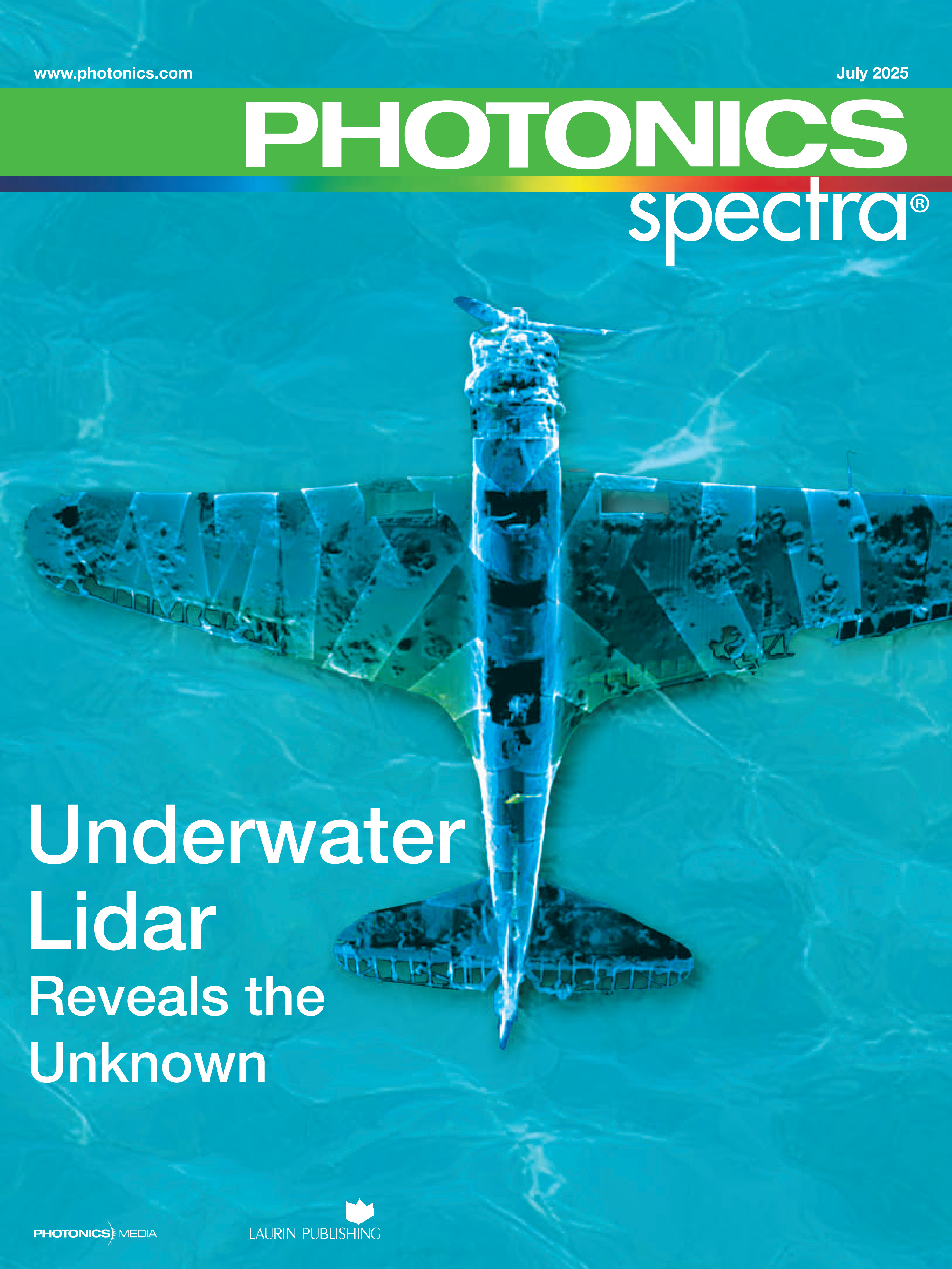
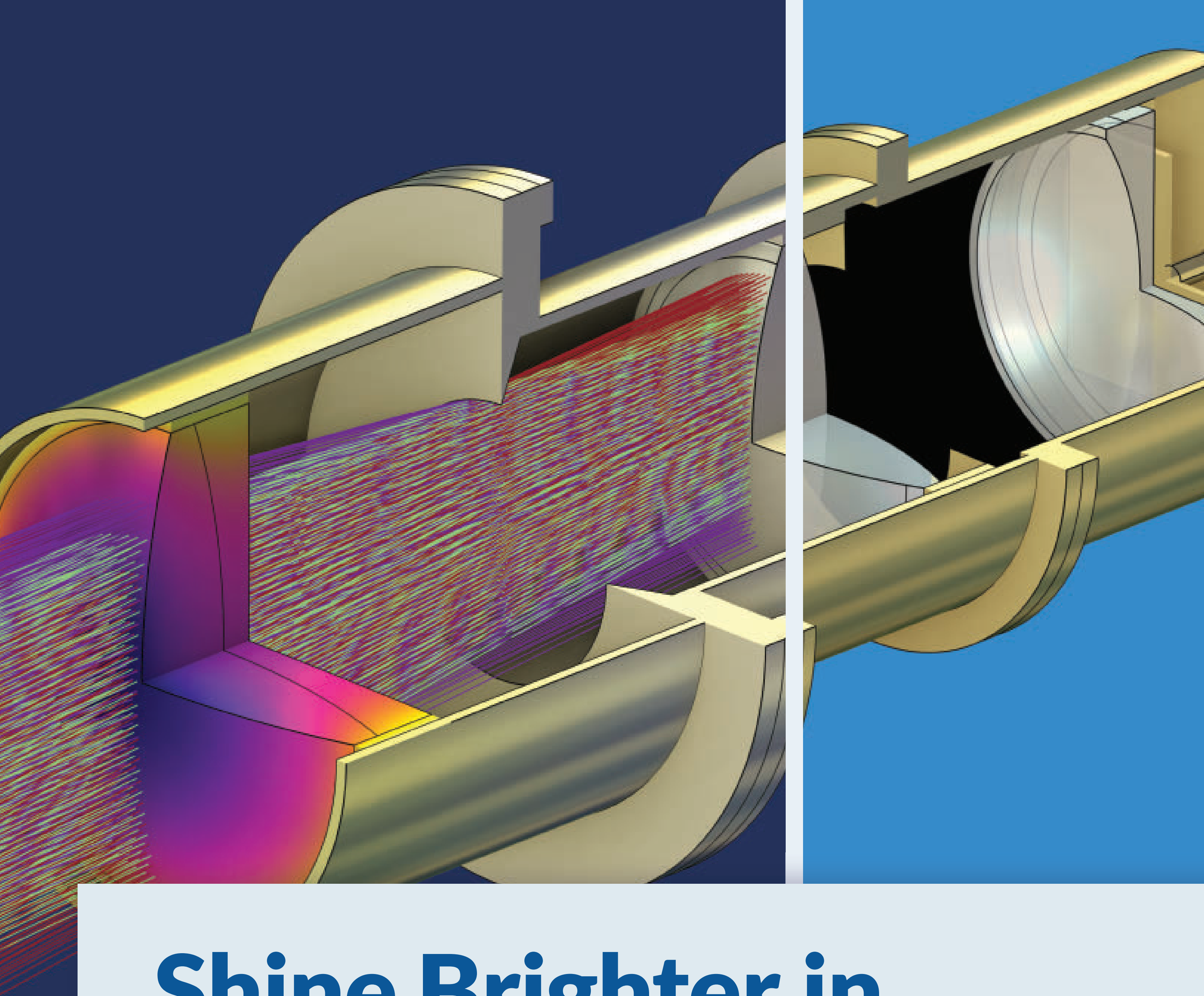
www.photonics.com
July 2025

PHOTONICS spectra®

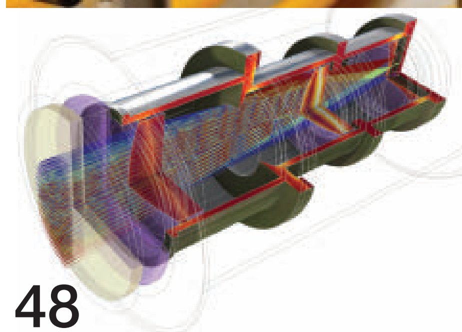


Underwater Lidar
Reveals the Unknown

PHOTONICS MEDIA
LAURIN PUBLISHING



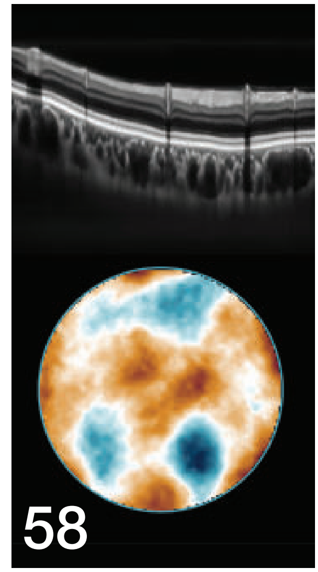
Features



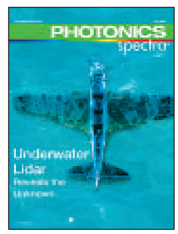
PHOTONICS SPECTRA ISSN-0731-1230, (USPS 448870) IS PUBLISHED MONTHLY BY Laurin Publishing Co. Inc., 100 West Street, PO Box 4949, Pittsfield, MA 01202, +1 413-499-0514; fax: +1 413-442-3180; email: photonics@photonics.com. TITLE reg. in U.S. Library of Congress. Copyright ® 2025 by Laurin Publishing 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

3D at Depth's subsea lidar system scans an underwater airplane. See page 42. Courtesy of 3D at Depth.
Cover design by Senior Art Director Lisa N. Comstock.

PHOTONICS spectra®

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

Editorial Staff

Group Publisher Erik W. Laurin
Managing Editor Jake E. Saltzman
Senior Editors Douglas J. Farmer
Joseph T. Kuczynski
News Editor Joel P. Williams
Departments Editor Dominic V. Acquista
Multimedia Editor Jacob H. Mendel
Chief Copy Editor Carol A. McKenna
Senior Copy Editor Carolyn G. Kenney
Events Coordinator Haley N. Sherman
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
***Vision Spectra* Art Director & Creative Designer** Devon A. Unwin
Digital Designer Brian W. Healey

Corporate Staff

President/CEO Thomas F. Laurin
Vice President Kristina A. Laurin
Vice President Erik W. Laurin
Chief Revenue Officer Matthew M. Beebe
Internal Audit Officer Mollie M. Armstrong
Controller Erika L. Boyce
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

Editor's Note

Lidar dips below sea level

In the U.S. alone, dozens of firms entered the 2020s with plans to capture share of the lidar market. Almost immediately, the large number of competing companies — many offering similar technology, and many targeting automotive applications — prompted rumors of impending market consolidation. By 2021, at least for those of us observing the market from the sidelines, these rumors had become an expectation.

The consolidation that many anticipated has started to take shape. Ouster's purchase of Sense Photonics in 2021 preceded its merger with Velodyne, which the companies closed in 2023. Koito finalized the acquisition of its longtime collaborator, Cepton, early this year. Additional companies active in the development and manufacture of lidar technologies, including MicroVision, FARO Technologies, and indie Semiconductor, have completed acquisitions of their own.

Other disruptors have emerged in the lidar sector, particularly among some of its major players. Luminar, cofounded by billionaire entrepreneur Austin Russell and photonics luminary Jason Eichenholz, went public in December 2020 and emerged as a darling of the industry. But financial challenges and sluggish growth in autonomous vehicles plagued the company. Luminar was in the news this spring when Russell resigned following a code of business conduct and ethics inquiry. Eichenholz had left previously to serve as cofounder and CEO of optical fiber startup Relativity Networks.

It is easy to allow the turbulence that gripped the lidar industry in the first half of this decade to overshadow the progress in the technology space. And while commercial technology does not exist in a vacuum, the lidar market is ripe with opportunity. Fortune Business Insights valued the global lidar market at $2.6 billion in 2024. It projects this value to reach $9.7 billion by 2032, exhibiting a compound annual growth rate of 18.2% during the forecast period. Much of this growth is owed to sustained innovation in R&D.

Still, lidar is an anomaly of a technology. The nature of its connection with automotive applications — specifically, self-driving cars — makes lidar ubiquitous as an application that has yet to mature, yet a key enabler to a host of others that are more established.

Some of these more established applications, explored by contributing editor James Schlett in the cover story on page 42, take place underwater. Companies such as Leica Geosystems, 3D at Depth, and Teledyne Optech are breathing life into maritime and subsea detections. Bathymetric lidar is the underlying technology for these deployments.

Mapping the ocean floor may not generate the same widespread intrigue as autonomous driving, but the fact that both applications rely on the same fundamental method highlights the impressive versatility and durability of the technology.

jake.saltzman@photonics.com

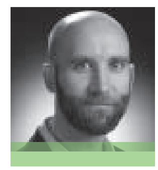
PHOTONICS spectra®

Contributors

Erik Beckert
Erik Beckert earned his diploma in precision engineering and a doctorate in optoelectronics system integration from TU Ilmenau, Germany. He heads the Opto-Mechatronical Components and Systems department at Fraunhofer IOF in Jena, Germany. Page 32.

James Schlett
Contributing editor James Schlett is an award-winning author, poet, and journalist. He is the former editor of *BioPhotonics*. Page 42.

Mark Crowley
Mark Crowley, Ph.D., is the director of device technology at Leonardo Electronics US Inc. He has more than 20 years of fundamental research, product development, and technology management experience in the field of semiconductor devices. Page 53.



Andrew Strikwerda
Andrew Strikwerda is a lead application engineer at COMSOL, specializing in electromagnetics. He served as a senior staff scientist at the Johns Hopkins University Applied Physics Laboratory, and conducted postgraduate research at DTU (Denmark). Page 48.

Marie Freebody
Contributing editor Marie Freebody is a freelance science and technology journalist with a master's degree in physics from the University of Surrey in England. Page 36.

Prabhu Thiagarajan
Prabhu Thiagarajan, Ph.D., is senior vice president at Leonardo Electronics US Inc. He manages the Laser Solutions business line, has more than 30 years of experience in the laser industry, and has authored more than 50 publications. Page 53.

Nicolaie Pavel
Nicolaie Pavel is a senior researcher at the National Institute for Laser, Plasma and Radiation Physics, Măgurele, Romania. He earned a doctorate in optics, spectroscopy, and lasers from the Institute of Atomic Physics, Bucharest, Romania. Page 32.

Andreas Thoss
Andreas Thoss, Ph.D., is a laser physicist, founder of THOSS Media, and 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 32.

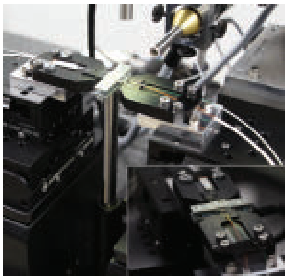
Jérémy Picot-Clémente
Jérémy Picot-Clémente oversees developments in optics, micro-optics, and all related technologies and applications at EPIC. He has a strong interest in photonics technologies as they apply to AR/VR, lidar, 3D sensing, and more. Page 58.

Photonics Spectra Webinars

View Webinars on Demand

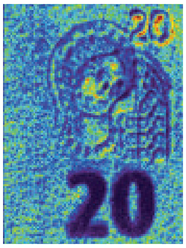
On-demand webinars are free to Photonics.com registered members. Watch informative seminars presented by experts in the field, at a time that is convenient for you! To view webinars on demand and to see the Photonics Media upcoming webinar listings, visit **www.photonics.com/webinars**.

How to Select a Precision Automation System for High-Volume Optical Alignment



Achieving submicron positioning in optical alignment applications is critical in the production of optical components and systems used in the consumer electronics, automotive, and defense industries. Precision motion control solutions, including direct-drive stages and hexapods, play a key role in optimizing active alignment processes and ensuring quality through repeatable results. This webinar will provide a technical overview of six-degrees-of-freedom positioning system architectures and their effect on alignment quality. It will examine the role of active alignment algorithms and control systems on alignment quality and repeatability. Additionally, it will examine real-world case studies that highlight trade-offs between different motion control technologies and demonstrate strategies for maximizing throughput while maintaining alignment integrity.
Presented by Aerotech.
To view, visit **www.photonics.com/w1172**.

Terahertz TDS: The Pulse Driving Industrial Innovation



This webinar will cover the fundamental principles of terahertz time-domain spectroscopy (TDS) while showcasing the latest advancements in Menlo Systems' cutting-edge solutions, now featuring up to 4× more terahertz power, 5× faster scanning, and improved detection capabilities with a dynamic range of up to 110 dB and a bandwidth of up to 6.5 THz. Learn how terahertz TDS complements traditional nondestructive testing techniques such as near-infrared spectroscopy, x-ray imaging, and ultrasonic testing. Prince Bawuah, Ph.D., will explore practical applications in pharmaceutical manufacturing, semiconductor testing, coatings inspection, ceramics assessment, and electric vehicle battery electrode analysis, among others. Attendees will gain actionable insights into how terahertz TDS helps to reduce operational costs, enhance product quality, and optimize industrial processes.
Presented by Menlo Systems.
To view, visit **www.photonics.com/w1179**.

PHOTONICS spectra

SUMMIT

Optical Design Summit

JMO Illumination Optics

Muschaweck.

LightPath Technologies

Huddleston.

Synopsys

Novak.

LightTrans International GmbH

Wyrowski.

The editors of *Photonics Spectra* magazine invite you to the Optical Design Summit, a one-day virtual event focused on solving real-world optical challenges. The event takes place on August 13, and all presentations remain available on demand after the premiere.

Join industry professionals from JMO Illumination Optics, LightPath Technologies, Synopsys, LightTrans International, and others for strategies to meet today's optical design demands — from material breakthroughs in IR imaging and radiometric modeling, to performance-driven lens design for near-eye displays. Viewers will also have the chance to explore the complexities of multiscale simulation through a case study on metalenses.

Registration is free and includes access to every session, networking opportunities, and actionable insights to strengthen your design capabilities and product performance.

Website

To learn more about the program and to register, visit **www.photonics.com/ODS2025**.

Illumination Calculus in Imaging Optics
Julius Muschaweck, JMO Illumination Optics

Advancing IR Lens Design:
New Materials for Low-SWaP Imaging
Jeremy Huddleston, LightPath Technologies

Accelerating Optical Solutions for Near-Eye Display Systems
Matt Novak, Synopsys

The Challenge of Multiscale Simulation:
A Case Study on Metalenses
Frank Wyrowski, LightTrans International GmbH

Upcoming Summits

Micromachining — *September 17*

Quantum — *November 19*

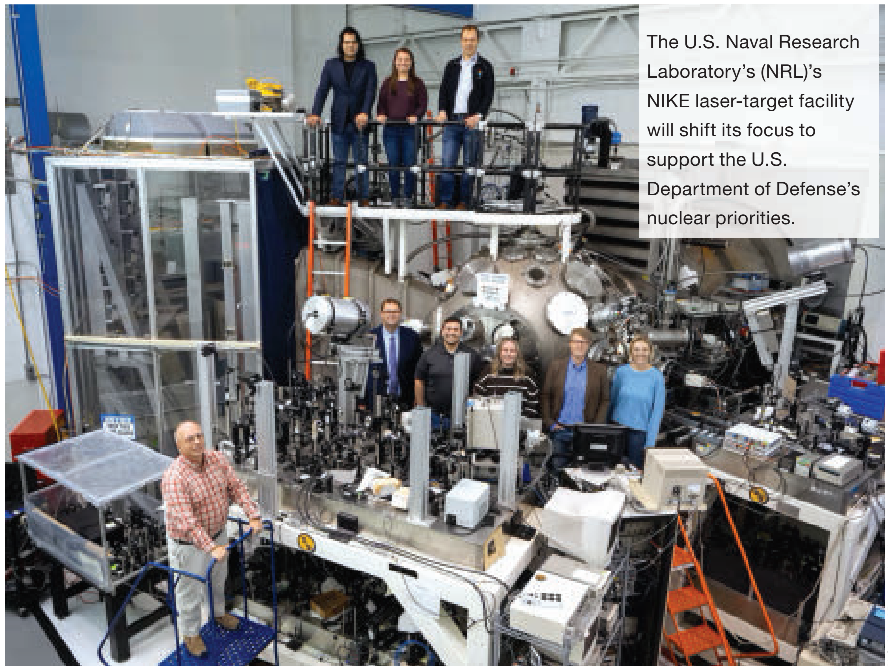
Inspection — *December 10*

Register today at
www.photonics.com/ODS2025.

US Military to use NIKE laser for nuclear deterrence efforts

The U.S. Naval Research Laboratory (NRL) will reprioritize the uses of its NIKE laser-target facility. The NRL is realigning the 30-year-old krypton-fluoride excimer laser's capabilities with the U.S. Department of Defense's nuclear priorities. The decision marks a shift from the facility's historic focus on Department of Energy missions, specifically those related to the National Nuclear Security Administration.

The NIKE laser was designed to explore the physics of direct-drive inertial confinement fusion in support of the nation's nuclear stockpile stewardship mission. The laser, housed at the NRL in Washington, D.C., delivers pulsed beams at a wavelength of 248 nm with 2 to 3 kJ of energy. "These unique capabilities enable researchers to generate strong, stable shock waves and create exceptionally clean experimental conditions for studying extreme physical states of



The U.S. Naval Research Laboratory's (NRL)'s NIKE laser-target facility will shift its focus to support the U.S. Department of Defense's nuclear priorities.

U.S. Naval Research Laboratory

This month in history

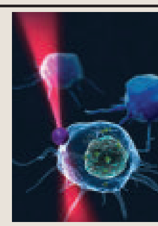
What were you working on five, 10, 20, or even 30 years ago? *Photonics Spectra* editors have perused past July issues and unearthed the following:

1995

A dual-band infrared imaging system developed at Lawrence Livermore National Laboratory to detect landmines was considered for retasking as a tool to detect potential civilian hazards, such as hidden cracks in roadbeds. Called dual-band infrared computed tomography, the technique located defects in materials by sensing temperature differences caused by faults.

2005

Scientists from Lawrence Berkeley National Laboratory completed a full-scale demonstration of a noncontact laser ultrasound sensor designed to inspect moving sheet material, such as paper. The system calculated two elastic properties of the paper from the measured propagation of laser-induced shock waves through it.



2015

Researchers at the Korea Advanced Institute of Science and Technology developed an optical diffraction tomography technique to measure the positions of optically trapped particles in 3D at high speed. Compared with traditional optical tweezers, the method provided a more streamlined and precise way to locate and move microscopic particles.

2020

Researchers from the Paul Scherrer Institute discovered a green luminescent substance containing the copper-based compound CuPCP that they believed could enable OLEDs to deliver high light yields inexpensively and on a large scale.

matter," said Jason Bates, head of NRL's Laser Plasma branch.

For decades, the NIKE facility and its scientific team contributed to the National Nuclear Security Administration's flagship laser program at the National Ignition Facility. Now, through the work of its research team and a partnership with the U.S. Air Force, NIKE's capabilities are addressing the central science and technology needs of the Department of Defense's nuclear deterrence mission.

"This partnership between NRL and the Air Force Research Laboratory represents a vital leap forward in our ability to simulate and understand the extreme environments that nuclear assets must navigate," Bates said.

With China and Russia working to build similar excimer laser technologies, a recapitalization and reinvestment strategy is underway to secure NIKE's future and support the revitalization of the U.S.'s nuclear deterrence capability.

"NRL's NIKE facility is an important national asset with unique capabilities that allow it to serve a broad range of missions supporting stockpile stewardship, fusion energy research, directed energy, hypersonics, and fundamental studies of materials at extreme conditions," said Joe Peñano, superintendent of NRL's Plasma Physics division. "Its continued operation for the good of the nation remains our goal through its new focus."

Briefs

MKS Inc. broke ground on its **Atotech** chemical manufacturing and TechCenter facility in Bangkok. The facility has a production capacity of 18,500 tons per year and is supported by an investment of more than $40 million. MKS expects the operations to begin in the second half of 2027. The facility supports regional collaboration with Thailand's growing printed circuit board industry and semiconductor advanced packaging sectors, the company said. MKS closed on its $4.4 billion acquisition of Atotech, a process chemical technology company, in August 2022.

Imec and **TNO** jointly opened the **Holst Centre Photonics Lab at High Tech Campus Eindhoven**. The laboratory is partially funded by **PhotonDelta** and dedicated to integrated photonics research and development in the Netherlands. It aims to bridge the gap between innovation and industrialization for applications in sectors such as automotive, health care, and data communications.

V-Optics, a provider of optical defect detection products, entered into a partnership with wavefront sensors company **Optocraft** and metrology company **Micro-Epsilon** to create a metrology portfolio for the contact lens, intraocular lens, and eyeglass industries. The partnership enables V-Optics to add a measurement modality to Optocraft and Micro-Epsilon's product ranges.

Laird Thermal Systems rebranded as **Tark Thermal Solutions**, following the expiration of a licensing agreement of the Laird brand name. Tark Thermal Solutions' portfolio will continue to include thermoelectric coolers and assemblies, temperature controllers, specialty pumps, and liquid cooling systems, among other solutions. While operating as Laird Thermal Systems, the company acquired Tark Inc., a supplier of pumps and cooling solutions for the medical and industrial computed tomography and x-ray tube industry, in July 2024. Additionally, the company appointed Max Kley CEO in April.

The **U.S. Navy** awarded a contract to additive manufacturing solutions supplier **EOS** to support the Navy's Maritime Industrial Base (MIB) initiative. The initiative provides end-to-end laser powder bed fusion process training for MIB suppliers. The training program, which started in May, combines online coursework with hands-on experience to equip these suppliers with skills in additive manufacturing software, laser powder bed fusion system operation, and more.

Aerospace and defense corporation **Safran** invested in **mirSense**, a French developer and manufacturer of quantum cascade lasers, through its **Safran Corporate Ventures** investment subsidiary. Safran made the investment as part of a total funding round of €7 million (approximately $8 million). The investment supports the development of advanced technologies to enhance the performance of Safran's optronics products used for military applications and miniaturized gas sensor solutions.

PI (**Physik Instrumente**) is building a production facility in Shrewsbury, Mass. The 140,000-sq-ft facility will triple the combined space of PI's current locations in Auburn, Mass., Hopkinton, Mass., and Nashua, N.H. The facility is scheduled to commence operations in fall 2025.

Quantum dot technology company **UbiQD** closed a $20 million series B financing round. The company plans to use the funds to scale up manufacturing, expand R&D capabilities, strengthen intellectual property, enhance marketing efforts, and support working capital needs. UbiQD's quantum dot technology enhances efficiency, durability, and sustainability of fluorescence for applications including greenhouse agriculture, solar energy, and security. UbiQD acquired perovskite materials company Blue Dot Photonics earlier this year.

AI supercomputers and quantum computing systems designer **ParTec AG**, a designer of AI supercomputers and quantum computing systems, entered into a partnership with photonic quantum computing company **ORCA Computing**. As part of the partnership, ParTec will integrate ORCA's photonic quantum computing capabilities into its AI factory infrastructure.

Vuzix Corp., a supplier of AI-powered smart glasses and waveguides, and **Fraunhofer Institute for Photonic Microsystems IPMS** (**Fraunhofer IPMS**) entered into a collaboration to develop a custom micro-LED backplane. The collaboration has led to the initial sample production of a high-performance micro-LED CMOS backplane that supports 1080P+ resolution, enabling both monochrome and full-color micrometer-size micro-LED arrays. According to the organizations, the first working samples were tested using OLED technology and validated the design's potential for advanced display applications.

Photona Group, the parent company to **LASER COMPONENTS**, acquired 100% of the shares in **FOC&T GmbH**, a fiber technology manufacturer. Per the acquisition, Lars Mechold, authorized signatory and technical director at LASER COMPONENTS Germany, will become managing director of

ams OSRAM in talks to sell part of its business

ams OSRAM announced during its first-quarter 2025 earnings call that it is exploring a sale of a portion of its business. As of press time, the company said that it is discussing whether to sell its unspecified assets, with the aim of generating more than €500 million ($565 million) in capital to reduce the company's debt.

According to the company's CFO, Rainer Irle, the LED semiconductor and sensor technology developer and manufacturer is looking at several options and speaking with potential buyers. These discussions will determine which portion of the business will be sold, Irle said.

"It is clear that if you want to get proceeds north of €500 million that you have to also sell something that is valuable," company CEO Aldo Kemper said during the first-quarter earnings call. "So, in that sense, depending on what direction we finally take, there will be potentially quite

FOC&T GmbH, taking over for founder and executive director Anton Pautz, who is retiring.

Aston University in Birmingham, England, established the **UK Multidisciplinary Centre for Neuromorphic Computing**. The center received £5.6 million ($7.4 million) over four years from the **UKRI Engineering and Physical Sciences Research Council** and aims to support networking and collaboration on fundamental neuromorphic computing research and technology. It will include researchers from the **University of Southampton**, the **University of Oxford**, the **University of Cambridge**, **Queen Mary University of London**, **Loughborough University**, and the **University of Strathclyde**.

Hamamatsu entered into separate strategic partnerships with **PredxBio**, an AI-powered spatial biomarker discovery company, and **Sirona Dx**, a provider of single-cell multi-omics and spatial biology services. With PredxBio, Hamamatsu will create a joint offering that integrates PredxBio's SpaceIQ spatial analytics platform with its MoxiePlex multiplex immunofluorescence imaging system. Through its collaboration with Sirona Dx, Hamamatsu and Sirona will streamline the technology evaluation process by providing customers with access to deep spatial biology expertise within a Good Clinical Laboratory Practice/Clinical Laboratory Improvement Amendments-accredited laboratory for imaging, staining, and bioinformatics analysis.

Artilux, a provider of germanium-silicon (GeSi) photonics technology and a developer of CMOS-based SWIR optical sensing, imaging, and communication, entered into a collaboration with **VisEra Technologies**. The partnership combines Artilux's core GeSi technology with VisEra's advanced CMOS processing capabilities to enable the fabrication of metalenses on a 12-in. silicon substrate. According to the partners, the metalens technology is ready for mass-production and significantly enhances optical system performance, production efficiency, and yield rates, supporting SWIR wavelengths.

Micro-LED-based optical interconnect architecture developer **Avicena** entered into a partnership with **Taiwanese Semiconductor Manufacturing Company** (**TSMC**). The partners aim to optimize photodetector arrays for Avicena's LightBundle interconnect technology.

PVA TePla, a provider of high-tech solutions for materials and measurement technology, acquired **DIVE imaging systems GmbH**, a provider of light microscopy systems for analyzing surfaces and layer thicknesses. The terms of the transaction were not disclosed. DIVE was founded in 2023 as a spinoff of the **Fraunhofer Institute for Material and Beam Technology IWS** (**Fraunhofer IWS**). The company's hyperspectral vision technology, supported by AI, enables precise and nondestructive material analysis of key components for the production of microchips and fuel cells.

