILA and NIST. "While we're not quite there yet, this research brings us closer to that level of precision."

The research was published in *Nature* (www.doi.org/10.1038/s41586-024-07839-6).

Quantum effect generates different view of Alzheimer's

WASHINGTON, D.C. — An exploration into quantum effects produced in nanoscale biological processes has the potential to upend traditional perceptions of the causes and effects of Alzheimer's disease and other neurological conditions. Researchers discovered that when tryptophan, an amino acid that is a fundamental building block of certain proteins, collects in a structural network within neural fibers, it can collect harmful ultraviolet (UV) light and release it at biologically safe intensities.

The scientists at the Quantum Biology Laboratory at Howard University focused their recent investigation on increased quantum yields (the ratio of photons emitted to those absorbed) on cytoskeletal structures, including microtubules and actin filaments, and amyloid fibrils of varying lengths — a concept called single-photon superradiance. They learned that when tryptophan is grouped in structures, such as in amyloid fibrils, they absorb high-energy photons at UV wavelengths, potentially dramatically reducing the phototoxicity caused by free radicals, or a buildup of unbound molecules produced during cellular metabolism. This buildup causes oxidative stress, which can lead to cell damage and harm biological systems.

"The superradiant enhancement of the quantum yield in tryptophan networks in amyloid fibrils is dramatically increased relative to other bioarchitectures," said Philip Kurian, principal investigator and founding director of Howard's Quantum Biology Laboratory. "This is primarily due to two features: an extremely high density of tryptophan in fibrils leading to stronger electromagnetic coupling strengths, and their highly organized helical symmetry."

Many attempts at treating Alzheimer's — characterized by brain cell death and a loss of memory and neurological functioning — have focused on pharmaceuticals or other therapies that reduce or eliminate amyloid "tangles" that are often present in the brains of people with dementia. These treatment attempts have been largely unsuccessful. The researchers believe that such treatments are unsuccessful because these tangles could be the body's way of compensating for the existence of the oxidative stress that can cause Alzheimer's, but they are not the root cause.

While significant research in this area remains to be completed, Kurian said that he hopes neuroscientists will shift their thinking about what causes Alzheimer's disease and how it can be treated.

"I could envision a nanoparticulate delivery system of UV superabsorbers that would enhance the fibrils' photoprotective effect, but this would only mitigate the oxidative stress in the cellular environment," he said.

The implications of the research, the researchers said, affect areas aside from neurodegenerative disease; they could also lead to new breakthroughs in the understanding of neural communications and messaging. Superradiant effects can last hundreds of femtoseconds and could effectively function as pulses that expand computational capacity far beyond what was previously understood in the context of chemical signaling, Kurian said.

With support from the Alfred P. Sloan Foundation, the team will begin experimenting with such increases in computational capacity in an aneural eukaryotic organism, *Physarum polycephalum*. It is a slime mold and single-cell amoeba with an extensive network of cytoskeletal tubes that stream intracellular fluid through muscle-like contractions.

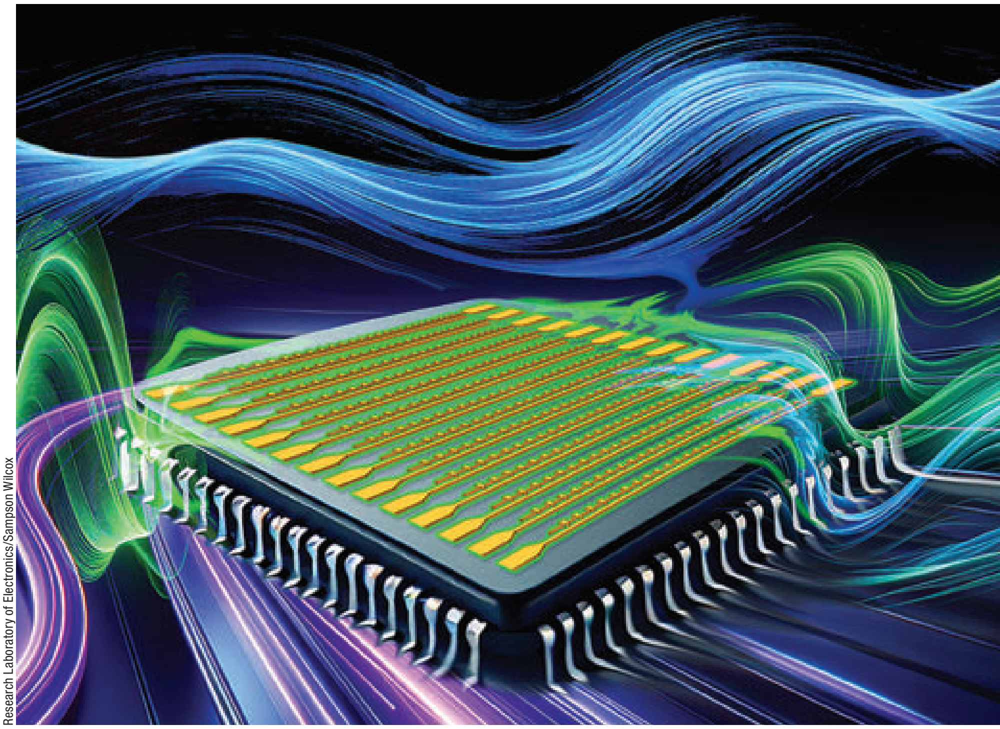
The research was published in *Frontiers in Physics* (www.doi.org/10.3389/fphy.2024.1387271).

Douglas Farmer, Senior Editor
doug.farmer@photonics.com

Electro-optical tech advancement to boost communications, imaging

CAMBRIDGE, Mass. — Lightwave electronics is an emerging field that aims to integrate optical and electronic systems at incredibly high speeds. The key idea is to harness the electric field of light waves, which oscillate on sub-femtosecond timescales, to directly drive electronic processes. This allows for the processing and manipulation of information at speeds far beyond what is possible with current electronic technologies.

A research team from MIT demonstrated a lightwave-electronic mixer at petahertz-scale frequencies, creating a first step toward making communication technology faster. The technology may



Research Laboratory of Electronics/Sampson Wilcox

The chip-scale, lightwave-electronic mixer is depicted at petahertz-scale frequencies. Researchers believe that the device will lead to the advancement of communications technologies and the development of nanoscale lightwave-electronic circuitry for transmitting optical signals.

also progress research toward developing new, miniaturized lightwave-electronic circuitry capable of handling optical signals directly at the nanoscale.

Operating beyond 0.35 PHz, the mixer uses tiny nanoantennae, which can mix different frequencies of light, enabling the analysis of signals oscillating orders of magnitude faster than what is currently accessible to conventional electronics. The team's study specifically highlights the use of nanoantenna networks to create a broadband, on-chip electronic optical frequency mixer that allows for the accurate readout of optical waveforms spanning more than one octave of bandwidth. Importantly, this process worked by using a commercial turnkey laser that can be purchased off-the-shelf, rather than a highly customized laser.

While optical frequency mixing is possible using nonlinear materials, the process is purely optical. Furthermore, the materials must be many wavelengths in thickness, limiting the device size to the micrometer scale.

In contrast, the lightwave-electronic method demonstrated by the authors uses a light-driven tunneling mechanism that offers high nonlinearities for frequency mixing and direct electronic output using nanometer-scale devices.

While this study focused on characterizing light pulses of different frequencies, the researchers envision that similar devices will enable one to construct circuits using light waves. This device, with bandwidths spanning multiple octaves, could provide new ways to investigate ultrafast light-matter interactions, accelerating advancements in ultrafast source technologies.

While such devices are still in development, the researchers currently see the potential for the mixer to create technologies and applications in fields such as spectroscopy, imaging, and communications, advancing the ability to explore and manipulate the ultrafast dynamics of light.

The research was published in *Science Advances* (www.doi.org/10.1126/sciadv.adq0642).

Integrated photonics shrinks down GPS-free navigation tech

ALBUQUERQUE, N.M. — Scientists are attempting to make a motion sensor so precise it could minimize reliance on global positioning satellites. Until recently, a sensor of this caliber — 1000× more sensitive than today's navigation-grade devices — would have filled a moving truck. But advancements are dramatically shrinking the size and cost of this technology.

Researchers from Sandia National Laboratories have used silicon photonic microchip components to perform atom interferometry, an ultraprecise quantum sensing technique that delivers a measure of acceleration. It is the latest milestone toward developing a kind of quantum compass for navigation when GPS signals are unavailable.

An atom interferometer system is typically so large that it fills a small room, whereas a complete quantum compass — more precisely, called a quantum inertial measurement unit — would require six atom interferometers. Sandia scientist Jongmin Lee and his team have been finding ways to reduce its size, weight, and power needs. They already replaced a large, power-hungry vacuum pump with an avocado-size vacuum chamber and consolidated several components that are usually delicately arranged across an optical table into a single, rigid apparatus.

The new modulator is the centerpiece of a laser system on a microchip. Rugged enough to handle heavy vibrations, it would replace a conventional laser system typically the size of a refrigerator.

Lasers perform several jobs in an atom interferometer and the Sandia team uses four modulators to shift the frequency of a single laser to perform different functions. However, modulators often create unwanted echoes called sidebands that need to be mitigated.

Sandia's suppressed-carrier, single-sideband modulator reduces these sidebands by an unprecedented 47.8 dB — a measure often used to describe sound intensity but also applicable to light intensity — resulting in a nearly 100,000-fold drop.

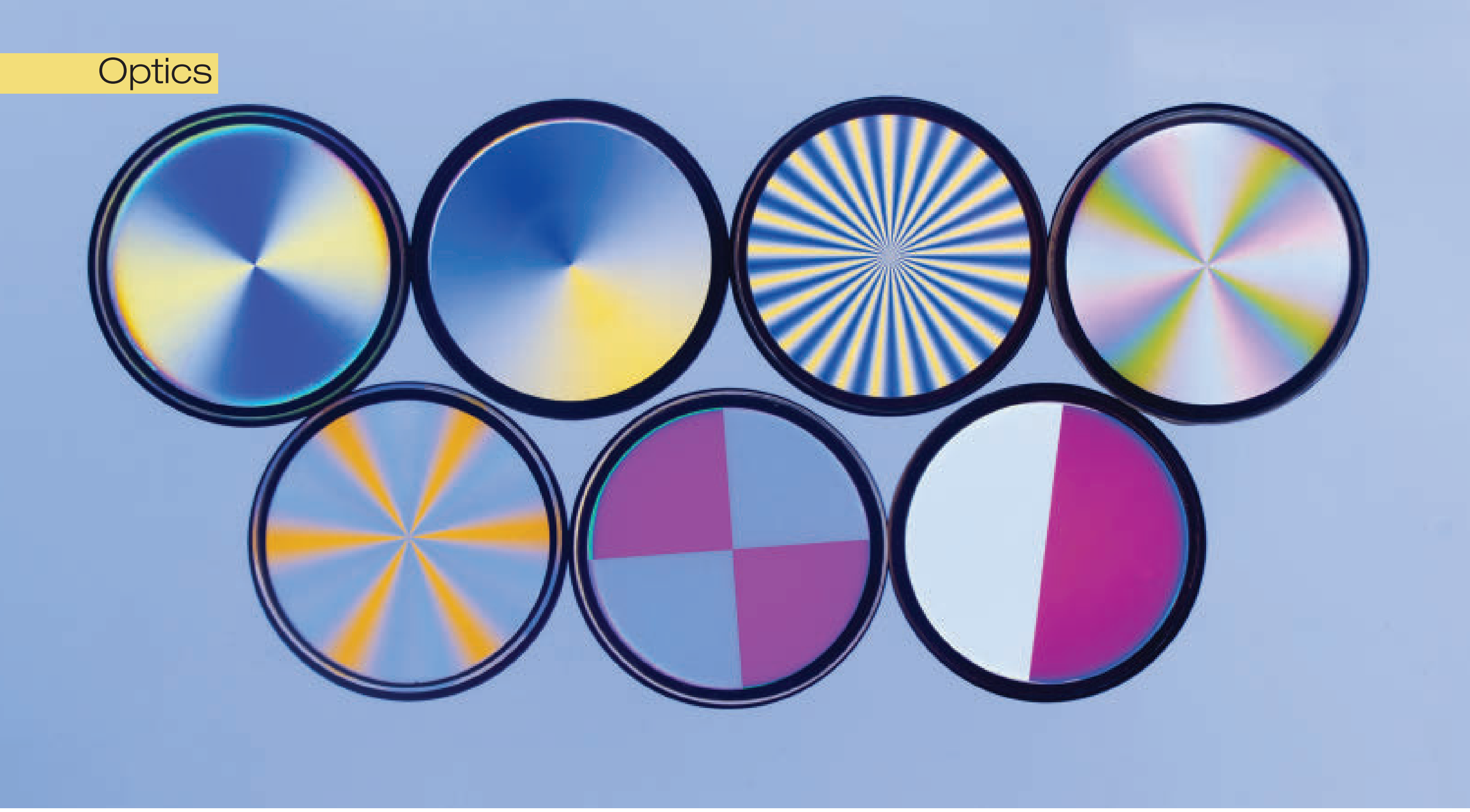
Besides size, cost has been a major obstacle to deploying quantum navigation devices. Every atom interferometer needs a laser system, and laser systems need modulators. Just one full-size commercially available single-sideband modulator costs more than $10,000, Lee said. Miniaturizing bulky, expensive components into silicon photonic chips helps drive down these costs.

"We can make hundreds of modulators on a single 8-in. wafer and even more on a 12-in. wafer," scientist Ashok Kodigala said.

"This sophisticated four-channel component, including additional custom features, can be mass-produced at a much lower cost compared to today's commercial alternatives, enabling the production of quantum inertial measurement units at a reduced cost," Lee said. This is because the team's modulators can be manufactured using the same process as virtually all computer chips.

As the technology moves closer to field deployment, the team is exploring other uses beyond navigation. Researchers are investigating whether it could help locate underground cavities and resources by detecting the tiny changes these make to Earth's gravitational force. They also see potential for the optical components they invented, including the modulator, in lidar, quantum computing, and optical communications.

The research was published in *Science Advances* (www.doi.org/10.1126/sciadv.ade4454).



Fourth-Generation Optics Surmount the Limitations of Planar Optics

Planar 4G optics offer increased control over broadband light with micrometer-thin, clear, and haze-free films switchable between different optical states.

All images courtesy of BEAM Engineering for Advanced Measurements Co.

BY NELSON TABIRYAN
BEAM ENGINEERING FOR
ADVANCED MEASUREMENTS CO.

A micrometer-thin film coated over a flat glass substrate can deflect a light beam in the same way as a prism. This film can be fabricated to be structurally smooth, at a molecular level, and as clear and haze-free as a polished window of fused silica or sapphire.

With an even wider transmission spectrum than classic optical windows, these flat prisms and lenses — as well as optical vortices, axicons, patterned phase plates, beam shapers, and numerous custom optics — find use for a variety of demanding applications. Many of these applications involve high-energy laser beams and take place in harsh environmental conditions, including in space and on the battlefield.

The components and devices that comprise this class of optics underscore a revolution in basic optical technology. Since the turn of the century, this has been marked by the feasibility to achieve control over broadband light over a large range of angles without absorption and scatter losses, to be switchable between different optical states independent of light polarization, and to achieve large aperture.

Diffraction efficiency exceeding 99% throughout the visible and IR bands for a wide range of angles, obtained in films of thickness(es) comparable to the wavelength of light, indeed seemingly defies textbook properties of conventional optics. However, this combination is inherent to diffractive waveplates — optical films that feature spatially varied orientation(s) of an optical anisotropy axis[1,2]. The phase of a circularly polarized light beam propagating through a waveplate gets modulated following the optical axis alignment pattern for wavelengths meeting the half-wave retardation condition.

As a result, the molecular alignment patterns that can be revealed between polarizers determine the optical function of the diffractive waveplate (Figure 1).

4G: the ultimate planar optics

The proliferation of planar optics is a result of three previous generations of optics, which themselves can be viewed iteratively: shape modulation (first generation); the modulation of refractive indices, such as in gradient index lenses (second generation); and the modulation of effective birefringence, such as in liquid crystal displays (LCDs, third generation). Though pioneered to overcome the low-light efficiency of LCDs caused by absorption by polarizers, the diffractive waveplates that mark the fourth generation of optics now find use in AR/VR glasses, adaptive ophthalmic glasses, and lidars. Applications span defense/aerospace, manufacturing, and remote sensing[3].

As noted by Bernard Kress, director for XR engineering at Google and 2023 SPIE president, there is no "Moore's law in optics." In other words, unlike in the realm of semiconductor devices, nature itself has not provided other opportunities to control light (excluding gravitation).

Liquid crystals are best suited for the fabrication of 4G optical components. First, their high elasticity — liquid crystals do not "break" — enables the production of modulated structures of optical anisotropy axis with micrometer resolution(s) using fast processes and inexpensive materials. Second, the optical anisotropy — the difference in refractive indices for light that is polarized parallel and perpendicular to the optical axis of liquid crystals — is as large or even

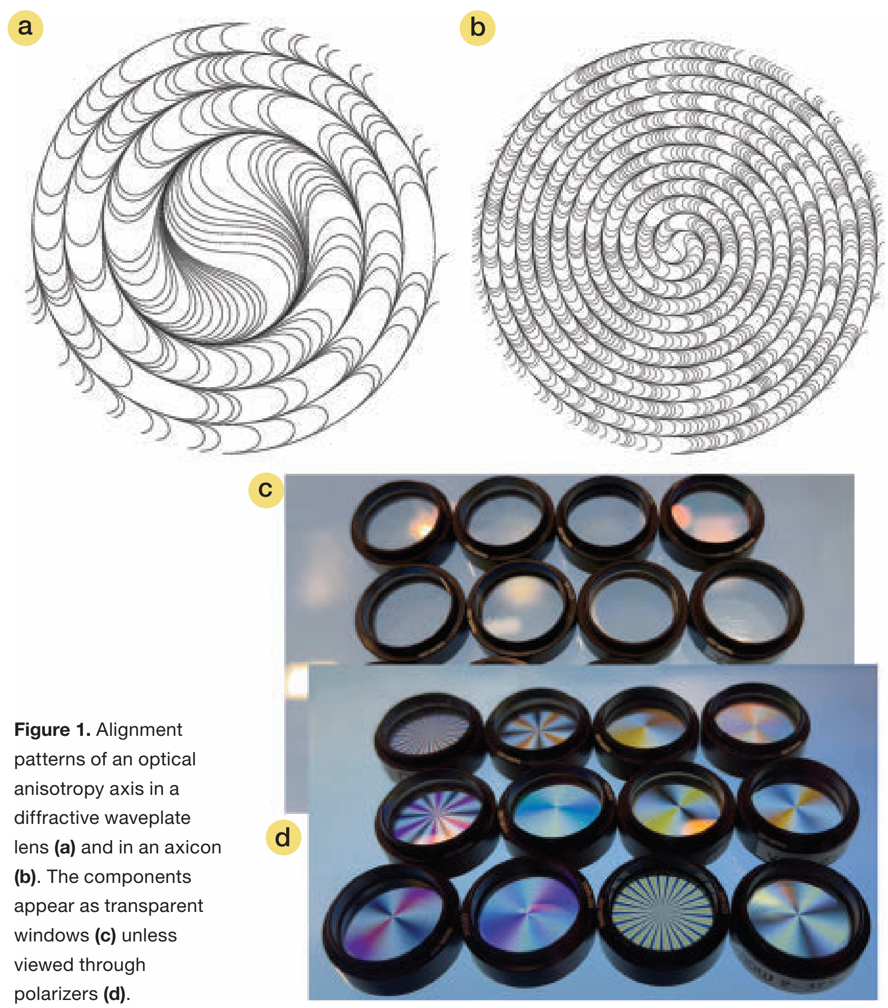


Figure 1. Alignment patterns of an optical anisotropy axis in a diffractive waveplate lens **(a)** and in an axicon **(b)**. The components appear as transparent windows **(c)** unless viewed through polarizers **(d)**.

