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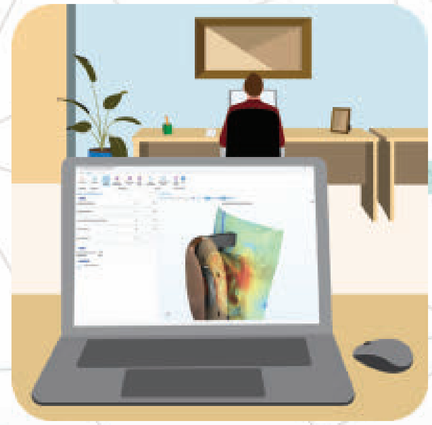

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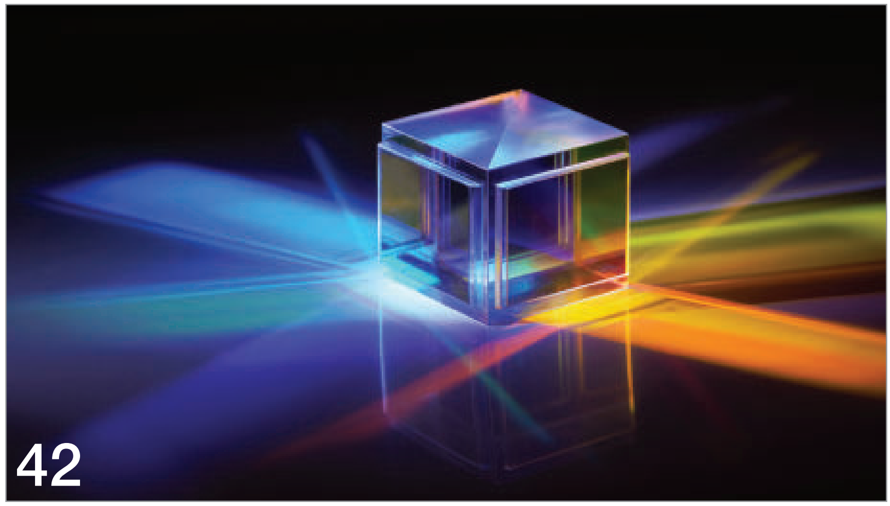

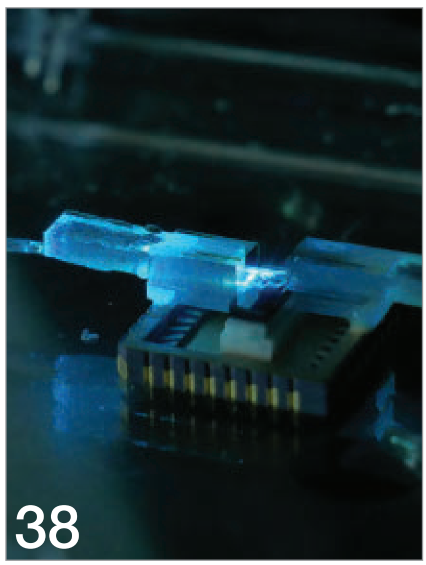

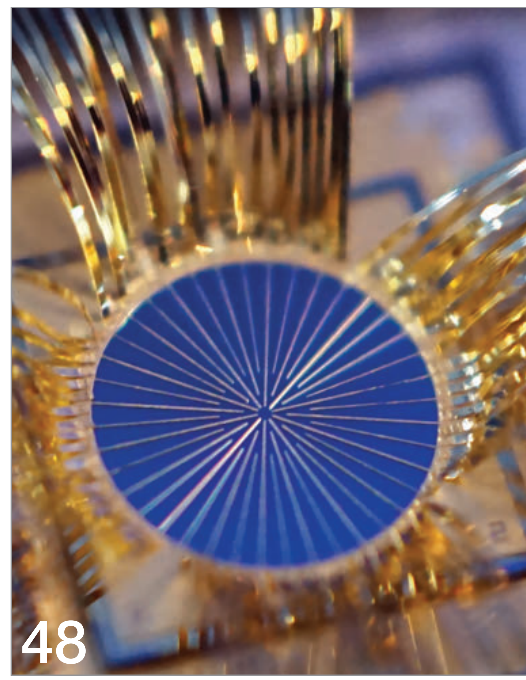

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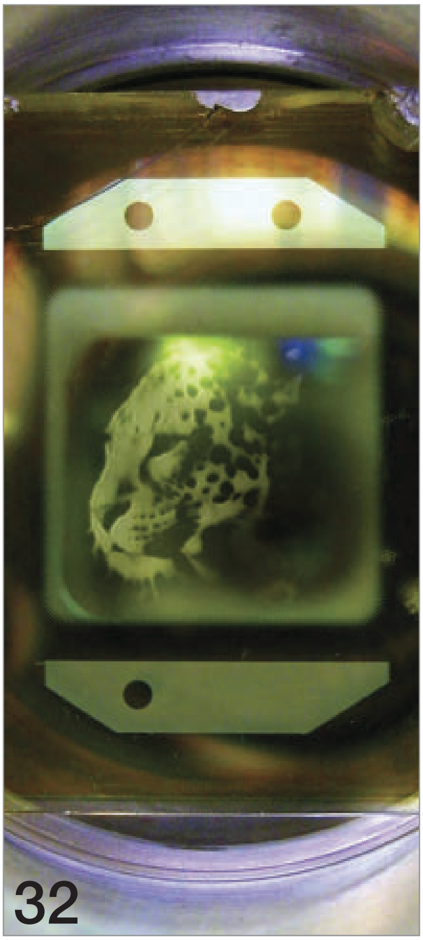
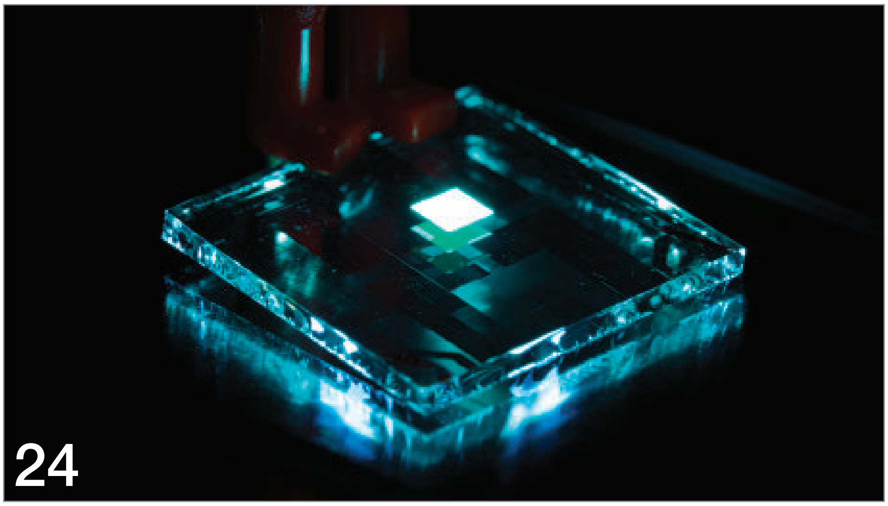
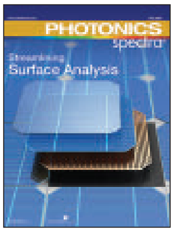
Departments

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

Solar panels rely on thin-film coatings for heat absorption and essential antireflective properties. White light interferometry is critical to measure and optimize these films. Cover image courtesy of iStock.com/laremenko. Cover design by Senior Art Director Lisa N. Comstock.

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Editor's Note

Opportunities in metrology

For those who have found the early spring news cycle inconducive to light reading, it is understandable if you missed last month's release of Invest-NL's report that scrutinizes the Dutch and European semiconductor sector. The 134-page report from the Netherlands-based deep tech firm identifies and exposits the core themes shaping the growth trajectory of this industry.

Certain elements of the report, which is available in English, will be familiar to *Photonics Spectra* readers; many similar reports taking stock of the U.S. and European chip sectors were published in the lead-up to the CHIPS and Science Act and European Chips Act, and updated perspectives continue to be published in their aftermath. Invest-NL focuses on the notion of scaling — namely, devices, circuitry, and architectures. Scaling up funding for startup companies is identified as a major non-technical hurdle. The technical challenges cited, meanwhile, are neither revelatory nor exclusive to Dutch or European players.

But the Invest-NL report accomplishes two things that distinguish it from similar reports and road maps. First, in its final sections, the messaging shifts from technical and monetary challenges to areas of opportunity. It is a subtle pivot, but a useful reframing of the current semiconductor technology landscape.

Second, the report devotes a section exclusively to metrology opportunities. Metrology is never far from any conversation on semiconductor technology, especially in the context of manufacturing. Too often, though, the potential to innovate test and measurement equipment and protocols is left undiscussed and unexplored.

There are several angles from which one can begin to approach semiconductor metrology. Through a materials lens, new material platforms are flourishing, establishing a need for measurement and evaluation methods that can ensure required levels of material purity. For equipment makers, emerging technologies are a catalyst for improved machines. The reverse can be true as well. Scanning probe microscopy and scatterometry are among the techniques well suited to support ongoing and anticipated gains in semiconductor technology, according to the report.

The report also discusses the dynamic that exists between metrology and the use of extreme-ultraviolet (EUV) sources in chipmaking. Netherlands-based ASML enjoys a bona fide commercial monopoly on EUV lithography machines. In this sense, advancements in EUV metrology, as it relates to chipmaking, have been tied to ASML just as much as they have been tied to EUV itself.

In recent weeks, questions regarding ASML's grasp of this technology space have surfaced, and this dynamic has become more intriguing. China-based Shanghai Micro Electronics Equipment and Huawei are both reported to be readying EUV technology for mass production next year. This is significant on the basis of global competition alone. But it is particularly noteworthy given the export controls that ASML faces, which aim to restrict its technology from spurring growth in China's chipmaking industry.

Just as metrology is never far from conversations on semiconductor technology, the realities of the U.S.-China trade war create a bubble around this conversation. The technologies enabling advanced chipmaking will certainly advance in the coming months, which will no doubt occur in a tense and high-stakes economic environment.

Advancements in metrology are likely, too. And they will surely garner much less attention. For many, the opportunities, however, are vast.

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Contributors

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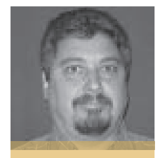

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Roger Posusta is a senior marketing application specialist at Bruker Nano Surfaces and Metrology. Posusta has a degree in metrology and more than 35 years of metrology experience in various industries. Page 42.

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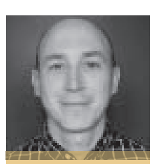

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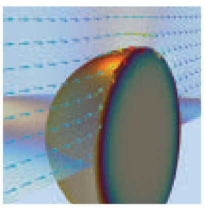
Simulating Nano-Optical Scattering Efficiently



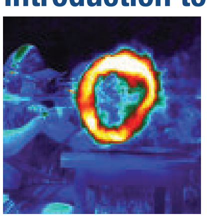
The design of optical scattering characteristics in nanostructures has become a building block for breakthrough devices in high-speed telecommunications, biosensors, solar cells, AR/VR, and more. The COMSOL Multiphysics® simulation platform together with the add-on Wave Optics Module contains functionality for simulating both single-scatterer and large-scale nanostructures. This webinar demonstrates how one can easily set up their first simulation model through an example that focuses on single-particle scattering. Joel Vonarburg of the ETH (Swiss Federal Institute of Technology) in Zürich, Switzerland, demonstrates how he integrates its latest surrogate model capabilities into a simulation app that can be used for teaching students about optical scattering. Then the discussion extends to typical nano-optical structures, such as diffraction gratings, metasurface deflectors, plasmonic structures, photonic crystals, distributed Bragg reflectors, and hyperbolic metamaterials.

Presented by COMSOL.

To view, visit **www.photonics.com/w1158**.

COMSOL

Introduction to Imaging Radiometry and FLIR Research Studio



Infrared imaging radiometry involves using an infrared camera to measure the infrared radiation emitted by objects in a scene. Each pixel in an image captured by a radiometrically calibrated camera provides quantitative data. These radiometric images are not only pictures; they are 2D grids of infrared radiation measurements from the scene, typically displayed as temperature per pixel in most commercial applications. During this webinar, Matthew Hasty will explore the fundamentals of infrared technology, how it works, and the various sensor technologies available. The presentation will also discuss radiometric calibration for temperature per pixel. Finally, Hasty will demonstrate how software, particularly FLIR Research Studio, can enhance efficiency and drive scientific discovery for global teams in innovative ways.

Presented by Teledyne FLIR.

To view, visit **www.photonics.com/w1188**.

FLIR

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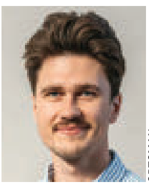
SUMMIT

Laser Optics Summit


OPTOMAN
Lukas Ceizaris.


Edmund Optics
Jay Small.

The editors of *Photonics Spectra* magazine are excited to announce the Laser Optics Summit — a one-day virtual event spotlighting the expanding potential of high-performance optics for lasers. Premiering June 11, 2025, all sessions will be accessible on demand after the event.

The program will explore the precision, control, and optical materials used to shape, steer, and focus laser beams — along with the optical engineering strategies and protocols that enable chromatic correction and performance. The summit is a must-attend for engineers and those in R&D who are developing, deploying, and optimizing relevant systems.

Experts from industry leaders, including Edmund Optics and OPTOMAN, will present real-world solutions as part of this exclusive summit.

Registration is free and includes access to every session, networking opportunities, and actionable insights to support your laser optics work.

Website

For more information and to register, visit **www.photonics.com/LOS2025**.

Designing Chromatically Corrected F-Theta Lenses for Ultrafast Materials Processing
Jay Small, Edmund Optics

Unlocking the Hidden Power of Laser Optics
Lukas Ceizaris, OPTOMAN

Upcoming Summits

Optical Design — *August 13*

Micromachining — *September 17*

Quantum — *November 19*

Inspection — *December 10*

Emerging Technologies Set the Stage for LASER World of PHOTONICS 2025

LASER World of PHOTONICS (LASER Munich) returns to Munich from June 24 to 27, relaunching after an off year in 2024. The trade show and fair convenes industry players and leading companies, spotlighting photonics components, systems, and applications.

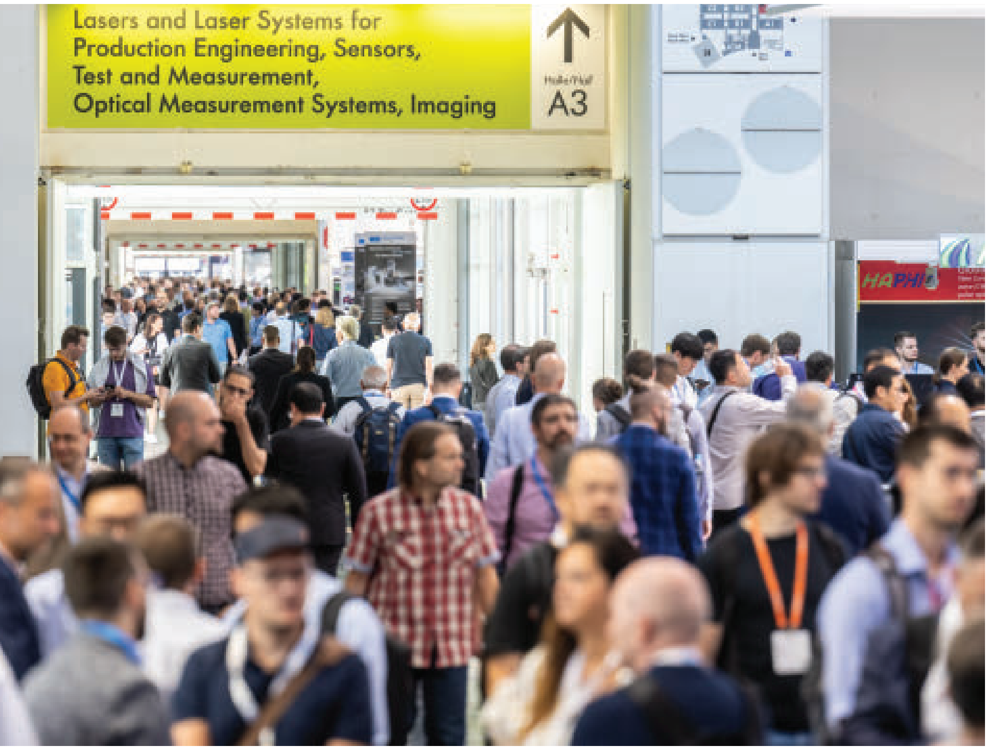
Event organizers are anticipating more than 40,000 visitors from over 70 countries for the fair's 27th iteration.

LASER Munich's program will include four forums offering a comprehensive program. Session topics range from those in integrated photonics, biophotonics, and laser materials processing to laser optics and test and measurement tools. The biophotonics and medical engineering forum will offer attendees access to panels addressing laser-enabled technologies in health care, medical robotics, and patient care. Session chairs include experts Jürgen Popp of Leibniz Institute of Photonic Technology eV, Mark Bischoff of Carl Zeiss AG, and Ronald Sroka of the Hospital of LMU Munich's LIFE Center.

Along with the trade fair portion of the event, the World of Photonics Congress — the largest photonics technical conference in Europe — will be co-located with LASER Munich, taking place June 22 to 27. The 2025 congress will return to a five-conference format, including CLEO/Europe-EQEC, which addresses all facets of optical technologies and photonics in basic research. Four additional conferences, Lasers in Manufacturing, Digital Optical Technologies, Optical Metrology, and European Conferences on Biomedical Optics, will focus on applied sciences based in their fields. Nobel Laureates Anne L'Huillier and Ferenc Krausz will also feature as part of the congress.

World of QUANTUM will run for the third time, during June 24 to 27. Building on its previous two iterations, the event will focus on technologies that bridge the gap between photonics and quantum applications, such as highly precise beam sources, polarizers, optical resonators, and photon counters, among others.

automatica will also once again be co-located with LASER Munich; the trade fair for smart automation and robotics will debut the newly created munich_i platform, a joint project from automatica, Messe München, and the Munich Institute of Robotics and Machine Intelligence,



Images courtesy of Messe München.

which offers a stage for ideas from the most acclaimed and promising pioneers in the space. Under the theme of intelligence empowering tomorrow, the high-tech platform provides networking opportunities for innovation drivers from science, business, politics, and society.

New to the comprehensive fair for this year is a joint area between LASER Munich and automatica, which will host the premier of the MedtecLIVE Healthtech Pavilion. For the first time, it will bring developers from medical technology manufacturers together with experts in laser technology, automation, and robotics. The joint stand is being organized by Messe München in cooperation with MedtecLIVE, Europe's leading trade fair for medical technology, as well as VDMA HealthTech and Bayern Innovativ.

The trade fair's supporting program will span topics that reflect a diverse field of applications for photonics. This will include guided tours and the "Photons in Production" special show, which will provide expert knowledge on all the applications of the technology. The Innovation Award will offer both companies and startups a stage for their innovations, and the career center will provide young talents with information on job prospects and career opportunities in the industry.

For more information and to register to attend LASER World of PHOTONICS, visit www.world-of-photonics.com/en/trade-fair.

IonQ to acquire ID Quantique

IonQ entered into a definitive agreement to acquire a controlling stake in ID Quantique (IDQ) in an all-stock transaction. Alongside the deal for IDQ's team, product offerings, and quantum networking business, IonQ and South Korea-based telecommunications operator SK Telecom signed a memorandum of understanding to collaborate on the future development of the AI and quantum industry.

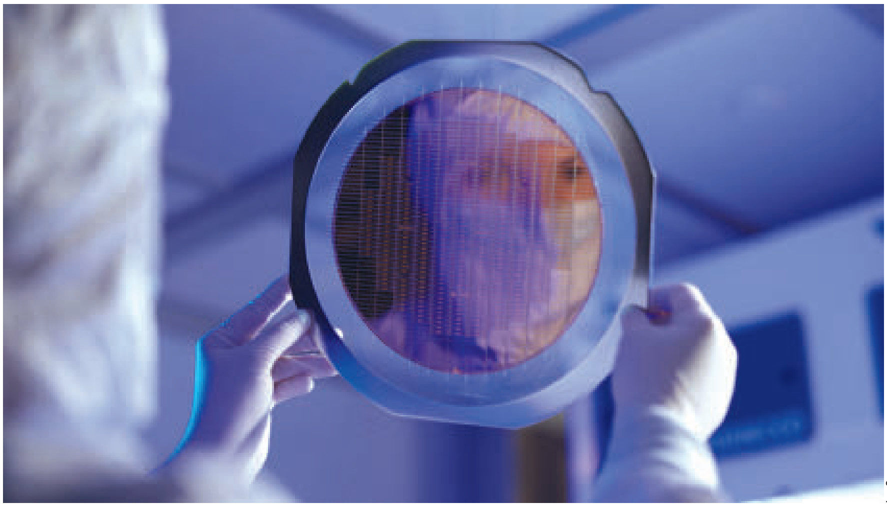
Per the agreement, SK Telecom and its investment arm, SK Square, will exchange their shares in IDQ for shares in IonQ.

The move, SK Telecom said, facilitates a closer business relationship with IonQ. SK Telecom purchased a stake in IDQ in 2018 via a $65 million investment.

"This strategic transaction and the expertise of ID Quantique furthers IonQ's role as a global leader in next-generation secure communications," said Peter Chapman, executive chair of IonQ. "And once finalized, we expect that our intended strategic partnership with SK Telecom, one of the most powerful technology companies in Asia, will significantly enhance the distribution of IonQ quantum technology, leading to many commercial and technical opportunities."

IDQ's products span quantum networking and quantum-safe communication, and include quantum key distribution, quantum random generators, and quantum detection systems. IDQ additionally commercializes high-performance single-photon detectors, which are key components to build quantum memories and scalable quantum computers. IDQ's patent portfolio of nearly 300 patents and patent applications will bring the total count of granted and pending patents that IonQ owns or controls to nearly 900.

The acquisition of IDQ directly follows a series of recent announcements from IonQ in the quantum networking space. Earlier this year, IonQ announced the completion of its acquisition of substantially all of the assets of Qubitekk, a quantum networking company in the U.S. IonQ also announced the close of two quantum networking contracts with the United States Air Force Research Lab in 2024, including the largest known 2024 U.S. Quantum Contract Award of $54.5 million to design, develop, and deliver quantum networking technology as well as another $21.1 million award to establish free-space optical links from ground stations to drones.


IonQ

IonQ's acquisition of ID Quantique (IDQ) comes after a series of announcements related to IonQ's business strategy and the development and commercialization of its quantum computing technology.

In November 2024, IonQ also formed partnerships with Ansys and NKT Photonics. The agreements target the integration of quantum computing into the computer-aided engineering industry, and NKT's supply of next-generation laser systems for IonQ's trapped-ion quantum computers and networking equipment, respectively. And in South Korea, IonQ signed a memorandum of understanding with the Metropolitan Government of Busan to advance quantum technology earlier this year. The company has previously announced customer contracts and strategic partnerships with Hyundai Motor Group and Sungkyunkwan University.

A day before announcing the acquisition, IonQ appointed as president and CEO Niccolo de Masi, who has served on IonQ's board of directors since 2021 and has held a number of C-level positions at publicly traded companies, including the role of CEO of dMY Technology Group III, the special purpose acquisition company that took IonQ public via merger in 2021.

IonQ expects to close the transaction within the year, subject to the satisfaction of customary closing conditions.

8.4%

— estimated compound annual growth rate of the global photodiode sensors market by 2034, according to Global Market Insights

Celestial AI secures $250M

Celestial AI, a developer of optical computing technologies, raised $250 million in a series C funding round. The capital will help the company commercialize its Photonic Fabric technology platform.

Celestial AI's Photonic Fabric optical connectivity solution enables the disaggregation of compute and memory, which allows each component to be effectively leveraged and scaled. The technology delivers >25× greater bandwidth and memory capacity while reducing latency and power consumption by up to 10× compared with existing optical interconnect alternatives and copper, according to the company.

"Cluster sizes must scale from a few AI processors in a server to tens of processors in a single rack and thousands of processors across multiple racks, all while relying on high-bandwidth, low-latency network connectivity to handle massive data transfers between processors," said David Lazovsky, CEO of Celestial AI.

The company's technology is designed to enable disaggregated, exascale compute and memory clusters. It is suited for applications such as AI models that require high levels of memory capacity and bandwidth, in addition to cloud services and data centers.

Celestial AI acquired Rockley Photonics' silicon photonics portfolio last year, in addition to closing a $175 million round. The company also added recently named Intel CEO (and Celestial AI investor) Lip-Bu Tan to its board of directors earlier this year.

The round was led by Fidelity Management & Research Company and saw support from new and existing investors. The funds bring the total amount raised to more than $515 million.

$344.6B — expected value of the global OLED market by 2034, according to Precedence Research

This month in history

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

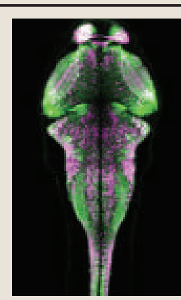
1995

A joint research group from Showa Optronics Co. Ltd. and the Photodynamics Research Center at the Institute of Physical and Chemical Research developed an extremely low scattering and low absorption tantalum pentoxide/silicon dioxide (Ta_2O_5/SiO_2) coating for broadband mirrors using electron beam deposition. The coating was developed for continuous wave titanium sapphire laser operation.

