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March 2025

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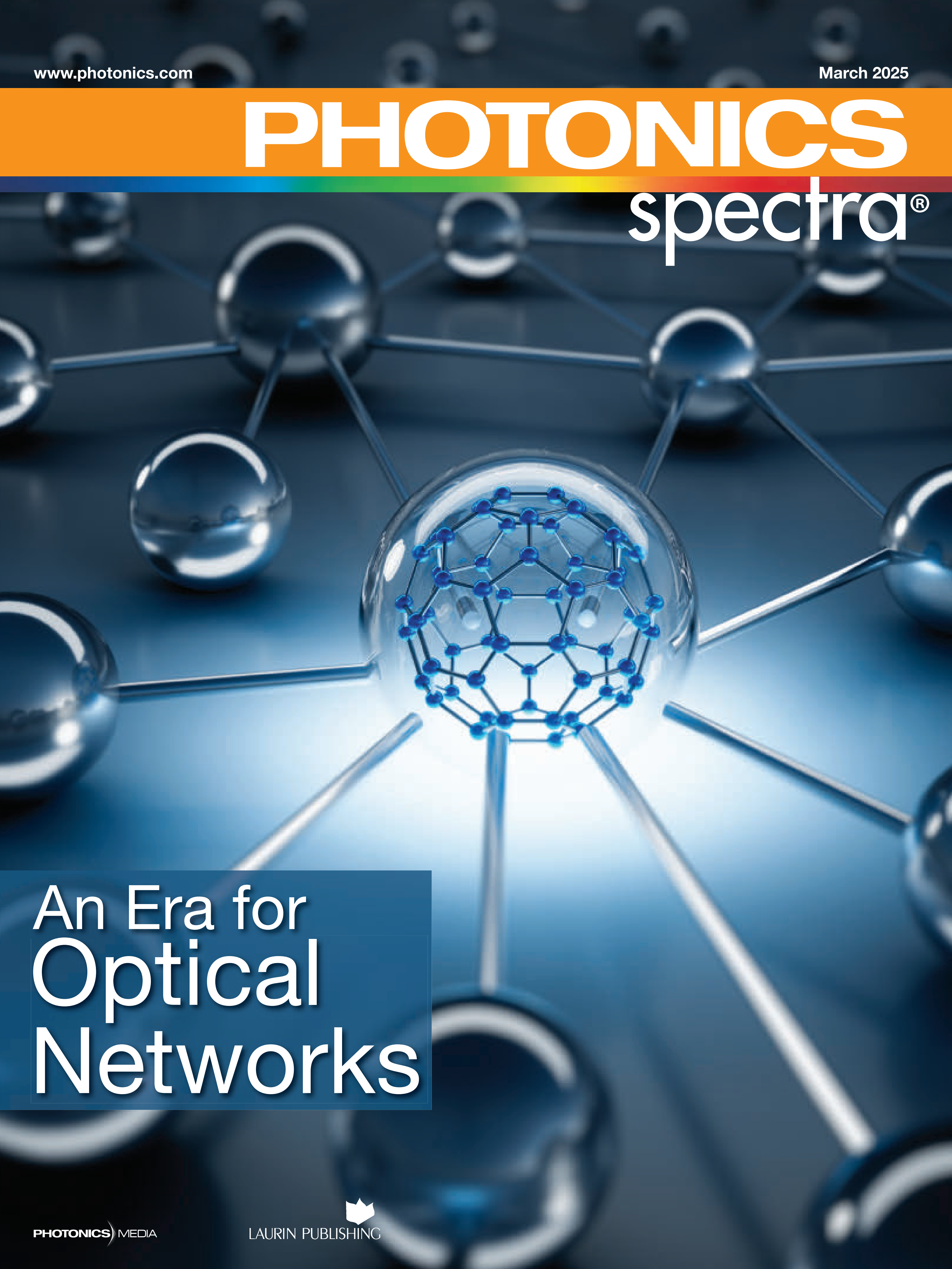

An Era for Optical Networks

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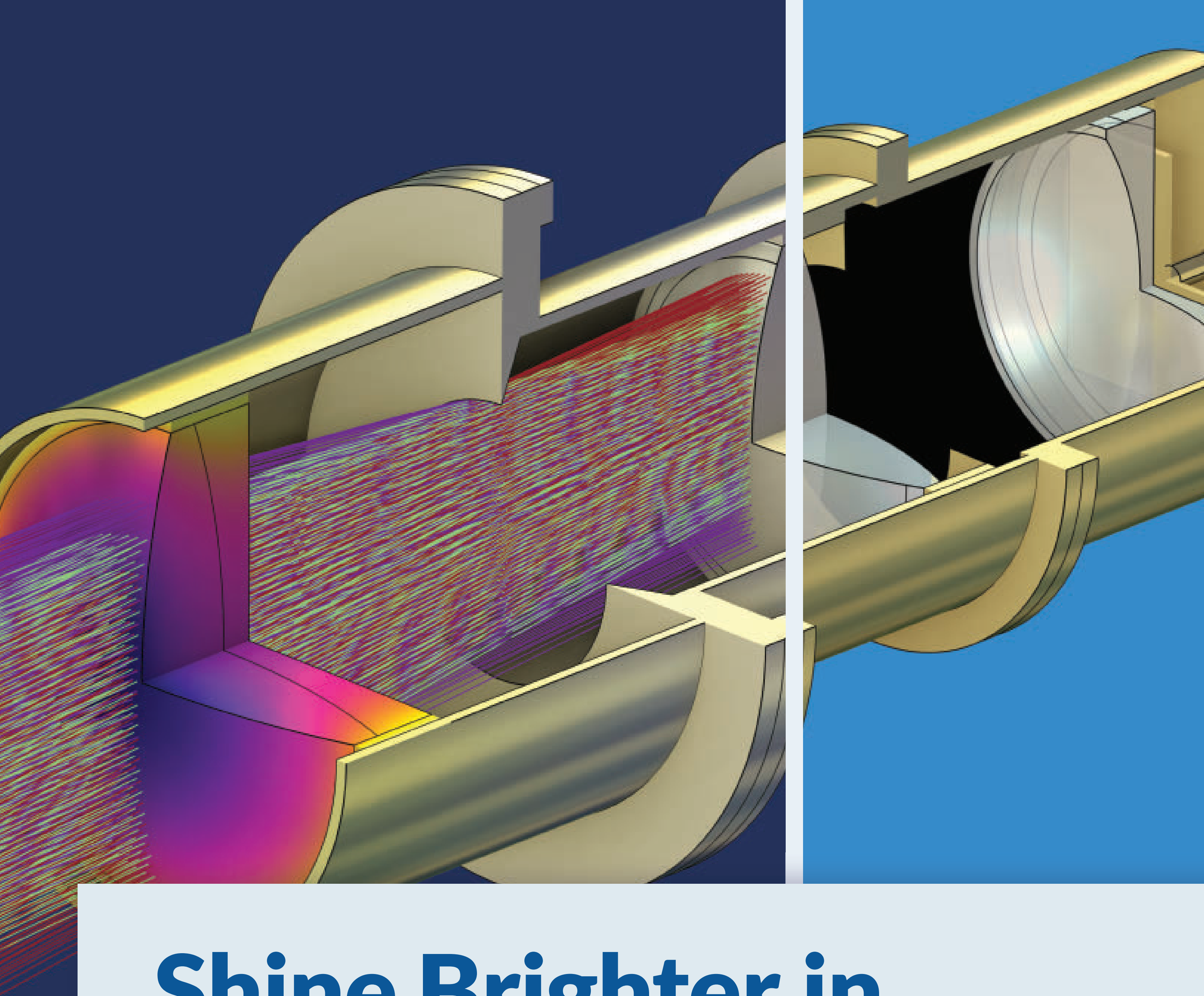

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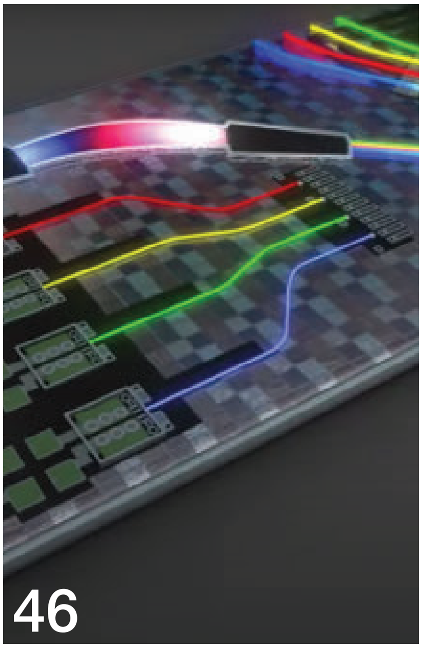
March 2025 volume 59 issue 3

Features



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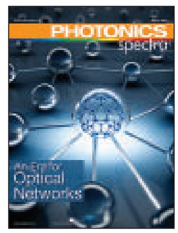
Departments

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.

Columns



The Cover

Unprecedented data volumes and resulting workloads require dynamic connectivity. Robust optical networking solutions are ramping up in response. The computing sector will be among the most immediate beneficiaries. Cover image courtesy of iStock.com/peterschreiber.media. Cover design by Senior Art Director Lisa N. Comstock.

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An era for optical networks

The stories that surround AI models trained on imprecise or incomplete language seem to follow a similar pattern. The model may show some initial degree of aptitude for the target task. Then over time, bias becomes apparent.

The silver lining is twofold. First, there is unanimous understanding that a more complete training leads to a more dependable model. And, in most cases, any of the would-be damage that a poorly or incompletely trained AI model might cause is identified well before the model sees use in the real world.

But there is no question that words matter when it comes to AI.

This notion occupies another context. Words such as "strain" and "burden" — insofar as they relate to the effect that computationally intensive/AI workloads are poised to have on current data infrastructure — are now used with ubiquity. Though these words are accurate in their meaning, they only encapsulate the *problem*. What they omit from the dialogue is the *opportunity*.

The opportunity, in the AI era, is for optimized, robust, and readily deployable optical networks.

This issue of *Photonics Spectra* isolates this message. It spotlights the innovations in networking, interconnects, transmissivity, and processing that are commanding a deep look from all reaches of the industry value chain. The implications are particularly consequential for optical (and quantum optical) computing. But it will be necessary and insightful to also track the storylines for upstream disciplines such as materials science, as well as for telecom, precision timekeeping, and other applications.

Such a deep dive into networking also marks a shift in scope from a focus on components to one on systems. Optical connectivity solutions provider NewPhotonics articulates this nuanced evolution in its article "In the All-Data Revolution, Optical Solutions Advance Beyond PICs" (*Photonics Spectra*, July 2024). The company wrote, "The broader optical realm is charting a more immediate and sustainable path. In its aim to replace electrical dependence, its most obvious targets are the latency and power imperatives facing data connectivity for compute and transmission."

Fast forward three-quarters of a year, and this message is front and center as OFC 2025 dawns.

One more event is important to mention; however, it is unrelated to OFC and optical networking: the 30th anniversary of the quantum cascade laser. Oliver Graydon, chief editor of *Nature Photonics*, flagged this celebratory occasion for the industry in the journal last month. Now, three decades after its debut, it is reasonable to wonder whether those behind its creation — Federico Capasso, Jérôme Faist, and Alfred Cho, among them — may earn a Nobel Prize for their efforts.

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Masahisa Kawashima is chair of the Technology Working Group at IOWN Global Forum and NTT's IOWN technology director. His expertise includes high-speed networking, software defined networking, cloud/edge computing, AI, and data management. Page 50.

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On-Chip Spectral Imaging: New Developments Toward Commoditizing Spectral Imaging

Wouter Charle offers an alternative to traditional hyperspectral imaging systems by using thin-film spectral filters directly deposited and patterned on image sensors. This design results in a compact, robust, and integrated sensor-level solution that requires no additional optical components, making a solution that is as user-friendly as a regular machine vision camera. Two key sensor configurations demonstrate the versatility of this technology: snapshot hyperspectral sensors, featuring a Bayer-like mosaic pattern with spectral filters per pixel, and the imec line-scan sensors, employing a striped filter pattern across pixel rows for high-resolution imaging. Charle presents solutions that have been effectively applied to spinal fusion surgery, detection of Alzheimer's disease-related proteins during eye examinations, industrial and food quality inspection, and Earth observation applications with small satellites. To view, visit **www.photonics.com/w1162**.

Enhancing Industrial Applications with Advanced SWIR and UV Imaging

SWIR and UV imaging are transforming industrial applications such as fruit inspection and sorting, packaging, IR microscopy, semiconductor inspection, and materials sorting. Alexis Teissié highlights the potential of SWIR imaging powered by new-age technology, enabling image capture across visible and invisible light spectra with remarkable pixel sizes of 5 μm and 3.45 μm. Additionally, advancements in UV imaging are highlighted, focusing on the latest high-sensitivity sensors capable of detecting UV light in the 200- to 400-nm range. Teissié uncovers how these technologies enhance precision, efficiency, and versatility in industrial environments.
To view, visit **www.photonics.com/w1164**.

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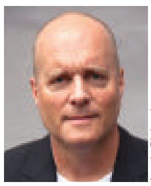
SUMMIT

Infrared Imaging Summit


LightPath Technologies
Liebert.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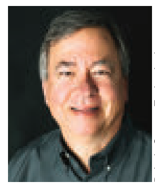

Polaris Sensor Technologies
Chenault.

The editors of *Photonics Spectra* magazine welcome all guests to attend the Infrared Imaging Summit — a virtual event exploring a full spectrum of infrared imaging innovation. The event premieres live on April 16, 2025, and all Summit presentations remain accessible on demand after the event.

Sessions will cover key topics such as polarization imaging, broadband imaging, and advancements in machine vision. The event will feature insights from experts at LightPath Technologies, Oculus Photonics, InfraTec GmbH, and Polaris Sensor Technologies.

Registration for the Infrared Imaging Summit is free for all guests, with attendance providing access to expert-led sessions and networking opportunities, plus actionable insights to improve infrared imaging practices in R&D and the field.

Website

For more information and to register, visit **www.photonics.com/IRIS2025**.

Broadband Thermal Imaging: The Future Is Now
Jason Liebert, LightPath Technologies

Introduction to Infrared Imaging Radiometry
Austin Richards, Oculus Photonics

Extending Machine Vision Capabilities with Calibrated Infrared Cameras
Stephan Larmann, InfraTec GmbH

Infrared Polarization Imaging: Supercharging Thermal Vision
David Chenault, Polaris Sensor Technologies

Upcoming Summits

Microscopy — *May 14*

Laser Optics — *June 11*

Optical Design — *August 13*

Micromachining — *September 17*

Quantum — *November 19*

Register today at
www.photonics.com/IRIS2025.

2025 Prism Awards
Honor Leading Photonics Innovators

SPIE named the winners of the 17th annual Prism Awards at a gala ceremony Jan. 29 at Photonics West.

SPIE, the international society for optics and photonics, recognized the top innovations in optics and photonics products at the 2025 Prism Awards held at Photonics West on Jan. 29. The gala event marked the Prism Awards' 17th anniversary.

The annual ceremony honored a range of established and emerging companies applying groundbreaking and creative solutions to critical problems in areas such as augmented and virtual reality, sensors, lasers, quantum technology, and biomedical optics solutions. In addition, the society recognized its second SPIE Catalyst Award recipient, honoring a for-profit company for a specific social or environmentally focused program that has had a significant positive impact, either within their workplace, on society at large, or on the environment.

Finalists and winners were selected by a panel of international judges who leveraged their knowledge and acumen from across the technology commercialization and funding sectors. The distinguished judges from nine countries included government-agency representatives, commercial business executives, academic researchers, and industry leaders. Presenters at the gala were Luminate's Sujatha Ramanujan, Edmund Optics' Katie Schwertz, ETH Zürich's Ursula Keller, NKT Photonics' Basil Garabet, Singular Photonics' Shahida Imani, Notal Vision's Nishant Mohan, Ruda Optical's Kate Medicus, Thorlabs' Jennifer Cable, and Imperial College London's Jessica Wade.

"By bringing these optics- and photonics-enabled products to market, these companies — the finalists as well as the winners — offer us transformative technologies that will impact lives across the world," said SPIE CEO Kent Rochford.

Here is the complete list of the 2025 SPIE Prism Awards categories, the winners, and their winning products:

Images courtesy of SPIE.

The Finalists by Category

Biomedical

Norlase (Ballerup, Denmark)
Ophthalmic medical device company Norlase develops next-generation laser solutions for the treatment of retina and glaucoma disease. Its product offerings include ECHO, a multi-spot pattern laser; LION, an indirect ophthalmoscope integrated with a green laser source; and LEAF, a green laser photocoagulator. The company was awarded for its newly developed **LYNX** product technology.

Cameras and Imaging Systems

NIL Technology
(Kongens Lyngby, Denmark)
The **metaEye Ultra-Compact Camera** can be used for applications such as eye-tracking, iris tracking, and automotive safety. The camera uses metalenses rather than refractive lenses to reduce stray light and for reduced dust and water system contamination in supported applications. The metaEye Ultra-Compact Camera's architecture allows for NIR sensing and features a 1.64- × 1.64- × 2.17-mm form factor and LED illumination of the eye at 850 nm.

Lasers

Scantinel Photonics GmbH
(Ulm, Germany)
The **Narrow Linewidth Hybrid-Integrated Laser** is a hybrid laser source on a PIC. The laser's narrow linewidth and high modulation linearity enables long-range detection and high-precision velocity data, while powering Scantinel's single-chip frequency-modulated continuous-wave lidar.

Optical Materials and Components

Omega Optical (Brattleboro, Vt.)
Omega Optical's **DeepUV Transmission Gratings** can be used in applications such as spectrometer instrumentation, capillary analysis, and high-performance liquid chromatography. The gratings demonstrate excellent transmission from 190 to 400 nm, environmental stability, and solarization resistance. They are available in sawtooth and holographic grating structures, and in sizes from 4 × 4 mm to 30 × 30 mm, and larger.

Quantum Tech

Leonardo DRS Daylight Solutions
(Arlington, Va.)
The **Stretto** family of high-precision external-cavity diode lasers covers the ultraviolet, visible, and infrared spectra. The lasers are geared toward applications in quantum information science, including computing, sensing, timing, and networking. Stretto is designed for seamless OEM integration and efficient volume production scaling.

Sensors

FluIDect GmbH (Jena, Germany)
The **SpheroScan Explorer** is a semiautomatic device that uses biofunctionalized microparticles µBeads sensor technology to enable the detection of pathogens in a sample. The device is suitable for both laboratory and production environment use, while eliminating the need for time-consuming sample preparation and reducing measurement time. The device is loaded manually and features numerous measurement modes.

Software

HyperSpectral Corp. (Alexandria, Va.)
SpecAI is an AI-powered spectral intelligence solution for industries including food safety, health care, and defense. The technology combines the capabilities of spectroscopic identification and AI to enable the detection of harmful gases and pathogens, and the identification of spectral signatures of threats such as *Escherichia coli*, methane, salmonella, ethylene, and listeria.

Test and Measurement

Quartus Engineering Inc. (San Diego)
The **OptiQuiver** metrology tool combines high dynamic range wavefront sensing with the precision angular measurement and internal reference source of an electronic collimator. The metrology tool provides surface figure measurements for multiple flat or curved optics simultaneously. It is compatible with coherent lasers and broad spectral sources, and the software supports both Windows and MacOS for live results, data logging, and application programming interfaces.

Catalyst

SCHOTT AG (Mainz, Germany)
To meet climate-friendly specialty glass production, **SCHOTT AG** has completed testing of its 100% hydrogen optical glass production capabilities. The tests were performed using gray hydrogen rather than green hydrogen as it is not yet available in sufficient quantities. Green hydrogen is produced solely from renewable energy sources. If the glass meets the high product requirements, it will be sent to the customer, though the lack of green hydrogen infrastructure is delaying industrial use.

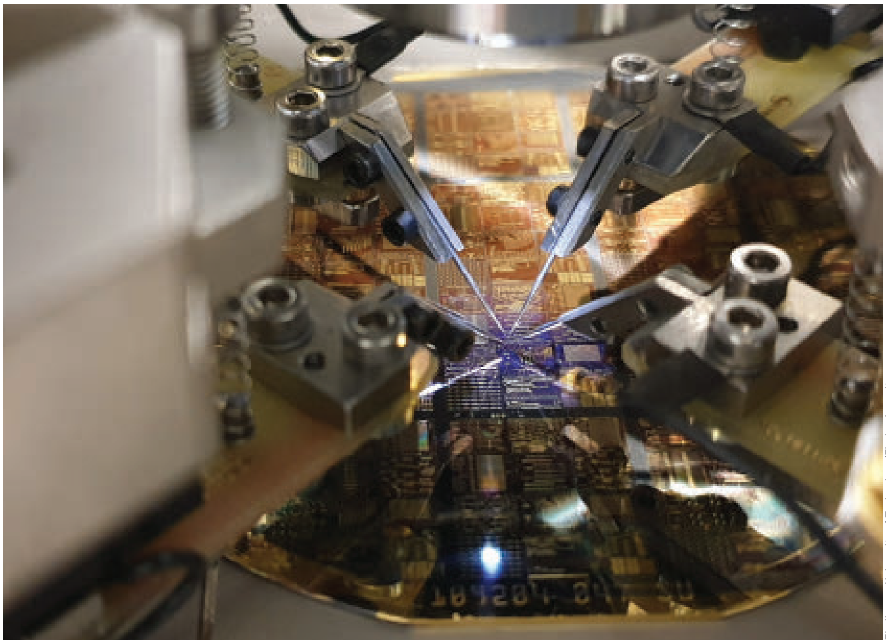
Industry News

Netherlands formalizes ChipNL Competence Centre

The Netherlands has launched a four-year project that aims to boost the European semiconductor industry — offering support for workforce development and funding opportunities as well as facilitating intra- and inter-industry connections. The ChipNL Competence Centre focuses on connecting parts of the value chains with small and medium Dutch enterprises, startups, and scale-ups in the semiconductor sector and related application markets, with a focus on semiconductor manufacturing equipment, chip design, integrated photonics, and quantum and heterogeneous integration.

Users of the ChipNL Competence Centre will be able to access European pilot lines that allow them to test and validate new technologies. In addition, an innovative design platform is being developed within the European Chips Act to support industry in designing and developing customized semiconductor solutions. The ChipNL Competence Centre also facilitates access to this by providing support and knowledge. TNO, imec, and JePPIX will be responsible for these activities.

The project has been allocated a budget of €12 million ($12.4 million) for the next four years by the European Commission and the Rijksdienst voor Ondernemend Nederland (Netherlands Enterprise Agency). The center is a collaboration between Brainport Development, ChipTech Twente, High Tech NL, TNO, Joint European Platform for Photonic Integration Components and Circuits (JePPIX), imec, and regional development companies OostNL, BOM, and InnovationQuarter.



Eindhoven University of Technology/Florian Lemaitre

The newly established ChipNL Competence Centre will aid businesses in the semiconductor industry by providing support with funding, research, and workforce development.

The center will additionally cooperate with the European Skills Initiatives and the Microchip Talent reinforcement plan (known as project Beethoven) to cultivate talent, and will offer support to entities seeking funding through the European Chip Fund.

Zebra Technologies to acquire Photoneo

Zebra Technologies will acquire Photoneo, a developer and manufacturer of 3D machine vision solutions. The acquisition will expand Zebra's portfolio and strengthen its position as a leader in the 3D segment of the machine vision market, combining Photoneo's 3D sensors with Zebra's capabilities in AI-powered imaging, inspection software, and autonomous data capture.

The financial terms of the acquisition were not disclosed.

Bratislava, Slovakia-based Photoneo is well known for its parallel structured light technology. The company's intelligent sensors are widely used in vision-guided robotics for applications including bin-picking and palletization/depalletization. The sensors are certified to interface with many leading robotics manufacturers for a variety of use cases, including robot-arm applications.

Photoneo partnered with embedded systems developer Neousys last year, entering into a collaboration that aims to develop a 3D-imaging solution for challenging use conditions. Zebra acquired advanced machine vision components, software, and systems developer Matrox Imaging in 2022 to augment its portfolio of fixed industrial scanners and machine vision sensors. The company also acquired intralogistics automation company and autonomous mobile robots developer Fetch Robotics and software company Adaptive Vision in 2021.

SCANLAB names CEO, institutes additional personnel changes

SCANLAB GmbH named Alexander Roth CEO, succeeding Georg Hofner, who will focus exclusively on his position of CEO at SCANLAB's parent company, TecInvest Holding AG. Alexander Staudt, who has overseen operations at SCANLAB since 2023, will take on the role of COO.

Roth has prior experience at Siemens and Giesecke & Devrient as well as in photonics at Rofin-Baasel Lasertech, Coherent-Rofin, and Fraunhofer-Gesellschaft. For the past five years, he has served as managing director of Coherent's Industrial Systems business unit.

Staudt, an industrial engineer with 20 years of experience in electronics production, was most recently plant manager of the Würth Elektronik Group, a specialist in printed circuit board production.

The management changes also include the appointment of Dirk Thomas as CFO.

SCANLAB

The SCANLAB management team as of January 2025. **(From left)** Alexander Staudt, Alexander Roth, Dirk Thomas, and CTO Christian Sonner.