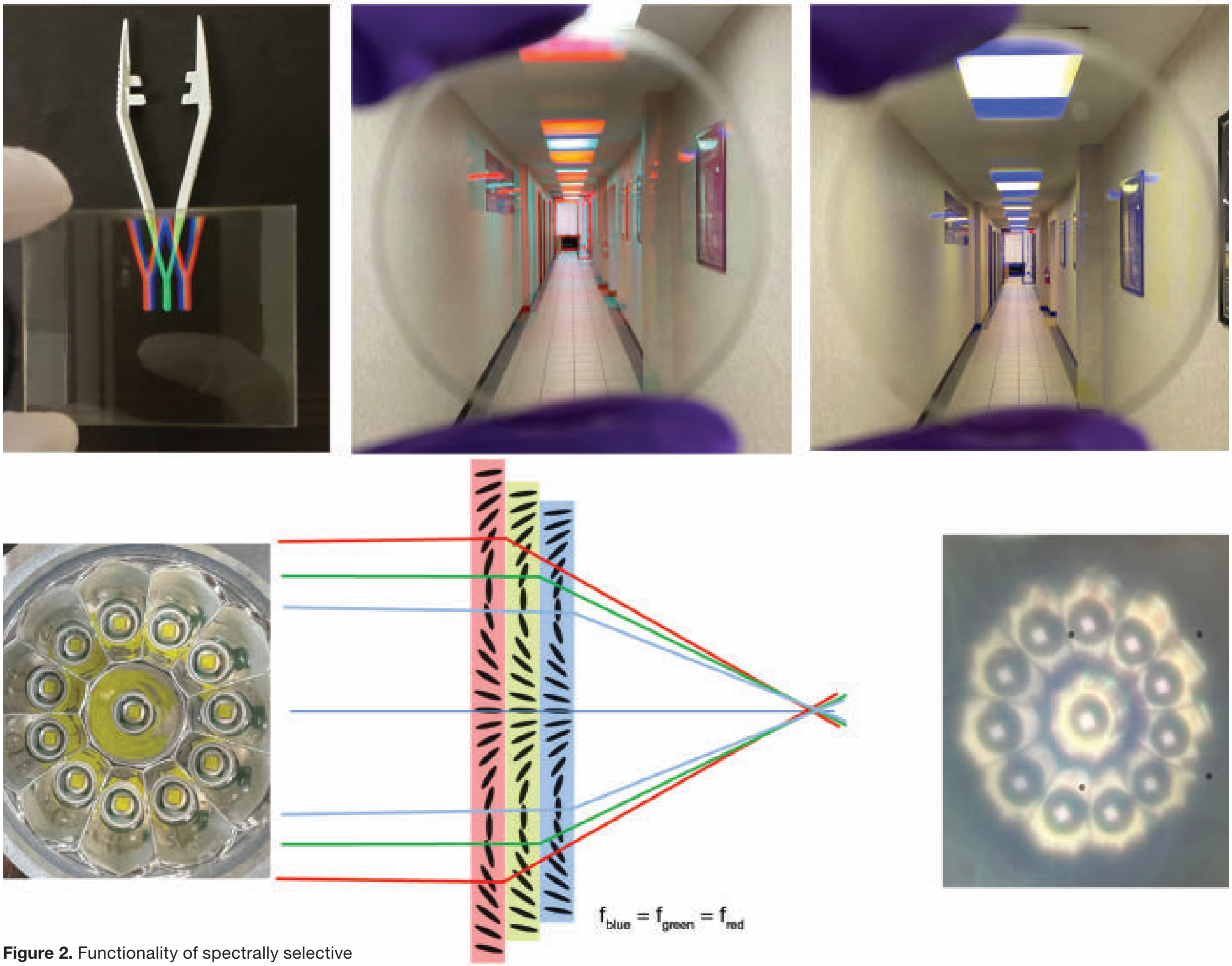


Figure 2. Functionality of spectrally selective cycloidal diffractive waveplates — planar analogs of a prism deflecting specific spectral bands only **(top row)**. The structure of a multispectral lens comprising planar lenses optimized for diffraction of different spectral components of incident white light is schematically shown, along with the pattern obtained in the focus of such a lens illuminated by a flashlight with circular distribution of LEDs **(bottom row)**.

larger than the change of refractive index during water evaporation. Thus, micrometer-thin liquid crystal layers can introduce half-wave retardation into a light beam for different parts of the spectrum.

Also, liquid crystal materials are highly transparent from UV to MIR wavelengths. Transmission lines even occur at LWIR and terahertz bands, and the same materials can be used to produce optics at different bands. This means that only a fraction of a milligram of a liquid crystal material per 1 sq cm of aperture is required to produce half-wave retardation films and coatings, supporting prisms and lenses of high efficiency and optical power. The spatial modulation of molecular alignment is commonly produced using UV-visible blue light, with exposure energy as small as 1 mJ/cm^2 obtained even in a single laser pulse or under sunlight.

The advantages of using liquid crystals in the fabrication of 4G optics extend to liquid crystal polymer films. These films can be released and transferred to different substrates or framed into pellicle optics; the substrates used in production are fully recyclable.

Custom optics and same-day fabrication

Retardation, alignment, and/or the number of films that can be integrated into diffractive waveplates enables a wide customization range of their diffraction efficiency. This provides an opportunity to control the propagation of light beams within desired wavebands without affecting the propagation of light at wavelengths outside of these bands. Spectrally selective lenses fabricated in this way are combined in a single film to focus light at the RGB wavelengths into the same focal plane, as shown in Figure 2, which also shows an image of a white light LED array obtained via a polychromatic 4G lens.

The spectra in Figure 3 represent diffractive waveplates that are optimized

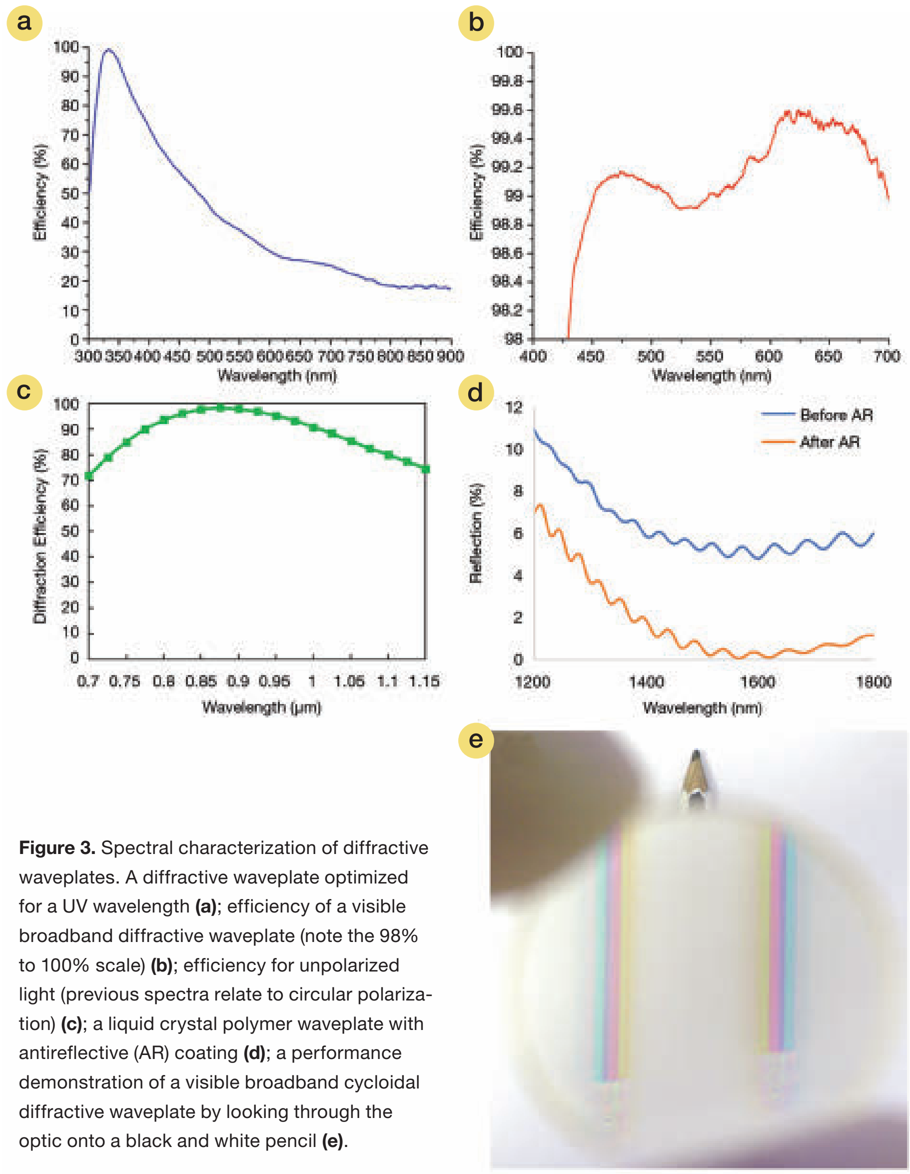


Figure 3. Spectral characterization of diffractive waveplates. A diffractive waveplate optimized for a UV wavelength **(a)**; efficiency of a visible broadband diffractive waveplate (note the 98% to 100% scale) **(b)**; efficiency for unpolarized light (previous spectra relate to circular polarization) **(c)**; a liquid crystal polymer waveplate with antireflective (AR) coating **(d)**; a performance demonstration of a visible broadband cycloidal diffractive waveplate by looking through the optic onto a black and white pencil **(e)**.

for UV and visible broadband optics for circularly polarized light, and broadband IR optics for unpolarized light. Basic diffractive waveplates diffract unpolarized or linearly polarized light into two beams of orthogonal circular polarization. This feature is used, for example, for instantaneous polarimetry and circular dichroism spectrometry. The architecture of diffractive waveplates, the slant angle of planes of equal molecular alignment, and the birefringence of the material can be chosen to achieve Bragg condition for one of the diffracted beams, as well as "anti-Bragg" condition, which cancels the diffraction for the second beam. Such films may then be combined for polarization-independent deflection or lensing with no compromise to diffraction efficiency.

Figure 3 also demonstrates near-100% throughput of a diffractive waveplate with an antireflection (AR) coating that can be deposited on liquid crystal polymers. The continuous and smooth surface of these polymers, as well as the very high levels of mechanical strength and thermal and chemical resistivity of liquid crystal polymers, enables this deposition. Such broad spectral bandwidth translates in turn into a wide angular range of high efficiency: The image of a clock on the wall illuminated by white ambient light is not leaking through a broadband 4G prism even at extreme/steep angles (Figure 4). Due to a high diffraction efficiency, the sun can be observed through a cycloidal diffractive waveplate with the naked eye, without dark filter glasses (Figure 5).

The simple relationship between the phase and the alignment pattern of the optical anisotropy axis means that the physical modeling of 4G optics lasts only minutes and can be presented without complex formulas. Simply, phase equals twice the angle of orientation.

This phase, known since the 1950s, is referred to as geometrical phase (and/or Pancharatnam phase, and/or Pancharatnam-Berry phase). However, spatial modulation, and not phase itself, influences light propagation. This notion was not perceived in the early years of geometrical phase research. It is possible that the alternative names of diffractive waveplates may have hindered the development of the technology, veiling its relative simplicity with complex definitions and descriptions.

No matter the case, 4G optical components of desired functionality can be modeled, designed, and produced within minutes, even in a large area. This fabrication technology today retains many commonalities with established LCD fabrication technology. This is particularly evident for liquid crystal-based switchable 4G optics, such as lenses of switchable focal length, switchable beam shapers, and prisms of switchable deflection angle.

Additionally, the maturity of the LCD industry ensures that liquid crystal physics and chemistry are well understood, and that materials optimized for all different electro-optical properties are available, and most often at low cost(s). Even specialized liquid crystals are available to be purchased for roughly \$100/mL, a quantity sufficient to produce a lens of 1000 sq cm.

Critical fabrication technologies including spin and inkjet coaters, polarization holography systems, and spatial light modulators, as well as the more specialized spatial light polarization modulators, are also widely available at affordable costs. Due to the use of polarization holography, some of those components are also referred to as polarization gratings, though not all polarization gratings are diffractive waveplates.

Ultimately, large-scale production is feasible without reliance on sensitive holographic recording systems. The use of polarization lithography — printing through polarization converter masks with low-power incoherent light sources — is an established method for fabrication at scale.

Reflective geometrical phase optics

Liquid crystals also enable geometrical phase modulation upon reflection, opening additional opportunities to deploy these optics[4]. This quality is obtained when circularly polarized light is reflected from a helical bandgap formed by a chiral liquid crystal, of which the periodic structure provides Bragg reflection. At the same time, the helical nature of the molecular alignment pattern makes the bandgap sensitive to the handedness of the circular polarization of the light;

namely, only light that is circularly polarized according to the handedness of the helix is reflected when its wavelength is within the bandgap.

Light of orthogonal circular polarization propagates through the material without being affected, as does light of non-bandgap wavelengths. In this way, the chiral liquid crystals function as perfect reflective circular polarizers.

Further, since the rotation of the helix around its axis changes the phase of a circularly polarized incident light upon reflection, spatial modulation of the helix alignment may focus, deflect, or otherwise manipulate light upon reflection. As with transmissive optics, polarization-

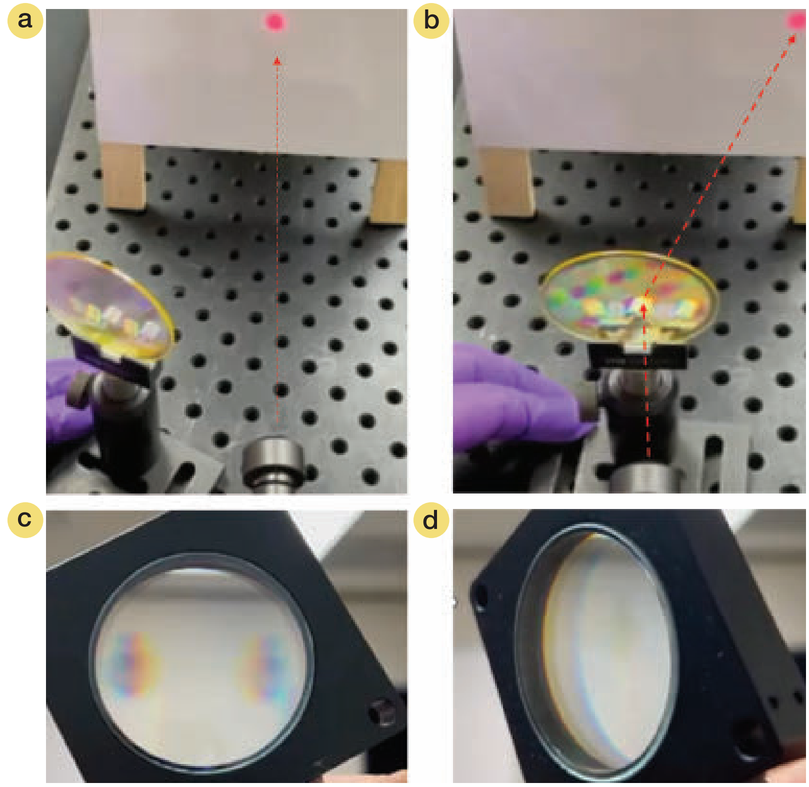


Figure 4. The cycloidal diffractive waveplate coated over a glass substrate of a 2-in. diameter. It is out of the beam **(a)** and brought into the beam **(b)**, deflecting it as a prism. High efficiency at very large angles is demonstrated **(c, d)** by looking at a diffraction pattern of a clock on the wall at large angles. No leakage is observed.

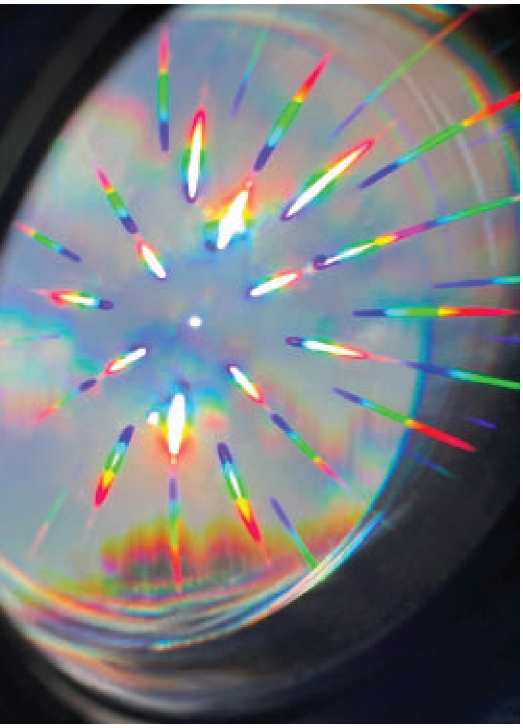


Figure 5. Imaging the sun through a pair of diffractive waveplates.

independent performance is achieved by combining chiral liquid crystals of right- and left-handedness, and spectrally broadband performance is achieved by combining chiral liquid crystals of different Bragg wavelengths or by chirping the helix. From a manufacturing standpoint, and ultimately for performance of the optic, avoiding the need to maintain half-wave retardation condition(s) results in a significant advantage.

Chiral liquid crystals are Bragg gratings of 0.1 and higher effective refractive index modulation versus 0.001 and lower for conventional (glass) volume Bragg gratings. This has important consequences. First, high contrast reflection is obtained in a thin film of several micrometers, compared with millimeters for conventional Bragg gratings. Second, the width of the bandgap can be as wide as ~10 to 50 nm for visible wavelengths. Third, the bandgap does not possess high angular selectivity of conventional volume Bragg gratings. Moreover, both the Bragg wavelength and the bandgap width in chiral liquid crystals are easily controlled by material engineering or external conditions.

4G vs. metaoptics

Typically, in discontinuous structures, such as Fresnel lenses and metalenses (in this case, referring to all metasurface optics technologies), the non-diffracted light is present in the image in the form of haze, which restricts the optical performance of these components. The portion of light that remains unfocused is a core consideration in optical imaging, and, more specifically, for the function of the optics used in imaging applications.

Structural discontinuities set fundamental limitations to metalens efficiency. And similarly, functional limitations of metalens technology encompass different considerations, each of which are apt to influence performance[5]. These factors include the inability to provide near-diffraction-limited performance at a varied range of Fresnel numbers as well as the inability to deliver large focusing power and broadband response in a simultaneous manner[6].

Manufacturing metalenses remains a bottleneck too, due to the inevitable presence of defects in their structure comprising billions of pillars of all different shapes and sizes. This is the case even for IR wavelengths. In contrast, 4G optics are manufactured for blue or even UV wavelengths by simply controlling the thickness of the liquid crystal layer. Metalens manufacturing challenges are also present in the modeling and simulation stages, both of which require considerable computational resources.

Further issues related to metalens manufacturability tie in cost considerations. Development of a so-called master metalens that could in theory be used for inexpensive replication is hindered by the need to maintain the sharpness of the features of the nano-micropillars during the pattern transfer processes from the resist to silicon. For example, an efficiency decrease from 45% (master lens) to 6% (for the nanoimprinted replica) has been reported[7].

Finally, there is the consideration of time. The fabrication of metasurfaces typically involves several time-consuming processing steps, and potentially the use of hazardous materials.

The holy grail of optics

The holy grail of optics — an optic as clear and efficient as glass shaped into lenses and prisms, yet not as thick and heavy, and overcoming efficiency and bandwidth limitations of diffractive optics and metasurfaces — is now within sight. The spread of this technology is evident in R&D, academic, and industrial settings, and members of all three communities are currently actively involved in the development of 4G optics and optical components.

This development is fueled by the novel opportunities that feed directly into the immediate needs of many modern technologies, enabling large and thin AR glasses that are switchable between multiple focal lengths; electronically switchable ophthalmic lenses; nonmechanical lidars for autonomous navigation; ultralight and compact beam directors for high-energy lasers; and photonic chips used to dynamically process an input light into a light of desired propagation and polarization properties. NASA, DARPA, and other advanced technology organizations are developing and supporting the development of applications that range from diffractive sails and coronagraph masks for exoplanet imaging to the aerial network of wireless energy transfer.

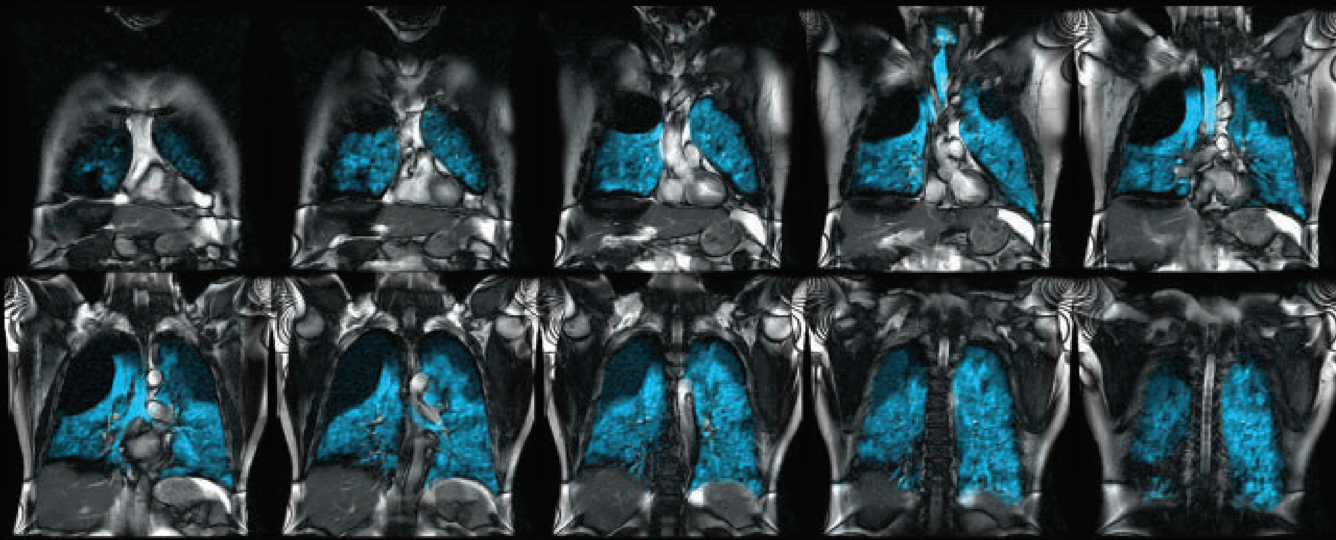
These achievements, plus a high level of technology maturity, are largely a result of collaboration between industry, high-technology organizations, military research, and R&D agencies. The support and active involvement of NASA, the U.S. Army, DARPA and, particularly, the Air Force Research Laboratory, have made it possible to establish the key functional material basis of the technology and to perfect fabrication processes to meet strict production tolerances typical to waveplates and the optical quality demanded by modern applications.