2005

Researchers at the University of Bath created a gas cell with high interaction efficiency between the sample and light. The cell was created by splicing a single-mode fiber to each end of a gas-filled, hollow-core photonic bandgap fiber and was believed by the researchers to be the first self-contained, fiber-based frequency stabilization system.

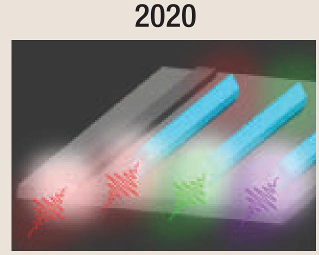
2015



Investigators from Howard Hughes Medical Institute developed a fluorescent label that allowed researchers to study complex neural activity in wide swaths of brain tissue in moving animals. Called CaMPARI, the label enabled scientists to bypass the use of a microscope to observe neural activity.

2020

Researchers from the Hong Kong University of Science and Technology directly grew 1.5-µm III-V lasers on 220-nm silicon-on-insulator wafers without a buffer. The work was performed in an effort to advance the use of III-V light sources with silicon-based photonic devices.



PsiQuantum unveils manufacturable chipset for quantum computing

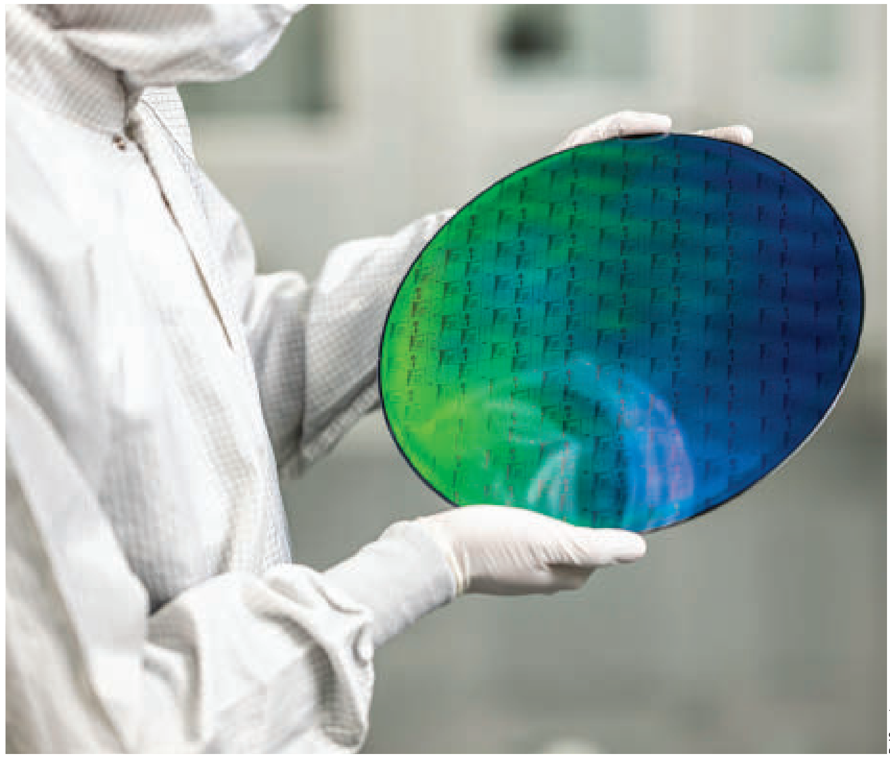
PsiQuantum reported its development of a quantum photonic chipset purpose-built for utility-scale quantum computing. Called Omega, the chipset is designed and fabricated on full-size wafers at GlobalFoundries' silicon photonics fab in New York and contains all the advanced components required to build million-qubit-scale quantum computers, the company said.

PsiQuantum introduced the chipset in a paper published in *Nature*.

Fabrication of the chips in a high-volume semiconductor fab, PsiQuantum said, represents a new level of technical maturity and scale in the field. The company also plans to break ground this year on two data center-size quantum compute centers in Brisbane, Australia, and Chicago.

The *Nature* paper shows high-fidelity qubit operations, and a simple, long-range chip-to-chip qubit interconnect — a key enabler to scale that has remained challenging for other technologies. The company said that it overcame challenges with background noise and low-temperature operation of the chip to demonstrate the circuit performance detailed in the paper, which cited measurements including 99.98% single-qubit state preparation and measurement fidelity, 99.5% two-photon quantum interference visibility, and 99.72% chip-to-chip quantum interconnect fidelity.

PsiQuantum also said that it has introduced a cooling solution for quantum computers — eliminating the iconic "chandelier" dilution refrigerator in favor of a simpler, more powerful, and more manufacturable cuboid design, closer to a data center server rack. The *Nature* paper shares details on this new approach to cooling, which is now deployed at PsiQuantum's U.K. facility and was used for many of the performance results that were described, the company said.


PsiQuantum

PsiQuantum reported mass-manufacturable chips purpose-built for utility-scale million-qubit quantum computers. The chips, described in a paper in *Nature*, are fabricated on full-size wafers.

PsiQuantum's focus is now on wiring these chips together across racks, into increasingly large-scale multi-chip systems. The company said that it is now expanding this work through its partnership with the Department of Energy at Stanford's Linear Accelerator in Palo Alto, Calif., as well as a new manufacturing and testing facility in Silicon Valley.

Rocket Lab to acquire Mynaric

Rocket Lab USA, a provider of launch services and space systems, entered into a nonbinding term sheet to acquire a controlling equity position in Mynaric AG, a provider of laser optical communications terminals for air, space, and mobile applications. If completed, the acquisition is expected to further strengthen Rocket Lab's capabilities as a launch provider, spacecraft manufacturer, and supplier of satellite components at scale.

With an initial purchase price expected to be around $75 million, Rocket Lab would establish its first European foothold in Munich, presenting incremental growth opportunities across Rocket Lab's products and services offerings.

The acquisition would also provide production assets, intellectual property, product inventory, and orders related to satellite-to-satellite optical connectivity solutions, Rocket Lab said.

Following the deal's completion, Rocket Lab intends to boost production of Mynaric's optical terminals to offer laser communication technology at affordable prices and at scale.

Mynaric is currently a subcontractor to Rocket Lab, providing CONDOR Mk3 optical communication terminals for the company's $515 million prime contract with the Space Development Agency (SDA) to produce 18 satellites for the Tranche 2 Transport Layer-Beta. Rocket Lab and Mynaric share multiple customers spanning commercial constellation operators, prime contractors, and defense and civil government agencies.

The transaction is expected to close after the completion of Mynaric's pending restructuring proceedings. Last year, Mynaric made changes to its leadership following a significant decline in revenue that the company ascribed to production delays related to its CONDOR Mk3 optical communications. The company named Andreas Reif chief restructuring officer and a member of the management.

Following the management changes, the company advanced its production for the CONDOR Mk3. The company faced challenges retaining compliance with the Nasdaq continued listing criteria, culminating in the company's delisting from the Nasdaq in February.

Wooptix nets $10.4M in series C funding

Semiconductor metrology company Wooptix raised more than €10 million ($10.4 million) in a series C funding round led by Samsung Venture Investment Corporation and Spanish Society for Technological Transformation. The company plans to use the funding to accelerate product development, expand international reach, and scale its team to meet growing industry demand.

Wooptix, based in both Spain and San Francisco, is focused on commercializing semiconductor metrology equipment incorporating wavefront phase imaging with its Phemet system. The Phemet system measures silicon wafer warpage and enables blank and patterned wafer-shape measurement in less time and with higher resolution than current systems used in the industry, according to the company.

"The Phemet capability of collecting over 16 million data points with sub-nanometer height resolution enables semiconductor manufacturers to reduce energy waste during production," said José Manuel Rodriguez Ramos, CEO of Wooptix.

Ramos said that Phemet is on track for full automation and factory floor deployment for in-line testing in the coming months. The solution has already been adopted by certain semiconductor manufacturers.

The funding round also saw participation from existing investors, including Bullnet Capital, the European Innovation Council Fund, Intel Capital, MONDRAGON Corporation, and TEL Venture Capital Inc. Wooptix additionally raised $11 million in a funding round last year.

Q.ANT debuts pilot line for photonic AI chip production

Q.ANT, a developer of photonic processing for AI, launched a dedicated production line for thin-film lithium niobate-based photonic chips at the Institute of Microelectronics Stuttgart (IMS CHIPS). The integration of Q.ANT's photonic chip technology and the upcycling of the existing CMOS production facility at IMS CHIPS created a blueprint for cost-effectively modernizing chip production worldwide, the partners said.

The line is expected to deliver faster, more energy-efficient processors to meet the growing computational demands of AI and high-performance computing. Q.ANT has invested €14 million ($14.7 million) in machinery and equipment to complement it.

"With this pilot line, we are accelerating time to market and laying the foundation for photonic processors to become standard coprocessors in high-performance computing," said Michael Förtsch, CEO of Q.ANT.

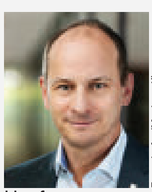
"By 2030, we aim to make our photonic processors a scalable, energy-efficient cornerstone of AI infrastructure," Förtsch said. According to Q.ANT, the line can produce up to 1000 wafers per year.

Q.ANT

(From left) Q.ANT CEO Michael Förtsch; minister of economic affairs of the state of Baden-Württemberg, Germany, Nicole Hoffmeister-Kraut; and director and CEO of IMS CHIPS Jens Anders. The trio present an enlarged, symbolic photonic wafer based on thin-film lithium niobate.

The pilot line is specifically designed for production using thin-film lithium niobate, which enables ultrafast optical signal manipulation at several gigahertz without the need for heat to modulate the light on the photonic circuit. While the line's establishment enables Q.ANT to refine its chip architecture to meet evolving market requirements, it also serves as the R&D basis for Q.ANT's photonic

People in the News



Fraunhofer/Markus Jürgens

Haefner.

Fraunhofer-Gesellschaft named **Constantin Haefner** executive vice president of Research and Transfer. Haefner served as the executive director of the Fraunhofer Institute for Laser Technology since 2019, and before that led the Advanced Photon Technologies program at Lawrence Livermore National Laboratory. Haefner also heads the expert commission on laser fusion appointed by Germany's Federal Ministry of Education and Research.

FISBA

Forrer.

FISBA, an optical components and systems company, appointed **Martin Forrer** CTO and head of development. Forrer has been with FISBA for 28 years in various leadership positions, including a previous tenure as CTO. He will continue to serve as senior vice president of business development and a member of the management team within the organization.

Cognex promoted **Matthew Moschner** to the positions of president and COO. Formerly senior vice president, Moschner will continue to report to CEO **Robert Willett**, who had served as president of the company prior to Moschner's appointment. Moschner joined Cognex in 2017 and has held key roles across product and engineering teams.

Intel Corporation

Tan.

The board of Intel Corporation appointed **Lip-Bu Tan** CEO. He succeeds interim co-CEOs **David Zinsner** and **Michelle Johnston Holthaus** who stepped into the role after the company parted ways with **Pat Gelsinger** at the end of last year. Tan will also rejoin the Intel board of directors after stepping down in August 2024. Tan is a longtime technology investor with more than 20 years of semiconductor and software experience. He served as CEO of Cadence Design Systems from 2009 to 2021 and is a founding managing partner of Walden Catalyst Ventures, and chairman of Walden International. He currently serves on the boards of Credo Technology Group and Schneider Electric.

Silicon Austria Labs named **Isabel Tausendschön** CFO. Tausendschön previously held the same position at Austrian Post International Deutschland GmbH and adverserve Holding GmbH.

Sivers Semiconductors AB named **Alexander McCann** strategic senior advisor to the board and the CEO, with a primary focus on strengthening and scaling the company's photonics operations. McCann joins Sivers Semiconductors with more than 25 years of executive leadership experience in the semiconductor industry. He previously served as senior vice president of global operations at Dialog Semiconductor and as COO at Linear Technology Corp.

native processing units and native processing server solutions. These solutions are designed to power high-performance computing data centers. According to Q.ANT, its native processing server solutions specifically aim to accelerate key workloads, including AI model training and inference, scientific and engineering simulations, real-time processing of complex mathematical equations, and high-density tensor operations for machine learning.

The development of the line stems from an agreement between Q.ANT and IMS CHIPS that the partners signed in 2023.

"By partnering with Q.ANT, we are leveraging our semiconductor manufacturing expertise to accelerate the industrialization of photonic processors and establish a scalable model for energy-efficient computing — a crucial step for the future of AI," said Jens Anders, director and CEO of IMS CHIPS.

Q.ANT is a 2018 spinout from TRUMPF R&D. The company has earned support from TRUMPF since its establishment, including an eight-figure investment in 2021 as well as numerous partnerships and consortia.

$36.6B

— estimated value of the global optical communication and networking equipment market by 2027, according to MarketsandMarkets

LightPath acquires G5 Infrared

LightPath Technologies acquired G5 Infrared LLC, a high-end infrared camera systems manufacturer. LightPath will pay $27 million in cash and stock to make the purchase. The deal carries the potential for additional performance-based consideration, LightPath said.

The deal expands LightPath's portfolio to include cooled infrared cameras and, according to officials, creates a more robust, vertically integrated solutions provider. LightPath expects the combined company to earn at least $55 million in revenue in the 12 months following the acquisition.

Founded in 2011, G5 specializes in long-range mission-critical detection solutions, focusing on defense, border security, and counter-uncrewed aerial system/counter-drone markets. The New Hampshire-based company is also a provider of infrared coatings, including materials such as LightPath's BlackDiamond glass.

According to LightPath, its BlackDiamond glass, offered as an alternative solution to germanium, and its acquisition and integration of Visimid Technologies in 2023, have positioned the company to become a global leader in infrared imag-

Allegro MicroSystems

Doogue.

Power and sensing semiconductor solutions provider Allegro MicroSystems Inc. named **Mike Doogue** president, CEO, and member of the board, succeeding **Vineet Nargolwala**. Doogue has spent the last 27 years at Allegro, originally as an engineer and business leader before his most recent roles as executive vice president and the company's first CTO.

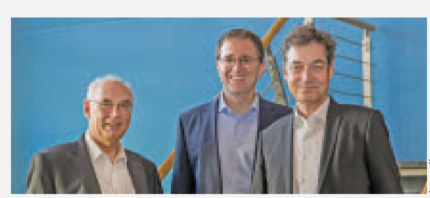
AIXTRON, a provider of deposition equipment to the semiconductor industry, designated supervisory board member **Alexander Everke** successor to the supervisory board chairmanship. Everke will replace current chairman **Kim Schindelhauer**. Additionally, the company intends to propose the election of **Ingo Bank** as a member of the supervisory board at its annual general meeting on May 15. Everke has been a member of AIXTRON's supervisory board since May 2024 and was previously the CEO of ams OSRAM. Bank currently serves as the CFO of the City Football Group and served as CFO of ams OSRAM from May 2020 to April 2023.

IDEX Corporation added **Stephanie Disher** and **Matthijs Glastra** to the company's board of directors. Disher, currently CEO of Atmus Filtration Technologies Inc., will serve on the board's nominating and corporate governance committee. Glastra, who is chair and CEO of Novanta Inc., will serve on the board's audit committee.

Nikon Metrology Europe NV appointed **Aiden Kenny** president. Kenny has held executive leadership roles in several global companies, including a nearly 20-year stint at Nikon Precision Europe GmbH in engineering and business management.

Teradyne, a developer of automated test equipment and advanced robotics systems, appointed **Shannon Poulin** president of its semiconductor test division. The appointment will take effect after the retirement of current president **Rick Burns**, which is set for June 1. Most recently, Poulin was the COO at Altera, formerly a part of Intel. Prior to Altera, he spent 22 years at Intel, where he held various general manager roles.

Laserline, a developer and manufacturer of laser diodes for industrial material processing, appointed **Claus Narr** its third managing director, alongside company founders **Christoph Ullmann** and **Volker Krause**. Narr has been with Laserline since 2011 and has held a variety of roles, most recently as managing director of the company's subsidiary Backes Electronic.



Laserline

(From left) Laserline managing directors Christoph Ullmann, Claus Narr, and Volker Krause.

ing through the development of a product portfolio of optical assemblies and cameras. Integrating G5's advanced MIR cooled camera products with LightPath's uncooled LWIR cameras will create a portfolio of complementary infrared imaging solutions including both long-range and short-range imaging applications, mobile and stationary solutions, and application-specific solutions, such as optical gas imaging.

LightPath announced the acquisition in conjunction with its release of its fiscal year 2025 second quarter earnings. The company posted revenue of $7.4 million, representing an increase of 1.5% year-over-year for the same quarter. The company's profit decreased 11%, to $1.9 million, in the second quarter of 2025, as compared to $2.2 million in the same quarter of the prior fiscal year. LightPath said that the decrease in gross margin owes primarily to differences in the product mix coupled with some manufacturing yield issues in infrared components.

Lumotive raises $45 million

Lumotive, a developer of programmable optical semiconductor products, closed a $45 million series B funding round to accelerate sales growth of its Light Control Metasurface technology. The company plans to use the funds to strengthen its international presence to provide responsive localized support and customized solutions for specific technical business needs.

Lumotive's Light Control Metasurface chips guide photons by using the light-bending properties of metamaterial surfaces. Nanostructures smaller than the wavelength of light work together to both shape and steer optical energy in any direction within the field of view. The technology is manufactured using conventional silicon fabrication processes, enabling scalability.

Earlier this year, Lumotive established a partnership with E-Photonics and forged agreements with Hokuyo Automatic and Namuga. The company began a collaboration with SkyWater Technology last year on the production of Lumotive's solid-state optical beamforming technology.

The series B round included new investors Swisscom Ventures, East Bridge, EDOM, Grazia, Hokuyo Inc., and TSVC as well as support from existing investors such as Gates Frontier, MetaVC Partners, Quan Funds, USAA, and Himax Inc. Lumotive raised a $13 million round two years ago, which brought the total amount raised at the time to $56 million.

Briefs

Rochester Precision Optics (**RPO**) secured a $50 million commitment to boost its development and manufacturing capabilities. The company said the funds will drive advancements across its operations and enable it to further compete with international manufacturers in the security, industrial, medical, and critical product sectors. RPO will focus on scaling production capacity, advancing optical technology innovation, and expanding its workforce.

The U.S. Space Force awarded **BAE Systems** $151 million to build upon Phase 1 of the Future Operationally Resilient Ground Evolution (FORGE) Command and Control (C2) prototyping effort. BAE Systems is to deliver a prototype ready for the Space Systems Command's Next-Generation Overhead Persistent Infrared system. FORGE C2's mission is to bolster Space Systems Command's missile warning and tracking ground systems.

Sensors developer **onsemi** disclosed plans to acquire industrial automation company **Allegro MicroSystems Inc.** Onsemi submitted a proposal to the Allegro board to acquire the company for $35.10 per share in cash for each share of Allegro's common stock on a fully diluted basis at an implied enterprise value of $6.9 billion. Allegro's board deemed the proposal inadequate. According to onsemi, it has made numerous attempts to enter into constructive discussions regarding a potential transaction.

Hamamatsu Photonics Korea Co. Ltd. completed construction on a factory in Hwaseong-si, South Korea. According to the company, the factory will boost Hamamatsu Photonics Korea's production capacity of semiconductor failure analysis equipment and expand sales in the global market. The company's manufacturing plant will now be moved to the newly built factory.

Hyperlume raised $12.5 million for the commercialization of its high-bandwidth, low-latency, low-power interconnects for data centers and high-performance computing systems. The company's technology uses specialized, ultrafast micro-LEDs and ultralow-power circuitry to achieve performance, cost, and energy-efficiency gains relative to traditional copper interconnects. Hyperlume plans to use the funds to accelerate development; expand its staff; and strengthen strategic partnerships with hyperscalers, chip manufacturers, and AI infrastructure providers as it prepares for the production of its optical technology to meet demands for 800G and 1.6T interconnects.

Laser technology developer **Luxinar** expanded its services to customers by setting up a smart applications laboratory at U.K. headquarters for its ultrashort-pulse laser sources. The company installed cameras to capture and livestream laser processing trials, including at microscopic levels, where its applications engineers can demonstrate processes and share information in real time during application trials.

STMicroelectronics released its next generation of 300-mm silicon platform proprietary technologies based on its silicon phosphorous and BiCMOS technologies for higher-performing optical interconnects in data centers and AI clusters. Developed in collaboration with Amazon Web Services, BiCMOS is a combination of bipolar resisters and CMOS technology based on silicon germanium. The products will include 800 Gbps and 1.6 Tbps optical

Teradyne to acquire Quantifi Photonics

Automated test equipment and robotics company Teradyne entered into a definitive agreement to acquire Quantifi Photonics, a provider of PIC testing. The terms of the deal have not been disclosed.

Following the acquisition, Teradyne intends to accelerate the development of cost-effective, high-throughput test solutions for wafer-level, die/multi-die, and co-packaged optical module testing, according to CEO Greg Smith. In addition to delivering scalable solutions for PICs testing, Quantifi Photonics provides test solutions targeting scalable and cost-effective high-volume manufacturing of co-packaged and pluggable optics.

Teradyne's solutions serve the semiconductor, electronics, warehouse, and manufacturing markets. In March, the company announced the addition of Shannon Poulin, who will assume leadership of the company's semiconductor test division this spring.

Formerly known as Coherent Solutions, Quantifi Photonics appointed Iannick Monfils CEO last year, and raised $15 million in a series C funding round in 2022 following its acquisition of Smartest Electronics. It also operates a German-based, European subsidiary, Quantifi Photonics GmbH, which it established in 2023.

"The silicon photonics market is at an inflection point that requires innovative, state-of-the-art solutions to unlock its full potential," Monfils said, in a shared release announcing the acquisition.

"By combining our strengths, Teradyne and Quantifi Photonics will provide customers with complete turnkey photonic test solutions that allow them to scale."

Beyond integrated photonics test solutions, Quantifi Photonics offers products enabling photonics test and measurement solutions, including laser sources and amplifiers, bit error rate testing, digital sampling oscilloscopes, optical power meters, variable optical attenuators, optical spectrum analyzers, polarization conditioners, and other solutions supporting coherent optical communications.

31.4%

— predicted compound annual growth rate of the global adaptive optics market by 2030, according to Grand View Research

modules. The company is also developing a road map with its partners across the value chain for higher energy efficiency pluggable optics.

QDI Systems, a developer of quantum dot-based imaging technology, received a €2.5 million ($2.6 million) grant from the European Innovation Council. Total funding available through the grant and accompanying equity financing is up to €7.5 million. QDI Systems plans to use the funding to scale its nanomaterial quantum dot technology for SWIR and x-ray applications. The company, a 2019 spinoff of the Zernike Institute for Advanced Materials at the University of Groningen, previously raised $5.4 million in a series A funding round.

Silicon photonics startup **Enosemi** entered into a collaboration with **Jabil**, which will provide Enosemi with packaging services to support higher-bandwidth interconnects within AI compute systems. Per the collaboration, Enosemi's chiplet and intellectual property (IP) customers will be able to leverage Jabil's expertise to develop highly integrated packages with AI application-specific integrated circuits and photonic chips. Enosemi, which emerged from stealth in 2023, has existing 1.6-Tbps photonic chiplets and design IP. The company uses a 300-mm wafer manufacturing process, and released a portfolio of high-speed IP in the GlobalFoundries Fotonix IP platform last year.

Samsung Display signed a memorandum of understanding with **Intel** to develop display solutions optimized for Intel's edge processor chips that enable enhanced AI capabilities. The companies will explore new possibilities in the fields of high-performance information technology (IT) devices and premium laptops, including AI PCs. They further plan to apply Intel's system-on-a-chip technology to Samsung Display's IT OLED panels to provide component solutions optimized for AI PCs, including high picture quality and low power consumption.

Norsk Elektro Optikk (**NEO**) launched the development of an advanced hyperspectral imaging system for satellite-based methane detection. The initiative is supported by the European Space Agency (ESA)'s InCubed program. The camera, built from NEO's existing SWIR-640 camera model, incorporates optimized hyperspectral technology for improved detection capability; a refined optical system for higher imaging precision; extended spectral range covering critical methane absorption bands; compact and lightweight design for satellite integration; and enhanced cooling mechanisms for stability in space.

ATLANT 3D, a provider of atomic-scale manufacturing technology, raised $15 million in a series A funding round. ATLANT 3D's direct atomic layer processing technology enables the precise development of advanced materials and devices for optics, photonics, microelectronics, quantum computing, sensors, and space applications. According to the company, the approach simplifies fabrication processes while reducing material waste by 90%. ATLANT 3D plans to use the funds to accelerate product development and commercial growth.

Laserax, an advanced laser solutions company, acquired **DPSS Lasers Inc.**, a manufacturer of 355-nm UV solid-state lasers. Laserax said that the acquisition supports its long-term strategic vision by expanding its U.S. operations, pursuing emerging applications, and driving global growth.