This month in history

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

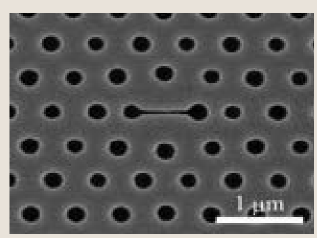
1995

Researchers at Sharp Laboratories of Europe developed a prototype display system that produces high-quality 3D pictures based on two superimposed flat-screen panels. Dubbed the "twin-LCD," The images were combined by a proprietary optical filter that transmitted the image from the vertical display and combined it with the reflected image from the horizontal display.

2005

A group from the University of Fudan in Shanghai used the phase-modifying property of liquid crystal displays to produce a tunable reflective lens. The researchers said that the approach would be useful for the handling of off-axis light and the freedom it would bring to a liquid-crystal-on-silicon lens.

2015



Researchers from the University of Minnesota created a microchip that generated both lightwaves and ultrahigh-frequency sound waves, forcing them to interact. The chip featured a silicon base coated with a layer of aluminum nitride that conducted an electric charge where applying an alternating electrical signal to the material caused it to deform periodically.

2020

A team of scientists led by the U.S. Department of Energy's Lawrence Berkeley Lab and the University of California, Berkeley developed a tool for performing experiments with diamond anvil cells that are inaccessible to conventional sensors. The developed sensor used nitrogen-vacancy centers that were generated in a few hundred atoms-thick layers inside 0.1-carat diamonds.

Focused Energy and Amplitude strike partnership agreement

Laser fusion company Focused Energy entered into an agreement with Amplitude, a developer of ultrafast lasers, to advance two laser systems beyond the current state-of-the-art for inertial fusion energy. The technology around which the partnership centers will help develop and determine the laser parameters needed to commercialize Focused Energy's direct drive laser fusion approach.

Beamlines established through the collaboration will be installed at Focused Energy's planned $65 million Laser Development Facility in the San Francisco Bay Area, which the company announced last year.

Focused Energy's scientists and engineers plan to use these laser systems to test and optimize laser performance and fusion target design to meet key milestones in their technology risk reduction program targeting inertial fusion energy. The kilojoule-class lasers are designed to test the physics needed for efficient direct-drive compression of deuterium-tritium fusion fuel targets. They will operate at enhanced repetition rates of one shot every 60 s, enabling rapid design iteration.

According to Focused Energy, the company's planned Laser Development Facility complements its fuel targetry lab in Darmstadt, Germany, where the company is already engaged in the development of low-cost, millimeter-scale deuterium-tritium fuel targets.

Focused Energy plans to combine its laser and target technology in an engineering facility that will integrate, test, and optimize all of the prerequisite technologies for a commercial-scale fusion pilot plant capable of net energy gain. Once commercial fusion is reached, three soda cans worth of deuterium-tritium fusion fuel will be able to power a city the size of San Francisco for a day, the company said.

Focused Energy has raised more than $175 million in private capital and public grant funding. It is one of eight fusion companies selected by the U.S. Department of Energy for funding under the Milestone-Based Fusion Development Program. In September 2024, the company was announced as the leader of a project funded by Germany's Federal Ministry of Education and Research to develop a laser-driven neutron source from individual components developed by the project partners and to demonstrate how it can be used for the nondestructive examination of nuclear waste containers.

VIAVI Solutions acquires Inertial Labs

VIAVI Solutions signed a definitive agreement to acquire Inertial Labs for initial consideration of $150 million at closing and up to $175 million of contingent consideration over four years. The acquisition, which closed in January, expands VIAVI's portfolio and extends its reach into aerospace, defense, and industrial end markets.

Headquartered in Leesburg, Va., Inertial Labs is a developer, producer, and supplier of high-performance orientation, positioning, and navigation solutions for aerospace, defense, and industrial applications. The company offers inertial measurement units, inertial navigation systems, assured position navigation and timing, global navigation satellite system tracking, lidar scanning, alternative navigation, and visual navigation solutions.

The offerings complement VIAVI's existing positioning, navigation, and timing capabilities, among other aerospace and defense solutions, VIAVI said. Inertial Labs' solutions also include enablement of utility inspection through lidar and photogrammetry algorithms, and smart system navigation for both airborne and autonomous ground vehicles.

The technology capabilities accelerate VIAVI's entrance into industrial and autonomous delivery and transportation end markets.

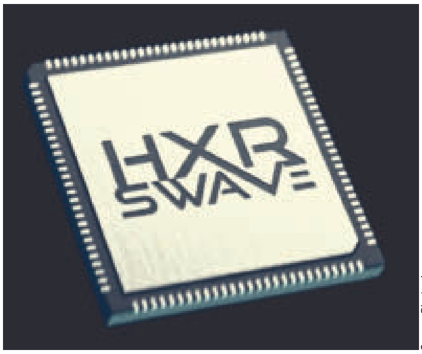
Swave Photonics raises $28.3M

Swave Photonics, a developer of holographic extended reality (HXR) technology, raised €27 million ($28.3 million) in a series A funding round. The investment is expected to expedite the development of Swave's HXR platform for AI-powered AR smart glasses and head-up displays.

Swave's diffractive optics-based technology enables 3D high-resolution images that adapt to the user's surroundings. The company's DynamicDepth technology allows the images to be processed naturally by the human vision system, bypassing challenges of focal depth and eye-tracking that commonly affect AR, according to Swave.

Investors imec.xpand and SFPIM Relaunch co-led the funding round, with participation from new investors EIC Fund, IAG Capital Partners, and Murata Electronics North America Inc. as well as existing investors. Swave previously raised a €10 million seed round, with an initial €7 million in June 2022, followed by a €3 million infusion the following year. Following its initial seed funding round, the company won the top prize at the 2023 SPIE Startup Challenge.

Swave cofounder and COO Dmitri Choutov said that the company is on track to introduce product development kits, and production devices soon thereafter.



Swave Photonics

Swave Photonics introduced its holographic extended reality (HXR) platform in April 2024. The technology earned a CES Innovation Award during the Consumer Electronics Show 2025.

Foxconn teams with Porotech on micro-LED display commercialization

Consumer electronics company Hon Hai Technology Group (Foxconn) partnered with micro-LED technology developer Porotech to commercialize micro-LED microdisplays for AR applications as well as wearable and smart devices. The companies intend to establish a complete end-to-end supply chain for the technology, the widespread rollout of which has been hindered by manufacturing challenges.

As part of the partnership, Foxconn will accelerate its strategic expansion in AR and micro-LED technologies. The company plans to establish a micro-LED wafer processing production line in Taichung, Taiwan, with mass production slated to begin by the end of the year. This will cater to the needs of future mainstream global clients, the partnering companies said.

The partnership follows the companies' collaboration started in 2023 to address challenges in micro-LED commercialization — namely, the difficulty in combining multiple disciplines such as semiconductor wafer manufacturing, hybrid bond, integrated chip design, optoelectronics, quantum physics, and optics. Following this initial partnership, Porotech entered into a collaboration in 2024 with Taiwan's Powerchip Semiconductor Manufacturing Corp. (PSMC) for the mass production of micro-LEDs on 200-mm gallium nitride (GaN)-on-silicon for consumer display applications.

Porotech, meanwhile, has also formally launched a partnership with General Interface Solution Holding that aims to produce high-pixel-density AR products for consumer applications.

German initiative aims to develop, scale inertial fusion targets

Funded by the Federal Ministry of Education and Research (BMBF) and led by the Fraunhofer Institute for Applied Solid State Physics IAF (Fraunhofer IAF), the IFE Targetry HUB consortium has begun research into the target component of laser-based inertial confinement fusion. Collaborators will contribute their expertise in basic, applied, and industrial research to the three-year project plan, which plans to jointly investigate suitable materials and processes for the functional and cost-efficient scalable production and characterization of targets for laser-based inertial confinement fusion.

The consortium is composed of 15 members across research and industry.

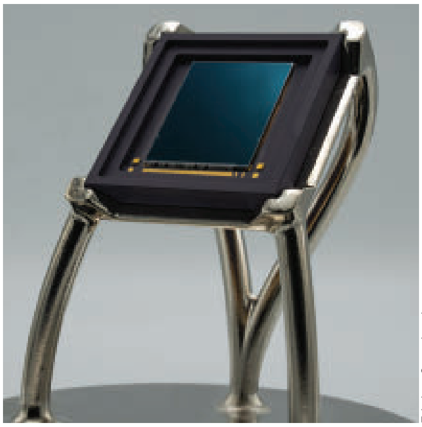
Laser-based inertial confinement fusion uses a target filled with the hydrogen isotopes deuterium and tritium. This target is compressed and then ignited in the pulsed process using high-energy laser beams as drivers. A temperature of up to 120 million °C is reached, vaporizing the target and simultaneously compressing and heating the fuel under enormous pressure. This triggers a fusion reaction in which the positively charged atomic nuclei overcome their mutual repulsion and fuse to form a new, more energetically favorable nucleus, which ultimately releases enormous amounts of energy.

Previous demonstrations have used spherical diamond targets, in some cases as small as 1 mm in diameter. Target geometry, interface properties, and purity as well as the quality of material(s) are critical to the success of nuclear fusion. Now, the IFE Targetry HUB is working to develop and implement high-precision manufacturing processes, such as additive manufacturing of foams or plasma coating and characterization of target components.

Partners on the project include Focused Energy GmbH, Karlsruhe Institute of Technology's Tritium Laboratory Karlsruhe, Technical University of Darmstadt, KERN Microtechnik, Fraunhofer ILT, Plasmatreat GmbH, and LightFab GmbH.

Teledyne Space Imaging selected to build payload for LISA mission

Teledyne Space Imaging was awarded prime contractor status for the Constellation Acquisition Sensor (CAS) instrument, which will contribute to the European Space Agency Laser Interferometer Space Antenna (LISA) mission. The imaging sensor manufacturer will deliver six CIS220 detectors as well as the control electronics for the international space observation project.


Teledyne Space Imaging

Teledyne Space Imaging is the prime contractor for the Laser Interferometer Space Antenna (LISA) mission's Constellation Acquisition Sensor (CAS) instrument. The company will deliver six CIS220 detectors and the control electronics for the international space observation project.

Teledyne will work in partnership with Thales Alenia Space in Switzerland, which will be responsible for the optical head.

The LISA mission will be the first space-based observatory dedicated to studying gravitational waves, or ripples in the fabric of space-time, emitted during powerful events such as two black holes coming together and merging into one.

Operationally, the LISA CAS instrument will help establish the interferometric laser links between spacecrafts positioned at the vertices of a triangular constellation and transform them into a single gravitational wave observatory. This will enable the mission to study the formation of compact binary stars and the structure of the Milky Way galaxy as well as to trace the origins and merger history of black holes and probe the rate of expansion of the universe.

The European Space Agency is leading the mission in partnership with its member states and NASA.

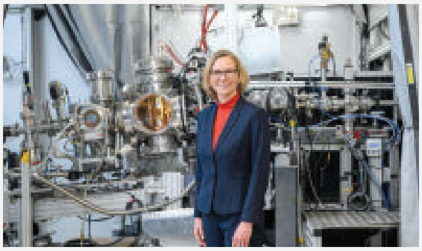
23.3% — predicted compound annual growth rate of the global metamaterials market between 2025 and 2033, according to IMARC Group

People in the News


Physik Instrumente (PI)

Physik Instrumente (PI) appointed **Beate van Loo-Born** CFO. Van Loo-Born brings more than 20 years of international leadership experience across financial services and data technology sectors, spanning roles at UBS and the Swiss Stock Exchange.

Applied Optoelectronics Inc. named **Kevin Jones** vice president of sales for its broadband access division, Quantum Bandwidth. Prior to joining Applied Optoelectronics, Jones held sales leadership roles at Ciena, CommScope, Casa Systems, and Scientific-Atlanta.


DESY

Britta Redlich was appointed Photon Science Director at DESY, Germany's national synchrotron research center. Redlich previously served as director of the FELIX free-electron laser (FEL) and the HFML high-field magnetic laboratory at Radboud University in the Netherlands. Redlich is a senator of the Helmholtz Association for Research Field Matter as well as a member of international consortia including LEAPS, LaserLab Europe, and FELs of Europe.


LPKF Laser & Electronics SE

Provider of laser-based solutions LPKF Laser & Electronics SE added **Peter Mümmler** as CFO on an initial contract term of three years, effective April 1. Mümmler's experience includes 20 years in executive-level finance and strategic leadership roles — most recently serving as interim CFO and managing director at Heramba PLC.

Photronics Inc., a photomask technologies and solutions company, appointed **David Garcia** to its board of directors, expanding the board to nine members. Garcia previously spent 30 years practicing law.

Lumentum Holdings Inc. appointed **Paul Lundstrom** to its board of directors, expanding the board to nine members. Lundstrom is currently CFO at Copeland.


Sondrel

Sondrel, a provider of custom chips, appointed **Oreste Donzella** as a nonexecutive director of its board. Donzella has more than 30 years of experience in the global semiconductor industry, currently holding the positions of executive vice president and CSO of semiconductor manufacturer KLA.

Syntec Optics Holdings Inc. appointed **Michael J. Ransford** site manager. Ransford has more than 30 years of experience in engineering, operations, and business leadership, most recently serving as COO of Omega Optical Holdings.

LLNL, Starris: Optimax Space Systems commercializing telescope tech

Lawrence Livermore National Laboratory (LLNL) and Starris: Optimax Space Systems partnered to commercialize LLNL's monolithic telescope technology, accelerating rapid deployment of modular optical designs for high-resolution or high-sensitivity space imagery.

Starris has collaborated during the last decade with LLNL's space program to develop the monolithic telescope technology and will manufacture — at scale and with customization options — the precision-fabricated optical lens that forms the image in the telescope.

The collaboration with LLNL is now extended via a government-use license for commercializing the technology through LLNL's Innovation and Partnerships Office.

Starris will commercialize and scale the technology specifically for space domain awareness: the detection, tracking, cataloging, and identification of artificial objects, including satellites, spent rocket bodies, asteroids, and debris. The compact yet robust monolith enables tactically responsive space, with the ability to deliver on-orbit capabilities with speed and agility.

"Our ability to scale production of the LLNL payload solutions will enable the rapid deployment of small satellite constellations to support continuously evolving mission needs," said Kevin Kearney, Starris director and CTO.

The monolithic optics are aligned with straightforward interfaces, low moments of inertia, and high thermal tolerance during manufacture. Because alignment occurs during their fabrication at Optimax, the LLNL monolithic technology is "shelf-stable," unlike traditional telescopes. It also does not need to be handled in high cleanliness environments, as the mirrors are encased inside the telescope.

Lawrence Livermore National Laboratory (LLNL)

Reflections are seen on the primary mirror surface of a flight-ready 175-mm aperture monolithic telescope.

Initially designed for intelligence and defense applications, the LLNL monolithic telescopes have been proven in several space missions and were chosen to fly on the upcoming U.S. Space Force's Victus Haze mission later this year, which is intended to test military capabilities to rapidly deploy satellites in response to threats in orbit.

Optimax launched Starris last year to accelerate space technologies with a pre-engineered modular approach combining optics, sensors, and electronics.

$97.3B

— expected size of the global semiconductor raw materials market by 2029, according to Mordor Intelligence

Polar Light Technologies touts micro-LED development

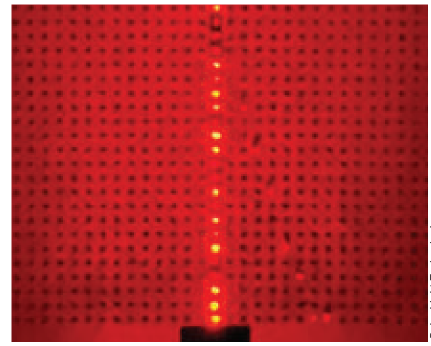
Polar Light Technologies reported its development of a 625-nm red light micro-LED based on the company's non-etching, bottom-up fabrication concept. According to the company, the demonstration marks its achievement of attaining red, green, and blue pyramidal micro-LEDs using the same material compound. The advancement lays the foundation for spatial computing and next-generation monolithic RGB display, Polar Light said.

Though blue and green micro-LEDs are widely available on the commercial market, achieving a red color has been difficult due to challenges in the necessary material properties. Several workarounds or alternatives allow a red color to be attained and each come with some compromises regarding efficiency, manufacturability, and the need to integrate with other material systems.

Using its bottom-up approach, Polar Light said, the strain in the lattice-mismatched indium gallium nitride/gallium nitride structures is reduced, which is necessary for the manufacture of blue, green, and red micro-LEDs with the same material system (i.e., to fabricate monolithic RGB). The technique also provides the possibility to integrate the frontplane with a backplane.

Because the method does not require etching, and therefore eliminates the related damages caused by the manufacturing technique, performance is maintained for smaller dimensions, Polar Light said. Also, the method enables the possibility of sub-micron LEDs and nano-LEDs.

In October 2024, Polar Light announced a partnership with FineTek. And earlier in the year, the company named Oskar Fajerson CEO.


Polar Light Technologies

Polar Light Technologies reported the capability to build red, green, and blue pyramidal micro-LEDs using the same material compound. The company created a 625-nm red light micro-LED using its non-etching bottom-up manufacturing concept.

6.8%

— predicted compound annual growth rate of the global precision optics market by 2030, according to Precision Business Insights

NVIDIA formalizes autonomous driving collaborations

NVIDIA established partnerships with Toyota, Aurora, and Continental in pursuit of autonomous driving for both consumer and commercial markets. The companies are building autonomous driving technologies to be based on the NVIDIA DRIVE system-on-chip (SoC) platform.

Toyota will build its next-generation vehicles on NVIDIA DRIVE AGX Orin, running the safety-certified NVIDIA DriveOS operating system. Other mobil-

Briefs

Civan Lasers opened two advanced demonstration labs — one at welding manufacturer **AMET**'s Rexburg, Idaho, campus and one at automated systems developer **Photon Automation**'s Detroit campus. The facilities will offer hands-on demonstrations and tailored process development to its customers for its welding solutions, Civan said.

Anatomic and digital pathology solutions company **Leica Biosystems** invested in AI-powered digital pathology software developer **Indica Labs**. Leica Biosystems and Indica Labs plan to launch a diagnostic digital pathology platform pairing Leica Biosystems' Aperio scanner portfolio with a customized version of Indica Labs' HALO AP image management software, for use by clinical customers. Additionally, Leica Biosystems expects to integrate Indica Labs into the company's companion diagnostic (CDx) development program, working with Indica Labs on next-generation AI-enabled CDx assays.

AIXTRON opened its innovation center at its headquarters in Herzogenrath, Germany. The €100 million ($104 million) center features 1000 sq m of cleanroom space capable of developing 300-mm wafers for gallium nitride and other compound semiconductor applications.

Photonic computing company **Opticore** raised $5 million in funding. The company is developing optical processing units that perform the same computational tasks as graphics processing units, but using light and waveguides instead of electrical components.

Aledia, a company specializing in 3D nanowire-based micro-LED technology, unveiled a $200 million state-of-the-art production line in Grenoble, France. The line uses semiconductor-grade silicon in 8- and 12-in. formats, lowering production costs for large-scale production of micro-LEDs. The company said that it can support customer demand ramp-up to nearly 5000 wafer starts per week.

Sivers Semiconductors AB entered into advanced discussions with customer **Ayar Labs** to partner on the next phase of engagement focused on manufacturing at scale to support deployment of Ayar's in-package optical interconnect solutions. The move will support moving AI data centers from copper-based interconnects to input/output interconnects and follows Ayar's 2024 securement of $155 million in financing.

POET Technologies formalized agreements with optical engine manufacturer **Globetronics Manu-**

ity companies adopting NVIDIA DRIVE AGX for their next-generation advanced driver-assistance systems and autonomous vehicle road maps include BYD, JLR, Li Auto, Lucid, Mercedes-Benz, NIO, Nuro, Rivian, Volvo Cars, Waabi, Wayve, Xiaomi, ZEEKR, and Zoox, among others.

Aurora, Continental, and NVIDIA also announced a long-term strategic partnership to deploy driverless trucks at scale, powered by NVIDIA DRIVE. NVIDIA's accelerated compute running DriveOS will be integrated into the Aurora Driver, an SAE (Society of Automotive Engineers) level 4 autonomous-driving system that Continental plans to mass-manufacture in 2027. Level 4 autonomy, as defined by automotive trade organization SAE, is the first of its five defined levels at which a human driver is not required.

Aurora is reportedly in the final stages of validating the Aurora Driver for driverless operations on public roads. The system features a fleet of sensors including lidar, radar, and cameras, and a computer powered by a dual NVIDIA DRIVE Thor SoC configuration running DriveOS.

Continental is developing a hardware solution for the Aurora Driver, specifically for high-volume manufacturing. The company is also developing a specialized independent secondary system that can take over operation if a failure occurs in the primary Aurora Driver computer.

The start of production is planned for 2027, and Continental will test prototypes of the future hardware kit in the coming months. Continental will then integrate DRIVE Thor with DriveOS into the primary Aurora Driver computer at its manufacturing facilities and ship the full hardware kit to Aurora's truck OEM partners for integration into customers' trucks. As Continental and Aurora prepare to manufacture self-driving hardware at scale in 2027, production samples of DRIVE Thor are planned in the first half of 2025.

Exail acquires laser-maker Leukos

Exail acquired laser technology company Leukos, a company specializing in advanced laser sources for metrology, spectroscopy, and imaging applications. Financial terms of the acquisition were not disclosed. Leukos will operate as a subsidiary of Exail, retaining its product portfolio and branding.

The acquisition combines Leukos' technologies, including pulsed micro-lasers, supercontinuum sources, and ultrafast fiber laser, with Exail's expertise in specialty fibers, modulation, micro-optical assemblies, and quantum systems. The combination additionally expands Exail's product offerings and solutions to address new markets including biophotonics and microelectronics.

Exail is a high-tech industrial company specializing in robotics, maritime, navigation, aerospace, and photonics technologies. The company was formed in 2022 through the combination of ECA Group and iXblue, following Group Gorgé's acquisition of iXblue.

7.2%

— estimated compound annual growth rate of the global mirror coatings market by 2032, according to Fortune Business Insights

facturing to manufacture optical engines for POET in Penang, Malaysia. This comes after POET signed a memorandum of understanding with **Quanzhou Sanan Optical Communication Technology Co. Ltd.** to transfer to POET its 24.8% stake in the joint venture **Super Photonics Xiamen** (**SPX**).

Park Systems Corp. acquired **Lyncée Tec SA**, a Swiss digital holographic microscope technology developer, to strengthen its optical metrology business. Digital holographic microscopy acquires 3D information of a sample over the full field of view without scanning, producing imaging speeds faster than interferometry-based optical profiling.

Fabless semiconductor company **Himax Technologies** partnered with **Calumino**, a provider of intelligent thermal imaging solutions. The companies have produced a CMOS imager-based optical thermal sensor featuring on-device edge AI. The partners expect to launch a final product this year.

Ansys entered into a definitive agreement for the sale of its PowerArtist business to **Keysight Technologies Inc.** PowerArtist is a comprehensive register-transfer level design-for-power platform used by semiconductor companies for early-stage power analysis, profiling, and reduction. Ansys and **Synopsys** determined that the sale of PowerArtist was necessary to obtain regulatory approval for Synopsys' proposed acquisition of Ansys, which, as of press time, is expected to close in the first half of 2025. Ansys entered into an agreement with Synopsys for its acquisition in January 2024 in a deal worth $35 billion.

PI Ceramic, a piezoceramic components developer, introduced a fully automated production line for multilayer technology at its manufacturing facility, to accelerate sample production for development projects. The system consists of a sheet cutter, screen printer, and a ceramic tape stacker, and will provide end-to-end traceability of intermediate products, according to the company. The system facilitates production of small-scale series and prototypes and nearly reduces the time needed for sample manufacturing for system development to a few weeks.

3M entered into a strategic licensing agreement with **US Conec Ltd.**, an optical interconnect designer, to help in the commercialization of 3M's expanded beam optical interconnect technology. As part of this agreement, US Conec will manufacture and supply products using 3M's expanded beam optical technology to help ensure a robust supply chain for future network deployments.

Quantum teleportation demonstrated over busy internet cables

EVANSTON, Ill. — Researchers from Northwestern University demonstrated quantum teleportation over a fiber optic cable that is already actively carrying internet traffic. The work introduces the possibility of combining quantum communication with existing internet cables — greatly simplifying the infrastructure required for advanced sensing technologies or quantum computing applications.

Only limited by the speed of light, quantum teleportation enables a new, ultrafast, secure way to share information between distant network users, wherein direct transmission is not necessary. The process works by harnessing quantum entanglement, a technique in which two particles are linked, regardless of the distance between them. Instead of particles physically traveling to deliver information, entangled particles exchange information over great distances without physically carrying it.

"In optical communications, all signals are converted to light," said Prem Kumar, director of Northwestern's Center for Photonic Communication and Computing. "While conventional signals for classical communications typically comprise millions of particles of light, quantum information uses single photons."

"By performing a destructive measurement on two photons — one carrying a quantum state and one entangled with another photon — the quantum state is transferred onto the remaining photon, which can be very far away," said Jordan Thomas, a Ph.D. candidate in Kumar's laboratory and first author on the paper describing the work. "The photon itself does not have to be sent over long distances, but its state still ends up encoded onto the distant photon."

Prior to this study, many researchers were uncertain whether quantum teleportation was possible in cables carrying classical communications. The entangled photons were expected to drown among the millions of other light particles.