Advanced Glass Industries acquired **Glass Fab Inc.** and established its plans to expand its business in Rochester, N.Y., through a $5 million investment partially funded through Empire State Development. The combined company, called **EvolvOptic**, is committed to creating up to 40 new jobs over the next five years.

some meaningful change to the profile of the group."

Early last year, ams OSRAM said that it was reassessing its micro-LED strategy following the unexpected customer cancellation of a cornerstone project. After the project's cancellation, the company said that it would revisit the plan for its assets related to its micro-LED strategy, in particular its 8-in. LED facility in Kulim, Malaysia. The company has since said that it plans to eliminate the facility.

The project cancellation followed an additional restructuring stemming from the implementation of the "Re-establish the Base" strategy, in 2023. The company subsequently exited its noncore portfolio in its semiconductors business and separated from its passive optical components portfolio. ams OSRAM sold the portfolio to Focuslight Technologies last May.

ams OSRAM's existing product line includes automotive and horticultural lighting solutions, LED drivers, photodetectors, and edge- and surface-emitting lasers.

Abrisa Technologies acquires Agama Glass Technologies

HEF Photonics' subsidiary Abrisa Technologies, a provider of custom glass optics and thin-film coatings, acquired Agama Glass Technologies, a manufacturer of etched antiglare glass and technical glass processing. The acquisition, Abrisa said, expands its manufacturing footprint and adds a vertically integrated solution for chemically etched antiglare display glass. Agama's flagship product, AgamaEtch, is used in high-performance display and optics applications.

Agama is based in Clarksburg, W. Va., and operates North America's only high-volume technical glass etching facility, according to Abrisa. The company's 85,000-sq-ft facility also offers precision glass fabrication, chemical strengthening, and silk-screen printing, serving markets such as avionics, defense, medical, industrial, and touchscreen displays. Combined with Abrisa Technologies' and HEF Photonics' thin-film coating and surface engineering capabilities, Agama's offerings will gain greater versatility and scalability, according to the companies.

Agama Glass Technologies will continue to operate under its current name, without undergoing immediate changes to management or operations. Susan Hirst, general manager of Abrisa Industrial Glass, will collaborate closely with Agama's leadership to integrate and enhance its processing capabilities.

The acquisition follows HEF Photonics' purchase of Telic Company, in January, which adds expertise in thin-film deposition, photolithography, and microfabrication for precision optics and microelectromechanical systems applications. These capabilities complement those of Abrisa and Agama by adding micropatterning, wafer-level processing, and cleanroom-based optical component manufacturing to the group's portfolio.

Abrisa Technologies

Agama Glass Technologies provides etched anti-glare glass and technical glass processing technologies. Abrisa, a subsidiary of HEF Photonics, acquired Agama in May.

ZEISS, Alpenglow Biosciences partner on whole-tissue imaging tech

ZEISS partnered with Alpenglow Biosciences, a 3D spatial biology company, to jointly develop an inverted light-sheet microscope and bioinformatics pipeline tailored for clinical applications. The collaboration aims to broaden the adoption of 3D pathology across research, translational, and clinical applications.

"Together, we are introducing an integrated solution for analyzing entire tissue samples and improving reproducibility to meet the evolving needs of both translational research and clinical settings," said Michael Albiez, CEO of ZEISS Research Microscopy Solutions. "This collaboration will enable researchers and clinicians to gain deeper insights into tissue and cellular structures with greater efficiency and precision, ultimately facilitating more personalized and effective treatments."

The partnership will combine ZEISS' engineering expertise and arivis visualization platform with Alpenglow's data processing and AI capabilities. Following imaging, a GPU-accelerated imaging analytics pipeline could enable users to move from tissue to clinically effective insights as quickly as, or faster than, traditional pathology workflows. According to the partner companies, generating 3D images from entire tissues provides opportunities for AI to make individualized treatment predictions for patients.

Jenoptik

Jenoptik's newly completed micro-optics facility in Dresden, Germany. The 11,000-sq-m factory includes 2000 sq m for production in ISO 5 and ISO 3 cleanrooms.

Jenoptik opens Dresden-based micro-optics fab

The Jenoptik Group completed its micro-optics fabrication site in Dresden, Germany, combining all former operations in the city. Representing an investment of just under €100 million ($113.7 million), the 11,000-sq-m factory — which includes 2000 sq m for production in ISO 5 and ISO 3 cleanrooms — employs almost 100 people.

The location also offers expanded production capacities for micro-optics and micro-optical sensors used in systems for semiconductor lithography and inspection and laser material processing. The facility is expected to contribute to the semiconductor ecosystems of Germany and Europe as a whole, as well as to European technological sovereignty, according to Saxony's minister president, Michael Kretschmer.

In addition to Dresden, Jenoptik manufactures high-precision and micro-optics at its sites in Jena and Triptis, Germany; Heerbrugg, Switzerland; Jupiter, Fla., and Huntsville, Ala. The company employs around 4600 people worldwide.

Astrape Networks secures $8.9M

Astrape Networks, a developer of integrated photonics-based optical networks, completed a €7.9 million ($8.9 million) seed round, which includes a €2.5 million grant from the European Innovation Council. Astrape aims to optimize short-distance data network performance, addressing critical performance bottlenecks by introducing dynamic optical bypass possibilities seamlessly into any data center network.

According to the company, its technology enables networks to handle 50% more traffic while requiring fewer servers for the same computational load. It delivers 2× higher utilization rates, expands hop capacity from 0 to 2, and scales to support more than 16 million GPUs/auxiliary processing units per network — all while reducing energy consumption by 60%.

Astrape Networks' Effiniti products use a highly modular design for simple maintenance, upgradability, and adaptability to emerging technologies. The technology handles both predictable and unpredictable traffic and allows for in-network computation.

In September 2023, Astrape secured a pre-seed funding round of €1.6 million, which it said it would use to develop sustainable data centers by eliminating multiple electrical-optical conversions during operation. The company said it would use the funds to develop photonic integrated circuits to build faster, cooler, and more energy-efficient data centers.

The recent funding round was co-led by PhotonVentures, Join Capital, and Brabant Development Agency, with participation from Shift Invest. Astrape Networks was founded in 2022 as a spinoff from Eindhoven University of Technology and incubated by HighTechXL.

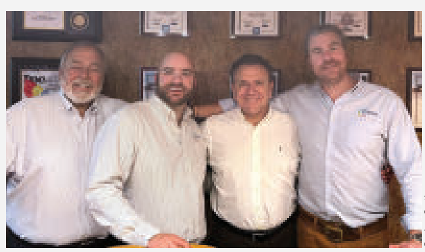
IPG partners with coatings developer AkzoNobel

IPG Photonics and coatings manufacturer AkzoNobel partnered on the development of a laser process for the curing of powder coatings. According to the companies, the method will offer a faster and more energy-efficient alternative to conventional curing methods.

The powder coating curing process involves lasers selectively heating the applied powder in a so-called cold oven, a system in which heat does not escape onto the factory floor and energy is not wasted while heating the atmosphere or the curing enclosure. High-intensity laser heating also enables curing times to be reduced to just a few minutes, compared with the 15 to 20 min that is currently required using traditional curing methods. Also, the process enables curing to occur in less than half the space required by a traditional oven.

Laser curing as a stand-alone technology offers multiple advantages. For example, it can be used to preferentially heat a coating, as opposed to heating the underlying substrate. Additionally, it is

People in the News



Sydor Optics

(From left) Jim Sydor, Jonathan Sydor, Michael Ognenovski, and Matthew Sydor.

Precision flat optics developer and manufacturer Sydor Optics named **Matthew** and **Jonathan Sydor** co-presidents, following the retirement of **Michael Ognenovski**. Ognenovski served as the company's president since 2018. Per the transition, **Jim Sydor** will continue to serve as chairman of the board. Matthew and Jonathan Sydor are the third generation of the Sydor family to lead the company.

InterOptics LLC, an optical metrology company, appointed **Chris Ames** sales and business development manager. Ames has previous experience in the semiconductor and optical capital equipment ecosystem.

PHIX Photonics Assembly, an integrated photonics packaging foundry, appointed **Thomas Hommes** head of strategy. Hommes' professional background includes several strategy management roles, most recently at telecommunications company VodafoneZiggo.

Teledyne Technologies Inc. named **George Bobb III** president and CEO following **Edwin Roks**' retirement as CEO. Roks will continue to serve in a special advisory role to the executive chairman through Aug. 31. Since 2008, Bobb has served in a variety of upper management roles at Teledyne, most recently as president and COO.

Laird Thermal Systems, a thermal management solutions developer, appointed **Max Kley** CEO. Kley has held various international leadership positions across the medical, industrial, and energy industries in the U.S., Europe, and Asia, including serving as CEO of Freudenberg Medical Group for six years, and most recently as CEO of Freudenberg e-Power Systems. In a separate move following this appointment, Laird Thermal Systems rebranded as Tark Thermal Solutions.

suitable for temperature-sensitive substrates and eliminates the long cool-down waiting times that are evident in typical production lines. In a high-volume environment, manufacturers saw reductions of >50% in both the investment and operational costs, while the carbon footprint and energy consumption was drastically reduced, the companies said.

IPG and AkzoNobel have signed an agreement for the partnership to serve customers in the Europe, Middle East, and Africa regions.

3.2% — projected compound annual growth rate of the global fiber optics gyroscope market between 2023 and 2030, according to Data Bridge Market Research

Space Force awards Enterprise Space Terminal contracts

The U.S. Space Force's Space Systems Command awarded contracts to CACI International, General Atomics, and Viasat to continue to develop space laser communication terminal prototypes as part of the second phase of the $100 million Enterprise Space Terminal (EST) program. The EST program aims to enable on-orbit crosslink compatibility among future space systems via the use

IonQ named **Jordan Shapiro** president and general manager of quantum networking. Shapiro previously served as IonQ's vice president of financial planning and analysis, corporate development, and investor relations. He joined IonQ's executive team in 2020 after working with the company as a venture capitalist.

Cognex appointed **Matthew Moschner** CEO. Moschner, who served as company president and COO at the time of the appointment, succeeds **Robert Willett**, who has retired. Cognex also named Moschner a director of the company.


Cognex
Moschner.

Corning Inc. appointed **Avery Nelson III** COO, **Lewis Steverson** vice chairman, and **John Zhang** chief corporate development officer. The changes in management follow president and COO **Eric Musser**'s announcement that he will retire. Nelson joined Corning in 1991 and has held a series of key management positions in the company's display and automotive market-access platforms. Steverson joined the company as senior vice president and general counsel in 2013, and will also continue to hold the role of executive vice president and chief legal and administrative officer. Zhang, who has held positions in strategy and corporate development at Corning, will continue to lead global operations for Corning's display and mobile consumer electronics market-access platforms. He will also assume leadership of the company's life sciences market-access platform.

Laser cutters producer Eagle Lasers named **Chad Jackson** CEO of its U.S. branch, Eagle Americas. Jackson has nearly 30 years of experience in the metal processing industry. He most recently served as regional sales manager for Bystronic Inc. and previously as a direct sales engineer for the company.

Olympus Corp. appointed **Bob White** CEO, succeeding **Yasuo Takeuchi**. White most recently served in executive positions at Medtronic.

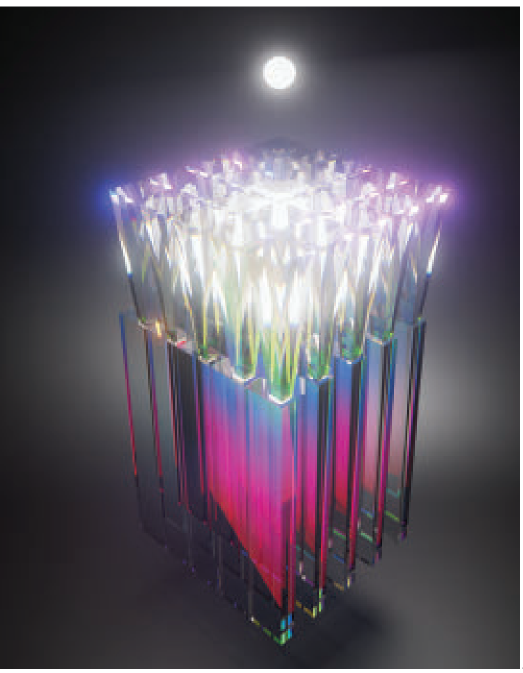

Olympus Corp.
White.

of a standardized enterprise waveform implemented in a long-range space optical communications terminal that is low size, weight, power, and cost.

The Space Systems Command selected the three companies from four competing companies who completed Phase 1 of the EST program, culminating in a preliminary design review from each company. Awarding Phase 2 of the program to three companies allows Space Systems Command to build the industrial base for long-range laser communications terminals while maintaining competition to control costs and maximize innovation. The selected companies were chosen based on cost, schedule, and performance factors and were determined to be the best value for the government.

ESTs are a key building block of the broader space data network known as MILNET, which aims to build a space mesh network for resiliency and information path diversity. The EST program leverages prior investment by the U.S. Department of Defense and commercial developers to operationalize a new enterprise waveform designed to communicate in the beyond-low-Earth-orbit regimes.

imec spinoff eyeo exits stealth with $17M



imec

A 3D rendering of eyeo's waveguide structure, which separates and guides individual photons to the proper pixels. According to the company, the technology enables far greater light sensitivity and color fidelity compared with traditional camera sensors technologies.

Eyeo, a spinoff of imec, raised €15 million ($16.9 million) in seed funding. The funding will help the company to develop an evaluation kit, prepare for scale manufacturing of its first sensor product, and expand partnerships to support the technology's commercialization.

Eyeo's novel image sensor architecture eliminates the need for traditional color filters, making it possible to maximize sensitivity without increasing sensor size. Using vertical waveguide-based technology that splits light into colors, the company's sensors efficiently capture and use all incoming light, tripling sensitivity compared with existing technologies, according to the company. This is particularly valuable in low-light environments, where current sensors struggle to gather enough light for clear, reliable imaging.

Additionally, unlike traditional filters that block certain colors — requiring the missing information to be interpolated through software processing — eyeo's waveguide technology allows pixels to receive complete color data. This approach doubles resolution, delivering sharper, more detailed images for applications that demand precision, such as computational photography, machine vision, and spatial computing.

Because this method preserves each photon and separates colors naturally, by manipulating light rather than blocking it, it achieves maximum light sensitivity, true-to-life color fidelity, and ultrahigh resolution through photon compression.

The technology's ability to drastically increase the light sensitivity of image sensors will have applications in the consumer, industrial, extended reality, and security sectors. Eyeo has already established partnerships with leading image sensor manufacturers and foundries to ensure the successful commercialization of its technology. The funding will be used to further improve eyeo's current camera sensor designs, optimize the waveguide technology for production scalability, and accelerate the development of prototypes for evaluation.

The first evaluation kits will be available for selected customers within the next two years.

The funding round was co-led by imec.xpand and Invest-NL, and joined by Qbic fund, High-Tech Gründerfonds, and Brabant Development Agency.

$2.6B

— estimated size of the global metamaterials market by 2030, according to Grand View Research

IonQ to purchase Harvard spinout Lightsynq, Capella Space

IonQ entered into a definitive agreement to acquire Lightsynq Technologies, a developer of optical quantum interconnects that enable hardware providers to link quantum processors. The acquisition adds a portfolio of more than 20 technology patents and patent applications related to quantum memory and further strengthens IonQ's intellectual property. This follows the company's acquisition of ID Quantique, which IonQ announced in February.

"IonQ's vision has always been to scale our quantum networks through quantum repeaters, and scale our quantum compute power through photonic interconnects," said IonQ president and CEO Niccolo de Masi. The addition of Lightsynq's team and intellectual property are expected to significantly accelerate both road maps, de Masi said.

Founded by former Harvard quantum networking experts and research leads from Amazon Web Services Center for Quantum Networking, Lightsynq emerged from stealth in November 2024 with $18 million in financing. The company's architecture is broadly compatible with leading quantum computing modalities and uses integrated diamond photonic circuits to link multiple limited-scale devices into a modular, full-scale quantum computer, similar to the methods used to build current high-performance computing systems. The solution, Lightsynq said, will provide a pathway to foundry-scale production of quantum interconnects, enabling more usable qubits across networks and accelerating wider industrial and commercial applications.

"Our photonic interconnect will integrate with IonQ's quantum processing units to boost connection speeds and ensure long-term market-leading scale and power in quantum computing," said Lightsynq CEO Mihir Bhaskar. According to Bhaskar, the interconnect technology will also be critical for the establishment of a quantum internet, enabling applications in financial, telecommunications, aerospace, and defense sectors.

In a separate transaction, IonQ announced a definitive agreement to acquire Capella Space Corp., a provider of space-based sensing and communications for government and commercial applications. The move supports IonQ's ambitions to deploy a quantum network and quantum computer in space, the company said. The transaction is additionally expected to contribute to the company's quantum networking position, as well as to expand its quantum computing partnerships with the U.S.'s top-secret agencies through Capella's Facility Security Clearance, IonQ said.

In addition to the ID Quantique acquisition, which IonQ closed in May, IonQ's recent acquisition history includes its purchase of Qubitekk, finalized earlier this year. IonQ also signed a memorandum of understanding with Intellian Technologies to explore quantum networking's potential in satellite communications in April. The company maintains additional partnerships with NKT Photonics, Ansys, the National Institute of Advanced Industrial Science and Technologies, General Dynamics Information Technology, and imec.

6.8%

— predicted compound annual growth rate of the global functional films market between 2025 and 2035, according to Future Market Insights

Xanadu forges partnership with Applied Materials

Photonic quantum computing company Xanadu formed a collaboration with materials engineering firm Applied Materials to develop a 300-mm high-volume-compatible process for building superconducting transition edge sensors (TESs). These TESs are a core component of photon-number-resolving detectors (PNRs), which are key elements that enable the qubit state preparation process in Xanadu's photonic quantum computers.

Xanadu said it was shifting its focus toward reducing optical loss across various components to achieve fault tolerance. The company is also preparing for the future scaling of its quantum computer into a full-fledged quantum data center. This transition will require mass semiconductor manufacturing capabilities of various components, including TESs for PNRs, to reduce production costs and meet the stringent demands of detector performance, quality, and production volume.

During the next year, the collaborators aim to demonstrate what they said will be the first 300-mm platform for building TESs for PNRs. Once a basic demonstration of the platform's capabilities is completed toward the end of this year, the Xanadu and Applied Materials teams plan to continue to optimize its performance to meet the demands of high-throughput, high-reliability fabrication before ramping up for mass manufacturing.

The collaboration builds on previous work between Xanadu and Applied Materials, which focused on materials optimization of TES fabrication processes.

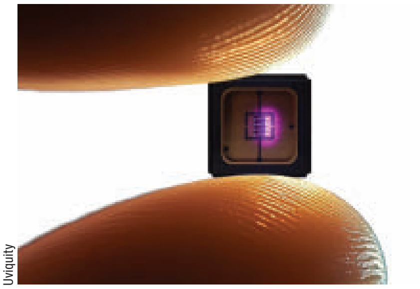
Photonic disinfection solution provider Uviquity raises $6.6M

Uviquity, a deep-tech startup developing next-generation photonic disinfection technologies, emerged from stealth with $6.6 million in seed funding. The funding will support the company's R&D efforts, accelerating the productization of its core technology. The company is developing solid-state far-UVC (200- to 230-nm) semiconductor light sources designed to deliver safe, continuous, and chemical-free disinfection for air, food, and water applications.

Unlike conventional UVC solutions, far-UVC light has proved to be safe for continuous exposure to human skin and eyes while rapidly inactivating all known pathogens, including viruses, bacteria, fungi, and mold spores. According to Uviquity, far-UVC systems have historically relied on bulky gas-discharge lamps with limited scalability and reliability.

The company's proprietary photonic integrated circuit, which couples blue laser light into frequency-doubling waveguides, enables a compact, energy-efficient, and durable solution that can be integrated into light fixtures, air handling systems, food packaging and processing equipment, agricultural crop protection systems, water purification systems, and consumer appliances.

The round was led by Emerald Development Managers, with participation from AgFunder and MANN+HUMMEL.



Uviquity's solid-state far-UVC semiconductor light sources can seamlessly integrate into a wide variety of applications using standard photonic packages.

Uviquity

Fujitsu launches network products company 1FINITY

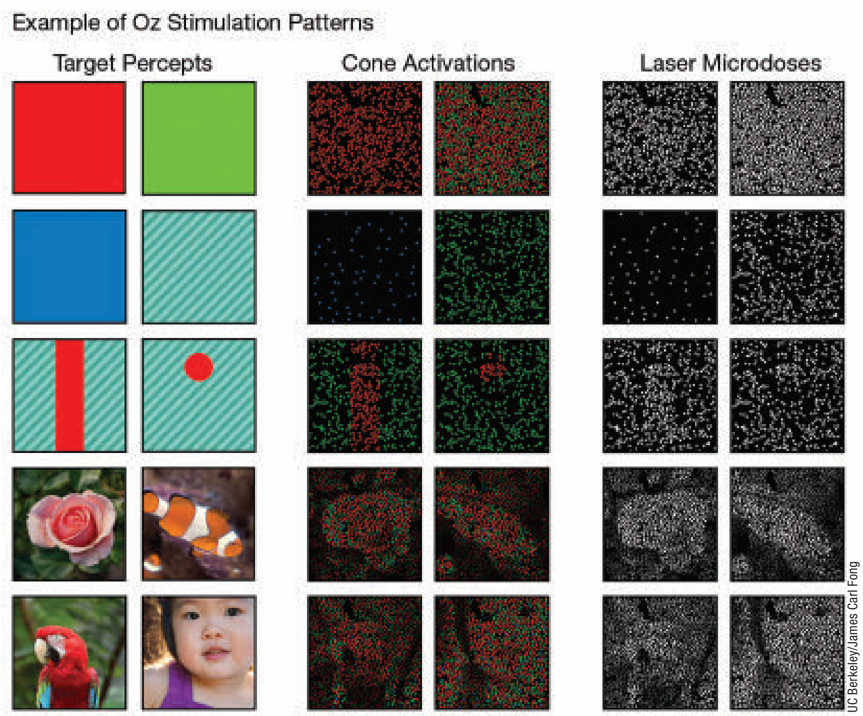
Fujitsu plans to transfer its networks products business to a spinout company, 1FINITY. The spinout will be formed on July 1 as a wholly owned subsidiary of Fujitsu. The parent company will consolidate functions related to the development, manufacturing, sales, implementation support, maintenance, and operation of network hardware — primarily optical transmission equipment and 5G base station equipment — as well as related software and 6G research into 1FINITY.

Through 1FINITY, Fujitsu aims to expand its share of the global network products market by strengthening existing business in Japan and North America and expanding into the European and Asian markets. It also plans to bolster competitiveness by developing high-quality products, leveraging its key technologies, including high-capacity optical data transmission and reception technology, and high-performance virtualized radio access network software that uses GPUs.

Fujitsu plans to transfer four of its group companies and its related companies to 1FINITY: Fujitsu Telecom Networks Ltd., Fujitsu Network Service Engineering Ltd., Mobile Techno Corp., and Fujitsu Network Communications Inc. Each group company will continue to provide its products and services following integration into 1FINITY.

The company names of the group companies being transferred are yet to be determined.

Researchers trick the eye into seeing new color



The Oz software takes a color image **(left column)** and calculates which cone cells in the retina must be activated for a person to see the image **(center column)**. It then calculates the pattern of laser microdoses that must be delivered to the retina to activate those cones **(right column)**.

Participants in the study described the new color as a blue-green or peacock green far more saturated than the nearest monochromatic color. The Oz software accomplishes this by using tiny doses of laser light to individually control up to 1000 photoreceptors in the eye at one time.

BERKELEY, Calif. — In L. Frank Baum's novel *The Wonderful Wizard of Oz*, the Emerald City is said to be such a brilliant shade of green that visitors must wear green-tinted glasses to protect their eyes from the "brightness and glory" of the city.

The glasses, however, are one of the wizard's many deceits: Green-tinted glasses would only make the city appear greener.

Using a technique called "Oz," scientists at the University of California, Berkeley (UC Berkeley), found a way to manipulate the human eye into seeing a new color — a saturated blue-green color that the team named "olo."

"It was like a profoundly saturated teal … the most saturated natural color was just pale by comparison," said Austin Roorda, a professor of optometry and vision science at UC Berkeley's Herbert Wertheim School of Optometry & Vision Science, and one of the creators of Oz.

Oz uses tiny doses of laser light to individually control up to 1000 photoreceptors in the eye simultaneously. Using Oz, the scientists demonstrated not only a green more stunning than anything visible with ordinary vision, but also other colors, lines, moving dots, and images of babies and fish.

They believe the platform could also be used to answer basic questions about vision and vision loss.

"We've created a system that can track, target, and stimulate photoreceptor cells with such high precision that we can now answer very basic, but also very thought-provoking, questions about the nature of human color vision," said James Carl Fong, a Ph.D. student at UC Berkeley. "It gives us a way to study the human retina at a new scale that has never been possible in practice."

Humans see in color due to three different types of photoreceptor "cone" cells embedded in the retina. Each cone type is sensitive to different wavelengths of light: S cones detect shorter, bluer wavelengths; M cones detect medium, greenish wavelengths; and L cones detect longer, reddish wavelengths.

Because of an evolutionary quirk, the light wavelengths that activate the M and L cones are almost entirely overlapping, meaning that 85% of the light that activates M cones also activates L cones.

"There's no wavelength in the world that can stimulate only the M cone," said senior author Ren Ng, a professor at UC Berkeley. "I began wondering what it would look like if you could just stimulate all the M cone cells. Would it be like the greenest green you've ever seen?"

For Oz to work, the unique arrangements of the S, M, and L cone cells on an individual's retina must be mapped. The UC Berkeley researchers collaborated with Ramkumar Sabesan and Vimal Prabhu Pandiyan at the University of Washington. The pair previously developed an optical system that can image the human retina and identify each cone cell.

With an individual's cone map in hand, the Oz system can be programmed to rapidly scan a laser beam over a small patch of retina. It delivers tiny energy pulses when the beam reaches a cone that it wants to activate, and otherwise stays off.

The laser beam is just one color — the same hue as a green laser pointer. But, by activating a combination of S, M, and L cone cells, it can trick the eye into seeing images in full technicolor. Or, by primarily activating the M cone cells, Oz can show people the color olo.

Aside from projecting movies and showing new colors, the researchers are finding additional ways to use the technique. "Many diseases that cause visual impairment involve lost cone cells," said Hannah Doyle, a Ph.D. student at UC Berkeley. "One application that I'm exploring now is to use this cone-by-cone activation to simulate cone loss in healthy subjects."

The scientists are also exploring whether Oz could help people with color blindness to see all the colors of the rainbow or if the technique could be used to allow humans to see in tetrachromatic color, as if they had four sets of cone cells.

It may also help to answer more fundamental questions about how the brain makes sense of visual complexities.

"We found that we can re-create a normal visual experience just by manipulating the cells — not by casting an image, but just by stimulating the photoreceptors. And we found that we can also expand that visual experience, which we did with olo," Roorda said. "It's still a mystery … if you expand the signals or generate new sensory inputs, will the brain be able to make sense of them and appreciate them?"

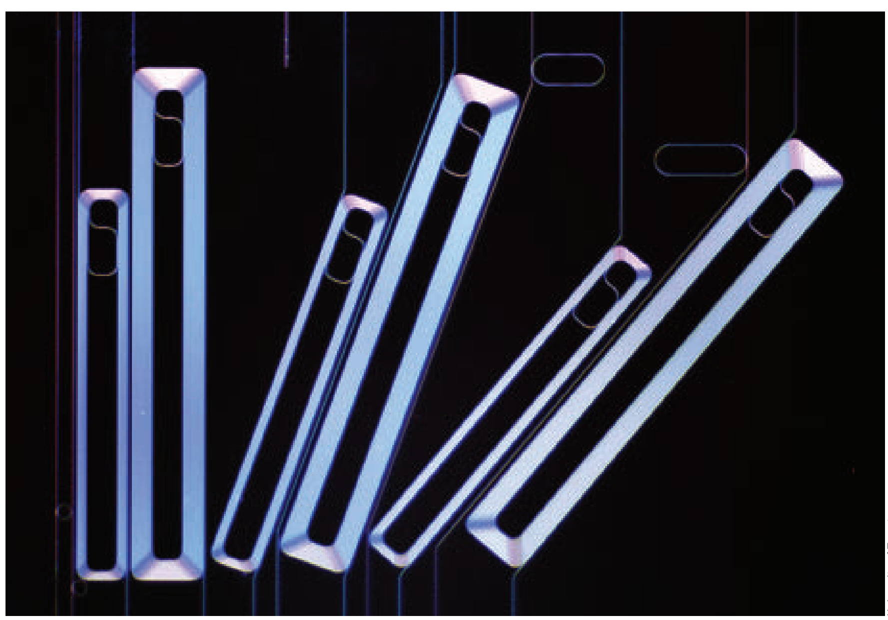
The research was published in *Science Advances* (www.doi.org/10.1126/sciadv.adu1052).

Optical platform enables sound-controlled light in photonic chips

ENSCHEDE, Netherlands — Researchers at the University of Twente developed a scalable, integrated platform that could be used to increase the scope and performance of photonic integrated circuits (PICs). The researchers developed the Stimulated Brillouin Scattering (SBS) platform using thin-film lithium niobate (TFLN), an established platform for light-based chips. In the optical material lithium niobate, acoustic waves can be steered by the direction of light and integrated in photonics technology.

The researchers harnessed strong SBS in their TFLN platform by exploiting the anisotropy of the material. Collaborating with a research group at the City University of Hong Kong, the University of Twente team, led by David Marpaung, fabricated an on-chip Brillouin amplifier and a laser — two key components in a PIC — within the TFLN platform. The significant SBS gain made TFLN suitable for developing a Brillouin photonics engine capable of diverse functions. For example, the team achieved notch filtering, bandpass filtering, and true time delay of an incoming signal using a programmable Brillouin microwave photonic processor.

According to Marpaung, integrating



University of Twente

A microscope image of a z-cut thin-film lithium niobate (TFLN) sample that contains waveguides with a rotational angle of 0°, 20°, and 40°. Researchers developed a scalable, efficient, integrated platform for Brillouin Scattering on TFLN.

Brillouin photonics in TFLN will enable ultraprecise filtering of unwanted signals.

"Integration with high-speed modulators will lead to higher performance, smaller size, and lower cost," he said. "These filters can be used for mitigation of unwanted interference and jamming, which is important for 6G radios and GPS navigation."

To date, using SBS for integrated photonics has been impractical. Acoustic waves have also presented a challenge, due to their tendency to propagate in all directions and disperse energy.

"Integrated Brillouin photonics is very fertile ground, both scientifically and commercially, and our work takes it from the lab to the fab," Marpaung said.