Meet the author

Nelson Tabiryan is a pioneer in liquid crystal photonics developments, an Optica Fellow, and CEO and president of BEAM Engineering for Advanced Measurements Co., founded in 1996; email: nelson@beamco.com.

References

1. N. Tabiryan et al. (2017). New 4G optics technology extends limits to the extremes. *Photonics Spectra*, Vol. 51, No. 3, pp. 46-50.
2. N. Tabiryan et al. (2021). Advances in transparent planar optics: enabling large aperture, ultrathin lenses. *Adv Optical Mater*, Vol. 9, No. 5.
3. N. Tabiryan et al. (2019). Diffractive waveplates: introduction. *JOSA B*, Vol. 36, No. 5, pp. DW1-DW2.
4. R. Barboza et al. (2016). Berry phase of light under Bragg reflection by chiral liquid-crystal media. *Phys Rev Lett*, Vol. 117, No. 5-29.
5. J.-S. Park et al. (2024). All-glass 100 mm diameter visible metalens for imaging the cosmos. *ACS Nano*, Vol. 18, No. 4, pp. 3187-3198.
6. J. Engelberg and U. Levy. (June 2021). Achromatic flat lens performance limits. *Optica*, Vol. 8, No. 6, pp. 834-845.
7. A.M. Baracu et al. (2021). Silicon metalens fabrication from electron beam to UV-nanoimprint lithography. *Nanomaterials*, Vol. 11, No. 9, p. 2329.



Polarean Imaging Plc

Xenon (Xe) magnetic resonance imaging is an essential solution for specialized bioimaging, especially of the lungs. This method necessitates the hyperpolarization of Xe, which is achieved via laser diode-drive spin exchange optical pumping.

Advancements in High-Power Laser Diodes Fuel Essential Applications

Laser diodes are enabling sophisticated applications, as the legacy advantages of these lasers pair with emerging benefits.

BY JEFFREY UNGAR
QPC LASERS

More than 30 years ago, acclaimed physicist Edward Teller said, “No one should use a laser unless it’s a diode laser.” Although those of us engaged in the manufacture of laser diodes will perhaps be forgiven for our uncritical endorsement of Teller’s statement, ample scientific justification supports such a perspective.

To start, consider the physical advantages that laser diodes offer users: For a given output power, laser diodes far surpass all alternatives in their compactness, low mass, ruggedness, and simplicity. Regarding their performance capabilities, laser diodes convert electricity directly to photons, with efficiencies that approach 80% — a value that is far beyond their nearest competitors. Laser diodes also benefit from maintenance-free lifetimes ranging from tens of thousands to millions of hours; operate at wavelengths from the ultraviolet to the infrared; are electrically or thermally tunable over hundreds of gigahertz; and can be amplitude- and frequency-modulated. And with appropriate designs, these sources provide single-frequency outputs that can be coupled to single-mode fibers.

Additionally, laser diode chips are mass manufactured at the wafer level using techniques borrowed and adapted from the silicon industry — at costs per watt lower than other laser types.

Together, these remarkable capabilities are fueling revolutions in fiber optic communications, remote sensing, machine vision, and optical data storage.

Versatile, but not omnipotent

Why, indeed, would anybody use any other kind of laser?

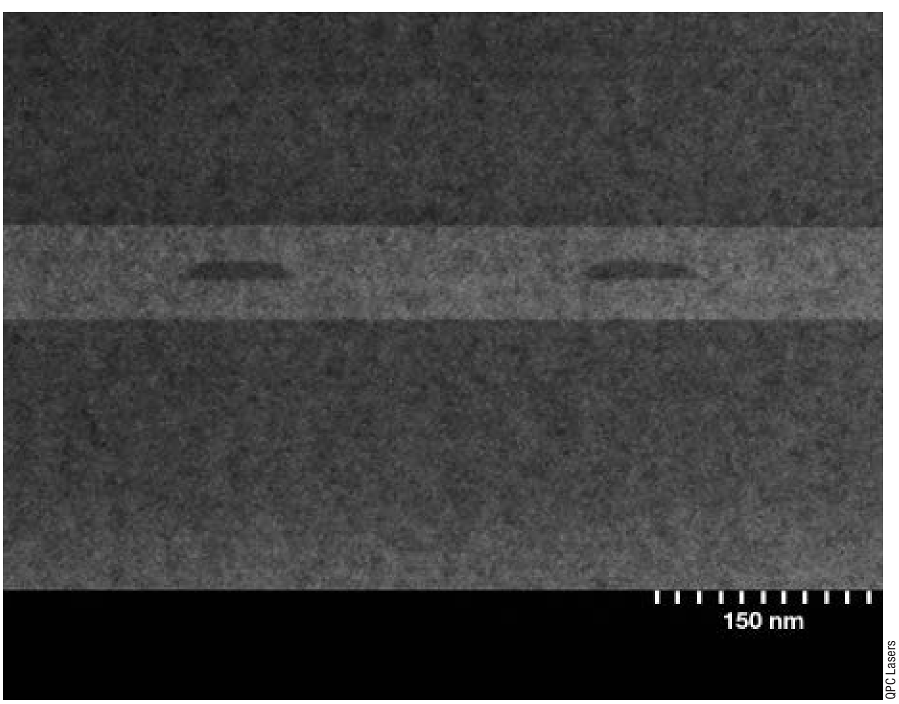
The answer to this question lies in the specifics of a given application. In, for example, use cases that require specific wavelengths, semiconductor alloys with the necessary and/or desired properties may not be available. Other cases may require short high-power Q-switched pulses, which cannot be created by laser diodes.

But most frequently, the use of a laser diode is precluded for one of two reasons: either because a narrow emission spectrum, accurately centered at a specific wavelength, is needed, or because a high optical quality (nearly diffraction-limited) high-power output beam is required.

Narrow, tightly specified emission spectra present a challenge to laser diodes because the semiconductors from which they are constructed have broad, compositionally and temperature-dependent gain spectra. These useful properties allow laser diodes to be manufactured and tuned to emit at any desired point within a continuous band of wavelengths. At the same time, this also makes it difficult to impose tight tolerances on emission wavelength and linewidth.

If required by the application, tighter spectral control can be obtained by introducing volume Bragg gratings (VBGs) into the external optics to “lock” the diode spectrum to the grating. Yet this is a critical and delicate process that adds complexity and cost, and which becomes increasingly difficult to implement when large numbers of diodes must be locked to a common wavelength. Ensuring long-term stability of the spectrum is also challenging because minor shifts in align-

Figure 1. A cross-sectional electron micrograph showing two “teeth” of an internal grating incorporated into a 976-nm Brightlock family laser diode.



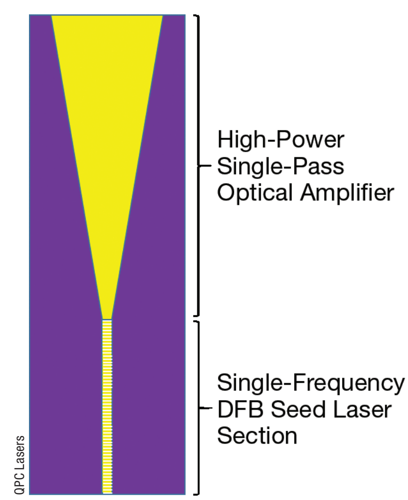
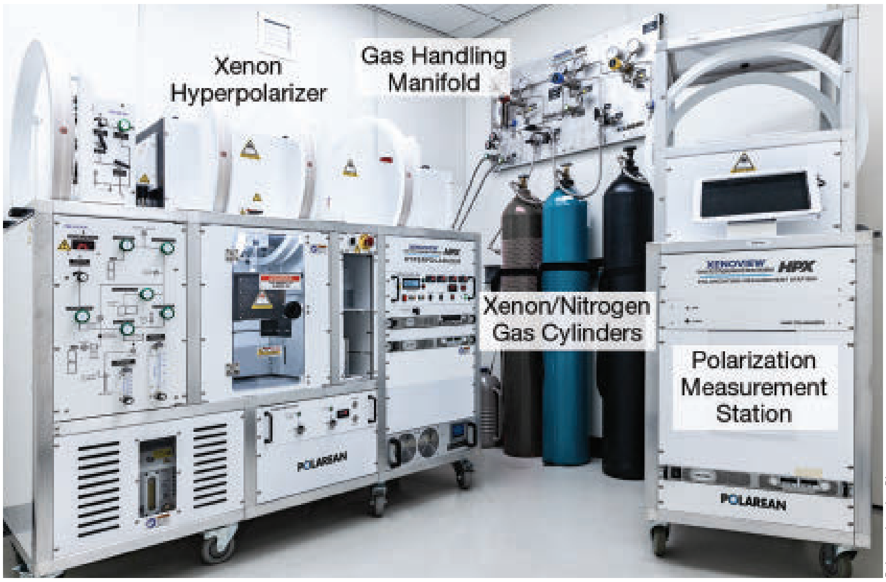


Figure 2. A schematic of a high beam quality, single-frequency master oscillator power amplifier (MOPA) Brightlase laser diode. DFB: distributed feedback.



Polarean Imaging Plc

Figure 3. The Polarean HPX Hyperpolarization System, using 694.8-nm Brightlock pump laser diodes to prepare hyperpolarized xenon (Xe) for medical imaging **(left)**.

Figure 4. Windar Photonics' WindEye laser diode-based anemometer used to gauge wind power and speed, deployed on a wind turbine **(below)**.

Windar Photonics

ment between the VBG and the beam that occur over time cause the output wavelength to drift. For these reasons, external VBG stabilization has seen only limited deployment.

Obtaining high beam quality, high-power beams from laser diodes also presents a challenge. The electrically pumped optical waveguide at the core of a laser diode governs the quality of the generated beam. If the waveguide is narrow and supports only a single lateral mode, the output beam will be essentially diffraction limited. If, on the other hand, the waveguide is large enough to support multiple modes, beam quality will worsen significantly because the output beam becomes a composite of many differently shaped beams, each of which carries a fraction of the total power.

Single-mode waveguide laser diodes with waveguides a few microns wide can generate powers of several hundred milliwatts, but higher-power laser diodes require larger waveguides that support tens or even hundreds of modes. Beams generated by these multimode laser diodes cannot be tightly focused or accurately collimated.

High-power laser diodes can be used for the direct welding of nonmetallic materials, such as polymers, where wavelength flexibility is a more important application parameter than beam quality. Laser diodes are also used for metal processing operations, such as heat treating and powder cladding, which do not require focused beams. But because of insufficient beam quality, laser diodes are not well suited for the direct performance of metal processing operations, such as cutting and welding, and they are relegated to supporting roles, such as optical pumping fiber lasers.

Enabling innovation

So much for the bad news.

The good news is that laser diode technology has been making steady progress toward eroding remaining performance gaps that separate these sources from fiber, solid-state, and gas lasers. Some of these gains are the result of steady but evolutionary improvement to the designs and epitaxial fabrication processes used to manufacture laser diodes. Others are the result of the incorporation of additional features to the architectures of these sources. For example, developments in epitaxial technology that enable the monolithic incorporation of diffractive spectral stabilization gratings into internals of the diode itself have considerably improved spectral performance (Figure 1). This Brightlock family of internal grating laser diodes accurately fixes the center wavelength and reduces linewidth by as much as an order of magnitude without external optical elements increasing cost or causing frequency drift.

In addition, adopting so-called master oscillator power amplifier (MOPA) laser diode designs can enable order-of-magnitude improvements in both beam quality and linewidth. As shown in Figure 2, these designs circumvent the multimode problem that plagues conventional laser diodes by combining a single-mode, single-frequency distributed feedback seed laser with a high-power tapered semiconductor amplifier monolithically. Laser diodes based on this principle have been developed and introduced into the Brightlase family at many infrared wavelengths, with single-mode power outputs as high as tens of watts per emitter.

Emerging applications

A recently developed medical imaging technique provides an example of a technology that is enabled by newly developed laser diode capabilities. Detailed imaging of lung function is fundamental to the detection and treatment of respiratory disease, but even after decades of development, standard imaging techniques provide only limited resolution, which supplies insufficiently detailed information. Specialized imaging techniques require the patient to inhale radioactive agents, which limits their use to situations in which the medical benefits outweigh the risks of the procedure.

The technique of xenon (Xe) magnetic resonance offers a critically needed solution. This method pairs specially tuned MRI scanners with a contrast agent consisting of nonradioactive Xe-129 atoms, whose nuclear spins are strongly hyperpolarized along an ambient magnetic field. The preparation of the hyperpolarized Xe uses a process called spin exchange optical pumping, in which circularly polarized photons transfer their angular momentum to the valence electrons of rubidium (Rb) atoms and by subsequent collisions to Xe-129 nuclei. The implementation of this process requires a laser source to provide hundreds of watts precisely matched to the 794.8-nm Rb D1 absorption line with linewidths of a fraction of a nanometer.

Internal grating laser diodes have made generating the required photons a matter of routine. Figure 3 shows an FDA-approved system for preparing hyperpolarized Xe-129 installed in a clinical setting. The HPX Xenon Hyperpolarization System, manufactured by Polarean Imaging Plc, incorporates a standard Brightlock laser pump and enables lung imaging with high levels of detail and contrast.

Beyond diagnostics, direct laser therapy represents another class of biomedical applications that relies on advancements in laser diode spectral stabilization. One representative example is the treatment of acne vulgaris, which in the U.S. alone is responsible for billions of dollars in costs to patients, and for which the baseline treatment is based on drugs, such as isotretinoin, that have serious side effects, including strong teratogenicity.

Academic studies dating back more than ten years showed that the overactive sebaceous glands that cause acne could be selectively destroyed without drugs and without damaging other tissue by narrowband laser illumination at 1726 nm. But at the time that many of these studies were published, clinically suitable sources of laser radiation were unavailable.

High-power narrowband 1726-nm sources using Brightlock laser diodes have made this laser treatment the reality. During the last two years, laser diode-based treatments have been FDA approved for all classes of acne, with clinical trials suggesting that the treatment is both effective and long-lasting, and thousands of lasers have been deployed in treatment centers.

Advanced laser diode designs are also making their way into emerging markets, many of which are already sizable and growing. One such market is the generation of electrical power by wind, which currently generates >10% of domestically produced electricity. Maximizing the power generated by the wind turbine and preventing damage to its blades requires dynamical optimization of airfoil pitch and direction to accommodate changes in incident airflow. Traditional anemometers — sensor devices that measure wind speed and direction — are typically located on the turbine nacelle, and only measure wind speed and direction after the gust has already reached the turbine. They cannot provide a proactive warning of incoming airflow and offer limited utility in preventing turbine damage and optimizing power generation.

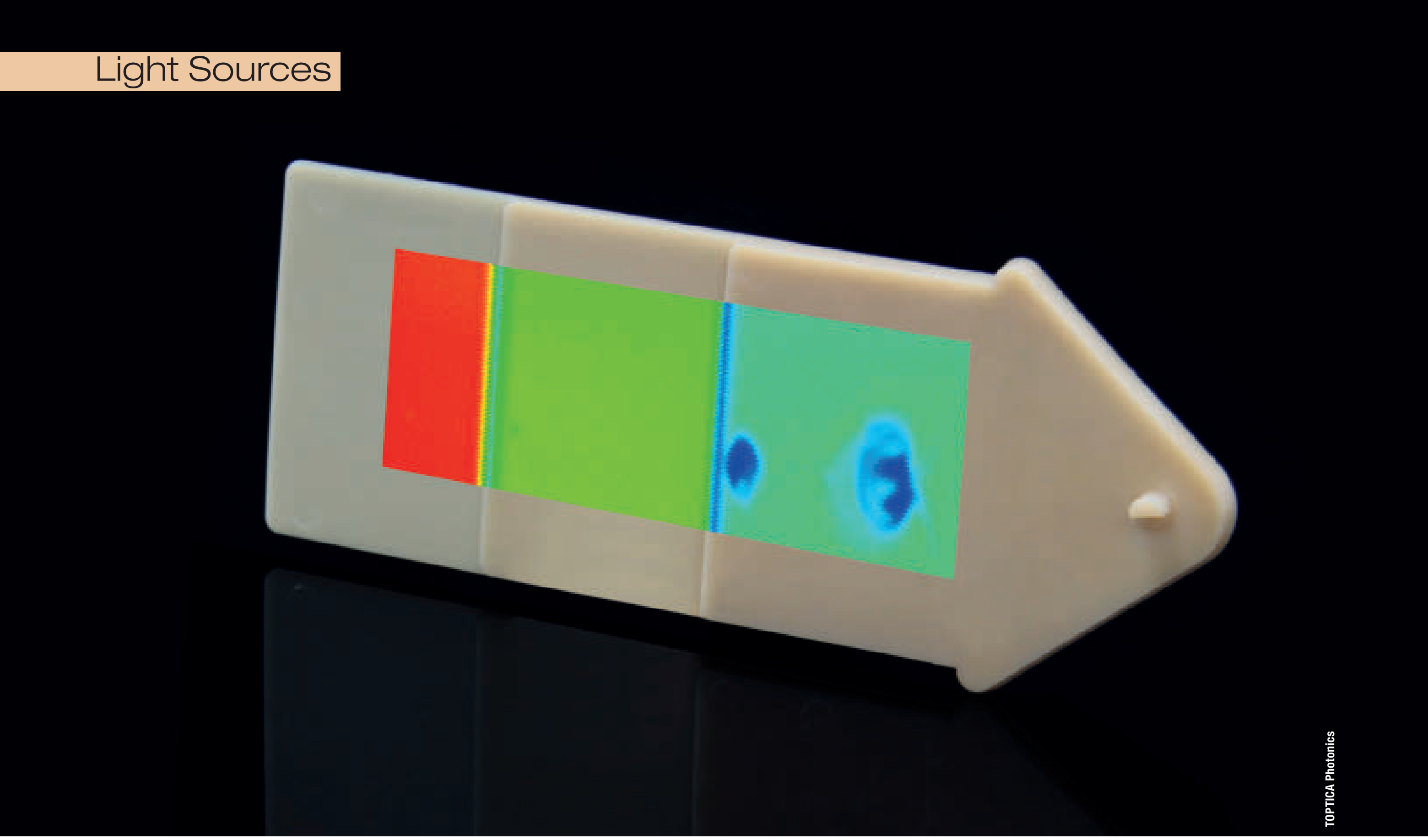
In contrast, Doppler lidar provides the required upstream wind measurement needed to optimize performance, and increases in power generated up to 5% have been reported. The lidars used in this method require watt-scale diffraction-limited beams with sub-megahertz spectral lines, preferably with emission at eye-safe wavelengths. This was once the domain of fiber lasers, but research conducted at the Technical University of Denmark and commercialized at Windar Photonics has led to the commercial deployment of wind sensors based on MOPA laser diodes that are much cheaper and lighter than fiber laser-based systems (Figure 4).

Environmentally beneficial applications of these new laser diode technologies are not confined to clean power generation; the narrow linewidth single-frequency, high-optical-quality beams are also helping to mitigate climate change by stemming the release of greenhouse gases. One major source of anthropogenic atmospheric methane is leakage from natural gas production fields and pipelines. Remote detection of leaks that exploit methane's strong absorption lines near 1650 nm is possible, but low-cost, compact sources with the required power, beam quality, and linewidth were commercially unavailable until recently. MOPA diodes have been transformational, and narrowband diodes providing hundreds of milliwatts at methane absorption lines are now commercially available.

With increased regularity, laser diodes are filling roles previously reserved for other types of lasers, and this trend will continue with increasing awareness of the capabilities enabled by new diode technologies. Laser diodes will never entirely replace other laser technologies, but where they find application, they will bring benefits in the form of significantly lower costs, reduced size and weight, reduced power consumption, and improved robustness.

Meet the author

Jeffrey Ungar is the founder of QPC Lasers and was formerly director of advanced R&D at Ortel, which was later acquired by Lucent Technologies. He has been involved in the development of high-power laser diodes for 40 years; email: jungar@laseroperations.net.



TOPTICA Photonics

Optoelectronic Solutions Give Rise to Terahertz Sensing

Once an exotic application of femtosecond lasers, terahertz sensing is now a preferred method for nondestructive analysis, with use cases in the automotive industry.