Lucent_Designs_dinoson20 via Pixabay

Researchers at Northwestern University demonstrated quantum teleportation over fiber optic cables already carrying internet traffic. The work overcomes the physical limitations to a long-held bottleneck and supports the coexistence of classical and quantum communications.

The Northwestern researchers, however, found a way to help the photons steer clear of the traffic. After conducting in-depth studies of how light scatters within fiber optic cables, the researchers found a less crowded wavelength of light to place their photons. Then, they added special filters to reduce noise from regular internet traffic.

"We carefully studied how light is scattered and placed our photons at a judicial point where that scattering mechanism is minimized," Kumar said. "We found we could perform quantum communication without interference from the classical channels that are simultaneously present."

To test the method, the researchers set up a 30-km fiber optic cable with a photon at either end. They then simultaneously sent quantum information and high-speed internet traffic through it. Finally, they measured the quality of the quantum information at the receiving end while executing the teleportation protocol by making quantum measurements at the mid-point. The researchers found the quantum information to be successfully transmitted — even with busy internet traffic whizzing by.

"This is incredibly exciting because nobody thought it was possible," Kumar said. "Our work shows a path toward next-generation quantum and classical networks sharing a unified fiber optic infrastructure."

"Although many groups have investigated the coexistence of quantum and classical communications in fiber, this work is the first to show quantum teleportation in this new scenario," Thomas said. "This ability to send information without direct transmission opens the door for even more advanced quantum applications being performed without dedicated fiber."

Next, Kumar plans to extend the experiments over longer distances. He also plans to use two pairs of entangled photons rather than one pair to demonstrate entanglement swapping, another important milestone leading to distributed quantum applications. Finally, his team is exploring the possibility of carrying out experiments over real-world, in-ground optical cables rather than on spools in the lab.

Even with more work to do, Kumar is optimistic.

"Quantum teleportation has the ability to provide quantum connectivity securely between geographically distant nodes," Kumar said. "But many people have long assumed that nobody would build specialized infrastructure to send particles of light. If we choose the wavelengths properly, we won't have to build new infrastructure. Classical communications and quantum communications can coexist."

The research was published in *Optica* (www.doi.org/10.1364/OPTICA.540362).

Wireless antennas monitor cellular communication with light

CAMBRIDGE, Mass. — Monitoring electrical signals in biological systems helps scientists understand how cells communicate, which can aid in the diagnosis and treatment of conditions such as arrhythmia and Alzheimer's disease.

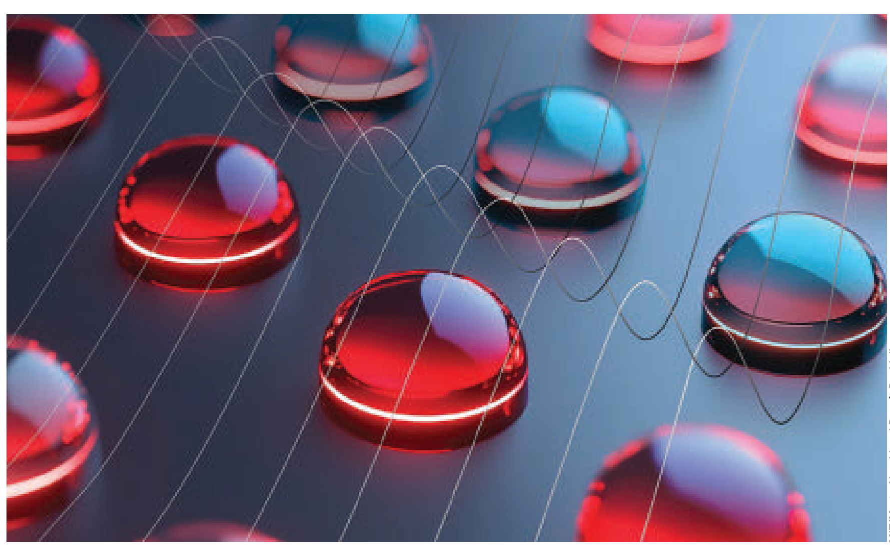
But devices that record electrical signals in cell cultures and other liquid environments often use wires to connect each electrode on the device to its respective amplifier. Because only so many wires can be connected to the device, the number of recording sites is restricted, limiting the information that can be collected from cells.

Researchers at MIT developed a biosensing technique that eliminates the need for wires. Instead, tiny wireless antennas use light to detect minute electrical signals. Small electrical changes in the surrounding liquid environment alter how the antennas scatter the light. Using an array of tiny antennas, each of which is one-hundredth the width of a human hair, the researchers measured electrical signals exchanged between cells, with extreme spatial resolution.

The devices are durable enough to continuously record signals for >10 h and could help biologists understand how cells communicate in response to changes in their environment. In the long run, such insights could pave the way for advancements in diagnosis, spur the development of targeted treatments, and enable more precision in the evaluation of new therapies.

"The organic electro-scattering antennas (OCEANs) we developed enable recording of electrical signals wirelessly with micrometer spatial resolution from thousands of recording sites simultaneously," said professor Deblina Sarkar of MIT's Media Lab, its Center for Neurobiological Engineering, and head of its Nano-Cybernetic Biotrek Lab. The OCEANs devices are composed of PEDOT:PSS, a polymer that attracts or repulses positive ions from the surrounding liquid environment when there is electrical activity nearby. This modifies its chemical configuration and electronic structure, altering its refractive index and changing how it scatters light.

To improve biosensing techniques that can aid in diagnosis and treatment, MIT researchers developed tiny, wireless antennas that use light to detect minute electrical signals in liquid environments, which are shown in this rendering.



MIT/Marta Airaghi and Benoît Desbiolles

When researchers shine light onto the antenna, the intensity of the light changes in proportion to the electrical signal in the liquid.

With thousands or even millions of tiny antennas in an array, each only 1 µm wide, the researchers capture the scattered light with an optical microscope and measure electrical signals from cells with high resolution. Because each antenna is an independent sensor, the researchers do not need to pool the contribution of multiple antennas to monitor electrical signals, which is why OCEANs can detect signals with micrometer resolution.

Intended for in vitro studies, OCEAN arrays are designed to have cells cultured directly on top of them. The arrays are also designed to then be put under an optical microscope where they can be analyzed.

A user starts with a glass substrate and deposits layers of conductive then insulating material on top, each of which is optically transparent. Then, they use a focused ion beam to cut hundreds of nanoscale holes into the top layers of the device. This special type of focused ion beam enables high-throughput nanofabrication.

"This instrument is basically like a pen where you can etch anything with a 10-nm resolution," said lead author Benoît Desbiolles, a former postdoc in the MIT Media Lab.

The chips are then submerged in a solution containing the precursor building blocks for the polymer. By applying an electric current to the solution, the precursor material is attracted into the tiny holes on the chip, and mushroom-shaped antennas "grow" from the bottom up.

The entire fabrication process is relatively fast, and the researchers could use this technique to make a chip with millions of antennas.

"This technique could be easily adapted so it is fully scalable. The limiting factor is how many antennas we can image at the same time," Desbiolles said.

The researchers optimized the dimensions of the antennas and adjusted parameters. This enabled them to achieve high-enough sensitivity to monitor signals with voltages as low as 2.5 mV in simulated experiments. Signals sent by neurons for communication are usually ~100 mV.

OCEANs also responded to changing signals in only a few milliseconds, enabling them to record electrical signals with fast kinetics. Moving forward, the researchers plan to test the devices with real cell cultures. They also want to reshape the antennas so they can penetrate cell membranes, enabling more precise signal detection.

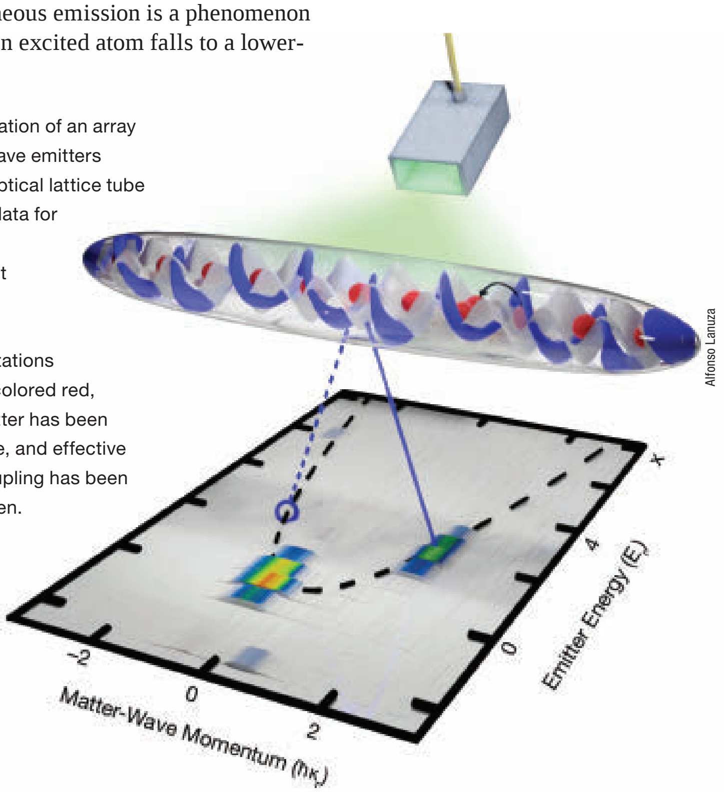
In addition, the researchers are interested in studying how OCEANs could be integrated into nanophotonic devices for next-generation sensors and optical devices.

The research was published in *Science Advances* (www.doi.org/10.1126/sciadv.adr8380).

Researchers find novel collective behaviors in quantum optics

STONY BROOK, N.Y. — Researchers at Stony Brook University, led by professor of physics Dominik Schneble, uncovered a regime (or set) of conditions within a system for cooperative radiative phenomena, casting light on a 70-year-old problem in quantum optics.

Spontaneous emission is a phenomenon in which an excited atom falls to a lower-energy state and spontaneously emits a quantum of electromagnetic radiation in the form of a single photon. When a single excited atom decays and emits a photon, the probability of finding the atom in its excited state falls exponentially to zero as time progresses.



A representation of an array of matter-wave emitters held in an optical lattice tube along with data for directional superradiant emission. In the tube, atomic excitations have been colored red, emitted matter has been colored blue, and effective vacuum coupling has been colored green.

In 1954, Princeton physicist Robert Dicke considered what happens when a second, unexcited atom is put in its immediate vicinity. He argued that the probability of finding an excited atom would fall to only one-half. The excited system consists of two simultaneous scenarios, one in which the atoms are in phase, leading to stronger emission (superradiance), and one in which they are opposite in phase, when emission does not occur (subradiance). When both atoms are initially excited, the decay always turns superradiant.

Schneble and his colleagues used a platform of ultracold atoms in a 1D optical lattice geometry to implement arrays of synthetic quantum emitters that decay by emitting slow atomic matter waves. In contrast, conventional processes emit photons traveling at the speed of light. This difference enabled them to access collective radiative phenomena in novel regimes.

By preparing and manipulating arrays of emitters hosting weak and strong interacting many-body phases of excitations, the researchers demonstrated directional collective emission and studied the interplay between retardation, super-, and subradiant dynamics.

"Dicke's ideas are of great significance in quantum information science and technology. For example, there are intense efforts to harness super- and subradiance in arrays of quantum emitters coupled to 1D waveguides," Schneble said.

"In our work, we are able to prepare and manipulate subradiant states with unprecedented control. We can shut off spontaneous emission and observe where the radiation hides in the array. To our knowledge, this is a first such demonstration."

Schneble explained that in Dicke's theory, the photons do not play an active role since they move quickly between nearby emitters on the time scale of the decay. However, certain situations or conditions can break this assumption, such as in a channel of a long-distance quantum network, where a guided photon escaping from a decaying emitter might need a long time to reach the neighboring one. This unexplored regime is exactly what the researchers accessed; the emitted matter waves in their system are billions of times slower than photons.

"We see how collective decay from a superradiant state containing a single excitation takes time to form," co-author Youngshin Kim said. "It only happens once neighboring emitters have been able to communicate."

The researchers pointed out that keeping track of slow radiation in a system of emitters is a daunting theoretical challenge, likening it to a game of catch and release. They explained that after being emitted, photons might find themselves being bound back to the atom permanently or bounce between temporary bindings before finally escaping. This becomes even more challenging when more atoms and photons are involved.

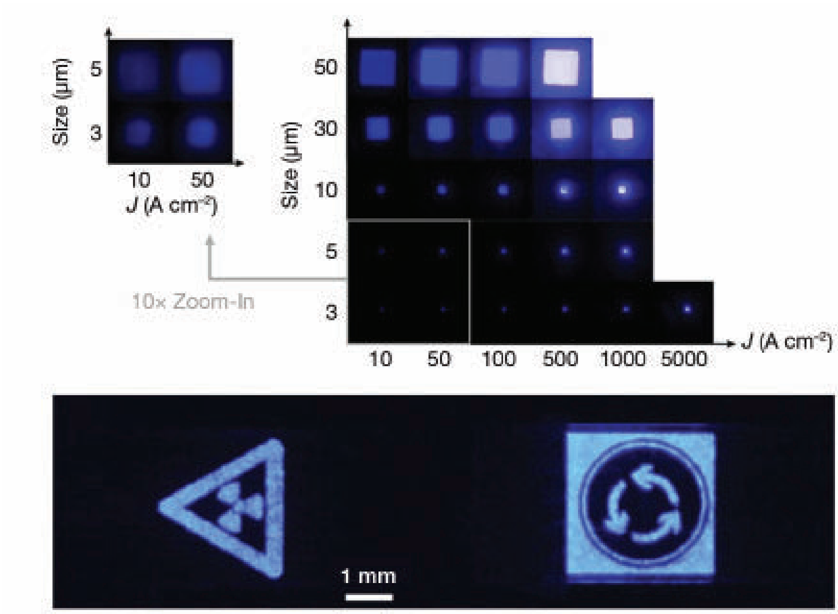
Despite this complicated photon and atom interplay, the researchers found mathematical solutions for the case of two emitters with up to two excitations and arbitrary vacuum coupling. This aspect of the work may lead to uncovering other complicated or unexpected collective atomic decay behaviors in future experiments.

"Overall, our results on collective radiative dynamics establish ultracold matter waves as a versatile tool for studying many-body quantum optics in spatially extended and ordered systems," Schneble said.

The research was published in *Nature Physics* (www.doi.org/10.1038/s41567-024-02676-w).

Hong Kong team develops deep-UV micro-LED display chips

HONG KONG — Research led by the Hong Kong University of Science and Technology (HKUST) yielded a deep-ultraviolet (DUV) micro-LED display array for lithography machines. The enhanced-efficiency DUV micro-LED — the world's first, according to the researchers — showcased the viability of a lower-cost maskless photolithography through the provision of adequate light output power density, enabling exposure of photoresist films in a shorter time. The research results address limitations that plague the traditional mercury lamps and DUV LED light sources that are used in lithography machines, related to large



Hong Kong University of Science and Technology (HKUST)

Research between the Hong Kong University of Science and Technology (HKUST), the Southern University of Science and Technology, and the Suzhou Institute of Nanotechnology of the Chinese Academy of Sciences produced a deep-ultraviolet (DUV) micro-LED display array for lithography machines. The work is a key step toward independent development of semiconductor equipment.

device size, low resolution, high energy consumption, low light efficiency, and insufficient optical power density.

The researchers built a maskless lithography prototype platform and used it to fabricate the micro-LED device by using DUV micro-LED with maskless exposure, improving optical extraction efficiency, heat distribution performance, and epitaxial stress relief during the production process. According to Hoi-Sing Kwok, founding director of the State Key Laboratory of Advanced Displays and Optoelectronics Technologies at HKUST, the manufactured device exhibits high power, high light efficiency, high-resolution pattern display, improved screen performance, and fast exposure ability. "This deep-UV micro-LED display chip integrates the ultraviolet light source with the pattern on the mask," Kwok said. "It provides [a] sufficient irradiation dose for photoresist exposure in a short time, creating a new path for semiconductor manufacturing."

In recent years, maskless lithography has seen a great deal of research interest due to its ability to adjust the exposure pattern, provide greater customization, and save on the cost of preparing lithography masks, Kwok said. As such, photoresist short-wavelength micro-LED technology is critical to the independent development of semiconductor equipment, he said.

Feng Feng, postdoctoral research fellow at HKUST's Department of Electronic and Computer Engineering, said, "Compared with other representative works, our innovation features smaller device size, lower driving voltage, higher external quantum efficiency, higher optical power density, larger array size, and higher display resolution. These key performance enhancements make the study a global leader in all metrics."

Looking forward, the team plans to continue enhancing the performance of aluminum gallium nitride DUV micro-LEDs, improve the prototype, and develop 2K to 8K high-resolution DUV micro-LED display screens.

The research was published in *Nature Photonics* (www.doi.org/10.1038/s41566-024-01551-7).

Laser-based artificial neuron surpasses its analog

HONG KONG — A laser-based artificial neuron that fully emulates the functions, dynamics, and information processing of a biological graded neuron could lead to breakthroughs in fields such as artificial intelligence and other types of advanced computing. With a signal processing speed of 10 GBaud — a billion times faster than its biological counterparts — the laser graded neuron overcomes speed limitations of contemporary photonic versions of spiking neurons and could operate even faster than they have demonstrated, according to its developers.

The body contains various types of nerve cells, including graded neurons that encode information through continuous changes in membrane potential, allowing subtle and precise signal processing. In contrast, biological spiking neurons transmit information using all-or-none action potentials, creating a more binary form of communication.

Leveraging its neuron-like nonlinear dynamics and fast processing, the researchers from the Chinese University of Hong Kong built a reservoir computing system that demonstrated exceptional performance in AI tasks such as pattern recognition and sequence prediction, team leader Chaoran Huang said. In their paper, the researchers reported that their chip-based quantum-dot laser graded neuron can achieve a signal processing speed of 10 GBaud, which they demonstrated in 1-s demos by processing data from 100 million heartbeats and 34.7 million handwritten digital images.

Laser-based artificial neurons, which can respond to input signals in a way that mimics the behavior of biological neurons, are being explored as a way to significantly enhance computing due to their ultrafast data processing speeds and low energy consumption. However, most of the artificial neurons developed so far have been photonic spiking neurons. These have a limited response speed, can suffer from information loss, and require additional laser sources and modulators.

The speed limitation of photonic spiking neurons comes from how they typically work: injecting input pulses into the gain section of the laser. This causes a delay that limits how fast the neuron can respond.

For the laser graded neuron, the researchers used a different approach, injecting radio frequency signals into the quantum dot laser's saturable absorption section to avoid this delay. They also designed high-speed radio frequency pads for the saturable absorption section to produce a faster, simpler, and more energy-efficient system.

"With powerful memory effects and excellent information processing capabilities, a single laser graded neuron can behave like a small neural network," Huang said. "Therefore, even a single laser graded neuron without additional complex connections can perform machine learning tasks with high performance."

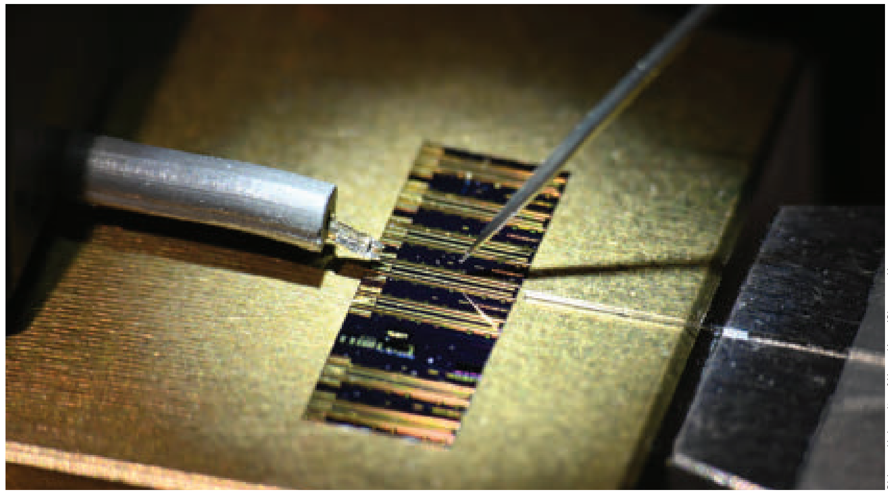
To further demonstrate the capabilities of their laser graded neuron, the researchers used it to make a reservoir computing system. This computational method uses a particular type of network, known as a reservoir, to process time-dependent data such as those used for speech recognition and weather prediction. The neuron-like nonlinear dynamics and fast processing speed of the laser graded neuron make it ideal for supporting high-speed reservoir computing.

The resulting reservoir computing system exhibited excellent pattern recognition and sequence prediction in tests, particularly long-term prediction, across various AI applications with high processing speed.

For example, it processed 100 million heartbeats per second and detected arrhythmic patterns with an average accuracy of 98.4%.

"In this work, we used a single laser graded neuron, but we believe that cascading multiple laser graded neurons will further unlock their potential, just as the brain has billions of neurons working together in networks," Huang said.

"We are working to improve the processing speed of our laser graded neuron while also developing a deep reservoir computing architecture that incorporates cascaded laser graded neurons."



Chinese University of Hong Kong/Chaoran Huang

Researchers developed a chip-based quantum dot laser that emulates a biological graded neuron while achieving a signal processing speed of 10 GBaud.

The technology, Huang said, could boost AI decision-making speeds in time-critical applications without sacrificing accuracy. She and her team anticipate its integration into edge computing devices, where it would facilitate faster and smarter AI systems that better serve real-world applications with reduced energy consumption.

The research was published in *Optica* (www.doi.org/10.1364/OPTICA.537231).

Researchers produce elliptically polarized incandescent light

ANN ARBOR, Mich. — Researchers at the University of Michigan showed that bright, twisted light can be produced with technology similar to an Edison light bulb. The finding adds nuance to fundamental physics while offering an avenue for robotic vision systems and other applications for light that traces out a helix in space.

"It's hard to generate enough brightness when producing twisted light with traditional ways like electron or photon luminescence," said Jun Lu, an adjunct research investigator in chemical engineering and first author of the study. "We gradually noticed that we actually have a very old way to generate these photons — not relying on photon and electron excitations, but like the bulb Edison developed."

Typically, the shape of an object emitting radiation does not get much consideration; for most purposes, the object can be imagined as a sphere. But while shape does not affect the spectrum of wavelengths of the different photons, it can affect a different property: their polarization.

Photons from a blackbody source are randomly polarized in most cases, meaning that their waves may oscillate along any axis. The study showed that if the emitter was twisted at the micro- or nanoscale, with the length of each twist similar to the wavelength of the emitted light, the blackbody radiation would also be twisted. The strength of the twisting in the light, or its elliptical polarization, depended on two main factors: how close the wavelength of the photon was to the length of each twist, and the electronic properties of the material — nanocarbon or metal, in this case.

Twisted, or chiral, light is named after the clockwise and counterclockwise rotations that are mirror images of one another. The researchers undertook the study to demonstrate the premise of a more applied project that the team would like to pursue: using chiral blackbody radiation to identify objects. They envision robots and self-driving cars that can "see" by differentiating among light waves with different directions of twirl and degrees of twistedness.

University of Michigan/Brenda Ahearn

University of Michigan/Brenda Ahearn

Researcher Jun Lu **(above)** is part of a team of researchers from the University of Michigan that demonstrated that a twisted filament could produce twirling light waves. The bulb's Edison-style filament is twisted at the microscale **(right)**. When the length of each twist matches the wavelength of the light emitted by the filament, the light waves twirl as they move through space.

While brightness is the main advantage of this method for producing twisted light — up to 100× brighter than other approaches — the light includes a broad spectrum of both wavelengths and twists. The team has ideas about how to address this, including exploring the possibility of building a laser that relies on twisted light-emitting structures. For example, Nicholas Kotov, the Irving Langmuir Distinguished Professor of Chemical Sciences and Engineering, director of NSF Center of Complex Particles and Particle Systems, and corresponding author on the study, also wants to explore further into the IR spectrum. The peak wavelength of blackbody radiation at room temperature is ~10,000 nm.

"This is an area of the spectrum with a lot of noise, but it may be possible to enhance contrast through their elliptical polarization," Kotov said.

The research was published in *Science* (www.doi.org/10.1126/science.adq4068).

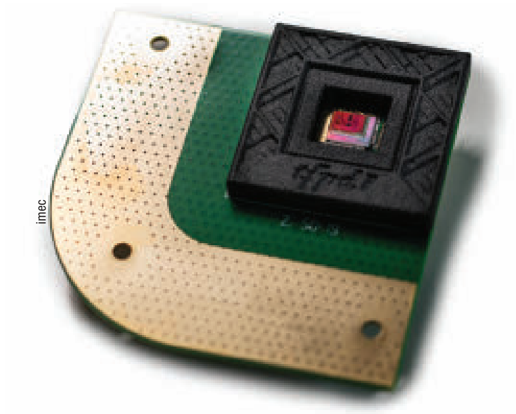
SWIR sensor showcases a second-generation quantum dot platform

LEUVEN, Belgium — As part of the research project Q-COMIRSE, researchers presented a prototype SWIR image sensor with indium arsenide quantum dot (QD) photodiodes. The sensor demonstrated 1390-nm imaging results, offering an environmentally friendly alternative to first-generation QDs that contain lead, which has limited their widespread manufacturing, according to the developers.