With SBS added to their toolkit, optical engineers will be able to incorporate subhertz linewidth lasers, ultraselective filters, and many other high-performance components into their PICs.

The researchers identified two distinct SBS processes on the TFLN platform — one driven by surface acoustic waves with a 20-MHz linewidth, and the other driven by bulk acoustic waves with a linewidth >4 GHz. The narrowband internal net gain amplifier demonstrated by the researchers overcame propagation losses within a 10-cm spiral waveguide. A stimulated Brillouin laser, generated in TFLN by incorporating SBS gain into a high-quality racetrack resonator, achieved a tuning range of >20 nm and supported the generation of high-purity radio frequency signals with a linewidth of 9 Hz.

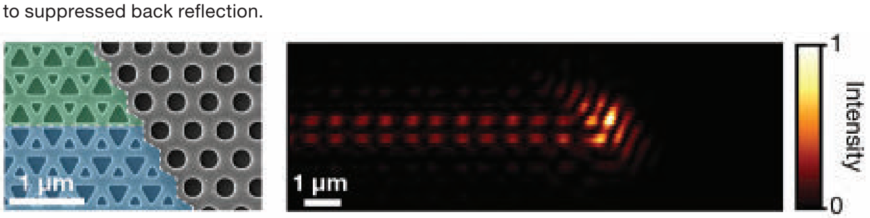
By using SBS to control the positive feedback loop between lightwaves passing through a medium and the sound waves generated in the material's crystal lattice, the researchers developed a way to transport and process information. "After electrons in electronics and photons in integrated photonics, think of the phonon-mediated interactions as a third way to shape, redirect, or process signals," Marpaung said.

"SBS can drastically reduce the dimensions of atomic clocks, since SBS allows for miniaturization of the ultraprecise and stable lasers required by these devices," Marpaung said. "Chip-scale lasers will enable cost-effective integration of atomic clocks in satellites and unmanned aerial vehicles (drones). Thanks to precise onboard timekeeping, these devices wouldn't have to rely on GPS for navigation."

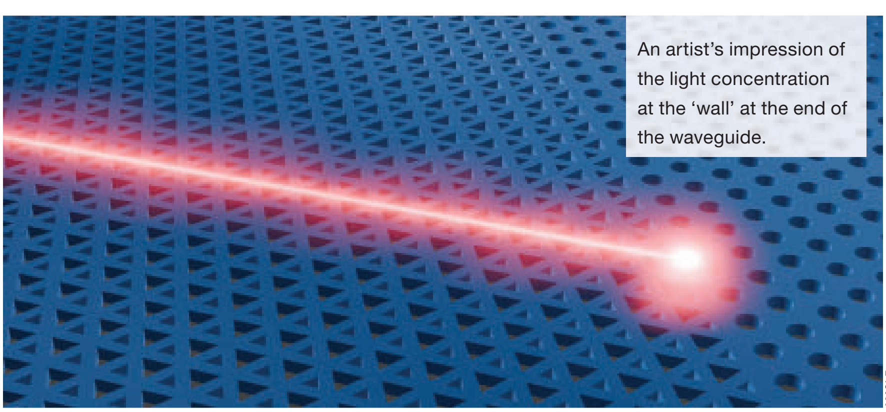
The research was published in *Science Advances* (www.doi.org/10.1126/sciadv.adv4022).

Enhanced localized optical field improves light-matter interaction

An electron microscopy image of the silicon photonic crystal **(left)**. The topological waveguide is formed at the boundary between the green and blue regions, and is terminated by the crystal with round holes on the right side. A measurement of the optical intensity in the photonic crystal **(right)**. Light enters through the topological waveguide from the left and accumulates at the end of the waveguide due to suppressed back reflection.



AMOLF



An artist's impression of the light concentration at the 'wall' at the end of the waveguide.

AMOLF

AMSTERDAM — Collaborating researchers from the Dutch research institute AMOLF, Delft University of Technology, and Cornell University demonstrated an approach that uses the topological properties of photonic crystals to concentrate light on a chip and achieve broadband localization of light. The mechanism for concentrating light at an extremely small scale could be used for a broad spectrum of wavelengths, supporting its use in photonic chip-based applications for quantum communication, optical sensing, and lasing, among other applications.

"What makes this design special is that the conduction of light is topologically protected, meaning that scattering or reflection of light by imperfections in the crystal is suppressed," researcher Daniel Muis said. Using valley photonic crystals as a topological photonic platform, the researchers demonstrated that light could be localized at the termination of a reciprocal topological waveguide. Reflection was only suppressed strongly enough to result in localization for terminations that approximately conserved the valley degree of freedom.

The researchers explored what would happen if the waveguide was terminated with a wall of material that light could not pass through. "Since the light has nowhere to go and reflections are suppressed, it should accumulate in front of that wall," Muis said. "The light does eventually bounce back through the waveguide, but only after a delay. This results in a local amplification of the light field."

To verify their predictions about the accumulation of light within the photonic crystal, the researchers used microscopy to scan the light fields with an ultrathin needle positioned above the surface of the crystal. The results confirmed that the team's approach to concentrating light led to strong confinement of light at the termination of the topological photonic waveguide.

"Interestingly, this only happened when the 'wall' terminating the waveguide was placed at a certain angle," Muis said. "This was exactly what our partners at Cornell had predicted. It proves that the light amplification is related to the topological suppression of back reflection."

The researchers compared different waveguide termination geometries, confirming that the origin of suppressed backscattering came from the near conservation of the valley degree of freedom.

Muis said that the light amplification is concentrated in a very small volume — as small as the wavelength of the light itself. Since the method is inherently broadband, it works for many different wavelengths.

AMOLF group leader Ewold Verhagen said that, until now, the only ways to concentrate light were through optical cavities or by using waveguides to compress the light like a funnel. "The first method uses resonance, which limits the focusing or concentration of light to a specific wavelength," he said. "The second method works similar to a traditional lens, only in a device much larger than the wavelength of the light used."

According to the researchers, the mechanism should apply to any type of wave in a structured medium, including sound waves or even electrons in specific crystals.

"For a next step, it would be interesting to use a pulsed laser to look at the time interval in which the light continues to accumulate, to see how much the field amplification can be maximized, and to use it for applications in light manipulation on optical chips," Muis said.

The research was published in *Science Advances* (www.doi.org/10.1126/sciadv.adr9569).

Targeting labeling conventions, scientists boost live-cell imaging

SYDNEY— To visualize the substructures and dynamic interactions within living cells, researchers developed an imaging technology that uses AI and deep learning to capture intracellular activity at superresolution. The technique, developed by researchers at Peking University, Ningbo Eastern Institute of Technology, and the University of Technology Sydney, enables fast segmentation and multiplexed imaging of organelles and their interactions within live cells.

Conventional microscopy methods image organelles in live cells but struggle to capture their interactome at the system level due to the organelles' small size, fast dynamics, and diverse types. Traditional microscopy can also cause damage to the sample through phototoxicity and photobleaching.

The ability to visualize multiple cellular processes at the same time could provide insight into the root causes of cancer, neurodegenerative disorders, and metabolic conditions.

The researchers abandoned the conventional one-to-one labeling strategy used in fluorescence microscopy and developed a "one-to-many" strategy for labeling organelles. They stained multiple intracellular compartments with one lipid dye that could stain all the membrane-associated organelles with nearly 100% efficiency. When the dye's emission spectrum responded to the lipid polarity of the membranes, the researchers used dual-color imaging channels to obtain high-resolution ratiometric measurements, enabling them to distinguish between organelles with similar shapes and sizes.

The method not only overcomes the constraints of using multiple colors by using a single dye label but also significantly speeds up the imaging process.

The resulting high-resolution images accurately captured the differences between organelles.

The researchers used a spinning disk confocal microscope with an extended resolution of ~143 nm for high spatiotemporal acquisition of images. "Current tools such as fluorescence microscopy have limitations in resolution that make it difficult to see the tiny structures within cells or track detailed cellular processes," researcher Dayong Jin said.

Using deep-convolutional neural networks (DCNNs), the researchers segmented 15 subcellular structures using one laser and two detection channels. They showed that a simple cell-staining protocol, combined with rapid acquisition of spatial and spectral imaging data, could enable a DCNN to predict these intracellular structures with high accuracy, speed, reproducibility, stability, and throughput. They also resolved the 3D anatomic structure of live cells at different mitotic phases and robustly tracked the fast, dynamic interactions among six intracellular compartments.

The multiplexed imaging technique is highly adaptable; the researchers transferred learning to predict 2D and 3D data sets from different microscopes, cell types, and complex systems of living tissues.

The approach will enable scientists to investigate the 3D structure of live cells during various stages of cell division and observe the rapid interactions among intracellular compartments.

Jin said the team is currently working with several medical research institutions that are exploring virus-cell interactions and cell defense mechanisms, as well as the imaging of cardiomyocytes for the study of heart disease.

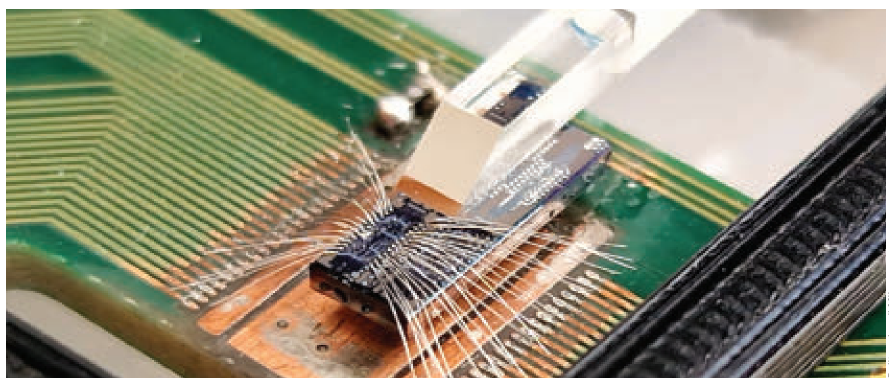
"It's like taking an airplane over a city at night and watching all the live interactions," Jin said.

"This cutting-edge technology will open new doors in the quest to understand the intricate world within our cells."

The research was published in *Nature Communications* (www.doi.org/10.1038/s41467-025-57877-5).

Optical receiver deploys micro-antennas to restore chaotic signals

MILAN — Researchers in Europe developed an optical receiver that can restore chaotic signals in free-space optical communication links that are distorted by atmospheric turbulence. By using a system of optical micro-antennas integrated into a programmable photonic chip, the receiver adapts in real time, maintaining the integrity of the signal even in harsh atmospheric conditions.



Politecnico di Milano

An optical receiver developed by researchers at Télécom Paris and the Politecnico di Milano captures chaotic signals via optical micro-antennas and reconstructs them with a photonic chip.

The study, conducted by a team of researchers led by Télécom Paris and the Politecnico di Milano, paves the way for the use of chaos-based encryption for secure, high-speed communications in hostile environments.

The idea behind secure, chaos-based communication is to encode a secret message into a light signal, which appears to be so unpredictable and complex that it is almost impossible to decipher. However, when these chaotic signals travel in the real wireless world, they encounter a major obstacle: atmospheric turbulence — which distorts signals and compromises their security.

In the newly developed receiver, the micro-antennas capture light from multiple points of view while the photonic chip self-calibrates in real time to rebuild these fragments into a secure and reliable chaotic signal. Even in the presence of heavy rain, wind, or pollutants, the signal can be fully retrieved.

"Chaos is a robust system, but can only be used in cryptosystems if its inherent nature is fully preserved. Atmospheric turbulence degrades the optical signal and apparently destroys the properties of chaos, making it hard to maintain secure and reliable communications," said Sara Zaminga of LTCI Télécom Paris at Institut Polytechnique de Paris.

"With our approach, we're not just mitigating the effects of turbulence, we're completely restoring the chaos of light in all its intrinsic complexity."

Chaos-based systems have an inherent advantage in that their unpredictability makes them naturally secure. However, atmospheric turbulence by its nature has long been a major obstacle to wireless communications.

And, as it relates to the researchers' design, the use cases extend beyond secure and wireless communications. "In remote areas or emergency zones, places where traditional networks fail, a chaos-based, turbulence-resistant system could provide a secure connection when it is most needed," said Francesco Morichetti, head of the Photonic Devices Lab at the Politecnico di Milano.

The research was published in *Light: Science & Applications* (www.doi.org/10.1038/s41377-025-01784-3).

Machine learning-aided spectroscopy ensures the safety of cell therapy

SINGAPORE — Cell therapies show promise for treating cancers, inflammatory diseases, and chronic degenerative disorders. These therapies involve the manipulation of cells and tissues in vitro using nutrient-rich stem cell cultures, which makes the process vulnerable to microbe contamination.

Cell therapy product (CTP) manufacturers need quick, effective ways to ensure that cells are free from contamination before they are administered to patients. Delays due to contamination testing of CTPs can be life-threatening for critically ill patients awaiting treatment.

To provide microbial contamination detection during the early stages of CTP manufacturing, researchers from the Critical Analytics for Manufacturing Personalized-Medicine group at the Singapore-MIT Alliance for Research and Technology (SMART) — in collaboration with MIT, A*STAR Skin Research Labs, and the National University of Singapore — developed a machine learning-aided, ultraviolet absorbance spectroscopy technique that can quickly and automatically detect and monitor microbial contamination in CTPs. The method can be used as a preliminary test during various CTP manufacturing stages, for real-time, continuous culture monitoring enabling early detection of microbial contamination, ensuring the safety of CTPs.

"Specifically, our method supports automated cell culture sampling at designated intervals to check for contamination, which reduces manual tasks such as sample extraction, measurement, and analysis," said MIT professor Rajeev Ram. "This enables cell cultures to be monitored continuously and contamination to be detected at early stages."

The spectroscopy method detects microbial contamination in <30 min, with minimal sample preparation and <1-mL sample volume.

The researchers used a one-class support vector machine to analyze the absorbance spectra of cell cultures and predict whether a sample was sterile or contaminated. They used mesenchymal stromal cell cultures, which are widely used in cell therapy, as a demonstrator. To train

SMART CAMP

Shruthi Pandi Chelvam, a senior research engineer at the Singapore-MIT Alliance for Research and Technology Critical Analytics for Manufacturing Personalized-Medicine (SMART CAMP), uses an ultraviolet absorbance spectrometer to measure the absorbance spectra of cell culture samples.

the support vector machine model, the team used the absorbance spectra of only sterile cell culture samples, measured by a commercial spectrometer. Using an anomaly detection approach, the team then identified spectral differences in the region of interest and predicted contamination in test cell culture samples. They hypothesized that the spectral differences between nicotinic acid and nicotinamide metabolites are underlying principles for the support vector machine model to predict contamination.

In tests, the machine learning-aided method detected contamination at the 21-h timepoint when 10 colony-forming units of *E. coli* were spiked into a mesenchymal stromal cell culture. Using the new method, researchers were able to detect as few as 10 colony-forming units of seven different microorganisms. They demonstrated the robustness of the approach by testing it across different commercial donor mesenchymal stromal cells.

By measuring ultraviolet light absorbance of cell culture fluids and using machine learning to recognize light absorption patterns associated with microbial contamination, this testing method could reduce the time required for sterility testing, enabling cell therapies to get to patients faster.

"Traditionally, cell therapy manufacturing is labor-intensive and subject to operator variability," Ram said. "By introducing automation and machine learning, we hope to streamline cell therapy manufacturing and reduce the risk of contamination."

This approach could offer significant advantages over traditional sterility tests, which can take up to 14 days, as well as over advanced techniques such as rapid microbiological methods, which involve complex processes and require highly skilled workers. Additionally, it provides label-free detection of cell contamination, eliminating the need for cell staining and the invasive process of cell extraction.

The researchers plan to broaden the machine learning-assisted spectroscopy method to encompass a wider range of microbial contaminants, specifically those representative of current Good Manufacturing Practice environments and previously identified CTP contaminants. Beyond CTP manufacturing, this method could be used by the food and beverage industry for microbial quality control testing to ensure food products meet safety standards, the team said.

The research was published in *Scientific Reports* (www.doi.org/10.1038/s41598-024-83114-y).

Materials science breakthrough paves the way for safer SWIR lidar

BARCELONA, Spain — Researchers at The Institute of Photonic Sciences (ICFO) developed a proof-of-concept SWIR lidar system architecture based on silver telluride (Ag_2Te) colloidal quantum dots (CQDs). The material is Restriction of Hazardous Substances (RoHS)-compliant.

The properties of SWIR make it a desirable option for several applications, including 3D imaging, machine vision, lidar, and electronics. SWIR light experiences less scattering in the atmosphere than visible light, allowing for greater penetration depth, especially in adverse weather conditions. SWIR is considered eye-safe, and it enables continuous sensing and ranging during day and night.

However, SWIR photodetectors are typically made with expensive materials that are difficult to manufacture. This limits the applications that use SWIR light to specialized areas such as scientific instrumentation and military operations.

Heavy metal-free CQDs have emerged as an alternative material for the development and manufacture of SWIR optoelectronics. Ag_2Te CQDs, for example, demonstrate device performance comparable to that of CQDs made with toxic heavy metals such as lead or mercury. But to meet the rigorous demands of sensing and lidar applications, the Ag_2Te performance of CQDs must tackle three challenges: high dark current, limited linear dynamic range, and limited response speed.

Silver telluride (Ag_2Te) colloidal quantum dot (CQD) SWIR photodiodes **(left)** and solution-processed Ag_2Te **(right)**.

ICFO/Jordi Cortés

The ICFO researchers optimized the synthesis of CQDs to eliminate the surface defects, which can reduce efficiency, by surface engineering Ag_2Te CQDs with tight-binding thiols. The surface engineering also improved colloidal stability, carrier lifetime, and photoluminescence quantum yield. However, this strategy alone was not enough.

"It wasn't until we applied a silver nitrate post-treatment to our quantum dot thin film that we saw major improvements, suggesting that this optimization approach was promising," said researcher Yongjie Wang.

The researchers engineered doping on CQD films by introducing a new cationic ligand of silver nitrate ($AgNO_3$) to further optimize the quantum dot stack of the photodiode. Using this approach, they developed SWIR photodiode devices made with CQDs that achieved a dark current density of <500 nA/sq cm, an external quantum efficiency at 1400 nm of 30%, a linear dynamic range of >150 dB, and a time response as fast as 25 ns.

The researchers then built a proof-of-concept SWIR lidar using CQDs made from nontoxic materials that are RoHS-compliant. To the best of the team's knowledge, this is the first SWIR lidar made with nontoxic CQDs. The device measured distances of >10 m with decimeter resolution, showcasing the potential of Ag_2Te CQDs for lidar.

This engineering strategy to enhance Ag_2Te CQDs could accelerate the development of SWIR optoelectronic devices. It leverages the cost-effectiveness and manufacturing advantages of CQDs while improving their performance as an environmentally friendly alternative to heavy metal-based CQDs.

Future research will focus on achieving faster response times, higher quantum efficiency, and more reliable operation under realistic temperatures and humidity levels.

The research was published in *Advanced Materials* (www.doi.org/10.1002/adma.202500977).

Quantum sensors offer path to next-generation particle experiments

PASADENA, Calif. — As plans to develop more powerful particle accelerators progress, the challenge of sifting through the chaos of the subatomic particles unleashed by their collisions is also growing.

To address this challenge, researchers from the U.S. Department of Energy's Fermi National Accelerator Laboratory (Fermilab), Caltech, NASA's Jet Propulsion Laboratory (JPL), and other collaborating institutions developed a novel high-energy particle detection instrumentation approach that uses quantum sensors to precisely detect single particles.

The research team, which also includes collaborators at the University of Geneva and Federico Santa María Technical University in Chile, tested its technology, called superconducting microwire single-photon detectors (SMSPDs) technology, at Fermilab. Team members exposed the quantum sensors to high-energy beams of protons, electrons, and pions, and demonstrated that the sensors were highly efficient at detecting the particles with improved time and spatial resolution compared with traditional detectors.

According to study coauthor Si Xie, the demonstration is a significant step toward developing advanced detectors for future particle physics experiments. "We have the potential to detect particles lower in mass than we could before, as well as exotic particles like those that may constitute dark matter," he said.

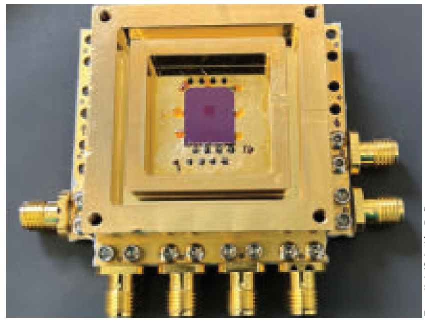
The quantum sensors used in the study are similar to a related family of sensors called superconducting nanowire single-photon detectors (SNSPDs), which have applications in quantum networks and astronomy experiments. For example, researchers at JPL recently used SNSPDs in the Deep Space Optical Communications experiment, a technology demonstration that used lasers to transmit high-definition data from space to the ground. Scientists from Fermilab, Caltech, and JPL have also used these sensors in quantum networking experiments. The program under which those experiments were performed, called Intelligent Quantum Networks and Technologies (INQNET), was jointly founded in 2017 by Caltech and AT&T.

For the particle physics tests in the recent work, the researchers used SMSPDs rather than the SNSPDs because they have a larger surface area for collecting the sprays of particles. They used the sensors to detect charged particles for the first time, an ability not required for quantum networks or astronomy applications, but essential for particle physics experiments.

"The novelty of this study is that we proved the sensors can efficiently detect charged particles," Xie said.

The SMSPD sensors can also more precisely detect particles in both space and time.

"We call them 4D sensors because they can achieve better spatial and time resolution all at once," Xie said. "Normally in particle physics experiments, you have to tune the sensors to have either more precise time or spatial resolution, but not both simultaneously."


Fermilab/Cristián Peña

Superconducting microwire single-photon detectors (SMSPDs) precisely detect single particles at a time. Detector technology based on these components was designed and fabricated at NASA's Jet Propulsion Laboratory and commissioned at the INQNET-Caltech Labs.

When researchers analyze the bunches of particles that fly out of high-speed collisions, they want to be able to precisely trace their paths in space and time. The team offered an analogy: Imagine you want to use security images to track a suspicious person hiding in a crowd of people flooding into Grand Central Station from various trains. You would want the images to have enough spatial resolution to track individuals. But you would also want enough time resolution to make sure you catch your person of interest. If you can only obtain images taken every 10 seconds, you might miss the person, but if you have pictures captured every second, you will have better odds.

"In these collisions, you might want to track the performance of millions of events per second," said Caltech physicist Maria Spiropulu. "You are swamped with hundreds of interactions, and it can be hard to find the primary interactions with precision.

"Back in the 1980s, we thought having the spatial coordinates were enough, but now, as the particle collisions become more intense, producing more particles, we also need to track time."

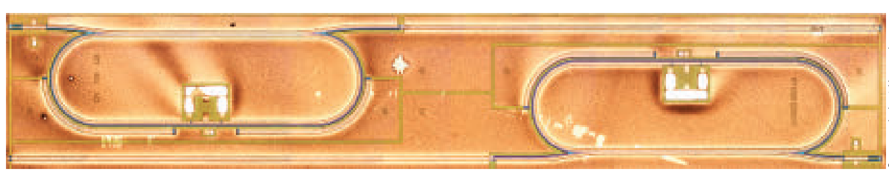
The research was published in the *Journal of Instrumentation* (www.doi.org/10.1088/1748-0221/20/03/P03001).

Capasso group develops quantum cascade integrated chip

CAMBRIDGE, Mass. — Physicists at the Harvard John A. Paulson School of Engineering and Applied Sciences (SEAS) developed a compact laser that emits extremely bright, short pulses of light in a useful but difficult-to-achieve wavelength range, packing the performance of larger photonic devices onto a single chip. According to the researchers, the work is the first demonstration of an on-chip, picosecond, mid-infrared laser pulse generator that does not require external components to operate.

The researchers used the device to make an optical frequency comb, offering evidence that the laser chip could eventually accelerate the creation of highly sensitive, broad-spectrum gas sensors for environmental monitoring, or new types of spectroscopy tools for medical imaging.

In addition to being a first-of-its kind demonstration, according to Federico Capasso, the Robert L. Wallace Professor of Applied Physics at SEAS, devices such as the on-chip mid-infrared device developed by the team can be readily produced using standard semiconductor fabrication processes at foundries.


Capasso Lab at Harvard

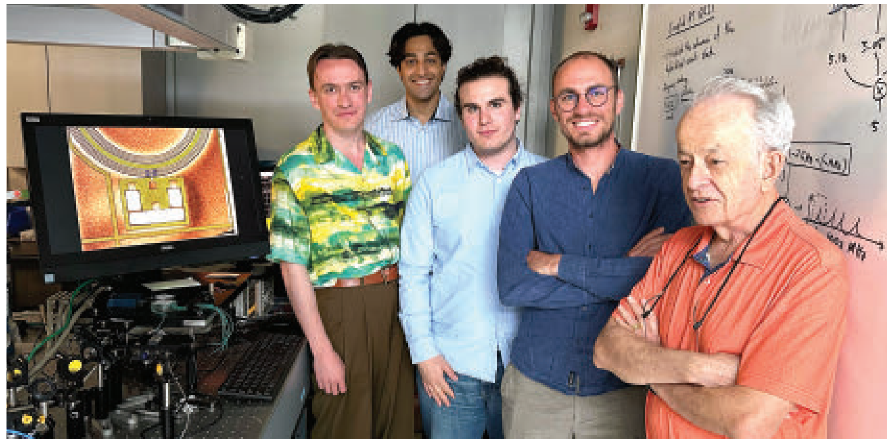
The quantum cascade photonic integrated chip contains two devices comprising four components each: a Fabry-Perot drive laser, a waveguide coupler, a resistive heater, and a racetrack resonator.

Because many gas molecules, including carbon dioxide and methane, absorb mid-infrared light efficiently, this wavelength range has been an important tool in monitoring environmental gases. The researchers' findings demonstrate a path to generating a broadband light source that could detect many different absorption fingerprints of gases in a single device.

"It's a key step to creating what we call a supercontinuum source, which can generate thousands of different frequencies of light, all in one chip," said Dmitry Kazakov, co-first author and research associate in Capasso's group.

The quantum cascade laser (QCL), which Capasso developed and demonstrated with a research team in the 1990s, is fundamental to the current group's feat of nanophotonic engineering. QCLs generate coherent beams of mid-infrared light by layering different nanostructured semiconductor materials. Unlike other semiconductor lasers that have relied for decades on mode-locking to generate their pulses, QCLs remain difficult to pulse due to their inherently ultrafast dynamics. Existing mid-infrared pulse generators based on QCLs typically require complex setups to achieve pulsed emission as well as many discrete hardware components. They are also generally limited to a certain output power and spectral bandwidth.

The pulse generator combines, into a single device, several concepts in nonlinear integrated photonics and integrated lasers to make solitons — specific types of picosecond light pulses. In designing their chip architecture, the researchers drew from a foundational theory published in the 1980s that established a framework for passive Kerr resonators, integrating the framework into the device's design. The device is made of a ring resonator that can be externally driven, an on-chip laser that drives the ring resonator, and a second active ring resonator that acts as a filter.

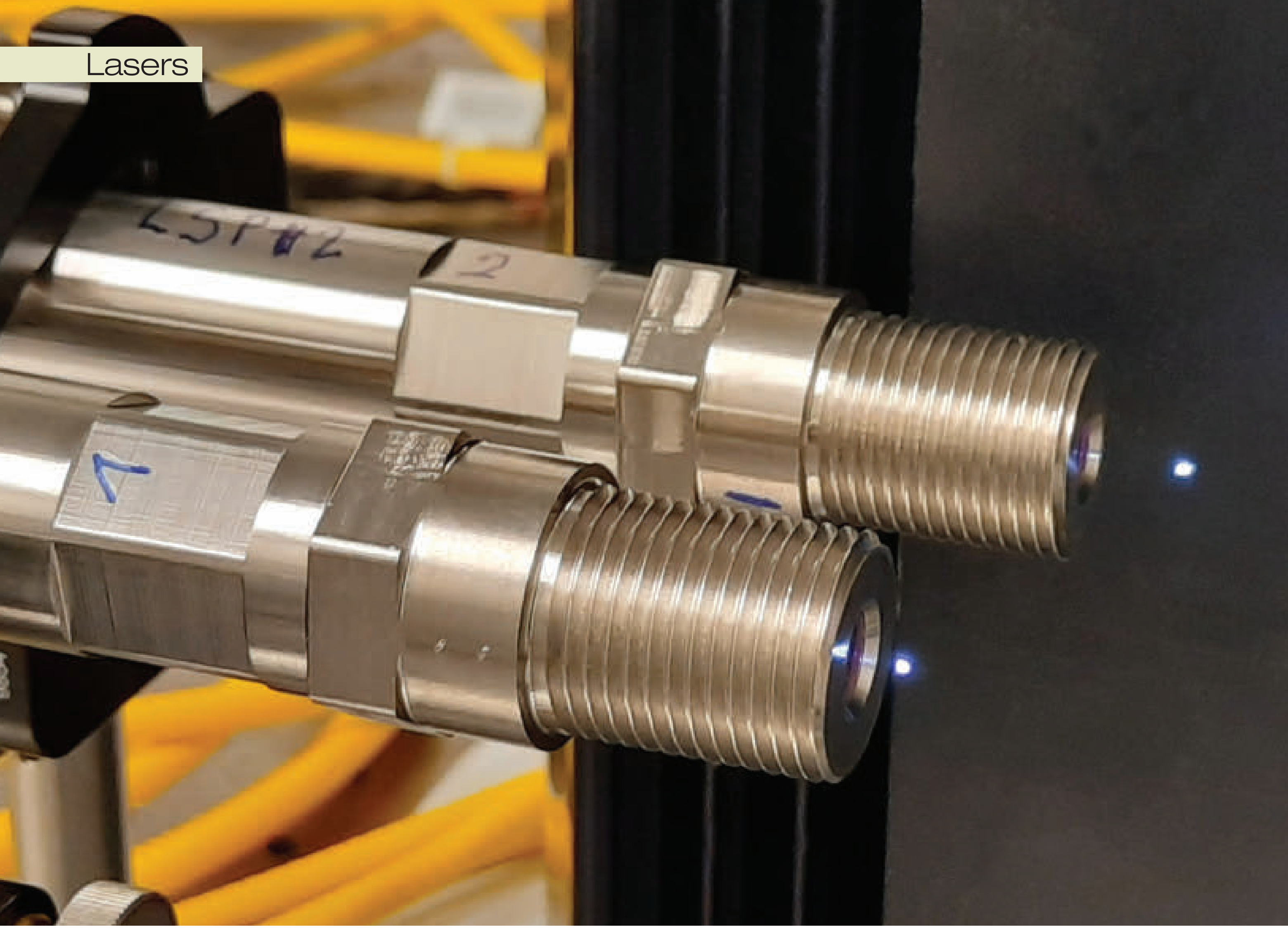


Capasso Lab at Harvard

(From left) Co-first author and research associate Dmitry Kazakov, research co-author Pawan Ratra, MIT graduate student and research fellow Theodore Letsou, research co-author Marco Piccardo, and senior author Federico Capasso, the Robert L. Wallace Professor of Applied Physics at the Harvard John A. Paulson School of Engineering and Applied Sciences (SEAS).