BY LARS LIEBERMEISTER AND ROBERT KOHLHAAS FRAUNHOFER HHI, AND ANDREAS THOSS CONTRIBUTING EDITOR

The terahertz portion of the electromagnetic spectrum refers to the frequencies between ~100 GHz and ~10 THz. This corresponds to wavelengths between 3 mm and 30 µm.

Lying between the electronic realm at lower frequencies and the optical (infrared) part of the spectrum — in effect, between two worlds — terahertz radiation has historically been difficult to generate. The efficiency of electronic devices, for example, transistors and oscillators, drops sharply as frequencies increase into the terahertz range. Photonic devices work well at higher (infrared and visible light) frequencies, but they struggle to produce terahertz radiation due to the need for highly precise and stable frequency mixing or efficient nonlinear optical processes. This bottleneck is the origin of the familiar term "terahertz gap."

Moreover, terahertz radiation has low photon energy (in the range of millielectronvolts), which makes it challenging to detect and generate efficiently. At the same time, this low photon energy makes terahertz radiation nonionizing and safe for humans.

The use of quantum cascade lasers offers one seemingly conventional method for generating terahertz radiation. However, these sources require cooling to cryogenic temperatures to reduce noise and achieve stable output, which can complicate and restrict their practical application.

Other techniques involve complex and expensive equipment, such as free-electron lasers and/or large-scale accelerator facilities. These devices and systems are more obviously unfeasible for widespread use.

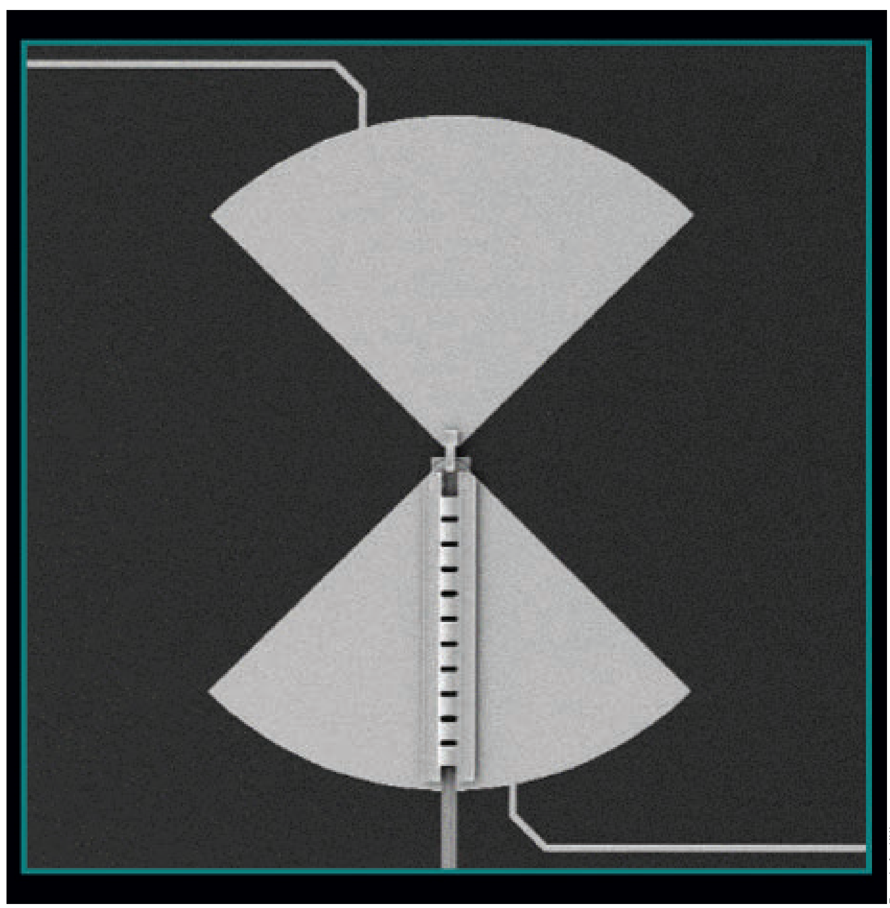
Nevertheless, terahertz technology is on the rise, especially in the domain of sensing and due to optoelectronic solutions. Much like legacy terahertz radiation sources, the basic functions and prospects for these emerging solutions promise to offer benefits in a range of application areas.

Terahertz sources and sensors

The advent of stable and compact femtosecond fiber lasers has facilitated the development of terahertz sources beyond scientific laboratory environments. Indeed, these lasers have effectively bridged the terahertz gap. In the basic setup of typical pulsed terahertz sources, a femtosecond laser signal is absorbed by an optoelectronic material. Through a bias field applied to the semiconductor, the optical signal generates a modulated current at the beat frequency of the input signals that again emits electromagnetic pulses at terahertz frequencies.

This underlying mechanism works not only for pulsed, but also for continuous signals. A hyperhemispherical high-resistivity silicon lens, similar to a half-sphere, also may be used to direct the emitted signal into a preferred direction.

For lasers in the telecommunications band at 1550 nm, indium gallium arsenide (InGaAs) is the most suitable material for signal generation. Previously, Ti:sapphire lasers at 800 nm were often used, with the photoconductive material gallium arsenide (GaAs). Each of these systems has advanced from laboratory setups toward rugged, integrated systems for industrial use, though titanium:sapphire sources remain far less advanced than the 1550-nm technology in terms of these important qualities.



Fraunhofer HHI

Figure 1. Terahertz source technology is enabling sophisticated deployments of terahertz radiation. This waveguide-integrated photodiode generates continuous-wave (CW) terahertz waves and uses a bow tie antenna for optimum radiation. The antenna "wings" have a width of ~500 µm.

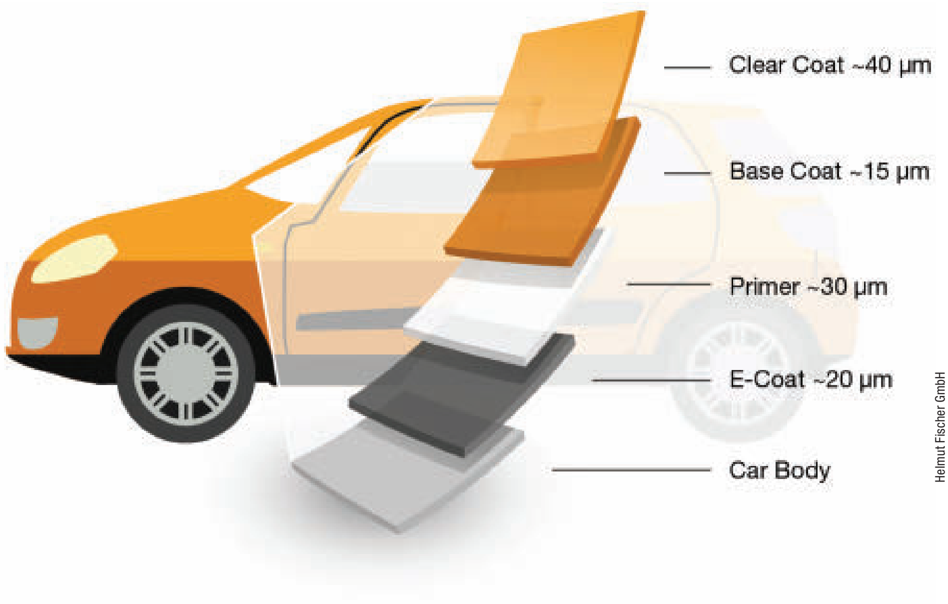
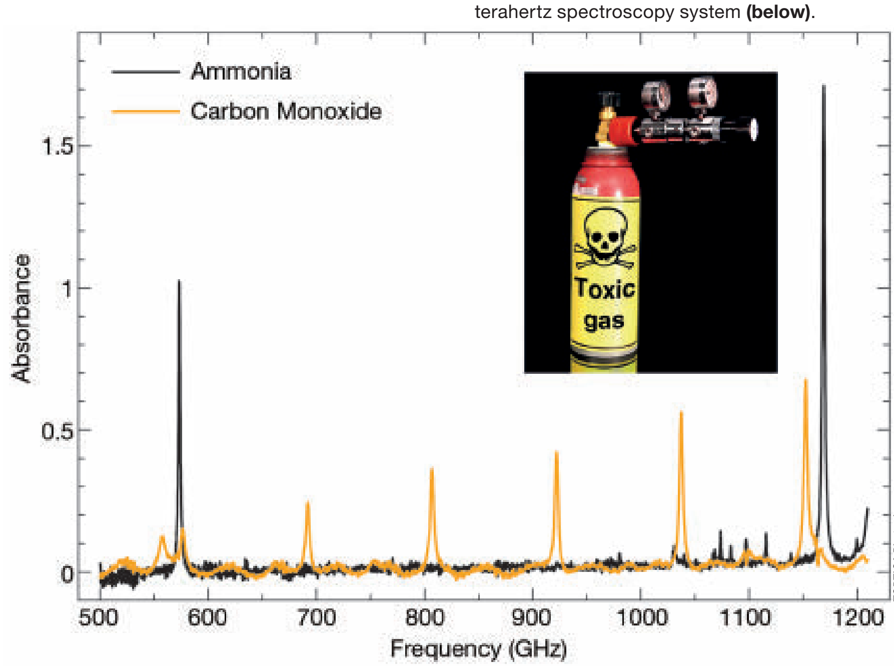


Figure 2. Cars are commonly coated with a system of protective and illustrative coatings. The multilayered approach ensures a favorable appearance and guards against scratches, corrosion, and chemicals **(left)**. The interfaces between the coating layers reflect part of the terahertz radiation. For radiation, 10 µm corresponds to 30 fs.

Figure 3. Absorption spectra of ammonia **(black curve)** and carbon monoxide **(orange)**, measured with a continuous-wave (CW) terahertz spectroscopy system **(below)**.



Pulsed vs. continuous-wave operation

The principal difference in terahertz sources today is between pulsed and continuous-wave (CW) operation. Pulsed terahertz radiation is more commonly deployed and is typically generated by femtosecond lasers. In time-domain setups, these ultrashort laser pulses generate current transients in terahertz emitters, resulting in broadband electromagnetic pulses. After emission, the terahertz signals are directed onto a sample. The reflected signal is then compared with a copy of the original pulse, and the time-dependent result typically reveals structural information about the sample.

In such a measurement, the detector is very similar to the emitter of the terahertz radiation. The photoconductive material generates an electric current in response to the interaction of an optical gate pulse with the incoming terahertz pulse.

CW terahertz radiation is obtained by mixing the outputs of two single-frequency laser diodes in a photomixer, which may be either InGaAs or GaAs. A specially designed ultrafast photodiode converts the beat frequency of the two CW lasers into a terahertz wave. Tuning one of the laser diodes enables the terahertz spectrum to be swept. The CW-terahertz receiver uses photoconductive material similar to that which is used in pulsed operation. It delivers a photocurrent proportional to the superimposed signal of the original and modified signal. The input from photodiodes allows for full integration of CW-terahertz sources (Figure 1).

The integration of sources and sensors has enabled engineers to conceptualize and develop professional systems; for example, frequency-modulated continuous-wave (FMCW) spectrometers. For instance, one such system, developed by Fraunhofer Institute for Telecommunications, Heinrich-Hertz-Institute, HHI (Fraunhofer HHI), offers up to 4-THz bandwidth and up to 500-Hz measurement rates.

ToF measurement: a dominant application

Terahertz sensors have conquered many fields of application. They range from materials science and quality control to gas sensing and security applications —

which nearly all of us have encountered at airports. These terahertz scanners use radiation between 50 and 100 GHz. Though these values are not squarely in the range of terahertz radiation, the scanners take advantage of terahertz radiation to penetrate many materials without ionization, which poses a health risk. This quality is unachievable using x-rays.

Two types of terahertz measurements are prevalent: The measurement may record a time-of-flight (ToF) signal, or a spectrum. Most often, ToF measurements use pulsed radiation, although the same information can be retrieved from the phase evolution of CW sources.

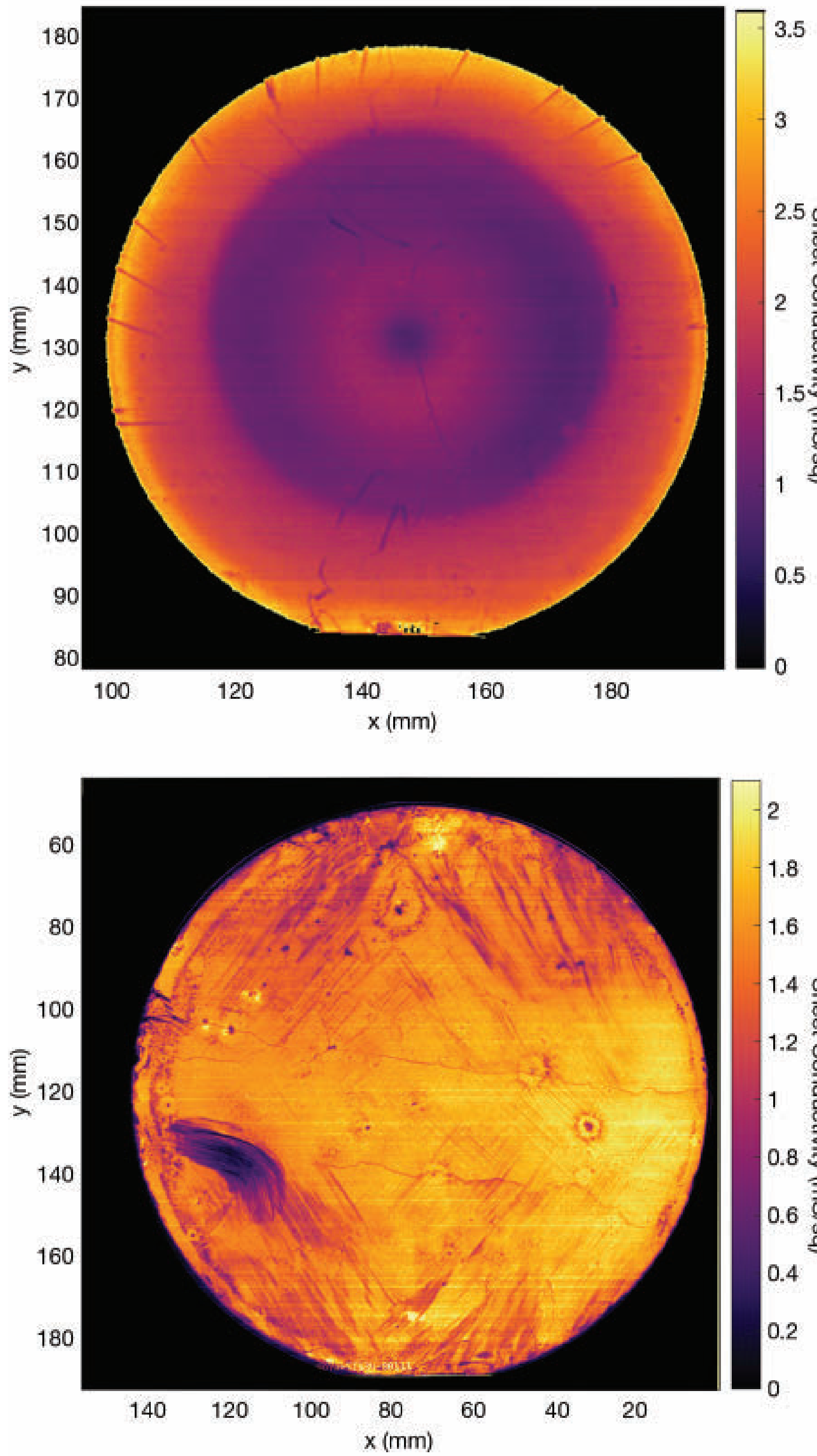
A typical application for a ToF measurement is the determination of layer thickness in automotive coatings. As shown in Figure 2, most cars are painted with several layers of color, both to achieve a shiny color as well as to protect against scratches, corrosion, and chemicals. The interfaces between the coating layers reflect part of the terahertz radiation. The resulting signal shows spikes, the temporal distance(s) of which can be converted into distances with a precision depending on the pulse width of the terahertz pulse.

Many materials are at least partially transparent to terahertz waves. And as this radiation is nonionizing, it can be used well on humans or sensitive materials. This applies to the obvious example of airport scanners, although as mentioned, their wavelength, in the millimeter range, corresponds to the lower limit of what is defined as terahertz radiation.

A less obvious example comes from TOPTICA Photonics in a test of fast terahertz screening of pharmaceutical packaging. European legislation demands that these packages are only to be sold with patient information leaflets enclosed. Weighing the packaging usually suffices to complete this test. However, this method may not always yield the correct "yes" or "no" answer regarding the presence of the leaflet.

In proof-of-principle measurements, TOPTICA researchers showed that fast terahertz screening detected the presence or absence of a package insert unambiguously. The method succeeded even for samples moving at >20 m/s and for boxes that overlapped in a tile-like manner.

In an additional application, terahertz sensors can be used to identify certain gases, especially in ambient settings and in trace amounts; many materials have



Protemics GmbH

Figure 4. Sheet resistance measurement on a 4-in. sapphire wafer with directly grown graphene **(top)**, and on a 6-in. silicon wafer with a transferred graphene layer.

fingerprint characteristics in the terahertz range as they do in the infrared. For this purpose, terahertz sensing is applied in a regular absorption spectroscopy setting. Figure 3 shows such a measurement system. A terahertz signal is sent through a low-pressure absorption cell with an optical path length of 5 m for the terahertz signal.

Terahertz imaging

In many applications, requirements go beyond point measurements; for example, a body scan requires a complete image of the suspect package or person.

Accordingly, a shift is underway toward 2D- and 3D-imaging techniques using terahertz radiation, especially in industrial environments.

Beyond the obvious ToF measurements, there are several innovative approaches to measure surface properties using terahertz radiation. The German company Protemics, for example, offers systems for measuring surface conductivity based on terahertz radiation. Its system emits a terahertz pulse generated by a micron-size waveguide on a chip. Within a near-field measurement setup, the technology enables scans of the sheet resistance on a surface.

Figure 4 shows this deployment for two types of graphene layers on silica wafers. One layer is grown directly on the surface. The other has been transferred. Protemics markets this system for measurements on solar cells, displays, transparent conductors, and flexible electronics. The maximum scan speed is 100 mm/s with a minimum scan time of 10 ms/pixel.

Looking ahead

Terahertz spectroscopy has left the scientific laboratory, and due to significant miniaturization, terahertz emitters and sensors presently on the market are housed in packages comparable to those of photodiodes. In addition, the advent of rugged femtosecond laser sources has supported the construction of rack-size control units.

Based on these advancements, terahertz spectroscopy is spreading into established applications, such as layer thickness measurements, as well as into new areas, such as semiconductor surface inspection. This technology is rapidly evolving toward greater integration and 2D- and 3D-imaging solutions.

Meet the authors

Lars Liebermeister has worked in the Terahertz Sensors and Systems Group at the Fraunhofer Heinrich-Hertz-Institute since 2016, becoming deputy group leader in 2019. He holds a Ph.D. in photonics from the Ludwig-Maximilians-Universität; email: lars.liebermeister@hhi.fraunhofer.de.

Robert Kohlhaas has served as head of the Terahertz Group at Fraunhofer HHI since 2022, researching photonic terahertz devices and systems. He studied physics at the Technische Universität Berlin, where he also completed his Ph.D.; email: robert.kohlhaas@hhi.fraunhofer.de.

Andreas Thoss, Ph.D., is a laser physicist, founder of THOSS Media, and a contributing editor to *Photonics Spectra*. He has been writing and editing technical texts, with a focus on the field of photonics, for two decades; email: th@thoss-media.de.

Deep learning offers a more versatile and flexible alternative to rules-based algorithms for many tasks, such as assembly line inspections.

Embedded Vision Systems

Usher Deep Learning into the Imaging Domain

The dynamic capabilities offered by AI are entering the realm of industrial imaging via integration into increasingly sophisticated embedded vision systems.

Image this page, courtesy of **Zebra Technologies**.

BY MICHAEL EISENSTEIN
CONTRIBUTING EDITOR

How would one decide which potato to select out of a group? Most people have an intuitive sense that guides them when selecting a spud, for example, at the market or from the garden, but it becomes difficult to pen an authoritative description of what differentiates healthy tubers from their underripe or infected counterparts.

Such tasks pose a significant challenge in the agricultural world, where food safety guidelines and quality standards extend from the farm to processing facilities and ultimately to retailers. Computer-guided machine vision systems are deployed in a wide range of industries, and most of these systems rely on rules-based algorithms that provide concrete guardrails for assessing and classifying parts and products. But these rules can be very hard to comprehensively define for organic products. This makes it challenging to implement machine vision for large-scale farming or produce-processing efforts.