Because SWIR sensors can distinguish between objects that appear to be identical to the human eye and penetrate through fog or mist, for example, they are useful in applications such as facial recognition and eye tracking in consumer electronics as well as in autonomous vehicle navigation. Current versions are costly and limited to high-end applications, though wafer-level integration promises broader accessibility.

QDs can be engineered to emit and absorb light at specific wavelengths. Tuned for SWIR, they offer compact, low-cost absorbers, since integration into CMOS circuits and existing manufacturing processes is possible.

However, first-generation QDs often contain toxic heavy metals. “The first generation of QD sensors was crucial for showcasing the possibilities of this flexible platform,” said Pawel Malinowski, imec technology manager and domain lead imaging. “We are now working [toward] a second generation that will serve as a crucial enabler for the masses — aiming at cost-efficient manufacturing that can be performed in an environmentally friendly way.



Researchers developed a proof-of-concept lead-free quantum dot (QD) photodiode integrated onto a SWIR optical sensor through the Q-COMIRSE project.

“With major industry players looking into [QDs], we are committed to further [refining] this semiconductor technology [toward] accessible, compact, multifunctional image sensors with new functionalities,” Malinowski said.

Researchers from imec and partners within the Q-COMIRSE project — Ghent University, QustomDot BV, Chemstream BV, and ams OSRAM — tested their proof-of-concept sensor on both glass and silicon substrates.

While QDs are considered fragile in nature, careful selection of stack materials resulted in >300-h air stability, enabling fab manufacturing compatibility. The pixel architecture can be readily integrated with CMOS technology for image sensing applications and also allows flat panel display integration.

According to Stefano Guerrieri, Engineering Fellow at ams OSRAM, the work paves the way toward a low-cost, lead-free SWIR technology that, once mature enough for industrial products, could enable unprecedented applications in robotics and automotive, as well as AR/VR, consumer electronics, and other application areas.

UV etching controls diamond surfaces

SYDNEY— Researchers at Macquarie University developed an etching technique for modifying the surface chemistry of diamond. The highly precise technique can be used to remove as little as 1% of a single atomic layer from the material. Precision etching of the diamond surface is achieved by dosing the surface with pulsed deep-ultraviolet (DUV) light at fluences below the ablation threshold.

The work aims to further improve the qualities of viable material for applications in the semiconductor industry and quantum applications. Properties such as high thermal conductivity and resistance to electrical breakdown make diamond a valuable material for high-power, high-frequency electronic devices. Moreover, diamond surfaces help stabilize quantum states. The ability to engineer diamond surfaces with atomic-scale precision could improve applications in electronics, quantum devices, and in advanced manufacturing, where even minor adjustments to the configuration of surface atoms can significantly enhance device performance.

The researchers demonstrated that precisely delivered DUV pulses can trigger a localized chemical reaction on a diamond surface. The reaction, driven by a two-photon process, removed carbon atoms selectively from the top atomic layer. Using x-ray surface analysis, Hall measurements, and resistance measurements, the researchers tracked the evolution of the surface chemistry and electrical properties of the diamond.

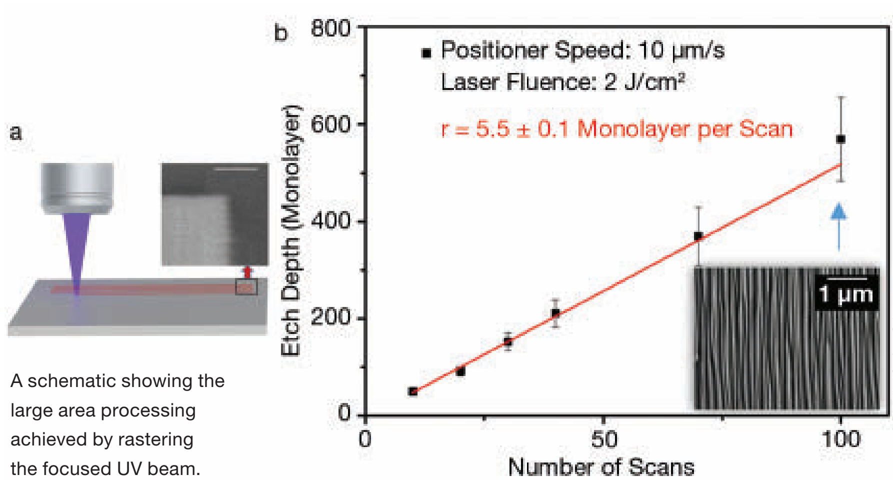
In measuring alterations in the surface populations after laser treatment, the researchers found that laser treatments in the form of sub-monolayer etch doses lowered the valence band by up to 0.2 eV. They also observed that diamond surface conductivity increased up to 7× after laser treatment — an enhancement that was independently confirmed by the team's collaborators at MIT Lincoln Laboratory. Similar enhancements in conductivity were obtained for doses that removed up to 1600 monolayers.

"We were amazed that such a minor adjustment to the surface could yield such a substantial boost in conductivity," said professor Richard Mildren, who led the research.

The changes in surface chemistry and electrical properties were substantial even when only a small percentage of the top lattice layer was removed. The surface properties of the material evolved rapidly, even for UV doses that removed <5% of the top carbon monolayer and fluences <1 J/cm^2.

The laser etching method for diamond surfaces provides atomic-level control over the surfaces in a standard air environment. "This level of precision is typically only possible with large, complex vacuum equipment," researcher Mojtaba Moshkani said.

The research was published in *Applied Surface Science* (www.doi.org/10.1016/j.apsusc.2024.161816).



A schematic showing the large area processing achieved by rastering the focused UV beam.

Dual laser system offers a view into laser-plasma interaction

BERKELEY, Calif. — Scientists at Lawrence Berkeley National Laboratory (Berkeley Lab) used the combination of lasers and a supersonic sheet of gas to accelerate a high-quality beam of electrons to 10 billion eV in only 30 cm. The energy and quality of the beam is a significant improvement compared with previous efforts, and the acceleration of a high-quality, 10-GeV electron beam in <1 ft, using a petawatt laser, is a major step forward in laser-plasma acceleration, the scientists said.

Laser-plasma accelerators could eventually reduce the size and cost of the particle accelerators used in high-energy physics, medicine, and materials science. Additionally, the technology could be used to produce particle beams for cancer treatments or serve as a power source for free-electron lasers that could be used to create advanced materials or provide insight into chemical and biological processes.

The team used a dual laser system to create the beam. The first laser served as a drill, heating the plasma and forming a channel to guide the driver laser, which accelerated the electrons. The plasma channel directed the laser energy much like a fiber optic cable guides light, keeping the laser pulse focused over long distances.

The researchers used a series of gas jets to shape the plasma. The jets created a sheet of gas traveling at supersonic speed, and the lasers passed through the sheet to form the plasma channel. This setup allowed the researchers to fine-tune the plasma and modify its shape.

Because of its resilience, the gas sheet can be scaled to high repetition rates — a potentially useful option for future applications, including particle colliders.

The researchers measured the high-intensity laser propagation throughout the channel-guided laser plasma accelerator by adjusting the length of the plasma channel on a shot-by-shot basis. They observed how the petawatt laser interacted with a long plasma channel frame by frame.

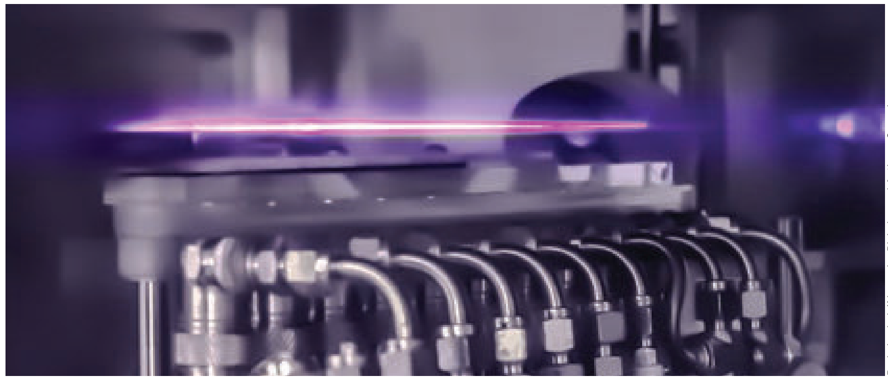
"Before, the plasma was essentially a black box. You knew what you put in and what came out at the end," researcher Carlo Benedetti said. "This is the first time we can capture what's happening inside the accelerator at each point, showing how the laser and plasma wave evolve, at high power, frame by frame."

The researchers created an efficient beam from an accelerating structure that was dark current-free — that is, no background electrons in the plasma diverted power from the laser. "If you have dark currents, they're sucking up the laser energy instead of accelerating your electron beam," researcher Jeroen van Tilborg said. "We've gotten to a point where we can control our accelerator and suppress unwanted effects, so we are making a high-quality beam without wasting energy. That's essential as we think about the ideal laser accelerator of the future."

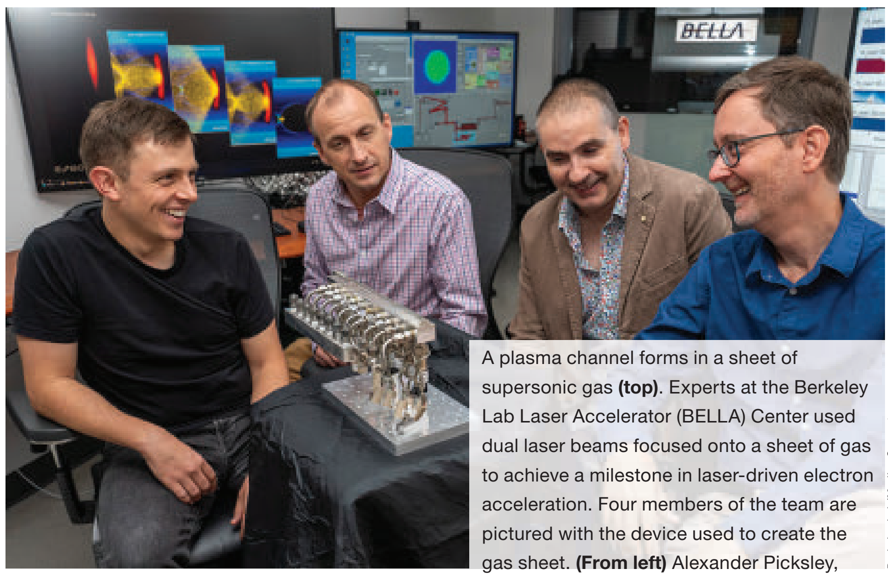
The team observed transverse energy transport of higher-order modes in approximately the first 12 cm of the plasma channel, followed by quasi-matched propagation, and the gradual, dark current-free depletion of laser energy to the wakefield. The researchers quantified the laser-to-wake transfer efficiency limitations of the currently available petawatt-class laser systems and demonstrated via simulation how control over the laser mode could improve accelerated beam parameters.

"We've jumped from 8 GeV to 10 GeV, but we've also significantly improved the quality and energy efficiency by changing the technology we use," researcher Alexander Picksley said. "This is a milestone step on the path to a future plasma-based collider."

According to researcher Anthony Gonsalves, "We've taken a big step toward



Berkeley Lab/Alexander Picksley and Anthony Gonsalves



Berkeley Lab/Marilyn Sargent

A plasma channel forms in a sheet of supersonic gas **(top)**. Experts at the Berkeley Lab Laser Accelerator (BELLA) Center used dual laser beams focused onto a sheet of gas to achieve a milestone in laser-driven electron acceleration. Four members of the team are pictured with the device used to create the gas sheet. **(From left)** Alexander Picksley, Jeroen van Tilborg, Carlo Benedetti, and Anthony Gonsalves.

enabling applications of these compact accelerators. For me, the beauty of this result is we've taken away restrictions on the plasma shape that limited efficiency and beam quality. We have built a platform from which we can make big improvements and are poised to realize the amazing potential of laser-plasma accelerators."

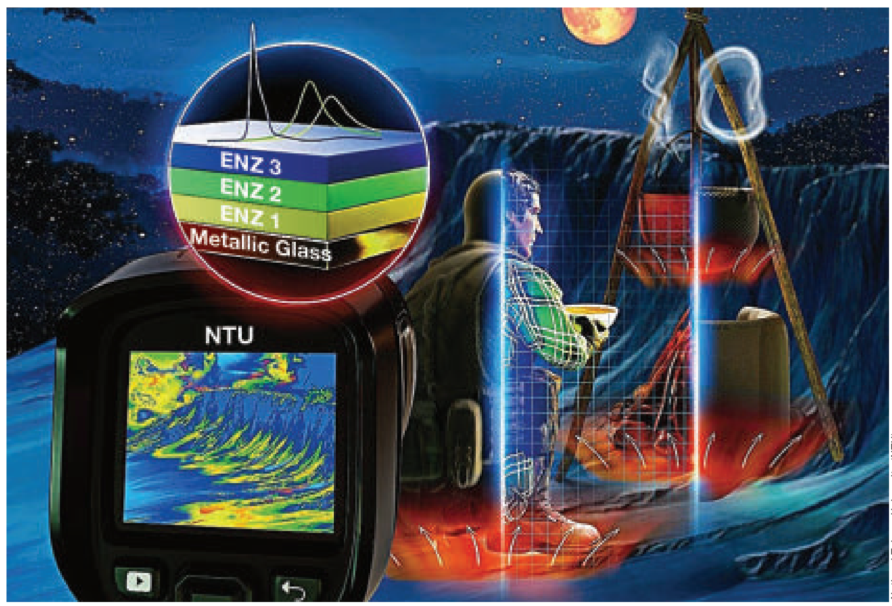
Laser-plasma accelerators could be used to produce beams of muons to image difficult-to-explore areas such as pyramids, volcanoes, mineral deposits, and the interior of nuclear reactors. In the future, the technology could power high-energy particle colliders to search for new particles and gain insight into the forces of the universe.

"Advancing laser-plasma accelerator technology has been identified as an important goal by both the U.S. Particle Physics Project Prioritization Panel and the Department of Energy's Advanced Accelerator Development Strategy," researcher Cameron Geddes said.

"This result is a milestone on our way to staged accelerators that are going to change the way we do our science."

The research is scheduled to be published in *Physical Review Letters*. A preprint is available at the online repository arXiv (www.arxiv.org/pdf/2408.00740).

Metal glass in thin-film structure improves IR thermal system



Epsilon-near-zero (ENZ) thin films stack on a metal-based bottom layer within a dual-functional system for thermal IR camouflage and thermal management within the atmospheric window.

TAIPEI CITY, Taiwan — An advanced design for IR thermal technology, developed by researchers at National Taiwan University (NTU), takes advantage of the tunable optical properties of metallic glass to combine IR camouflage and IR thermal management functions in a single system. The system provides dual functionality for IR camouflage and IR thermal management within the same wavelength region of the atmospheric window.

A conventional, low-emissivity design approach to thermal camouflage is only useful for concealing targets at temperatures >350 °C. It is not effective for applications that aim to reduce the ability to detect targets in the near-room to medium-high temperature range, below 350 °C.

Also, given the typically high thermal emissivity of environments on a day-to-day basis, the thermal emissivity of a target's background environment should be a consideration in the design of an IR thermal camouflage and management system.

To achieve versatile thermal camouflage while maintaining effective thermal management, the researchers combined metallic glass with the Berreman mode of epsilon-near-zero (ENZ) thin films (SiO_2, Al_2O_3, and TiO_2), and they stacked the ENZ thin films on a metal-based bottom layer. The adjustable emissivity of the metallic glass enabled the system to accommodate diverse IR thermal camouflage scenarios.

In the LWIR regions of 8 to 14 μm, the researchers found that the small viewing angle of the thermal management system exhibited the optical properties of metallic glass. When the viewing angle increased above 45°, the system demonstrated high thermal emissivity in transverse-magnetic polarization. The system could therefore provide an effective thermal management function without compromising the performance of the thermal camouflage function. Increases to the viewing angle were driven by the multiple Berreman modes of the ENZ thin films.

Also, the team found that the cooling power of ENZ thin films on metallic glass surpassed that of the conventional, low-emissivity design strategy for thermal camouflage by a factor of 1.79. Moreover, the thermal images from the NTU system indicated over 97% similarity in thermal radiation between the target and background environments.

This innovative, multilayer thin-film design approach for thermal management could contribute to the development of new approaches to reducing the detectability of a target using thermal imaging devices.

The research was published in *Materials Horizons* (www.doi.org/10.1039/D4MH00711E).

3D-printed device generates vortex beams, targets wireless systems

XI'AN, China — Researchers from Xi'an Jiaotong University developed a 3D-printed device that generates twisting light beams with orbital angular momentum (OAM), a form of rotational energy that can carry more data than regular beams. The efficient, compact, and low-cost vortex beam generators could help enhance the capacity and reliability of future wireless systems.

"The growing demand for high-capacity, interference-resistant communication systems in applications like 5G/6G wireless networks requires innovative solutions," said research team leader Jianxing Li. "Although vortex beams carrying OAM can potentially enhance spectral efficiency and communication capacity, current methods to generate these beams are hindered by low efficiency, high fabrication costs, and vulnerability to interference from unwanted frequency bands."

The researchers' device generates high-capacity vortex beams and features an integrated gain-filtering feature that amplifies desired signals while blocking interference to ensure clear, efficient transmission.

"Our OAM beam generator is particularly well suited for 5G/6G wireless communication as well as remote sensing and imaging," said Yuanxi Cao, corresponding author of the paper. "For example, integrating this device into communication towers could improve streaming and online connectivity at large gatherings like music festivals or sports events, where high user density often overwhelms existing networks, causing slow speeds and dropped connections."

The beam generator uses an integrated gain-filtering power divider to split the signal evenly while also filtering out unwanted frequencies at the source. This minimizes interference and reduces the need for additional external components.

The researchers also used an air-filled, all-metal structure to avoid dielectric losses, ensuring higher radiation efficiency and greater power-handling capacity.

The device works by first dividing an incoming signal into eight equal parts using the built-in power divider, which filters out unnecessary frequencies along the way. Each signal then passes through a special pathway that adjusts the phase to accomplish the precise alignment necessary to create the vortex beam. Finally, the signals are transmitted through a circular array of antennas to produce a vortex beam with the desired properties.

After performing advanced simulations to fine-tune the filtering power divider for precise in-band signal transmission and effective out-of-band suppression, the researchers used selective laser melting to 3D print a prototype device using an aluminum alloy known for its high precision and low surface roughness.

According to Cao, fabricating the device as a monolithic structure via selective laser printing technology served to bypass the need for assembly. This reduces manufacturing costs and ensures precise alignment of components, all of which are critical for high-frequency applications in the developed scheme, Cao said.

Experimental testing confirmed that the prototype device achieved the desired beam characteristics with a mode purity of ~80%. It also exhibited high out-of-band suppression of >30 dB. This quality significantly reduces interference and also ensures clean transmission of the signal.

The researchers are working to enhance the OAM beam generator's performance by improving gain, efficiency, and signal filtering. They also plan to expand the potential applications by exploring multimode OAM generation and testing it across broader frequency ranges, such as terahertz communications. The researchers said that commercializing the device will require refining 3D printing for scalability, integrating it with existing systems, ensuring compliance with regulations, and validating performance in real-world applications, such as 5G and satellite communications.

The research was published in *Optics Express* (www.doi.org/10.1364/OE.542046).

A Photonic Solution Facilitates Scale-Up Networks in AI Data Centers

A full-stack optical networking platform will meet the forthcoming demands of AI model data flows, at once overcoming bandwidth, power, latency, and switching bottlenecks.

Image this page courtesy of iStock.com/Henrik5000.
All other images courtesy of Celestial AI.

BY SUBAL SAHNI
CELESTIAL AI

At a time when AI processors (XPUs) are firmly in the limelight, interconnects are the true unsung heroes of AI infrastructure. This is true not only in the present, but also with an eye toward the future. With trillion-parameter generative AI models now a reality, focus has shifted from the system on chip (SoC) to the system of chips.

This shift marks a profound change in the networking technology landscape. No longer is the principal bottleneck only the compute capability of XPUs. Now, it is also the bandwidth, latency, power, and reach of the interconnects that string these processors together so that they act in unison.

Copper's reach as a physical medium for interconnects at current bandwidths is limited to a few meters, even with the use of active electric cables with sophisticated retiming. Conventional optical transceiver modules are power constrained (~15+ pJ/bit) and do not offer the required bandwidth densities. Co-packaged optics solutions alleviate these problems, though only to an extent, and hence represent an incremental step toward the scale of performance and efficiency needed for forthcoming AI networks.

An optical networking platform to address these shortcomings must therefore meet the distinct challenges of the present as well as these upcoming advancements in AI networking. Given the multifaceted nature of this need, a full-stack solution that combines platform building blocks — sophisticated silicon photonics, complex application-specific integrated circuits (ASICs), and advanced 2.5D/3D packaging — presents a viable solution.

Data center networks in an AI context

Traditional data centers targeting general-purpose computing in enterprise, software as a service, and mobile applications have a networking architecture that is designed for supporting thousands of applications for millions of users. AI, which represents an entirely different kind of application, has transformed networking design requirements due to its massive data flows, which are characterized by wide point-to-point links, high-bandwidth needs, and strict latency requirements as well as a focus on optimizing cost and power efficiency.

An AI data center essentially features four distinct types of networks (Figure 1). The front-end network is the traditional data center network. It is used to connect compute servers to the outside world: All data that comes from cloud-based software and/or mobile applications travels back and forth using this front-end network.

The out-of-band network is used to connect servers to the data center manager and to perform firmware updates, collect telemetry, and perform certain other diagnostic functions. Though the out-of-band network is a low-performance network, its function is crucial to an optimally performing AI data center.

From an AI perspective, though, the scale-up and scale-out networks are the most important, with scale-up being the newest and arguably the most critical network given increasing model sizes. By definition, "scale-up" means increasing the capability of a system by increasing the performance of its individual components. "Scale-out" refers to adding more components to a system to increase its capability. Together, the scale-up and scale-out networks compose what is commonly called a back-end network in AI data centers (Figure 2).

Scale-up and scale-out

Today's AI models no longer fit into the memory of a single XPU for processing. Models have exceeded 1 trillion parameters in terms of size, which means that one may need several terabytes of memory simply to store the model. XPUs only have limited co-packaged memory (in the range of a few hundred gigabytes), and so these models must be sharded and/or linked across multiple XPUs. Additionally, these massive models generate intermediate data and artifacts during both training and inferencing that can be hundreds of gigabytes in size, which also must be shared and moved around.

For AI training, the models are partitioned to fit into the memory of each XPU. This is carried out using tensor parallelism, whereby individual layers of a neural network are split across processors; or pipeline parallelism, whereby a model is split by layers for distribution; or a combination of the two techniques. In these partitioned models, the gradients calculated during the back-propagation phase must be synchronized to calculate updates and apply new weights. Therefore, the communication infrastructure

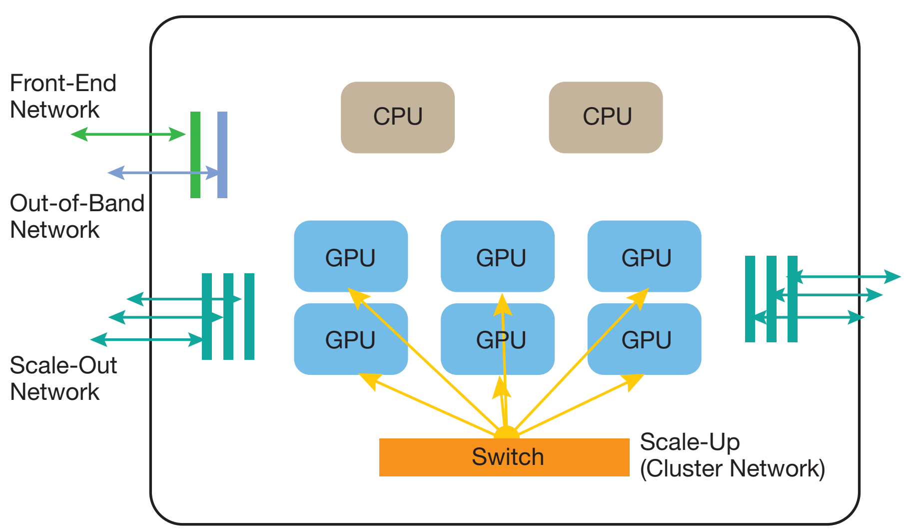


Figure 1. A conventional AI server with multiple networks comprising central processing units (CPUs) as well as graphics processing units (GPUs).