Additionally, the mid-infrared source reliably maintained pulse generation for hours at a time. Crucially, its widespread adoption could be significantly accelerated due to its mass-producibility via existing industrial fabrication processes.

The research was published in *Nature* (www.doi.org/10.1038/s41586-025-08853-y).



A Laser Spark Plug Saves Fuel and Reduces Emissions

Lasers may soon conquer another common application: igniting engines. Tests on a first prototype were shown to reduce fuel consumption and nitrogen oxides emissions.

All images courtesy of Fraunhofer IOF and INFLPR, Romania.

BY ERIK BECKERT, FRAUNHOFER IOF; NICOLAIE PAVEL, INFLPR;
AND ANDREAS THOSS, CONTRIBUTING EDITOR

Many of us will recall the science fiction comics of the 1970s, when lasers were imagined for everything from free-space communications to rocket propulsion. Some of these ideas have become reality — such as a new level of laser-based data transport around the world. Others, meanwhile, never made it past our wildest dreams.

One application that several companies and research institutions have pursued is laser ignition of combustion engines. But so far, a breakthrough has eluded these efforts.

Now, a joint German-Romanian collaboration of scientists and engineers from research institutions and one engine building company have presented a solution that worked for 19 h — until it was turned off by the operator.

Though the solution is not yet for sale at the car shop next door, the team has developed and tested prototypes and today has a clear road map for what to try next.

Combustion engines meet the task

Even at a time when wind and solar energy infrastructure are ramping up, there is a solid need for gas engines for energy generation. Combined heat and power (CHP) systems are highly desirable technologies for industrial, commercial, and municipal entities, often reaching energy efficiencies of >90%. The requirements for future energy-generation systems such as these are obvious: maximum efficiency with ever-lower emissions. Hydrogen engines allow for zero emission. As long as hydrogen remains unavailable, natural gas or biogas can be used to power CHP systems.

The German firm 2G Energy AG, a publicly traded supplier of CHP systems ranging from 20 to 4500 kW was the industry partner for the laser spark plug tests in real engines. These components are used in many settings, from private housing to data centers, and from agriculture to the packaging industry.

2G Energy's gas engines are sophisticated combustion engines, and the company suggested developing the laser spark plug for a highly charged lean-mixture engine. The so-called lean mixture is a mix of air and gas in which the share of air is larger than that which is stoichiometrically needed. In other words, if a gas molecule needs one oxygen molecule for combustion, then these engines use a mix where there are a few more air molecules than are needed.

In a car, a lean mix would lead to sputter, and the engine would stall, and the overcompensation could lead to backfiring. In a stationary engine with fixed rotation numbers and controlled conditions, this can be avoided. Burning all the fuel, a lean mix therefore allows for higher efficiency. Furthermore, the mix leads to lower combustion temperatures, and lower formation of nitrogen oxides (NOx) as a result.

Lean-mix engines require higher pressure, which leads to earlier degradation of the electric spark plugs. Laser ignition works better at higher pressure, and, as other published results have shown, leads to more stable ignition processes.

Also, the laser focus can be placed in an almost free-to-choose distance from the spark plug, and a train of several ignition pulses for one combustion can be generated.

The laser inside the spark plug

Conventional spark plugs generate an electric arc between two electrodes. A laser spark plug, in contrast, can generate a plasma spark at a point that is defined by its focusing optics for a pulse energy of several millijoules. This spark can be placed deeper in the prechamber since electrodes do not hinder the movement of the flame front.

The engineers' task was to develop a laser powerful enough to create a plasma spark that is compatible with regular engine operation. This meant that the laser system had to fit into the socket for an electrical spark plug, and its optics must create a laser focus at a proper distance of 8 to 11 mm.

The collaborators developed a small but powerful laser concept for this purpose. A composite Nd:YAG/chromium-doped yttrium aluminum garnet (Nd:YAG/Cr^{4+}:YAG) combination, purchased from France's Cristal Laser, was at the heart of this solution. The Nd:YAG ceramic laser medium is bonded to a piece of Cr^{4+}:YAG saturable absorber ceramic. One side of the Nd:YAG is coated for

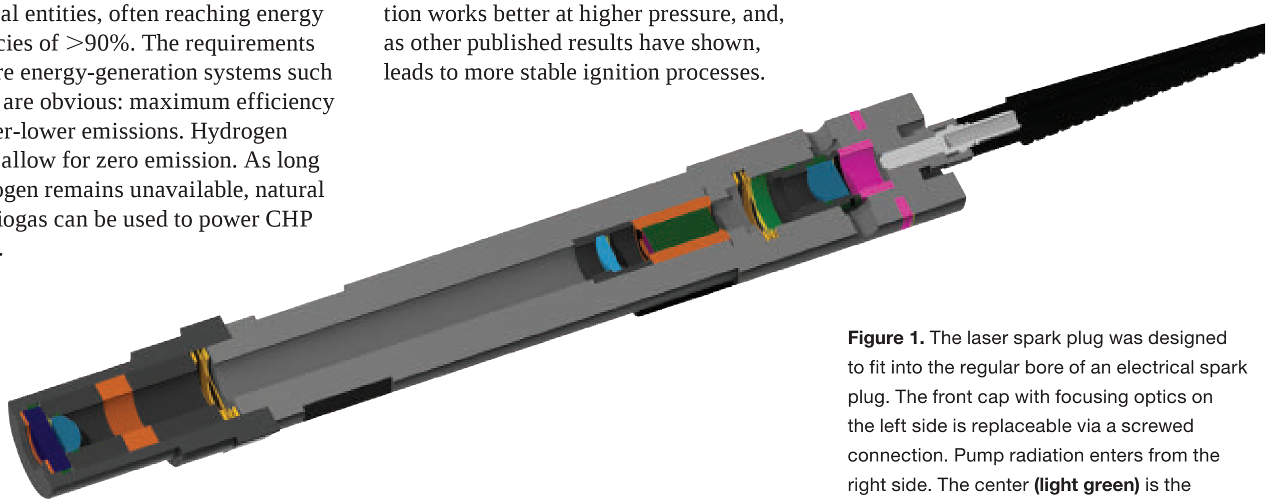


Figure 1. The laser spark plug was designed to fit into the regular bore of an electrical spark plug. The front cap with focusing optics on the left side is replaceable via a screwed connection. Pump radiation enters from the right side. The center **(light green)** is the composite laser/Q-switch crystal.

Figure 2. A set of four laser spark plugs during assembling and performance tests. The small sparks are laser plasmas, created due to air breakdown.

high reflectivity of the laser radiation at 1064 nm and high transmission of the pump radiation at 807 nm. The end facet of the Cr^{4+}:YAG is used as an outcoupling mirror. The short resonator length of ~11 mm and the characteristics of the composite Nd:YAG/Cr^{4+}:YAG ceramic medium yielded laser pulses shorter than 1 ns.

The team consists of researchers from the University of Bayreuth, Germany; the Fraunhofer Institute for Applied Optics and Precision Engineering IOF (Fraunhofer IOF) in Jena, Germany; and the National Institute for Laser, Plasma and Radiation Physics' (INFLPR)'s Laboratory of Solid-State Quantum Electronics, in Măgurele, Romania. Researchers at Fraunhofer IOF devised the mechanical design of the laser ignition system based on specifications provided by 2G (Figure 1). Fraunhofer IOF additionally manufactured and tested the laser spark plugs with assistance from INFLPR and the University of Bayreuth for the general flame-front formation properties during combustion (Figure 2).

Tests reveal limits — and opportunities

In motor tests, the energy and duration of a laser pulse reached 3.4 mJ and 0.9 ns, respectively, corresponding to a peak power of almost 3.8 MW. By adjusting the pump pulse duration at 807 nm, the Nd:YAG/Cr^{4+}:YAG laser spark plug could generate a single laser pulse or operate in pulse train mode with up to 10 laser pulses per train. The researchers designed the laser spark plugs to allow lenses with different focal lengths to be used for focusing the laser beam, as well as for in-chamber and prechamber configurations (Figure 3).

Initial experiments, performed in 2022, proved that laser ignition can be used in a gas engine. During the following months, the team performed a series of modifications on its first prototype; for example, the scientists redesigned the front cap housing the optics, making it replaceable and screwing it into place. This adjustment allowed further modifications to the optics without changing the laser itself (Figure 1).

At the end of 2023, the team began testing on a standard six-cylinder engine for lean-mix natural gas. The tests were designed for unsupervised operation within a laser-safe cabinet. Laser triggering was initiated via pump laser modulation, and issues with moisture inside the laser as well as soot on the windows were identified and resolved. The team also identified self-cleaning capabilities, which enabled the system to resolve the issue of soot on the laser windows.

The engineers applied standard engine testing methods such as high-speed pressure measurements. This enabled them to characterize combustion stability and peak pressure.

They then tested the spark plugs at several stationary operating points. The speed was kept constant at 1500 rpm and power levels were set to 200 kW, 250 kW, and 275 kW. This corresponds to mean pressures of 14 bar, 17.5 bar, and 19 bar, respectively. After the initial tests at 8 mm, the laser focus was set to 11 mm, and spark plugs with and without a prechamber were tested. The spark plugs were also tested with a clamped/glued window.

With an engine output of 200 kW, tests showed that the laser spark plug is, at minimum, as good in every tested mixture versus a regular electric prechamber spark plug. Moreover, if the engine is operated with a highly lean-gas mixture, the laser spark plug shows clear advantages in combustion. This advantage is discerned in a few-percent higher maximum pressure, faster combustion, and a decrease in NOx emissions.

At higher power levels, the laser spark plug loses this advantage. While it performs almost equally at 250 kW, it trails behind the electrical spark plug at the maximum power of 275 kW.

Another important parameter is the combustion stability, which is determined as the variance over several combustion cycles (coefficient of variation). For 200 kW, tests showed that the combustion was more stable with a laser spark plug that had a prechamber. Without a prechamber, the laser triggered combustion that is less stable than with an electrical spark plug, which always had a prechamber. The stability was higher for mixtures with less air — 500 NOx in exhaust — than for the leanest mixture — 120 to 190 NOx. Still, the laser ignition was more stable than the electrically ignited combustion.

One interesting issue involves the durability of the laser spark plug. For a too-short focal length of 8 mm, the lenses were fractured. However, this fracture did not occur at a focal length of 11 mm. The problem of debris on the windows, made of sapphire, was prevalent with the prechamber and nonexistent without the prechamber. In some cases, the laser burned through the debris, which established a self-cleaning process.

Next steps

The laser spark proved to be a viable solution for a serial gas engine. In certain conditions, the laser ignition was better than the electrical ignition. Future investigations will focus on modifications to the prechamber geometry, which is where the experts expect further optimization potential.

The team conducted tests with natural gas, such as methane. Hydrogen-fueled engines, for example, will require a different geometry. This should also eliminate any debris problems. In such a case, the laser ignition will offer a reliable solution for maximum efficiency and lifetime.

Based on the results of this project, laser spark plugs for stationary engines, such as those used in CHP systems, are now one step closer to reality. Other applications, such as laser-based rocket ignition, could become feasible as well.

This may again sound like a story from a 1970s comic book. But, as recent advancements in space technology have shown, many of these dreams have now become reality.

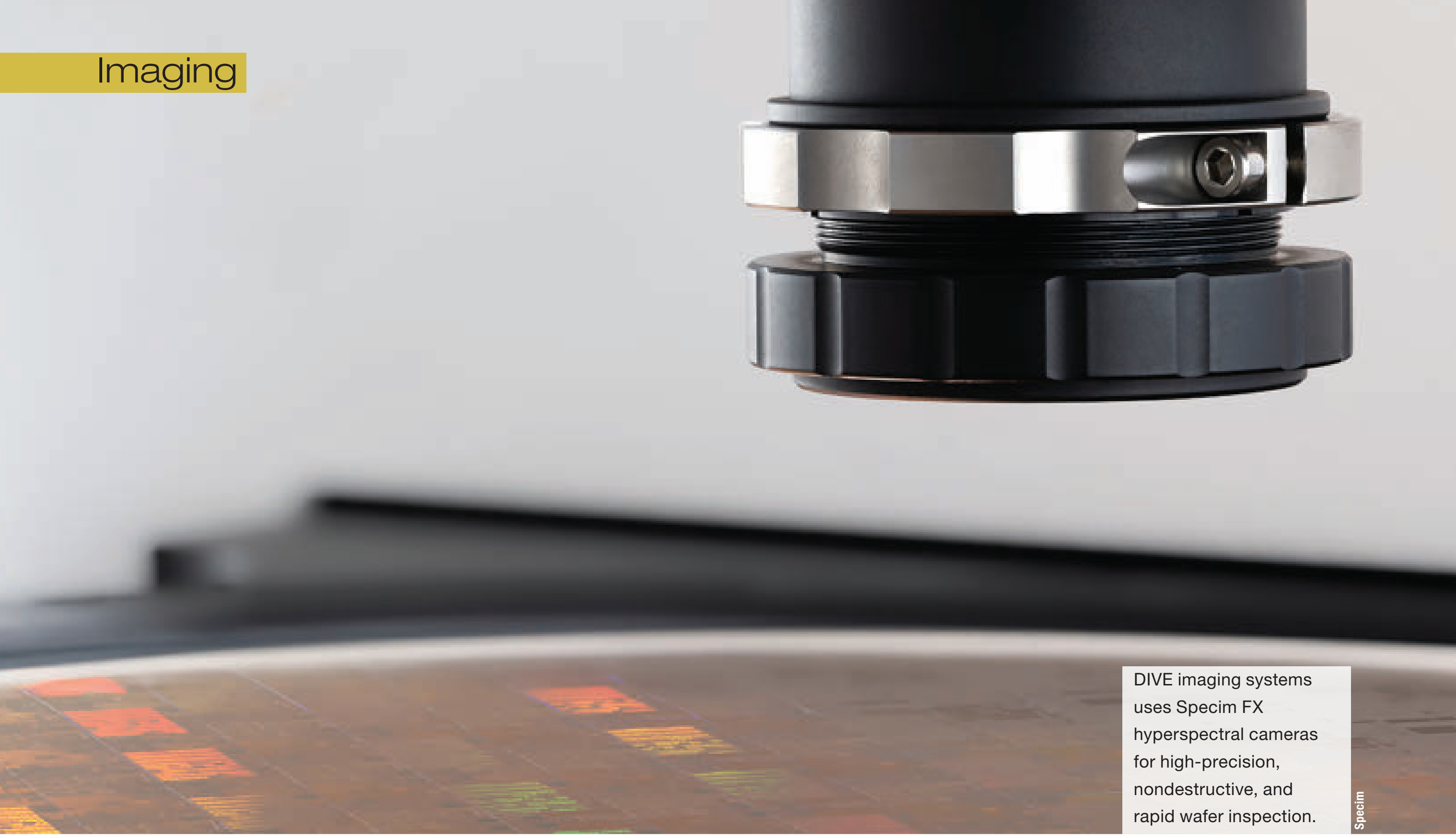
Meet the authors

Erik Beckert earned his diploma in precision engineering and a doctorate in optoelectronics system integration from Technical University of Ilmenau, Germany. He heads the Opto-Mechatronical Components and Systems department at Fraunhofer IOF in Jena, Germany; email: erik.beckert@iof.fraunhofer.de.

Nicolaie Pavel is a senior researcher at the National Institute for Laser, Plasma and Radiation Physics, Măgurele, Romania. He earned a doctorate in optics, spectroscopy, and lasers from the Institute of Atomic Physics, Bucharest, Romania; email: nicolaie.pavel@inflpr.ro.

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.

Figure 3. A close-up view of the type of laser spark plug used in the ignition experiments. A plug without a prechamber **(left)**.



DIVE imaging systems uses Specim FX hyperspectral cameras for high-precision, nondestructive, and rapid wafer inspection.

Hyperspectral Imaging Permeates Mainstream Manufacturing

Barriers to the manufacturing sector's adoption of hyperspectral imaging are falling, improving high-precision process inspections and real-time analyses for pivotal industries.

BY MARIE FREEBODY
CONTRIBUTING EDITOR

Hyperspectral imaging is firmly established in environmental monitoring and aerospace applications, and the technology is gaining favor across mainstream manufacturing. In sectors including semiconductors, thin films, energy materials, and displays fabrication, hyperspectral imaging provides detailed in-process insights. Precision and yield are paramount in these sectors; hyperspectral imaging optimizes these parameters while also offering high speeds of operation and a nondestructive approach to inspection.

Industry's appetite for hyperspectral imaging coincides with falling costs and greater availability. The benefits of the technique are obvious for many adopters. For example, unlike traditional point-based measurement methods, hyperspectral imaging enables users to capture both spatial and chemical composition data over large areas in real time. It also enables smarter and increasingly automated decision-making.

"We, as does most of the industry, regard hyperspectral imaging as the next major step in the evolution of industrial imaging," said Alexandre Fong, CTO of Hinalea Imaging Corp. "As expectations for product safety and quality evolve, there is a demand for higher image information density.

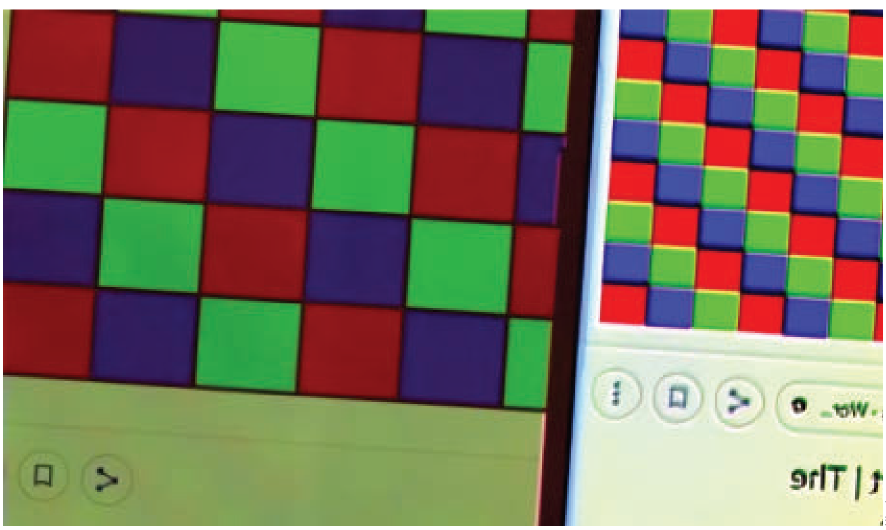
"I really believe we are at a convergence and inflection point with hyperspectral imaging. It has been in the wings as a research tool for some time, but the supporting data from that phase is out there and providing proof of its potential."

Into industry

Historically, industries in which material composition and uniformity are critical have been prominent users of hyperspectral technologies. In metallurgy, for example, hyperspectral imaging is used to monitor alloy composition, detect impurities, and ensure material quality. In the paper industry, it is used to analyze fiber distribution, coatings, and defects. And in mining, the technique is used to identify mineral compositions for sorting and extraction.

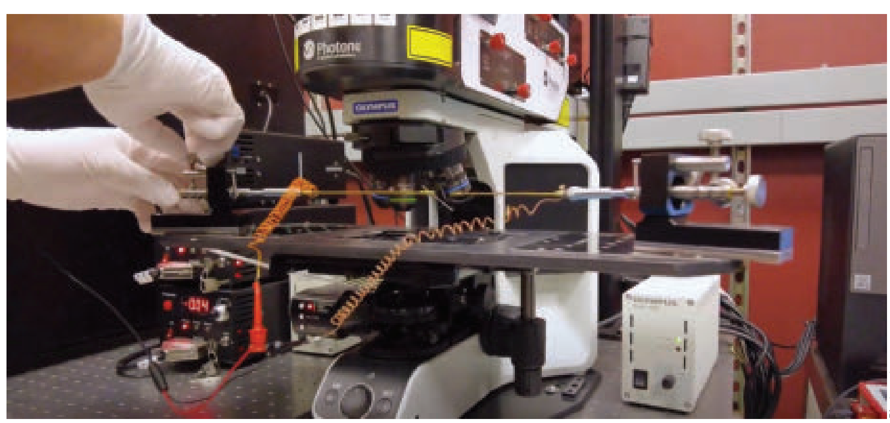
The technology's long road into manufacturing stems from several factors. A high entry price point, coupled with the complexity of its analysis methodologies, posed a multilayered barrier to adoption. In some cases, technical specifications, such as imaging and analysis speed, resolution, and the repeatability of hyperspectral cameras, presented challenges to prospective users in manufacturing. A nontechnical factor — a general lack of awareness of the technique — also contributed to the delayed rollout of hyperspectral imaging into mainstream manufacturing.

According to Julio Hernández, hyperspectral applications manager at Norsk Elektro Optikk (NEO) AS, the technology has evolved to address most of these issues. Further, owing to recent advancements in computing and data science and machine learning, experts today view hyperspectral imaging as more than



Hinalea

Data cubes of active-matrix organic light-emitting diode (AMOLED) displays from smartphone and tablet displays were captured and compared using a Hinalea Imaging VNIR hyperspectral camera to identify spectral and uniformity differences **(above)**.



Photon etc.

A setup for electroluminescence hyperspectral microscope imaging of photovoltaic materials **(right)**.

Hinalea

good science. Now, it is a viable tool for industry.

Oliver Grass, managing director of inno-spec GmbH, a Headwall Group company, said that this opportunity for hyperspectral imaging exists in parallel with the potential for broader adoption in industrial applications. "Until now, the high cost of hardware and the complexity of analyzing hyperspectral data have hindered widespread adoption," Grass said.

"However, the economics are changing, not only because the value of the products being inspected or graded has risen, but also because the barriers to entry are being effectively addressed."

The data is out

Thin films, lithium batteries, photovoltaics, and printed circuit board and LED displays fabrication are logical sectors in which to implement hyperspectral imaging systems, according to Hernández. "These industries require high spatial uniformity in chemical properties for quality control, but high-volume production often limits detailed inspections," he said.

HySpex is an early demonstrator of hyperspectral imaging for the evaluation of thin-film coatings. Using its VNIR-1800 hyperspectral cameras, it has conducted assessments on titanium dioxide (TiO_2)-coated polymer substrates with varying thicknesses. TiO_2-coated surfaces support multiple applications, including solar cells and antifogging and self-cleaning windows.

Beyond detecting the presence and position of a component in a captured image, hyperspectral imaging enables users to chemically identify and quantify it. This level of detail is an improvement on the capabilities of conventional color cameras and standard image processing algorithms. It is also essential for revealing phase changes in materials, enabling operators and automated systems to make timely and informed adjustments.

According to Minna Törmälä, global marketing manager of spectral imaging firm Specim, compact and easy-to-integrate hyperspectral solutions compare favorably to these other approaches, especially in industrial environments. In such settings, higher resolution and speed enable real-time monitoring.

"Traditional imaging methods, such as multispectral and RGB cameras with AI or laser interferometry, are valuable

Hinalea

Hinalea's Model 4400, mounted to a 'magnetic crawler,' images a decommissioned nuclear reactor head **(left)**. The hyperspectral camera is tested for its ability to detect pipe leaks by identifying the presence of boric acid corrosion **(above)**.

for specific applications, but have limitations," she said. "For example, multispectral cameras are designed to detect specific contaminants using predefined spectral bands, making them highly specialized but less adaptable to new detection needs. RGB cameras with AI analyze materials based on color and shape, but cannot determine their chemical composition." These approaches, particularly those using deep learning, require large training data sets and offer limited flexibility. Hyperspectral imaging captures more detailed spectral information, supporting its use in broader and more versatile applications.

Further, many quality control processes still rely on experienced specialists, Grass said. He emphasized the need to transfer this expertise to automated, impartial systems.

In this context, hyperspectral imaging offers a promising solution.

"While conventional RGB color cameras or multispectral cameras with a limited number of wavelengths may appear less expensive at first, they may need to be replaced when the customer's needs change, which can significantly [influence] the overall economics," Grass said.

Inspections beyond surface-level

In the semiconductor sector, manufacturers and engineers use hyperspectral imaging throughout the lithography and deposition processes to analyze the spatial distribution of thin-film thickness in oxides, resists, and surface parameters. Combining detailed spectral data with high-resolution imaging helps manufacturers to ensure wafer consistency and monitor quality in various stages of production.

Hinalea's hyperspectral system is one of the commercial options supporting this range of applications: Its system is configurable to monitor both critical changes in semiconductor wafer etching processes as well as to inspect the finished product. In wafer inspection, hyperspectral imaging offers significant advantages compared with traditional methods, enabling noninvasive, full-area inspection as an alternative to random sampling.

A different technique, photoluminescence mapping, is commonly used to identify variations in material composition, crystal defects, and contamination at a microscopic level. "[Photoluminescence] spectra are acquired using standard classic dispersive spectrometers either point-by-point or line-by-line (push broom) spatial scanning," said Marc Verhaegen, CTO of Photon etc. "On the other hand, hyperspectral imaging instruments can use wavelength-tunable filters to capture the entire field of view with no spatial scanning, while scanning wavelength bands."

Although these so-called "staring" instruments have mainly been used for semiconductor characterization in academic research, the approach can be faster than using spatial scanning systems when only a limited number of spectral bands are required.

Given the distinct capabilities of both techniques, hyperspectral imaging can be used to complement photoluminescence with spectral information. For materials composed of multiple elements — such as perovskite or gallium arsenide photovoltaics, for example — hyperspectral imaging provides important information for determining exact composition, going one step beyond simply determining the presence or absence of compositional variations. Photon etc. has developed a solution platform that supports hyperspectral photoluminescence imaging.

Another adopter, Radeberg, Germany-based DIVE imaging systems, has integrated Specim's FX10 and FX17 hyperspectral cameras into semiconductor manufacturing processes. DIVE offers precise surface and layer analysis of semiconductor wafers. The technology can be used to inspect a 300-mm wafer in just 30 s, helping to reduce cost and waste.

Elevating battery and electronics coatings

Thickness is a fundamental parameter in thin films, directly affecting functionality and performance. Traditional inspection methods rely on point spectroscopy, which produces an incomplete zigzag inspection pattern. Hyperspectral imaging inspects the entire film or coating, capturing each line and generating spectroscopic data for the whole film at a high spatial resolution.

Specim's GX17 near-infrared hyperspectral camera analyzes the homogeneity and thickness of protective coatings on printed circuit boards.

Specim

Specim hyperspectral cameras are used to detect contaminants and measure areal distributions of resists, oxides, nitrides, and more. The metal industry uses these cameras to check the homogeneity of coatings in lithium-ion batteries, evaluate the protective and functional coating inspection of electronic components, and provide surface inspection. In lithium-ion, as well as in other advanced batteries such as solid-state or sodium-ion, the electrode materials contain active material particles and often include conductive additives. Creating a uniform, electrochemically active layer that enables consistent ion and electron flow during charging and discharging cycles is crucial for consistent performance and durability, and to prevent dangerous overheating.

"With the rise of electric vehicles and energy storage solutions, monitoring electrode coatings to ensure consistency in battery production is becoming critical," Törmälä said.

According to Grass, ultraviolet hyperspectral imaging is vital for these types of inspections.

"A benefit of deeper UV, down to 220 nm in this case, is that manufacturers [can] better characterize thinner films," he said. Inno-spec has introduced an integrated system that uses a hyperspectral camera operating deeper in the UV than prior solutions.

Spectral precision in display inspection

According to a Market Research Future report, the global 4K resolution display market was valued at $31.5 billion in 2024 and is projected to grow from $34.4 billion in 2025 to $75.7 billion by 2034, increasing at a compound annual growth rate of 9.2% during this period. Rising consumer demand for high-performance visual experiences in ultrahigh-definition televisions, professional-grade monitors, smartphones, and immersive AR/VR systems is driving this growth.

Resolution, contrast, and color accuracy are key differentiators between current and next-generation displays. Precise spectral control is no longer optional. It is essential for both image fidelity and viewer comfort.

The careful selection and integration of light-emitting components, particularly LEDs and/or micro-LEDs, are at the heart of determining display quality. The spectral characteristics of these emitters — peak wavelength, full width at half maximum, and spectral purity — directly influence the color gamut, white point accuracy, and overall energy efficiency of the display. The color conversion layers, such as quantum dots or phosphors, antireflective coatings, encapsulation layers, and optical diffusion or enhancement films, must be of uniform thickness and composition to ensure minimal spectral shift over time, accurate pixel-level brightness, and enhanced visibility under varying lighting conditions.

To this end, hyperspectral imaging fills a current gap of knowledge in process and quality control. For example, in display tests, conventional methods for measuring color and brightness use cameras with sets of discrete color filters. Such systems often miss subtle spectral differences that influence the trueness of the captured image. Hyperspectral images, however, reveal subtle reflected color differences that are not observable by the human eye or even RGB camera images. The color metrics of tablets or smartphones, for example, are immediately identifiable by a comparison of spectra between pixels.

These advantages are critical because even minor deviations in film thickness or chemical makeup in advanced manufacturing lines can lead to color banding, image artifacts, and performance inconsistencies. Hyperspectral imaging enables manufacturers to monitor and optimize deposition processes in real time, to detect subtle variations in material properties that traditional RGB or multispectral cameras cannot resolve.

"A high-resolution hyperspectral camera, [either] spectral [or] spatial, can be used to simultaneously monitor these properties with great accuracy using an interferometric approach in addition to the chemical signature identification," NEO's Hernández said. "These results can be used in a feedback loop to fine-tune the deposition process and improve the final product."

The next generation of solar cells

As quality control in semiconductor and displays manufacturing drives the growth of hyperspectral imaging systems, demand is increasing for advanced characterization tools in the photovoltaic industry. In photovoltaic facades, hyperspectral imaging enables detailed color resolution inspection, which is needed to ensure uniformity and precision — factors that themselves are important for architectural integration.

Further, the rise in popularity of materials such as perovskite and perovskite/silicon tandem cells, which are now being produced at large scales, increases the need for precision in photovoltaic inspections.

"Unlike traditional silicon solar panels, which typically do not require spectral measurements for quality control, perovskite-based technologies benefit significantly from hyperspectral imaging," Photon etc.'s Verhaegen said. "This technology enables the assessment of electrical performance, defect detection, and layer thickness in these advanced solar cells, ensuring higher efficiency and reliability."