Europe approves $237M for ams OSRAM plant

Company ams OSRAM is receiving €227 million ($237 million) in state aid from the Austrian Ministry of Economy and Labor to support the construction of an advanced manufacturing facility in Premstätten, Austria. The plant, expected to be operational in 2030, bolsters Europe's semiconductor supply chain, particularly for automotive applications.

The facility will be based on a toolbox approach that combines CMOS technology for transistors with a through silicon via (TSV) technique. This allows for a vertical electrical connection of chips and/or optical filters, and thereby provides specific capabilities to the final chip. The advantage of such a tightly integrated process is the ability to produce Grade 0 automotive qualified products with reliability and high performance.

The construction of an additional cleanroom at the Premstätten site, with an area of 1800 sq m for CMOS production, will also double filter capacity and increase TSV capacity by a factor of four.

The plant, expected to be the first facility in Europe with such an integrated process and producing Grade 0 automotive qualified products, will also be partially open to other semiconductor companies. The facility will produce highly differentiated next-generation optoelectronic sensors that are qualified for applications in medical technology and in the automotive industry. In addition, the production of products for use in industry or consumer goods is planned.

The aid is a direct grant to ams OSRAM to support its investment during the construction period in Premstätten. Under the agreement established with the European Commission, ams OSRAM will implement priority-rated orders in the case of a supply shortage in line with the European Chips Act and will also develop and deploy educational and skills training to increase the pool of a qualified and skilled workforce.

In total, ams OSRAM plans to invest €567 million in the project by 2030. The European Commission's approval of the Austrian state aid funding is the seventh such decision. It follows previous approval of a German measure to support Infineon in establishing a semiconductor manufacturing facility in Dresden, Germany.


ams OSRAM's Premstätten, Austria, headquarters.

ams OSRAM

UbiQD acquires BlueDot Photonics


U.S. Chamber of Commerce/Ian Wagreich

UbiQD, a developer and manufacturer of quantum dot technology, acquired BlueDot Photonics. The deal includes perovskite-based quantum cutting technology and exclusive rights to BlueDot's associated intellectual property, initially developed and licensed by the University of Washington.

BlueDot's doped perovskite materials convert high-energy photons into nearly twice as many lower-energy photons, according to the company, and the tech-

Seattle-based BlueDot Photonics develops solutions to improve solar panel performance.

nology could increase silicon solar panel efficiency by up to 16%. The company said that its technology has the potential to reduce the cost of solar energy generation and push photovoltaic performance beyond the limits of traditional silicon-based cells.

For UbiQD, the acquisition of BlueDot signals growing momentum in solar. UbiQD has been building a business unit focused specifically on developing down-conversion products for the industry. In 2023, the company expanded its partnership with First Solar to explore the potential to incorporate fluorescent quantum dot technology in advanced solar modules. The company also received an Advanced Energy Pilot Program award from the State of New Mexico Economic Development Department to bolster its advanced solar energy innovation and commercialization. And last year, UbiQD entered into a collaboration with Los Alamos National Lab to explore quantum-enhanced materials for clean energy applications.

Cailabs, DataPath deploy transportable SATCOM terminals

Cailabs has entered into a partnership with satellite communications (SATCOM) solutions and services provider DataPath Inc. to deploy a new class of transportable optical SATCOM terminals. The collaboration combines Cailabs' advanced optical reassembling technology and optical ground stations with DataPath's experience in deploying ruggedized, tactical SATCOM systems for U.S. and allied militaries.

Cailabs' optical beam-shaping technology, which enables high-speed space-to-ground optical communications by compensating for atmospheric turbulence, will be integrated by DataPath into the transportable terminals. The 10-Gbps optical SATCOM terminals will provide low probability of intercept, low probability of detection, low probability of exploitation, and anti-jamming capabilities.

The partnership follows Cailabs' decision in 2023 to expand its presence in the U.S. by opening an office in Washington, D.C. The expansion was made to support the U.S. Department of Defense and the Space Development Agency in its laser communications road map, the company said.

Cailabs

The transportable optical satellite communications (SATCOM) terminals will be integrated with Cailabs' optical beam-shaping technology.

Ultra-broadband chip-size amplifier enhances network technologies

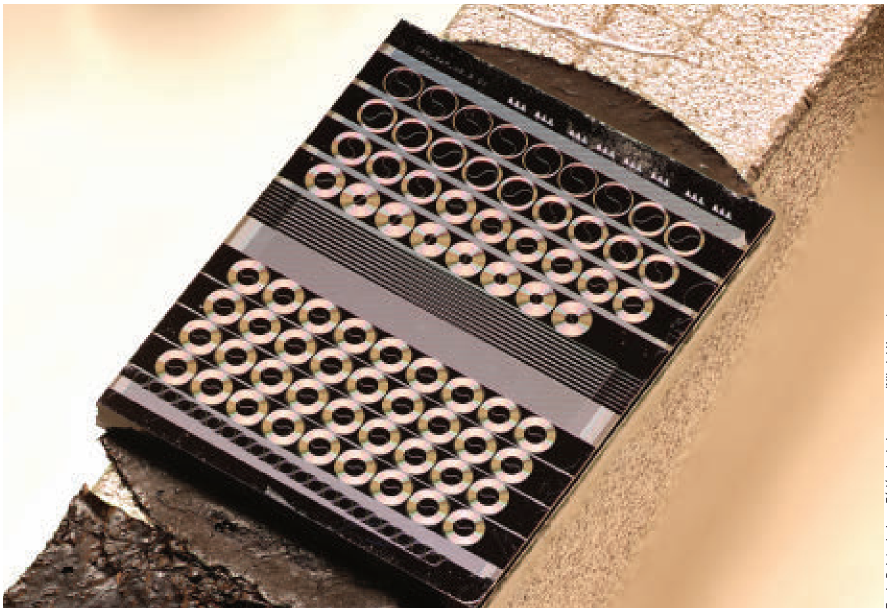
LAUSANNE, Switzerland — Similar to a weak radio signal, the optical signals on which modern communication networks rely must be amplified to travel long distances without losing information. The most common amplifiers in the optical realm, erbium-doped fiber amplifiers, have served this purpose for decades. These critical components effectively enable longer transmission distances without the need for frequent signal regeneration. However, they operate within a limited spectral bandwidth, restricting the expansion of optical networks.

To meet the growing demand for high-speed data transmission, researchers have been seeking ways to develop more powerful, flexible, and compact amplifiers. Existing solutions, such as Raman amplifiers, offer some improvement, but are still too complex and energy hungry for widespread use in all settings.

Researchers led by Tobias Kippenberg at Ecole Polytechnique Fédérale de Lausanne and Paul Seidler at IBM Research Europe - Zürich developed a photonic chip-based traveling-wave parametric amplifier that achieves ultra-broadband signal amplification in an unprecedentedly compact form. Using gallium phosphide-on-silicon dioxide technology, the amplifier attains a net gain of >10 dB across a bandwidth of ~140 nm — 3× wider than a conventional C-band erbium-doped fiber amplifier.

Most amplifiers rely on rare-earth elements to strengthen signals. Instead, this developed amplifier uses optical nonlinearity. By carefully designing a tiny spiral waveguide, the researchers created a space where light waves reinforce each other, boosting weak signals while keeping noise low. This method not only makes the amplifier more efficient but also allows it to work across a much broader range of wavelengths, all within a compact, chip-size device.

The team chose gallium phosphide because of its exceptional optical properties. First, it exhibits strong optical nonlinearity — light waves passing through it can interact in a way that boosts signal strength. Second, it has a high refractive index, which allows light to be confined tightly within the waveguide, leading to more efficient amplification. By using gallium phosphide, the scientists achieved high gain with a waveguide only a few centimeters long, significantly reducing the amplifier's footprint and making it practical for next-generation optical communication systems.



Ecole Polytechnique Fédérale de Lausanne/Nikolai Kuznetsov

A chip-based amplifier achieves ultra-broadband signal amplification in a compact form. The high-performance device addresses concerns, such as spectral bandwidth limitation and energy consumption, and could offer a viable solution for optical networking and other technologies.

The researchers demonstrated that their chip-based amplifier could achieve up to 35 dB of gain while keeping the noise low. Additionally, remarkably weak signals could be amplified, with the amplifier handling input powers ranging more than six orders of magnitude. These features make the new amplifier highly adaptable to a variety of applications in addition to telecommunications, such as precision sensing.

Amplification was also achieved for optical frequency combs and coherent communication signals — two key technologies in modern optical networks and photonics — showing that such photonic integrated circuits can surpass traditional fiber-based amplification systems.

The chip-size amplifier has far-reaching implications for the future of data centers, AI processors, and high-performance computing systems, all of which can benefit from faster, more efficient data transfer. And, the applications extend beyond data transmission to optical sensing, metrology, and lidar systems used in self-driving vehicles.

The research was published in *Nature* (www.doi.org/10.1038/s41586-025-08666-z).

Fluorescence microscopy resolution increased by factor of 30

MUNICH — Superresolution microscopy techniques, such as the Nobel Prize-winning stimulated emission depletion (STED) and photo-activated localization/stochastic optical reconstruction (PALM/STORM) microscopy, provide resolutions of a fraction of the wavelength of light. But to image adjacent fluorescent molecules separately, the microscopes must be sequentially switched between a fluorescent (on) and a nonfluorescent (off) state.

A team of scientists led by Stefan Hell increased the resolution by a factor of 30 for the first time without molecular on/off switching. By using an illumination beam with a zero-intensity stripe (node) in the beam, the scientists separated constantly emitting molecules down to distances of a few nanometers. The study implies the possibility to break the diffraction barrier for other molecules too — not just fluorophores.

Moreover, this superresolution concept can be extended to imaging with other types of waves.

Due to the wave nature of light, even the best lens cannot produce a light spot with a diameter of <250 nm. All molecules within this bright spot are illuminated at the same time and therefore appear inseparable as a blurred whole. In the early 1990s, Hell found that molecules could be separated by briefly switching the molecular signal off and on in such a way that forced closely neighboring molecules to signal consecutively. Molecules that signal consecutively can be readily distinguished.

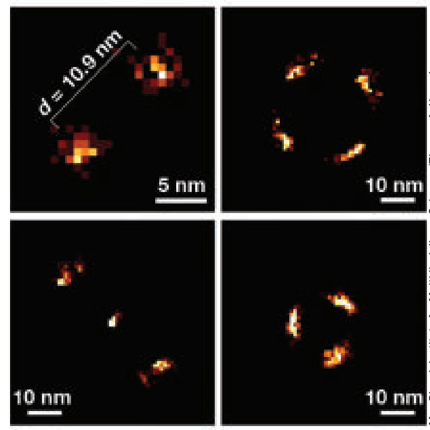
In fluorescence microscopy, this on/off separation principle could be implemented to perfection, since molecular fluorescence can be easily switched on and off. In fact, STED and PALM/STORM as well as the more recent superresolution fluorescence microscopes are all based on this on/off principle. Transferring nearby molecules briefly from a fluorescent on to a nonfluorescent off state and vice versa became the foundation of the burgeoning field of superresolution fluorescence microscopy. In 2014, Hell and the American scientists Eric Betzig and William Moerner received the Nobel Prize in chemistry for the development of super-resolution fluorescence microscopy.

The scientists, led by Hell, from the Max Planck Institute for Multidisciplinary Sciences in Göttingen, Germany, and the Max Planck Institute for Medical Research in Heidelberg, Germany, showed that a countable number of molecules can be separated without on/off switching. The researchers demonstrated experimentally that point objects such as molecules can be clearly separated down to small distances of 8 nm.

To accomplish this, they scanned the molecules with a beam of light that featured a zero-intensity line (node) in the center. As the beam scans across the sample, the measured signal is registered. In the case of fluorescent molecules, the signal is fluorescence. For a single fluorescent molecule, the signal is zero if, and only if, the zero-intensity node of the illumination beam matches the position of the molecule.

However, if the sample contains two or more neighboring molecules, the measured signal cannot be zero. This is because, at any rate, at least one molecule cannot coincide with the zero-intensity point of the illumination light. Therefore, the location of the molecules is encoded in the deviation of the measured signal from zero.

The scientists demonstrated both theoretically and experimentally that this principle of scanning with an intensity minimum can be used to precisely determine the molecular positions. For example, they separated two permanently emitting fluorophores at a distance down to 8 nm. They also resolved a group of three or four molecules at distances of ~20 nm.



Max Planck Institute for Multidisciplinary Sciences/Thomas A. Hensel

With a diffraction minimum in the illumination, simultaneously emitting identical fluorophores on the nanoscale can be resolved for the first time, well below the diffraction limit. Two molecules are separated at a distance of ~11 nm, which corresponds to 1/58 of the light wavelength used **(top left)**.

"On/off switching has been considered a necessary prerequisite for optical high resolution since introducing the STED principle for shutting off fluorescence over three decades ago. The concept of separating constantly emitting molecules just with a minimum is a breakthrough," Hell said.

"With this new concept, it is in principle even easier to spatially register molecules that are closer together than those that are further apart," said Thomas Hensel, first author of the study and a Ph.D. student on Hell's team. "This is not obvious, because it turns the intuition about resolution upside down."

Previously, the closer the molecules were together, the harder it was to resolve them. If molecules are separated using bright light spots and signal maxima is produced, as was the case in the past, it is difficult to distinguish between them, due to the signal-to-noise ratio of the respective molecules.

"If you work with a dark spot or node and examine the deviation of the signal from zero, it is practically the other way around," Hell said.

The Max Planck scientists believe that their results have great potential. "The idea of resolving with a minimum applies not only to fluorescent molecules, but generally to any molecules providing a signal with a good contrast. And it applies not only to optical waves, such as light, but in principle to any type of wave," Hell said.

"Resolving at the smallest distances without on or off is important because it allows continuous observation of all molecules. There is no interruption by the necessity of turning the molecules off."

Continuous observation presents a further application: If a molecular machine, such as a protein or a protein complex, is labeled at different points with constantly signaling molecules, one should be able to track their fine changes in position, making it possible to "film" the actual working of these nano-size machines of life. In the future, this could help to design drugs that, as needed, either prevent or support specific proteins to carry out their function. By providing insights into how proteins work mechanistically, this microscopy method may eventually even accelerate drug discovery.

The research was published in *Nature Physics* (www.doi.org/10.1038/s41567-024-02760-1).

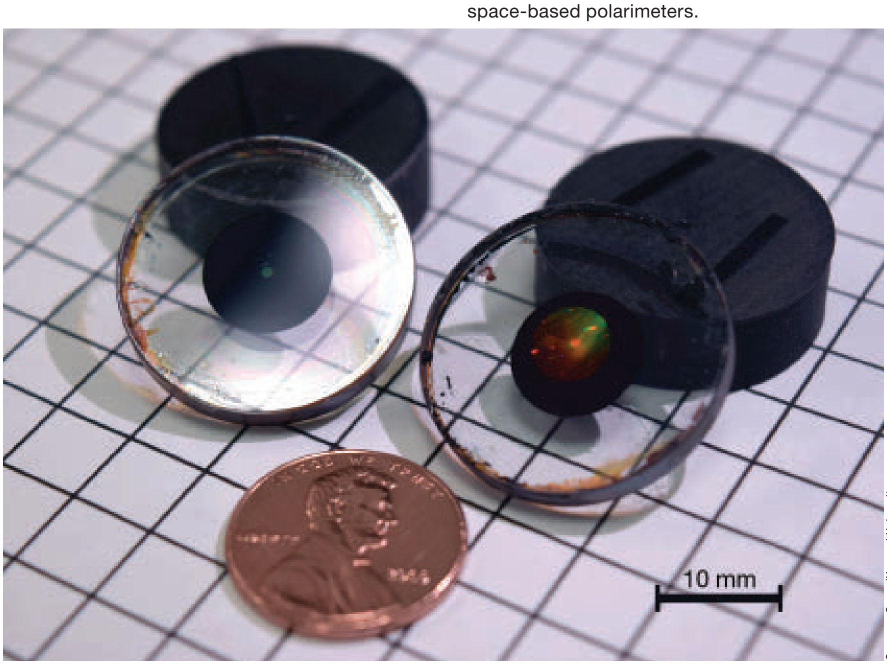
Metasurface optic keeps an eye on atmospheric aerosols

CAMBRIDGE, Mass. — Because aerosols affect a range of commonly used gauges for environmental wellness, from severe weather to air quality, understanding aerosol composition and physics is vital to improving climate forecasting. Polarimeters, which characterize aerosols and cloud particles by observing how they interact with light, are among the best tools scientists have to help develop their understanding of the role of these tiny particles in predicting atmospheric events.

Although many airborne polarimeters are available to scientists, only a few of these instruments have ever flown in space. NASA's Plankton, Aerosol, Cloud, Ocean Ecosystem (PACE) mission, launched in 2024, marked the first space-based science mission featuring polarimetry in more than a decade.

A team of researchers from the Capasso Group at Harvard University, supported by NASA's Earth Science Technology Office, recently completed an early concept study exploring a technology for space-based polarimetry. Specifically, the team investigated whether a novel polarization-sensitive metasurface optical element might be useful for observing atmospheric particles.

Two fully fabricated flat polarimeter samples. Metasurfaces could become the foundation for future ultralight instruments, including space-based polarimeters.



Capasso Group/Harvard University

The study concluded that the metasurface optical element can reliably detect polarized light within the 550 nm, 670 nm, and 870 nm wavelengths, which are ideal light signatures for observing aerosols and cloud particles.

"I think all of this will play well for the long-term plans of NASA," said Federico Capasso, Robert Wallace Professor of Applied Physics at Harvard and principal investigator of this project.

Metasurface optics, lighter and smaller than their traditional counterparts, are therefore less expensive to send into orbit. As NASA plans future Earth science missions, metasurface optics could be key to building a new generation of compact polarimeters.

"The size, weight, and mass production possibility are often quoted as advantages for metasurface optics," said Lisa Li, a former member of the Capasso Group who played a key role in manufacturing this unique metasurface. Lighter, smaller components that are easily produced at scale can reduce the overall cost of a science mission.

Capasso's metamaterial is unique due to its custom grating pattern, etched across a silica glass substrate, that splits an observed scene into distinct polarization channels. Discriminating between polarization states without bulky subsystems could enable researchers to produce a complete polarimetric system (a sorter and an imager) within a single element.

Noah Rubin, a former member of the Capasso Group and a coinvestigator for this project, explained that this was the key achievement of their project — proving that their metasurface grating could measure signatures of polarized light with the accuracy researchers would require from a space-ready science instrument.

"We realized it would be possible to make, essentially, what we call a flat polarimeter," Rubin said.

There is still much work to be completed before NASA has a flight-ready metasurface polarimeter at its disposal, but this early work produced a scientific bedrock on which future metasurface breakthroughs will rely, Rubin said. "I'd like to extend some of this work, some of this polarization-sensitive imaging, to include infrared light, which is a very important wavelength regime for ice cloud remote sensing," he said.

The research was published in *Optics Express* (www.doi.org/10.1364/OE.450941) and *Applied Optics* (www.doi.org/10.1364/AO.480487).

Achromatic flat lens captures detailed images of sun, moon

SALT LAKE CITY — Researchers at the University of Utah developed a multilevel diffractive lens that could serve as a lightweight alternative to conventional refractive systems for long-range imaging. The large-aperture flat lens focuses light as effectively as traditional curved lenses and captures color accurately. Astrophotography imaging systems could use the lens to acquire images in applications where space is at a premium, such as on aircraft, satellites, and space-based telescopes.

The researchers used a computational framework to design and test the lens. Using an inverse-design approach and grayscale lithography, the researchers created a flat lens that is 100 mm in diameter and 2.4 µm thick. The lens has a 200-mm focal length and is optimized for the 400- to 800-nm wavelength range.

For centuries, lenses have worked the same way — that is, by using curved glass or plastic to bend the light and focus the image. The thicker and heavier the lens, the more it bends the light and the stronger the magnification.

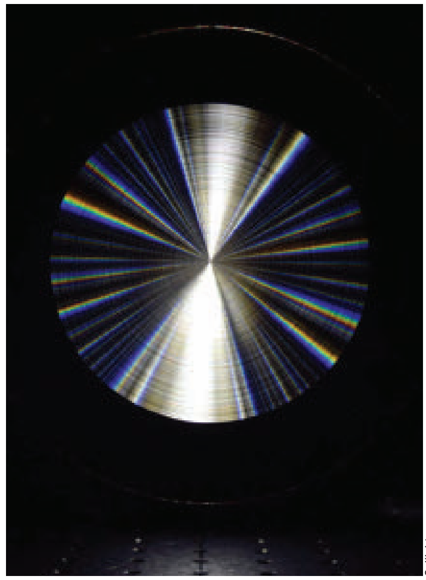
The weight and bulk required for curved lenses to be powerful enough to support large telescopes makes them impractical for ground- and space-based telescopes. These telescopes instead rely on massive, curved mirrors, which are thinner and lighter than curved lenses, to bend light and bring the image into focus. However, mirrors can also blot or distort portions of the image.

Diffractive lenses can be just as lightweight as mirrors without the drawbacks. However, the diffractive lenses that are currently in use tend to be limited in their capacity and challenging and expensive to make.

A Fresnel zone plate (FZP) is a type of flat lens that uses concentric ridges instead of a thick, curved surface to focus light. This approach makes the lens lightweight and compact, but the drawback is that it prevents it from producing true colors. Rather than bending all the wavelengths of visible light at the same angle, the ridges of an FZP lens diffract the wavelengths at different angles, resulting in an image with chromatic aberrations.

To create a flat lens that could depict colors accurately, the researchers created a pattern of microscopic, concentric rings on the substrate of their lens. They optimized the concentric rings of microscopic indentations on their flat lens to bring all wavelengths of light into focus at the same time. Unlike the ridges of FZPs, which are optimized for a single wavelength, the size and spacing of the indentations on the new lens keep the diffracted wavelengths of light close enough together to produce a full-color, in-focus image.

In experiments resolving spatial frequencies up to 181 line-pairs per millimeter, the researchers used the flat lens to capture high-quality, full-color images of the moon, sun, and distant terrestrial scenes. The lens acquired color-enhanced lunar images that revealed geological features and solar images that identified sunspots.



Scilight

Researchers at the University of Utah developed a large-diameter diffractive lens that enables detailed, color-accurate imaging in air and space.

The team used hyperspectral point-spread function characterization to confirm achromatic focusing. It also integrated the multilevel diffractive lens with a refractive achromatic lens to form a hybrid telescope, which could significantly reduce the weight of the lens for airborne and space-based imaging applications.

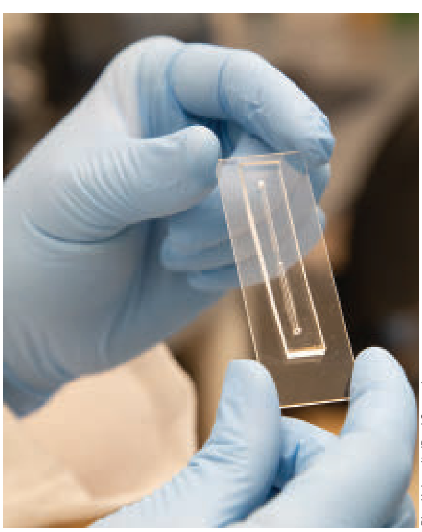
"Simulating the performance of these lenses over a very large bandwidth, from visible to near-infrared, involved solving complex computational problems involving very large data sets," said professor Apratim Majumder, who led the research. "Once we optimized the design of the lens' microstructures, the manufacturing process … required very stringent process control and environmental stability."

The simulations and experimental results demonstrate the exciting potential of large-area, achromatic flat lenses for astrophotography as well as other fields.

"Our demonstration is a stepping stone toward creating very large aperture, lightweight flat lenses with the capability of capturing full-color images for use in air- and space-based telescopes," Majumder said.

The research was published in *Applied Physics Letters* (www.doi.org/10.1063/5.0242208).

AI-enhanced cytometer brings low-cost analysis to point of care



Rice University/Doni Soward

A slug flow-driven microfluidic chip, part of a cytometry system that incorporates an AI mechanism. The cytometer could be used for applications such as disease diagnosis, including at the point of care.

HOUSTON — An AI-enabled, low-cost microfluidic cytometry device for rapid cell analysis could make flow cytometry more affordable and accessible for low-resource and remote settings. Rice University researchers developed such a device, which demonstrates a level of accuracy comparable to conventional flow cytometers.

Though flow cytometry is considered the gold standard lab test for clinical diagnosis and care and is used extensively in biomedical research, its use is limited to diagnostic labs and medical centers because it requires large, expensive equipment and complicated sample preparation and processing protocols. The AI-enabled, microfluidic cytometer is significantly cheaper and more compact than conventional cytometers. At the same time, it requires minimal sample preparation and instrumentation.

To reduce the cost and size of the device, the team used gravity-based slug flow in its design of the microfluidic cytometer. The device uses a microfluidic chip to drive the sample via gravity-based slug flow, eliminating the need for a pump and simplifying operation. Gravity-driven slug flow allows the sample to flow at a constant velocity through the microfluidic device, which is crucial for achieving accurate cell detection using an AI-based object detection technique.