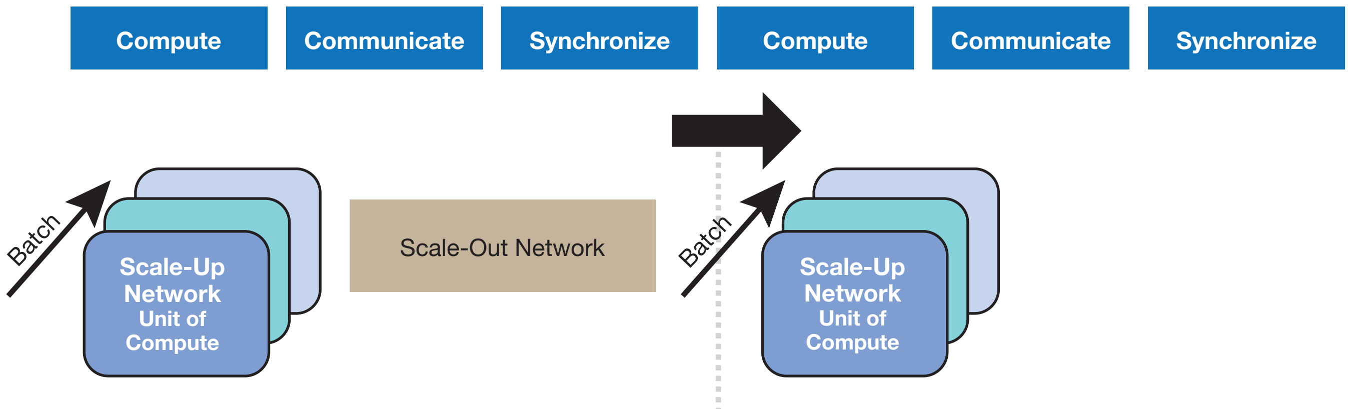


Figure 2. AI training leveraging scale-up and scale-out networks **(above)**.

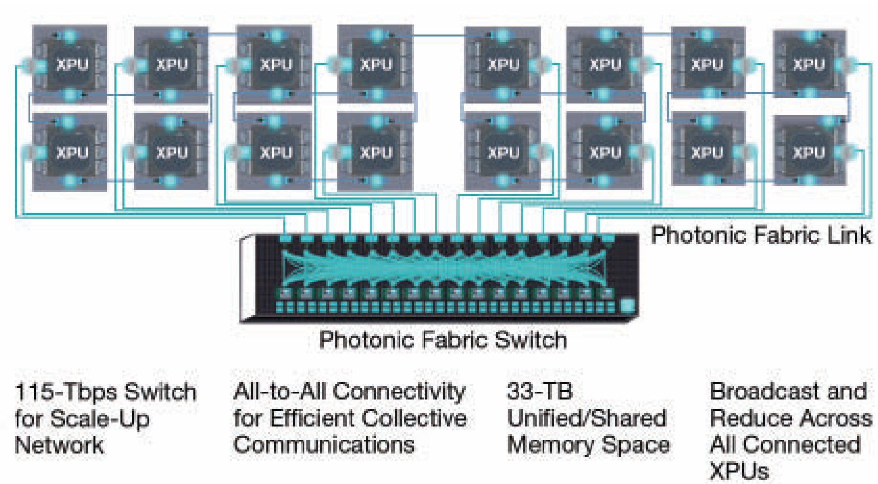


Figure 3. The Photonic Fabric platform enables cluster-scale AI processing, using high-bandwidth XPU-XPU links and electronic switches. XPU: X processor/processing unit.

must perform at a very high level to ensure that the XPUs always achieve high model flop usage.

Inferencing describes when a trained model is used in an application — for example, a large language model responding to prompts. Inferencing is typically an auto-regressive function; the current output depends on the current input plus the previous output. The previous outputs, to avoid redundant computation, are stored in a buffer memory called key value (KV) cache. Depending on the batch size and context length, the size of the KV cache can easily be hundreds of gigabytes or even terabytes, which again necessitates the interconnection of tens to hundreds of XPUs.

It is also worth mentioning in this context that with emerging chain-of-thought models, the volume of required unified compute and memory increases significantly. This further drives the need for a high-performance interconnect between tens to hundreds of XPUs.

The network that connects these hundreds of XPUs for both training and inference must be as high bandwidth and low latency as possible. The scale-up network provides this functionality. The scale-out network is used primarily for data parallel training, where multiple copies of the model are instantiated and different inputs are applied to each individual copy.

In practice, a scale-up network with as large a domain or cluster size as possible is desired since it enables all XPUs in the domain to act as a single "virtual super XPU," sharing compute and memory. Today's domain sizes are in the tens of XPUs. In the near future, meanwhile, this size will scale by a full order of magnitude.

Latency's full effect on a given system is unlikely to be as obvious as that of bandwidth or power. But low latency is critical in all facets of AI model execution. In training, lower latency allows larger domain sizes, which enables continued scaling in the size of the models (number of parameters). And during inferencing, lower latency enables the scaling of the KV cache size, which implies longer context lengths or larger batch sizes, which in turn translates to enabling new use cases such as generative video, document summarization, inference-time compute, retrieval augmented generation, and a greater number of simultaneous users supported.

Scale-up and scale-out: A deep dive

Fundamentally, a functioning scale-up network enables all of its connected XPUs (domain) to act in unison as one single, super XPU. To do so, it must achieve a range of deliverables and exhibit certain crucial characteristics.

First, the scale-up network must provide high package bandwidth, on the order of >10 Tbps, and low latency (approximately hundreds of nanoseconds) at low power consumption (<5 pJ/b). To support forthcoming demands, these bandwidth values should soon be scalable to several tens of terabits per second. The scale-up network must also pair with a compatible high bandwidth, low latency, medium radix switch to facilitate connections across processors.

Given the low-latency application context, the scale-up network must additionally support flit-based flow-control and routing, thereby enabling reduced latency. By contrast, Ethernet protocols — which use packet switching — are not a suitable component for low-latency applications. A scale-up network also must be scalable to hundreds of XPUs physically located across several racks, implying a reach of tens of meters.

Because a scale-out network will need to support hundreds of thousands to possibly a million XPUs in the future, it also must meet basic, though precise, requirements. The scale-out network must first be scalable to hundreds of thousands to a million XPUs, implying a reach of hundreds of meters. It must also pair with a high-radix switch supporting multi-tier networking to scale to the large number of endpoints. Finally, the scale-out network uses cost-efficient standards, such as Ethernet (RoCE) or InfiniBand, which implies that the bandwidth per port is typically 400/800 Gbps in the short term with an intermediate road map to 1.6 Tbps.

A platform solution

Given the volume (and the distinct nature) of these requirements, a single platform to directly address the gaps in current and upcoming scale-up requirements is an essential next step — even at this point. At a fundamental level, such an optimized platform should provide an extremely high-performing optical network to an XPU package, supporting inter- and intra-chip connectivity along with full-stack support for standard electrical protocols used in chip input/output.

Realizing such a platform architecture starts with consideration for the required silicon photonics components. Transmitters, which typically dictate the core features of any silicon photonics platform, use electro-absorption modulators (EAMs) that are much more compact than widely used Mach-Zehnder interferometer (MZI)-based solutions. This dramatically increases input/output density and reduces transmitter power dissipation. Additionally, EAMs have much higher thermal stability than ring-resonator-based implementations that may be used in an optical interconnect platform.

For Celestial AI, this quality of thermal stability enables the direct integration of its Photonic Fabric platform's nodes with a high-power XPU, even with the extremely dynamic thermal environment that this presents. This combination of density and temperature resilience is imperative for fulfilling upcoming scale-up bandwidth demands.

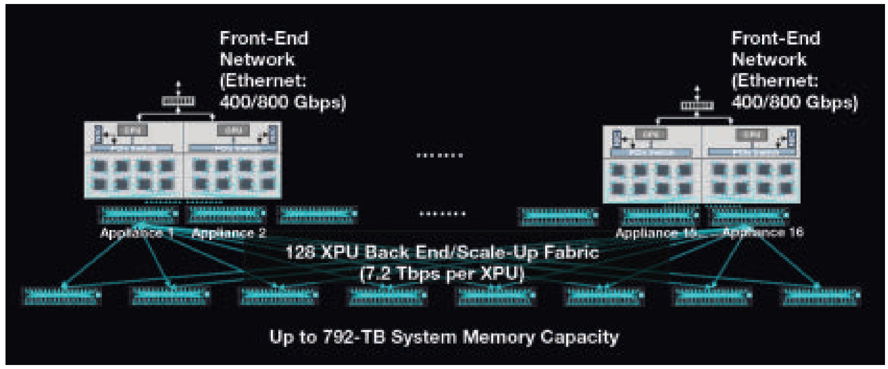


Figure 4. 128 XPU (X processor/processing unit) cluster-scale photonic fabric for accelerated computing. CPU: central processing unit; NIC: network interface card; PCIe: peripheral component interconnect express.

An additional benefit stems from the implementation of the optics in a stand-alone PIC. This decouples the PIC process node from the one that is used to build the ASICs that drive the photonics and interface with the processors in the network. In Celestial AI's platform, these ASICs can additionally use state-of-the-art CMOS nodes to obtain the highest possible performance and efficiency, which also allows for straightforward integration of those blocks into customer XPUs when needed. This freedom to choose a process node also enables additional downstream advantages. These include the opportunity to achieve protocol adaptation and the flit-based flow-control referenced earlier.

Packaging technology also plays a critical role in elevating the performance of a solution. Celestial, for example, uses high-volume 2.5D/3D packaging to integrate the ASIC and the PIC, and if needed, an external XPU. But such direct packaging with an XPU is a vital feature no matter the solution properties, because it may ultimately improve die area and power consumption levels. Celestial's approach first aims to eliminate the need for advanced digital signal processing to improve the fidelity of the links to achieve these lowered consumption values.

This packaging approach can additionally eliminate the latency involved in using network interface controllers (NICs) and the need to transfer data from the XPU to the NIC over serial communication standards (such as PCIe). Combining these ingredients can also yield low-latency, medium-radix, high-bandwidth electronic switches for the scale-up networks needed to handle forthcoming data demands.

Current requirements and future gains

Current copper-based scale-up networks are incapable of meeting the upcoming demands on bandwidth, power, and latency. Innovative photonic links with optimized switching architectures can greatly augment network performance, thereby charting a course to the anticipated next wave of AI model innovation (Figures 3 and 4). Though these solutions are still under development, substantial progress in component and system-level design, packaging, and overall usability indicates that innovation is spread across all reaches of the value chain.

Meet the author

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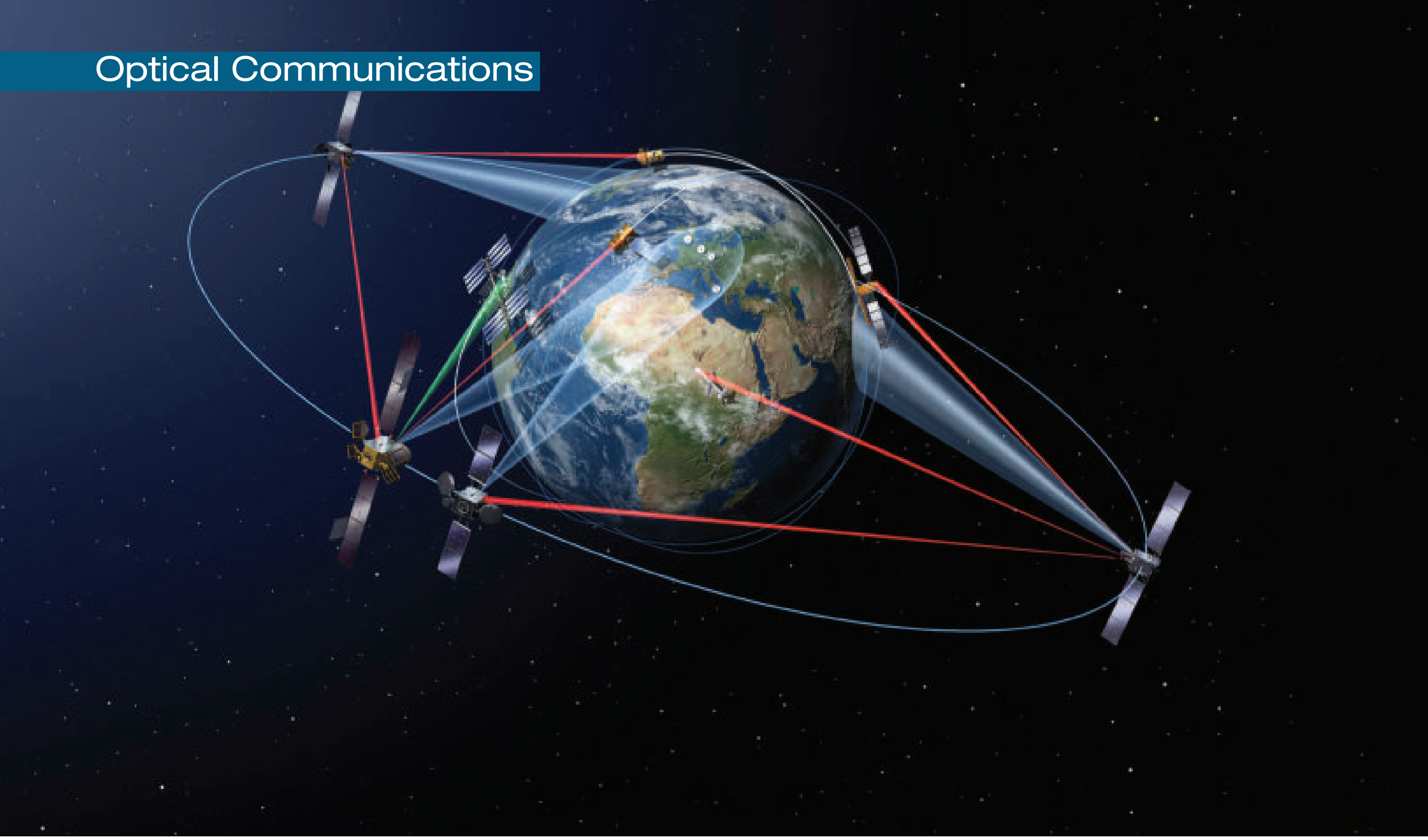


Laser Communication Terminals Spark a Silent Revolution

Laser communication terminals deliver ultrafast, secure data transmission. With the capability to transform satellite constellations, science missions, and defense operations, this technology has matured and is taking off.

Image this page, courtesy of ESA/P. Carril.

BY ANDREAS THOSS
CONTRIBUTING EDITOR, AND
MICHAEL ULLRICH, MO-SPACE

In September 2024, the *New York Times* published a report on a spectacular flight by a SpaceX capsule carrying two private astronauts. The crew performed the first-ever commercial spacewalk, among a few other headline-grabbing feats.

Notably, the last sentence of the article read: “They have also tested laser communications between the Crew Dragon and SpaceX’s constellation of Starlink internet satellites”[1].

So far, most satellites in operation send and receive information via radio waves or microwaves. They use radio frequencies between 3 and 31 GHz (superhigh frequency) from the S-band to the Ka-band. Starlink, the company that runs the largest satellite configuration in existence, was granted permission to use V-band frequencies between 40 and 50 GHz.

The higher the frequency, or the shorter the wavelength, the more data that can be carried on a signal. In this respect, the move to laser communications is a game changer. Telecom wavelengths of ~1.5 µm have frequencies of ~10,000× higher than Ka-band radio waves. Lasers and electronics for telecom wavelengths are available in large numbers and have a high level of technological readiness.

Although it took several decades to bring laser communication terminals (LCTs) to maturity, the technology has arrived. It has not been without major technical challenges, such as the issue of pointing accuracy from one satellite to another — it is not easy to hit a receiver terminal on a satellite flying at a speed of 30,000 km/h with a narrow laser spot. But this problem has been solved, and today the small diameter of the laser spot has in fact turned from a challenge into a selling point, because it is much harder to eavesdrop on such a beam than to scoop radio waves.

Even though additional obstacles pose more recent problems, such as the micro vibration generated by reaction wheels and solar panel movements, NASA summarized the major benefits of LCTs in one sentence: “[It] weighs less, uses less power, and occupies less space than a comparable [radio frequency] system”[2].

How laser terminals work

The development of LCTs began in the 1970s. Significant advancements in several technologies, including lasers, were required to make LCTs the off-the-shelf products that they are today. The laser source is one of the main components of an LCT. The others include a beam pointing and tracking system; a telescope to send and receive optical signals; and a detector to convert the optical signals into electronic information.

The onboard laser source generates high-power laser beams, often operating in the NIR spectrum at 1064 nm or 1550 nm. The beam pointing and tracking system ensures that these beams are precisely directed at receivers, even across tens of thousands of kilometers. Coarse pointing is often performed by gimbals to steer the beam in the general direction of the receiver. The precision here is better than 1°. Fine steering optics compensate for vibrations, jitter, and relative motion, achieving microradian alignment accuracy. Most often, piezos are applied to realize fast steering with a microrad precision. Beacon beams may be used to support the pointing and tracking system.

The telescope is the largest component of an LCT, and its size determines both the overall shape of the system and its range. Even a laser beam diverges over a long distance, meaning that the telescope for geostationary satellite links must be larger than that for an intersatellite link in low Earth orbit (LEO) only, which is on the order of several hundred kilometers. Accordingly, major LCT suppliers have developed a range of systems of different sizes, for different purposes (see the table on page 40).

On the receiving end, photodetectors, such as avalanche photodiodes and/or advanced single-photon detectors, convert optical signals into electrical signals. Data processing units handle signal modulation, error correction, and encryption, which ensures reliable and secure communication. To establish a connection, the transmitting terminal starts with a spiral beam movement. Initial random “hits” are used to calculate the optimal direction. The challenge is to reconcile the different inertial systems: coarse and fine pointing mirrors; Earth; the sun; and the orbital position and attitude of the sending and the receiving satellite. Of course, each possesses its own coordinate system(s).

Stepping toward the space laser network

The first intersatellite laser link was established in November 2001 when the European geostationary satellite Artemis connected with the Earth observation satellite SPOT 4 (see Reference 3). The system used a 60-mW laser diode with a 25-cm telescope aperture to achieve 50 Mbit/s. The system’s total weight was 160 kg, and it consumed 150 W of power.

LCTs have been used in defense applications from some of the early stages of

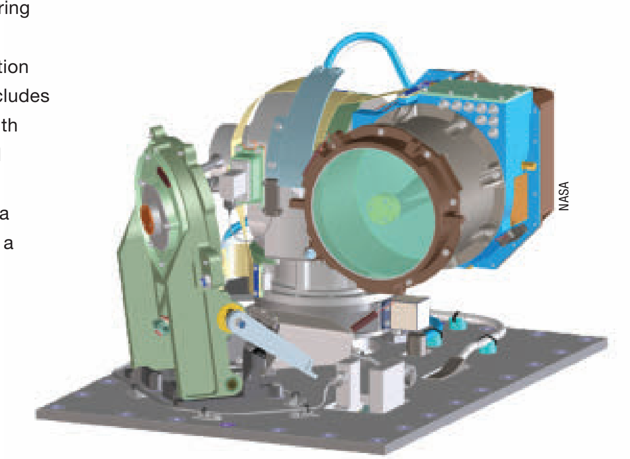


Figure 1. A computer rendering of NASA’s Lunar Laser Communication Demonstration (LLCD) optical module. It includes a 0.5-W laser transmitter, with the optical module mounted to the exterior of the LADEE spacecraft, and consists of a 4-in.-diameter telescope on a two-axis gimbal. The entire system weighs ~65 lbs.

their development. In February 2008, a German LCT was used onboard the U.S. Missile Defense Agency's NFIRE satellite. It was designed to accelerate the transmission of missile tracking information, especially over long distances.

NASA commenced laser communications in 2013 with its Lunar Laser Communication Demonstration (LLCD) (Figure 1). The LLCD consisted of a space terminal on the LADEE spacecraft and three ground terminals on Earth. Together they demonstrated that it is possible to transmit up to 622 Mbps of data over a distance of 385,000 km between a spacecraft and a ground station on Earth using a space terminal[2]. The same year, the geostationary orbit (GEO) satellite

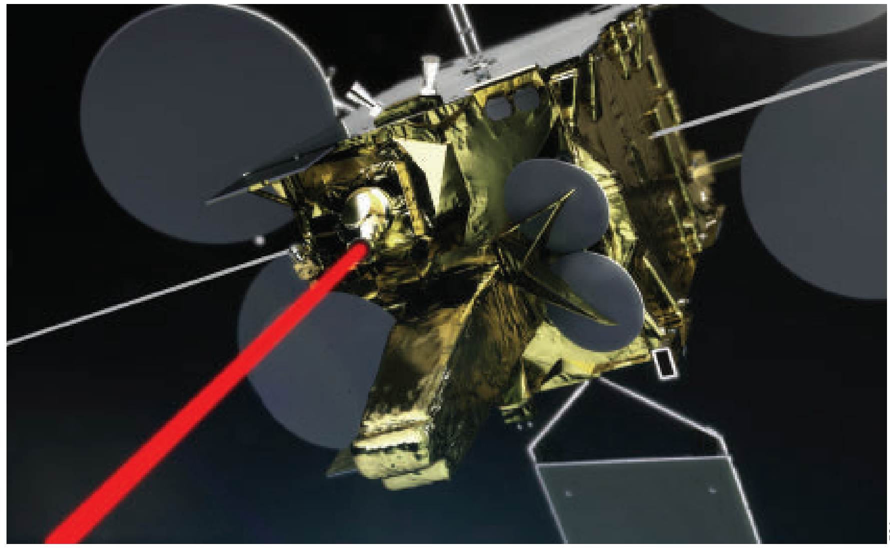
Technical Data of Laser Communication Terminals from Manufacturer TESAT

	LCT135	SmartLCT70	SCOT135	SCOT80	SCOT20
Laser Wavelength	1064 nm	1064 nm	1550 nm	1550 nm	
Range	80,000 km	45,000 km	80,000 km	8000 km	2000 km
Power Consumption	<150 W	<150 W	75 to 340 W, depending on configuration	50 W	<35 W
Weight	53 kg	30 kg	28 kg per optical channel	11.9 kg	4 kg
Size	$60 \times 60 \times 70$ cm^3	4 subunits $35 \times 35 \times 20$ cm^3 per subunit	2 subunits $40 \times 68 \times 40$ cm^3 (optical head)	2 subunits $30 \times 25 \times 40$ cm^3 (optical head)	$10 \times 10 \times 11.35$ cm^3 (1 unit)
Data Rate	1.8 Gbps, bidirectional	1.8 Gbps, unidirectional	2.5 Gbps/10 /100 Gbps, bidirectional	2.5 Gbps/10 /100 Gbps, bidirectional	100 Mbps

Alphasat was launched to demonstrate GEO-to-ground and GEO-to-LEO laser communication links. In 2014, the Optical Payload for Lasercomm Science (OPALS) was tested onboard the International Space Station. It downlinked a video of the 1969 Apollo 11 moon landing in merely 7 s, compared with 12 h using existing radio links.

The next major steps in LCT history were the integration of LCTs on the LEO satellites Sentinel 1 and 2 and the GEO satellites European Data Relay Satellite (EDRS)-A and -C. These satellites are part of the Space Data Highway, which was established to transfer data from LEO satellites to ground stations via GEO satellites. The data transfer between LEO and GEO over >35,000 km is performed by intersatellite links with LCTs. The data rate from space to ground amounts to 1.8 Gbps. Sentinel 1A was launched in 2014, and EDRS-A in 2016 (Figure 2). The Space Data Highway has been in regular operation since the launches.

NASA has its own plans with its Laser Communications Relay Demonstration (LCRD) (Figure 3). Launched in 2021 to a GEO orbit, NASA tested communications to several ground terminals. With LCRD, NASA engineers also proved that laser communications systems can enable more precise navigation capabilities. An ongoing navigation experiment has already shown that engineers can receive more precise location data over a laser link than over standard radio waves.



ESA

Figure 2. European Data Relay Satellite (EDRS)-A is the first node of the EDRS.

LCRD became instrumental as a relay station in 2023, when the Integrated LCRD Low Earth Orbit User Modem and Amplifier Terminal (ILLUMA-T) was sent to the International Space Station to establish a two-way laser connection. The latest record in space communication meanwhile was set when NASA's Psyche mission transmitted video over 31 million km from deep space to Earth in a demonstration that serves to enable future human missions beyond Earth orbit. Capable of sending and receiving NIR signals, the instrument used an encoded NIR laser to transmit 267 Mbps to the Hale Telescope at Caltech's Palomar Observatory in California.

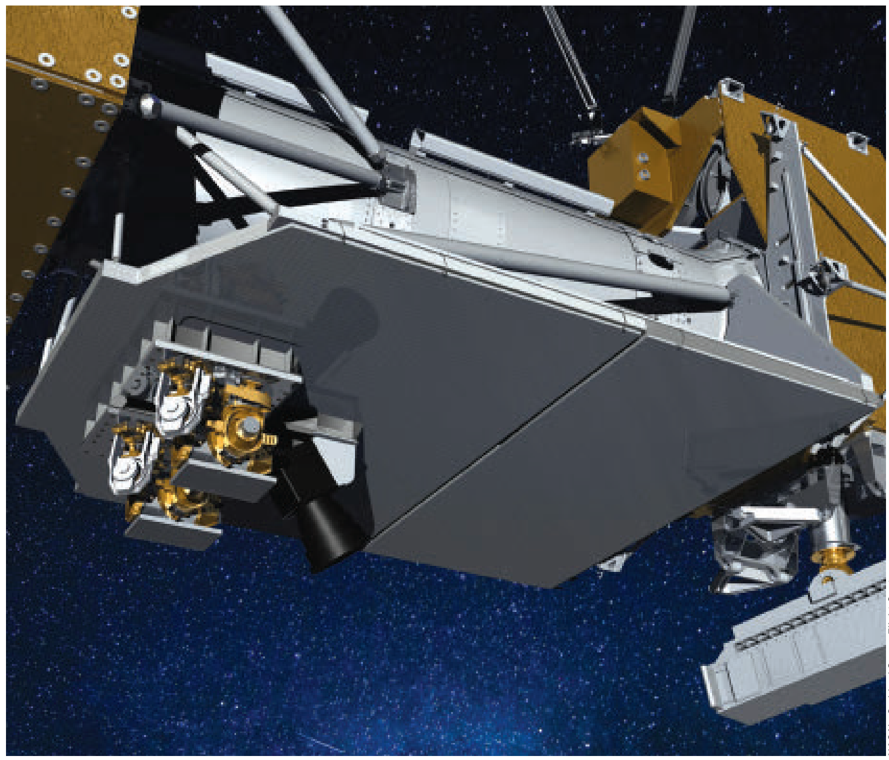
SpaceX began to deploy LCTs in 2022; its Starlink satellites were originally designed to receive signals from a portable terminal on the ground and to relay these signals to the next ground station with internet connection. By enabling communications from one satellite to another on the same or adjacent orbital plane, a ground station does not need to be in the same satellite footprint as user terminals. This is poised to be a major change to Starlink operation.