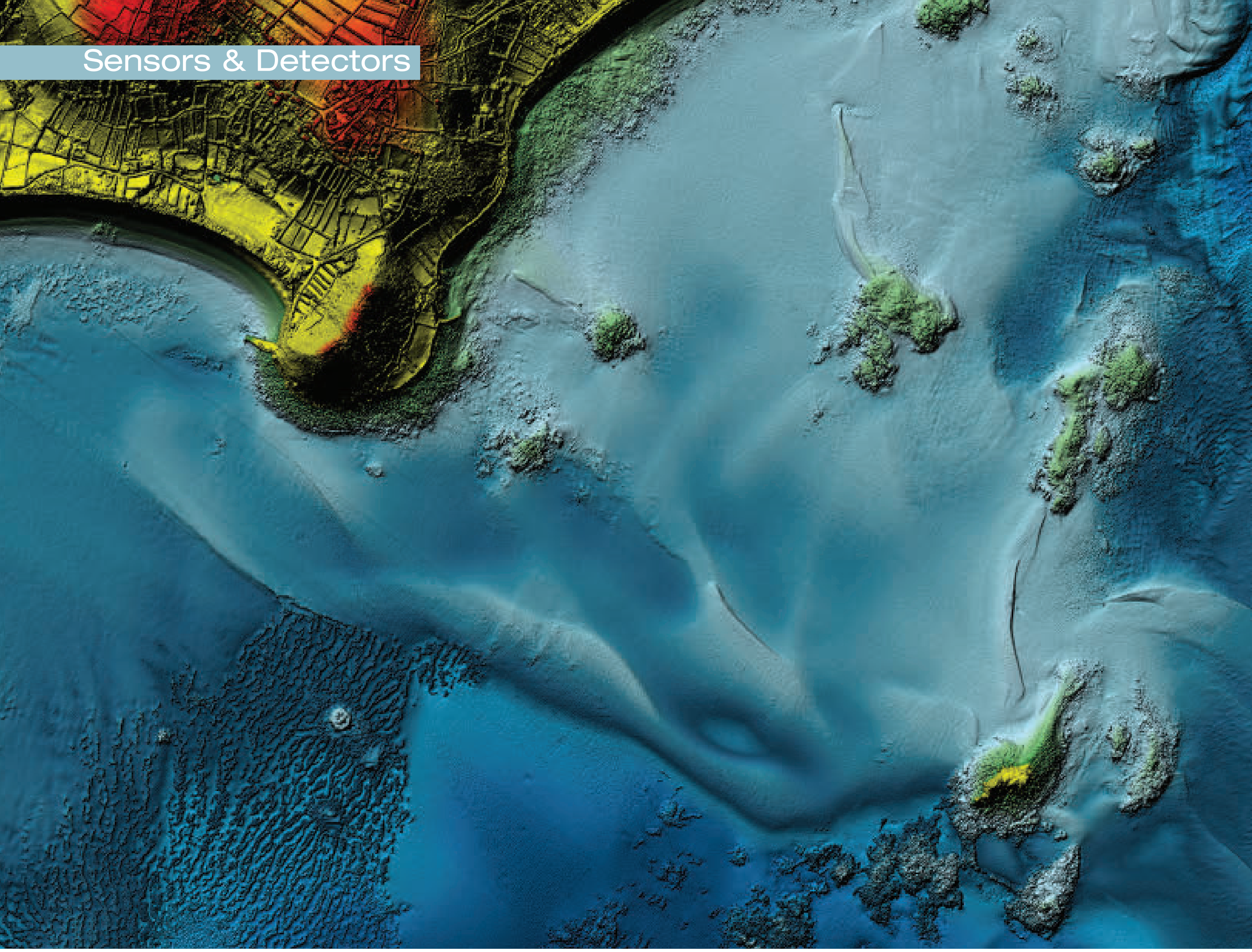
Photon etc. uses what it calls both "macro-" and "microscopic" hyperspectral imaging to map electroluminescence and photoluminescence, identify defects, and analyze compositional inhomogeneities and degradation processes across large sample areas. These detailed analyses contribute to the development of more efficient and reliable solar energy solutions.

From emerging to essential

Hyperspectral imaging's future in manufacturing is technically robust and, increasingly, within reach. As hardware costs fall and integration becomes simpler, this technology is moving beyond niche applications into mainstream use. Its utility to detect, identify, and quantify materials with high spatial and chemical accuracy makes it invaluable in sectors where traditional machine vision and/or human inspection fall short.

The final hurdle to a broader adoption is confidence, which is poised to grow through continued collaboration. As trust in the technology builds, so too will economies of scale, further accelerating adoption.

mariefreebody@physics.org



Underwater Lidar

Gives Maritime and Subsea Applications the Green Light

Lidar systems are helping scientists to push into new markets below the surface.

Opening image courtesy of **Leica Geosystems**.

YellowScan

A drone carries YellowScan's bathymetric lidar system. The lidar system uses a green laser at 532 nm for underwater scanning.

BY JAMES SCHLETT
CONTRIBUTING EDITOR

The rollout of self-driving cars onto metropolitan roadways is proof that lidar systems play a major role as an enabling technology to next-generation solutions. With providers such as Waymo and DeepRoute.ai debuting versions of their self-driving vehicles in North American and Chinese hubs, respectively, lidar technology is more synonymous than ever with autonomous mobility.

Advancements to laser sources and optical components are behind the increased durability and high performance of lidar solutions on the market today. These improvements offer users higher stability, increased power efficiency, and better signal clarity. Additionally, systems designers may combine lidar with the capabilities of sensing modalities such as radar and camera imaging, to create increasingly integrated systems that yield data from multiple sensors.

These benefits extend to off-road applications. Lidar systems are providing engineers and end users with a literal green light to operate in maritime, coastal, and deep-sea environments. The same component- and system-level improvements that are pushing lidar's sustained adoption for self-driving vehicles are broadening lidar's utility for underwater industrial applications and subsea research.

Quantum lidar

Last year, Hoboken, N.J.-based Quantum Computing Inc. (QCI) completed the sale of its quantum lidar prototype to Johns Hopkins University. The prototype system is engineered to float on a raft or mount on the deck of research vessels. The collaborators plan to use it to monitor phytoplankton movement and nutrient distribution, among other studies.

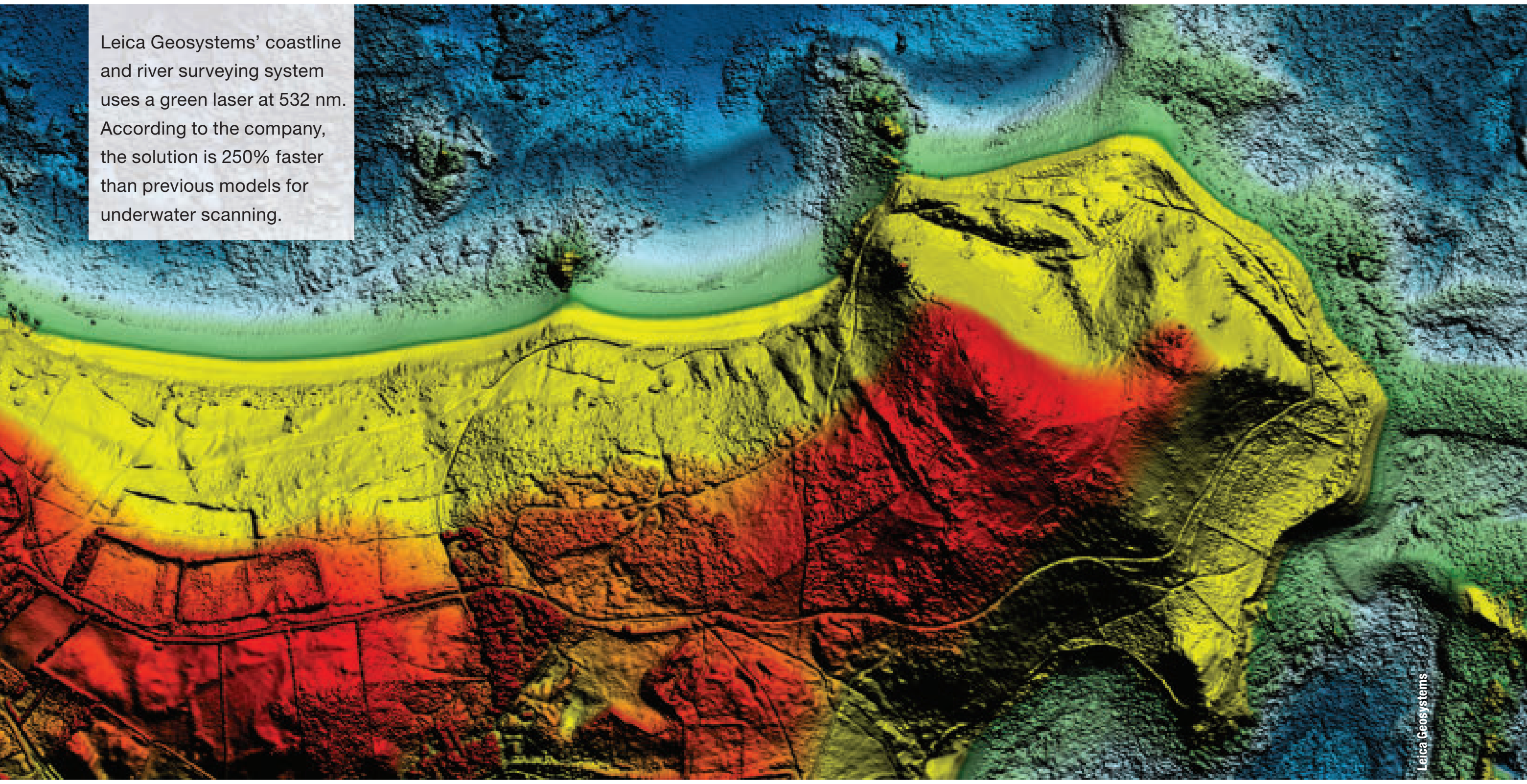
Unlike traditional underwater lidar systems, QCI's prototype detects individual photons rather than relying on the aggregate of many. This single-photon approach has a direct effect on enhanced depth performance. The method enables the quantum lidar mechanism to detect faint signals from only a handful of photons bouncing back from an underwater object, according to QCI CEO William McGann.

Further, because quantum lidar solutions such as these precisely record the arrival time of individual photons, the method delivers more accurate distance measurements than alternative techniques. It also enables more effective 3D imaging, and the single-photon mechanics of quantum lidar improve the filtering of background noise. The result is a finer distinguishment between true signal and unwanted interference.

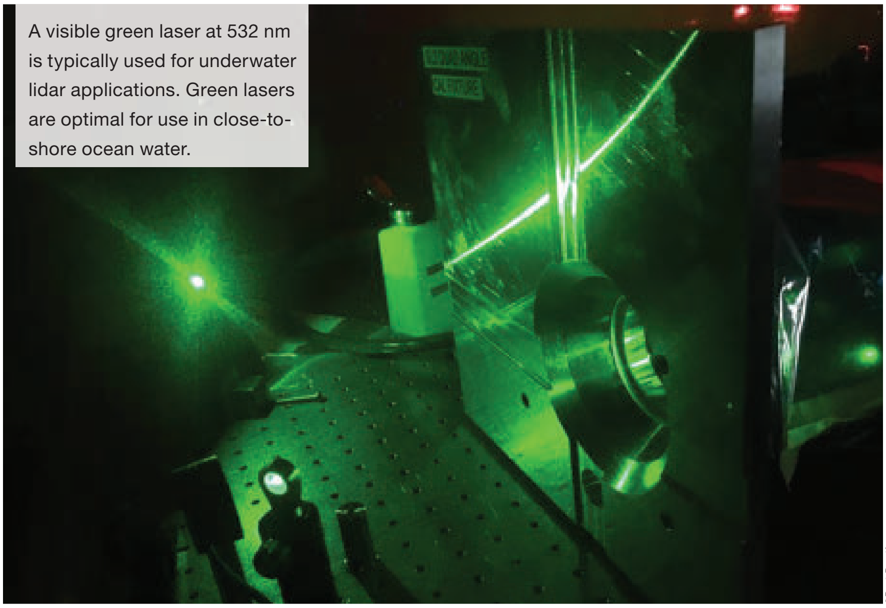
"In simpler terms, it's like listening for a whisper in a noisy room, and our technology is finely tuned to catch that whisper," McGann said.

QCI's quantum lidar protype uses a picosecond-pulsed laser with an output power of 3 W at a 1-MHz repetition rate. The system delivers 3-mm resolution and measures depths of ~100 m in clear water, though this range could be extended with a low-repetition-rate laser with sufficient power. To achieve submillimeter resolution, McGann said that the quantum lidar system could be supplemented with quantum parametric mode sorting.

The early-stage development of this technology carries a cost and a physical size-of-system that is more applicable to maritime research, but engineering improvements could chart a course for



Leica Geosystems' coastline and river surveying system uses a green laser at 532 nm. According to the company, the solution is 250% faster than previous models for underwater scanning.



A visible green laser at 532 nm is typically used for underwater lidar applications. Green lasers are optimal for use in close-to-shore ocean water.

quantum lidar to become more enticing to the underwater surveying, industrial inspection, and environmental monitoring industries, McGann said. Compared to research, subsea industrial applications require different lidar systems with distinct technical and physical parameters.

The green light

QCI's quantum lidar system uses a green laser at 532 nm, which is the standard wavelength for lidar for underwater applications. "[Five hundred thirty-two] nm is used because frequency doubling from 1064 nm is a mature path," said Xiyuan Lu, a postdoctoral researcher in National Institute of Standards and Technology's Microsystems and Nanotechnology division. "Depending on the ocean water condition, different wavelengths are needed in different cases." According to Lu, in deep ocean water, for example, blue lasers typically offer better performance than their green wavelength counterparts. In close-to-shore ocean water, or water with more phytoplankton, green lasers provide superior performance.

The use of blue-green light for underwater imaging enables a greater scatter, which, according to McGann, supports greater depth penetration. Water also achieves less absorption of blue-green light than pure green, at 532 nm. And it travels farther, produces better images, enhances contrast, and can even induce fluorescence in certain organisms.

Despite these benefits, blue-green light poses challenges for underwater lidar; silicon detectors are less efficient in this range. Photomultiplier tubes and/or superconducting nanowire single-photon detectors (SNSPDs) offer alternatives, but each comes with its own drawbacks.

Photomultiplier tubes are bulky and sensitive to magnetic fields. SNSPDs, meanwhile, require cryogenic cooling and are costly.

Manned aerial lidar

Earlier this year, Leica Geosystems, a Hexagon subsidiary, introduced a coastline and river surveying system that uses a green laser at 532 nm. For underwater scanning, according to the company, the solution is 250% faster than previous models.

From 2012 until the rollout of the solution earlier this year, Leica used 515-nm sources for its bathymetric lidar systems. According to Anders Ekelund, vice president of airborne bathymetric lidar at Hexagon, the physical difference between 515 and 532 nm is minimal. Leica has favored a 515-nm solution due to an increase in efficiency in internal system components.

Leica's newly introduced system is designed for manned aircraft. It integrates bathymetric lidar, topographic lidar, and high-resolution imaging into a single system. The solution synchronizes and co-aligns the 1030-nm pulses, used for water surface measurements, with the 515-nm laser pulses. The "topo-bathy" system can cover 360 sq km/h.

According to Ekelund, the increased scanning speed lowers users' flight costs and increases revenue potential. Its depth penetration ranges from ~40 m in clear waters to 20 m in moderately clear waters to 10 m in turbid waters. The system can capture 1 million bathymetric and 2 million topographic data points/s, with high-resolution imagery at a 5-cm ground sampling distance. Its capture rates were up to 1000 kHz for bathymetric data and 2 MHz for topographic data, and its scan speeds were up to 84 Hz, or 168 scans/s.

This increased performance enables geospatial data to be scrutinized via AI-driven analysis, which is critical for alerting government agencies to shoreline retreats, shifting riverbeds, and underwater infrastructure vulnerabilities, according to Ekelund.

Leica's solution is not the only one of its kind on the market. Last year, Teledyne Optech introduced a system that combines bathymetric and topographical lidar sensors and a multispectral camera. With a coverage rate of 50 sq km/h for coastal areas, the manned aircraft system offers real-time processing that allows data to be mined as it is collected.

"Data is being collected to be actioned, whether it is an industrial application like monitoring disturbances around a pipeline, or disturbances in a port, or an offshore infrastructure. Real-time processing enables a faster response to data, which in turn will deliver a faster resolution," said Malek Singer, a senior product manager for Teledyne Optech.

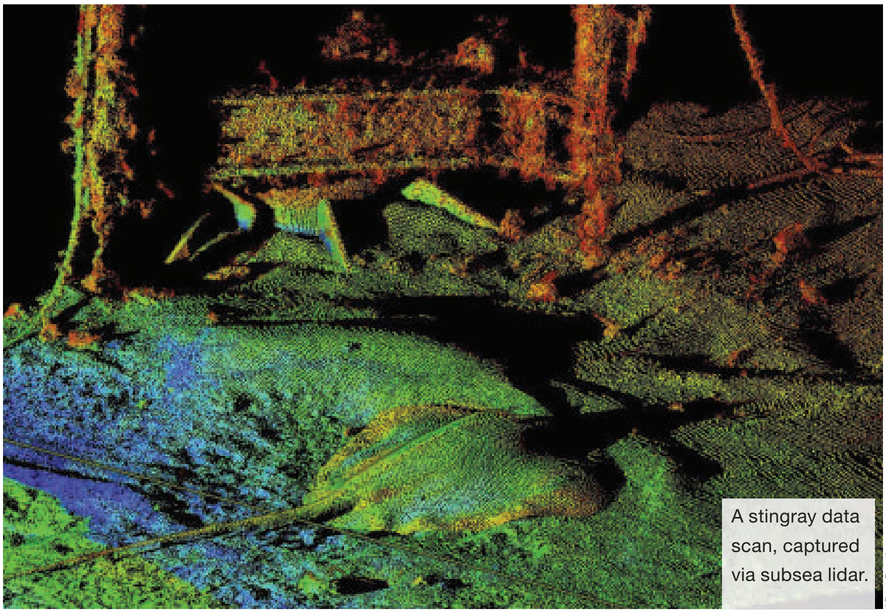
The bathymetric element of the Teledyne Optech system features a high-power laser that uses both a 1064-nm IR wavelength for mapping the water surface, and a 532-nm green wavelength for mapping submerged terrain. This combination of IR and visible green wavelengths contributes to higher georeferencing accuracy, because their returns are coaxial and there is more precision in the refraction correction between the surface of the water and the bathymetric system, according to Singer. It uses four shallow channels, each pulsing at up to 60,000 shots/s. The topographic subsystem pulses up to 2 million points/s. It can collect data independently at up to 1200 m of altitude.

However, the 50 sq km/h coverage rate for coastal areas is contingent on maintaining an altitude of 475 m. The coverage rate could be accelerated at higher altitudes, but this would decrease the system's depth potential, which ranges from 45 m in clear waters to 25 m in more typical water conditions to 5 m in dark waters with organic bottoms.

"Systems have historically benefited from bigger lasers — higher-power lasers with more sensitive optics," Singer said. "That trajectory has been successful, and we expect it to continue to improve in developing lasers with shorter pulse widths, higher pulse repetition frequencies, and [in] digitizing hardware with higher sample rates."

Unmanned aerial lidar

Bathymetric lidar systems for manned aircraft are designed for large-scale projects exceeding 100 sq km per day. For smaller-scale projects, unmanned



A stingray data scan, captured via subsea lidar.

3D at Depth

aerial vehicles (UAVs) are a better option. Drones equipped with bathymetric lidars can fly at low altitudes, which supports greater depth penetration even though it is limiting to the potential area that the system can cover.

The coverage area of UAVs is further constrained by slow collection speeds and flight times that last ~30 min before the battery needs to be exchanged, according to Ekelund. Nevertheless, the trade-off between a smaller coverage area and a deeper penetration may be appealing for several industrial applications, such as pipeline and subsea cable inspections, oil and gas, offshore wind farm development, and port and harbor maintenance.

Last year, aerial solutions firm Volatus Aerospace entered into a partnership with Dragonfly, a drone developer. The collaborators are combining Volatus' bathymetric lidar systems with Dragonfly's heavy-lift drones to provide precise underwater mapping and improved efficiency in oil and gas exploration.

"The size and weight reduction of bathymetric lidar systems over the last few years has opened new possibilities for deployment on drones, giving them more access for surveying hard-to-reach areas, expanding the range of applications," said Lee Dodson, strategic projects leader for Volatus Aerospace. For underwater surveys, Volatus uses a bathymetric lidar system developed by YellowScan, a company whose system uses the 532-nm wavelength with 3-cm precision and a laser range of up to 120 m.

Obtaining accurate results in hard-to-reach areas feeds into considerations of water quality and other environmental factors. "Depth penetration is highly dependent on water clarity, with turbid or murky waters significantly reducing accuracy and range," Dodson said. "Additionally, reflections from surface waves, bubbles, and submerged vegetation will introduce noise and reduce data quality.

"Complex bottom topography and high reflectance variability also affect results: Lidar technology cannot overcome these physical limitations. Only integration with other types of sensors can overcome these challenges. More advancements in laser power in smaller systems and improved AI and algorithms may overcome some limitations, but there is not much else that can be done with this technology due to its dependence on light penetration."

Subsea lidar

Due to water clarity limitations, bathymetric lidar, which is typically airborne, becomes ineffective beyond depths of 50 to 75 m. Beyond these depths, subsea lidar — deployed via remotely operated vehicles (ROVs) and/or autonomous underwater vehicles (AUVs) — operates more effectively in complete darkness and high-pressure environments, according to Brook Rodger, director of business development for 3D at Depth. In 2017, the Longmont, Colo.-based company introduced a subsea lidar system that can be operated at depths of up to 4000 m. This year, it plans to debut a model with a depth rating of 6000 m.

Though 3D at Depth's subsea lidar systems are typically used for oil and gas and nuclear facility inspections, last year, a deployment of its 4000-m technology used the solution to scan the Titanic. The company's subsea lidar systems use Nd:YAG lasers that operate at 532 nm and achieve submillimeter measurement precision. Demand for higher-resolution measurements with 0.001-in. accuracy or better is especially high in the nuclear industry. The laser and optics in 3D at Depth's most recent model, with a 6000-m depth rating, provide a wider field of view, smaller package volume, and improved signal clarity for deepwater environments and high-speed scanning, according to Rodger.

In addition to these improvements, the 2025 system offers data collection capabilities that are 10× faster than previous models, enhanced by real-time processing optimizations and AI-driven enhancements. The system also has a smaller footprint, making it easier to integrate with a wider range of vehicles, from ROVs to torpedo-style AUVs. Its 360° scanning capabilities make it ideal for pipeline inspections, both internal and external. The system has a pulsed time-of-flight measurement method with a pulse rate between 200 and 300 kHz and a range of up to 45 m.

"A few years ago, real-time lidar scanning from an AUV was considered impractical due to power and data limitations. Today, our lidar systems can autonomously collect and process high-resolution 3D data while operating untethered, revolutionizing offshore inspections, decommissioning, and marine research," Rodger said.

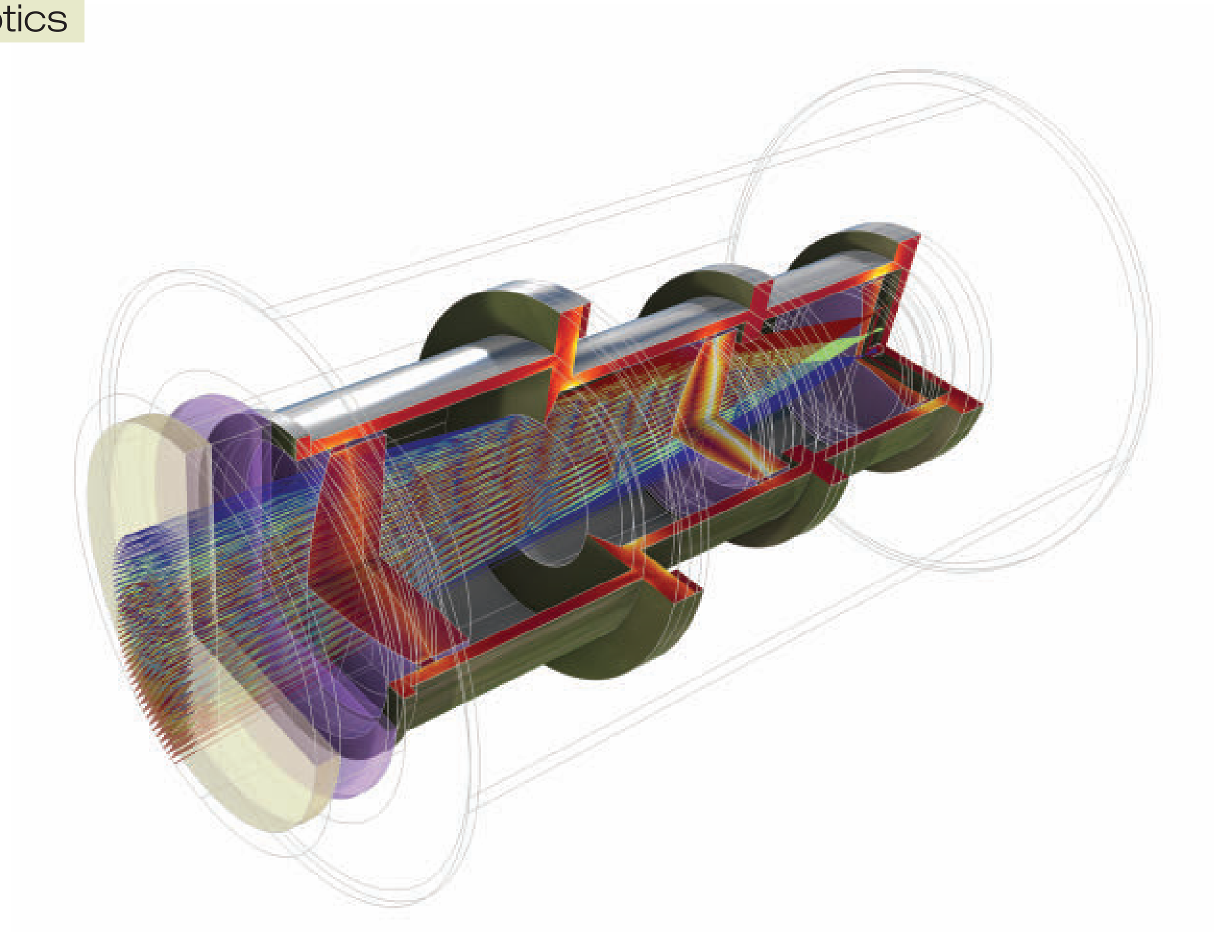
MBARI, the Monterey Bay Aquarium Research Institute in Moss Landing, Calif., is among the early adopters of 3D at Depth's subsea lidar system. Since 2013, it has used iterations of 3D at Depth's subsea system attached to ROVs to scan the ocean floor and study deep-sea creatures.

Now, the use of the company's latest subsea lidar system in an AUV is especially appealing to the nonprofit oceanographic research center. ROVs tethered to vessels only enable researchers to scan a 100- × 100-m patch of ocean floor in one day. Using the subsea system with an AUV would enable personnel to scan vastly larger swaths.

"It is going to be faster, it is going to produce more data, it is going to be a wider swath, and it is going to be a simpler, smaller low-power system," said David Caress, MBARI's principal engineer of seafloor mapping.

"And the reason that is so important is because we want to put this on an AUV."

jschlett180@gmail.com



Surrogate Models and Simulation Apps Revamp the Optical Design Toolkit

Simulation apps and surrogate models, including their use with digital twins, make design processes more efficient. Organizations in optics and photonics are exploring applications for these tools.

Opening Image courtesy of COMSOL.

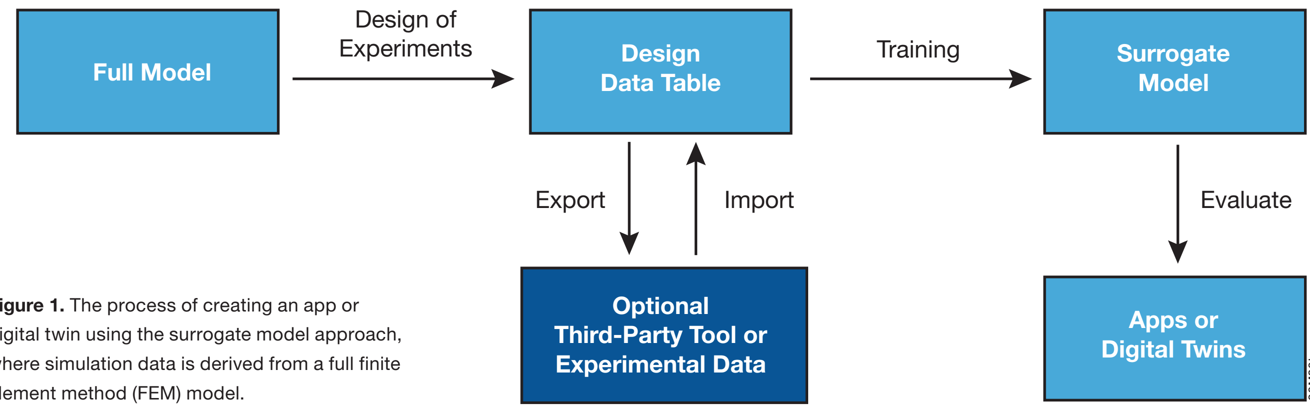


Figure 1. The process of creating an app or digital twin using the surrogate model approach, where simulation data is derived from a full finite element method (FEM) model.

BY ANDREW STRIKWERDA
COMSOL

Simulation enables engineers working across a broad range of disciplines to properly characterize, predict, and improve the behavior of systems. Numerous industries, including telecommunications, health care, and manufacturing, have embraced simulation as a fundamental aspect of the design process. Fiber optics, imaging technology, and lasers for cutting and welding are among the high-performance, high-precision applications in optics and photonics that benefit from increasingly sophisticated simulation capabilities.

Optimizing the alignment between a simulation and the real world requires engineers to account for all the physics phenomena that influence the optical behavior of a device. Traditionally, such multiphysics modeling has been conducted by engineers who have a strong understanding of modeling workflows and the expertise necessary to fine-tune the setup of a model and evaluate its results.

However, by creating a simulation app based on a model — with custom-controlled inputs and outputs in an intuitive user interface — and then distributing the app to colleagues, modeling experts can extend access to simulation, thereby streamlining the design workflow. To boost design efficiency even further, simulation engineers can incorporate surrogate functionality to approximate model behavior when creating apps.

Using apps to overcome design challenges

Relying on a small team of simulation experts can create bottlenecks in the design process. At the same time, devoting time and resources to train engineers to build models from the ground up — and then troubleshoot, debug, and analyze them effectively — poses its own challenges.

Easy-to-use customizable simulation apps offer a practical solution to this dilemma. The feature set of an app can be simplified to include only the precise functionality that specific users require, enabling project stakeholders who do not regularly use modeling and simulation to extract model results with the same confidence as a seasoned simulation expert. For example, a laser cavity model might necessitate many input parameters — but if an app based on this model were built for an engineer focused solely on the laser cavity's thermal aspects, it would only include settings for modifying the parameters that influence the thermodynamics.