Gravity-driven slug flow is used primarily for transporting large volumes of liquids through industrial equipment. "To our knowledge, this is the first time gravity-driven slug flow has been employed for a biomedical application," professor Peter Lillehoj said.

The researchers then used the AI mechanism to enable the device to provide a quick, accurate count of CD4+ T cells — a marker of the body's immune status — from unpurified blood samples.

The device labels CD4+ T cells in the blood with anti-CD4 antibody-coated microbeads.

An optical microscope and video camera recorded the sample flowing through the microfluidic chip. To accelerate image analysis and quantification, the researchers trained a convolutional neural network-based model to detect only the bead-labeled cells in the blood flow.

An analysis of blood samples obtained from healthy donors showed that the microfluidic cytometer could quantify CD4+ T cells with accuracy comparable to traditional flow cytometers, with a <10% deviation between the two methods.

In addition to being less expensive and easier to operate than commercial flow cytometers, the microfluidic cytometer is at least 4× faster than traditional cytometers, with a rapid, 15-min turnaround time. Due to its speed, portability, and ease of use, the microfluidic cytometer has the potential to be used for point-of-care applications for cell quantification.

The AI-aided microfluidic cytometry system can be readily modified to quantify other cell subpopulations by replacing the anti-CD4 antibody-coated beads with beads that are coated with antibodies targeting other proteins expressed on different cell types. The team envisions that the platform could also be modified for multiplexed cell quantification by using different colored antibody-coated beads.

"Identifying and quantifying CD4+ T cells from unpurified blood samples is just one example of what one can achieve with this platform technology," professor Kevin McHugh said. "This technology can be easily adapted to sort and analyze a variety of cell types from various biological samples by using beads labeled with different antibodies.

"Based on the promising results we've obtained so far, we are very optimistic about this platform's potential to transform disease diagnosis, prognosis, and the biomedical research landscape in the future."

The research was published in *Microsystems and Nanoengineering* (www.doi.org/10.1038/s41378-025-00881-y).

Model predicts how polaritons increase OLED efficiency

TURKU, Finland — Lightweight, flexible, and eco-friendly, OLEDs continue to reshape the lighting industry with innovative illumination solutions and high-definition displays. However, they also continue to be slow at converting electric current into light. Only 25% of the electronic states of organic molecules can emit light upon electrical excitation, which limits the overall efficiency of OLEDs.

With only a 25% probability of emitting photons efficiently and rapidly, OLEDs tend to be dimmer than other lighting technologies.

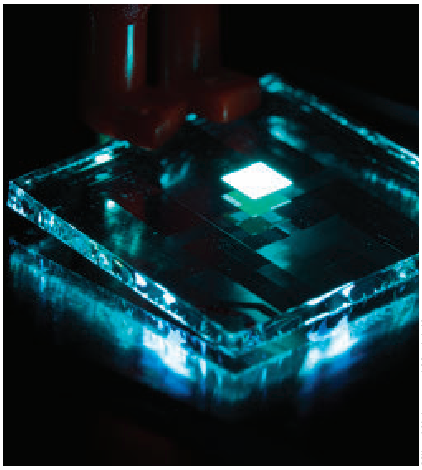
To map out a potential solution to OLED inefficiency, researchers at the University of Turku and Cornell University developed a theoretical model predicting that the brightness of OLEDs can be increased by fine-tuning polaritons.

Polaritons are hybrid states of light and matter created through strong light-matter coupling. The coupling is achieved by using mirrors to confine light within the OLEDs. When sandwiched between two semitransparent mirrors, the organic emitters couple with the confined light, creating polaritons.

Polaritons have the potential to activate the remaining 75% of the electronic triplet states in OLEDs.

Thermally activated delayed fluorescence emitters are a class of OLED emitters with high internal quantum efficiency. In thermally activated delayed fluorescence emitters, triplet excitations are efficiently converted into singlets by reverse inter-system crossing (RISC).

Microcavity polaritons have the potential to achieve high RISC rates without compromising the emitters' ability to emit photons. In the context of OLEDs, this means that by using straightforward cavity designs, the emitters inside a cavity can exhibit high RISC rates and high internal quantum efficiency, resulting in optoelectronic devices that combine simple architectures and superior performance.



A standard blue OLED with a width of 15 mm and an emitting pixel width of 2 mm. A polariton OLED could be obtained by replacing the thin films above and below with a semitransparent material with a thickness of 10 to 100 nm.

However, existing theoretical models for this approach are rudimentary and provide a limited view of how polaritons interact with these molecular processes.

The researchers saw the lack of an effective model as a bottleneck hindering efficient triplet harvesting in actual OLED devices. Their theoretical model for polaritonic OLED processes is not restricted to the single-excitation subspace. The model allows the researchers to explore RISC together with triplet-triplet annihilation (TTA) and singlet-singlet annihilation (SSA).

Using the Marcus theory of electron transfer and Fermi's golden rule, the researchers derived rates for both polaritonic RISC and TTA. By scanning the parameter space of the model, they constructed enhancement maps for both RISC and TTA. They also analyzed the effect of the number of molecules and studied how SSA could be reduced with strong coupling. They applied the model to six molecules previously studied under strong coupling.

"While the general idea of using polaritons in OLED technology is not entirely original, a theory that examines the boundaries of performance gains has been missing," associate professor Konstantinos Daskalakis said. "In this work, we carefully examined where the polariton sweet spot lies in different scenarios. We found that the strength of the polaritonic effect in OLEDs' performance depends on the number of coupled molecules. The fewer, the better."

By tuning the polaritonic states, it is possible to find where the 75% dark states start to become bright polaritons.

"With the molecules we studied and a single coupled molecule, the efficiency improved significantly," researcher Olli Siltanen said. "The dark-to-bright conversion rate increased by a whopping factor of 10 million at best."

The team further found that the polaritonic effect was negligible in many of the molecules, which could indicate that the dark-to-bright conversion rate of existing OLEDs cannot be enhanced simply by equipping them with mirrors.

"The next challenge is to develop feasible architectures facilitating single-molecule strong coupling or invent new molecules tailored for polariton OLEDs," Daskalakis said.

"Both approaches are challenging, but as a result, the efficiency and brightness of OLED displays could be significantly improved."

The results of this study could additionally open a path for more advanced hybrid light-matter technologies.

The research was published in *Advanced Optical Materials* (www.doi.org/10.1002/adom.202403046).

Terahertz wave generator delivers high radiating power on a chip

CAMBRIDGE, Mass. — Researchers at MIT created a chip-based, terahertz amplifier-multiplier system that achieves high radiating power within a streamlined design. The compact device for generating terahertz on a chip could be used to improve data transmission, medical imaging, high-resolution radar, environmental monitoring, and many other applications.

Though it is known that a chip-based source for terahertz power could improve the efficiency of electronic devices and chip-based applications, the generation of terahertz waves on a semiconductor chip is difficult and represents a bottleneck to such a source. One approach to generating terahertz waves on a chip is to use a CMOS, chip-based amplifier-multiplier chain that increases the frequency of radio waves until the waves reach the terahertz range. The waves pass through the silicon chip and are emitted into the open air.

However, the amount of terahertz radiation that is either absorbed, reflected, or transmitted is affected by the dielectric constant. Since the dielectric constant of silicon is higher than that of air, most terahertz waves are reflected at the silicon-air boundary, instead of being transmitted. Most of the terahertz signal strength is lost at this boundary, and silicon lenses are often used to boost the power of the remaining signal.
These lenses, which can be larger than the chip itself, make it hard to integrate the terahertz source into an electronic device.

The MIT researchers took a different approach: They used a matching material to equalize the dielectric constants of silicon and air.

The researchers attached a thin sheet of material with a dielectric constant between silicon and air to the back of the chip. The matching sheet increased terahertz wave transmission and reduced the reflection of terahertz waves. As a result, the team minimized the loss of signal strength at the boundary.

For the matching component, the researchers chose a low-cost, commercially available substrate material with a dielectric constant that was close to what they needed. With a laser cutter, they punched tiny holes into the material to tailor its dielectric constant to suit their needs.

"Since the dielectric constant of air is 1, if you just cut some subwavelength holes in the sheet, it is equivalent to injecting some air, which lowers the overall dielectric constant of the matching sheet," researcher Jinchen Wang said.

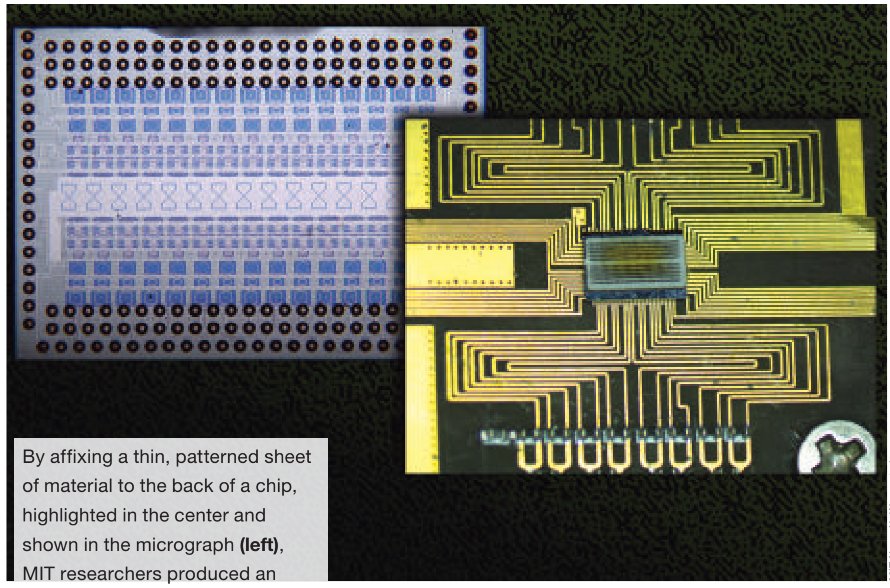
To further improve performance, the

researchers included transistors developed by Intel in the chip's design. These transistors have a higher maximum frequency and breakdown voltage than traditional CMOS transistors.

"These two things taken together, the more powerful transistors and the dielectric sheet, plus a few other small innovations, enabled us to outperform several other devices," Wang said.

The chip demonstrated the ability to generate terahertz signals with a peak radiation power of 11.1 decibel-milliwatts (dBm), achieving higher terahertz radiating power than existing state-of-the-art techniques.

To ensure fabrication scalability, the researchers had to determine how the chip would manage power and temperature when generating terahertz waves. "Because the frequency and the power are so high, many of the standard ways to design a CMOS chip are not applicable here," Wang said. The team also devised a scalable technique for installing the matching sheet at a manufacturing facility.

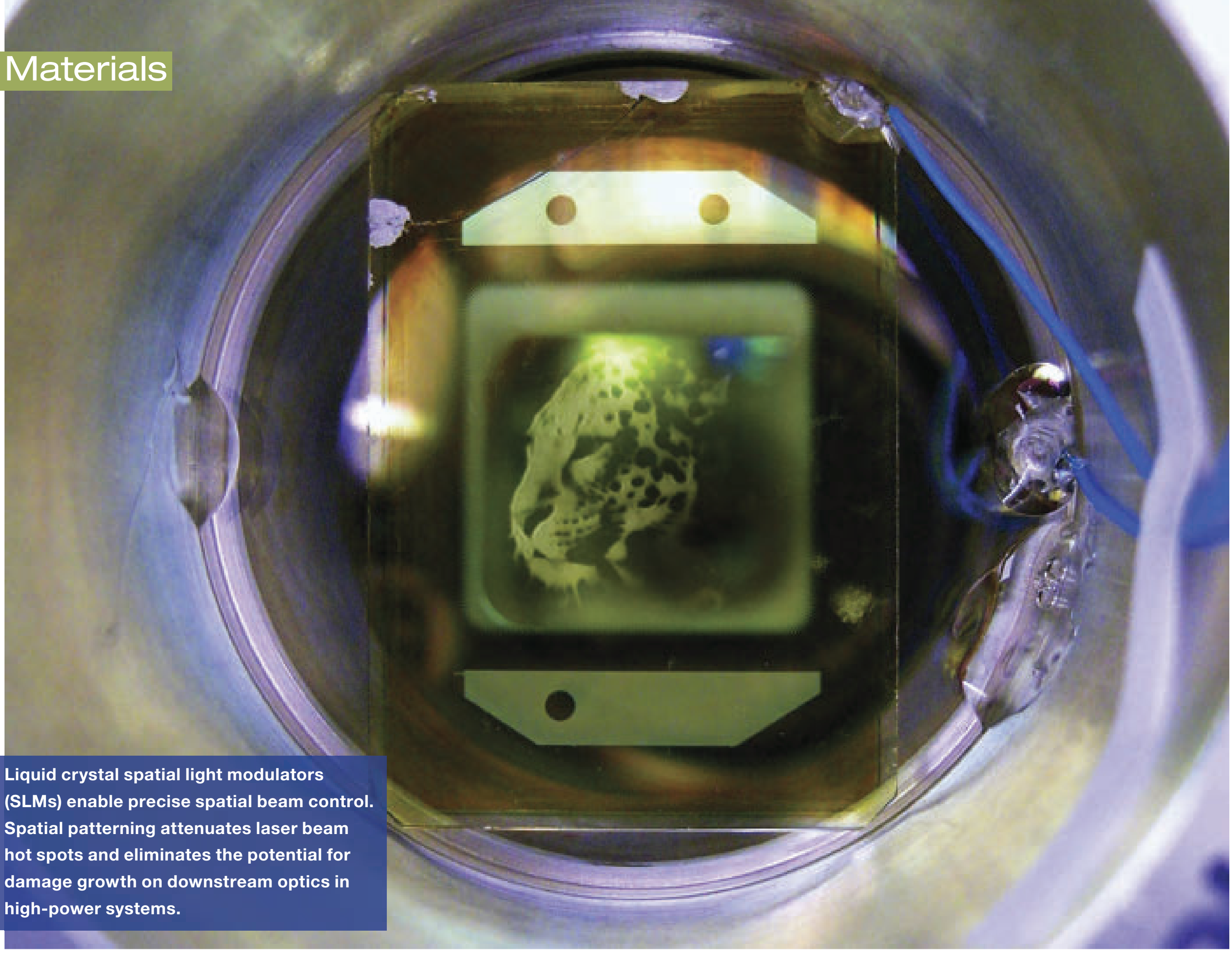


By affixing a thin, patterned sheet of material to the back of a chip, highlighted in the center and shown in the micrograph **(left)**, MIT researchers produced an efficient, yet scalable, chip-based terahertz wave generator.

MIT News/J. Wang et al.

The researchers plan to demonstrate the chip's scalability by fabricating a phased array of CMOS terahertz sources that will enable them to focus a powerful terahertz beam with a low-cost, compact device.

The research was presented at IEEE International Solid-State Circuits Conference 2025 (ISSCC 2025) in San Francisco.



Liquid crystal spatial light modulators (SLMs) enable precise spatial beam control. Spatial patterning attenuates laser beam hot spots and eliminates the potential for damage growth on downstream optics in high-power systems.

Beyond Displays, Liquid Crystal Optical Devices Harness Rugged Dynamics

Not all optically useful crystals are solid. Liquid crystals are at the heart of vital components for polarization and phase control in precision optical and high-power laser systems.

Opening image courtesy of the **National Ignition Facility** at **Lawrence Livermore National Laboratory**.
All other images courtesy of **Meadowlark Optics**.

BY TOM BAUR AND
CHRISTOPHER HOY
MEADOWLARK OPTICS

Liquid crystals are undoubtedly most widely used in display technologies. But beyond this context, the ability of liquid crystals to avoid certain critical size limitations that affect most solid crystals enables their usefulness for applications in precision optics. Their use in flat panel displays such as television screens and computer monitors, in fact, demonstrates that liquid crystals do not face these size limitations. This allows them to be particularly effective as optical devices, enabling users to take advantage of important properties of laser light.

Applications using liquid crystals to optimize these properties — polarization, phase, intensity, and direction — are growing. Liquid crystals are increasingly replacing mechanical motions of fixed optical elements. Less than 10 V applied to a thin, 1- to 10-µm layer of liquid crystal between glass plates will control and change laser light properties without any mechanical motions or high voltage. As a result, designers and developers are harnessing these properties to reduce size, weight, and power in laser-enabled optical systems.

Liquid crystal waveplates

Waveplates, or retarders, are historically made using solid birefringent crystal. Most commonly, the crystal materials used to fabricate these elements are quartz, mica, magnesium fluoride, and/or sapphire. Recently, birefringent polymers have started to replace these materials.

These waveplates are fixed in the action that they have on a laser beam — or on any light beam. They are polarization modifiers, and the modification is fixed for a given wavelength and crystal orientation.

The use of liquid crystals in this application enables the electrical modification of the crystal structure. This serves as a beneficial in-application advantage; modifying the crystal structure changes how a thin crystal layer modifies the polarization of a light beam.

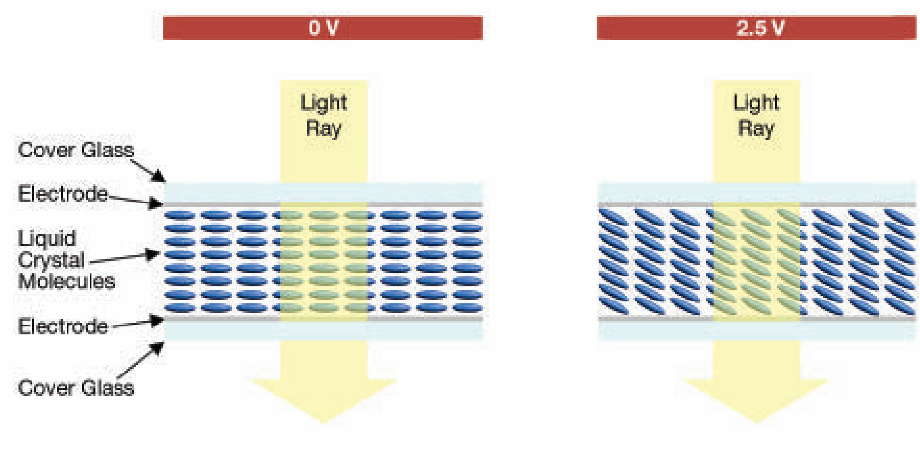


Figure 1. The function of a liquid crystal variable retarder (LCVR) and, specifically, the effect of a small voltage on liquid crystal alignment. This voltage increase from 0 to 2.5 V alters the birefringence of the liquid crystal layer, thereby altering the polarization of the transmitted light.

A liquid crystal variable retarder (LCVR) is a common liquid crystal structure for this function (Figure 1). It provides a waveplate retardance that varies with applied voltage. An electric field is provided to the thin liquid crystal layer through transparent indium tin oxide electrodes on the inner surfaces of the glass cell windows. The electric field induces a dipole in the rod-shaped liquid crystal molecules, which produces a torque that tilts the molecules out of the plane of the windows. This effect changes the birefringence of the liquid crystal layer for rays at normal incidence. A change in the waveplate retardance results in a subsequent polarization change produced on a transmitted beam.

Applications of LCVRs

As mentioned, LCVRs are electrically variable polarization modifiers. Adding a linear polarizer following the LCVR makes the device a variable intensity filter when the incoming laser light is linearly polarized. It is preferable that this takes place with a polarization direction at 45° to the alignment direction of the liquid crystal molecules, which are rod-shaped. A transmission variation of two to three orders of magnitude is nonmechanically varied in this way with a voltage varying from 0 to 10 V. Welding helmets, for example, darken in this way when an arc is struck. The LCVR becomes a variable beamsplitter if the linear polarizer on the exit beam is a polarizing beamsplitter cube. This serves to expand the liquid crystal application to that of a nonmechanical beam path director.

Numerous application examples demonstrate the variable transmission function of LCVRs. They can be used for the control of laser intensities in systems for surgery or texturing of metal surfaces, as well as for laser tattoo removal. Additionally, the variable transmission function can be extended to create combinations of LVCRs that together provide a wavelength-tunable bandpass filter or, in some cases, a notch filter.

In addition to protecting imaging sensors and eyes from laser damage (both tunable and notch filters), tunable bandpass filters are useful for applications spanning hyperspectral microscopy imaging, astronomy, and remote sensing of Earth resources. One lesser-known liquid crystal tunable filter application that Meadowlark has advanced is in grading the color of diamonds, which exhibit colors that range from white to pink to yellow (Figure 2).

An additional example of liquid crystals enabling useful beam dynamics involves beam path switching. For example, this occurs in the lidar system(s) used for guiding and docking a space capsule to the International Space System. In this case, the function is used to facilitate

Figure 2. Clear diamonds surround a rarer yellow diamond. Pink is also a less common — though occasionally found — color for diamonds, and all are graded for color using a liquid crystal tunable filter.

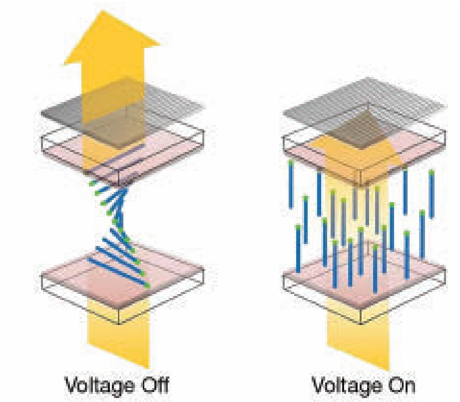


Figure 3. This twisted liquid crystal configuration is often used in simple digital displays. Applying <10 V destroys the twist, which allows light to pass through the exit polarizer. Removing the voltage reestablishes the twisted configuration in a few milliseconds.

a "switch" from a long-range lidar beam path to a close-in path for the final docking maneuver.

As long as they experience protection from strong UV radiation, liquid crystals survive well on space missions — but this is not the only example of their utility for applications in extreme conditions. Liquid crystals are useful in very high-power laser systems, such as those that are used for laser fusion research. Two prominent inertial confinement fusion research facilities in the U.S. — the Laboratory for Laser Energetics (LLE) at the University of Rochester and the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory — use liquid crystal devices. The LLE uses liquid crystals for polarization control and the NIF uses them for control of beam shape[1-2]. In the NIF application, high-powered laser beams are patterned prior to amplification to minimize hot spots and avoid further damage to defects on downstream optical elements (opening image). A spatially variable electrical field across the thin liquid crystal layer enables spatial beam intensity patterning. Meanwhile, the LLE has shown liquid crystal tolerance to pulsed fluences as high as 30 J/cm^2 at a wavelength of 1053 nm in 1-ns pulses[3].

A time-varying liquid crystal retardance followed by a linear polarizer encodes polarization information onto the time variation of polarizer transmission. This combination functions as a polarimeter for the measurement of both linear and circular polarization. Solar astronomers use this polarization information to measure and map magnetic field distribution in sunspot regions with the aim of predicting solar magnetic storms. Past storms show the potential to cause severe damage to the electrical grid by inducing power line currents that can damage transformers.

Liquid crystal alignment can also be twisted. An applied volage will destroy the twist and remove it in the polarization direction (Figure 3).

It should be mentioned that the described liquid crystal devices are fabricated using liquid crystals in the nematic phase. Both the variable retarders and the twisted alignments switch usually in a few milliseconds. By contrast, ferroelectric liquid crystals switch even faster, in ~100 µs or less. These devices have a retardance that is unchanged by voltage. Instead, the fast and slow axes rotate in-plane by a fixed amount with the applications of only a few volts. A 45° rotation is most useful here since it can function as a shutter for linearly polarized light when the liquid crystal device is followed by a linear polarizer.

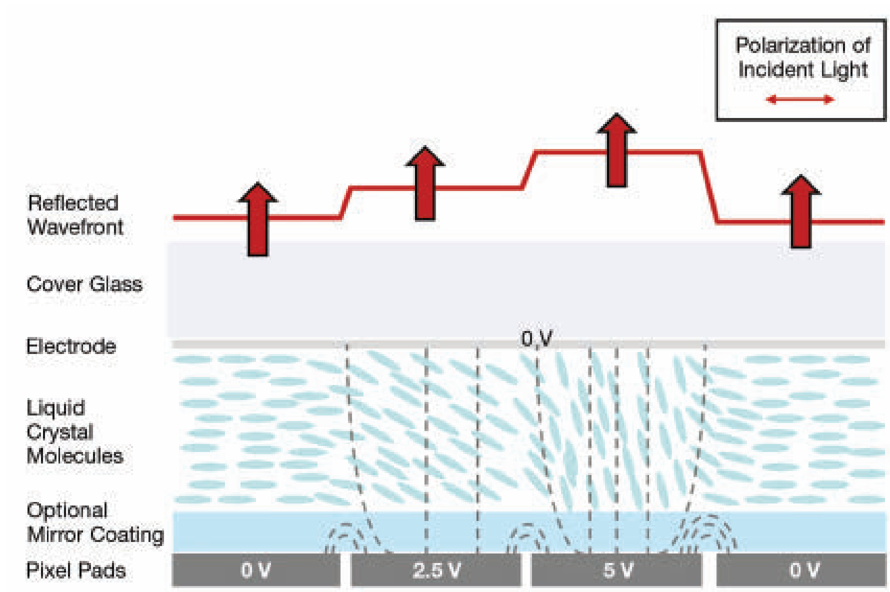
Spatial light modulators

LCVRs including those that have been described find myriad applications in precision optics. These liquid crystal components are essentially single-pixel light modulators, used to modulate the properties of an optical beam uniformly across the entire aperture.