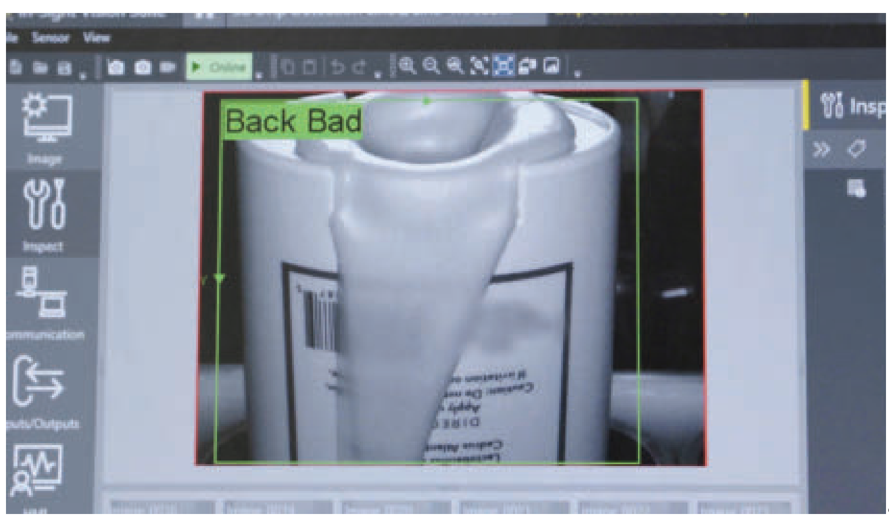
"Sometimes they're dirty, and sometimes they're misshapen, and how do you differentiate a potato from a rock?" said Jeff Bier, president and cofounder of engineering consultancy firm BDTI. "That's where you really need deep learning."

Deep learning describes a subset of AI methods in which algorithms are trained to recognize hidden patterns in data. In the machine vision world, this means algorithms are initially trained on carefully chosen, labeled images that depict — in the case of the aforementioned example — both consumer-grade and low-quality potatoes as well as non-potato objects. This yields a model that allows the algorithm to interpret new data based on complex and subtle features that it discerned from the training data set.

These algorithms have proved to be an empowering force for machine vision, as deep learning can imbue cameras and sensors with expertise that would be impossible or difficult to encode. It can also offer a more efficient alternative for tasks

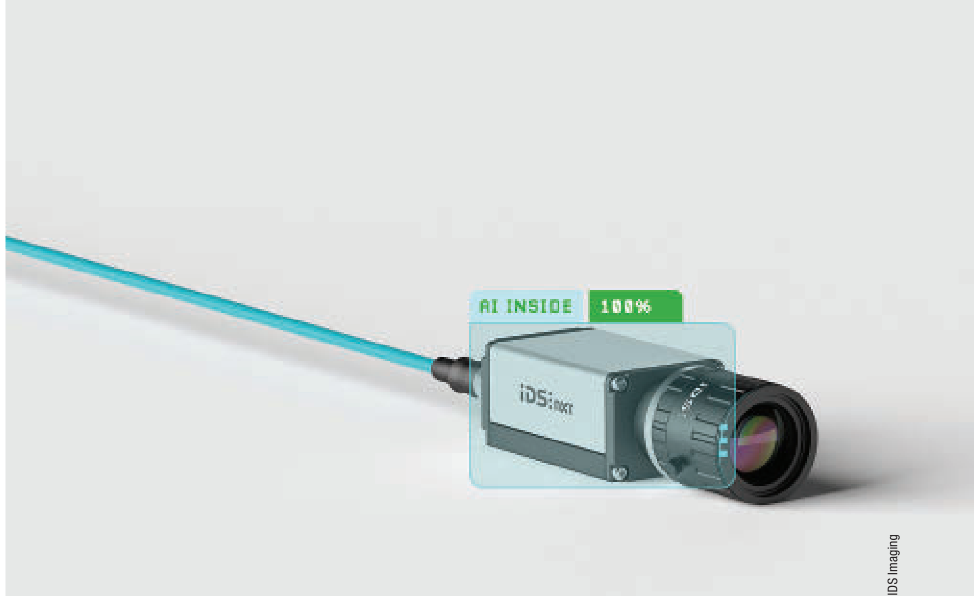
Cognex

Cognex



Cognex

Embedded vision systems are increasingly benefiting from deep learning capabilities. In this inspection scenario, a camera system focuses on a product **(bottom right)**. The machine vision system uses deep learning to analyze the resulting image and identify a defect. Hundreds of hours of training on 'good' and 'bad' examples enable the system to deliver an accurate assessment of inspected parts or products.



Deep learning capabilities are increasingly integrated into imaging systems themselves, enabling sophisticated image processing in a compact package.

that are amenable to rules-based analysis, for example, analyzing packages or machine parts on an assembly line. Eric Hershberger, applications engineering manager at Cognex, recalls laboring over a standard algorithm for optical character recognition (OCR), in which a camera is used to read and interpret written text. “It literally took me two months of programming to make that system work,” Hershberger said. Using deep learning, it took just a few hours of effort to achieve the same task, and with superior performance.

Increasingly, these capabilities are being directly integrated into the cameras themselves, enabling users to achieve remarkably sophisticated image processing in a single, compact package. While this democratization of deep learning holds transformative potential for numerous industries, manufacturers are still working out how to make this technology as accessible as possible. “They want an easy solution, but very powerful — this is the main expectation from the customers,” says Gerard Ester, manager of vision solutions at SICK, a developer of sensor solutions supporting a wide range of industrial applications.

All aboard

The idea of bringing image analysis capabilities off of computers and into cameras is not new; according to Hershberger, such so-called embedded vision systems began to enter the market in the late 1990s. Embedded vision systems greatly reduce the hardware and equipment required for a machine vision setup and mitigate the security risks associated with, for example, having all the image data on a factory floor flow into a single PC for analysis.

In the last quarter century, these systems have become increasingly compact, resulting in machine vision systems being routinely deployed for consumer use — and not exclusively in industrial environments. The same underlying concepts are being applied to help cellphone users take better pictures and in vehicles to support driver safety features.

By 2010, Bier had become so enthusiastic about the technology that he founded a dedicated industry organization. “We realized this is going to be a game changer — the ability to embed computer vision in everyday devices,” Bier said. The organization, founded as the Embedded Vision Alliance and since renamed the Edge AI and Vision Alliance, is well known as the host of the annual Embedded Vision Summit.

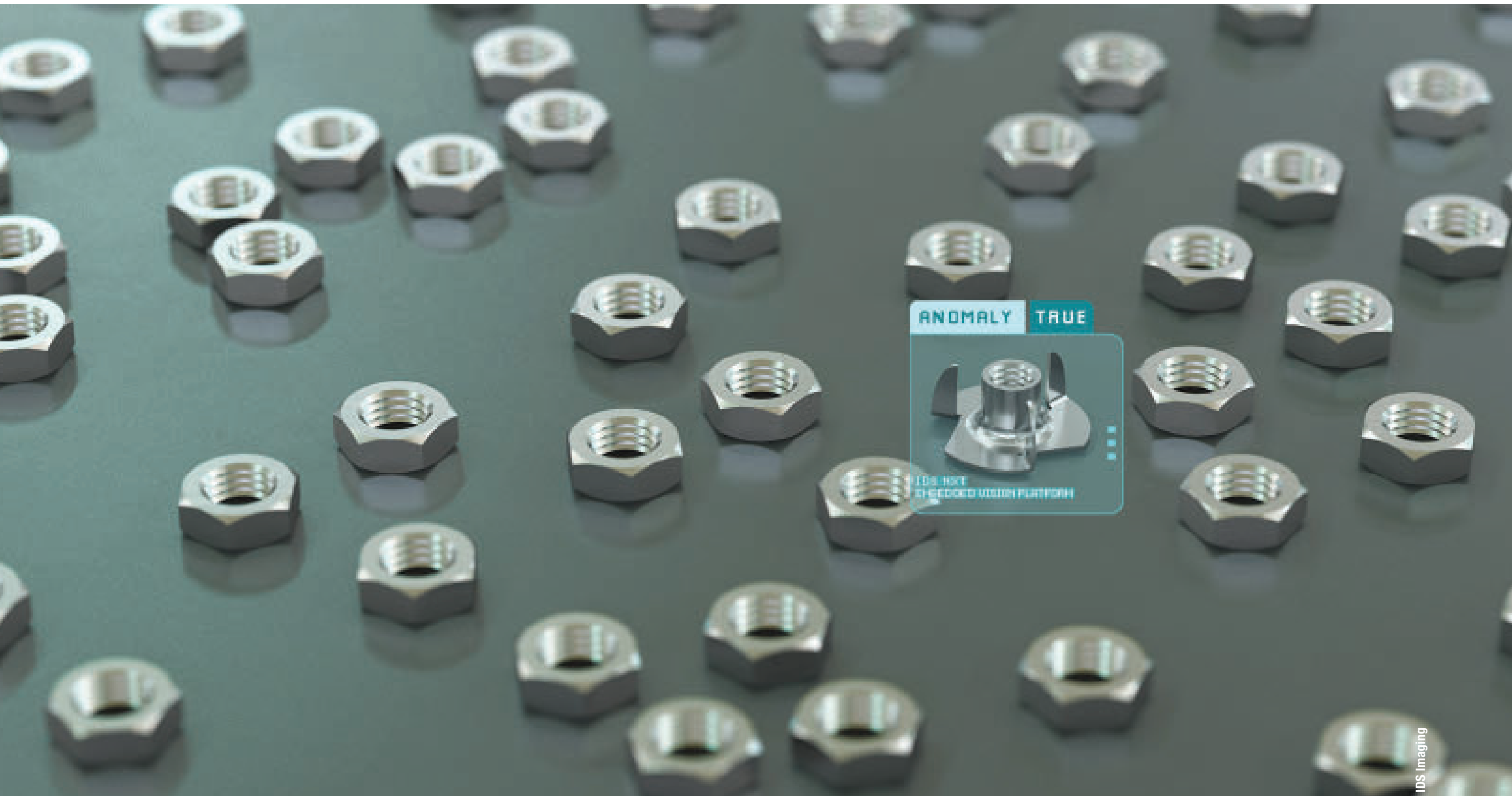
Amid the ascent of embedded vision technology, however, engineers and systems designers did not immediately overcome the logistical difficulty of cramming the sophisticated graphics processing units (GPUs) that power AI applications into compact systems. These mighty processors require considerable power as well as strategies for controlling the heat that they produce as by-products. Until recently, virtually all embedded vision devices relied on rules-based algorithms. Most of the early implementations of deep learning in machine vision systems were based on more traditional designs, in which image data from “dumb” cameras is relayed to a centralized PC or cloud-based system for GPU-powered analysis.

In the past decade, the rapid evolution of smartphones and other Internet of Things devices has been a major boon, motivating chip developers to find creative strategies to shrink their processors. “There has been this huge surge of R&D investment over the last 10 years … to create these domain-specific architectures that are 20, 50, 100 times more efficient at running these deep learning models,” Bier said. This new generation of GPUs, developed by the likes of Sony, Qualcomm, Intel, and NVIDIA, reduce both the financial and energy requirements needed for AI computers. At the same time, they are also more manageable in terms of controlling heat dissipation.

Patrick Schick, product owner at industrial camera developer IDS Imaging Development Systems, said that technology for accelerating deep learning processing is now available as system-on-a-chip (SoC) devices, in which all the core components of a computer have essentially been shrunk down to a tiny camera-scale form factor. This leads to even greater processing efficiency.

And critically, this integration minimally affects the camera design itself, such that embedded vision system developers are generally able to avoid a return to the design drawing board. For example, SICK launched its first deep learning-powered system, the Inspector 83x, in June. Aside from the product’s deep learning element, Ester said that these systems use the same fundamental components, including the camera optics and lighting components, as in the company’s other embedded vision offerings.

Deep learning can be intimidating for customers without coding experience, and user-friendly software has been critical to the broad commercialization of these platforms. Software companies, such as MVTec, specialize in deep learning for machine vision, but many pioneers in this space have opted to internally develop their own toolboxes. For example, IDS offers users its Lighthouse suite as a streamlined tool for training its NXT family of deep learning embedded vision systems. “The basic idea behind this is that a customer or a user could come to us and only have images and say, ‘this



IDS Imaging

A deep learning-based machine vision system detects and indicates the presence of an abnormality.

is good; this is not good,'" Schick said. "They do not have to have an in-depth understanding of AI."

From factories to farms

As barriers to adoption and costs continue to decrease, the application space for deep learning-powered machine vision has steadily grown. Some of these applications involve tasks that are relatively routine yet require a level of precision and repeatability that would be difficult or impossible for human workers. Deep learning also has the advantage of codifying expert knowledge without requiring humans to formally identify and define rules to guide the algorithm.

Most current implementations of deep learning fall into one of two broad categories. The first is classification, where embedded vision is used to sort through a steady procession of objects and determine which are ready for production and which are not — and why. Regarding one implementation, Andy Zosel, senior vice president for Advanced Data Capture, Machine Vision & Robotic Automation at Zebra Technologies, said that customers are using Zebra's embedded vision systems on automotive assembly lines to inspect the connectors that couple electrical wiring harnesses in cars. "If they are not clipped together correctly, it's going to vibrate and fall apart, and you're going to start running into electrical issues," Zosel said. "But verifying those as 'clipped' or 'not clipped' with traditional cameras is extremely difficult." Deep learning makes it straightforward to classify assemblies as clipped or unclipped even when all the various components are black and difficult to distinguish in an image.

The other major category of deep learning tasks is anomaly detection, in which the system is used to detect defects or damage. In such a use case, SICK's cameras are being deployed to identify flaws in the packaging or loading of consumer products, such as bottles of detergent or food containers, or to inspect the equipment used for injection molding to ensure a steady flow of consistently manufactured plastic components.

A properly trained deep learning algorithm can also acquire a level of flexibility that is inaccessible to rules-based algorithms. "It's better at handling environmental changes — so if it gets a bit brighter or darker, or if the object under inspection is now a bit further to the left or right, the AI doesn't care," Schick said.

This can be a major asset when embedded vision is used outside the controlled environment of a factory floor. One example, Bier said, involves the John Deere See and Spray system, which pairs machine vision and deep learning to guide the precise dispersal of agricultural chemicals. "It looks at each individual little plant and it says: 'Is that a weed or is that a crop?'" Bier said. "If it's a weed, it gets the herbicide, and if it's a crop, it doesn't." In 2022, John Deere reported that this system was allowing farmers to cut their herbicide use by up to two-thirds.

Training day

Implementing deep learning is becoming considerably easier, but there are still important considerations and challenges that both users and camera manufacturers are continuing to grapple with.

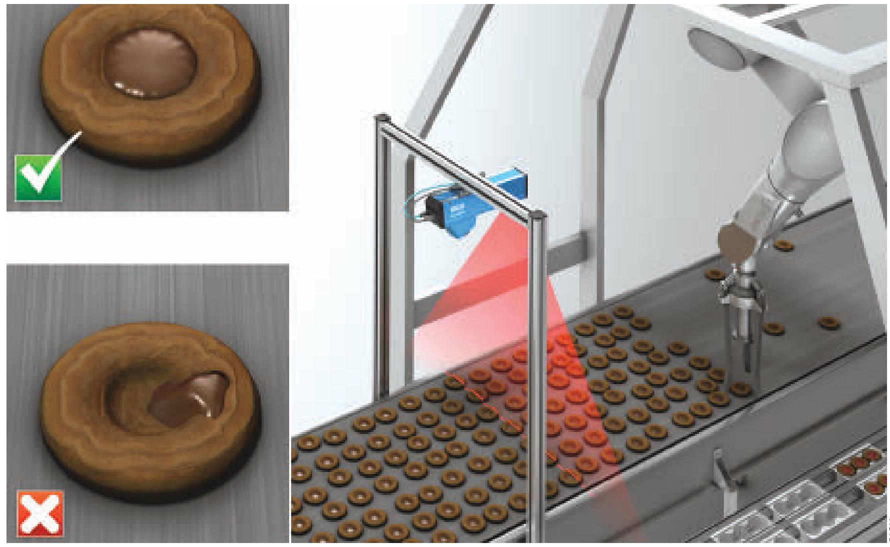
One is the training process, in which the deep learning algorithm is fed examples that allow it to build a model for interpreting visual data. Sometimes, this can be a breeze. “If we’re just trying to find a couple differences, we can do a quick train with just a few images to figure out what’s good [and] what’s bad,” Hershberger said. A few days of testing with this rough model is often sufficient to achieve robust performance, he said.

Other applications require more extensive training to ensure that the algorithm reaches solid conclusions. “If you only train it on a few images, it’s very easy for it to get fooled,” Zosel said. An inadequately trained or undertrained system is apt to misinterpret data when the samples on which it is trained are insufficiently varied. As an example, Zosel cites a scenario in which the AI concludes that “every time I saw a Y in the corner, there was a defect, so that must mean a Y in the corner means there’s a defect.”

This can become a substantial burden. Some products have an inherently slow production process, such as aerospace components, and in such cases, Ester recommends that users assemble a stockpile of training examples before rolling out their deep learning system. Additionally, it can be tough to authoritatively detail all the possible flaws and failure modes for a product, Hershberger said. He said that his team spends a lot of its time developing and reviewing training procedures with quality control experts.

In some cases, embedded vision developers can formulate generalizable deep learning models, and these can essentially be run “out of the box.” Zebra specializes in OCR applications, and Zosel said that the company’s Aurora deep learning model can be run off a standard central processing unit while still delivering accurate text interpretation for English alphabet-based languages. Importantly, these capabilities can still be extended to other alphabets with additional training.

Trade-offs in terms of image quality also exist. Embedded vision GPUs are generally weaker and slower than their PC-scale counterparts, and this makes it difficult to work with large, high-resolution picture data.



A depiction of a real-time ‘good/no-good’ inspection for food products using SICK’s Inspector 83x camera.

The use of deep learning can compensate for poor image quality to some extent. But, experts caution against settling for less. “I really don’t like that argument at all,” Hershberger said. Better image quality improves the algorithm’s analytical performance and reduces the amount of effort required for training. Speed is also a common limitation with current processors, although a few embedded vision systems on the market are achieving the throughput needed for many areas of manufacturing. “We can do this kind of AI inspection in tens of milliseconds,” Ester said, regarding SICK’s Inspector 83x camera.

Embedded vision systems can also gain a speed and efficiency boost by combining the strengths of rules-based and deep learning approaches. “If you can find the object and locate it in some segment using traditional algorithms and then pass that found object to the AI … you can kind of balance speed and requirements,” Zosel said.

A vision for the future

At present, a relatively limited number of deep learning-enabled offerings exist in the embedded vision space. But Bier envisions that the availability of such systems on the market will evolve rapidly, as will their performance capabilities. “If somebody looked at an application two or three years ago and it wasn’t feasible, it might be feasible today or a year from now,” Bier said.

3D imaging is one example of a capability that was previously out of reach. Multiple companies released 3D embedded vision systems enhanced by deep learning capabilities in the past year, including Zebra’s 3S Series of sensors, as well as the In-Sight L38 from Cognex.

“Finding random defects in a 3D space is something that we’ve needed for a very long time,” Hershberger said, highlighting that differences in surface reflection in 3D can reveal scratches and flaws that would escape notice in a 2D image. But this is still evolving technology and introduces additional challenges. For one, these cameras can be much harder to set up to achieve consistent and accurate imaging. They may also require significantly more training than 2D systems.

As progress marches on, the emergence of ever faster and more energy-efficient GPUs — and their more advanced cousins, the neural processing units — could equip the next generation of embedded vision systems with the speed, resolution, and accuracy needed to start completing tasks that were once the sole domain of human experts.

“It opens up a whole set of applications,” Zosel said. “But it’s definitely more complex than just saying, ‘unplug the human, plug in the camera.’”

michael@eisensteinium.com

Laser Safety and the Cleanroom

BY KEN BARAT
LASER SAFETY SOLUTIONS

The commonly accepted definition of a cleanroom is a controlled environment that filters out pollutants such as dust, airborne microbes, and aerosol particles to provide the cleanest area possible. Cleanrooms are grouped, or classified, by the number of particles allowed in the air per cubic meter. These work areas control additional variables, such as temperature, airflow, and humidity.

The precise function of a cleanroom depends on its group. Certain cleanrooms are dedicated to fabrication operations. Others support Class 1 products used in automated operations — similar to a manufacturing environment. Cleanrooms that contain a high-power laser system, such as terawatt or petawatt systems, are classified separately.

Given these different groupings and classifications, the size of cleanrooms varies. Some are hundreds of thousands of square feet. Others may be only a few hundred square feet.

For these reasons, the cleanroom is inherently an environment that presents unique safety controls and challenges for the use of lasers. For the laser safety officer (LSO) responsible for the cleanroom, there are a number of challenges that extend beyond the scope of those that can be addressed using traditional control measures.

Warning signage

Many of the safety controls that are available to the LSO in a cleanroom environment qualify as preventative measures. Warning signage, for example, is an essential device in this type of controlled setting.

iStock/RGtimeline

Cleanrooms demand that their users follow a stringent set of rules to keep the environment pure. The Safe Use of Lasers standards do not always mesh well with these rules, presenting a unique challenge for laser safety officers (LSOs).