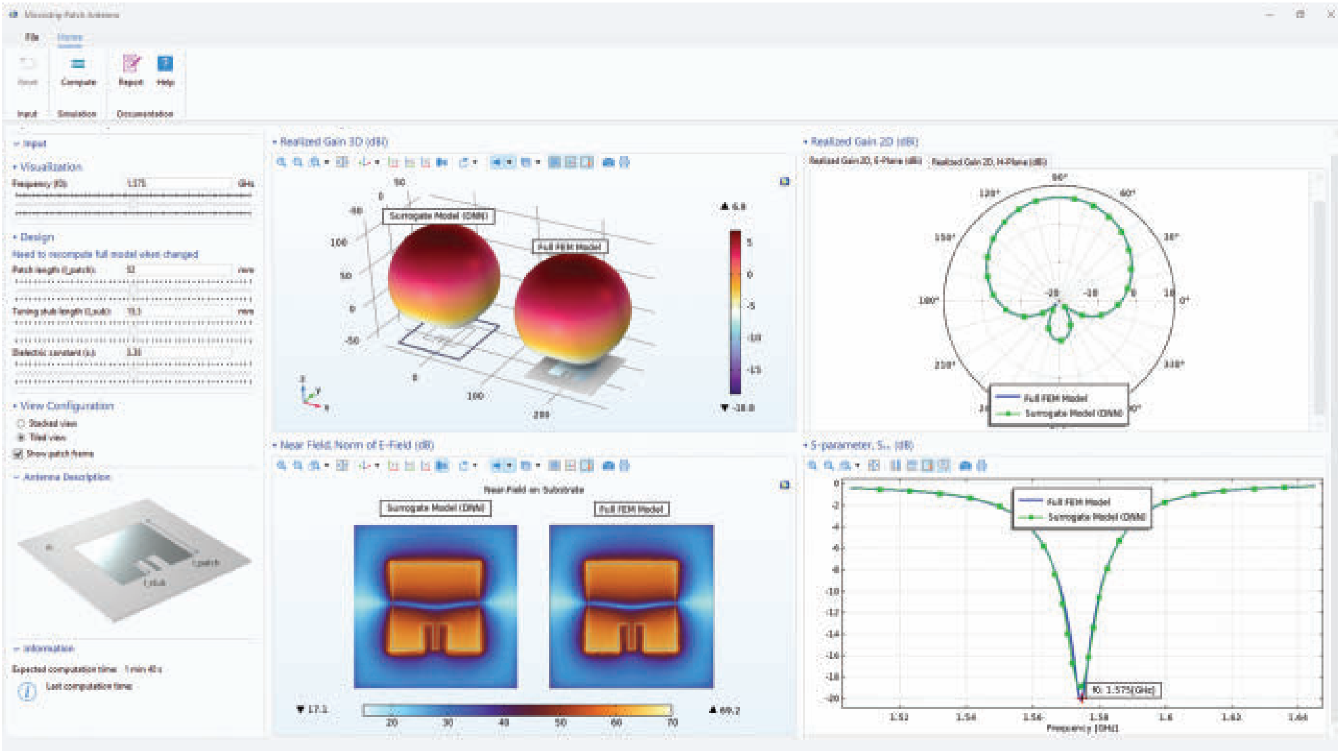
Having convenient access to apps via web browsers, mobile devices, and standalone compiled files allows simulation results to be accessible wherever engineers need them, such as on the factory floor or in the field. It also enables multiple teams operating anywhere in the world to work in concert on the same project; for example, one designer can focus on testing the performance of an image sensor while another optimizes the performance of an aperture. An app dedicated to each purpose can be distributed to each designer, and the data generated by the apps can be exchanged between them and shared with the simulation expert and even customers.

Simulation apps can also increase the efficiency of testing, a necessary but often time-consuming and expensive design task. An app created for testing can be used repeatedly, ensuring that users save time and costs while preserving vital institutional knowledge.

Surrogate models and simulation data

The addition of surrogate-model-based functionality can further improve the effectiveness of an app. A surrogate model must first be created from a full model, but the payoff for this upfront investment of work and time is considerable. Design iteration and analysis with an app powered by a surrogate model is significantly less computationally demanding and provides results within milliseconds.

Figure 1 shows a workflow for surrogate model integration, where the initial step is using the COMSOL Multiphysics software to generate simulation data. The surrogate model is trained on this simulation data, and it can ultimately be used as a replacement for the full model evaluation. A design engineer can then use the app to rapidly explore a design space or process. Once optimal parameters are obtained, there is value in rerunning the full finite element model to validate the



COMSOL

Figure 2. The antenna app user interface **(above)**. The design parameters are shown, along with comparisons between the surrogate model and FEM model results.

RadiaSoft

Figure 3. The app built by RadiaSoft and Argonne National Laboratory, showing synchrotron radiation ray tracing in a vacuum chamber.

surrogate model results and achieve additional certainty.

Surrogate models can also be used in digital twins. A digital twin differs from a traditional model in that it is tightly coupled to the latest sensor data about a specific device. An engineer or user may have a full simulation model of a specific component, but once the design has been fabricated, the user may need the model to account for additional factors such as the material properties of a specific batch from a supplier. Based on need, digital twins can be created for components from different batches, or for each individual component, depending on additional considerations. Each digital twin re-creates the behavior of that specific component based on the best and most recent available data. Multiple digital twins of different components that work together can be used to simulate accurate system-level behavior that reflects the underlying state of their constituent parts.

Using surrogate models or digital twins is not always the optimal simulation approach. For example, for “one-off” models, the overhead required to create a surrogate model or digital twin may not be justified. Therefore, engineers should consider the needs of their design and the project timeline and goals before choosing which simulation tools, if any, to use.

Additionally, machine learning techniques are neither a direct replacement for design teams nor a way to bypass crucial aspects of a design process. If there is an error in the coding, an app will not be able to naturally correct itself. Rather, apps and surrogate models should be viewed as computational tools that enable teams to save resources while keeping the human mind at the center of innovation.

Apps in action

The ease-of-use benefits and design freedom(s) that apps can unlock is a powerful combination: Engineers are taking advantage, tailoring simulation apps to aid in the design of advanced and even novel components.

Yet simulation apps are equally effective tools to optimize the design process of mainstay optical components such as filters. With the Application Builder functionality in COMSOL Multiphysics, for example, a user can customize an app for color filter design to perform two distinct functions. A first function is to predict the color of light transmitted through a prescribed color filter under white light illumination. Its aim is to solve the "forward" problem, wherein the app user provides the input parameters, such as material properties and geometry specifications. When the user modifies these parameters, the results will immediately be updated using a surrogate model, which, in this case, will be a trained deep neural network. The app will also include functionality that allows the user to solve the full finite element method (FEM) model to confirm the prediction from the surrogate.

The app's second function will solve the "inverse" problem, which is often of greater interest to design engineers and consumers. The user can provide the wavelength that they would like the filter to transmit, and the surrogate-model-based app will determine the necessary design parameters to achieve that output. Identifying these parameters is a nontrivial problem, solved by optimizing the inputs to the surrogate model. Once the surrogate-model-based approach has generated suggested parameters for the desired color, these parameters can be used as input to the forward problem, providing the app user with additional confirmation of their accuracy.

Microstrip patch antenna performance

Faster delivery of results is a tangible outcome of using a deep neural network-trained surrogate model app instead of a full FEM simulation. For example, such an app can provide estimates of the performance of a microstrip patch antenna. These compact and cost-effective components are widely deployed at microwave frequencies to enable robust mobile communications in aerospace and defense and consumer applications.

The microstrip patch antenna app shown in Figure 2 delivers estimates by first examining the patch length, tuning stub length, and the dielectric constant of the substrate. Then, the surrogate model quickly updates the antenna S-parameter, near and far fields, and other results for the chosen input parameters. The deep neural network training for the surrogate model was performed for each quantity of interest. Other parameters — the learning rate, weight decay, and batch size — were tuned to minimize validation loss.

Similar to the color filter example, the patch antenna app also simulates an FEM model to confirm the surrogate model predictions. In this case, it uses an adaptive frequency sweep to quickly calculate broadband S-parameters. The app user interface shows the surrogate model and FEM-based model side by side. The results show model performance and highlight how the surrogate model offers faster design iteration using arbitrary inputs than the FEM model.

A real-world use case

One area where optics-based apps are finding use in the real world is in the development of particle accelerators. For example, teams at RadiaSoft and Argonne National Laboratory collaborated to create an app that streamlines the design of synchrotron vacuum chambers and can be used to improve the brightness of the synchrotron beams (Figure 3). The app is based on a multiphysics vacuum chamber model, and the propagation of synchrotron radiation is analyzed using ray optics simulation.

With this app, users can define parameters, such as the electron beam source and the strength of the dipole magnets, and then visualize the resulting rays' path and power as well as the chamber's temperature. These results can help particle accelerator engineers determine how the radiation power distribution changes due to beam behavior.

Users can also easily calculate gas desorption and power with the app. Achieving sufficient beam lifetime requires maintaining the vacuum pressure, which itself requires engineers to determine the amount of gas desorption from the chamber walls. When users import a flux profile into the app, it automatically computes how much gas consequently escapes and provides the material properties.

The app has been distributed to particle accelerator facilities worldwide, and feedback from those in the field has allowed the engineering team to customize the app's interface based on user needs. Importantly, team members without simulation expertise can use the app to perform calculations without digging into the underlying model themselves, thereby avoiding any reliance on the engineer who created the original code.

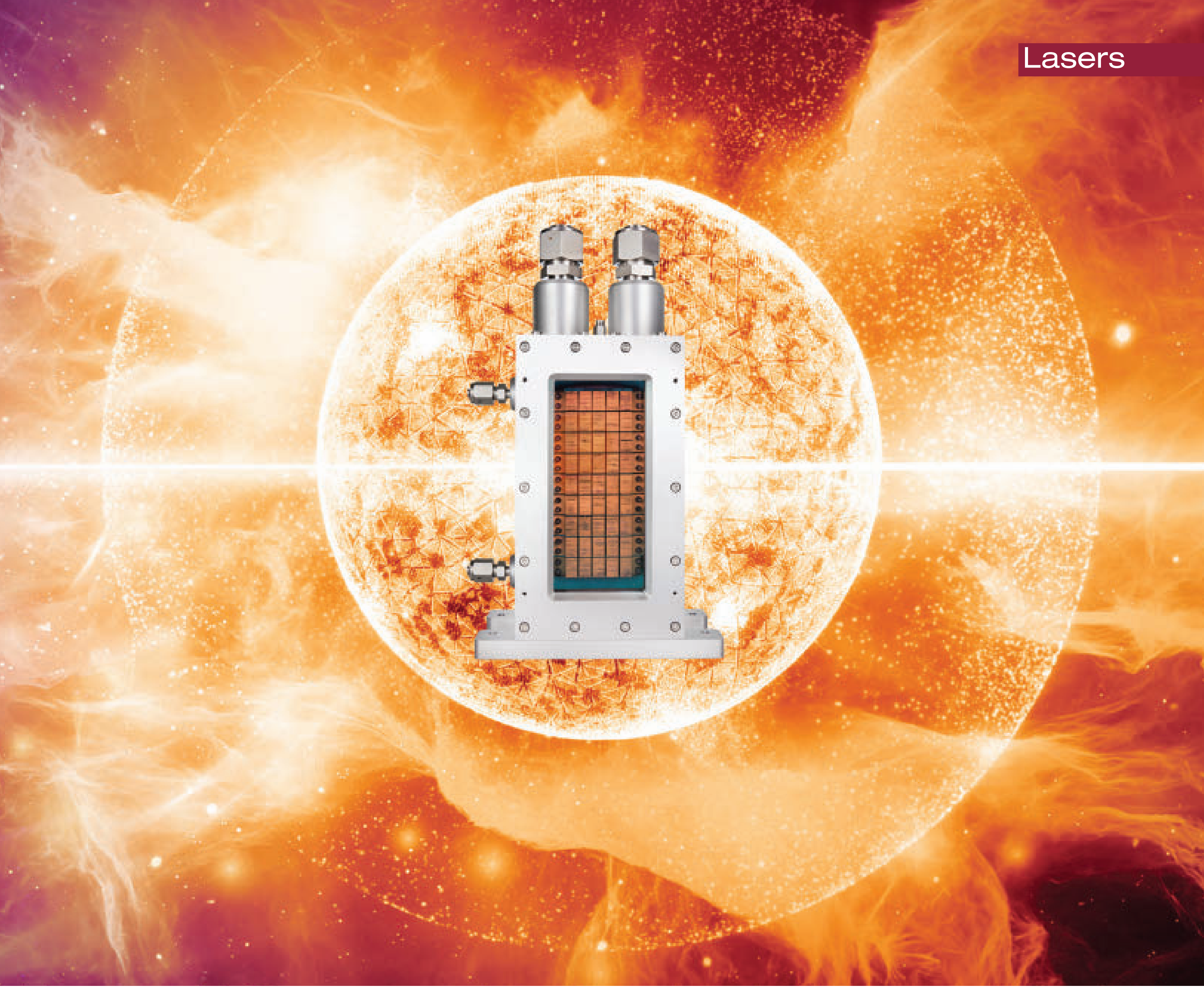
The future of integration

As optics and photonics engineers increasingly adopt modeling and simulation, they are driving innovation in the many industries that benefit from advanced imaging, communications, and optical fiber systems, among other applications. By integrating simulation apps, surrogate models, and digital twins into this work, teams are accelerating design iteration and analysis, achieving better accuracy by incorporating real-time model feedback. And they are placing simulation into the hands of team members who need it, regardless of their modeling expertise.

Of course, individual organizations must test the feasibility of integrating these simulation tools into their workflows and evaluate which simulation method makes the most sense on a case-by-case basis. Fortunately, simulation apps — including those that use surrogate models and digital twins — have unlimited potential in the optics and photonics space.

Meet the author

Andrew Strikwerda is a lead application engineer at COMSOL, specializing in electromagnetics. He previously served as a senior staff scientist at the Johns Hopkins University Applied Physics Laboratory. Strikwerda conducted postgraduate research at the Technical University of Denmark; email: andrew.strikwerda@comsol.com.



Five Drivers Will Shape the Future of High-Power Laser Diode Technologies

All images courtesy of Leonardo.

As high-powered laser diode technology enters its next phase of growth, the drivers shaping the technology's success are opening opportunities for device designers to innovate.

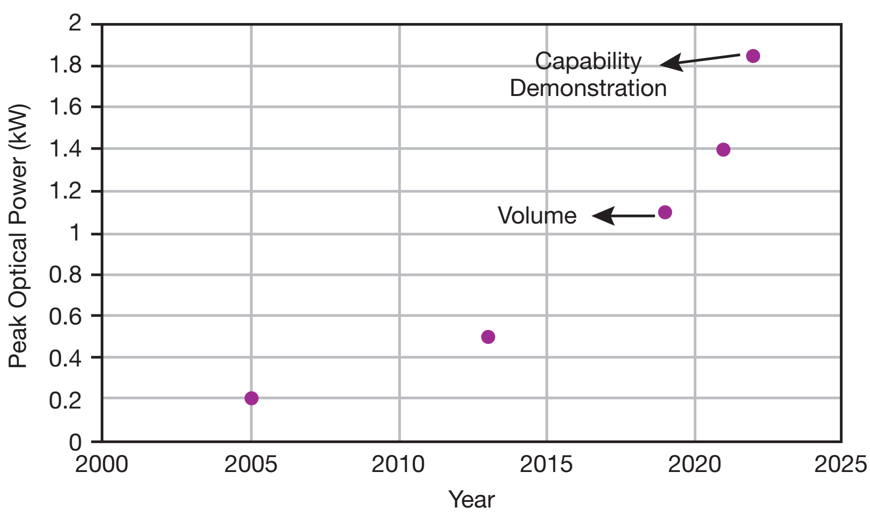
BY MARK CROWLEY AND PRABHU THIAGARAJAN
LEONARDO ELECTRONICS US INC.

High-power laser diode (HPLD) technologies are driving innovation across a range of applications, from industrial — in materials processing and aerospace and defense — to those in the domains of medical, sensing and detecting, and communications. HPLD technologies are also critical enablers of fundamental scientific research, such as particle accelerator systems and laser fusion-based energy production.

In most of these application scenarios, the laser diode is typically a variation of the broad-area, edge-emitting HPLD and functions as the initial photon source for the given system. These devices are used to pump an external gain material, such as an optical fiber or a solid-state gain material. The external gain material is used as a brightness converter to mitigate the inherently divergent beams of edge-emitting HPLDs. Despite the need for this additional component, the gallium arsenide-based, broad-area, edge-emitting HPLD remains the world's most efficient light source.

As applications emerge and existing applications evolve, advancements in emitter epitaxy, novel device concepts, improved packaging concepts, and cooling technologies are among the factors that promise to shape the progress of HPLD technologies. In conjunction, these areas of progress are already pushing the boundaries of device performance.

Fundamentally, however, five drivers — namely, higher optical powers and efficiency, higher brightness, smaller size and weight, improved reliability, and



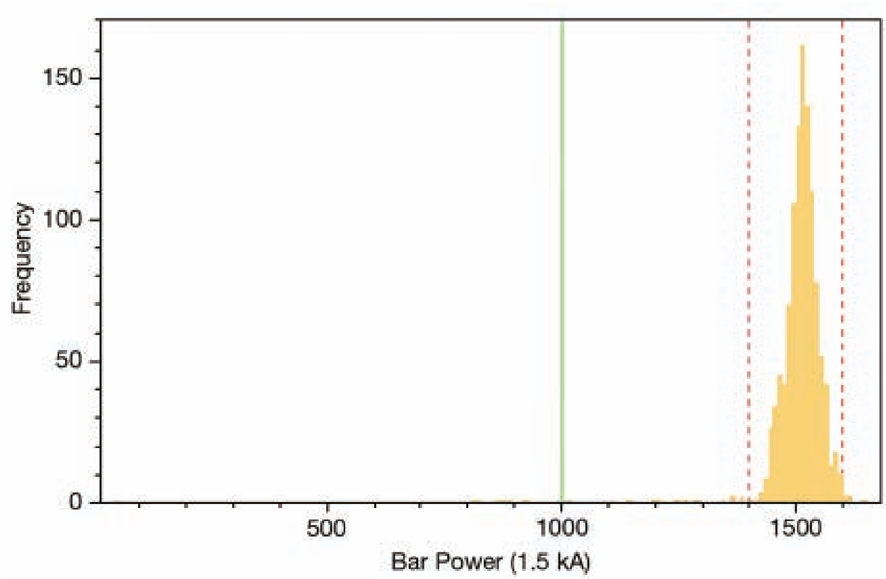


Figure 1. Leonardo high-peak-power laser diodes at wavelengths spanning 750 to 1600 nm, producing peak output powers >1200 W/bar. The evolution of peak optical power for a single *p*-*n* junction under quasi-continuous-wave operation at 25 °C ambient temperature **(above)**. Production distribution for Leonardo kilowatt-class diode bars (~1000, 3-in. wafers) **(right)**. The quasi-continuous-wave value is 250 µs and 20 Hz.

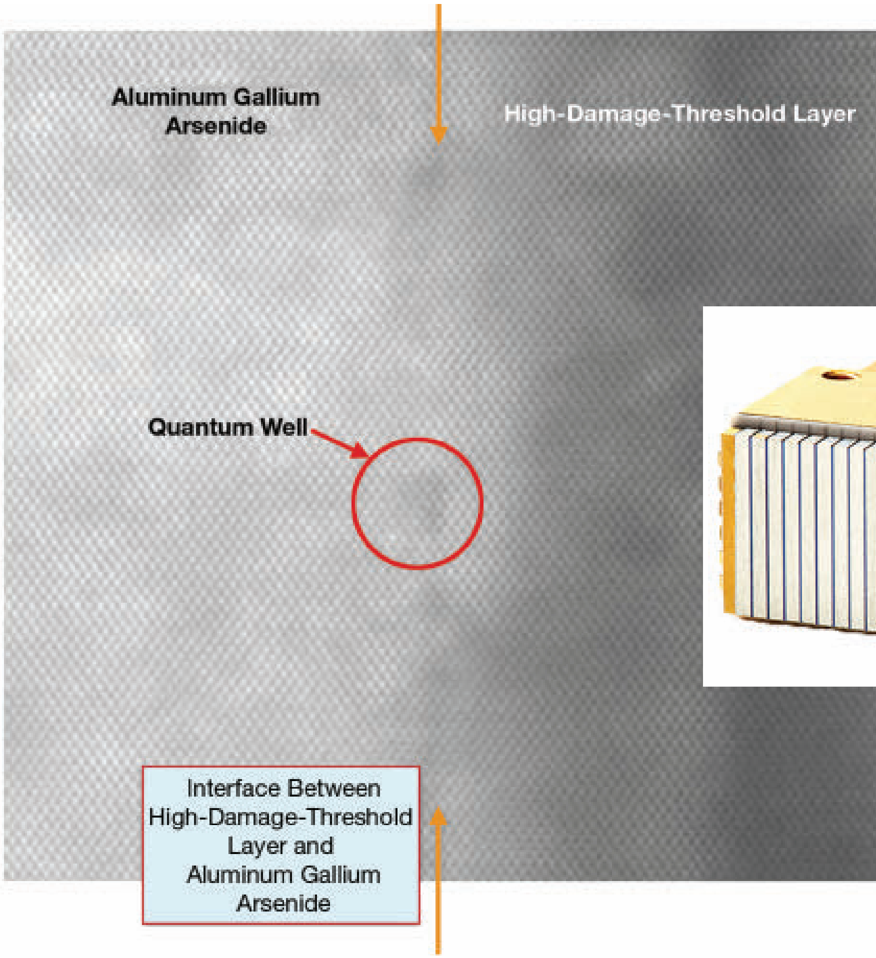


Figure 2. Advancements in facet passivation technology have increased the damage threshold of the facet to withstand ever-higher photon densities in laser diode architectures **(above)**. Aluminum gallium arsenide (AlGaAs) is the semiconductor material in the laser structure. The crystalline layer adjacent to the AlGaAs layer is the high-damage-threshold (HDT) facet protection layer **(left)**.

lower cost — hold the greatest influence over the future of HPLDs. With device developers actively working to improve technologies for each of these considerations, it is unclear which HPLD technology will dominate in the years ahead.

Toward next-generation systems

The electrically pumped area of broad-area, edge-emitting HPLD single emitters typically ranges from tens to hundreds of micrometers in width by a few millimeters in cavity length. Broad-area HPLD bars are collections of many single emitters arranged adjacent to one another in a single semiconductor chip with a width of 1 cm and thickness of 120 µm. The single emitters are optically isolated from each other using physically etched trenches or ion implantation.

The process of producing broad-area HPLDs begins with the deposition of epitaxial layers on a 3- to 6-in.-diameter substrate. This action is performed via III-V growth techniques such as metal-organic chemical vapor deposition and/or molecular beam epitaxy. The vertically grown stack of semiconductor layers includes an active layer sandwiched between waveguide and cladding layers, which serve to guide the light field and transport electrical energy to the active region where it is converted to photons. Wafers are processed through a series of steps based on ultraviolet lithography to define the individual emitters and their metal contacts. Bars are then cleaved, and their facets are passivated and subsequently coated with dielectric layers to form a rear facet of high reflectance and an output facet of lower reflectance.

Advancements in several important device characteristics over the last decade have enabled significant improvements to performance, particularly in optical power (Figure 1). For example, facet passivation technology gains have increased the damage threshold of the facet to withstand ever-higher photon densities. As a result, kilowatt-class diodes have become available in volume, and the power envelope continues to reach new heights (Figures 1 and 2).

Meanwhile, the introduction of new epitaxial designs that minimize electrical and optical losses has charted a path for steady improvements in electrical-to-optical efficiencies. Single-bar peak efficiencies of >70% have been reported for broad-area HPLDs with values approaching >60% for kilowatt-class bars (Figure 1)[1].

These advancements have direct ties to laser diode improvement across the spectrum of powers and broad applications. They also set the stage for the parameters of higher optical powers, higher efficiency, higher brightness, smaller size and weight, improved reliability, and lower cost to define forthcoming growth in HPLDs. As technology advances, there is an ongoing drive to lower size, weight, power consumption, and cost — critical to next-generation laser systems.

Yet, despite these advancements, the brightness of broad-area HPLDs remains a challenge, and these lasers are typically used to pump another optically active gain medium such as fiber lasers or solid-state lasers. Additionally, to fully realize the potential of these high-power devices, it is imperative that cooling technologies keep pace with advancements in both diode technology and material quality.

Surface-emitting architectures

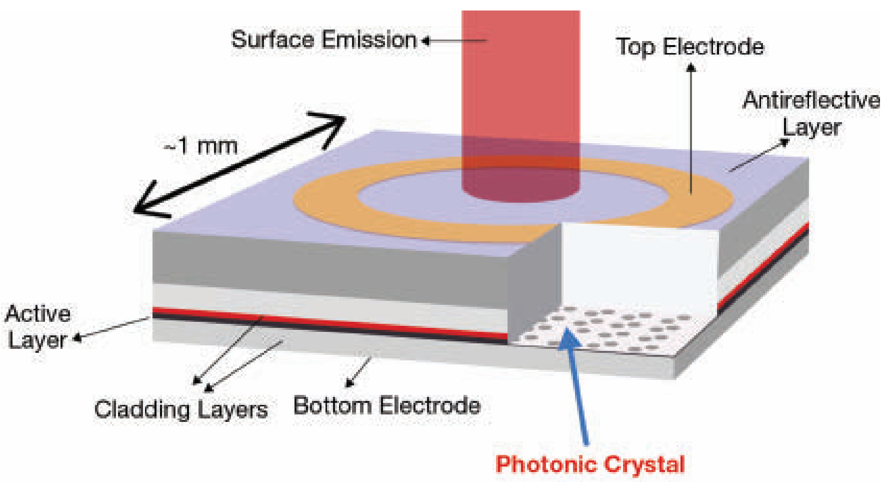
An alternative approach to laser system architectures involves eliminating the brightness converter and using diodes directly in the final application. Such direct diode solutions can be far more compact, efficient, and cost-effective.

Photonic-crystal surface-emitting lasers (PCSELs) are one example of this emerging technology trend. These sources have the potential to achieve many benefits — namely, high-brightness coherent lasing — compared with more traditional edge-emitting lasers as well as more established types of surface-emitting lasers.

A typical PCSEL structure consists of a photonic crystal layer composed of a 2D in-plane periodic refractive-index distribution, an active layer for light amplification, waveguiding layers, and electrodes for current injection (Figure 3). The periodicity of the air holes in the photonic crystal is designed to create a 2D standing-wave resonance over a large area, culminating in lasing oscillation accompanied by coherent surface emission.

A 3-mm-diameter PCSEL can operate at power levels up to 1 kW under pulsed conditions. Continuous-wave lasing at 50 W has also been demonstrated, with an extremely narrow divergence of $<0.5°$[2].

Figure 3. A schematic of a photonic-crystal surface-emitting laser (PCSEL) structure. Adapted from Yoshida et al. See Reference 4.



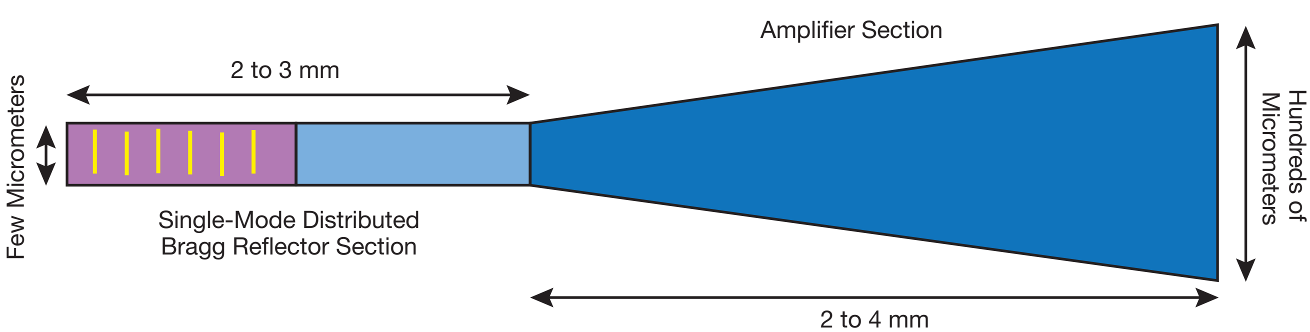
However, challenges remain concerning the manufacturability and efficiency of these specialized diodes. That being said, the direct diode concept can, in principle, be achieved by any of the various HPLD technologies. It is widely regarded as the holy grail of laser diode technology.

A more widely adopted surface-emitting source, the vertical-cavity surface-emitting laser (VCSEL), can achieve emission of a single spatial optical mode. Additionally, due to its use of monolithic distributed Bragg reflectors (DBRs), VCSELs can also achieve a significant degree of spectral brightness. VCSEL arrays can also be arranged on a single chip, establishing a critical advantage and enabling burgeoning application opportunities for these lasers.

However, VCSEL brightness is less than that of a PCSEL, and their efficiency falls short of edge-emitting lasers. Edge-emitting, tapered, single-mode ridge waveguide lasers have emerged as a technology that can achieve high brightness that rivals current PCSEL technology[3]. Such devices are based on a flared chip architecture, which can deliver high output power(s) with nearly diffraction-limited beam quality.

In Figure 4, light generation occurs in the rear section of the architecture, which has the geometry of a single-spatial-mode ridge waveguide that is combined with a DBR. This section produces both a single-spatial and spectral-mode optical output, which serves as the input for the subsequent power amplifier section. Then, the power amplifier allows the emission from the rear section to expand through diffraction. This occurs as it

Figure 4. A schematic of a single-spatial and spectral-mode high-power, edge-emitting laser diode **(below)**.



propagates toward the exit facet to the right of Figure 4.

This design approach enables a much lower peak optical intensity within the cavity and on the exit facet compared with a traditional single-mode diode. Therefore, the output power and reliability of the device is enhanced. Additionally, the thermal resistance of the device is significantly reduced, enabling much higher optical power extraction compared with the regular single-mode device.

Even though these device architectures achieve excellent brightness, their overall efficiency still falls short when compared to a broad-area HPLD.

Road map and opportunity

The demand for, and competition among, different HPLD technologies is apparent, spurred by clearly defined technology drivers. Looking ahead, substantial investment is required to improve each of these drivers in parallel.

Achieving this goal requires both continued innovation and a focus on large-scale applications. These drivers also have eventual limitations; for example, recombination processes that compete with stimulated emission, the finite conductance of semiconductor materials, and the turn-on voltage of a diode are each fundamental limitations to higher optical power. Unless a paradigm shift in technology occurs, improvements in power and efficiency will eventually reach a point of diminishing returns.