But what happens when the aperture is subdivided into many small pixels?

In many ways, the answer lies with liquid crystals' most recognizable ap-

Figure 4. A liquid crystal on silicon (LCOS) spatial light modulator (SLM) consists of a layer of liquid crystal overlaying a pixelated backplane. By applying varying electric fields at each pixel, the local birefringence can be controlled. This enables pixel-by-pixel shaping of the reflected wavefront. The fastest SLMs can provide full 2π phase modulation at millisecond timescales.



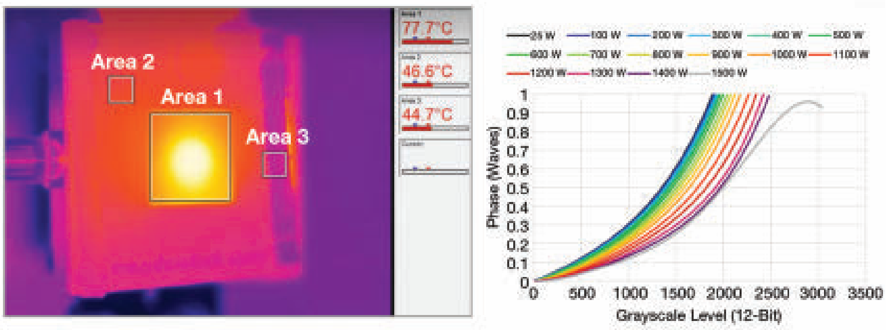


Figure 5. Liquid crystal on silicon (LCOS) spatial light modulators (SLMs) are used with high-power lasers. The thermal image of a Meadowlark Optics 1024- × 1024-pixel SLM under steady-state illumination of 1-kW average power at 1070 nm **(left)**. A plot of phase modulation versus grayscale pixel value shows a full 2π of phase modulation maintained at up to 1.4 kW under the conditions described **(right)**.

plication: Displays and image projectors themselves are pixelated spatial light modulators (SLMs). Here, the liquid crystal is used for intensity modulation by rotating polarization in line with a polarizer.

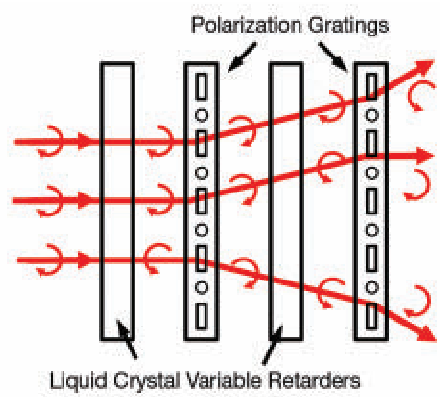
A powerful aspect of SLMs for precision optics arises when the liquid crystal is used to modulate phase. When the liquid crystal is aligned such that each individual pixel acts as an LCVR, the spatially varying retardance can be used to create a pixel-by-pixel shaping of the phase of the incident wavefront. Figure 4 illustrates the anatomy of a reflective SLM. A pixelated silicon backplane is fabricated through large-scale-integration integrated circuit processes. A liquid crystal is sandwiched between the resulting backplane and a uniform transparent electrode.

By arbitrarily shaping the phase of an incident wavefront, a phase-modulating SLM is a programmable optic that can mimic conventional optics. These include lenses or prisms for nonmechanical beam focusing and steering, Zernike basis modes for wavefront correction, and complex phase objects for mode conversion and display of computer-generated holograms. Also, unlike their display counterparts, SLMs for precision optics can provide analog phase modulation at kilohertz rates, modulate wavelengths from UV through MIR, and withstand kilowatt-level average powers.

Since their initial demonstrations in the late 1980s, liquid crystal on silicon (LCOS) SLMs have steadily evolved to meet the needs of demanding scientific applications. Use cases for SLMs are numerous and wide-ranging in this application space. For example, SLMs are used in the field of neuroscience to holographically project ultrashort-pulse lasers into the brains of awake and behaving animals. Modern commercially available SLMs provide full analog wavefront shaping at up to 800 Hz in the NIR, which enables optical control of 3D neural circuits with the single-cellular precision and millisecond-scale timing of natural brain activity.

Similarly, SLMs can create arrays of optical traps using computer-generated holograms. In conventional optical trapping, a focused laser uses optical force gradients to hold a small particle, which can range from atoms to biological cells. Using an SLM, hundreds of optical traps from a single laser can be generated and independently controlled. This technique is finding increased deployment for quantum computing, where SLMs are used to create arrays of optical traps for neutral atoms and ions, and optically address these qubits to implement logic gates. Improvements to UV and short blue wavelength-tolerant SLMs are aiding this application.

In addition to increasing tolerance to the shorter wavelengths of light that traditionally degrade many liquid crystal molecules, emerging materials are pushing the useful range for liquid crystals further into the IR. Recent improvements in the MIR band (λ = 3 to 5 μm) are opening opportunities for hardware-in-loop testing of IR sensors and modalities for chemical



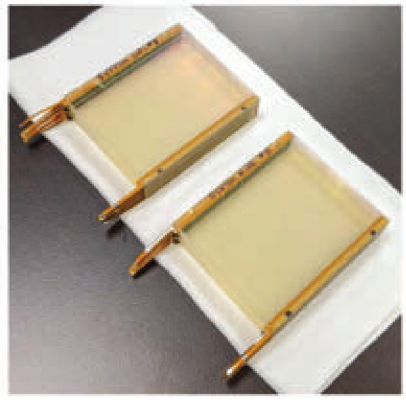


Figure 6. Nonmechanical beam-steering assemblies using polarization gratings and liquid crystal variable retarders (LCVRs). Polarization gratings direct light based on the handedness of circular polarization **(left)**. By combining them with LCVRs to control polarization, these gratings can be used to make transmissive nonmechanical beam-steering assemblies. The two nonmechanical beam-steering assemblies, designed for lidar applications with >50-mm clear aperture and 120° × 25° field of regard **(right)**.

sensing based on IR vibrational spectroscopy.

Finally, manufacturers continue to improve the power handling of LCOS SLMs. Some components in this class have recently demonstrated robust modulation of >1-kW average laser power (Figure 5). In terms of applications, beam shaping for laser manufacturing and laser accelerators is among the most obvious beneficiaries to these increases in the average and peak power handling levels of LCOS SLMs.

Geometric phase optics

The phase modulators previously described rely on changing the effective refractive index along the optical path. Liquid crystals can also be used to induce another sort of phase delay that occurs when two optical paths undergo different transformations of polarization between the same beginning and ending polarization states. This delay is known as the Pancharatnam-Berry phase, or geometric phase. It is realized in practice by patterning a liquid crystal waveplate so that its slow axis orientation varies across the surface of the optic. As a result, these geometric phase optics are also sometimes referred to as diffractive waveplates.

Geometric phase optics exhibit two fundamentally distinguishing properties. First, their theoretical diffraction efficiency is 100%, with diffraction efficiencies ≥99.5% routinely achieved in practice. This is because a geometric phase grating provides a smooth phase function — without the discontinuities of blazed gratings. Second, geometric phase optics are inherently polarization-sensitive and typically designed so that one handedness of circularly polarized light diffracts into the +1 order of the grating while the opposite handedness diffracts into the −1 order.

When the slow axis varies linearly across the optic, the resulting polarization grating can be used to steer light by controlling the handedness of the incident polarization. By stacking up many LCVRs and polarization gratings, it is possible to create transmissive electro-optics to nonmechanically steer light to many discrete angles with both large optical apertures and large steering angles. These enabled capabilities, along with the inherent ruggedness and low power consumption associated with these optics, make beam steering using polarization gratings a popular choice for steering long-range lidar sensors and free-space optical communications systems (Figure 6)[4-5]. Steering large optical apertures also permits the steering of large beams for long-range applications and enables handling of high laser powers when low-loss coatings are used.

In the same manner, if the slow axis rotation varies radially instead of linearly, it is possible to generate polarization lenses that focus or defocus light depending on the incident polarization state. These lightweight and flat lenses have applications in wearable displays for augmented, virtual, and mixed reality as well as nonmechanical refocusing of imaging systems. More complex patterning of the retarder axis can lead to a wide range of useful geometric phase optics, such as highly efficient vortex waveplates used in coronagraphs to reveal exoplanets orbiting distant stars. BEAM Engineering for Advanced Measurements Co. (BEAM Engineering) in Orlando, Fla., has pioneered this challenging application of liquid crystals. Meadowlark Optics and BEAM Engineering are among the liquid crystal technology companies that have trialed and achieved additional useful applications of polarization gratings[4,6-8].

The view ahead

The durability of liquid crystals heightens their importance as components for polarization and phase control in precision optical and laser systems, especially those with high powers. They enable beam steering, polarimetry, wavefront shaping and correction, polarization switching for shuttering, and variable flux control.

Importantly, the use of liquid crystals allows all these functions to be achieved nonmechanically without the use of moving parts. It is therefore apparent in theory and in application that liquid crystal optics are ideal for rugged environments.

And, in addition to uniform, single-pixel devices, a host of applications are enabled by SLMs consisting of a million or more individually electrical addressable pixels. With emerging applications in optics, integrated photonics, and materials science (as well as in displays) the photonics community and those who use photonics products should expect further increases in the use of liquid crystals in the coming years.

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Acknowledgment

The opening image shows custom liquid crystal modulators designed by scientists at the National Ignition Facility (NIF) of the Lawrence Livermore National Laboratory (LLNL) and built by Meadowlark Optics. The components were developed and deployed for the Laser Energy Optimization by Precision Adjustments to the Radiant Distribution (LEOPARD) project, managed by LLNL.

References

1. S.D. Jacobs et al. (June 1988). Liquid crystal optics for laser systems. *Proc SPIE*, Vol. 895, pp. 120-151, Los Angeles, Calif.
2. J. Heebner et al. (February 2011). Programmable beam spatial shaping system for the National Ignition Facility. *Proc SPIE*, Vol. 7916, p. 79160H, San Francisco, Calif.
3. K.L. Marshall et al. (October 2021). The effect of incident polarization handedness and ellipticity on the laser damage resistance of oriented liquid crystals in the nanosecond regime. *Proc SPIE Laser Damage 2021*, Vol. 11910, p. 119100T.
4. C. Hoy et al. (2021). Non-mechanical Beam Steering with Polarization Gratings: A Review. *Crystals*, Vol. 11, No. 4, p. 361.
5. M.J. Escuti, J. Kim, C. Oh, S. Serati (March 17, 2015). Beam Steering Devices Including Stacked Liquid Crystal Polarization Gratings and Related Methods of Operation. U.S. Patent No. 8982313 B2.
6. C. Oh et al. (2009). High-Throughput Continuous Beam Steering Using Rotating Polarization Gratings. *IEEE Photonics Technol Lett*, Vol. 22.4, pp. 200-202.
7. N. Tabiryan. (2024). Fourth-Generation Optics Surmount the Limitations of Planar Optics. *Photonics Spectra*, Vol. 58, No. 11, pp. 30-37.
8. N. Tabiryan et al. (2010). The Promise of Diffractive Waveplates. *Opt and Photonics News*, Vol. 21, No. 3, pp. 41-45.

Two reticles of arrays of photonic crystal cavities.

An Openly Accessible Foundry Process Aims to Accelerate Quantum Commercial Realities

The Quantum Flex Platform will become the first accessible 300-mm platform developed for quantum systems.

Opening image courtesy of **AIM Photonics** and the **Air Force Research Lab** (AFRL/Rome, N.Y.)

BY LEAH SCOTT, LEWIS G. CARPENTER, AND GERALD LEAKE, AIM PHOTONICS

Considerable advancements during the last decade have begun to reveal the critical role of integrated photonics for the successful construction and scaling of quantum systems. Broadly, these industry- and R&D-led efforts are defining the possibilities of this technological space. As support for future quantum technologies continues to grow, so does the anticipation that advancements in this area will soon transition into commercial realities.

At the same time, widely accessible capabilities that can be easily leveraged by the quantum community have yet to be realized. Growth of the industrial base today relies on the emergence of an openly accessible photonic integrated circuit (PIC) foundry process capable of meeting the challenging requirements associated with quantum systems. Inherently, such a solution must enable qubits to be implemented across various frequencies, from the ultraviolet (UV) to the telecommunications (infrared) regimes.

The Quantum Flex Platform (QFlex) developed at the American Institute of Manufacturing Integrated Photonics (AIM Photonics) is addressing this need and working to provide early access to quantum photonics capabilities for U.S. organizations. QFlex is focused on producing an application-specific PIC offering for quantum technologies. At present, it is positioned to be the first accessible 300-mm platform developed to address the distinct needs of quantum systems.

At the heart of QFlex

QFlex offers low-loss silicon and silicon nitride waveguides with propagation losses as low as 0.1 dB/cm. At the same time, the platform still provides access to active optoelectronic devices such as photodiodes and Mach-Zehnder and ring modulators, all based on doped silicon and/or germanium. QFlex can support both active and passive optical devices, including lasers, low-loss fiber attachments, thermal isolation trenches, and various additional trenches for the post-process integration of heterogeneous materials. The platform supports data communications and telecommunications bands and offers active devices such as PIN photodiodes and ring and Mach-Zehnder modulators that have 3-dB bandwidths exceeding 30 GHz.

The first release of the QFlex process design kit (PDK) is earmarked for later this year. This PDK will feature components and associated models identifying radio frequency and optical performance with statistically verified compact models. PDK offerings with augmented component libraries are scheduled to be released during the next five years and will be available through commercial and open layout formats.

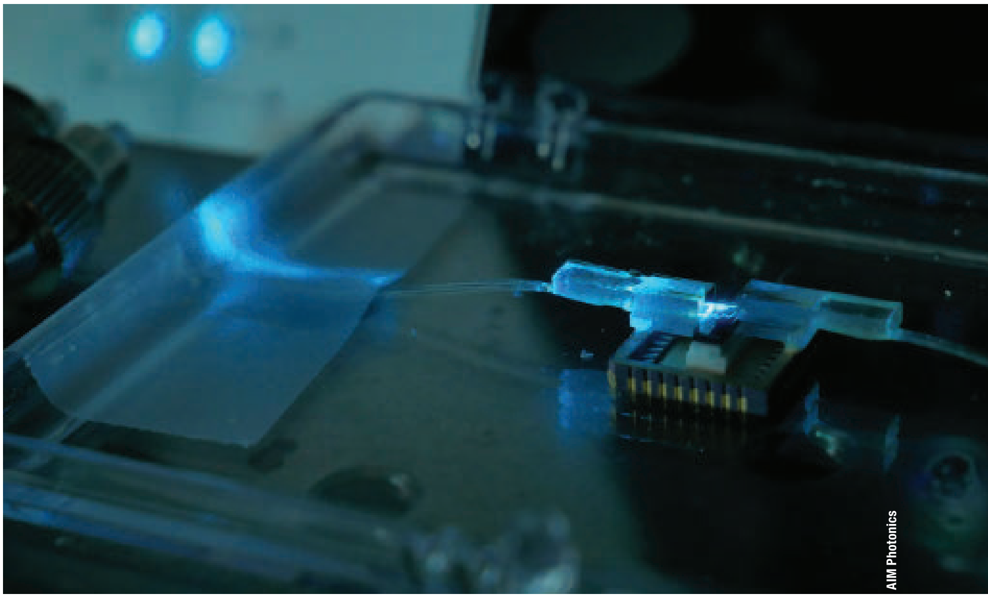
These offerings are designed to include documentation with measured data and process stack files for custom component development. This is essential for quantum-enabled systems to address practical, real-world needs and applications. AIM Photonics is also working to accelerate the quantum photonics community's adoption of PICs by providing access to the platform through a recent design competition, QFlexDC, an initiative that will provide as many as 20 organizations with complimentary QFlex PICs.

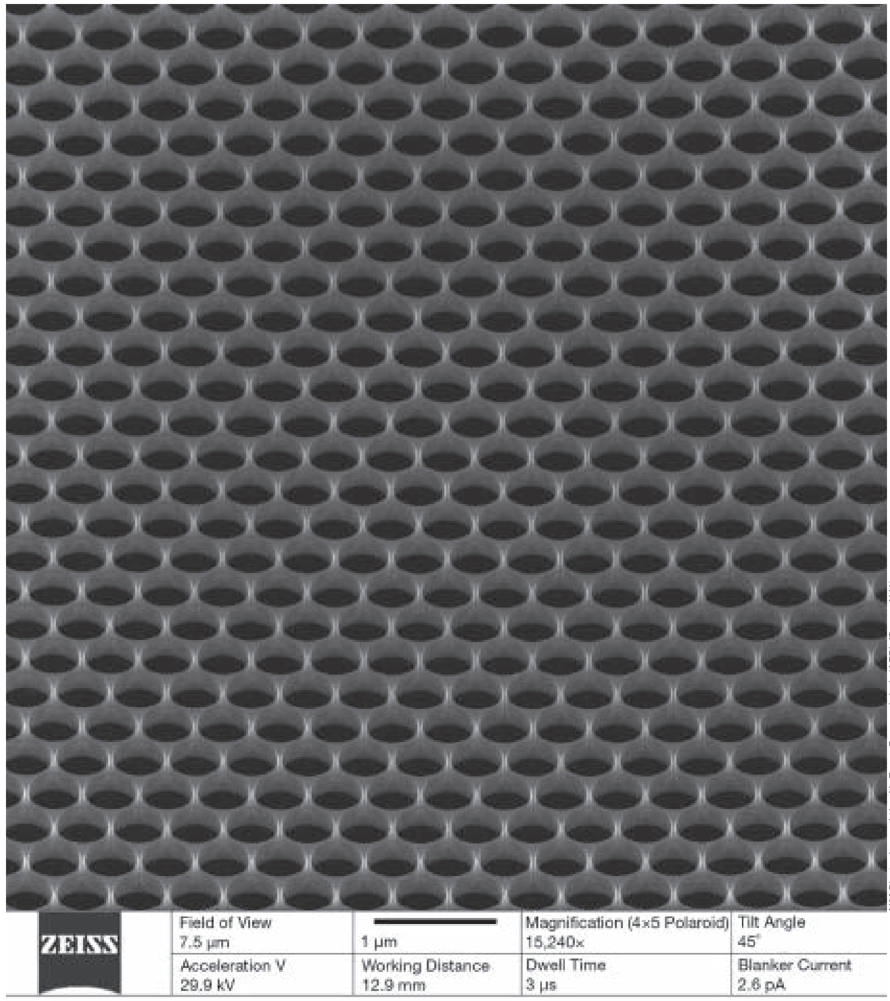
By releasing QFlex as a new multiple-project wafer offering as part of its suite of offerings, AIM Photonics can begin to work with members of the U.S.-based quantum community to support their current needs. The release will also facilitate continued growth of the platform into a transformative capability to help develop quantum applications to technology readiness level (TRL) ~7. Supported application areas include quantum computing, networking, timing, and sensing.

Quantum dynamics

Previously, AIM Photonics collaborated with government partners to develop high-performance quantum capabilities,

An openly accessible photonic integrated circuit (PIC) foundry process targeting quantum system requirements must enable qubits to be implemented across various frequencies, from the UV to the infrared. This packaged quantum photonic system features low-loss visible optical and electrical input/output.


AIM Photonics



AIM Photonics and the Air Force Research Lab (AFRL/Rome, N.Y.)

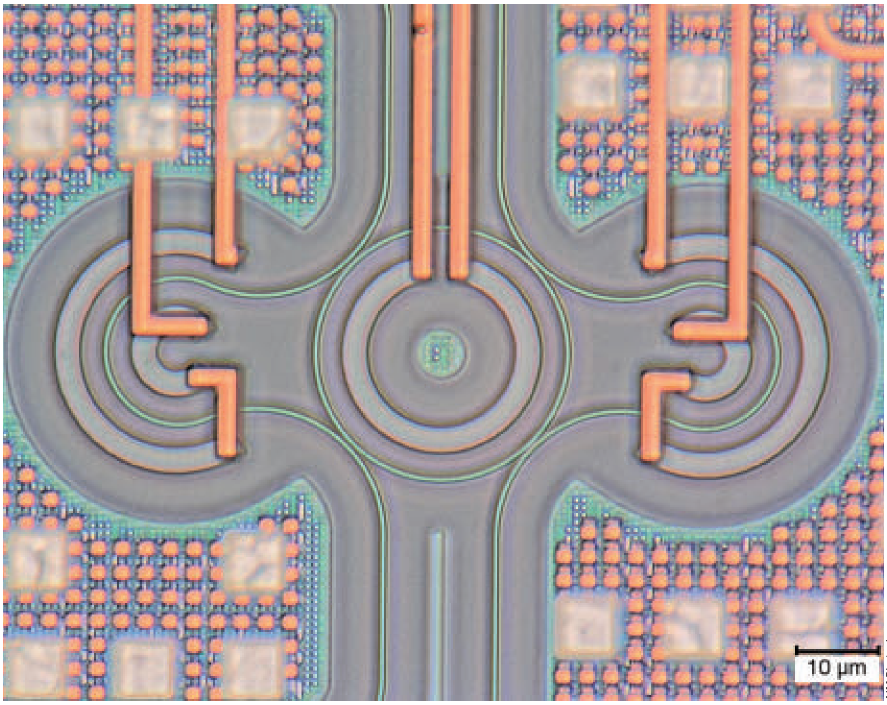
A close-up view of a silicon photonic crystal with quality factors of 10 million.

and subsequent platforms, enabling excellent performance in the visible and UV regions. PIC platforms to date, however, have focused heavily on operating wavelengths in the O, S, C, and L bands (1260 to 1360 nm and 1480 to 1610 nm, respectively). This is due to their applicability in data communications and telecommunications applications. Quantum applications require working with wavelengths in the visible and UV in addition to the O, S, C, and L bands.

Realizing UV to telecommunications operation on a PIC and its optoelectronic control serves to increase the number of different types of qubits that can interface with a PIC. Barium ions, for example, which are studied particularly for quantum capabilities, could be trapped on a QFlex PIC with the expanded wavelength range, since the photonic control beams are in the red (650 nm) and blue (494 nm) with megahertz radio frequency trapping fields. PICs trapping barium are used for a range of quantum systems, including computation, memory, and sensing. The low size, weight, and power of the PICs offers the manufacturability and repeatability benefits of 300-mm CMOS fabrication. The expanded window of operation supported by existing platforms that offer strong performance in the visible and UV regions can be used to unlock PIC-based quantum applications and their miniaturization.

Ongoing efforts

In integrated photonics, most are aware that launching a multiple-project wafer platform is a major feat. It requires significant commitments of time, talent, expertise, and capital to move from the



AIM Photonics

Advancements in single-photon sources have further established this enabling technology for quantum integrated photonics systems. This single-photon source shows silicon waveguides, heaters, and copper wiring.

bench into the commercial space. The QFlex platform effort is bolstered by the Department of Defense funding initiated by the Air Force Research Lab (AFRL) in Rome, N.Y., with additional support from the Micro Electronics Commons Northeast Regional Defense Technology Hub's (NORDTECH) Quantum Ultra-Broadband Photonic Integrated Circuits and Systems (QUPICS), and the Heterogeneous Quantum Networking projects.

Current work that is aimed at broadening QFlex's operational spectrum into the visible and UV stands at TRL 3 and is targeted to reach TRL 6 in 2029. For visible, passive, and active components, as well as nonlinear elements, research efforts are ongoing to add optical materials to the stack. These materials include alumina, aluminum nitride, and thick silicon nitride (~0.8 µm). Upcoming additions to the current QFlex PDK are focused on transmission characteristics in the visible and UV with propagation losses in the decibel per centimeter range, and electro-optic modulation of visible signals in the tens of gigahertz range.

Obtaining early access to these capabilities for U.S.-based organizations performing R&D in quantum systems will be a critical step toward unlocking the potential of quantum systems and applications.