Important factors must be considered when implementing signage: Depending on the size of the cleanroom and location of laser systems, a required laser warning sign at the entrance could be useless to system users. This might be because the actual laser hazard is scattered around the cleanroom, or in an open spot far away from the location of the door. In smaller cleanrooms, the warning sign should be positioned in the vicinity of the laser protective eyewear.

Access control

Measures to be put into place prior to the start of cleanroom operations also extend to access control. Before entering a cleanroom, workers must ensure they are wearing appropriate cleanroom equipment. In some cleanrooms, it is even required that workers go through an airlock station before entering the cleanroom. Although this is a rare case, such protocols for entry commonly accompany added measures for high-power laser systems, such as petawatt or optical accelerator setups. It is rare in most cases, however, that the access control system (interlocks) serves as the access protocol and facility entrance system.

Wearing cleanroom clothing

Cleanroom-appropriate clothing falls under two categories, with the broader of the two, personal protection equipment (PPE), widely known even to those outside cleanroom environments. For laser system users, as well as cleanroom workers who may not actually encounter beam hazards, PPE does inflict restrictions on the wearer: Anyone who has geared up fully can attest to the restrictive and uncomfortable nature of working in such clothing. This clothing is designed to prevent particles generated by the human body from contaminating items in the cleanroom. Such apparel can also be designed to offer a degree of protection to the wearer and other present personnel.

Cleanroom clothing can include the following articles: bouffant caps, lab coats, shoe covers, face masks, beard guards, and gloves. The American National Standards Institute (ANSI) Z136.7-2020 Testing and Labeling of Laser Protective Equipment standard does not presently address cleanroom clothing from a laser protective perspective.

Laser protective eyewear

For cleanroom workers, laser protective eyewear is no different from the standard laser protective eyewear used in a traditional laser laboratory. However, consideration to storing and cleaning the eyewear may necessitate extra attention, due to the stringent need to prevent contamination from entering the workspace. This consideration will depend on the rating of the cleanroom.

Training

The potential for a beam hazard to cause serious harm to a cleanroom worker or to equipment intensifies during times of operation. Proper training is vital to reducing risk in cleanrooms where this may be a concern.

Two groups should receive training when working in cleanrooms. First are those with access to the laser or laser system. Members of this group should be considered the traditional laser users — and fundamental institutional training is imperative. These workers should receive documented on-the-job training (as referenced in Z136.8). And after a predetermined length of time, these workers should receive a refresher lesson spanning all necessary training and instructions.

Next are those who may work in the cleanroom, but who have no hands-on contact with the lasers. These may be staff members who are delivering parts or picking up completed work for the next step in a fabrication process. For these individuals, awareness training is an important requirement, serving to not only ensure that any control measures are respected but also to remove inaccurate perceptions of concerns.

Stopping an errant beam is extremely important, since significant equipment damage can occur in a short time. In this way, an e-stop does offer value.

Standard operating procedure

Standard operating procedure (SOP) should function in tandem with proper training and instruction. Too often in cleanrooms, outside of the science laboratory cleanroom, SOPs exist as operational work documents that do not qualify as a laser safety SOP. In a cleanroom that contains Class 1 laser systems with embedded Class 3B or Class 4 lasers, effective SOPs must address requirements for service and/or maintenance.

In the absence of an SOP, a temporary control area document can be an acceptable, similar alternative, and can be considered acceptable. In this case, if temporary or mobile barriers are to be used during service, the chosen barrier or curtain must be cleanroom compatible. The same must be true for any temporary signage that is used. Space to properly store these barriers when not in use also needs to be planned for.

Emergency stop

Due to the nature of laser use in cleanrooms, a master emergency stop button is rarely used and may not be helpful as designed. In a fabrication cleanroom that consists of individual workstations, for example, each station might have an “off” button on the power supply — but little more. Further, in a cleanroom containing Class 1 products, such as semiconductor tools, each unit may have its own emergency stop. And, while some cleanrooms may feature such units with an “e-stop” at the exit, these devices or mechanisms are far less effective than a control room that oversees operations for cleanrooms that contain terawatt, petawatt, or similar systems. The control rooms for cleanrooms that contain these systems must have a way to stop procedures. These systems all have defined and precise beam paths; these beams are not like a rouge firehose spraying in random directions.

Stopping an errant beam is extremely important, since significant equipment damage can occur in a short time. In this way, an e-stop does offer value. The questions are how many are needed, and where they ought to be located.

Many important factors must be considered when answering these questions. E-stops that are put into place too early in the design process ensure that access issues presented by the equipment are not considered. I have also observed e-stops placed on walls but never connected to the laser equipment, which presents an obvious absence of effectiveness.

Traffic

Traffic must also be considered. In the traditional laser control area, spectators and visitors are discouraged or restricted from entering. Cleanrooms that contain multiple workstations will have staff members who circulate in the area but who are not involved in direct fabrication or testing that involves laser use. It is not uncommon to have only the system operators wearing laser protective eyewear. This causes the appearance of a lack of safety. To some degree, issues here can be resolved by adding to the training section.

> **In a cleanroom that contains Class 1 laser systems with embedded Class 3B or Class 4 lasers, effective standard operating procedures must address requirements for service and/or maintenance.**

Area warning device, visible warning light

Warning lights and/or devices also offer tangible benefits to cleanroom workers and systems, although they are rarely found at the entry points of fabrication cleanrooms. This is because many of these lights are tied to the power supply and may be on at all times.

Also, warning lights may indicate equipment status and be a cause of confusion to staff members, even after training. In cases in which multiple laser workstations are in the cleanroom, it is rare to find a laser warning light or indicator at each station. And it should go without saying that one must consider how such lights look when wearing protective eyewear.

For the laser safety officer

It is clear that laser use in cleanrooms does not easily mesh with the general guidance found in the existing Z136: Safe Use of Lasers standards. These laser standards give the LSO considerable leeway to apply controls and modify required controls (termed “alternate control measures”) based on hazard evaluations.

LSOs given the responsibility of overseeing Class 3B or Class 4 lasers should work in a cleanroom environment “gown up” and spend time in the shoes of its users. Alternative controls, or any rationale to deviate from the requirements of the laser standards, must be documented. Hopefully, laser safety in the cleanroom will be specifically addressed within the laser standards or as an appendix in future editions of the laser user standards.

lasersafetysolutions@gmail.com

Sussex County Community College
Newton, New Jersey

LASER-TEC is the Center for Laser and Fiber Optics Education, founded in 2013 by the National Science Foundation (NSF) and headquartered at Indian River State College in Florida. It was established to help meet the goals of educating and sourcing domestic talent in the areas of optics and photonics. As a service to students, recent graduates, and prospective employers, Photonics Spectra *runs a profile of one of the LASER-TEC colleges each month.*

Sussex County Community College (SCCC) has developed a quartet of programs aimed at providing students with the knowledge, training, and experience required to excel in the fields of optics and photonics. Whether pursuing a two-year associate of applied science (AAS) degree or one of three one-year certificate programs, students will learn from experts in the field while expanding their own networks in the industry. SCCC structures all its optics technology programs to provide hands-on and experiential learning that includes substantial use of industry-standard machinery. This helps to prepare the students for successful careers within the optics industry — often with SCCC partner organizations such as Thorlabs, Inrad Optics, or Esco Optics.

Program descriptions

SCCC's Optics Technology associate degree program provides students with the opportunity to gain knowledge and skills in the field of optical manufacturing through integrated general education coursework that will qualify them to work in the industry. Students can develop advanced skills in the comprehension of technical drawings, materials handling, conventional grinding and polishing, optomechanical assembly, metrology, and quality control. Students will receive training in programming, setting up, and operating computerized numerical control (CNC) grinding and polishing machines.

The three certificate programs offered at SCCC focus respectively on CNC manufacturing, conventional manufacturing, and metrology. Students will gain theoretical and hands-on knowledge.

A student in the Optics Technology program at Sussex County Community College (SCCC) uses an interferometric-based optical-thickness gauge to determine the size of an optic to sub-micrometer accuracy.

Graduates of SCCC's degree and certificate programs have the skills to:

- Employ safety skills in industrial settings while using conventional machinery, CNC machinery, coating materials, lasers, and more.
- Perform conventional and CNC polishing and grinding of optics.
- Use both conventional and CNC methods to determine whether parts meet technical drawing specifications.
- Use industry-standard machinery, manufacturing techniques, and processes.
- Apply metrology skills for the purpose of creating first article inspection reports.
- Perform setup procedures on CNC grinding and polishing systems.
- Assemble multiple optical elements.
- Properly handle and clean various optical elements.
- Use military and ISO specifications to execute inspection plans.

How to recruit from this college

If you are interested in recruiting students from SCCC, please reach out to the program supervisor listed. Arrangements for in-person or virtual meetings can be made. Internship opportunities for current students are always welcome. Graduates are available each May.

Contact information

Jason Fruge
Dean of Technical Occupations
jfruge@sussex.edu
1 College Hill Road
Newton, NJ 07860

Program website

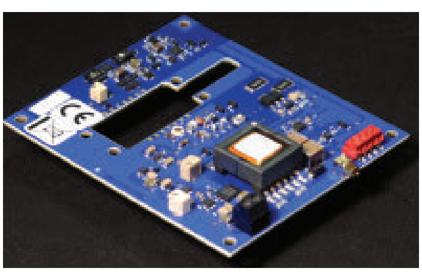
www.sussex.edu/academics/degrees/optics-technology

Image courtesy of Sussex County Community College.

Product News

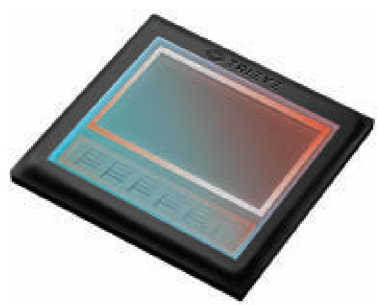
Fast Steering Mirror

The S-335 from **PI** (**Physik Instrumente**) is a two-axis fast steering mirror for directing laser light or improving image resolution by correcting errors in a wavefront before it reaches an imaging sensor. The mirror is based on solid-state piezo drives and has a long angular travel range along with closed-loop controls with feedback sensors. The S-335 can provide 35 mrad of mechanical angular deflection in two axes and 70 mrad optical deflection.
info@pi-usa.us



Laser Diode Driver

The Model 766A from **Analog Modules Inc.** is a picosecond pulsed seed laser diode driver designed for driving Type 1, 14-pin butterfly packaged laser diode modules in materials processing, medical treatments, time-resolved spectroscopy, and lidar applications. The driver circuitry operates from a single 5-V power source, including a low-noise, bidirectional proportional-integral-derivative thermoelectric cooler controller with a current capability of 2.2 A and a voltage capability of 4 V. The Model 766A features an adjustable pulse width from <150 ps up to 1 ns at currents up to 2.5 A via on-board potentiometers or external control voltage signals.
ami@analogmodules.com



SWIR Image Sensor

The TES200 from **TriEye** is a SWIR image sensor designed for machine vision, robotics, biometrics, and automotive applications. The full-stack sensor operates in the 700- to 1650-nm wavelength range at a 1.3-MP resolution. The TES200 also features a 2/3-in. optical format, a global shutter mode, a maximum frame rate of 120 fps, a pixel pitch of 7 µm, and an iBGA 13- × 13-mm package size.
info@trieye.tech

CW DFB Lasers

Coherent's high-efficiency continuous-wave distributed feedback (CW DFB) lasers are engineered for silicon photonics transceiver modules in AI-driven data centers. The lasers are designed to operate in the O-band (1310-nm region) for modulators used in 800G and 1.6T optical transceivers. The CW DFB lasers feature a low series-resistance design and indium phosphide laser technology.
info@coherent.com

Fabry-Pérot Laser Diodes

Exalos' 488-nm Fabry-Pérot laser diodes (FP-LDs) are suited for fluorescence microscopy, flow cytometry, and spectroscopy applications. The laser diodes feature in-house epitaxial growth of III-nitride semiconductor layers and are available in uncooled TO56 cans with free-space light output with a monitor photodiode for power monitoring during device operation or for implementing automatic power control. The 488-nm FP-LDs also come in a 14-pin butterfly version with single-mode fiber or polarization-maintaining fiber output.
sales@exalos.com

Stereo Vision Camera

The Ensenso B from **IDS Imaging Development Systems** is a 3D vision camera that can be used in industrial applications, such as in pick-and-place and bin picking. The stereo vision camera can capture objects over a large area and localize all parts in a container at a working distance of between 30 cm and 2 m. The Ensenso B housing can accommodate two 5-MP color cameras and features dimensions of 120 × 56 × 104 mm and IP65/67 standards.
usasales@ids-imaging.us

Oscilloscopes

The MXO series from **Rohde & Schwarz** are application-specific integrated circuit-based zone triggering oscilloscopes for testing and debugging applications. The oscilloscopes' zone triggering can be used for triggering on non-monotonic edges, serial bus patterns, math waveforms, events across multiple channels, and events in the frequency domain. The MXO series has a zone trigger update rate of up to 600,000 waveforms/s and <1.45-µs blind time between trigger events.
info@rohde-schwarz.com

Neutral-Density Attenuator

The Model 801 from **LASNIX** is a neutral-density attenuator for broadly tuned lasers, nonlinear generation via ultrafast pulses, level setting for mode analysis and detector calibration, and use in nonlinear-interaction studies applications. The infrared to visual attenuator uses all-metal,

substrate-less, diffractive technology so transmitted beams retain their original properties, such as mode structure, propagation direction, M2 factor, divergence, polarization state, and phase-front shape. The Model 801 features four steps of attenuation up to 30 dB, is spectrally flat from 500 nm to 15 μm, and can be used for laser beams with power levels of up to 100 W.
info@lasnix.com

SMT Pulsed Laser
The SPL S8L91A_3 A01 from **ams OSRAM** is an eight-channel surface mount technology (SMT) pulsed laser that can be used in long-range lidar systems for autonomous driving vehicles such as passenger cars. The laser has four individual addressable anodes, where each anode is connected to two parallel operating laser channels, as well as a monolithically integrated eight-channel design. The SPL S8L91A_3 A01 comes in a QFN (quad flat no-lead) package and features a wavelength of 915 nm, a total peak optical power of 1000 W, and an efficiency of up to 30%.
sensors@ams.com

Miniature Linear Voice Coil Motors
The LVCM-016-019-01M and the LVCM-016-019-01 from **Moticont** are metric and imperial, respectively, linear brushless voice coil servo motors that can be used in applications such as assembly, testing, wafer handling, scanners, and laser beam steering and filtering. The motors have a 12.7-mm (0.5-in.) long stroke, a high force-to-size ratio of 1.7 N (6.1 oz), and a peak force of 5.4 N (19.3 oz) at 10% duty cycle. The LVCM-016-019-01M and the LVCM-016-019-01 also feature a length of 30.2 mm (1.19 in.) at mid-stroke, a diameter of 15.9 mm (0.625 in.), and M2.2X0.45 threaded mounting holes for the metric version and 2-56 UNC-2B threaded holes for the imperial version.
moticont@moticont.com

Optical Transceiver
Integra Optics' 10G SFP+ transceiver has a reach of 120 km and is designed to deliver

performance for metro Ethernet transport and access networks, without the need for amplification. The transceiver supports up to 120-km (74-mile) reach over single-mode fiber at 10-Gbps data rates and complies with the industry-standard SFP+ multi-source agreement. Integra Optics' 10G SFP+ transceiver can operate within a commercial temperature range of 0 to 70 °C and is available with coding for compatibility with several platforms.
sales@integraoptics.com

Dual-Axis Stages

The ZVR-60-60 Series from **Optimal Engineering Systems** (**OES**) are dual-axis lift and pitch stages for applications including laser pointing, laser milling and drilling, camera mounting, mirror alignment, range finding, and scanning in laboratory and manufacturing settings. The stages have a scissor lift design combined with roller bearings and slide rails for smooth motion and high parallelism while raising and lowering with capability for continuous 360° clockwise or counterclockwise rotation. The ZVR-60-60 Series feature 60 mm +/−2 mm of vertical travel, +/−5 µm of typical vertical repeatability, and a typical positional accuracy of 15 µm.
sales@oesincorp.com

Digital Fluorescence Microscope

The Mateo FL from **Leica Microsystems** is an AI-powered digital fluorescence microscope for cell culture checks in research applications. The microscope combines transmitted light for label-free imaging with multichannel fluorescence and automated analysis tools which offer reproducible results, even in challenging cell culture samples. The Mateo FL features multimodal capabilities, AI-powered confluency checks, and smart measurements for transfection efficiency as well as built-in audit trails and user management functionalities that support FDA 21 CFR Part 11 compliance.
info@leica-microsystems.com

UV LED COB Modules

The VC4X4 COB Modules from **Violumas** are UV LED COB modules for high-dosage UVB/UVC LED applications such as disinfection, spectroscopy, and phototherapy. The modules are available in 265-nm, 275-nm, 295-nm, and 310-nm wavelengths and are composed of the company's UV LED COB and a fan-cooled heatsink. The VC4X4 COB Modules also feature high-density 16-chip LED arrays under a single 90° fused silica lens, optical outputs of up to 1600 mW, and intensities of up to 299 mW/cm^2 at 10-mm distance.
info@violumas.com

Remote Centralized Drivers

The LumaDrive Pre-wired Systems series from **Advanced Energy Industries** are high-efficiency remote centralized drivers for large-scale industrial, horticultural, and greenhouse LED lighting applications. The drivers combine up to 36 units of 4-kW modules that eliminate extra dimming control connections and enable simple hot swap repairs. The LumaDrive family offers configurations of 144 kW, 72 kW, 36 kW, and 24 kW and uses native three-phase power with a centralized architecture to power large-scale LED lighting installation.
info@aei.com

Dark-Field LED Platform

The MR-Dark Field from **TPL Vision** is a modular illumination platform with dark-field effect for surface inspection, defect detection, and edge detection applications. The remote-controlled platform is made up of a bi-color LED modular ring light and a dark-field reflector with embedded overdrive and IP65 protection. The MR-Dark Field's peak wavelength variation does not exceed 10 nm and is suitable for use with white LED, infrared LED, red LED, and cyan LED bandpass camera filters.
contact@tpl-vision.co.uk

Laser Soldering Unit

The VersaSolder from **nanosystec** is designed for applications including quantum computing, in which the product is used to attach single-mode fibers to silicon photonic chips. The modular unit uses a laser system with different modules depending on the needed wavelength and an optical head that generates up to 40 individual sub beams that can process more than one connection at the same time. The VersaSolder also features hot bar soldering and a CCD camera that monitors solder joint quality through the solder optics.
sales@nanosystec.com

Semiconductor Metrology Device

The Vista 300 from **Molecular Vista Inc.** is a nano infrared instrument that can be used in advanced semiconductor process monitoring and defect analysis. The instrument combines infrared spectroscopy with atomic force microscopy to provide photoinduced force microscopy that performs chemical mapping with a spatial resolution of <5 nm. The Vista 300 is designed to handle full 300-mm wafers with a 1.1- × 1.1-m footprint and can map chemical differences between exposed and unexposed 16-nm half-pitch patterns in extreme-ultraviolet resist films before the resist is developed.
info@molecularvista.com

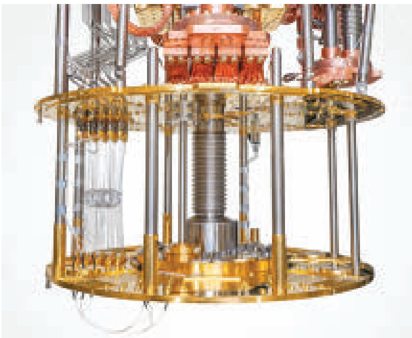
Double Shutter Cameras

The pco.edge 5.5 DS CLHS (shown) and pco.edge 26 DS CLHS from **Excelitas Technologies** are double shutter cameras for applications including particle image velocimetry, particle tracking velocimetry, and flow visualization in gaseous and liquid media and wind tunnel experiments. The pco.edge 5.5 DS CLHS features a high resolution of 5.5 MP, a 16-bit dynamic range, an interframing time of 100 ns, and a frame rate of 25 fps at full resolution. The pco.edge 26 DS CLHS has a 26-MP image sensor, an interframing time of 350 ns, a pixel size of 2.5 × 2.5 µm, and a frame rate of 74 fps at full resolution.
photonics@excelitas.com

400G Spine Switch

The DCS511 from **Edgecore Networks** is a 400G-optimized open network data center spine switch for data centers, service providers, and cloud operators. Powered by the Broadcom Tomahawk 4 chipset, the switch offers 32 × 400G ports on a single device and can be deployed as a spine switch supporting 100/400 gigabit Ethernet spine-to-spine or spine-to-leaf interconnects. The DCS511 has up to 16 ports for 400G ZR or ZR+ coherent optics, with a

24-W power budget per port along with support for SONiC NOS, VXLAN routing and bridging, and cognitive routing, global load balancing, path rebalancing, and RoCEv2 over VXLAN.
sales@edge-core.com



Quantum Measurement System

The XLDHe High Power System from **Bluefors Oy** is a cryogen-free, helium-4-powered measurement system for applications such as spin qubit quantum computing devices and single-photon detectors for photonic quantum computers. The measurement system uses helium-4 to generate cooling power between 200 and 700 mW at 1 to 1.2 K and uses two PT425 Pulse Tube Cryocoolers. The XLDHe High Power System features a flange of 540 mm, the ability to reach a base temperature of <900 mK in 12 to 16 h, and can provide experimental height options of 175 mm or 776 mm.
info@bluefors.com

SiC Photodiodes

The MTSM1057SMF2-046 and MT12-001 from **Marktech Optoelectronics** are silicon carbide photodiodes for the detection of deep-UVC wavelengths between 220 and 358 nm in applications such as surface sterilization, water purification, and analytical instrumentation. The hermetic characteristics of the photodiodes' ATLAS hermetic surface mount device and TO-46 metal can packaging, respectively, protect the compound semiconductor photodiode chip from the damaging effects of moisture, oxygen, gases, and other vapors. The MTSM1057SMF2-046 and MT12-001 are insensitive to visible and solar light, allowing them to have accurate detection of UVC light in diverse environmental conditions.
info@marktechopto.com

Portable Fiber Optics Cleaner

The Sticklers Pro360° from **Sticklers** is a portable touchless fiber optic connector cleaner for applications such as data centers, OEM, military, and high-volume FTTx. The system combines a microdose of atomized cleaning

fluid with a Coanda effect airstream to clean and dry fiber optic connector end faces and remove signal-blocking contamination from the entire end face of both male and female connectors. The Sticklers Pro360° includes tips for both 1.25 mm and 2.5 mm connectors.
techsupport@microcare.com

Gas Sensor

The Sunlight R290 gas sensor from **Senseair** uses nondispersive infrared technology with LED light sources and photodiode sensors to detect R290 refrigerant along with an automatic baseline correction algorithm. The Sunlight R290 has an operating temperature range of −40 to 70 °C, a relative humidity range from 0% to 95%, a lower flammable limit measurement range of 0% to 100%, a size of 34 × 21 × 12 mm, and a power consumption of 94 μA.
info@senseair.com

STATEMENT OF OWNERSHIP MANAGEMENT AND CIRCULATION OF PHOTONICS SPECTRA

September 30, 2024

(This statement is published in compliance with the Act of October 23, 1962)

Published monthly.
President: Thomas F. Laurin
Editor-in-Chief: Michael D. Wheeler
Senior Editor: Jake E. Saltzman

The owner is Thomas F. Laurin, 100 West Street, PO Box 4949, Pittsfield, MA 01202-4949.