Nevertheless, current applications will push the cost envelope further as volumes and markets mature. Improvements in manufacturability — which have often characterized and stimulated growth in the electronics industry in the past — along with the implementation of AI-based automated defect screening, are anticipated to increase yields, enhance quality, and improve cost efficiency. And as noted, additional technological developments to improve performance, such as novel chip designs and/or improved thermal packaging, are reducing the price per watt.

The current expectation that these factors will converge to define the future of HPLD technologies does not diminish the progress that was achieved during the last two decades. During this time, R&D and industry have pioneered a tremendous evolution in laser diode technologies. Yet, while different technologies offer distinct sets of strengths, combining all features into a single uber-device has continued to elude the diode community.

Today, opportunities continue to develop in emerging and existing markets that demand higher and higher levels of performance. As new, more demanding, and higher-volume applications arise, the drivers will remain relevant and push the frontiers of what is possible.

Meet the authors

Mark Crowley, Ph.D., is the director of device technology at Leonardo Electronics US Inc. He has more than 20 years of fundamental research, product development, and technology management experience in the field of semiconductor devices; email: mark.crowley@leonardo.us.

Prabhu Thiagarajan, Ph.D., is senior vice president at Leonardo Electronics US Inc., where he manages the Laser Solutions business line. He has more than 30 years of experience in the laser industry and has authored more than 50 publications; email: prabhu.thiagarajan@leonardo.us.

Acknowledgments

The authors wish to thank Leonardo's Laurel Lunsford and Robert Walker for their contributions to this article and assistance in completing the text.

References

1. P. Crump et al. (2025). Power and efficiency scaling of GaAs-based edge-emitting high-power diode lasers. *IEEE J Sel Top Quant Electron*, Vol. 31, No. 2, pp. (99):1-12.
2. S. Noda et al. (2024). Photonic-crystal surface-emitting lasers. *Nature Reviews*, Vol. 1, pp. 802-814.
3. A. Müller et al. (2017). 10.5 W central lobe output power obtained with an efficient 1030 nm DBR tapered diode laser. *Proc IEEE High Power Diode Lasers and Systems Conference*, pp. 61-62, Coventry, England.
4. M. Yoshida et al. (2021). Photonic-crystal lasers with high-quality narrow-divergence symmetric beams and their application to LiDAR. *J Phys Photonics*. Vol. 3, No. 022006, pp. 1-15.

Artificial Intelligence and Machine Learning Are Transforming the Photonics Industry

BY JÉRÉMY PICOT-CLÉMENTE,
EUROPEAN PHOTONICS INDUSTRY
CONSORTIUM (EPIC)

The fields of optics and photonics have always stood at the forefront of technological innovation. From early lenses and telescopes to sophisticated laser systems and fiber optics, these disciplines demand the highest levels of technical precision and control, as well as complex modeling.

As AI and machine learning transform industry, their profound influence on optics and photonics is growing, too. The integration of AI into the design and manufacturing of optical components, for example, is unlocking unprecedented efficiency and enabling previously unattainable performance.

Even in this early era of AI integration, leading institutions and companies are adopting these technologies in ways that are groundbreaking and signal broader implications for the future.

AI and photonics: The synergy

AI and machine learning technologies excel at recognizing patterns, making predictions, and optimizing complex systems — all of which are essential in photonics. Fabricating components such as lenses, mirrors, and waveguides, as well as integrated photonics systems, requires designers to work with large data sets, consider nonlinear behaviors, and impose stringent performance requirements. AI helps engineers to analyze this data more effectively. Further, it helps them simulate performance under various conditions and automate the discovery of optical configurations.

Similarly, engineers can deploy machine learning algorithms trained on simulation, experimental, and production data to model optical system behavior with remarkable accuracy. This accelerates design cycles. At the same time, it reduces costs and improves component performance; machine learning is used to handle high-dimensional data and identify subtle correlations often missed by traditional methods.

Regression analysis and classification are among the techniques that are increasing in popularity among end users. Neural networking — specifically, convolutional neural networks (CNNs) for image analysis and recurrent neural networks for sequential data — is also gaining traction for predicting optical properties, identifying defects, and optimizing manufacturing parameters.

Today, five distinct application areas exemplify the synergy between AI/machine learning and essential optics and photonics tasks (see sidebar on page 60).

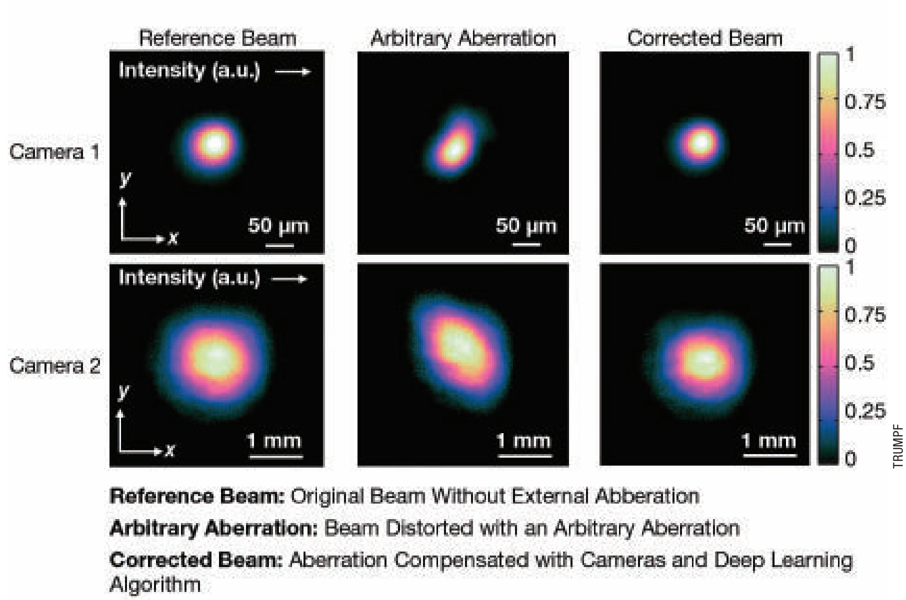


Figure 1. TRUMPF's machine-learning-driven laser beam characterization mechanism. Wavefront correction occurs in ~150 ms.

Functions range from real-time inspections and process monitoring to data analysis and recovery.

Laser beam characterization

TRUMPF, a global leader in laser technology and industrial machine tools, is deploying machine learning to enhance laser beam characterization, a foundational aspect of optics manufacturing. Beam quality is crucial for precision lasers applications, including cutting and welding, additive manufacturing, and semiconductor lithography. Maintaining consistent and precise beam properties is paramount to process reliability and product quality.

Traditionally, beam characterization approaches involve manual calibration and analysis, which can be slow and prone to errors. Moreover, beam characterization via these methods often requires skilled operators and can lead to costly periods of downtime if issues are not detected early in-process.

TRUMPF has integrated machine learning into diagnostic systems that automatically assess beam parameters such as shape, focus position, and power distribution in real time (Figure 1). TRUMPF's neural networks are trained on historical beam data to detect anomalies, recommend adjustments, and predict failures before they occur.

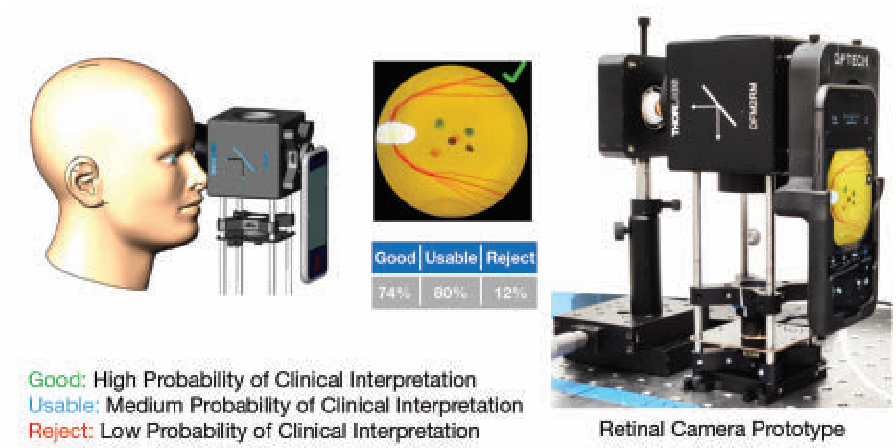
In addition to reducing downtime and improving quality, this machine learning deployment also enables tighter tolerances. This transition from reactive maintenance to predictive maintenance is a major benefit, as it ensures consistent output and minimizes waste.

Optimization in optical equipment

CCTT Optech, a Montréal-based center of expertise affiliated with Cégep de La Pocatière in Québec, is pioneering the use of AI in optical equipment development. A key initiative involves optimizing imaging systems for industrial inspection. By applying machine learning to massive data sets from high-speed cameras and sensors, engineers fine-tune lighting, focus, and image processing parameters, resulting in highly accurate inspections. CNNs are particularly well suited for analyzing image data to identify defects or features automatically. Often, they surpass human capabilities in speed and consistency.

In another project, CCTT Optech developed a retinal camera that features an innovative LED lighting system and smartphone integration. AI is used to assess image quality, improve acquisition, and reduce the workload for ophthalmologists. Early tests showed only 8% of images were classified as "good," and 12% as "usable," while 74% were rejected (Figure 2). After optimization, these metrics improved dramatically: 74% were classified as "good," 80% "usable," and

Figure 2. CCTT Optech's retinal camera, featuring LED ring lighting and smartphone integration capabilities to yield high precision results.



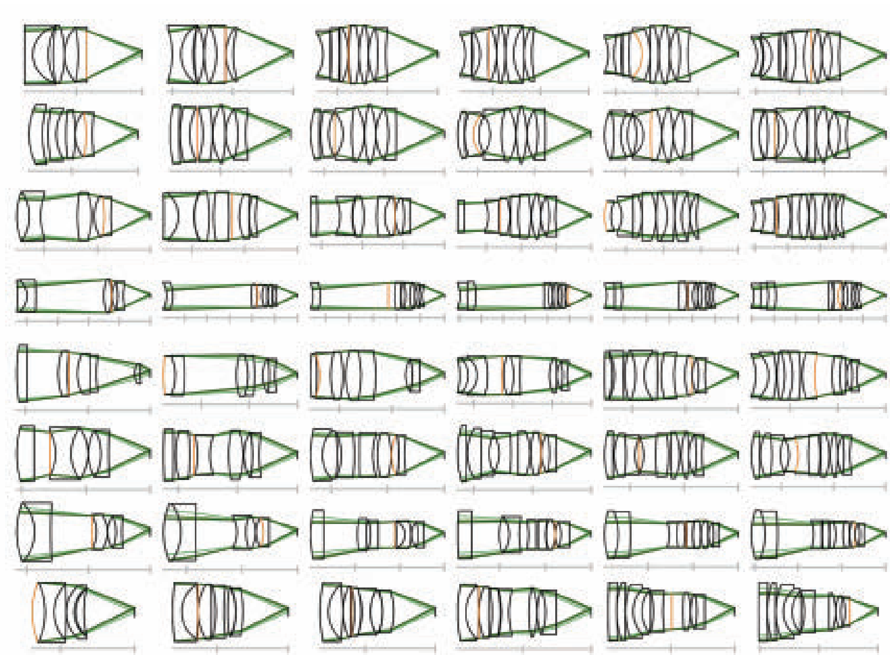


Figure 3. Researchers at the Laval University-based Centre for Optics, Photonics and Lasers (COPL) are using AI to streamline and enhance optical design **(right)**. The image shows an example of the output produced by the researchers' AI assistant lens designer. The tool can output thousands of optical designs for a particular application.

only 12% were rejected. In this case, the AI supports better diagnostic workflows and potentially increased access to screening.

CCTT Optech is also exploring reinforcement learning to develop adaptive optical systems that respond dynamically to environmental or target changes. Reinforcement learning allows systems to learn optimal control strategies through trial and error. These systems can then dynamically adjust optical parameters such as focus or aberration correction in response to changing conditions, without requiring explicit programming for every distinct scenario. This initiative, therefore, has the potential to revolutionize automated inspection, autonomous vehicles, and remote sensing.

Automating optical design

Designing high-performance systems typically requires balancing dozens or even hundreds of variables, such as curvature, thickness, and refractive index. Traditional optical design often uses iterative optimization algorithms that can become stuck in local minima and require significant human expertise to redirect and guide the process.

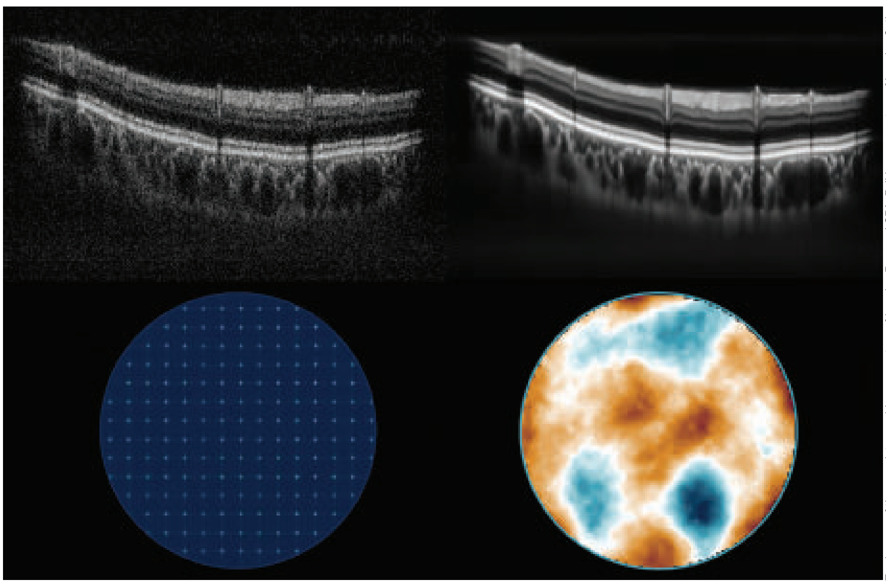
Researchers at the Centre for Optics, Photonics and Lasers (COPL) at Laval University in Québec City are using AI to streamline and enhance optical design. Instead of relying only on traditional ray tracing and iterative optimization, the researchers are using machine learning models to identify optimal design parameters based on desired outputs (Figure 3). This automation approach considerably reduces computational overhead and design time. Techniques such as genetic algorithms and neural networks are being used in parallel to explore the vast design space more efficiently and discover non-intuitive solutions.

The Laval researchers are also advancing inverse design techniques, in which a desired optical function is specified first, and AI algorithms then “invent” the structure needed to achieve it. These methods have enabled the researchers to develop compact, high-performance components for photonic integrated circuits (PICs).

The inverse technique represents a paradigm shift from the concept behind forward design, in which a structure is designed and its function then simulated. In the inverse technique, AI explores potential structures to fulfill a predefined function. This approach is particularly powerful for complex nanophotonic structures, where intuition based on traditional optics breaks down.

High-resolution wavefront sensing

Wavefront sensing is critical for high-precision applications, including adaptive optics, microscopy, and laser processing. Imagine Optic, a leader in this field, is using AI to push the limits of wavefront sensing. Its sensors, powered by a machine learning algorithm called local iterative fitting technique (LIFT), detect ultrafine aberrations in optical wavefronts. The company’s standard HASO SWIR sensors deliver 28 × 28 resolution. Incorporating LIFT, resolution increases fourfold to 112 × 112. This significant increase makes it possible for users to



Top images of the complete graphic are courtesy of Imagine Eyes and CEA. Full image courtesy of Imagine Optic.

Figure 4. Imagine Optic’s use of AI pushes the limits of wavefront sensing. An image of a human retina **(top images)** acquired via optical coherence tomography before **(top left)** and after **(top right)** AI image denoising. AI phase reconstruction **(bottom right)** from a Hartmanngram raw signal **(bottom left)**.

AI and Machine Learning: Broad-Based Photonics Applications

1. **Design and simulation:** Accelerating the exploration of parameter spaces, enabling inverse design, and optimizing complex multicomponent systems.
2. **Manufacturing and fabrication:** Real-time process monitoring, predictive maintenance, quality control, and robot-automated inspection.
3. **Characterization and testing:** Automated analysis of optical properties, defect detection, and high-throughput metrology.
4. **System control and optimization:** Adaptive optics, intelligent feedback loops, and self-calibrating systems.
5. **Data analysis and discovery:** Identifying trends in large experimental or simulation data sets and accelerating the discovery of materials and/or phenomena.

detect and then correct for finer details in the wavefront. The final result is improved quality for imaging applications or improved laser performance (Figure 4).

AI-driven analysis enhances both the sensitivity and speed of wavefront evaluation. These systems filter noise, identify subtle patterns, and suggest real-time corrections, all of which are vital for dynamic imaging and high-throughput environments. Processing large amounts of sensor data quickly and accurately, via AI, is invaluable for real-time adaptive optics systems used in applications such as high-resolution microscopy and free-space optical communications.

Enhancing optical testing and automation

The German firm ficonTEC Service specializes in automated assembly and testing of photonic devices, functions that are critical for scaling up the production of complex PICs and other optical components. FiconTEC's AI-driven robotic systems achieve submicron alignment accuracy using computer vision technology to detect alignment errors, assess quality, and optimize process parameters (Figure 5). Current iterations of the company's AI systems have "learned" to self-correct, and they are continuously improving. Machine vision, often powered by deep learning, is used to guide robotic arms with high precision and perform automated visual defect inspections.

Additionally, ficonTEC's AI-enabled platforms simulate environmental and operational conditions to ensure product reliability for high-volume production. Predictive modeling using AI helps to identify potential failure points and optimize manufacturing processes to improve the yield and reliability of photonic devices.

AI-driven photonics market intelligence

Netherlands-based software developer and solutions provider SCITODATE takes an altogether different approach to the application of AI, using its solution to bridge science and market opportunity. The company's platform uses AI and expert systems to analyze vast volumes of scientific literature, patents, and market data, helping organizations to identify emerging trends in optics and photonics.

These insights assist businesses in identifying white spaces, anticipating

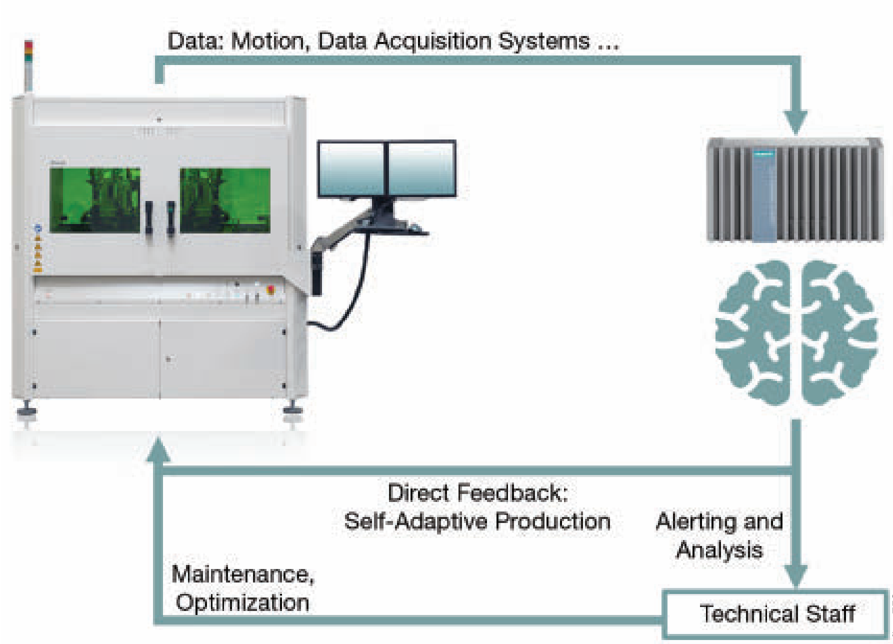


Figure 5. The layout of the ficonEDGE edge computing platform for improving machine key performance indicators. Data is streamed from the machine to the edge device and automatically evaluated by machine learning algorithms. Two pathways are used to improve performance, and self-adaptive production uses model outputs directly on the machine to improve performance without human intervention. Two interfaces, for alerting and analysis, trigger local technical staff to perform maintenance actions or identify bottlenecks for optimization.

demand, and strategically directing R&D efforts. For example, in the energy sector — where optics plays a key role in sensing and laser-based processing — SCITODATE's AI solution helps to reveal untapped applications for photonics technologies. By analyzing the language and trends in scientific publications and patent filings, AI is also used to identify connections and potential applications that might not be immediately obvious through manual review.

Toward a smarter photonics era

AI and machine learning are not just tools: They are catalysts for redefining the possibilities in optical engineering. From reducing development cycles to enabling real-time adaptive systems, these technologies are reshaping how optical components are designed, tested, and manufactured.

While challenges remain — including data requirements, model interpretability, and integration with systems — ongoing innovation is steadily addressing these barriers.

Looking ahead, AI will penetrate even deeper into the optical value chain. Generative AI will enable the creation of entirely new optical architectures, potentially leading to the discovery of novel optical phenomena and devices with unprecedented properties. And quantum machine learning could soon converge with quantum optics to open a frontier of capabilities beyond classical limits and revolutionize quantum computing and communication.

The implications extend to edge AI, which is poised to bring intelligent optical processing closer to the data source by supporting improved real-time optical sensing and decision-making in autonomous systems, wearables, and remote devices. In digital twins, the creation of virtual replicas of optical systems or manufacturing processes powered by AI will allow for highly accurate simulations, predictive maintenance, and process optimization in a virtual environment. This step must take place before changes can be implemented in the physical world.

It is apparent from this forecasted growth that demand for professionals who understand both photonics and data science will continue to grow, driving the emergence of a hybrid discipline. These professionals will be tasked with meeting other challenges that must be considered. They include the computational resources required for training complex models, the need for high-quality and diverse data sets, and the ethics of deploying AI in critical applications.

As these technologies evolve, we are already witnessing the dawn of an era in which optics becomes not only more powerful but also profoundly more intelligent. The integration of AI and machine learning is not just an enhancement; it is a fundamental shift that will drive the next wave of innovation in optics and photonics.

jeremy.picot-clemente
@epic-photonics.com

Fluorescence Microscopy Light Source

The X-Cite TETREM from **Excelitas** is a four-channel, switchable light guide-coupled LED light source designed to optimize fluorescence microscopy workflows. The system uses the company's smartDIAL control interface, which enables researchers to control multiple channels manually via a display, and is available in two models that measure at 365 nm and 385 nm DAPI excitation, respectively. The X-Cite TETREM features a filter holder for fine-tuning excitation between 500 and 600 nm and supports DAPI, FITC, TRITC/mCherry, and Cy5 fluorophore excitation.
photonics@excelitas.com

Optical Power Meters

The AQ23211A (left) and AQ23212A from **Yokogawa Test & Measurement Corp.** are optical power meter modules for manufacturers of semiconductor devices and optical components such as optical fibers. Available in both one- and two-channel variations, the modules offer a synchronous connection function between the modules and source measure unit, faster communication speeds within the frame, and faster file transfer speeds outside the frame. The AQ23211A and AQ23212A also feature a 20-μs sampling and data transfer rate and 50-μs wide-pulse waveform generation.
info@yokogawa.com

Laser Line Mirrors

The TECHSPEC Laser Line Zerodur Mirrors from **Edmund Optics** are manufactured with Schott AG's Zerodur glass-ceramic substrate with low thermal expansion for minimal alignment drift, consistent beam quality, high reflectivity, and increased resistance to laser-induced damage when combined with dielectric coatings. Designed for integration into laser systems in the aerospace, satellite systems, and research industries, the mirrors are available with ytterbium-doped and Nd:YAG coatings.
sales@edmundoptics.com

Lidar Depth Sensor

The AS-DT1 from **Sony** is a lidar depth sensor for applications requiring limited space, such as autonomous robots and drones. Using direct time-of-flight lidar technology and a single-photon avalanche diode sensor, the lidar sensor can measure distances to low-contrast subjects and objects with low reflectivity at a range of 40 m indoors and 20 m outdoors. The AS-DT1 features a form factor of 29 mm × 29 mm × 31 mm and weighs 50 g.
arnaud.destruels@sony.com

Industrial Camera

The shr811 from **SVS-Vistek** is an industrial camera for the inspection of large-scale areas such as display, wafer, and solar panel inspection. The 245.8-MP resolution camera is integrated with Sony's IMX811 rolling shutter CMOS sensor that allows for noise-free imaging and defect pixel correction. The shr811 also features a CoaXPress-12 interface with four connections for delay-free data transfer of up to 12.4 fps and an input/output interface with galvanic interface isolation, a sequencer, and integrated multi-channel LED light control.
info@svs-vistek.com

Rotation Stage

The V-625 from **PI** (**Physik Instrumente**) is a direct-drive rotation stage for applications such as metrology, semiconductor inspection, optics test and alignment, aerospace, and industrial automation. The stage has a direct- and absolute-measuring precision encoder, providing sensor resolution down to 0.0015 μrad and features 10-μrad-calibrated accuracy, a central aperture of 100 mm, and a load capacity of 400 N.
info@pi-usa.us

Color Sensor

The VEML6046X00 from **Vishay Intertechnology** is an AEC-Q100-qualified RGBIR color sensor for automotive display backlight controls, interior lighting control systems, head-up displays, color recognition, correlated color temperature measurement, and laser front light monitoring applications. The sensor features separate red, green, blue, and infrared channels, as well as a sensitive photodiode, low-noise amplifier, and 16-bit analog-to-digital converter in a miniature, opaque 2.67- × 2.45-mm surface-mount package with a 0.6-mm profile.
business-americas@vishay.com

Tunable Laser Assembly

The nano-iTLA from **Pilot Photonics** is a nano-integrable tunable laser assembly for pluggable transceivers in the C- and O-bands. The module is based on fast switching, low-linewidth tunable laser technology and features a multisource-agreement-compliant miniaturized footprint for pluggable transceiver integration.
sales@pilotphotonics.com

Encircled Flux Meter

The MPX-1A from **Arden Photonics** is an encircled flux meter developed for multimode

network validation. Integrated with automatic focusing and exposure systems and CMOS camera technology, the flux meter automatically measures modal launch conditions in real time. The MPX-1A meets specific standards, such as TIA-526-14-A, IEC 61280-4-1, TIA/EIA-455-203, IEC 61280-1-4, and IEEE 802.3.
enquiries@ardenphotonics.com

Nonbrowning Lens

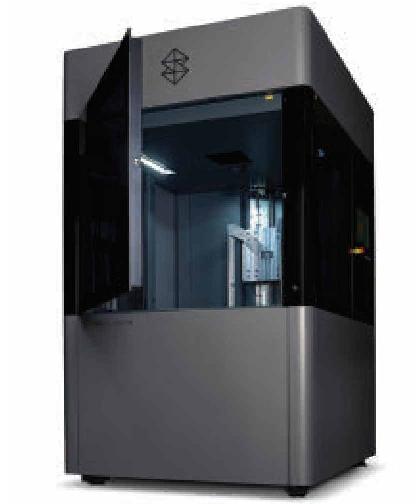
The Model 414 from **Resolve Optics** is a 16-mm f/2.8 fixed-focus nonbrowning lens that delivers high image resolution and minimal geometric distortion between 400 and 750 nm. Manufactured with cerium-doped glass, the lens can withstand accumulated radiation exposure of up to 100 million rad and temperatures of up to 55 °C, while maintaining effective transmission.
sales@resolveoptics.com

Fiber Couplers

The 60FC-SF series from **Schäfter+Kirchhoff** features fiber couplers with a 0.35-mm thread pitch, designed for use as collimators for laser radiation from single-mode fibers, and as fiber couplers with high pointing stability. The fiber couplers are available with achromats featuring shorter focal lengths of 3.1 mm and 4 mm, and each achromat is available with a choice of three different broadband antireflective coatings, covering the UV to IR range.
info@sukhamburg.de

Stereolithography 3D Printer

The Neo800+ from **Stratasys** is a stereolithography 3D printer for applications including



wind tunnel testing, prototyping, and tooling. The printer features vacuum system protection, z-stage collision detection, and real-time environmental monitoring.
info@stratasystore.com

Bidirectional Optical Transceiver

Pro Optix's bidirectional small-form-factor pluggable transceiver is designed to simplify FTTx network upgrades from 1 to 10 G in telecom applications. The transceiver houses two lasers to support dual-wavelength operation for 1310/1550-nm and 1270/1330-nm connections, and features QUAD-OSA laser technology for automatic detection of incoming wavelengths and subsequential adjustments.
sales@prooptix.se

3D Sensor

The ECCO X 012 from **SmartRay** is a 3D sensor for the automated inspection of ball grid arrays, printed circuit board assemblies, and wafers, as well as medical applications. The sensor's small field of view — 12 mm at mid-field and up to 13 mm at far-field — enables a lateral resolution of 2.7 to 3.2 µm and a measurement range of 6 mm. The ECCO X 012 also features a scan rate of up to 40 kHz, providing 4096 3D points of resolution per profile and delivering up to 163 million points per second.
info@smartray.com

Lab Automation Solution

The POLATIS from **HUBER+SUHNER** is a radio-frequency-over-fiber optical circuit switch for the continuous, remote testing of multiple devices. It reduces the time required for test setup and software introduction operation during regression testing and can be implemented to allow agile feature testing.
info.polatis@hubersuhner.com

Laser Fume Extractor

The LAS 260.1 MD.14 from **ULT** is a laser fume extractor for the laser processing of materials including metal, plastic, and glass. The extractor features a multistage filter system consisting of a prefilter, HEPA filter, and activated carbon filter, and uses optical signals to communicate the corresponding filter status. LAS 260.1 MD.14 accessories include hose and adapter sets, extraction arms, and additional post-filters for cleanroom installation or noise reduction.
ult@ult.de

High-Bandwidth FPGA

The Agilex 7 FPGA (field-programmable gate array) M-Series from **Altera** is a high-density FPGA solution featuring integrated high-bandwidth memory and support for DDR5 and LPDDR5 memory technologies. It offers more than 3.8 million logic elements and a hardened memory network-on-chip interface that delivers up to 1 TB/s of memory bandwidth, using in-package HBM2E and hardened DDR5/LPDDR5 memory controllers. The Agilex 7 FPGA M-Series is suitable for applications including AI, data centers, next-generation firewalls, 5G communications infrastructure, and 8K broadcast equipment.
media@alterainfra.com

1.6-T Transceivers

Jabil's 1.6-T transceiver, which can transmit data at rates of up to 1.6 Tb/s, were developed to support AI and machine learning, high-performance computing, cloud computing, and high-speed data center interconnects. The transceivers, built using an Intel silicon photonics engine, can reach speeds of up to 200 Gb/lane on both its electrical and optical interfaces. They are available in DR8, DR8+, and 2×FR4 variants to support intra-data center connectivity.
info@jabil.com

Longwave Infrared Camera

The Dione XP series from **Xenics** is a SWaP (size, weight, and power) core camera suited for safety and security markets, as well as industrial and embedded applications. Equipped with a 640 × 480 microbolometer sensor and 12-µm pixel pitch, the camera achieves noise-equivalent temperature difference values of 35 mK or 40 mK and features integrated image enhancement algorithms, edge detection, column noise filtering, extended temperature calibration, and automatic calpack switching.
advancedimaging@exosens.com

Spectral Light Meter

The LIGHTmetric ONE from **Gigahertz-Optik** is a spectral-light color meter that offers readings of color temperature, illuminance, spectrum,

and color rendering through a Bluetooth-enabled application that provides real-time data visualization. The LIGHTmetric ONE also features a rotatable sensor head and tripod mount for 360° movement, a flash synchronization port, and ISO 17025-certified calibration.
info-us@gigahertz-optik.com

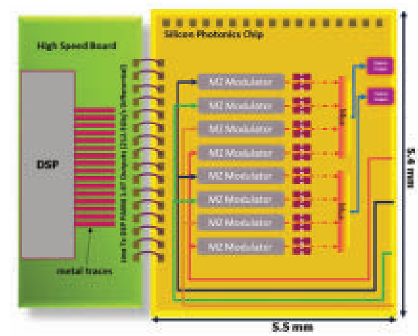
Multispectral Imaging Solutions

The FLIR MIX Starter Kits from **Teledyne FLIR** are multispectral imaging solutions that can

capture and synchronize high-speed thermal and visible imagery at up to 1004 fps. The cameras and integrated software deliver one data set with spatial and temporal alignment, and feature thermal cameras and high-speed visual cameras.
sales@flir.com

High-Resolution Encoder

The SFD-M from **Kollmorgen** is a high-resolution encoder with multiturn feedback for machine builders. The encoder features a resolution of 24 bits per revolution, a multiturn absolute range of 16 bits, and an accuracy of <+/−1 arc-min typical at 25 °C or <+/−3 arc-min worst case.
kollmorgen.support@regalrexnord.com



2xFR4 PICs

The Tamar200 (shown) and Tamar from **Dust-Photonics** are 1.6 T-2xFR4 and 800 G-2xFR4, respectively, PICs designed for AI workloads and hyperscale data center environments. The Tamar200 supports two transmit channels of 800 G-FR4, with each optical lane operating at 200 Gbps per lane, while the Tamar delivers two transmit channels of 400 G-FR4, operating at 100 Gbps per lane. Both products include a low-loss thermal integrated multiplexer and low-loss Mach-Zehnder modulator and are designed for external lasers at only 40 mW per wavelength.
sales@dustphotonics.com

Spatial Resolution Camera

The BlackIndustry SWIR 1.7 Pro Max from **HAIP Solutions** is a hyperspectral camera designed for applications such as geology, mining, recycling, and advanced material analysis. With a spectral resolution of <3-nm full width at half maximum and a 5-μm slit entrance, the camera can detect fine absorption features across a wavelength range of 900 to 1730 nm. The BlackIndustry SWIR 1.7 Pro Max features a spatial resolution of 2560 pixels and includes an integrated NVIDIA GPU.
info@haip-solutions.com

JULY

Optica Advanced Photonics Congress
(July 13-17) Marseille, France.
Contact Optica, +1 202-223-8130, **info@optica.org**; www.optica.org/events/congress/advanced_photonics_congress.