LCT developers

Until recently, LCT installations were test deployments. Only a few systems, such as EDRS, were used for regular data transmission. But this has changed, and LEO constellation operators have started to place orders for large batches of LCTs.

Accordingly, LCT market leader TESAT opened a production facility with a capacity of 100 LCTs per month. The opening in August 2024 followed TESAT's launch of a production facility on Florida's Space Coast in 2023.

At that time, TESAT said in a press release, "With more than 500,000 h of operation and 10 optical communication terminals in space, TESAT is the only provider worldwide for in-orbit-verified optical communication terminals."



NASA's Goddard Space Flight Center

Figure 3. The Laser Communications Relay Demonstration (LCRD) payload is attached to the LCRD Support Assembly Flight (LSAF) **(right)**. Attached to the LSAF are the two optical modules, which generate the IR lasers that transmit data to and from Earth.

Figure 4. Stationary airships in the stratosphere could be a cost-efficient alternative to low Earth orbit (LEO) satellites for free space data transmission **(below)**.

MO-SPACE

TESAT-Spacecom was founded in 2001 in Backnang, near Stuttgart, Germany. The company formed as a rebrand of an established player in the field of satellite payloads and has become a market leader. The company has roots in AEG Telefunken, which was forced to flee Berlin in 1949. It ultimately changed names and ownership several times until 2001, when EADS Astrium (now part of Airbus Defence and Space) acquired TESAT and kept it as a separate company. Today, TESAT employs approximately 1100 people, primarily in Backnang.

The promising market has yielded a strong competitor: In March 2024, SpaceX President Gwynne Shotwell announced that the company had started to sell LCTs. News on this has been quiet since. When SpaceX promoted a successful test of a laser link on two satellites built for the U.S. Space Development Agency in September 2024, it used TESAT terminals. The successful test involved two of the four SpaceX satellites equipped with Leidos IR sensors and TESAT terminals.

Meanwhile, other LCT providers are evolving. In June 2024, the U.S. Space Systems Command announced that it had awarded contracts to four companies to develop prototypes for laser communication terminals, kicking off the first phase of the $100 million Enterprise Space Terminal program. The four companies contracted are Blue Origin, CACI International, General Atomics, and Viasat.

German competitor Mynaric previously won an order from Northrop Grumman as the sole supplier of optical communications terminals for the Space Development Agency's Tranche 1 Transport and Tracking Layer programs. It was one of several contracts for the company, whose CEO left the firm in the summer of 2024 because the ramp-up of LCT production was not going to plan. Mynaric lost most of its valuation, though ramp-up has nevertheless continued for the firm.

LCT technology has additionally become a military priority, spurring activities around the world. China successfully deployed its first two-way LCT into orbit in February 2024. Shenzhen, China-based HiStarlink developed the terminal in collaboration with AdaSpace, a satellite maker from Chengdu, China. The terminal has a maximum transmission speed of 10 Gbps, according to *China Daily*. China had previously launched a research satellite with optical connection in 2016, called Micius. It established the first quantum encrypted connection from a satellite by sending entangled photon pairs to ground stations.

In Japan, NEC partnered with California-based Skyloom Global Corporation, and the collaborators are aiming to develop LCTs by 2025. In Europe, defense contractors Thales Alenia Space and Hensoldt joined the pack: While the former started LCT development for quantum communication, the latter promotes LCT even for submarines.

Laser connections to the ground are still seen as special and impressive accomplishments, because the presence of clouds, fog, and air turbulence can always reduce the transmission capacity. It therefore seems likely that such stations would be located in high mountains or arid regions, similar to astronomical telescopes. And they might borrow unblurring techniques such as adaptive optics from neighboring technologies.

Cailabs has suggested another approach. The French laser developer and manufacturer proposes spatial composition/decomposition (demux) of the optical field for turbulence mitigation at high data rates. Cailabs' proprietary optics can handle up to 45 modes for multiplexing/demux and up to 100 W per channel. The company currently runs several test lines of up to 10 km on the ground.

What's next

It is doubtless that the large satellite constellations hold the most promise for LCT manufacturers. For example, Starlink plans to have 12,000 satellites in space; Project Kuiper (Amazon) has discussed 3000+; and Qianfan's Spacesail constellation aims to rival Starlink with an additional 15,000 satellites. If each of these carries two or four LCTs, then thousands of LCTs will be needed per year. So far, launch capacity seems to be the biggest limit for LCT deployment. And LEO satellites have a lifetime of about 7 years, which necessitates ongoing demand. Assuming unit prices are to be below $1 million, one can make a rough estimate of a new market on the order of $1 billion annually. This estimate deserves scrutiny far beyond the scope of this article.

So far, the largest constellations have been planned for end user service. Rivada Space Networks, a German-American constellation, adds a commercial dimension; its planned constellation of 600 satellites is intended to serve the maritime, telecom, enterprise, energy, and government services markets. Rivada has not yet launched a single satellite, though it said in a November 2024 press release that it had secured more than $13 billion of business for its LEO network.

Such markets — the maritime, telecom, enterprise, energy, and government services, for example — could further influence the growth and deployment of this technology. Starlink has shown impressive numbers with its latest generation of user terminals, which could be used on cars and ships. And certainly, stationary terminals in underserved regions, such as the Brazilian jungle or Australian Outback, hold opportunity. The staunchest believers in the promise of the Internet of Things are eager to discuss the promise of a fast uplink everywhere, at any time. Internet on airplanes may require more sophisticated solutions, and certainly, governmental agencies will ensure that the uplinks reach to their jets, rockets, submarines, and more. This will drive more encryption technology. The first quantum encrypted satellite connections have been demonstrated already, and much more is in the pipeline.

German company MO-SPACE is developing a laser and quantum communication network with airships in the stratosphere. This idea has a range of benefits. For one, airships are cheaper to launch than spaceships and easier to recover. They can serve as relay stations between satellites and ground stations; offer redundancy related to space debris risks; and do not contribute to environmental issues caused by disintegrating satellites in the stratosphere (Figure 4).

Compared to satellites, airships can also be stationary with low latencies, thereby bypassing the issue of beam-blocking clouds. Finally, airships can support direct smartphone links much more easily than satellites. Although airships have an exotic touch, the idea is expanding. For example, Sceye, headquartered outside of Albuquerque, New Mexico, is also preparing airships with LCTs.

The future is now

LCTs have been discussed for at least 40 years. Now, they are reality, and hundreds of systems have been ordered from LEO satellite constellations already. LCTs possess a technology readiness level 9. And given price and order estimations, one can see a hardware market (for LCTs only) evolving toward a volume of $1 billion per year.

Should the technology meet this projection, it will serve as the backbone of global satellite fleets with low latency internet connections. Internet access anywhere, anytime, with a kitchen plate-size antenna is just the beginning. Direct smartphone connections will follow, and improved GPS precision through optical signals is one more application. More ideas are abundant, and rapid technological progress will bring such innovations to daily life.

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AI Demands Speed:

A Photonics Platform Can Deliver It

Amid the AI boom, technology's role in ensuring unimpeded access to data hinges on photonic-electronic integration.

Opening image courtesy of iStock.com/ipopba.
All other images courtesy of POET Technologies.

BY SURESH VENKATESAN
POET TECHNOLOGIES

As the technology world settles into 2025, the race is on to achieve 1.6 Tbps and 3.2 Tbps — speeds that are critical for the future generations of high-performance computing solutions for the data center industry. Hyperscale data centers, which are increasingly driven by demands from artificial intelligence (AI) hardware and software developers, require far more bandwidth than early-iteration data centers to satiate the global desire for advancements in medical technology, wearables, robotics, automotive, financial services, and other sectors. Large language models, at the root of AI development and machine learning, can only get "smarter" by having more data and faster times.

During the past year, the optical interposer has established itself as the rising star in chip-scale architectures, enabling the next level of data speeds. The best optical interposers that are currently on the market do not require wire bonds or active alignments, which dramatically reduces costs and results in coveted power savings. Dependent on the efficient performance of lasers, optical interposers are likely to power data centers in the future.

Though AI technology is still considered to be in its infancy, this era is advancing steadily. Current market projections forecast the global data center market to grow by >5× its current levels by 2032, due to the massive demand for AI. This projection points to an insatiable desire for more data. It also signals challenges for an industry that has struggled to get more performance out of traditional platform technologies.

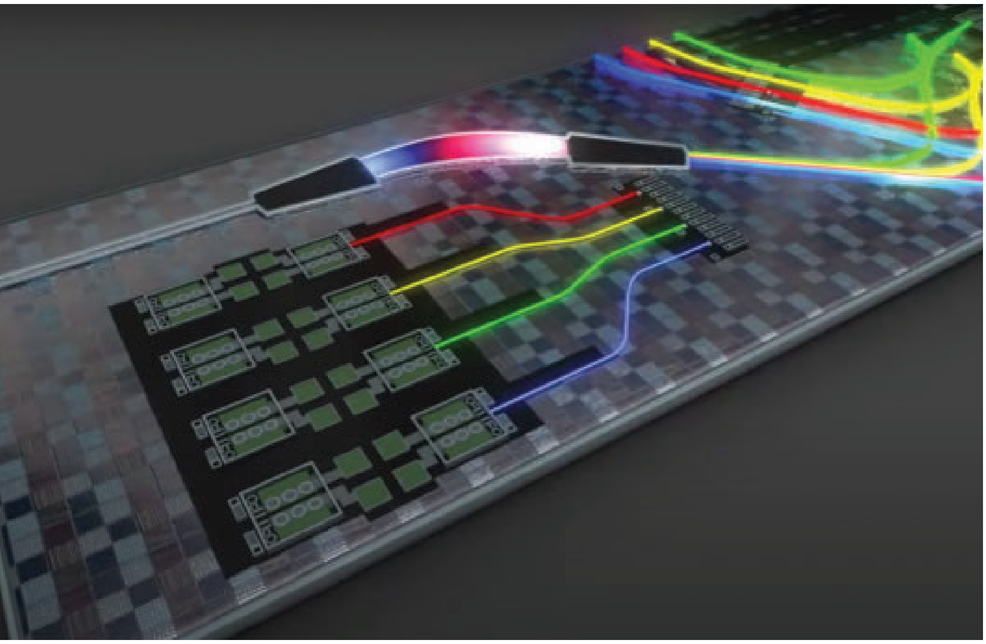
A forecast takes shape

In a *Forbes* article published last fall, Kazuhiro Gomi, CEO of NTT Research, described how the ongoing demand for increased compute power has created bottlenecks that the components that are currently used cannot satisfy[1]. These component-level limits extend to current computer architectures. They also serve to underscore the tech sector's overall appetite for energy, Gomi said.

Simply, AI workloads are pushing the boundaries of what copper connections can manage. Optical fibers, on the other hand, can transmit more data per second and lose much less signal over the same distance.

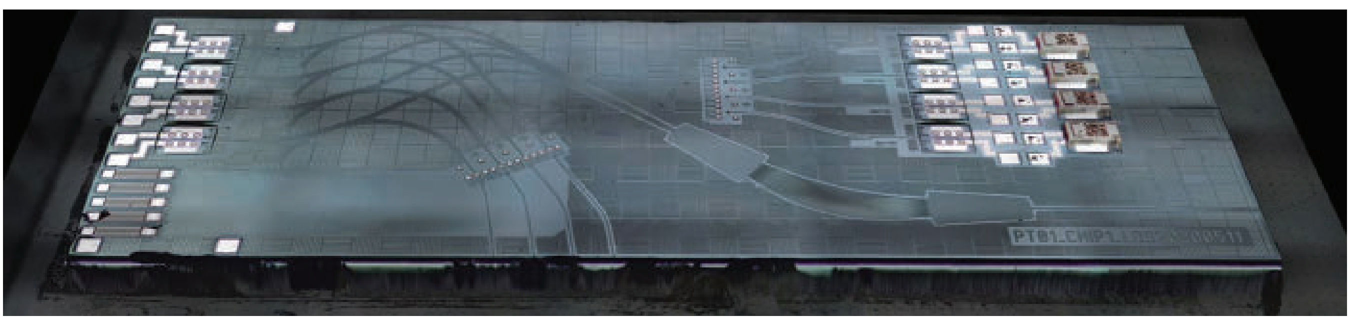
This one-for-one comparison of components is a core driver behind the massive shift from AI data centers to fiber optics, including well-known examples, such as NVIDIA's NVLink for chip-to-chip connections and InfiniBand, which is used to connect multiple racks.

One server rack contains 32 graphics processing units, all of which are connected to each other by 18 switch nodes. NVIDIA's Blackwell chip — which it has introduced to enable companies to build and run real-time generative AI on



Optical interposers, which rely on the efficient performance of integrated lasers, are positioned to power data centers in the AI era **(left)**.

An interposer. Flat, combined electronic and photonic capabilities power the modern data center **(below)**.



trillion-parameter large language models — will hold 1296 optical transceivers per Blackwell rack. This value corresponds to 1 million transceivers for every 800 racks, on average, with each to be powered by optical engines. For context, Amazon Web Services alone has at least 30 data centers around the world, each of which has around 2400 racks, or around 3 million transceivers.

This use of data centers is the key reason as to why the optical transceiver market is forecast to more than double during the next eight years. But at the same time, the market for 800-Gb optics is specifically projected to increase by >10× by 2029. This is the direction in which AI developers are urging the industry to move. Once 1.6-Tbps applications dominate the market, their growth path will be similar.

Meanwhile, 3.2 Tbps is a target that few companies can currently dream of reaching. Soon enough, however, it will be necessary to operate at that level, too.

On a forward path

Meeting such unprecedented need for speed depends on innovation — a reality that creates a conundrum on top of opportunity. An enormous volume of innovation flooding into the ecosystems of the world's largest data center companies requires tremendous power to run and cool. For example, according to Goldman Sachs, a single ChatGPT query uses nearly 10× as much energy as a Google search. Meanwhile, the Boston Consulting Group estimates that data centers will account for 16% of the total U.S. power consumption by 2030, increasing from 2.5% in 2022.

Photonic integrated circuits (PICs) offer a potential solution in this context. The PICs technology space has undergone considerable growth and diversification, and multiple market forecasts anticipate the PICs market to exceed $45 billion by the start of the next decade. According to industry observer Akash Anand, growth in the PICs market between 2024 and 2032 will occur at a compound annual growth rate of 18.1%, owing to the components' increased adoption in optical networks used for data transmission.

A burgeoning PICs space in support of existing data needs, however, only underscores the fact that the energy requirements of AI compute networking are more intensive than anything yet to be seen in the world. Existing AI programs must execute trillions of computations to achieve their optimal performance.

The price of delivering this kind of performance, as well as the environmental cost, are significant hindrances for traditional semiconductor devices and processes. As Juniper Networks said in a 2024 industry report, despite the efforts of semiconductor infrastructure vendors to design more efficient products, current AI model training demands are increasing power requirements[2].

The optical interposer introduces a novel way to address the problem areas of an industry that knows it must brave fresh paths in order to sustain Moore's law.

The optical interposer

An optical interposer populated with tightly integrated electronic and photonic components reduces power consumption, eliminates crosstalk from copper wire bonds, uses fewer components, and can be built with lower labor costs than optical transceiver modules that are produced any other way. As a critical enabling technology for future data centers, optical interposers fundamentally ensure lower levels of power consumption. This translates to the data center industry's having a lesser effect on the environment, which is an increasingly important feature given how much data is being consumed by AI applications.

The reduction of these losses is key to photonics' success in future data centers, which heightens the significance of optimized components in controlling the flow and efficiency of lasers at chip scale — which is itself vital to producing a scalable photonic component for commercial applications.

One proven way to harness lasers is with optimally performing waveguides; a low-loss waveguide will usher each laser consistently through its lane, creating a steady, predictable flow of power that can be used to transfer data. And, unlike traditional silicon photonics, the interposer platform can be material agnostic, integrating with traditional silicon and indium phosphide platforms as well as alternatives, such as thin-film lithium niobate (TFLN), which is showing incredible aptitude to scale to higher speeds while reducing power consumption. Already, device developers are favoring TFLN modulators for their low levels of power consumption, paired with their high bandwidth capabilities and low insertion losses. The material also holds promise in aiding heterogeneous integration for packaging.

The optical interposer offers another critical benefit. Miniaturization through TFLN (or through any means) is essential to meet the needs of hyperscalers, and the optical interposer makes this achievable on commercial scales. The optical interposer introduces a novel way to address the problem areas of an industry that knows it must brave fresh paths in order to sustain Moore's law.

As a result, companies including POET are pioneering the conceptualization and development of optical interposers, targeting applications that can scale to high-volume production and seamlessly integrate into existing infrastructure — without increasing capital expenditures or power consumption. The passive alignment of the optical interposer yields significant cost reduction compared with traditional active alignments as well as the ability to ramp to high volume with less capital equipment. At the component level, optimized waveguides can be fabricated to ensure that their lasers deliver necessary levels of performance — namely, high efficiency and low error rates. Such an approach simplifies chip-level engineering and increases flexibility. With all components on POET's optical interposer integrated onto a single chip, via an adaptation of existing CMOS manufacturing methods, assembly time and labor cost savings are additional benefits that the company has realized.

Of course, the critical parameter to gauge is the point of view of the end user. Whether it is POET's optical interposer, or another commercially available solution, the goal remains the same: to design and deploy optical transceivers that are high-speed light-to-voltage and voltage-to-light converters or radio frequency (RF)-to-light and light-to-RF converters that can generate data speeds that are magnitudes higher than current generations and within budget constraints. How each optical interposer on the market gets to this detail depends on their respective designs and the Internet Protocol behind them. But without optical transceivers, graphic processing units will be unable to meet AI compute and/or AI workload market demands in a manner that is timely or cost-effective, and certainly not in a manner that delivers on both.

The case for photonics

As Gomi and other experts have said recently, the idea of optical computing predates by many years the current interest and attention that it is commanding from industry[1]. As the need for chip-level innovation intensifies, photonics has already been shown to drive innovation. Data centers are one of the first industries to see what photonics can achieve.

But other sectors will benefit. On the heels of AI, quantum compute, for example, will increase demand even further for optical computing. If AI is at its dawn during today's digital technology transformation, then quantum computing is rising from the shadows, preparing to have a dramatic effect on all aspects of science. Eric Mounier, chief analyst of photonics and sensing at Yole Group, is among the experts who has shared projections that the quantum computing market will be worth hundreds of millions of dollars by 2034.

As for the immediate future, expect the photonics era to continue its trajectory in 2025 as the data center industry shifts its approach to fulfill what it sets out to: address the demands of a world that is highly dependent on connectivity and data.

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Light-Powered Networks Prepare to Meet the Demands of 2030 and Beyond

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Innovative applications and the resulting demands of power consumption and data bandwidth require a paradigm shift in communication and network infrastructure.

BY MASAHISA KAWASHIMA
IOWN GLOBAL FORUM

In today's fast-paced digital world, speed is everything. Low latency is critical for enabling the need for speed, which can transform industries, enhance our digital lives, and create a smarter world. By reducing the time required for data to travel from one point to another, low latency can help applications to run faster and more smoothly, improving the user experience and ensuring customer satisfaction.

However, current compute and network infrastructures must achieve quantum leaps in latency to achieve the performance needs of latency-sensitive applications. These range from banking systems with synchronous data replication across data centers to critical life situations, such as AI-driven surgical robots.

The limitations of existing networks owe to probabilistic packet losses and delay variations that are inherent to electronic packet switching systems. These drawbacks are evident in key metrics such as message transfer latency and power efficiency because computing nodes must perform buffering and resending to cope with packet losses and delay variations. Message transfer latency, measured in milliseconds, may not impede a user waiting for a webpage to load. But this parameter becomes critical for latency-sensitive applications in which even a 10-ms delay can compromise performance.

At the same time, the energy requirements for sustaining this data explosion are plagued by unsustainable rates of growth. Data centers already account for

~1% of global electricity consumption, with projections indicating an increase to 3% to 4% by 2030. This rising power usage exacerbates the environmental impact, because each byte of data transferred requires energy for processing, cooling, and transmission.

By contrast, photonic networks offer unparalleled speed, efficiency, and scalability, addressing the dual challenges of managing latency-sensitive applications while aligning with global sustainability goals. Photonic networks do not cause probabilistic packet losses or data variations, therefore the technology is particularly suited for latency-sensitive applications. Moreover, the recent evolution of optical transmission technology has made it possible to send gigabits per second data over long distances without using intermediate relay nodes.

To prepare the marketplace for photonic network technology, like-minded organizations from the tech world and key industry verticals have been brought together by the IOWN (Innovative Optical and Wireless Network) Global Forum to create a smarter world through next-generation communications infrastructure. The forum has published proof-of-concept use cases to drive network rollouts, which include multi-data center infrastructure for financial services institutions (FSIs), remote media production and streaming, and green computing.

Financial services' digital transformation

Perhaps more than any other industry, the financial services sector is already engaged in its digital transformation. This journey has not been seamless. The performance limitations of current

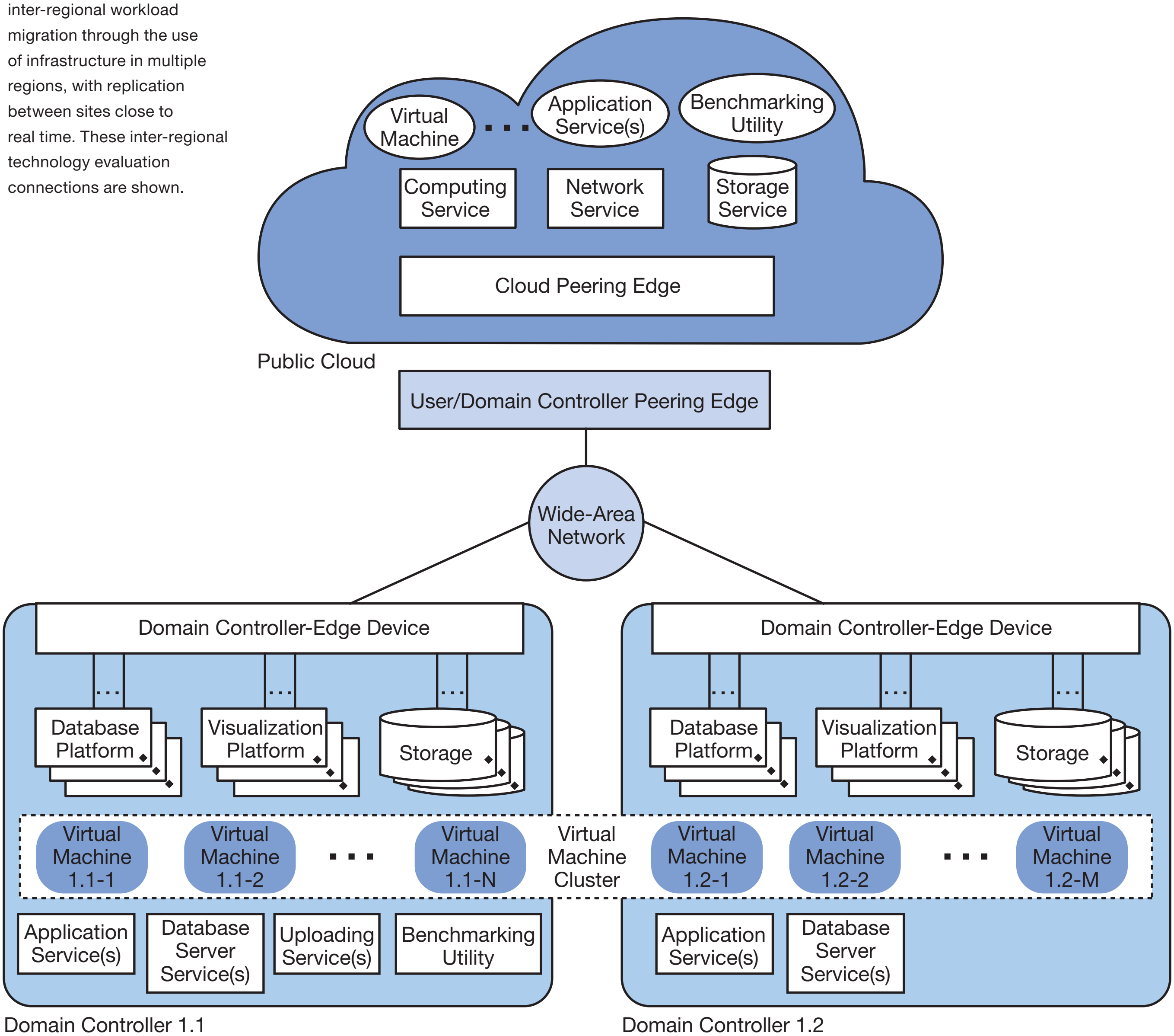


Figure 1. Financial services institutions (FSIs) achieve disaster recovery and inter-regional workload migration through the use of infrastructure in multiple regions, with replication between sites close to real time. These inter-regional technology evaluation connections are shown.