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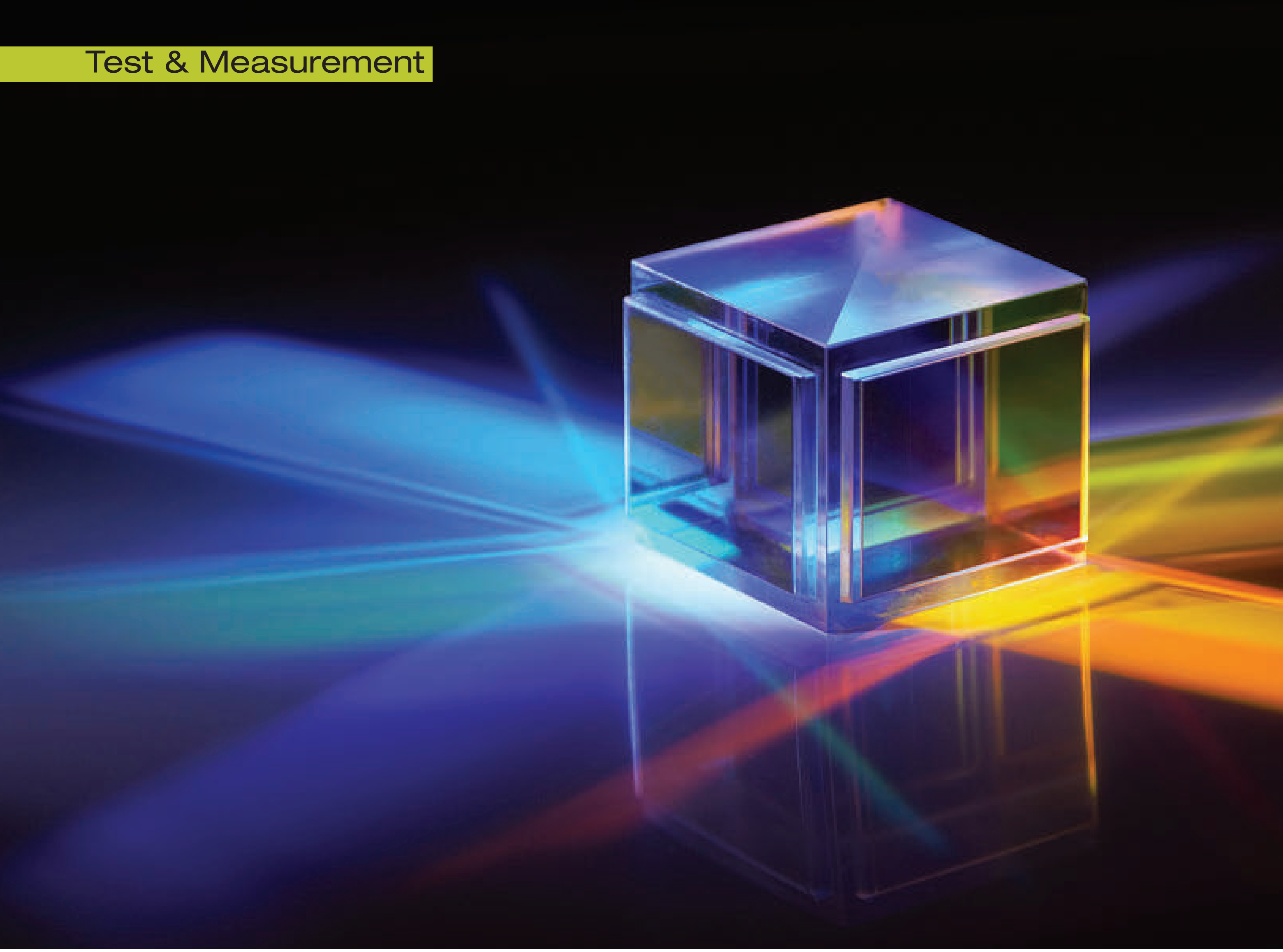

White Light Interferometry

Returns Vital Measurement Values in a Single Shot

Opening image courtesy of iStock.com/Wirestock.
All other images courtesy of Bruker Nano Surfaces and Metrology.

An interferometric approach delivers detailed information on both the film and the substrate surface for improved control over thin-film coatings.

BY ERICA ERICKSON AND
ROGER POSUSTA
BRUKER NANO SURFACES AND
METROLOGY

Obtaining accurate control over film thickness and uniformity is critical for applications ranging from optics, flexible electronics, and microelectromechanical systems (MEMS) manufacturing to semiconductor advanced packaging and energy technologies. Many methods — both contact and noncontact — are used to obtain film thickness measurements. These include stylus profilometry, ellipsometry, and x-ray reflectivity. Each offers benefits that depend largely on the application and application environment.

In terms of cost-effectiveness and speed of operation, white light interferometry (WLI) offers considerable advantages to system designers and developers. In addition to film thickness and coating uniformity, this characterization technique is effective for defect detection and can provide information on roughness for both film and substrate over large areas.

Critically, WLI can provide these insights in a single measurement that takes only a few seconds. This makes the approach ideal for applications where speed is critical, parts are large, samples are fragile, and where physical contact of the surface can cause damage or there is nonuniform surface texture.

The prospect of gauging numerous parameters via a single-shot technique is especially important. Inspecting only the top of a film coating, for example, does not tell the whole story. As a result, this singular measurement may not be an appropriate determinant of the viability of a given thin film for a given application. And whether the initial substrate is rough or has imperfections can also influence the coating surface (Figure 1). Fundamentally, determining the root cause of film surface texture requires analyses of both substrate surface and film top surface.

WLI enables users to access both the substrate and film surfaces for nonopaque films. This quality, paired with large-area measurement capabilities of up to 15 mm in a single image, makes it invaluable for developers and users of thin films.

Technique basics and advantages

In WLI profilers, interference patterns are generated using split and recombined light waves. These interference patterns are used to calculate surface topography with sub-angstrom-scale resolution. Among other inherent advantages, this technique offers high throughput, a lack of mechanical damage, low maintenance, and deep trench/sidewall capabilities.

WLI uses areal scanning, where everything within the field of view is measured simultaneously. This enables the technique to achieve a higher throughput than the point-by-point profiling method used by stylus profilers. As an optical-only, noncontact, and nondestructive method, WLI also avoids any risk for mechanical damage and does not have consumables. These systems may also self-calibrate, which decreases maintenance requirements.

Another major benefit to the use of WLI is its magnification-insensitive height resolution. WLI profilers use interferometric objectives that generate a moiré pattern only when proper focus is reached. WLI performs scans through focus, generating the moiré fringe pattern when the light returning from the surface is superimposed with light returning from a high-precision mirror inside of the interferometric objective. This sharp determination of the interferometric fringe focal plane relies entirely on this moiré interference pattern and is independent from the objective. The result is sub-nanometer height precision even with low-magnification lenses.

This objective-lens freedom creates several tangential advantages to the use of WLI. Long working-distance objectives can be used without compromising vertical resolution, and sidewall surfaces can be accessed by adding a mirror along the focusing beam. If lateral resolution is not of concern, a low-magnification lens can be used to cover large areas in a single

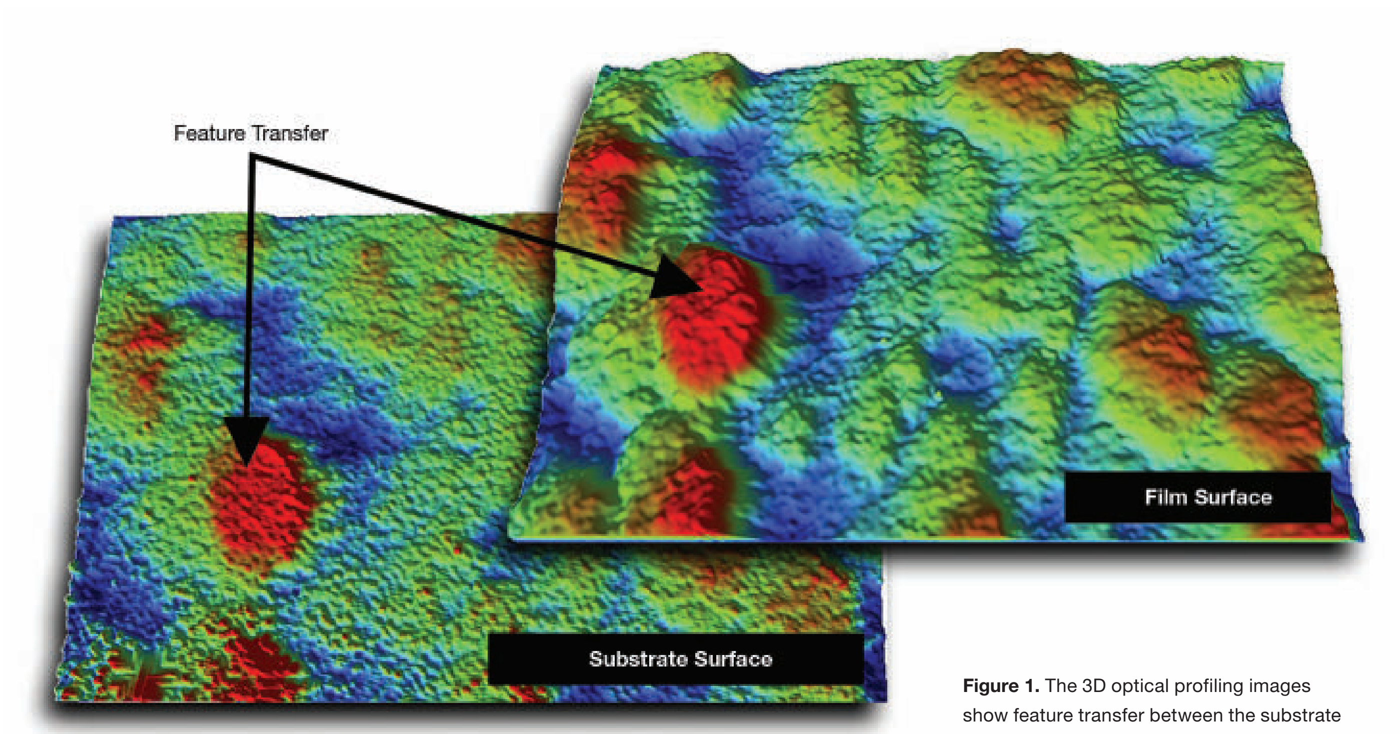

Figure 1. The 3D optical profiling images show feature transfer between the substrate surface and film surface.

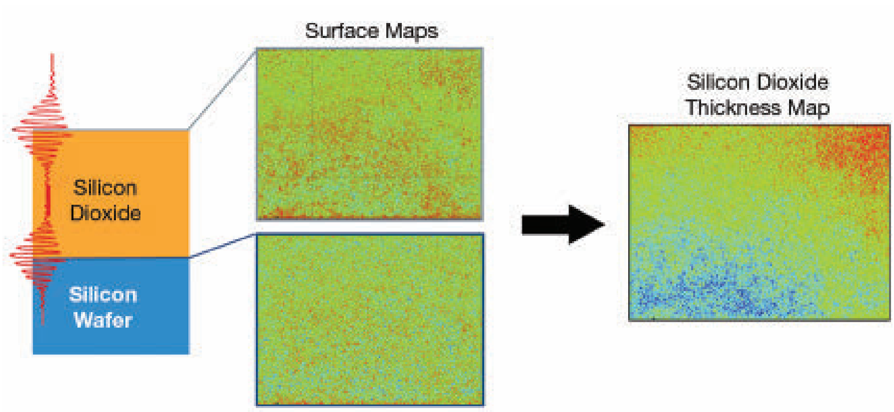

Figure 2. A silicon wafer coated with silicon dioxide, showing fringe envelopes for both material surfaces **(left)**. Surface maps generated from the top of the substrate and the top of the film **(middle)**. When substrate surface value is subtracted from film surface, the resulting value is a thickness map of the silicon dioxide material **(right)**.

scan, which can be combined with stitching capabilities to cover even larger areas.

Through-film measurements of thickness

Historically, step measurements have been used to determine the thickness of films. The substrate height is subtracted from the film surface height, resulting in a thickness measurement at the interface. This method can be limiting since it only measures thickness along an edge of the coating and it requires a distinguishable step.

In cases in which a film is at least somewhat transparent, a through-film measurement with optical profiling can alternatively be used to measure thickness anywhere on the sample. These types of measurements provide complete area maps of film thicknesses without requiring a visible step. To ensure accuracy with this method, the film's index of refraction must be well known and homogenous. The index of refraction is generally measured using independent methods, though it can also be back-calculated by using the step method before progressing to the through-film method.

To obtain through-film thickness measurements using WLI, the interferometric objective is translated vertically such that the upper and lower film surfaces pass through focus. Each surface then has its own fringe envelope pattern that can be analyzed separately as well as in relation to each other. This process is shown in Figure 2 with silicon (wafer material) and silicon dioxide, along with the film thickness map generated by subtracting substrate surface from the film surface.

Measurable film thickness is largely determined by objective lens, due to both light penetration and fringe envelope separation. Thicker films require a lower numerical aperture (NA) to allow more vertical light to enter — a feature of lower-magnification lenses. Thin films, meanwhile, require a higher NA to limit depth of focus and improve vertical resolution, thereby avoiding overlapping fringe envelopes. The thinnest films will have overlapping fringe envelopes regardless of objective choice, and these require a dedicated thin-film analysis. Figure 3 shows the interferogram overlap that occurs when a film becomes very thin.

Analyzing the thickness of relatively thick films (thickness ≥2 µm) is a straightforward process based on the fringes and separation of fringe envelopes. Upon determining the vertical center of each fringe envelope, distance between the centers is calculated for each camera pixel. Dividing the fringe envelope separation by the film's index of refraction provides an accurate thickness.

Measuring thin-film (<2-µm) thickness is more complex due to the overlap of the fringe envelopes. Calculations of thin film thickness depend on using an accurate fitting model that can deconvolute the two envelopes. This can be performed using a fringe signal modeling algorithm with a merit function that assesses agreement between the measured data and the built fitting model. Such a fitting model is created by a measurement model from the bare substrate after selecting magnification and film/material calibration models.

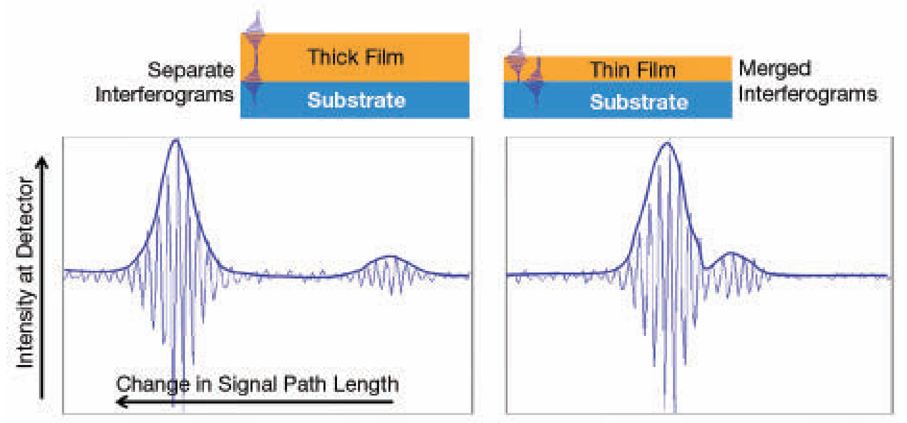

Figure 3. As film thickness decreases, the fringe envelopes from the film surface and substrate surface begin to overlap. Thick-film interferograms show clear separation **(left)**. Thin-film interferograms are merged and are difficult to distinguish without dedicated analysis **(right)**.

Optimizing system selection

Thin-film coatings are found on all kinds of samples, of all shapes and sizes. They exist in all types of environments, from high-throughput manufacturing to small-scale research. Each situation and environment presents distinct challenges for choosing the optimal WLI system.

A key step for determining the appropriate WLI system for a given application is identifying the necessary objective lens(es). This choice requires consideration of the field of view and lateral resolution requirements. Lower-magnification lenses with larger fields of view also mean lower lateral resolution, so it is

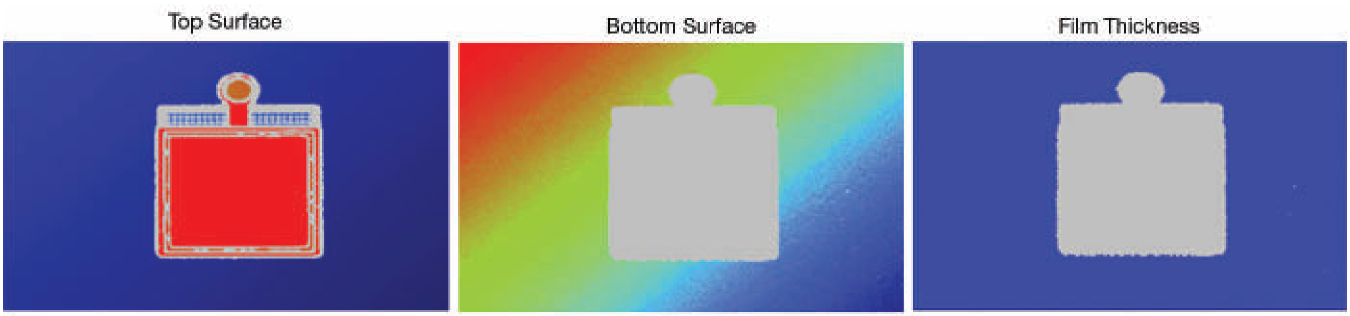

Figure 4. An example of film thickness quality control for microelectromechanical systems (MEMS) manufacturing.

essential to understand the priorities of the application. High-throughput semiconductor applications, such as MEMS manufacturing quality control, may require a larger field of view in a single measurement (Figure 4). Alternatively, nanostructure research may prioritize higher magnification for high lateral resolution. No matter the use case, WLI's subangstrom vertical resolution and accuracy are the same at all magnifications.

In ensuring that the selected objective lens for the WLI profiler fits the application needs, it is important to consider that certain interferometric lenses — unlike standard low- and high-magnification lenses — offer specialized features. Sidewall applications will require a mirror attachment to deflect the light beam, whereas deep trenches may require long working-distance lenses. Most objectives are turret mountable, meaning that they allow for one turret to have multiple objectives that cover magnifications from 0.5× to 220×.

Though field of view per scan is defined by objective lens choice, the use of high-quality stitching algorithms can extend the full size of the data array. This enables the user to acquire multiple images and "stitch" them into one resulting image. Using the best stitching algorithms, individual scan frames are indistinguishable in the final height maps. An automated xy stage is required for automated stitching.

The difficulty of focusing on the surface is one traditional challenge to operating a WLI profiler. This becomes a concern and may even become a drawback to WLI in situations in which operator ease of use is essential. Systems that offer automatic focus-finding are a good option in these cases. For these systems, the operator only needs to ensure that the objective is somewhat near focus. The software will then automatically find focal point and optimal illumination settings.

The right system for a given application will also need the necessary measurement modes available to ensure optimal performance. For example, the larger vertical translation of the measurement head in vertical scanning interferometry presents the best approach for tracking rougher surfaces. Meanwhile, phase-shifting interferometry — in which the phase of a monochromatic light beam (often green) is shifted slightly with a piezo to shift the fringe envelope and measure surface height — is typically used to deliver accurate measurements of ultrasmooth surfaces. Surfaces that are somewhere between rough and ultrasmooth, with features of both qualities, are ideally measured using a universal measurement mode. This mode should automatically detect surface texture properties and appropriately adjust resolution.

Lateral resolution, which is defined by objective choice and the wavelength of the light that is used, can be improved by overcoming the diffraction limit through a combination of hardware and software techniques. Technology now exists to extend a measurement well beyond the diffraction limit, enabling detection of much smaller features. Adding stitching of multiple images into one image further enables high-magnification, high-resolution lateral resolution with large fields of view.

Finally, any combination of unique floor-space, sample, and automation requirements further dictate the WLI model that is needed for a given use case. Small laboratories limited in space may need to choose a benchtop system. Large samples, such as engine blocks or large lenses, may require a floor-standing system with an open gantry and a high weight limit for the stage. Added high complexity, as in the case of an engine block, could additionally require a tilting head to reposition the objective lens as opposed to the part itself. Available automation levels for ease of use and throughput enhancement range from automated analysis to full automation of the entire measurement, analysis, and reporting process.

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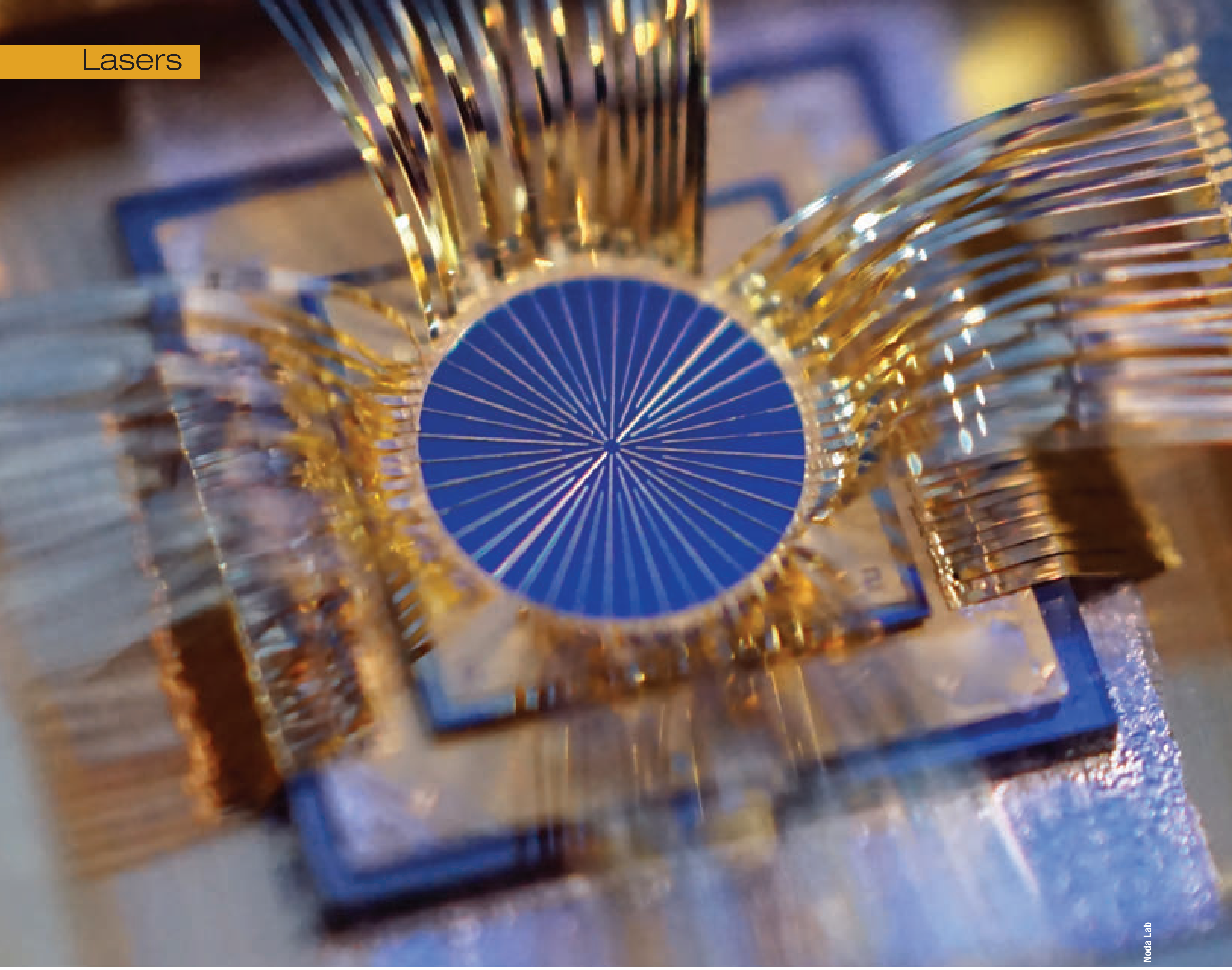
Noda Lab

PCSELs May Redefine Diode Lasers in Industry and Lidar

BY ANDREAS THOSS
CONTRIBUTING EDITOR

Can diode lasers offer high power — and a good beam profile? Photonic-crystal surface-emitting lasers achieve these qualities and show promise for numerous applications.

The concept of diode lasers was born early in the age of laser technology and has come a long way. From a fragile, liquid nitrogen-cooled laboratory device, it has evolved into an integrated, highly energy-efficient laser system. Today, laser diodes are the fundamental solution in most laser materials processing devices. They also drive the internet, enable quantum research, and are a prerequisite for any laser fusion scheme. Diode lasers have been a central technology to several Nobel Prizes and even experienced their own technology bubble when the internet boom swept stock markets around the year 2000.

One might think of such a technology — whose products are sold as commodities — as mature. To some extent, this is true of diode lasers.

On the other hand, there has always been a quest for improvement. The simplest approach looks to achieve more power from an emitter at a lower cost per watt. This has led, and continues to lead, to the development of ever-better edge-emitting laser (EEL) diodes. Still, it is well known that these lasers require external focusing, which makes packaging and alignment complex.

As a result, efforts to overcome the poor beam characteristics of laser diodes have been on the rise. The concept of vertical-cavity surface emitting laser (VCSEL) diodes, for example, evolved out of this desire. Unfortunately, this concept is power limited.

Diodes with special spectral emission characteristics have been developed as well. These DFB lasers achieve distributed feedback from a complex layered structure inside the laser diode's cavity, enabling them to emit stabilized radiation with a small spectral bandwidth.

A laser diode setup that combines these three optimization efforts may offer the best of all worlds: ease of manufacturability, high power, and an effective beam profile.

Edge-emitting and vertical-cavity lasers

For comprehensive consideration of new diode lasers, one must look closely at the two main types of diode lasers: EELs and VCSELs. These laser types differ fundamentally in their structure, emission direction, and performance characteristics (Figure 1).

A typical EEL consists of low-bandgap-material layers sandwiched between two high-bandgap semiconductor layers. The ends of the horizontal (Fabry-Pérot) resonator are formed by cleaved facets. The laser beam propagates along the plane of the active region in the middle and exits through one of the facets.