Optica Sensing Congress
(July 20-24) Long Beach, Calif.
Contact Optica, +1 202-223-8130, **info@optica.org**; www.optica.org/events/congress/optical_sensors_and_sensing_congress.

Microscopy & Microanalysis
(July 27-31) Salt Lake City.
Contact the Microscopy Society of America, +1 703-234-4115, **AssociationManagement@microscopy.org**; www.microscopy.org/events.

AUGUST

● SPIE Optics + Photonics
(Aug. 3-7) San Diego.
Contact SPIE, +1 360-676-3290, **customerservice@spie.org**; www.spie.org/conferences-and-exhibitions/optics-and-photonics/attend/invitation.

Optica Nonlinear Optics
(Aug. 4-7) Honolulu.
Contact Optica, +1 202-223-8130, **info@optica.org**; www.optica.org/events/topical_meetings/nonlinear_optics.

Optica Imaging Congress
(Aug. 18-21) Seattle.
Contact Optica, +1 202-223-8130, **info@optica.org**; www.optica.org/events/congress/imaging_and_applied_optics_congress.

European Optical Society Annual Meeting (EOSAM) 2025
(Aug. 24-28) Delft, Netherlands.
Contact Boglárka Selényi, **eosam@europeanoptics.org**; www.europeanoptics.org/events/eos/eosam2025.html.

SEPTEMBER

FABTECH
(Sept. 8-11) Chicago.
Contact FABTECH, +1 888-394-4362, **information@fabtechexpo.com**; www.fabtechexpo.com.

● CIOE
(Sept. 10-12) Shenzhen, China.
Contact China International Optoelectronic Exposition, 0755-8629-0901, **cioe@cioe.cn**; www.cioe.cn/en.

MEMS & Sensors NextGen 2025
(Sept. 16-18) Milpitas, Calif.
Contact Michelle Fabiano, **mfabiano@semi.org**; www.semi.org/en/event/mems-sensors-nextgen.

● ECOC
(Sept. 28-Oct. 2) Copenhagen, Denmark.
Contact +45 70-20-03-05, **info@cap-partner.eu**; www.ecoc2025.org.

World Molecular Imaging Congress
(Sept. 29-Oct. 3) Anchorage, Alaska.
Contact the World Molecular Imaging Society, +1 310-215-9730, **wmis@wmis.org**; www.wmis.org/wmic-2025.

MEDevice
(Sept. 30-Oct. 1) Boston.
Contact Informa Markets, +1 310-445-4273, **registration.ime@informa.com**; www.medeviceboston.com/en/home.html.

OCTOBER

● SCIX
(Oct. 5-10) Covington, Ky.
Contact FACSS, +1 856-224-4266, **scix@scixconference.org**; www.scixconference.org.

● AutoSens Europe
(Oct. 7-9) Barcelona, Spain.
Contact Sens Media, +44 (0)208-133-5116, **info@sens-media.com**; www.auto-sens.com/europe.

● Manufacturing Technology Series WEST
(Oct. 7-9) Anaheim, Calif.
Contact SME, +1 800-733-4763, **westec@sme.org;** https://west.mtseries.com.

● SEMICON West & FLEX
(Oct. 7-9) Phoenix.
Contact SEMI, +1 408-943-6900, **semiconwest@semi.org**; www.semiconwest.org/special-features/FLEX-Conference-and-Exhibition.

● ICALEO
(Oct. 13-16) Orlando, Fla.
Contact the Laser Institute, +1 407-380-1553; www.icaleo.org.

● European Machine Vision Forum 2025
(Oct. 16-17) Fürth, Germany.
Contact European Machine Vision Association, +34 931-80-70-60, **info@emva.org**; www.emva.org/events/more/european-machine-vision-forum-2025.

Optica Laser Applications Conference
(Oct. 19-23) Prague.
Contact Optica, +1 202-223-8130, **info@optica.org**; www.optica.org/events/congress/laser_congress/program/laser_applications_conference.

● SPIE Optifab
(Oct. 20-23) Rochester, N.Y.
Contact SPIE, +1 360 676 3290, **customerservice@spie.org**; www.spie.org/conferences-and-exhibitions/optifab.

● Manufacturing Technology Series SOUTHEAST
(Oct. 21-23) Greenville, S.C.
Contact SME, +1 800-733-4763, **southtec@sme.org**; https://southeast.mtseries.com.

● Frontiers in Optics + Laser Science Conference and Exhibition
(Oct. 26-30) Denver.
Contact Optica, +1 202-416-1907, **info@optica.org**; www.frontiersinoptics.com/home.

NOVEMBER

● Neuroscience
(Nov. 15-19) San Diego.
Contact Society for Neuroscience, +1 202-962-4000, **meetings@sfn.org**; www.sfn.org/meetings/neuroscience-2025.

PAPERS

SPIE Photonics West 2026
(Jan. 17-22) San Francisco.
Deadline: Abstracts, July 9
Contact SPIE, +1 360-676-3290, **customerservice@spie.org**; www.spie.org/conferences-and-exhibitions/photonics-west/attend.

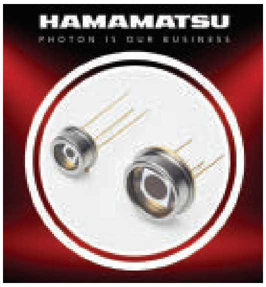
SPIE Medical Imaging 2026
(Feb. 15-19) Vancouver, British Columbia.
Deadline: Abstracts, Aug. 6
Contact SPIE, +1 360-676-3290, **customerservice@spie.org**; www.spie.org/conferences-and-exhibitions/medical-imaging.

Cell Bio
(Dec. 6-10) Philadelphia.
Deadline: Abstracts, Sept. 3
Contact ASCB, +1 301-347-9300, **info@ascb.org**; www.ascb.org/cellbio2025.

● 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

High-Sensitivity, Low-Noise APDs



Hamamatsu's newest APDs, the S17353 series, feature improved sensitivity from short wavelengths to 800 nm. While they offer high sensitivity in the short wavelength region, they also achieve high gain at longer wavelengths compared to conventional APDs, while maintaining low noise levels. The six-product lineup is ideally suited for very low-level light measurement applications and analytical instruments that require a wide wavelength range.

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

Optimize Galvo Laser Drilling Motion

Optimize step and settle motion for laser drilling and achieve maximum performance for any move size with zero move delay. Aerotech galvo scanners use advanced control capabilities like DrillOptimizer to perform percussion drilling with high-dynamic point-to-point motion without sacrificing quality. Maximize throughput, cut cycle times and enhance part quality with Aerotech.

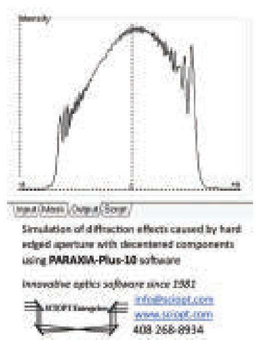
Aerotech
(412) 963-7470
sales@aerotech.com
www.aerotech.com

Fiber-Coupled Square Beam Diode

Introducing the cutting-edge Fiber-coupled Diode Laser with a Square Beam Profile. This product is designed to deliver precision and reliability, making it an ideal choice for various OEM applications. The laser is available at 450nm, 808nm, 915nm, 980nm and 1064nm, providing versatility for diverse applications. With a maximum optical power of 300W CW, this diode laser ensures robust performance, meeting the demanding needs of modern technology.

PhotonTec Berlin GmbH
info@photontec-berlin.com
+49-30-83409380
www.photontec-berlin.de

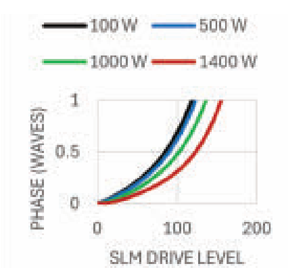
Paraxia-Plus-10 Laser Design Software



The Paraxia-Plus-10 highly interactive "Digital Laser Workbench" and rigorous beam propagation method enables easy laser system setup and simulation of beams interacting with apertures and decentered components with or without transmission or phase variations. This helps designers to optimize laser beam characteristics, to diagnose beam problems, and to set tolerances for system components. Gaussian, Top-hat, and arbitrary beams are supported.

Sciopt Enterprises
info@sciopt.com
(408) 268-8934
www.sciopt.com

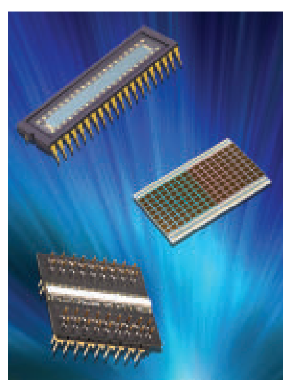
High-Power Spatial Light Modulator



The newest SLM from Meadowlark Optics boasts CW power handling of ≥1 kW at 1070 nm. In tests at SPICA, the SLM retained its full >1 wave range of phase modulation at powers up to 1.4 kW. With sapphire coverglass, built-in water cooling, and a suite of calibration tools, the high-power SLM can maintain calibrated performance under extreme laser power loads.

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

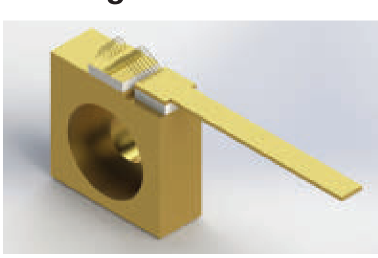
Multi-Element X-Ray Photodiodes



OSI Multi-element X-Ray series consists of 16-element arrays. The individual elements are grouped together and mounted on PCB for X-ray or Gamma-ray application. These multi-channel detectors offer scintillator-mounting options such as BGO, $CdWO_4$ or CsI(Tl). Visit our site for further information.

OSI Optoelectronics
(310) 978-0516
sales@osioptoelectronics.com
www.osioptoelectronics.com

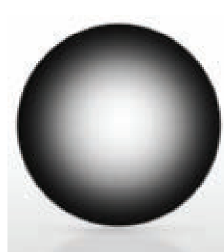
Ultrahigh-Power Lidar Diodes



QPC Lasers offers the world's highest performance single-mode diode lasers for TOF and FMCW lidar. These monolithic MOPA diodes offer single-mode, single-frequency peak powers exceeding 100 W, rapid modulation, and narrow spectral lines at 1500 nm.

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

Bullseye® Apodizing Filters

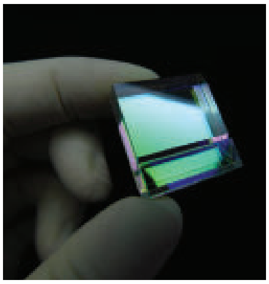


Bullseye® Apodizing Filters radially modify beam distribution in optical systems. Standard Gaussian or customized filters inserted in line with a light source reduce undesirable intensity variations. Configurations include both dark-in-the-center, typically used to reduce low-frequency variations or create top-hat wave fronts, and clear-in-the-center functions, typically used to reduce high-frequency variations outside of the main beam profile. ISO9001:2015, ITAR, Cybersecurity compliant.

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

Photonics Showcase

The VIPA: A Resolution Revolution



To resolve spectral features at 0.5 picometers, traditional echelle spectrometers need to be massive — four to five times larger than the HyperFine Spectrometer from LightMachinery. VIPAs pack high angular dispersion into an ultra-compact form, enabling LightMachinery's HyperFine Spectrometers to deliver echelle-level resolution in a fraction of the footprint (and cost) — with higher throughput and faster acquisition.

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

The NYFORS SMARTSPLICER

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**

70kW Ultra-High Power Laser Sensor

The Ophir® 70K-W Ultra-High Power Laser Sensor is a lightweight, water-cooled, calorimetric sensor that accurately and dependably measures ultra-high power levels up to 70kW in CW mode and up to 100kW from a short exposure using the new Power from Pulse™ feature. Ideal for High Energy Laser Weapon Systems (HELSW) where the laser can lase for only a few seconds, the sensor covers the spectral range from 900-1100nm and 10.6µm.

MKS Ophir **(435) 753-3729**
sales.ophir.usa@mksinst.com **bit.ly/43pJa4B**

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**

Fiber Focusers and Accessories

Our FC10 Fiber Collimator paired with our Focusing Cells yields 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 and other optic modules can be attached for a compact optical module.

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

872 Series Laser Wavelength Meter

The 872 Series High-Resolution Laser Wavelength Meter is ideal for the frequency stabilization of lasers. Offering a frequency resolution as high as 200 kHz, the 872 Series provides exceptional sensitivity to wavelength deviations. With a built-in PID controller and 1 kHz sustained measurement rate, the 872 Series is well suited to precisely stabilize lasers used in applications such as atomic cooling and trapping.

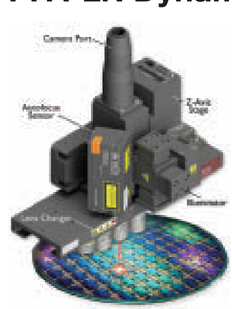
Bristol Instruments Inc. **(585) 924-2620**
info@bristol-inst.com **www.bristol-inst.com**

Flexible High-Speed Signal Routing

The T740 is a dual-channel DC-coupled fiberoptic-to-electrical converter with built-in adjustable delay and width generator. A fast pulse-follower mode is included, accommodating externally-defined trigger pulse widths up to 125 MHz and 100% duty. The compact T740 is ideal for benchtop or OEM applications.

Highland Technology Inc. **(415) 551-1700**
sales@highlandtechnology.com **www.highlandtechnology.com/product/t740**

PFA-LN Dynamic Adaptive Aufofocus



WDI's NEW PFA-LN sensor provides continuous focus on multi layer, varied substrate, pattered and mixed reflectivity surfaces. It features an improved design with higher speed, greater accuracy, and flexible integration, making it ideal for semiconductor, flat panel display, optical metrology applications. PFA-LN can be used alone or with WDI's new high-performance modular microscope system including lens changers, Z-stages, and illuminators.

WDI Wise Device Inc.
(905) 415-2734
info@wdidevice.com
www.wdidevice.com

Photonics Showcase

Custom Precision Optics & Assemblies

For three generations, LaCroix has been dedicated to empowering our customers' success. We don't just meet the demand for precision optics – we anticipate it. From prototype to production and assembly, we can guide and grow with you every step of the way. Experience the LaCroix advantage.

LaCroix Precision Optics **(870) 698-1881**
info@lacroixoptics.com **www.lacroixoptics.com**

CARBIDE High-Power Ultrafast Lasers

CARBIDE features market-leading output parameters — up to 120 W average power, 2 mJ pulse energy, and tunable pulse durations from 250 fs to 10 ps at repetition rates up to 10 MHz — without compromising beam quality or stability. Its compact and robust optomechanical design supports the most demanding applications in research and industry, with reliability proven by hundreds of systems operating 24/7 in industrial environments.

Light Conversion **052472232**
sales@lightcon.com **www.lightcon.com**

Hyperspectral Intelligence

Cubert's ULTRIS cameras captures the full spectrum in one shot – no scanning, no delay. This real-time hyperspectral imaging is a game-changer for precision tasks in agriculture, medical diagnostics, and material analysis. It solves the need for fast, accurate data with compact, scalable systems. From drones to labs, VNIR to SWIR, enabling photonics innovation across research, industry, and OEMs. Hyperspectral intelligence. Real-Time.

Cubert GmbH **+49 731-708-156-25**
matthias.locherer@cubert-gmbh.de **www.cubert-hyperspectral.com**

Nano-OP Series Nanopositioners

A versatile range of compact, single axis piezo nanopositioners. With travel ranges up to 100 microns and a robust design, these nanopositioners offer speed and precision. The inclusion of our PicoQ® sensors ensures low noise performance under closed loop control. The Nano-OP series has been used for AFM, interferometry, and optical microscopy. Fast lead times.

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

ContourX-200 Optical Profilometer

ContourX-200 provides an ideal blend of advanced characterization, customizable options, and ease of use for best-in-class fast, accurate, and repeatable non-contact 3D surface metrology. The gage-capable, small footprint system offers uncompromised 2D/3D high-resolution measurement capabilities using a larger FOV 5 MP digital camera and motorized XY stage. It also includes Vision64®, the industry's most advanced operation and analysis software.

Bruker Nano Surfaces and Metrology
(866) 262-4040
productinfo@bruker.com
www.bruker.com/contourx-200

GLIDER Mid-IR External Cavity

The GLIDER mid-infrared external cavity is designed for single-mode operation with wide spectral tunability. It uses Alpes Lasers QCL or ICL broad gain chips which can cover up to 25% of their central wavelength selected in the range 3.2 microns to 13.7 microns. The system can combine up to four chips and includes drivers and software for a complete light source.

Alpes Lasers **+41 32-729-9510**
sales@alpeslasers.ch **www.alpeslasers.ch**

Quad Photodiodes and Photoreceivers

Discovery Semiconductors' patented Shortwave Infrared (SWIR) quadrant photodiode technology not only provides resilience to radiation, but also leads to ultra-low noise performance & low crosstalk. The TIA design lends itself to customization as per end user's requirements without any impact on radiation hardness. Applications include Gravitational Wave Sensing, Satcom Links, and Position Sensing. Extensive Reliability & Radiation testing done.

Discovery Semiconductors Inc.
(609) 434-1311
sales@discoverysemi.com
www.discoverysemi.com

Hi-Res Microscope Objective Lens

Hyperion's microscope objective lenses are precision-engineered for high-resolution imaging in advanced research and diagnostic systems. With custom optical designs using CaF_2 elements, long working distances, and high numerical apertures, these objectives offer exceptional clarity and chromatic correction. Ideal for biomedical, semiconductor, and fluorescence applications, combining performance with flexibility for specialized applications.

Hyperion Optics **(908) 899-1918**
rfq@hypoptics.com **www.hypoptics.com/lens-assembly**

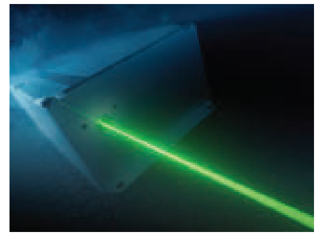
Photonics Showcase

Norland Optical Splice

Norland's optical splice provides a high-performance connection for optic fibers in a unique one-piece design.

Norland Products Inc. **(609) 395-1966**
info@norlandproducts.com **www.norlandproducts.com**

New Novanta GEMultra DPSS Laser



Overcome DPSS 532 nm laser specification breakdown and sub-par performance with stable power output despite changes in operating or ambient temperatures. Engineered for the extreme with temperature fluctuation protection, greater power output, and impressive spectral stability from the new air-cooled design. The ideal solution for in-line Raman spectroscopy, metrology, and semiconductor inspection applications.

Novanta **+44-161-975-5300**
salesleads-lq@novanta.com **www.novantaphotonics.com**

WinCamD-GCM GigE CMOS Beam Profiler

Using the same sensor as DataRay's WinCamD-LCM (11.3 × 11.3 mm active area, 4.2 Mpixels, 5.5 × 5.5 µm pixels, global shutter), the WinCamD-GCM utilizes a GigE Vision® connection for long-range applications (cable lengths up to ~100m) and can be easily scaled and integrated into existing networks, for scalable GigE Vision beam profiling with DataRay's powerful, familiar, full-featured software.

DataRay Inc.
(831) 215-2200
sales@dataray.com
www.dataray.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.

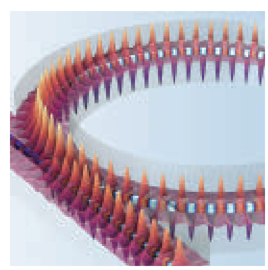
Admesy BV **+31 475-600232**
info@admesy.com **www.admesy.com**

In-Line Fiber Speckle Homogenizer

OZ Optics' new in-line multimode fiber speckle homogenizer significantly reduces contrast by over 90% at 100 Hz, delivering highly uniform illumination for multimode fiber systems across broad UV to NIR wavelengths. This compact solution is ideal for life sciences, ultra-microscopy, flow cytometry, laser projection, and metrology, improving image quality and stability.

OZ Optics Ltd. **(613) 831-0981**
sales@ozoptics.com **www.ozoptics.com**

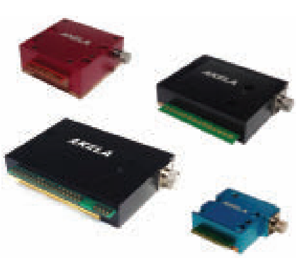
Multiphysics Modeling and Simulation



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**

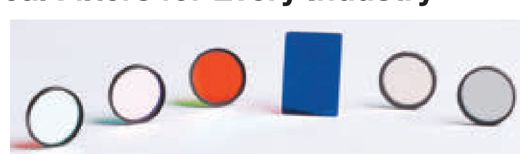
Multi-Wavelength Laser Diode Modules



Versatile lines of multi-wavelength and high-power fiber-coupled laser diode modules for medical and industrial applications combining emitters from 375 to 2000 nm. Over fifty standard module designs and wavelengths combinations. Limitless potential custom configurations. Quick prototyping. One module, multiple applications. Seamless and fast transition from pilot batches to volume production.

AKELA Laser Corporation **(732) 305-7105**
info@akelalaser.com **www.akelalaser.com**

Optical Filters for Every Industry



Unlock unmatched precision with Chroma's hyperspectral imaging solutions—engineered optical filters for high sensitivity, custom configurations, and exceptional spectral performance. Trusted by researchers and innovators worldwide. Our bandpass filters deliver high sensitivity and custom optical filters for agriculture imaging, medical diagnostics, food inspection, and aerospace.

Chroma Technology **(802) 428-2644**
sales@chroma.com **www.chroma.com/markets**

Photonics Showcase

Special High-Speed InGaAs Products

Fermionics Opto-Technology manufactures special products that support your photodiode requirements, including High-Speed Optical Converters which can be used to observe optical waveforms using any instrument equipped with BNC or SMA inputs. Our High-Speed Digital Arrays are ideal for multichannel fiber applications and our special High-Speed Optical Receiver combines a preamplifier with a high speed InGaAs photodiode in a convenient TO-46 pkg.

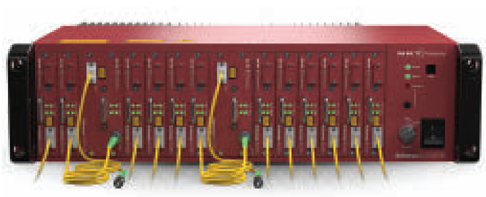
Fermionics Opto-Technology **(805) 582-0155**
ingaas@fermionics.com **www.fermionics.com/Special-and-Custom-Products.html**

FX Hyperspectral Cameras

Specim FX series hyperspectral cameras deliver rapid, non-contact material analysis, enabling real-time classification based on chemical composition. With high-speed line-scan imaging and spectral coverage from 400 nm to 12.3 µm, they are ideal for industrial machine vision applications such as food quality control, waste sorting, and mineral exploration. Their compact design and standard interface ensure easy integration into production lines.

Specim **+358104244400**
info@specim.com **www.specim.com**

Modular Laser Systems for Quantum



Have you always dreamed about designing your own laser system for quantum applications? Now you can! Mix and match our modular building blocks to create the laser system you need for your quantum sensing, quantum computing, or quantum metrology projects. Pick your wavelength and power. The low noise, narrow linewidth, and industrial reliability are standard.

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

Stay at the Forefront of

Photonics Innovations

PHOTONICS spectra®

Scan to Subscribe

www.photonics.com

Available in print and digital.

WORLDWIDE COVERAGE OF

LASERS • OPTICS • POSITIONING • SENSORS & DETECTORS

IMAGING • TEST & MEASUREMENT • SOLAR • LIGHT SOURCES

MICROSCOPY • MACHINE VISION • SPECTROSCOPY • FIBER

OPTICS • MATERIALS & COATINGS

PHOTONICS® MEDIA 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.

Europe, Middle East,
& Asia-Pacific
Matthew M. Beebe
Chief Revenue Officer
Voice: +1 413-499-0514, Ext. 103
Fax: +1 413-443-0472
matt.beebe@photonics.com

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

Southeastern U.S., Midwest,
CT, ME, NH, NJ, NY, PA, RI, & VT
Michael D. Wheeler
Senior Sales Manager
Voice: +1 413-499-0514, Ext. 204
Fax: +1 413-443-0472
michael.wheeler@photonics.com

Rocky Mountains, South Central U.S.,
& Canada,
Wyatt L. Young
Sales Manager
Voice: +1 413-499-0514, Ext. 108
Fax: +1 413-443-0472
wyatt.young@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

Lighter Side

A stronger, cheaper cup of Joe brewed at new heights

Not to be a downer, but it is a universal truth that the world is getting increasingly expensive. From textiles to groceries and other basic consumer goods, unless we're all about to make a nice windfall in the next financial quarter, most of the global population will have to take these price hikes on the chin. But what about our creature comforts?

Highly caffeinated coffee is one of the binders holding many of our post-industrial lives together, making minor inconveniences less noticeable and major ones a little more bearable. But with recent strains on the climate from consecutive seasons of adverse weather, the price of raw arabica beans — the most widely used species of coffee bean — has spiked, with no sign of coming down. Thankfully, scientists also need caffeine to survive, and in lieu of creating a more potent tea leaf, they discovered a more powerful, cost-effective way to brew coffee.

The method, developed by researchers at the University of Pennsylvania, has more to do with the pour than the actual beans themselves, allowing the at-home barista the ability to create a stronger brew with less grounds. It involves a pour-over technique using a gooseneck kettle. This provides an even, controlled pour and creates a laminar, or a smooth and nonturbulent flow of water over a bed of grounds for a more turbulent mixing effect. The process allows the water to extract and dissolve more of the coveted coffee flavor.

Because it's hard to see fluid dynamics in action in coffee due to its lovely mocha splendor, the researchers tested the technique using silica gel particles in a glass cone serving as a coffee filter stand-in. A laser sheet and high-speed camera allowed them to watch water streams create what they poetically called "miniature avalanches" of particles that revealed the flow's inner workings. In doing so, they also discovered that the height from which the water is poured will determine the resulting strength of the coffee.

Too low of a pour resulted in a gentle spread that wouldn't effectively mix the grounds, while too high of a pour resulted in the laminar breaking apart into droplets, which can decrease coffee extraction due to the added air in those droplets. Attaining the happy median between these two allows the water to effectively penetrate farther into the bed of coffee grounds, enabling a higher surface area of water coverage and a better steep, without additional air in the coffee cone.

Though brewing at home helps the wallet, the search for a better morning cup wasn't the by-product of caffeine-starved physicists, but rather this finding occurred during a grander scope of research within the university. The broader aspirations of this work include creating microscale active surfaces that use rotating magnetic fields to clean biofilms from medical devices, investigating ultrafast biological flows, understanding rock erosion under waterfalls, and looking at wastewater treatment.

While humanity's love of java was not the motivation behind this discovery, the researchers' findings have nonetheless laid the groundwork to help make sure that coffee enthusiasts get more kick out of their cup while saving a few beans. So, until there's a fruitful growing season that generates an arabica surplus, or another research group comes along to develop a new caffeinated elixir, consider the height of your next pour over those coffee grounds.

The research was published in *Physics of Fluids* (www.doi.org/10.1063/5.0257924).

Image courtesy of iStock.com/Jag_cz.


LIVE
LIVE
LIVE


A HAMAMATSU COMPANY
SOLUTIONS FOR INNOVATORS
Drive innovation further with our lasers and fibers! Innovators across the World use our lasers for quantum experiments, neuroscience, nanomaterial characterization, and space applications. Choose from a wide range of ultrafast lasers, supercontinuum white light lasers, single-frequency fiber lasers, and an extensive variety of specialty fibers.
What's your next innovation?
Contact us!
nktphotonics.com/contact
NKT Photonics