The rapid advancement of media production technology poses a multifaceted challenge. Industry must secure enough highly and appropriately skilled media production operators to meet demand, especially in rural areas.

technologies, increased regulation(s), and reliability requirements all conspire to affect business agility and service resiliency even amid emerging opportunities to improve infrastructure and advance service models. And existing hybrid cloud solutions are significantly complex, expensive, and challenging to implement.

A transition to photonic infrastructure in financial services would both expedite and streamline this technological shift. By using infrastructure in multiple data centers with replication between sites close to real time, operational resilience, agility, and cost optimization will improve (Figure 1). This approach will support FSIs' disaster recovery and workload migration following a human-induced or natural disaster, such as earthquakes. It will also introduce an improvement in the flexible usage of computing resources, such as resource pooling and dynamic resource allocation.

If applications could deploy without service outages, and computing resources could be used more flexibly, improvements to scalability would follow. It would also help to facilitate the provision of services, such as banking-as-a-service, which relies on external service requests and makes it challenging to predict transaction volumes. This approach not only streamlines the system architecture but also significantly improves data security and system efficiency.

FSIs have the highest priority for business-critical data and services, such as account systems and ledger data (known as Tier 1 systems). This level of reliability is crucial to support business continuity planning. With traditional infrastructure, it is challenging to replicate data synchronously to a remote data center; this causes either application performance degradation or asynchronous replication that tolerates either a certain level of data inconsistency or assumes operational coping. Essentially, these Tier 1 systems require synchronous replication to ensure the continuity of financial transactions. This is where the IOWN All-Photonic Network (APN) comes in. With APN, systems will be able to achieve synchronous replication with much less performance degradation.

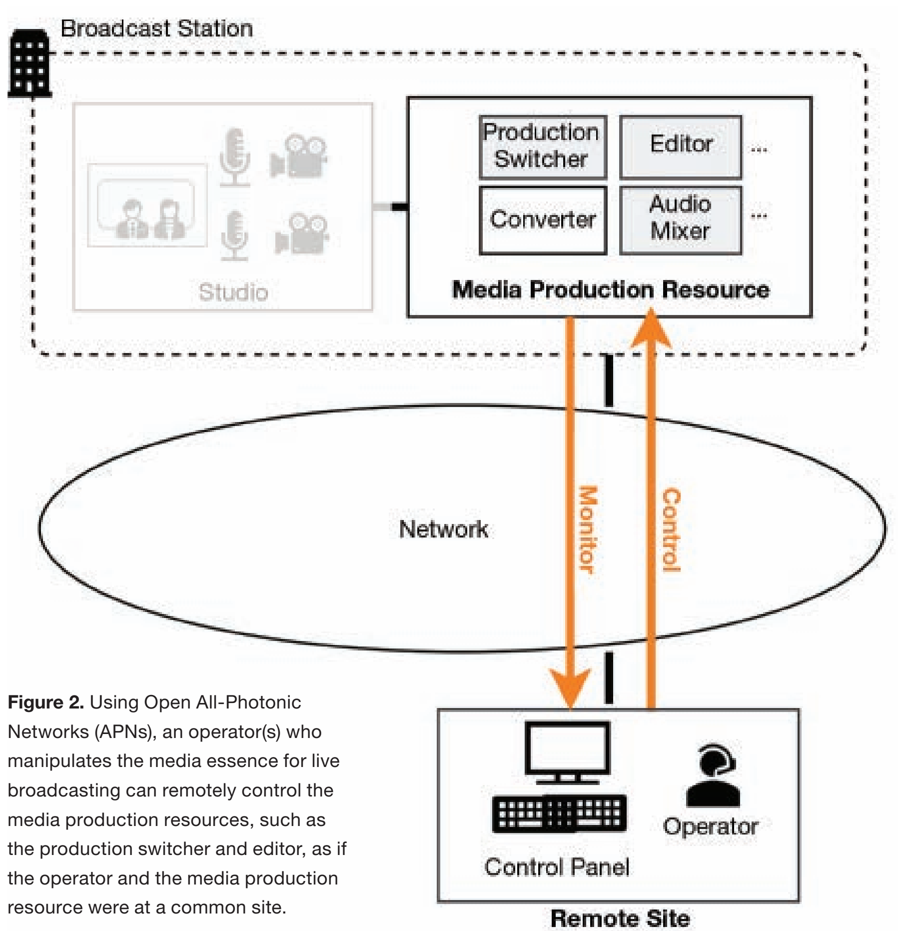


Figure 2. Using Open All-Photonic Networks (APNs), an operator(s) who manipulates the media essence for live broadcasting can remotely control the media production resources, such as the production switcher and editor, as if the operator and the media production resource were at a common site.

Remote media production

The rapid advancement of media production technology poses a multifaceted challenge. Industry must secure enough highly and appropriately skilled media production operators to meet demand, especially in rural areas. A lack of qualified personnel, paired with limited resources for acquiring advanced solutions, plus high networking costs, make distributing and developing quality content a daunting prospect. As a result, there is increasing demand to develop technologies and architectures that provide an optimized profit structure to address these new realities of the market.

Open APNs provide dynamic, flexible, resilient, high-bandwidth, and low-latency connections to enable distributed applications, including high-quality video production. Using this technology, an operator or operators who manipulate the media essence for live broadcasting can remotely control the media production resources, such as the production switcher

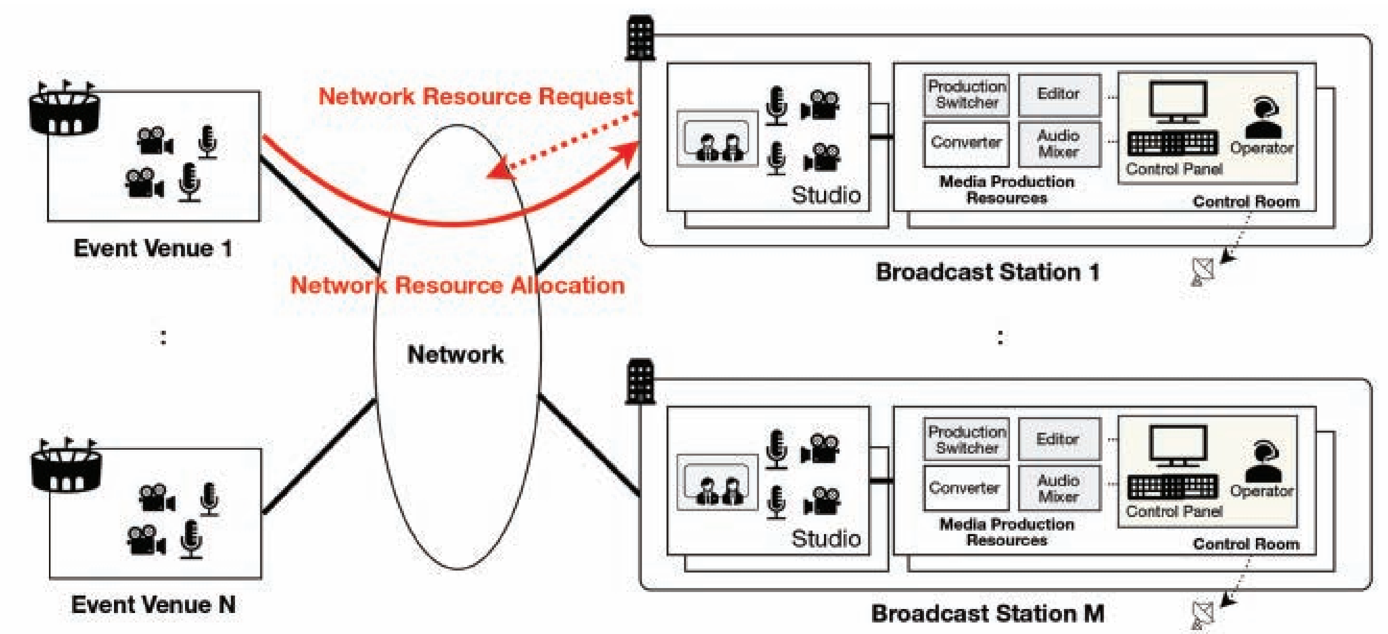
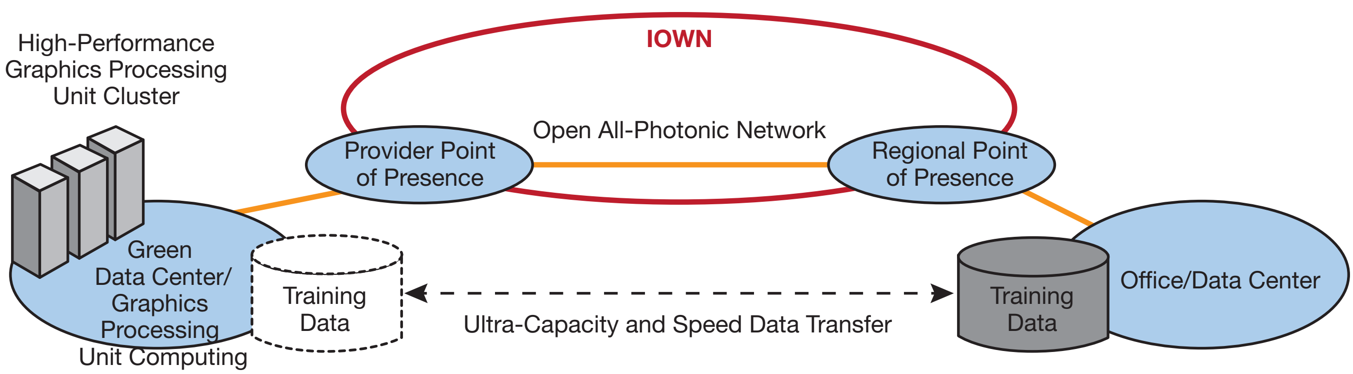


Figure 3. Broadcasters benefit from network resource sharing, as the broadcast station can request network resources from the event venue to the broadcast station whenever an event occurs, resulting in high-quality connectivity **(above)**.

Figure 4. Training data transfer on the Open All-Photonic Network (APN) to graphics processing unit (GPU) clusters for large-language models (LLMs) **(below)**.



and editor, as if the operators and the media production resource were together at the same site (Figure 2). The flexible workflow enabled by this model will help secure necessarily skilled media production professionals who may be geographically distributed.

And, unlike today's leased lines, Open APNs enable users to turn on/off connections. This will enable significantly reduced wide-area network (WAN) infrastructure cost, and connection to many venues and production sites as a result.

Broadcasters themselves can also benefit from network resource sharing. The broadcast station can request network resources from the event venue to the broadcast station, at any time that an event occurs, to provide high-quality connectivity at an affordable cost (Figure 3). Unlike conventional media production taking place at the event venue, in these instances raw media essence streams are sent directly from the venue to then undergo editing at the broadcast station itself.

Green computing

The use of environmentally friendly green data centers is an effective approach to accommodate large-scale calculations for generative AI/large language models (LLMs), which consume considerable electrical power. However, today's graphics processing unit (GPU) computing services assume that computing and data storage resources are located in the same data center. This makes it difficult for enterprises to use GPU computing resources at green data centers, because enterprises cannot readily store their confidential data in green data centers — which are typically operated by third parties. To effectively use the large amount of data located beyond the data center, end users will require a high-performance network such as an IOWN-based APN. An IOWN-based APN will provide a solution for enterprises to build generative AI/LLMs using green data centers and maintain data confidentiality.

Here, the vision is for users to build an LLM by performing training on GPU computing located on Open APN-connected green data centers, using the training data that exists at their own location. The training process runs by retrieving the training data from the remote site on a chunk-by-chunk basis. As APN(s) provide guaranteed-bandwidth, fixed-latency, and packet-loss-free connections, the time for retrieving a chunk of data is predictable and constant. This will enable the training process to keep running in parallel with the data retrieval process.

It is assumed that many packets used for data reference will be transferred on the Open APN, and that the network latency will affect model training time and power consumption regarding GPU computing (Figure 4). Additionally, high-performance GPU computing consumes more power and has higher threat density in proportion to its performance. This means that a green power supply and water-cooling system are essential. A green data center, in which both of these elements are present and available, is therefore the core of efficient operation of high-performance GPU computing.

The road to 2030

While the benefits are clear, achieving this vision of APN adoption requires a global effort. The success of APNs depends on collaboration across industries, governments, and academia, which must unite to capitalize on the opportunities offered by photonic solutions. By increasing capacity to unprecedented levels, reducing delays to near zero, and slashing energy consumption, photonics offers a sustainable and scalable solution to the challenges of tomorrow.

Fortunately, the shift to photonic networks is already underway. The IOWN Global Forum's work on open standards and proof-of-concept initiatives has laid the groundwork for scalable, globally deployable solutions.

However, this transition is not without its challenges. Building a new type of network involves rethinking not only technology but also the way we design, build, and manage infrastructure. It requires investment, innovation, and a shared commitment to creating a more connected and sustainable future.

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LIVE
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Silicon Carbide Bridges the Gaps Between Electronics and Photonics

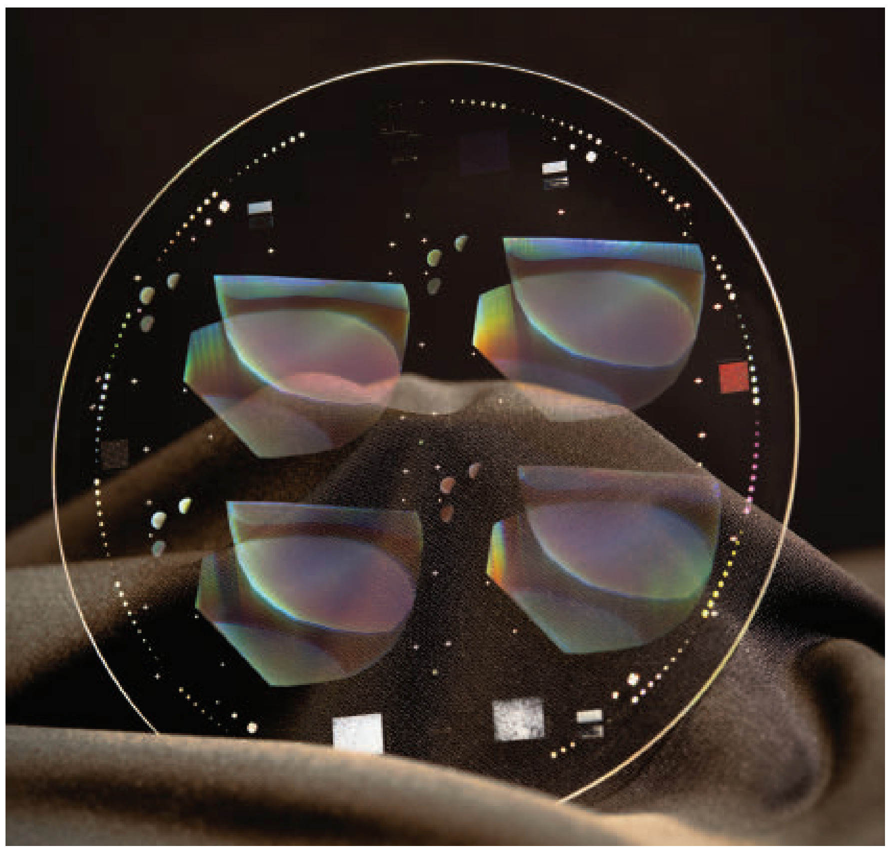
BY BARRY SILVERSTEIN
META'S REALITY LABS

Industrial manufacturing has long favored silicon carbide (SiC) for its utility as a cutting material, exhibiting exceptional hardness that resembles diamond at roughly half the cost. Other desirable qualities, including SiC's mechanical strength, thermal conductivity, and low density, have steered the material into the field of optics to be used as a thin, lightweight, and stable coated optical mirror substrate for space applications.

More recently, SiC's distinct electrical and mechanical properties have been applied to gain efficiencies and reduce costs for power electronics. When manufactured as a single crystal (with sufficient purity and doping), SiC delivers a wide bandgap, high critical electric fields, and thermal conductivity that enable commercial power electronics to operate at high voltages and temperatures without breakdown.

In turn, this enables lighter, smaller, thermally resilient, and more efficient components for electrical applications in transmission and inversion/conversion for the rapidly growing electric vehicle and alternative energy sectors. In data center usage alone, such efficiency gains are expected to drop cooling costs by roughly 25% to 40% per system. And in alternative energy switching, it is estimated that using SiC can enable system efficiencies as high as 98% from the kilowatt to megawatt power ranges[1].

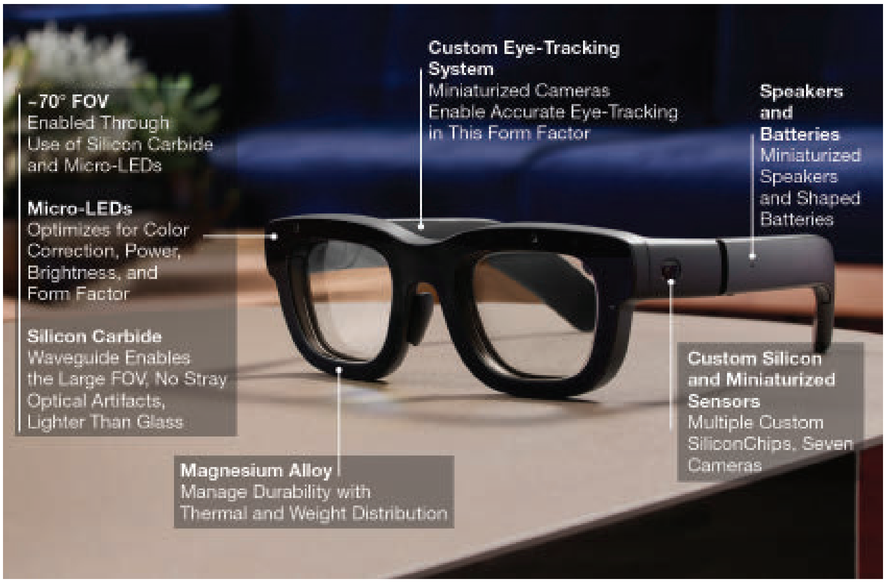
Further, as grown SiC crystals are increasingly purified and manufactured with suitable defects, fabricators have realized single crystal wafers with very high resistance in support of high-speed microwave radio frequency switching. High electron mobility transistor devices are already used to enable 5G and next-generation communication systems.



AR devices promise to expedite the adoption of silicon carbide (SiC) and unlock possibilities for human-computer interaction — including wide FOV wearable displays.

At the same time, bottlenecks hinder the broad and widespread adoption of SiC. The material is hard to produce compared with silicon due to the high temperature physical vapor transport growth method. This technique involves heating precursor SiC powder to temperatures between 2300 and 2500 °C inside a graphite crucible. The individual steps involved in this process are prone to yielding unwanted material defects that may destroy necessary electronics properties. In situ

All images courtesy of Meta.



Meta's 2024 demonstration of the usage of silicon carbide (SiC) as a substrate was highlighted by its Orion AR glasses protype, featuring a 70° FOV.

monitoring of the process is challenged by the high temperatures. Subsequent processing steps of creating wafers and devices are more time-consuming and costly as a result of the robust mechanical properties.

Despite this significant limitation, however, manufacturers around the world broadly appreciate that SiC is a critical material supporting the shift toward a more electrically centered power infrastructure and an increased need for high-speed electronics with greater bandwidths. And improvements are currently underway, targeting intrinsic material properties, completed wafer quality, and subsequent processing advancements.

As a result, production wafer sizes continue to increase, with typical sizes currently including 150 mm, and 200 mm is becoming available (with 14 global foundries coming online), and 300 mm is under development[2]. Current market needs in electronics components are well supported on older 200-mm fabrication lines. Meanwhile, components, such as Schottky barrier diodes, junction-gate field-effect transistors, and metal-oxide-semiconductor field-effect transistors, continue to benefit from steady advancements.

SiC: A material photonic enabler

The SiC crystalline structure can take many forms; more than 200 polytype crystalline structures are possible. Several of these are of high interest for applications in electronics as well as in photonics.

3C-SiC (cubic or beta phase) and 4H or 6H (hexagonal or alpha phase) are the most common forms for demanding applications. Typically, 3C is the simplest material to make, and as a result, most precursor powders start with a high percentage of this structure. Certain electronics applications use this structure, but 4H and 6H crystal structures are preferred as performance requirements are increasing. It seems likely that the electronics industry will come to favor the 4H crystalline structure due to its large bandgap of 3.23 eV; breakdown field of 2.8 MV/cm; electron drift velocity of 2.2×10^7 cm/s; thermal conductivity of 280 to 390 K; density of 3.2 g/cm^3; coefficient of expansion of 5.1 ppm/K; and index of refraction of 2.6 to 2.7 in the visible spectrum. Crystalline selection is dependent on the physical vapor transport chamber conditions and initial seed crystal structure. Improvements in these variables have driven a shift toward 4H.

Regardless of the material polytype selected, electronics functionality depends on correct doping and induced defects. SiC is most often doped with carefully controlled proportions of impurities, such as nitrogen or phosphorus for *n*-type materials, aluminum or boron for *p*-type materials, and vanadium for semi-insulating functionality (where high resistivity is desired to isolate current flow between components for high-speed electronics[3]).

In optics and photonics applications, however, material purity is often the most essential determinant to low absorption losses. This makes optical-grade SiC an interesting and perhaps universal base substrate choice for the broadest applications where doping can be subsequently processed. Given this, it could be beneficial to localize both doping and defects so that electronic, photonic — and even quantum — processes would be possible on a singular substrate[4].

AR and SiC: The next-volume wave

Advancements in the electronics industry increasingly rely on and highlight the distinct capabilities of SiC. Coupled with growing awareness and the development of higher-quality materials, this has spurred continued investigations into SiC's optical and photonic properties. In October 2024, for example, Meta demonstrated the usage of SiC as a substrate for Orion, its 70° FOV augmented reality (AR) glasses prototype. Meta partnered with the existing base of industrial SiC material and device manufacturers to deliver this demonstration. The collaboration proved that optical-grade SiC substrates can be fabricated using established commercial means to reach the high optical transmission and tolerances required to create high-quality optical and photonics structures. These wafer substrates were processed using standard lithographic techniques to create the nanostructured gratings necessary for superior AR waveguides.

The development of the prototype validated the value of wide FOV AR glasses in a consumer-friendly form factor. This could present a major shift on the trajectory of SiC, the AR industry, and photonics. It is hard to explain the "wow" factor that users experience when donning a pair of AR glasses, for example, to convey the importance of a wide FOV that SiC enables. Perception — the fundamental quality on which AR relies — is itself a personal perspective. And future commercial success of AR devices will ultimately hinge on factors such as space constraints, social acceptability, portability, and cost.

But even against this backdrop, it is obvious that a wide FOV provides world-locked digital content to remain in a wearer's FOV when they reposition their heads, bodies, and eyes. This is a fundamental difference between "information" or "smart" displays and full AR, in which contextual objects can be overlaid on top of the real world to increase our hybridized perception in a meaningful way. While both experiences have value, full AR's experience exceeds what any display system or human computer interface has yet achieved in an always-available format. In this context, Meta's Orion prototype demonstration is positioned to represent a milestone for the future of AR devices and their architectures.

Additionally, considering historical consumer behaviors toward televisions, computer monitors, and mobile devices, it is reasonable to expect that many consumers will want a larger display if there is not a corresponding sacrifice to other important product attributes. It therefore seems possible, and even likely, that the rollout of AR glasses will begin with small displays, though once a wide FOV display is commercially mature, a sizable proportion of wearers will migrate toward this enhanced experience. The significance of this pivot is difficult to predict. The profound shift from mobile phones to smartphones could offer context.