This architecture enables high output power, efficient heat dissipation along the length of the device, and broad wavelength tunability. However, EELs need precise facet cleaving, which is a requirement that makes manufacturing complex. Their emission exhibits elliptical beam divergence, necessitating external optics for beam shaping. And packaging and alignment can be challenging, especially for high-power applications.

In contrast, VCSELs emit light perpendicular to the wafer surface. Their structure relies on multiple layers of alternating high- and low-refractive-index materials forming distributed Bragg

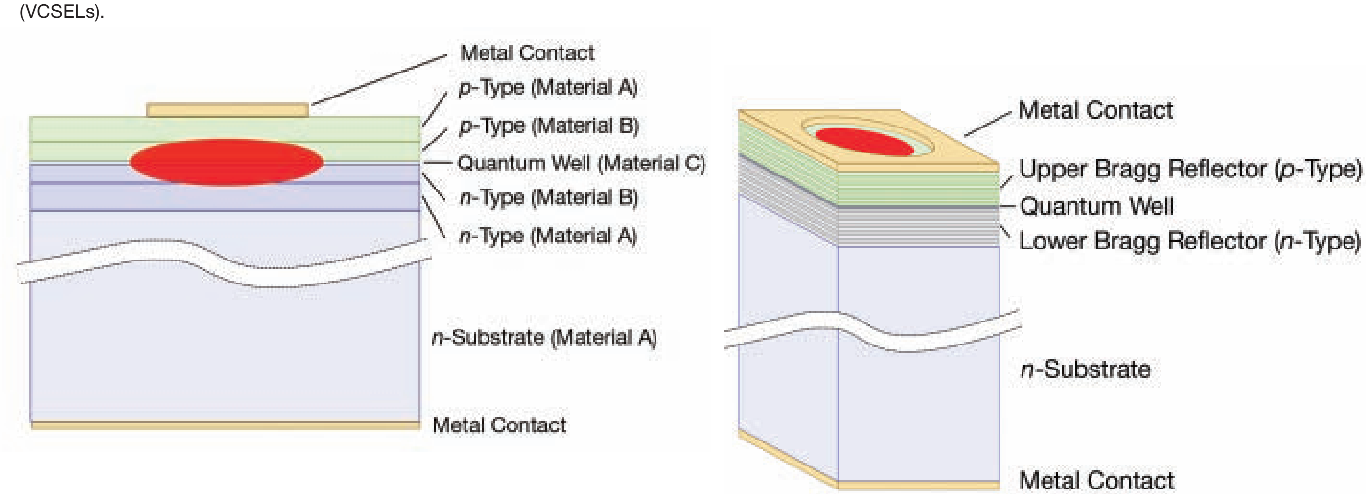

Figure 1. A comparison of diode lasers: edge-emitting lasers (EELs) **(left)** and vertical-cavity surface emitting lasers (VCSELs).

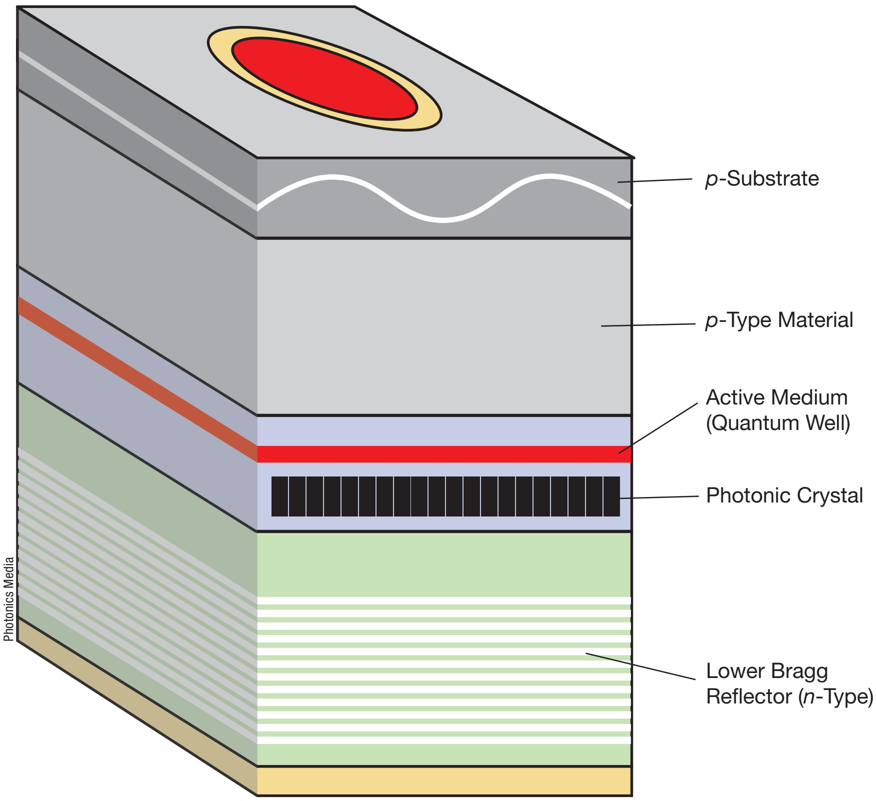

Figure 2. A typical photonic-crystal surface-emitting laser (PCSEL) has an active horizontal layer next to the photonic crystal layer in the center. The horizontal resonator emits vertically to the top and has electrodes on the bottom and the top.

reflectors (DBRs), which create a vertical optical cavity. The active region, typically a quantum well or a quantum dot layer, is placed between these reflectors. The DBR typically defines a small emission spectrum.

The VCSEL structure allows for on-wafer testing and easy integration into 2D laser arrays, making VCSELs highly scalable for mass production. They also offer circular beam profiles with low divergence, which simplifies optical coupling.

Despite these advantages, VCSELs have limitations. Their output power is lower than that of EELs, and their spectral tuning range is relatively narrow due to their reliance on the DBRs. Heat dissipation can also be a challenge, as the current flows vertically through the device.

As VCSELs dominate applications requiring low-power, compact, and high-efficiency light sources — such as optical fiber data transmission and 3D sensing — EELs remain the preferred choice for high-power applications such as materials processing, either directly or as the energy source for industrial fiber lasers.

Photonic-crystal surface-emitting lasers

Members of the Kyoto, Japan-based research group led by Susumu Noda have investigated diode laser setups for several decades and developed a horizontal resonator with vertical outcoupling. They added a 2D structure to the active layer that allows the laser to emit vertically. This structure consists of a periodic pattern of gaps, or holes, called a photonic crystal.

Accordingly, these diode lasers are named photonic-crystal surface-emitting lasers (PCSELs, pronounced “pick-cells”, Figure 2).

A recent article in the journal *Nature Reviews Electrical Engineering* explains the process in more detail[1]:

“When the current is injected into the active layer through the cladding layers, light is generated within the active layer and is trapped between the active and cladding layers by total internal reflection while also being coupled to the photonic crystal layer. Inside the photonic crystal, light waves propagating in several in-plane directions are coupled with each other, leading to 2D coherent lasing with surface emission.”

In other words, in a PCSEL, the optical waves generated by stimulated emission travel parallel to the layers. Feedback is provided by a 2D structure in a layer next to the active layer with a certain periodicity. Crucially, this structure allows the area of the laser to be scaled as well as the output power, all while maintaining high-quality single-mode emission in contrast to EELs and VCSELs. In fact, the periodicity corresponds to second-order Bragg diffraction for wavelengths around the peak of the gain spectrum. Therefore, a part of the optical field is radiated vertically. As in VCSELs, the beam shape in a PCSEL can be circular, with an ultra-narrow divergence angle. A single DBR, such as in a VCSEL, can be implemented beneath the periodic layer to force the outcoupling from one surface.

The effect of the photonic crystal on the modes oscillating in the resonator depends on the shape and distribution of photonic crystal features, and on the index contrast between the feature and the surrounding material. For the PCSELs made in Kyoto, and most PCSELs worldwide, the photonic crystal structure consists of air voids embedded in the surrounding semiconductor material, which has a very large index contrast.

Alternatively, the photonic crystal can be “all-semiconductor” where the index contrast between different semiconductor materials is much smaller. A number of players are exploring this technological path for more manufacturable PCSELs, including groups at Germany’s Ferdinand-Braun-Institut and at the Glasgow, Scotland-based startup Vector Photonics.

The industrial case

The Noda group has worked on PCSELs for more than two decades. In November 2024, a workshop at Aston University in Birmingham, England, showed that the interest in this technology has grown far beyond this group. One hundred twenty people attended, including a strong Japanese delegation. Several companies, including Huawei Technologies (via its Ipswich, England, research center), Vector Photonics, nLight, TRUMPF, Lumentum, Mitsubishi Electric, and ASML sent representatives, according to coverage of the workshop[2].

The Noda group has reported PCSELs suitable for a number of industrial operations. Its reported brightness of 1 GW cm^{-2} sr^{-1} for pulsed and continuous-wave operation is a record for laser diodes and could cut metal[1]. In its paper, the group referred to PCSELs with short-pulse (<100 ps) and high-peak-power (>100 W) operation, as well as short-wavelength (~430 nm) operation[1].

Vector Photonics, a Scottish startup developing PCSELs, claims that the cost for PCSELs is 50% that of EELs while delivering 10× the power of VCSELs.

Vector mentiond another advantage of PCSELs: They can be used to emit a matrix of coherent beams[3]. In this case, one horizontal resonator would be connected to a matrix of vertical beam outlets. All the beams in this matrix would come from the same modes in the resonator and be inherently coherent as a result. This is an optical phased array in which all beams can be coherently combined. With distributed phase delays, such combined beams can have almost arbitrary shape, and even steer aside depending on the respective phase delay.

Such a phased array would be well suited for lidar applications without moving parts, or for materials processing with beam profiles that may change during the process. At the same time, PCSELs can be controlled with multi-gigahertz rates — a quality that would make them ideal for data applications.

Future prospects

Regarding the future options for PCSEL technology, Noda and his co-authors said, “[Continuous-wave] kilowatt-class operation is expected to become possible by expanding the laser diameter from 3 to 10 mm and optimizing Hermitian and non-Hermitian coupling coefficients, which will enable a further tenfold to hundredfold improvement in the output power and beam brightness.[1]”

All things considered, PCSELs have a number of promising properties already. They unite potentially low manufacturing costs with high output power and high beam quality, and in a circular beam.

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Acknowledgment

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References

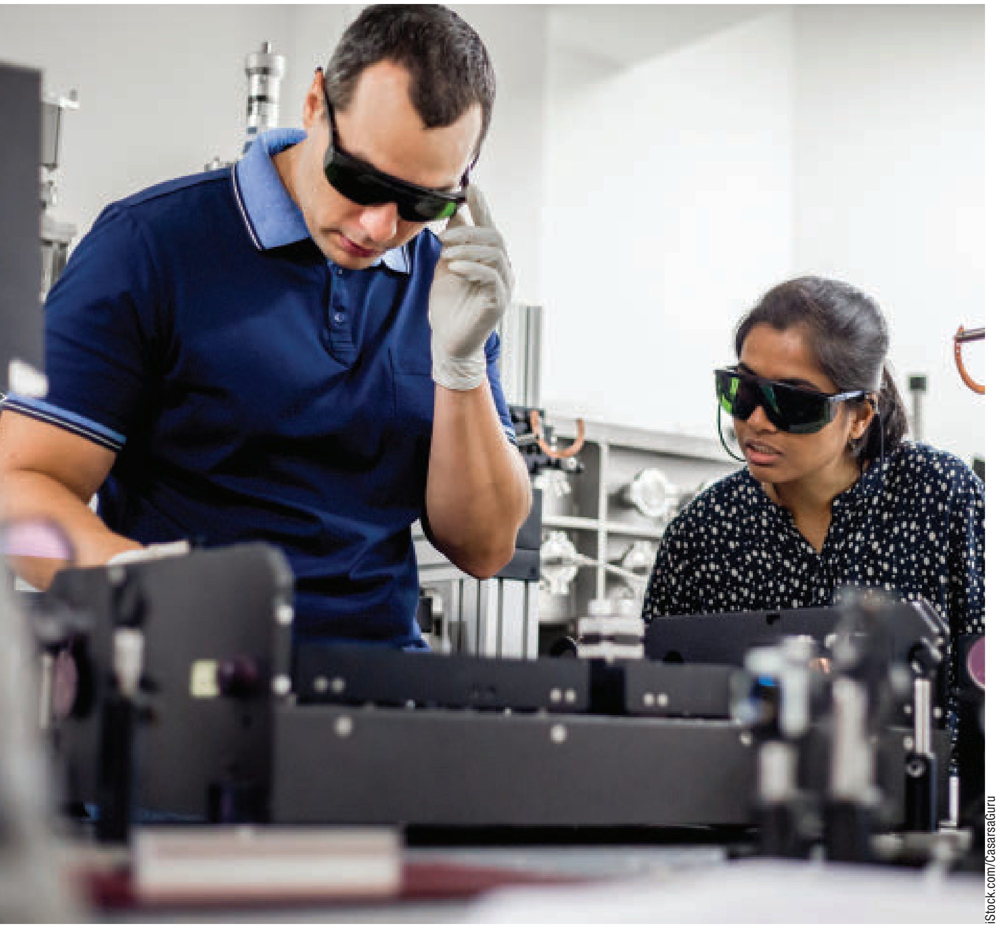
1. S. Noda et al. (2024). Photonic-crystal surface-emitting lasers. *Nat Rev Electr Eng*, Vol. 1, pp. 802-814.
2. R. Stevenson. (2024). Promoting the PCSEL. *Compound Semiconductor*, Vol. 30, No. 9, pp. 30-34.
3. Vector Photonics. The semiconductor laser revolution, www.vectorphotonics.co.uk/technology.

Assessing the State of Laser Safety

BY KEN BARAT
LASER SAFETY SOLUTIONS

The future for laser-driven applications is bright and poised to continue to spread globally. A significant component of this future will undoubtedly involve the use of Class 4 laser products, which are increasingly geared toward consumers. A growing number of industries demand on-site laser welding and laser stripping. The use of commercial lasers in the agricultural and autonomous vehicles sectors is a core driver of the increased use of these devices outside of traditional laboratory and research settings.

The nature of these applications, and many that are yet to be discovered, places a premium on the implementation of practical and up-to-date laser safety practices. However, establishing consistency in this area is a multifaceted challenge. It begins with product and user safety, envelops standards, and underscores the pressing need for qualified laser safety professionals.


iStock.com/CasarsaGuru

The origins of product safety

Laser safety has historically addressed considerations of both product and user safety. In the U.S., the biggest struggle with effectively pursuing product safety is in fact not with safety requirements themselves, but instead in ensuring that manufacturers are actually complying with them.

Engaging in the sale of commercial laser products in the U.S., the Center for Devices and Radiological Health (CDRH, part of the FDA) requires companies to submit a cursory form to address 10 topics (see the list on page 54).

Considering this form, CDRH officials determine whether the seller of the prospective product meets the necessary product safety requirements. If the CDRH determines that the devices meet these requirements, they become eligible to earn certified product status in the U.S.

From a consumer standpoint, buyers can purchase these products with the knowledge that these certified products have been deemed to meet established standards. Still, some filers are less than truthful. And, due to the number of submissions each year, a submitted form may await necessary reviews for months, if not years. Certain types of products, particularly in the medical domain, also receive priority consideration. Most users are unaware that once the CDRH file is submitted, the unreviewed product is legal to sell with the conformance label on it. The user is buying with the understanding that the product is compliant with federal requirements.

Issues concerning reporting

In the event that a user discovers an issue with a laser product, the CDRH reporting system places the onus on the user to report the issue to the manufacturer. Responsibility then shifts to the manufacturer, which must file a CDRH noncompliance product finding.

This step gives the manufacturer an opportunity to evaluate the reported problem, which in some cases may be more accurately characterized as user error. Users can report directly to CDRH. This process offers advantages; most obviously, it enables the CDRH to discern trends in systematically reported issues, through multiple filings, versus the one-off filing from an individual facility.

Not all parties wish to take the time to complete the filings required by the CDRH reporting process. Issues that fall into the category of "counterfeit lasers," for example, tend to raise considerable grumblings in the laser safety field. Here, concerns range from mislabeled products to unexpected performance features to missing components. These issues stem from a combination of factors. The user may lack knowledge about reporting requirements, or even foster indifference around noncompliance. No matter the case, many of the lasers that face these types of issues can be traced to online purchases from vendors with which the user is unfamiliar.

The product and user safety relationship

Training is an essential facet of product safety. In many cases, training buyers on how to safely and effectively use a product necessitates more than instructional manuals and how-to literature. Company-created videos and materials that surpass concern for the operator alone represent more comprehensive training resources. The knowledge of how to operate a machine does not always equate to or ensure safe operation.

For user safety, standards are the first logical resource to consider — and numerous standards must be followed. Standards for laser safety establish and define best practices, and as a result, they serve as the core of many laser safety programs. Regulatory bodies also rely on standards.

Yet as important as they are, laser safety standards are only updated every three to 10 years. This considerable span means that, in many cases, standards fail to keep pace with technological changes.

The primary standards pertaining to laser safety, ANSI Z136.1 — Safe Use of Lasers and 60825-14 Safety of Laser Products — Part 14: A User's Guide, clearly establish the role and responsibilities of the laser safety officer (LSO). Several additional regulatory bodies maintain responsibility for user safety, including the federal Occupational and Health Administration (OSHA) as well as a few regulatory programs in individual states. In my experience, these agencies are often intimidated by the nature of laser applications. These bodies may have only rudimentary understanding of laser standards.

A well-documented anti-regulatory atmosphere has also existed in the U.S. for years. Consider that even amid a large number of reported burns to the skin stemming from dermatology procedures using lasers in recent years, few states have taken any action to improve laser safety or accountability. OSHA laser rules do not provide much depth, and the few rules that exist focus principally on lasers for construction. OSHA's General Duty Clause aims to push users to comply with safe lasing practices by promoting laser-user standards as the acceptable means to demonstrate laser safety. But there is a considerable gap between OSHA inspectors' understanding of lasing practice and safety and that of the LSO. As a result, many inspectors permit the judgment of LSOs to supersede these very standards — which obviously runs counter to how inspectors typically operate.

Improving safety through training

The current growth of laser applications elucidates the increased need for trained professionals to oversee and evaluate laser safety. But how do we attract professionals to take on laser safety?

Guide for Preparing Product Reports for Lasers and Products Containing Lasers

- Part 1 — Manufacturer and report identification
- Part 2 — Product and model identification
- Part 3 — Compliance with the labeling requirements
- Part 4 — Compliance with the informational requirements
- Part 5 — Description of the product
- Part 6 — Levels of accessible laser radiation and classification of the laser product
- Part 7 — Compliance with the performance requirements
- Part 8 — Quality control tests and testing procedures
- Part 9 — Life and endurance testing
- Part 10 — Instrumentation and calibration

The Office of Compliance, Center for Devices and Radiological Health (CDRH) covers 10 specific topics in laser safety guide, FORM FDA 3632 (4/23). This guide is intended to assist manufacturers working with lasers in providing adequate reporting of radiation safety testing and compliance with federal performance standards.

Again, appropriate training belongs at the heart of this effort. Enthusiasm for the field coupled with a sound understanding of the importance of the LSO is a dynamic combination. When it is present in a prospective laser safety professional, it is paramount that the employer recognize the need to provide proper training.

The way that most LSOs receive training today unfortunately does not serve to heighten interest, nor does it promote dialogue during the training stage. In-person laser safety classes may run for five days or less, and while they are based on the acceptable laser standard requirements, an overwhelming amount of information is provided. At the end of these courses, attendees can say they have completed the course — not that they are a competent LSO.

In-house training is an alternative to an in-person class. Here, the instructor comes to the prospective laser safety professional. It is extremely important to demand site-specific training rather than an office presentation (in fact, it is best to have the instructor complete a site visit prior to the course to determine where the challenges specific to a given company may be). These training courses offer opportunities to not only train by doing but also spark further interest and conversation.

Finally, online course offerings should not be discounted, even if their limitations are well known. Though these virtual courses (at least for laser safety) may not provide attendees with necessarily comprehensive training or sufficient experience to be a qualified laser safety professional, they still serve to introduce prospective LSOs to the discipline.

There is also a large opportunity to harness the inherent advantages to online coursework and build a more encompassing offering. The University of Utah, for example, is trialing a more comprehensive training program for university-based LSOs, but not until 2026. I look forward to evaluating its efforts.

Future thoughts

How we attract interested people to safety disciplines remains an open question. This is a relevant consideration for the majority of LSOs, for whom the position is not a stand-alone position but rather an added responsibility. I have encountered situations in which the LSO is looked upon highly — and frequently — and collaborates proactively with the user population to find solutions. But, I have seen many more situations in which an incentive to perform the job is absent, often due to insufficient training segueing into a lack of time, authority, respect, or recognition for the task.

Given that regulatory agencies are unlikely to make any changes to timelines and current product safety guidelines are insufficient for consistent user protection, the need for qualified LSOs is essential. The industry must find ways to promote interest and involvement in laser safety, as society must encourage students to become involved in STEM. Establishing a new set of laser safety controls and processes with the help of qualified LSOs may be the best way to achieve this goal.

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Indian River State College
Fort Pierce, Florida

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

For more than 15 years, Indian River State College (IRSC) has offered associate-level degree and certificate programs relevant to lasers, photonics, fiber optics, and solar energy. More than 350 technicians have graduated and are working in the laser and photonics industries throughout the U.S. and internationally. Companies that have hired graduates include Northrop Grumman, Lockheed Martin, AT&T, Gooch & Housego (G&H), Jenoptik, LASER COMPONENTS, Rockwell Collins, and L3Harris.

Program description

IRSC's associate degree in electronics engineering technology, with a deep specialization in photonics and robotics, is a two-year program with strong technical core teaching and hands-on training in state-of-the-art labs stocked with the latest industrial-grade equipment.

Technicians receive a solid foundation in electronics, automation, and robotics during the first year. In their second year, they learn photonics, fiber optics, geometrical optics, laser technologies, and photovoltaic systems. Graduates of this program work as technicians for industrial production companies in R&D, and in national labs, field service, system repair, and more.

Graduates of IRSC's associate degree in electronics engineering technology have the skills to:

- Troubleshoot integrated photonic systems using microscopes, oscilloscopes, pulse generators, power meters, beam analyzers, spectrometers, and energy measurement devices.
- Tune Nd:YAG, HeNe, and CO_2 lasers for maximum power and a high-quality beam.
- Align optical systems.
- Perform high-quality fusion splicing for single- and multimode fibers.
- Use an optical time-domain reflectometer to identify problems in fiber optic links.
- Properly clean and maintain precision optics.
- Use optical source and meter to measure the attenuation of optical links.
- Document procedures such as calibration of optical or fiber optic equipment.
- Apply laser safety rules according to ANSI and OSHA standards.
- Compute or record photonic test data.
- Troubleshoot robotic systems, using knowledge of programmable controllers, electronics, circuit analysis, mechanics, sensor or feedback systems, hydraulics, or pneumatics.
- Disassemble and reassemble robots or peripheral equipment to make repairs such as replacement of defective circuit boards, sensors, controllers, encoders, and servomotors.
- Perform preventive or corrective maintenance on robotic systems or components.
- Maintain service records of robotic equipment or automated production systems.
- Install, program, or repair programmable logic controllers (PLCs), robot controllers, end-of-arm tools, and conveyors.
- Program PLCs using ladder logic.
- Program SCADA (Supervisory Control and Data Acquisition) systems and human-machine interfaces.

Short-term certificates

Four-, six-, or eight-month duration
Lasers and Photonics
Solar Energy
Robotics and Simulation
Basic Electronics
Electronic Technology

How to recruit from this college

Visit IRSC to present your company and employment opportunities to students. The college will make available, free of charge, a private room to interview interested students. Please contact the person below to arrange a recruiting visit. Students graduate each December and May.