Known bondholders, mortgagees, and other security holders owning or holding 1 percent or more of total amount of bonds, mortgages, or other securities: None.

The average number of copies of the publication during the 12 months preceding the date shown above are: Printed – 69,255; paid and/or requested subscription by mail – 43,414; total paid and/or requested circulation – 43,414; free distribution by mail, carrier, or other means, samples, complimentary, and other free copies – 23,883; total nonrequested distribution – 24,539; office use, left over, unaccounted, spoiled after printing – 1,302; requested and paid electronic copies – 32,927; percent paid and/or requested circulation (both print and electronic copies) – 76%; total above – 100,880. Actual number of copies of single issue published nearest to the filing date: Printed – 62,740; paid and/or requested subscription by mail – 40,982; total paid and/or requested circulation – 40,982; free distribution by mail, carrier, or other means, samples, complimentary and other free copies – 20,460; total nonrequested distribution – 21,260; office use, left over, unaccounted, spoiled after printing – 498; requested and paid electronic copies – 39,022; percent paid and/or requested circulation (both print and electronic copies) – 79%; total above – 101,264.

I certify that the above statements made by me are correct and complete.
Thomas F. Laurin
President

Industry Events

NOVEMBER

ICALEO
(Nov. 4-7) Hollywood, Calif.
Contact the Laser Institute of America, +1 407-380-1553; www.icaleo.org.

EMVA Machine Vision Forum
(Nov. 7-8) Mulhouse, France.
Contact European Machine Vision Association, +34 931-80-70-60, **info@emva.org**; www.emva.org/events/more/european-machine-vision-forum-2024.

SEMICON Europa 2024
(Nov. 12-15) Munich.
Contact SEMI Europe, +49 30-3030-8077-0, **semiconeuropa@semi.org**; www.semiconeuropa.org.

DECEMBER

SEMICON Japan 2024
(Dec. 11-13) Tokyo.
Contact SEMI, +81 3-3222-5755, **semijapan@semi.org**; www.semiconjapan.org/en.

Cell Bio
(Dec. 14-18) San Diego.
Contact ASCB, +1 301-347-9300, **info@ascb.org**; www.ascb.org/cellbio2024.

JANUARY

SPIE BiOS 2025
(Jan. 25-26) San Francisco.
Contact SPIE, +1 360-676-3290, **customerservice@spie.org**; www.spie.org/conferences-and-exhibitions/photonics-west/exhibitions/bios-expo.

SPIE Photonics West 2025
(Jan. 25-30) San Francisco.
Contact SPIE, +1 360-676-3290, **customerservice@spie.org**; www.spie.org/conferences-and-exhibitions/photonics-west.

FEBRUARY

SPIE Medical Imaging
(Feb. 16-20) San Diego.
Contact SPIE, +1 360-676-3290, **customerservice@spie.org**; www.spie.org/conferences-and-exhibitions/medical-imaging.

SEMICON Korea 2025
(Feb. 19-21) Seoul, South Korea.
Contact SEMI, +82 2-531-7800, **semiconkorea@semi.org**; www.semiconkorea.org/en.

PAPERS

ASLMS Annual Conference
(April 24-26) Orlando, Fla.
Deadline: Abstracts, Nov. 4
Contact ASLMS, +1 715-845-9283 / +1 877-258-6028, **information@aslms.org**; www.aslms.org/home.

11th International Conference on Machine Vision and Machine Learning
(Aug. 17-19) Paris.
Deadline: Abstracts, Jan. 23
Contact International ASET Inc., +1-613-834-9999, **info@mvml.org**; www.mvml.org.

MARCH

Pittcon 2025
(March 1-5) Boston.
Contact The Pittsburgh Conference, +1 412-825-3220, **info@pittcon.org**; www.pittcon.org/pittcon-2025.

SPIE Smart Structures + Nondestructive Evaluation
(March 17-20) Vancouver, British Columbia.
Contact SPIE, +1 360-676-3290, **customerservice@spie.org**; www.spie.org/conferences-and-exhibitions/smart-structures-nde.

OFC 2025
(March 30-April 3) San Francisco.
Contact OFC, +1 972-349-7840, **ofc@mcievents.com**; www.ofcconference.org/en-us/home.

APRIL

PIC International Conference
(April 7-9) Brussels.
Contact Angel Business Communications, +44 0-24-76718970, **info@picinternational.net**; www.picinternational.net.

SPIE Defense + Commercial Sensing
(April 13-17) Orlando, Fla.
Contact SPIE, +1 360-676-3290, **customerservice@spie.org**; www.spie.org/conferences-and-exhibitions/defense-and-commercial-sensing.

Optica Biophotonics Congress: Optics in the Life Sciences
(April 20-24) Coronado, Calif.
Contact Optica, +1 202-223-8130, **info@optica.org**; www.optica.org/events/congress/biophotonics_congress.

OPIE
(April 23-25) Yokohama, Japan.
Contact OPIE, **event@optronics.co.jp**; www.opie.jp/en.

ASLMS Annual Conference
(April 24-26) Orlando, Fla.
Contact ASLMS, +1 715-845-9283 / +1 877-258-6028, **information@aslms.org**; www.aslms.org/home.

MAY

CLEO 2025
(May 4-9) Long Beach, Calif.
Contact CLEO, +1 800-766-4672, **info@cleoconference.org**; www.cleoconference.org/home.

Automation UK
(May 7-8) Coventry, England.
Contact Automate UK, +44 (0)20-8773-8111, **sales@automation-uk.co.uk**; www.machinevisionconference.co.uk/seminar-programme.

25th China (Guangzhou) Int'l Laser Equipment and Sheet Metal Industry Exhibition 2025
(May 10-12) Guangzhou, China.
Contact Zheng Lisy, +86 135-7059-8541, **julang@julang.com.cn**; www.julang.com.cn/english/banjin.

Automate
(May 12-15) Detroit.
Contact the Association for Advancing Automation, +1 734-994-6088, **info@automateshow.com**; www.automateshow.com.

EASTEC
(May 13-15) West Springfield, Mass.
Contact SME, +1 800-733-4763; www.easteconline.com.

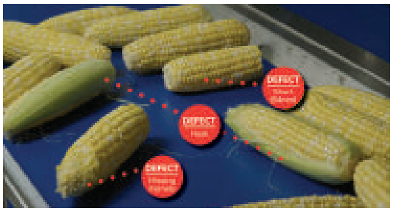
23rd EMVA Business Conference
(May 22-24) Rome.
Contact European Machine Vision Association, +34 93-220-7201, **info@emva.org**; www.emva.org/events/business-conference/23rd-emva-business-conference.

5th Annual Conference on Lasers, Optics, Photonics Sensors, Bio Photonics, Ultrafast Nonlinear Optics & Structured Light 2025
(May 31-June 2) Hollywood Beach, Fla.
Contact Keerthi Rajana, +1 647-952-4467, **support@lopsnews.com**; www.exceleve.com/photonoptics.

Indicates shows **Photonics Media** will be attending.
Complete listings at **www.photonics.com/calendar**.
Submit your event online at **www.photonics.com/eventsubmit**.

PHOTONICS SHOWCASE

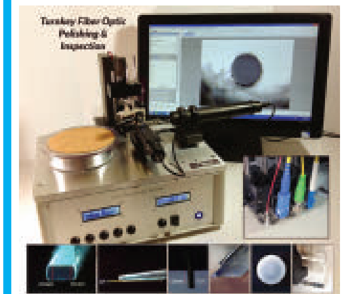
Visual AI for Inspection and Robots



Oxipital AI offers a fully integrated, intuitive visual AI inspection system that provides actionable insights for more resilient, efficient, and sustainable manufacturing in complex, high-variability manufacturing environments, including food processing, agriculture, and consumer packaged goods. User-friendly, web-based setup tools and dashboards take the mystery out of AI, providing your business with insights that you can act on immediately.

Oxipital AI **(617) 391-0612**
info@oxipitalai.com **www.oxipitalai.com**

Cila Fiber Optic Polishing



The Cila Fiber Optic Polishing System offers automated, turnkey, processing/inspection workflows within one flexible and versatile system. The “quick change” work holder allows for a simple transformation from one application to another. The Cila pulls double duty by inspecting and polishing cable assemblies, optical waveguides, bare fibers, and miniature optical components used in biomedical devices.

Clarus Engineering Corp. **(732) 406-3291**
info@clarusengineering.com **www.clarusengineering.com**

P940 Modular Power Solution

Simplify your test bench power requirements with Highland Technology’s compact and economical P940. Mix and match DC and 3-phase AC supplies, loads, alternator simulators, and more in a single 3U chassis with a unified USB and Ethernet interface with programmable monitor outputs. Featuring front panel GUI and waveform monitor outputs, synchronized multi-module control, SCPI, and fast UDP monitoring.

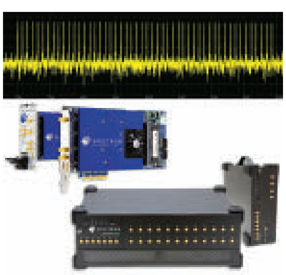
Highland Technology Inc. **(415) 551-1700**
sales@highlandtechnology.com **www.highlandtechnology.com**

Mid-IR Laser Pointer

The QCL Laser Pointer is compact laser system embedding a QCL or ICL laser encapsulated into a laser housing, a coaligned visible laser, a laser driver and a temperature controller, making it an all-in-one complete laser source with simple on/off operation with either a push-button or in remotely controlled operation. Key applications include Mid-IR/Visible Target Pointer or Alignment Beam.

Alpes Lasers **0327299510**
olivier.landry@alpeslasers.ch **www.alpeslasers.ch**

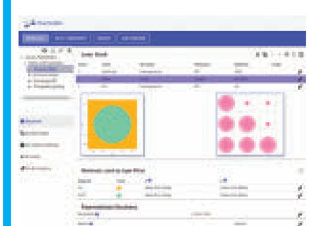
DDS Generators with 50 Tones



Spectrum Instrumentation launched a family of DDS Instruments which generate up to 50 sine wave carriers on one single output channel. This feature provides a new way for engineers and scientists to produce and independently control multi-tone sine signals. The 12 new models provide fine frequency resolution and ultrafast switching of only 6.4 ns between output frequencies up to 200 MHz.

Spectrum Instrumentation **(201) 562-1999**
sales@spectrum-instrumentation.com **www.spectrum-instrumentation.com**

Expert Meta Optics Design Software



PlanOpSim is a multiscale simulation software with an integrated workflow from the nano to the system level, created by a team dedicated to Meta Optics. It produces the GDS necessary for manufacturing in a easy to use interface. Powerful unique features such as Overlapping Domain, Optimization, a Software Development Kit (scripting) are available and enable rapid, accurate, large area designs to unlock maximum potential for your optical system.

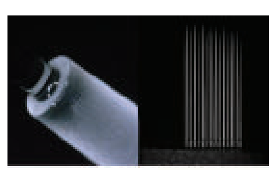
PlanOpSim **+32 496-68-72-20**
jonas.vandewalle@planopsim.com **www.planopsim.com/software**

Circular Variable ND Filters

Custom Circular Variable Neutral Density (CVND) filters change light intensity from 100% to less than 0.1%. Densities are supplied 0 to 1, 2, 3, 4, or 5 as a standard linear or customized gradient function, which can range from 45° to 360° of rotation. Features include laser and broadband coatings, substrates from 1- to 8-in. diameters, and functional wavelength from the UV to the far IR.

Reynard Corp.
(949) 366-8866
sales@reynardcorp.com
www.reynardcorp.com

The NYFORS SMARTSPLICER



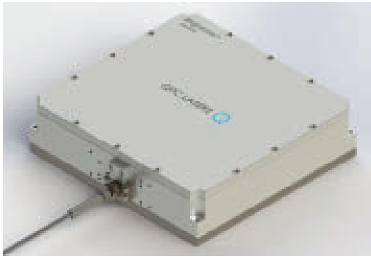
NYFORS

The NYFORS SMARTSPLICER offers CO_2 laser glass-processing capabilities designed to produce high-power and sensitive photonic components and complex structures. It offers contamination-free fiber array splicing, ball lensing, end-capping, and many other challenging processes. NYFORS also provides automated high-precision solutions for fiber preparation, such as stripping, cleaving, recoating, and end-face analyzing. NYFORS also offers custom workcell automation solutions.

NYFORS **+46 8712-1021**
sales@nyfors.com **www.nyfors.com**

PHOTONICS SHOWCASE

1726-nm Acne Therapy Lasers



QPC Lasers offers fiber-coupled, highly reliable laser OEM modules with optimal performance for acne treatment. Features include powers to 100 W, Brightlock® spectral locking ensuring narrow, stable output at the 1726 nm line, internal power and wavelength monitoring sensors, as well as visible pilot beams and protective blast shields.

QPC Lasers Inc. **(818) 986-0000**
info@qpclasers.com **www.qpclasers.com**

Max Performance Flash Lamps

Hamamatsu's 2 W xenon flash lamp modules are built with a power supply and trigger socket, creating a design that extracts maximum performance from the lamp. Available in a housing that is the smallest size among comparable products, these modules integrate easily into portable analytical instruments for spectroscopy, water quality analysis, air pollution analysis, imaging cytometry, and so much more.

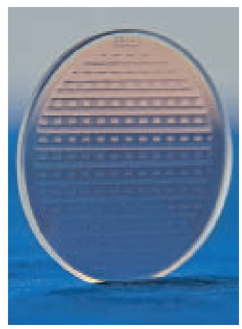
Hamamatsu **(908) 231-0960**
photonics@hamamatsu.com **bit.ly/4ek6weT**

MadAFM™ Sample Scanning AFM

The MadAFM™ is a new multi-modal sample scanning AFM. Simple to install with compact table top design. Includes Mad City Labs picometer precision nanopositioning systems to give outstanding AFM performance. User friendly AFMView® software features automated calibration and initialization. MadAFM™ is compatible with MountainsSPIP® and Gwyddion analysis software.

Mad City Labs Inc. **(608) 298-0855**
sales@madcitylabs.com **www.madcitylabs.com/madafm.html**

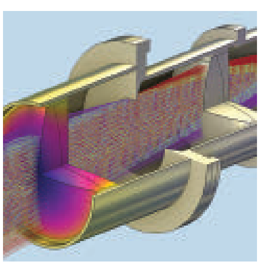
Tailshaper



PowerPhotonic's Tailshaper optic allows EV laser welding to be optimised by beam shaping. It redistributes intensity and changes the shape of the laser profile, improving stability and controlling the melt-pool thermal characteristics at the weld spot, as well as in pre and post weld regions. Consequently, weld strength and efficiency are improved. Spatter is also reduced leading to improved safety of EV batteries and fuel cell weld processes.

PowerPhotonic Ltd
+441383825910
sales@powerphotonic.com
www.powerphotonic.com

Multiphysics Modeling and Simulation



COMSOL Multiphysics® is a software environment for creating physics-based models and standalone simulation apps. Add-on products provide specialized functionality for electromagnetics, structural, acoustics, fluid flow, heat transfer, and chemical simulations. Interfacing products offer a unified workflow with all major technical computing and CAD tools. COMSOL Compiler™ and COMSOL Server™ are used for deploying simulation applications to colleagues and customers.

COMSOL Inc. **(781) 273-3322**
info@comsol.com **www.comsol.com/products**

Liquid Light Guides

Liquid Light Guides are flexible, unbreakable, and very durable, and they have significantly better transmission, more homogeneous illumination, and a larger aperture than fiber bundles at lower costs! They are the perfect solutions for applications that demand uniform, high-intensity light. We offer four different series designed for diverse spectra ranging from ultraviolet to infrared and a broad selection of end fittings.

Lumatec GmbH **+49 89-742822-0**
sales@lumatec.de **www.lumatec.de**

Advanced Optical Coatings

PFG Precision Optics offers advanced optical coatings, both as a service and as part of complete custom optics fabrication. Coating offerings include AR, HR, and beam-splitting designs. With over 40 years of expertise, PFG provides coating solutions for the semiconductor, defense, research, and advanced metrology industries, ensuring precision and reliability at the highest levels. Prototype through production in the USA.

PFG Precision Optics Inc. **(228) 875-0165**
sales@pfgoptics.com **www.pfgoptics.com**

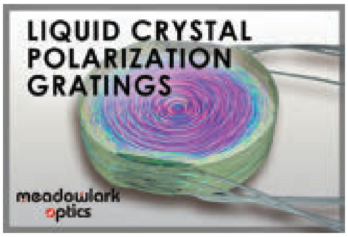
Laser Safety Glasses

HHV AT's innovative multilayer thin-film coated Laser Safety Glasses protect users from Class 3B And Class 4 harmful lasers. High optical densities up to OD7+ for enhanced laser protection. All of the laser-coated glasses are EN208 compliant. Coatings can be done on BOROFLOAT-33 and optical filter glass from 400- to 1100-nm wavelength range. Customized shapes of glasses can be done.

HHV Advanced Technologies Pvt. Ltd. **+91 80-67003700**
infotfod@hhvadvancedtech.com **www.hhvadvancedtech.com**

PHOTONICS SHOWCASE

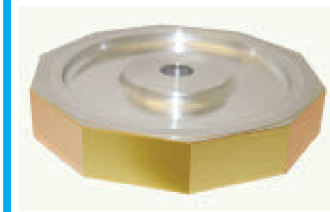
Liquid Crystal Polarization Gratings



Liquid crystal polarization gratings (LCPGs) are diffractive elements that provide near-100% diffraction for circularly polarized light. When layered with thin polarization-controlling liquid crystal elements, LCPGs provide a means of nonmechanically reconfiguring light into different states, such as for beam steering or focusing. Using LCPGs in nonmechanical beam steering is a novel technique and Meadowlark has the patent on this approach.

Meadowlark Optics Inc. **(303) 833-4333**
sales@meadowlark.com **www.meadowlark.com**

Scanner Wheels



NiPro Manufactures Precision mirrors of all types and sizes but is also a supplier of precision scanner wheels of any prototype or production quantity. All scanners are produced using Precitech, 4-axis diamond flycutting machines, Taylor Hobson automated autocollimator, 4D interferometer and a Zygo Z gauge. The finish is routinely measured at 5nm's, flatness at 1/4 wave, positioning accuracy of +/− 0.1 arcseconds and tilt less than 20 arcseconds.

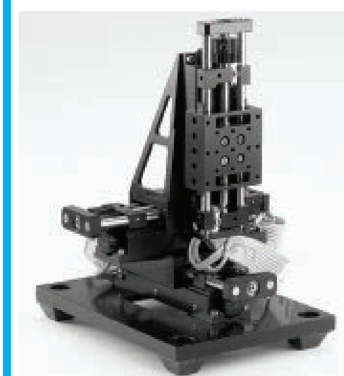
NiPro Optics **(949) 215-1151**
sales@niprooptics.com **www.niprooptics.com**

Hyperfine One Spectrometer

Compact 250 — 1000nm spectrometer with 1nm resolution at all wavelengths Leveraging LightMachinery's world class design and manufacturing for higher sensitivity Onboard image processing and serial data output with a easy to use user interface The right choice whenever a brighter, faster, or wider spectrum is required. The wide range and high sensitivity enable high speed process control for spectroscopic measurements from UV to NIR

LightMachinery Inc. **(613) 749-4895**
gsenechal@lightmachinery.com **www.lightmachinery.com**

MM-3M-F Translation Stage



The MM-3M-F-XX is our most popular stage, available with an anti-backlash, in speeds from 0.1033 mm/s to 25 mm/s, with resolutions from 1 µm to 100 nm per encoder count. Available in 1-, 2-, or 3-axis configurations and travel from 0.5 to 2.5 in.

National Aperture Inc.
(800) 360-4598
sales@nationalaperture.com
www.nationalaperture.com

World's Broadest Tunable Laser

The SuperK CHROMATUNE fiber laser gives you a gap-free tuning from 400 to 1000 nm. The CHROMATUNE has excellent reliability and a lifetime of thousands of hours. It requires no maintenance or service, no alignment or adjustments. You can trust it to run 24/7. Finally, a laser that is easy to use and lets you focus on your work.

NKT Photonics **+45 4348-3900**
sales@nktphotonics.com **www.nktphotonics.com**

High-Precision OEM Optical Systems

We design, engineer, and produce optics and optomechanical systems, ultra-high precision semiconductor optical sub-systems, medical and scientific instruments, ophthalmic optical sub-systems, digital cinematic projection optics, optical systems for aerospace technologies, military optical systems and consumer sports optics. We are vertically integrated and produce optics and mechanics in-house with over 1M square feet of manufacturing space.

Meopta s.r.o. **+420581241111**
meopta@meopta.com **www.meopta.com**

High-Quality Optical Coatings

Evaporated Coatings Inc. is a professional and experienced resource for your Thin-Film Optical Coating requirements. ECI has been supplying high-precision optical coatings for more than 60 years — from minute biomedical and fiber optic components to defense and aerospace optics. ECI manufactures optical coatings for glass, plastic, molded polymer optics, fiber optic devices, LED lighting components, crystals, and semiconductor materials.

Evaporated Coatings Inc. **(215) 659-3080**
sales@evapcoat.com **www.evaporatedcoatings.com**

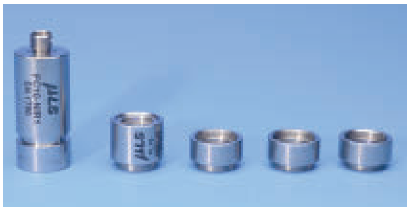
Neo High-End Spectrometer

Admesy's new Neo Series offers a versatile solution for different spectral measurement needs, fit for a wide array of applications. Its well-thought-out optical and mechanical construction assures the highest optical performance, even under tough conditions. Creating an OEM solution? Integrating spectral measurements into your production testing? Needing spectrometer answering to the highest expectations for development applications? Neo is your choice.

Admesy BV **+31 475-600232**
info@admesy.com **www.admesy.com**

PHOTONICS SHOWCASE

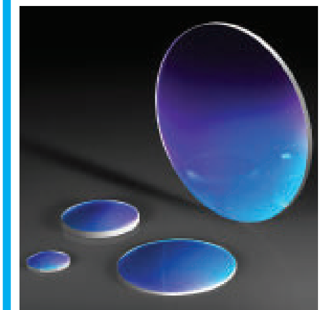
Fiber Focusers and Accessories



Our FC10 Fiber Collimator paired with our Focusing Modules gives micron size spots and eliminates extra optical mounts. From 1:1 imaging of fiber's MFD to longer focal lengths, small spots can be generated from near UV to 2 microns. Besides focusing, polarizers, lines and other optic modules can be attached for a compact optical module. These can be customized for a complete optical assembly and be made very compact.

Micro Laser Systems Inc. **(714) 898-6001**
info@microlaser.com **www.microlaser.com**

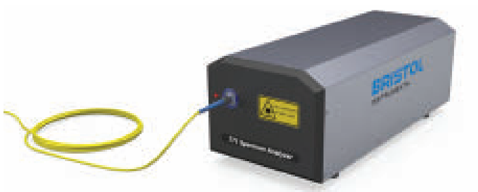
TECHSPEC® Sapphire Windows



TECHSPEC® Sapphire Windows are manufactured from single-crystal sapphire, making them ideal for demanding applications (such as laser systems) because of their extreme surface hardness, high thermal conductivity, high dielectric constant, and resistance to common chemical acids and alkalis. Sapphire windows can be made much thinner than other common windows with improved transmittance due to their structural strength.

Edmund Optics **(800) 363-1992**
techsup@edmundoptics.com **www.edmundoptics.com**

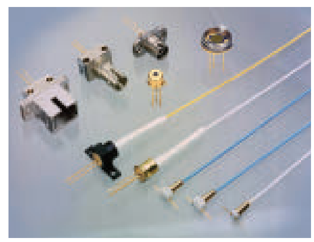
771 Laser Spectrum Analyzer



The model 771 operates as both a high-resolution spectrum analyzer and a high-accuracy wavelength meter. With spectral resolution up to 2 GHz and wavelength accuracy as high as ±0.0001 nm, this system provides the most detailed information about the spectral properties of lasers operating from 375 nm to 12 µm.

Bristol Instruments Inc. **(585) 924-2620**
info@bristol-inst.com **www.bristol-inst.com**

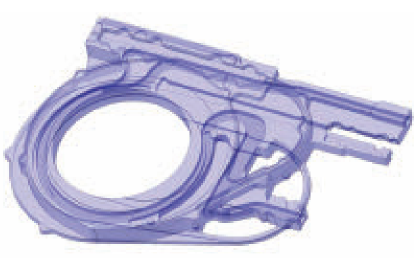
Fermionics InGaAs Photodiodes



Fermionics Opto-Technology provides indium gallium arsenide (InGaAs) photodiodes and InGaAs-related devices. Fabricated with planar-passivated technology, our devices provide superior and reliable performance. High-speed photodiodes are ideal for analog/digital communication systems, instrumentation, and fiber optic sensors. Ask about our large area InGaAs photodiodes with superior responsivity from 800 to 1700 nm for sensing/instrumentation tasks. Our devices are also widely used in various medical applications.

Fermionics Opto-Technology **(805) 582-0155**
ingaas@fermionics.com **www.fermionics.com**

Experienced Precision Brazing!



We have 20+ years machining complicated brazed cold plates with a specialization in aluminum cold plates. We also have experience with copper and stainless steel, as well as machining finned and dip brazed heat exchangers for passive heat exchanger systems.

Lux Manufacturing Inc. **(408) 617-0635**
sales@luxmfg.com **www.luxmfg.com**

Compact 594 nm 100 mW for Bioimaging

HÜBNER Photonics announces the addition of a new orange wavelength on the Cobolt 06-01 Series of modulated lasers. The 06-DPL 594 nm has 100 mW output power and can be directly modulated in either digital or analogue modulation up to 50 kHz, making it ideal for exciting red fluorophores, such as AF594, mCherry, mKate2, that are often used in optogenetics and other bioimaging applications.

HÜBNER Photonics **(408) 708-4351**
sales@hubner-photonics.com **www.hubner-photonics.com**

Advertiser Index

Tell our advertisers you found them in *Photonics Spectra*.

Photonics Media Advertising Contacts

Please visit our website at www.photonics.com/mediakit for all our marketing opportunities.

Canada, Europe, Middle East, & Asia-Pacific
Matthew M. Beebe
Vice President of Sales
Voice: +1 413-499-0514, Ext. 103
Fax: +1 413-443-0472
matt.beebe@photonics.com

Pacific Northwest, Rocky Mountains, CA, HI, MA, & NV
Robert L. Gordon
Account Executive
Voice: +1 413-499-0514, Ext. 207
Fax: +1 413-443-0472
robert.gordon@photonics.com

South Central U.S., Southeastern U.S., Midwest, CT, ME, NH, NJ, NY, PA, RI, & VT
José D. Amor
Account Executive
Voice: +1 413-499-0514, Ext. 108
Fax: +1 413-443-0472
jose.amor@photonics.com

Rebecca L. Pontier
Director of Sales Operations
Voice: +1 413-499-0514, Ext. 112
Fax: +1 413-443-0472
becky.pontier@photonics.com

Reprint Services
Voice: +1 413-499-0514
Fax: +1 413-442-3180
editorial@photonics.com

Mailing Address
Send all contracts, insertion orders, and advertising copy to:
Laurin Publishing
PO Box 4949
Pittsfield, MA 01202-4949

Street Address
Laurin Publishing
100 West Street
Pittsfield, MA 01201
Voice: +1 413-499-0514
Fax: +1 413-443-0472
advertising@photonics.com

Watching as the sun sets on jet lag

Air travel is not for everyone. Whether you're afraid of heights, your wallet can't cover the rising cost of a ticket, or you're too tall to cram yourself into the ever-dwindling confines of a seat, there are many conceivable reasons as to why someone would forgo a trip in a flying aluminum can in favor of four-wheeled travel.

For the brave souls who can look past all of the prerequisite fears of boarding an airplane, and find it in themselves to surrender to their small uncomfortable seat, there may also be the threat of losing sleep that makes flying that much less appealing. Jet lag is rarely inescapable when flying across time zones due to our pesky circadian rhythm telling our bodies when night and daytime should occur.

But what if you could cut off your own biology at the pass?

This was the subject of a recent partnership between the University of Sydney's Charles Perkins Centre, Australian airline Qantas, and industrial design company Caon Design Office. The group tested a lighting method in airplane passenger cabins that mimics the natural lighting of the plane's final destination. The results will be part of a series of Qantas ultra-long-haul flights called Project Sunrise.

The design is the product of more than 150 h of testing in the Airbus Customer Definition Centre in Hamburg, Germany, where representatives from the three entities created and tested hundreds of lighting patterns and sequences in a mock Airbus A350 cabin.

The researchers used light with high melanopic illuminance to simulate different parts of the day. Melanopic illuminance affects circadian rhythms rather than regular old illuminance and dictates how the brain will set its internal clock. The researchers found that blue-enriched light with high melanopic illuminance helps to shift body clocks. Meanwhile, long-wavelength light (such as red light) with low melanopic illuminance does a better job at preventing the clock from shifting in an undesired direction.

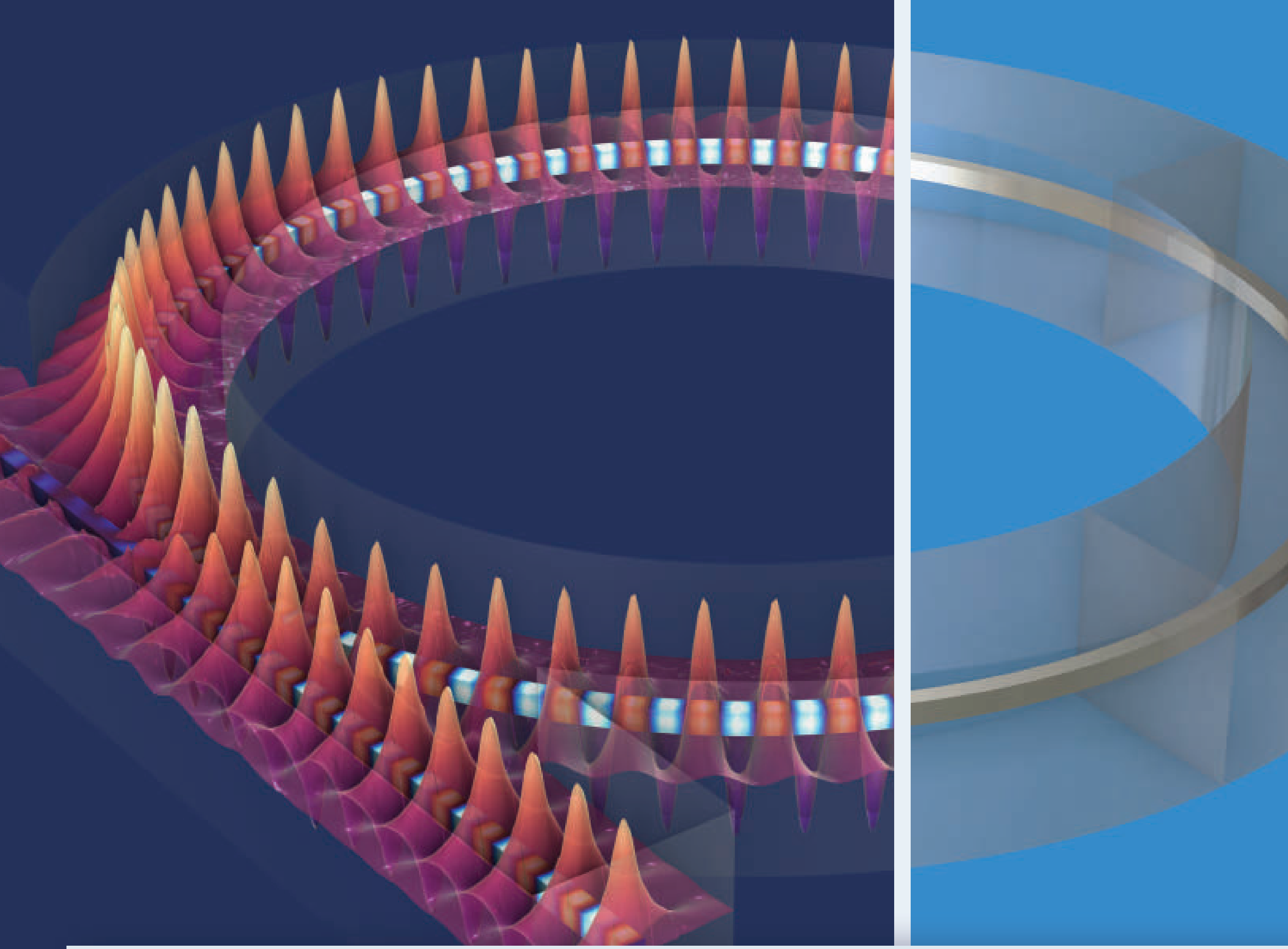
Rounds of trials produced 12 unique lighting scenes for the Project Sunrise flights. They included an "awake" scene that lets passengers adjust to the destination time zone, a "sunset" scene for transitioning passengers from day to night by moving through the colors of a sunset into a night sky with moonlight and slow cloud effects, and a "sunrise" scene featuring the simulation of a sunrise rolling from the front of the cabin to the rear. Unfortunately, there is no scene labeled "happy hour" just yet, but depending on how you like to travel, every air mile can be flown during happy hour.

If the project goes well, we could soon see a new era of comfortable and somewhat immersive travel through the sky. But until then, prepare to be a bit groggy when traveling from Australia to Monaco, Nigeria to Cambodia, or California to Massachusetts. And brace yourself for some sticker shock when you see the price of extra leg room.

iStock.com/frantic00

Qantas

An airplane's cabin with the sunrise setting **(right)**.



PHOTONICS SPECTRA REFERENCE CHART

Since 1986, the *Photonics Spectra* Reference Chart has provided an important at-a-glance industry resource describing the functional spectral windows for common optical materials, detectors, and lasers. Printed copies of the 2024 edition, with or without lamination, are available by ordering online at www.photonics.com/wallchart.

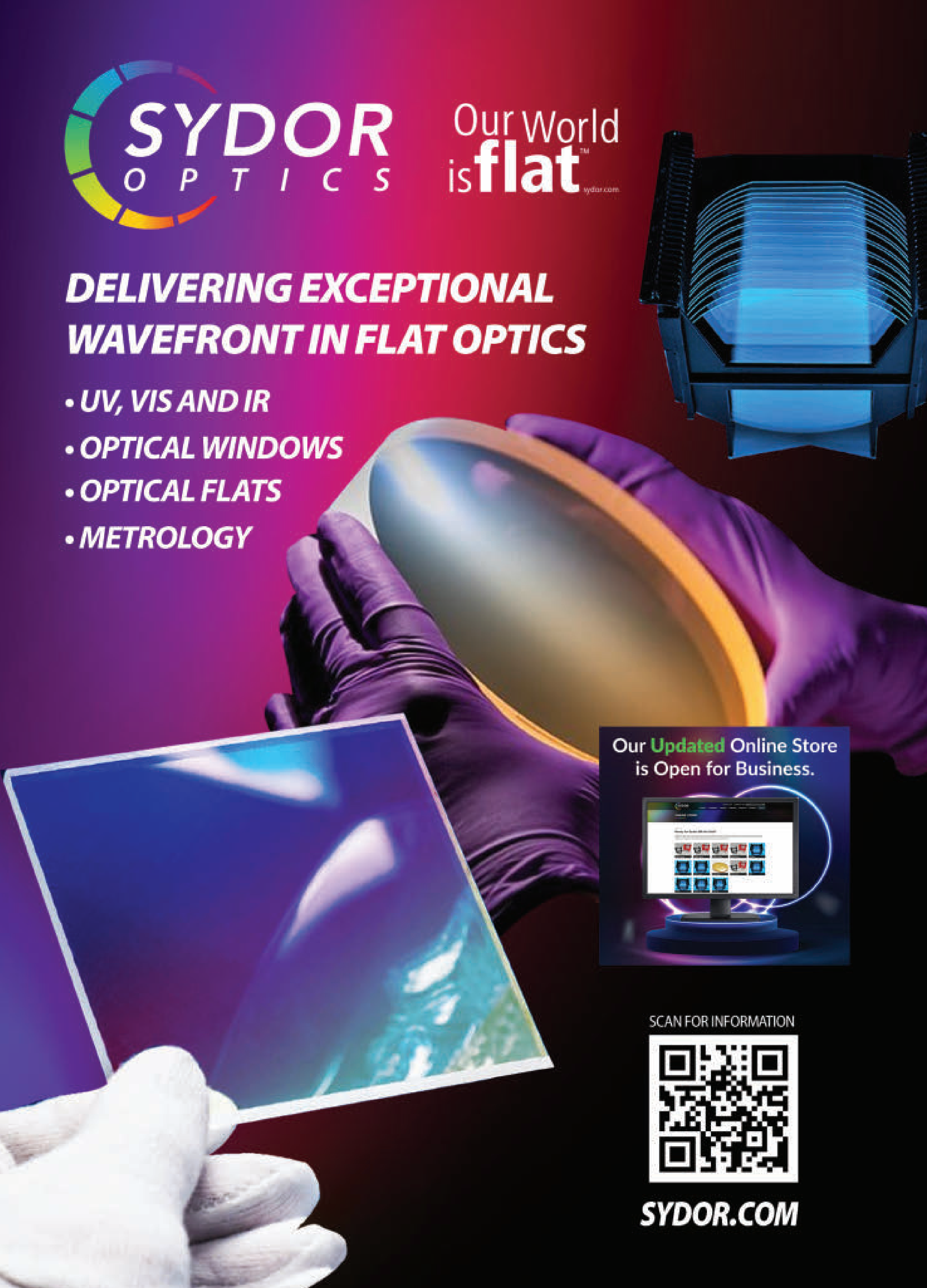
We are deeply grateful for the expert support and guidance from participating reviewers in 2024 and previously in 2021. They include David Hagan, associate dean for academic programs at CREOL, The College of Optics and Photonics at the University of Central Florida; John Ballato, professor of materials science and engineering at Clemson University; Joel Bagwell, senior staff systems engineer at Elbit Systems of America; and a team of experts from Hamamatsu, including Dino Butron, senior applications engineer; Columbine Robinson, applications engineer; and Gary Spingarn, product manager.

The following eight pages are ads from sponsors of the *Photonics Spectra* Reference Chart that appear on the back of the printed version. The sponsors for the 2024 edition are Admesy BV, Chroma Technology Corp., LightMachinery Inc., LightPath Technologies Inc., MKS/Newport, Optimax Systems Inc., QED Technologies, and Sydor Optics Inc.

Presented By

PHOTONICS MEDIA

Laurin Publishing
100 West Street, PO Box 4949, Pittsfield, MA 01202-4949, USA
Phone: +1 413-499-0514 • Fax: +1 413-442-3180
Email: info@photonics.com • Web: www.photonics.com


SYDOR
OPTICS
Our World is flat™
sydor.com
DELIVERING EXCEPTIONAL WAVEFRONT IN FLAT OPTICS
• UV, VIS AND IR
• OPTICAL WINDOWS
• OPTICAL FLATS
• METROLOGY
Our Updated Online Store is Open for Business.
SCAN FOR INFORMATION
SYDOR.COM