Contact information

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+1 772-462-7573
pgodfrey@irsc.edu
3209 Virginia Ave.
Fort Pierce, FL 34981

Program website

www.irsc.edu/programs/electronics-engineering-technology.html#electronics-engineering-technology-as

Product News

Single-Photon Counter

The HydraHarp 500 from **PicoQuant** is a time-correlated single-photon counting (TCSPC) unit with flexible trigger options to support a range of detectors, from single-photon avalanche diodes to superconducting nanowire single-photon detectors. The TCSPC unit is freely scalable with up to 16 independent channels and a common sync channel, which can serve as an additional detection channel if sync is not required. The HydraHarp 500 also offers 16+1 fully independent channels for true simultaneous multichannel data recording and data transfer via USB or the dedicated field-programmable gate array interface, along with low dead-time per channel and no dead-time across channels.
info@picoquant.com

Rotary Stages

The AY110-200 Series from **Optimal Engineering Systems** (**OES**) are rotary stages for applications such as microscopy, laser positioning and machining, inspection, assembly, and testing. The range of travel of the series is 360° of continuous rotation in both directions. The tables are driven by a high-precision 180:1 worm gear and have a resolution of 3.6 arcseconds with 10 micro steps-per-step micro-stepping drivers. The AY110-200 Series has a weight of 12 kg and features a black anodized stage with a 100-kg load capacity.
sales@oesincorp.com

Semiconductor Laser

Nuvoton Technology Corporation Japan's indigo semiconductor laser enables the development of smaller light source devices compared with mercury lamps. The laser features an optical output power of 1.7 W at a wavelength of 420 nm and a compact TO-56 CAN package.
salessupport@nuvoton.com

Frequency Comb Extensions

The RUBRIComb and RUBRIColor from **Vescent Technologies** are optical frequency comb and wavelength extensions for applications including atomic clocking and time transfer, quantum computing, and dual comb spectroscopy. The RUBRIComb sustains femtosecond-level stability with its laser being contained in a single 2U 19-in. rack mount chassis. The RUBRIColor extends the RUBRIComb platform wavelength coverage from 490 to 2000 nm and its modular design and compact footprint make it adaptable and scalable in quantum systems.
sales@vescent.com

Clock Recovery Instrument

The QCR Series from **Quantifi Photonics** is a clock recovery instrument designed to extract clean, stable clock signals from high-speed data streams to trigger a digital sampling oscilloscope for communication systems. It is designed to support design verification testing and high-volume manufacturing testing with a jitter noise floor as low as 180 fs. The QCR Series locks to 100 Gbps data signals, tracks clock phase-locked loops, features a 60- × 244- × 327-mm footprint, and can make standards-compliant IEEE 802.3ck measurements.
sales@quantifiphotonics.com

Mechanical Probe Station

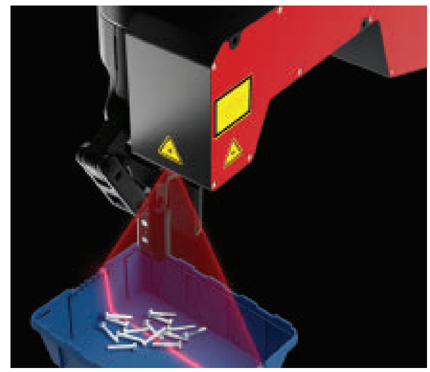
The PS1016A from **Bold Laser Automation** is a scalable mechanical probe station for testing in electronics, PCBs, medical devices, automotive, and aerospace manufacturing applications. The probe station integrates 16 mechanical probes with the capacity to scale up to 64 probes and higher and features an adjustable vertical stroke of 4 to 12 in.
info@boldlaserautomation.com

Four-Quadrant Photodetector

ElFys' four-quadrant detector is meant for use in fields ranging from laser guidance to optical communication. The detector uses the company's black silicon technology, which allows for external quantum efficiency across the UV-VIS-NIR spectrum for the capture of incident photons and conversion of the photons into a measurable signal.
info@elfys.fi

InGaAs Photodiodes

The G1719X series from **Hamamatsu Photonics** is a line of compact indium gallium arsenide photodiodes for applications including gas sensing and remote temperature measurements. The NIR sensors are available in wavelengths between 1.7 and 2.6 μm and three photosensitive areas from φ0.3 to φ1.0 mm. The G1719X series features a surface-mount ceramic package type and a small form factor of 2.9 × 2.9 × 1.2 mm.
photonics@hamamatsu.com



3D Sensor

The ECS 4090 from **AT Sensors** is a wide-FOV 3D sensor for demanding applications in industries such as bin picking in robot guidance, baked goods inspection, and package scanning in logistics. Able to capture large objects, the sensor has a 1020-mm FOV at a profile resolution of 4096 points per profile. The ECS 4090 features a nominal working distance of 744 mm, a z-range of 700 mm, an x-resolution of 251 μm, a profile speed of 24 kHz, and a 660-nm laser class 2M.
sales@at-sensors.com

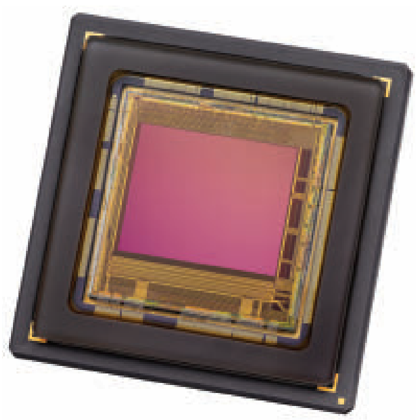
UV LEDs

Violumas' 255-nm LEDs can be used in application developments in ozone monitoring, water quality management, disinfection, bioanalysis, semiconductor processing, and environmental sensing. The single-chip 255-nm LED is offered in a compact surface mount device package of 5.2 × 5.2 mm with a radiant flux of 51 mW (If:500 mA) as well as four-, nine-, and 16-LED chip-on-board configurations. Each LED is encapsulated with a single, high-transmission fused silica lens and includes a selection of 30°, 60°, 90°, 120°, and 135° optics for UVC applications.
info@violumas.com

Inverted Stage

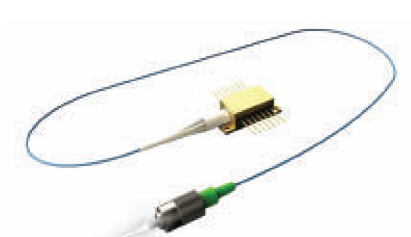
The H117N1E4 from **Prior Scientific** is an inverted stage designed for use with the Evident/

Olympus IX85 microscopes. The stage's flat top design facilitates compatibility with many stage-top incubation systems and allows flexible positioning of peripheral equipment around samples for complex imaging operations. The H117N1E4 features the company's intelligent scanning technology for stage accuracy and is typically configured with a 1-mm pitch ballscrew and 400-step motor for maximum resolution.
info@prior.com



CMOS Sensor

The Lince5M NIR from **Teledyne e2v** is a high-speed CMOS image sensor for low-light applications such as motion capture, industrial metrology, retinal imaging, and intelligent traffic monitoring. The monochrome image sensor combines high-speed capabilities and high quantum efficiency of 35% at 850 nm and is designed around the company's 5-μm global shutter pixel. The Lince5M NIR achieves a frame rate of 250 fps, a resolution of 5.2 MP, and a dynamic range of 55 dB in standard mode and >100 dB in high dynamic range mode.
imaging@teledyne-e2v.com



Distributed Feedback Laser Line

DAYY Photonics' distributed feedback laser product line is designed to serve telecommunications and gas detection industries. The distributed feedback lasers comply with industry standards, including Telcordia GR-468 and RoHS/Reach regulations and are available in both single-mode and polarization-maintaining fiber configurations. The lasers also feature a center wavelength tolerance of +/−0.2 nm, narrow line widths of 1 to 3 MHz, ≥10 mW output power, and wavelength coverage from 1530 to 1610 nm.
sales@dayyphotonics.com

NIRS Liquid Scanner

The Liquid Scanner from **Spectral Engines GmbH** is a scanner for identifying liquids using near-infrared spectroscopy (NIRS) in incoming goods, production and process control, pharmaceuticals, counterfeit detection, improved product conformity, and supply chain security applications. The scanner can be used offline and via the cloud through an app.
info@spectralengines.com

Vapor Deposition System

The Diamond Exploratory and Applied Research Microwave Plasma Chemical Vapor Deposition (DEAR MPCVD) system from **Blue Wave Semiconductors** is meant for exploratory and applied research in diamond-based technologies. The system uses a microwave cavity that supports a larger diameter quartz tube with differential pumping vacuum seals, multiple optical viewports for temperature, plasma process, and growth monitoring, and a sample stage that creates efficient microwave plasma above the substrate at sizes of up to 12 × 12 mm and at substrate temperatures ranging from 650 °C to 1100 °C. The DEAR MPCVD system features microwave power ranging from 650 W to 1.5 kW, achieving growth rates from 0.2 to >10 μm/hr.
info@bluewavesemi.com

Photoreceiver

The QL03 Photoreceiver from **Hobbs Electro-Optics** is a low-noise optical receiver designed

for making measurements in low-light applications, such as diffuse light measurements, spectroscopy, and fluorescence detection. With a 150- × 150-mm active area and an immersion lens, the receiver's 1-Mohm transimpedance gain and direct current to 750-kHz bandwidth provides a combination of high sensitivity and fast response, while its low-noise design allows for shot-noise-limited performance >100 nA in its full 750-kHz bandwidth.
info@hobbs-eo.com

Spectroradiometer

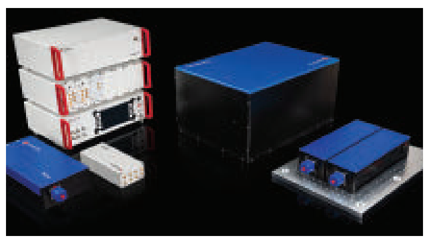
The SpectraScan PR-1050 from **Photo Research** is a spectroradiometer for display metrology as well as measuring near-eye displays with an attachable AR/VR lens. The spectroradiometer can perform wavelength and radiometric calibrations across multiple spot sizes, including spectral radiance estimation for modern display technologies such as OLED, micro-LED, and quantum dot displays. The SpectraScan PR-1050 is available in AR/VR aperture diameters of 3 mm, 4 mm, and 5 mm.
info@jadaktech.com

Miniature Linear Servo Motors

The LVCM-013-019-02 and LVCM-013-019-02M from **Moticont** are imperial and metric, respectively, miniature linear servo motors for scanners, laser beam steering and filtering, haptic feedback, dispensing, work holding and clamping, assembly, testing, and wafer handling. The brushless servo motors have 4-40 UNC-2B threaded holes in the center of the housing and the coil end for the imperial version and M3X0.5 threaded mounting holes for the metric version, and they are 1.156 in. (30.2 mm) long at mid-stroke. The LVCM-013-019-02 and LVCM-013-019-02M also feature a 0.75-in. (19.1 mm)-long stroke, a force-to-size ratio of 2.9 oz (0.81 N), and a peak force of 9 oz (2.51 N) at a 10% duty cycle.
moticont@moticont.com

Line-Scan Camera

The allPIXA evo DXGE 15K from **Chromasens** is a 15K line-scan camera for color line-scan vision tasks such as food, printed circuit board, and electric vehicle battery inspection. The camera incorporates a dual 10-GigE vision interface and is built on a quad-linear CMOS color line-scan sensor architecture attaining a resolution of 15360/5.6-μm pixels. The allPIXA evo DXGE 15K also features 15360- × 3-pixel true RGB color image acquisition capabilities, a multi-flash mode, a maximum line speed of 49 kHz, and the facilitation of SFP+ (small form-factor pluggable) fiber cables up to 300 m.
sales@chromasens.de



Clock Laser System

The clock laser system from **TOPTICA Photonics AG** is a clock laser system developed to add stability for quantum computing and optical clock applications. The system is controlled by a single interface that supports full remote operation and can drive the narrow atomic clock transitions of neutral atoms including Yb and Sr, as well as ions such as Yb+, Sr+, Ca+, and Ba+. The clock laser system features diode lasers with an ultranarrow linewidth <1 Hz, frequency stability far beyond a 1-s integration time, passive shielding, active vibration compensation, and temperature stabilization.
sales@toptica.com

Ribbon Cables

Linden Photonics' ribbon cables are meant for high-temperature and robust fiber optic applications. Engineered to perform in challenging conditions, the ribbon cables have a robust buffering system and a compact profile as well as the ability to transmit data with low optical loss across multiple channels. The cables feature a temperature rating of up to +125 °C and wavelength transmissions at 850 and 1300 nm.
info@lindenphotonics.com

Positioning Stages

The YPR-45-45-100 Series from **Optimal Engineering Systems** (**OES**) are pitch, roll, and yaw three-axis stages for identifying crystals, estimating hyperspectral bidirectional reflec-

tance, measuring radiation patterns of LEDs, examining cutting edges of medical instruments, laser machining and drilling, aligning mirrors, and scanning. The stages integrate two +/−45° goniometers for lower and middle axes and a large upper 100-mm diameter rotary stage. The YPR-45-45-100 Series rotary axis is equipped with an index switch to signal the motion controller to the home position, and the goniometer axes are equipped with positive and negative limit switches to signal the motion controller when the end of travel is reached.
sales@oesincorp.com

Spatial Imaging System

The Invitrogen EVOS S1000 from **Thermo Fisher Scientific** is a spatial imaging system for applications in spatial tissue proteomics. The system leverages spectral technology to capture images of up to nine different targets simultaneously, which helps reduce the need for multiple rounds of imaging and preserves tissue integrity. The Invitrogen EVOS S1000's compatibility with a wide range of reagents and antibodies enables it to integrate into existing laboratory setups.
info.spectroscopy@thermofisher.com

Small Area Curing Lamp

The DELOLUX 30 from **DELO Industrial Adhesives** is a small-area curing lamp intended for end applications such as chip encapsulation in the automotive sector. The lamp is available in an all-in-one package, including integrated water-cooling and a control unit, and as an individual lamp head that can supplement the appropriate equipment to be implemented into existing production lines. The DELOLUX 30 includes a higher peak intensity of up to 22.5 W/cm^2, an 80-mm tall and 30-mm diameter cylindrical lamp head, and wavelength options from 365 to 460 nm.
info@delo.us

MAY

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

SENSOR + TEST
(May 6-8) Nuremberg, Germany.
Contact AMA Service GmbH, +49 0-5033-9639-0, **info@ama-service.com**; www.sensor-test.de/en.

CONTROL
(May 6-9) Stuttgart, Germany.
Contact P.E. Schall GmbH & Co. KG, +49-0-7025-9206-0, **info@schall-messen.de**; www.control-messe.de/en.

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

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

SID Display Week
(May 11-16) San Jose, Calif.
Contact Mari Ramirez, +1 813-381-3667, **registration@sid.org**; www.displayweek.org.

Automate 2025
(May 12-15) Detroit.
Contact the Association for Advancing Automation, +1 734-994-6088, **info@automateshow.com;** www.automateshow.com.

Manufacturing Technology Series EAST
(May 13-15) West Springfield, Mass.
Contact SME, +1 800-733-4763; www.eastecon-line.com.

Optica OIC — Optical Interference Coatings
(May 18-23) Tucson, Ariz.
Contact Optica, +1 202-223-8130, **info@optica.org**; www.optica.org/events/topical_meetings/optical_interference_coatings.

Embedded Vision Summit
(May 20-22) Santa Clara, Calif.
Contact Edge AI + Vision Alliance; www.embeddedvisionsummit.com.

MD&M East
(May 20-22) New York.
Contact Informa Markets, +1 310-445-4273, **registration.ime@informa.com**; www.mdmeast.com/en/attend/show-sectors/automation.html.

Photonics North
(May 20-23) Ottawa, Ontario.
Contact Photonics North, +1 418-522-8182, **pn.info@conferium.com**; www.photonicsnorth.com/en.

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

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

PAPERS

SPIE Optifab
(Oct. 20-23) Rochester, N.Y.
Deadline: Abstracts, May 7
Contact SPIE, +1 360-676-3290, **customerservice@spie.org**; www.spie.org/conferences-and-exhibitions/optifab.

Neuroscience 2025
(Nov. 15-19) San Diego.
Deadline: Abstracts, June 4
Contact Society for Neuroscience, +1 202-962-4000, **meetings@sfn.org**; www.sfn.org/meetings/neuroscience-2025.

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

JUNE

Optica Quantum 2.0 Conference and Exhibition
(June 1-5) San Francisco.
Contact Optica, +1 202-223-8130, **info@optica.org**; www.optica.org/events/topical_meetings/quantum.

AutoSens USA
(June 10-12) Detroit.
Contact AutoSens, +44 (0)208-133-5116, **info@sense-media.com**; www.auto-sens.com/usa.

Optica Design and Fabrication Congress
(June 15-19) Denver.
Contact Optica, +1 202-223-8130, **info@optica.org**; www.optica.org/events/congress/optical_design_and_fabrication_congress.

European Conferences on Biomedical Optics
(June 22-26) Munich.
Contact Optica, +1 202-223-8130, **info@optica.org**; www.optica.org/events/topical_meetings/european_conferences_biomedical_optics.

Sensors Converge
(June 24-26) Santa Clara, Calif.
Contact Questex, **info@sensorsconverge.com**; www.sensorsconverge.com.

automatica 2025
(June 24-27) Munich.
Contact Messe München GmbH, +49 89-949-11538, **info@automatica-munich.com**; www.automatica-munich.com/en/trade-fair.

LASER World of PHOTONICS Munich
(June 24-27) Munich.
Contact Messe München GmbH, **info@world-of-photonics.com**; www.world-of-photonics.com/en/trade-fair.

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,

Indicates shows **Photonics Media** will be attending.
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+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, Hawaii.
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.

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.

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.

Photonics Showcase

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Hinds Instruments' Stokes Polarimeter Systems offer unparalleled sensitivity for measuring the polarization state of a light beam or source in a single measurement. The excellent sensitivity (0.005), repeatability and ease of operation of the Stokes Polarimeter have made this system invaluable to challenging applications in optical component characterization, astronomy, fiber optic research and manufacturing, and laser quality control.

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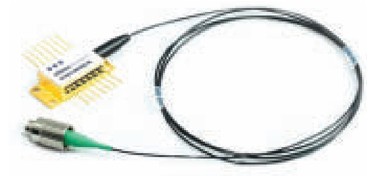
A Light Source for the Quantum Age



The future of quantum is photonics. From enabling secure global communications to building the next generation of sensors and processors, Eblana Photonics powers the quantum frontier with reliable, high-precision lasers and gain chips built for real-world deployment. At Eblana, we work alongside innovators to tailor optical solutions for complex quantum architectures, spanning research to scalable product development.

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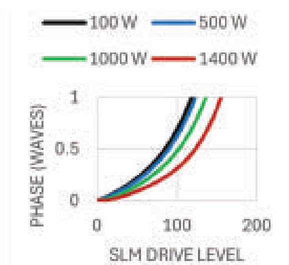
High-Power Spatial Light Modulator



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.

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ContourX-500 is the world's most comprehensive automated benchtop system for fast, non-contact 3D surface metrology. The gage-capable system boasts unmatched Z-axis resolution and accuracy, and provides all the advantages of Bruker's white light interferometry floor-standing models in a much smaller footprint. The profiler is easily customized for the widest range of complex applications, from QA/QC metrology to R&D characterization.

Bruker Corporation **(866) 262-4040**
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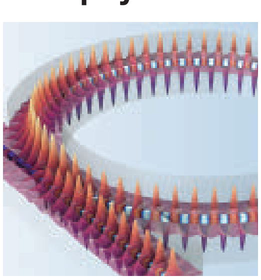

COMSOL Multiphysics® is a software environment for creating physics-based models and standalone simulation apps. Add-on products provide specialized functionality for electromagnetics, structural, acoustics, fluid flow, heat transfer, and chemical simulations. Interfacing products offer a unified workflow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

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Alluxa Inc. **(855) 425-5862**
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Catch our demo at SID Display Week, May 13-15, Booth #739! The ProMetric® 151 MP Imaging Colorimeter and AR/VR Lens Solution enables efficient measurement of near-eye displays, ideal for augmented (AR), mixed (MR), and virtual reality (VR) headsets, delivering ultra-high resolution color and light measurements that precisely reflect human visual perception.

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Lock-in Camera heliCam C4/C4M

The heliCam C4/C4M by Heliotis revolutionizes imaging with over one million lock-in amplifiers on a single chip. With in-pixel signal processing, the heliCam C4 achieves real-time, high-resolution dual-phase demodulation at up to 250 kHz and an impressive 21-bit dynamic range. Perfect for researchers needing massive parallel detection of weak optical signals.

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Ultralow-profile nanopositioning systems with sub-nanometer precision under closed loop control. Center aperture and low profile for microscopy applications. Products include Nano-Z, Nano-ZL, Nano-Z50HS, Nano-BioS, Nano-LPS, and Nano-LPQ nanopositioners. Exclusive PicoQ® sensor technology which ensures high stability and low noise performance. High speed and vacuum compatible models available. Lead times 30-45 days.

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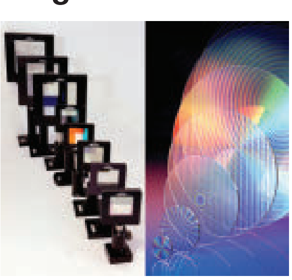

Planar optics technology pioneered by BEAM is over 99% efficient in VIS to MWIR bands with up to 8" sizes. Overcoming the deficiencies of metasurfaces, BEAM's flat lenses, prisms, beam shapers, vortices are haze-free and allow AR coatings for high throughput due to their planar continuous structure. Fixed or switchable between multiple optical states, they enable non-mechanical beam steering for LiDAR and adaptive glasses for AR/VR applications.

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www.beamco.com **sales@beamco.com**

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Fiber Focusers and Accessories

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

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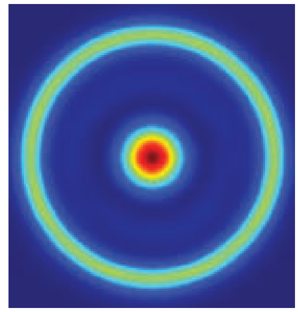
info@microlaser.com **www.microlaser.com**

Trident Generator



Improve process quality, increased throughput and reduce operating costs with a Trident Generator. Designed to transform a collimated single mode beam into small ring + core at the focus of a focusing lens, these optics can integrate into your existing laser system. In remote welding, it can be used to control the melt pool, while keeping the keyhole intact. This can lead to a less viscous melt pool, reducing spatter and porosity of the weld.

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Dual Sandwich Detectors

Dual Sandwich Detectors or Two-Color Detectors are mostly employed for remote temperature measurements. They are independent of emissivity and unaffected by contaminants in the field of view or moving targets. Typical applications Flame Temperature sensing, Spectrophotometer, Dual-wavelength detection, IR Thermometers for Heat Treating, induction heating, and other metal parts processing.

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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.

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info@wdidevice.com
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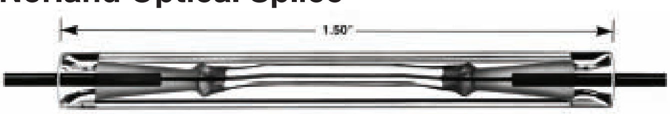
Norland Optical Splice



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

Norland Products Inc. **(609) 395-1966**
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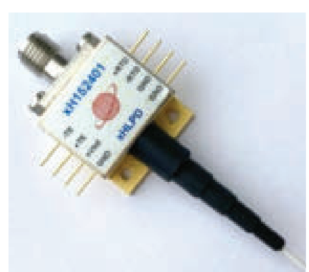
Extra Highly Linear Photodiode xHLPD



The xHLPD photodiodes provide high power operation up to 10 GHz bandwidth, and deliver up to 4 V peak-to-peak (+16 dBm CW) RF output power with exceptional phase linearity <5 rad/W. The thermo-electrically cooled modules enable reliable device operation with multiple biasing options. Applications include ultra-low noise optical clocks, photonic time transfer, antenna remoting, and RF-over-Fiber.

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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.

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Ooey, goopy, slimy electric innovation

If you were given a nickel for every time an invention was created for industrial purposes, only to become an iconic and best-selling children's toy, you might have just two nickels … which isn't a lot, but it is still odd that it happened twice.

The first toy to receive this treatment was Play-Doh, whose original purpose was to serve as a wallpaper cleaner before being marketed as a moldable putty that taught kids that they could be great sculptors (at least of rolled snakes or simple boulders). The second, the Slinky, has its origins in the defense sector as a tension spring, developed by a naval mechanical engineer while at work. While these are two of the most famous examples of a grown-up industry coming to play, there are not many examples of childhood trinkets maturing from a plaything to a real-world industrial application.

Except for a certain amorphous substance that is the subject of plenty of elementary school playtimes and science experiments alike.

Though Newtonian in nature, researchers from the University of Guelph (UG) developed a slime-like material that produces electricity when compressed. The material was studied at the Canadian Light Source at the University of Saskatchewan to understand just how useful it can be.

Instead of glue, borax, cornstarch, and optional food coloring, the research team's prototype goo is composed of natural materials that are highly compatible with the human body. Made up of 90% water plus oleic acid, which is found in olive oil and amino acids, the goal for the researchers was to create something completely benign that could be put on a subject's skin without any concern of physical harm. This doesn't account for those with an aversion to odd textures, but the benefits might just outweigh the potential gross-out.

While under a laser-based microscope, UG associate professor Erica Pensini and her colleagues found that the slime could form different structures at the microscopic level so that it either arranged itself like a sponge, formed layers like a lasagna, or took on a hexagonal form. She explained that this structure could offer an opportunity for a myriad of applications, such as the targeted delivery of pharmaceuticals within the body.

The team also sees the substance being used in other medical, analytical, and industrial contexts. This could include clean energy production when installed under well-trodden floors or within shoe insoles to analyze a person's gait. They even produced a theory that it might be used as the basis for a synthetic skin to train robots on how much pressure to use when checking the pulse of a patient.

Though these are promising applications, Pensini plans to treat herself as the guinea pig and will use the prototype as a salve for her hands after rock climbing. If that goes well, then perhaps someday we will have a new version of slime enter the pantheon of useful and playful inventions.

The research was published in the *Journal of Molecular Liquids* (www.doi.org/10.1016/j.molliq.2024.126823).

Slime courtesy of iStock.com/Nikolay Zaiarnyi.
Lightning courtesy of iStock.com/seamartini.