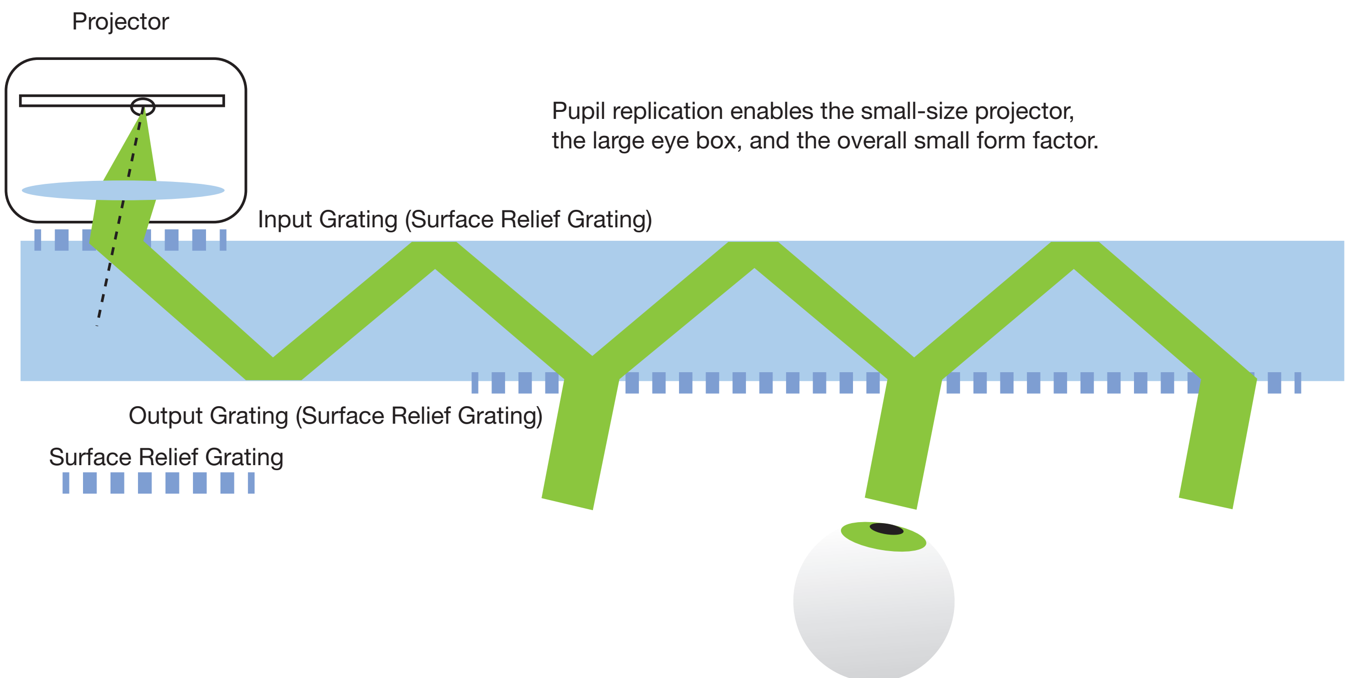
In all waveguide-based AR displays (including Meta's Orion prototype) two factors fundamentally limit the FOV of the system.

First is the overall display efficiency. A combination of the waveguide and projector engine electrical-to-optical efficiency to the eye, within the allowable optical system etendue, dictates this efficiency. The system's thermal (head dissipation availability) and power density given a weight constraint limit the FOV.

The second factor is a limitation of the optical system etendue itself, which is controlled by the difference in the index of refraction between the waveguide substrate and its interface, commonly air or a low-index material. The higher the index difference between these interfaces, the greater the angular acceptance of the optical system — and the freedom for waveguide or grating designers to balance key image trade-offs. Waveguide designers, as is true of lens designers, must trade performance parameters in addition to cost and complexity. In waveguide design, these parameters include off-color uniformity (corrected by imager calibration, though at the cost of efficiency losses), modulation transfer function, ghosting, overall efficiency, and front side grating leakage to the outside world. Another parameter is rainbow artifacts. These are especially troubling for all-diffractive waveguides. They describe the coupling of outside light sources into the waveguide diffraction gratings and the dispersive release of light within the wearer's FOV. These rainbow artifacts move and change with the wearer's positioning relative to the light sources.

In the case of the Orion demonstration, the displays are three tiny micro-LED projectors. These elements deliver red, green, and blue optical pupils that each advance through a diffractive input coupler fabricated as a surface relief grating that feeds the image into the SiC substrate to support total internal reflection. The total internal reflection

Additionally, considering historical consumer behaviors toward televisions, computer monitors, and mobile devices, it is reasonable to expect that many consumers will want a larger display if there is not a corresponding sacrifice to other important product attributes.



Waveguide functionality gauged by its effect on the human eye. Meta's Orion demonstration featured a prototype with three micro-LED projectors. A diffractive input coupler, fabricated as a surface relief grating in the silicon carbide (SiC) substrate, supports total internal reflection until it is released to the eye by a surface relief grating output coupler.

replicates the optical pupils and presents these multiple pupils onto the output face of the substrate that contains a diffractive output coupler to deliver light into the eyes regardless of location. This substrate makes up a portion of the lens structure of glasses.

A second output grating is built onto this surface and selectively couples pupils out to present an eye box within which the wearer receives the light regardless of eye position. SiC's high index of refraction between 2.6 and 2.7 in the visible range enables the substrate to support a larger total internal reflection angular range inside the substrate and a >70° diagonal FOV as well as the large required etendue.

Designers are also able to leverage the increased bending power associated with this high index of refraction to shift the rainbow positions toward the edges of the FOV. This serves to reduce the effect on the wearer. In fact, it becomes possible to eliminate most obtrusive rainbows with an index of refraction roughly >2.5. This makes SiC, with its high index of refraction in the visible range, an optimal substrate choice regardless of the FOV: Alternate material options such as high-index glasses and lithium niobate will retain rainbow artifacts in such conditions.

Material and supply chain considerations

Beyond material properties, considerations given to the scaling and development of existing supply chains and associated cost reductions are critical to a mass adoption of optical-grade SiC by the optics and photonics industries, starting with the AR sector. For this mass adoption to take place, the specifics of an ideal supply chain must be determined. First, it must facilitate the reliable delivery of both substrates and completed waveguides at a consumer-friendly price. This requires a mental and business shift away from electronics with scaling small devices toward optics with relatively large components. AR waveguides are ~50 mm diagonal, with two required per pair of glasses. Therefore, even a small consumer volume of glasses of 1 million pairs requires roughly 300,000 substrates with somewhere around four pairs of lenses per 200-mm wafer.

This math presents an important opportunity for SiC substrate manufacturers to diversify their business. The importance of a diverse customer portfolio has become apparent as the growth of the power electronics business slowed through 2024, along with an unanticipated decrease in the rate of electric vehicles sold and infrastructure conversion in Europe and North America. This has left SiC capacity underutilized, with many prepared facilities available or ready to scale, but paused.

Additionally, pricing pressure has appeared for electronics substrates. This has closed some of the pricing gaps required to support consumer AR waveguides. The release of the Orion prototype and momentum stemming from it has enlivened and engaged the SiC supply chain toward developing and scaling optical-grade SiC. The timing of this transition may indicate ideal conditions to seed the initial launch of wide FOV AR glasses starting with 200-mm infrastructure and rapidly moving toward 300 mm to increase volumes and further lower costs.

Driving electronic-photonic convergence

Though challenges in moving toward mass adoption are real, they are no longer wholly technical problems. Rather, they are more precisely defined by engineering and business concerns. History — specifically in solar panels and batteries, both characterized by massive price drops during the last decade — has shown that these concerns can be overcome when large markets are involved as processing and material developments progress. The speed of such changes is typically driven by collaborations between academic, industrial, and government agencies engaging in parallel to drive the inevitable changes.

It is also a safe assumption that the volume and quality of SiC material will continue to improve from the planned investments. Higher-purity materials will spur a second push toward even better electronics and a new market of wide FOV AR displays.

The individual next steps of the transition toward SiC are more speculative, though equally compelling. Many photonics researchers began their work with SiC even before the availability of optical-grade substrates. This provides some context for the R&D undertakings that have demonstrated many different active and passive photonic devices, including beamsplitters, polarization beamsplitters, optical switches, combs, and micro-ring and micro-disk resonators. Also, selected material defects in SiC crystal structures have been demonstrated to support the creation and addressability of single photon sources for quantum computing. Now, localized doping and defect treatments, along with nanofabrication processes of coating, etching, stacking, and more, could enable a convergence of electronics, photonics, and quantum photonics, all sharing a common substrate to seamlessly mate cross functional platformed integrated circuitry and computing.

It is obviously interesting to hypothesize about a future self-reinforcing ecosystem creating a path for combined integrated optoelectronics around SiC. Currently, massive gains in AI infrastructure and quantum computing breakthroughs are defining the technology landscape. Should quantum supremacy be validated, scaling is anticipated to begin, with efforts guided toward applying this computing toward AI inference and training. This will require a low-cost electronic-to-photonic and quantum-supporting infrastructure.

Meanwhile, AI computation is already scaling, with data processing requiring enormous infrastructure investments of servers as well as the power systems to support them. This will make efficiency even more important than it is currently. And, it will further drive research and increase the business of SiC electronics.

AR glasses will be a major user of the AI infrastructure as training on live contextual information becomes necessary and the resulting information is delivered on SiC-based wide FOV glasses. Perhaps quantum computing on SiC will eventually deliver the next AI infrastructure buildout that feeds this future of wearable computing.

This is not unlike the self-fulfilling circular ecosystems, driven by the solid-state transistor integrated circuit toward computing, that have led to both display and AI.

But now, if this occurs again, electronics, photonics, and quantum physics will have merged.

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Opportunities and Challenges Illuminate the Path to Scalable Quantum Computing

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Quantum is still in its early days, but the technology has been heating up. During the last five years, companies such as Google, IBM, Honeywell, and Microsoft have developed quantum computers, and some now offer cloud quantum computing services. In 2021, the European Union (EU) launched the HPCQS project, which is aiming to integrate two quantum simulators — each capable of controlling more than 100 qubits — with two existing European Tier 0 supercomputers, located in France and Germany, by the end of 2025. Here, the broader objective was to provide noncommercial cloud access to public and private European users to solve complex challenges in areas such as materials and drug design, logistics, and transportation.

Market forecasts reflect such an uptick in activity: The global quantum computing market is projected to grow from \$1.2 billion in 2024 to \$12.6 billion by 2032, at a compound annual growth rate of 34.8%, according to Fortune Business Insights. During this period, the highest market share (by end user) is predicted to be health care. This is due to the increase in the use of quantum-enhanced machine learning methods and the creation of virtual environments in which specialists can examine variables, such as skin temperature, electrolytes, and circulation, on digital human replicas.

Next is the banking, financial services, and insurance sector. This owes to the increased use of computing services to resolve complex financial calculations

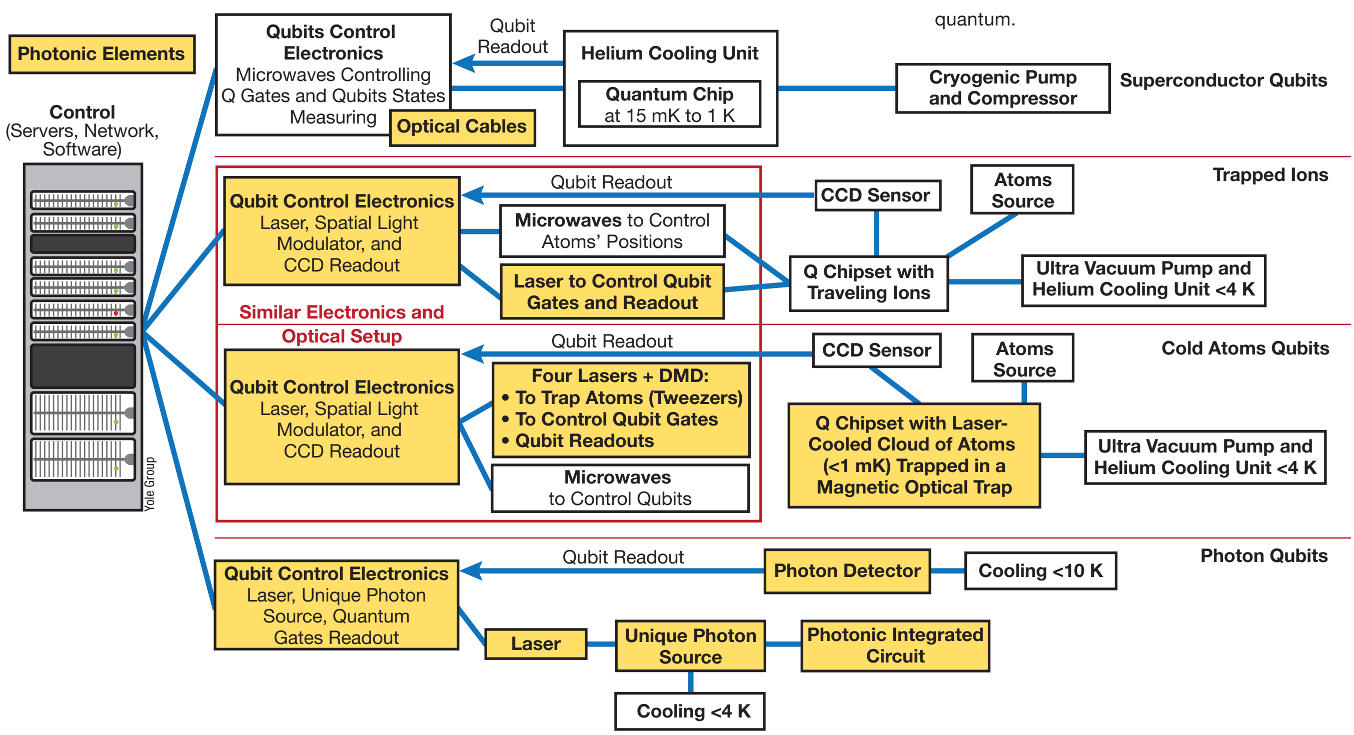


Figure 1. The different architectures of quantum computers, their applications, and requirements. DMD: digital mirror device; Q: quantum.

faster as well as the need to address the security challenges posed by quantum computers. In terms of market share, automotive, energy and utilities, chemical, manufacturing, transportation, and logistics follow the health care sector and the banking, financial services, and insurance sectors.

Yet, the systems that comprise this iteration of quantum computers that some of industry's largest and most influential companies have introduced remain in the prototype stage. Currently, developers are focused on resolving bottlenecks related to scaling the required number of physical qubits and decreasing error rates and noise, among other challenges. This technology is also expensive, with costs particularly high for platforms that require intricate cooling technologies on top of the cost to develop and operate. There is also a well-documented skills gap.

For these reasons, global consulting firm McKinsey & Company has estimated that only 5000 quantum computers will be operational by 2030. The agency's forecast said that the hardware and software necessary for managing the most complex problems will not be available until 2035 or later.

Photonic quantum computers

The fundamental unit of information in quantum computing is the qubit. Unlike classical bits, which can be either 0 or 1, qubits can exist in a superposition of states, meaning they can simultaneously represent both 0 and 1 to varying degrees. This property enables quantum computers to process vast amounts of information more efficiently and far more rapidly than classical computers for certain tasks.

A variety of technologies can be used to make qubits. These include trapped ions, photons, artificial atoms (which can be real and/or artificial), and spin qubits. Superconducting materials, such as aluminium, can also make qubits. Each fabrication approach offers advantages and disadvantages based on physical

QuiX Quantum

Figure 2. QuiX Quantum's universal quantum computer, using photonic technology. The system supports health care, AI, logistics, high-tech, and finance applications.

properties, scalability, and practical implementation.

Photonic quantum computers use several critical elements for their operation. Cluster states, using either single photons from quantum dots, integrated photon-pair sources, or squeezed light are among the most crucial. Fast and low-loss feedforward, which can adapt to measurements settings in between the arrival of bunches of photons, is another essential component for pumping the sources, as are integrated lasers. Efficient photon detection is enabled by single-photon detectors. Waveguides, beamsplitters, phase shifters, and optical switches facilitate the necessary photon guidance, interference, modulation, and routing in quantum circuits. Quantum memory elements, such as color centers and optical delay lines, provide storage and synchronization. Additionally, error correction, feedforward circuits, and real-time error correction codes are necessary to maintain quantum coherence and to counteract noise that is created due to photon loss.

Between 2019 and 2024, the highest investment in quantum technology platforms was in photonics ($1.2 billion), according to Yole Group's Quantum Technologies 2024 report (Figure 1). This is due to the platform's stability, ambient temperature operation, and market availability of photon sources and detectors. Another key driver for this investment is that photons are already used in telecommunications and data communications applications, and therefore, photonics offers a mature platform for interconnecting many photonic quantum computers. Plus, photonics enables hybrid approaches that combine the strengths of different quantum technologies. Photons effectively interact with other qubit system types, such as trapped ions or superconducting qubits.

The next biggest area of investment is superconducting, at $1.1 billion over the same timeframe. Superconduction is the most mature technological approach, and its primary advantage is fast gate operations. At the same time, it requires extremely low temperatures in the millikelvin range, which is energy-intensive and costly. Trapped ion, neutral atom, and silicon qubit approaches followed in Yole's investment rankings. Neutral atom and silicon qubit approaches both benefit from a scalability advantage through the use of wafer-scale technologies and existing industrial foundry infrastructure.

Technology advancements in Europe

In 2018, as part of a move toward quantum European sovereignty and better production facilities, the EU launched its Quantum Technologies Flagship. The launch aimed to provide €1 billion to support numerous projects in quantum technology and to thereby consolidate and expand European scientific leadership and excellence in quantum technologies. The response has been swift, and European companies are meeting this challenge in the realm of photonic quantum computing.

QuiX Quantum, founded in the Netherlands in 2019, is one of Europe's leading quantum computing companies based on integrated photonics technology (Figure 2). The company is developing a scalable and energy-efficient universal quantum computer for health care, AI, logistics, high tech, and finance applications. QuiX is under contract to deliver prototype 8-qubit and 64-qubit versions to the German Aerospace Center (DLR) by 2027.

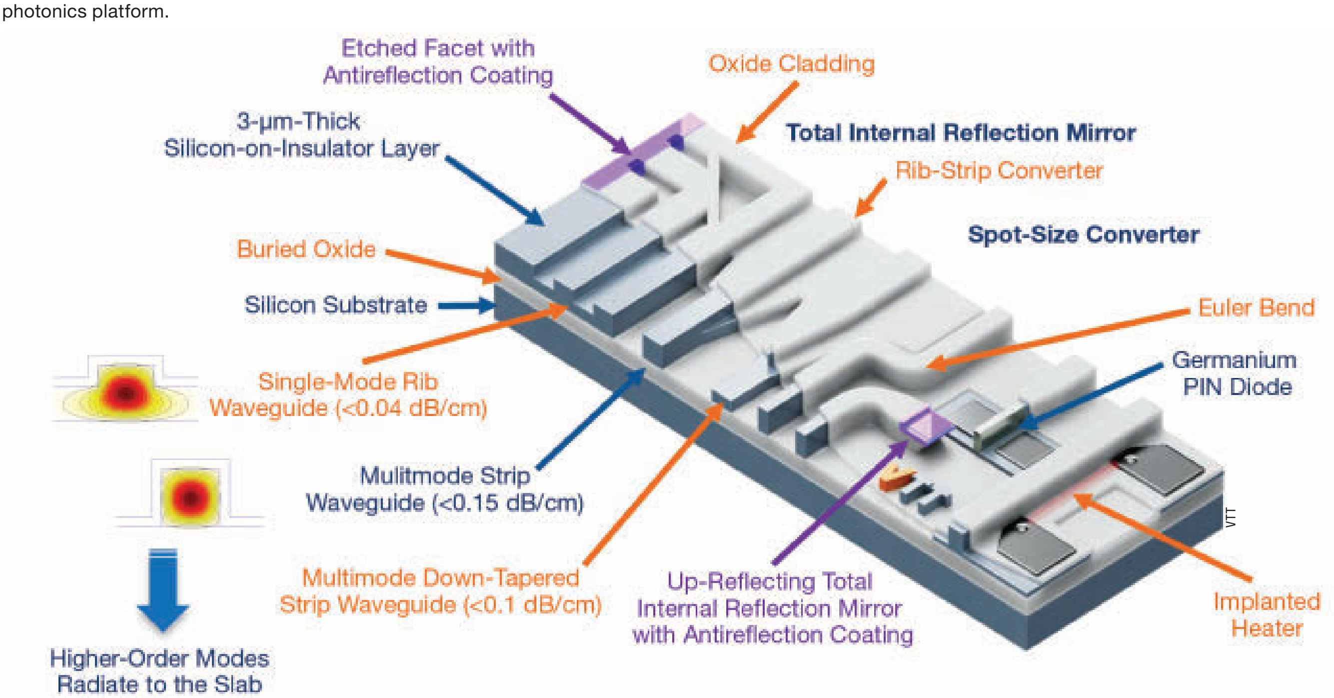
The core elements of QuiX's platform include its quantum light sources and universal quantum processors. In combination, these elements generate *n*-dimensional entangled states, i.e., cluster states, and a fast feedforward mechanism for adapting the measurement settings in between clock cycles. QuiX's quantum computers are modular, which means they contain many fiber interconnects. The company's use of silicon nitride waveguides ensures low coupling losses. The underlying physics here is the refractive index of the optical fiber and waveguide, which are matched, as is the diameter of the mode field.

QuiX has also developed a special-purpose quantum computer to solve specific problems in the optimization and simulation field. The company launched this computer in September 2024 as the Bia quantum cloud computing service. The 20-optical channel Bia system comprises a light-generation module, a quantum processing unit, a light detection module, and advanced quantum control software. Bia technology can be combined with off-the-shelf components, and the complete package is designed for seamless integration with traditional computing infrastructure, representing a pivotal movement toward hybrid computation. The processing unit, called Alquor, is a low-loss, multichannel, reconfigurable interferometer, which allows the user to perform arbitrary, controlled linear optical unitary transformations between several optical channels. The processor therefore provides a solution for applications in quantum communication, quantum random number generation, and machine learning.

VTT Technical Research Centre of Finland Ltd. is another organization that has achieved milestone strides in quantum computing. In collaboration with IQM Quantum Computers, VTT developed Finland's second quantum computer, a 20-qubit system, in work that builds on a 5-qubit quantum computer — and that now includes an ambitious road map to scale to a 50-qubit system. The center's vision includes creating quantum systems with up to 300 qubits to achieve quantum advantage, enabling practical and transformative applications. VTT additionally works as part of Qu-Pilot, an EU-funded project to develop and provide access to the first pilot production facilities for quantum technologies in Europe. Qu-Pilot runs in parallel to the Qu-Test initiative to provide an infrastructure for testing and experimentation with quantum technologies.

VTT's thick silicon-on-insulator (SOI) platform in 3 µm provides the possibilities for both hybrid and monolithic inte-

Figure 3. Key building blocks of VTT Technical Research Centre of Finland Ltd.'s integrated photonics platform.



gration of active and passive components. The dimension of the current waveguide provides effective mode confinement and is equipped to handle issues arising from wall roughness, enabling the SOI platform to benefit from ultralow-loss properties.

Other capabilities from VTT include cryo-compatible, low-loss optical opto-electronic packaging, 3D integration, and photonic integrated circuits (PICs) assembly (Figure 3). The organization is working on devices, such as germanium avalanche photodiodes and germanium PIN photodiode receivers, for quantum key distribution applications. It is also developing superconducting nanowire single-photon detectors, also primarily for quantum key distribution applications.

At the same time, VTT is developing a low-loss silicon nitride platform for quantum sensing and communication applications. This platform is comprised of active and passive devices that cover a wavelength range between 900 and 1550 nm. The platform offers active components such as graphene photodetectors and modulators. VTT previously developed wafer-scale graphene-based photodetectors with high responsivity in this way.

VTT's work in integrated photonics highlights the importance of the sustained development of PICs, which function as a core computation unit on which photonic quantum computers rely. In these architectures, the PIC is connected to several optical fibers — though current expectations are that the numbers of optical fibers in these systems will exceed 100 by 2030. The performance of such a quantum computing system can be compromised by optical path losses; saving even 1% in the fiber-to-chip connection is critical.

Clearly, one of the main challenges in realizing photonic quantum computers is the implementation of a highly efficient optical system, which requires exceptionally low optical loss performance to properly achieve quantum supremacy. A percentage of the optical power of the system is lost in the optical interfaces connecting these architectural blocks of a quantum computer, and the insufficient fiber array accuracy currently available in the market is unable to overcome this bottleneck.

Founded in 2021, Eindhoven, Netherlands-based MicroAlign has developed an approach to enable precision alignment of fiber arrays. The company is maximizing the reach and efficacy of newly developed technology based on high-complexity photonic chips. MicroAlign's solution is a high-accuracy fiber array, for which all fibers are assembled via an active alignment method to provide a core pitch accuracy of <100 nm, which can be scaled to tens of fibers in an array. These fiber arrays could be fundamental for the manufacturers of quantum photonic computers endeavoring to accelerate the development and adoption of the technology into new markets.

Finally, TOPTICA Photonics AG is also driving gains as a developer and manufacturer of lasers for quantum computing and quantum communications as well as quantum sensing. In support of quantum computing, the company provides a range of laser solutions for ion, neutral atom, and nitrogen-vacancy center qubit systems. TOPTICA's laser offerings include highly coherent tunable diode laser systems, both amplified and nonamplified; high-power amplifiers; stable frequency reference systems including wavelength meters, spectroscopy cells, and frequency combs; complete laser system solutions, optionally fiber-coupled; and 19-in. rack-mounted lasers for wavelengths ranging from 330 to 1770 nm. These systems are highly modular, fully integrated, and frequency stabilized to enable customers in the quantum realm to mix and match different laser types.

Future outlook

Quantum computing holds immense potential but faces critical challenges on the path to large-scale implementation. Scalability is a major hurdle, with current devices housing only tens to hundreds of qubits — far from the thousands or millions needed for practical use. Environmental noise and decoherence threaten qubit stability, and high error rates in quantum gates demand breakthroughs in error correction. Optimized quantum algorithms for real-world problems are scarce, and existing quantum programming tools remain underdeveloped compared with classical software. Lastly, a skills gap in quantum expertise highlights the need for robust training programs to prepare future researchers and engineers. This skills gap is evident in the need to put these critical algorithms toward application and the need for improved hardware and components that can support systems developed at scale.

Looking toward 2035, Paris-based Institut d'Optique has made several recommendations for addressing the current limitations of quantum computing technologies within Europe. Technical issues identified by the institute include those involving lasers, which will need more power, greater wavelength range, lower noise, and a higher technology readiness level, and at a lower cost, with a reduction in user interaction. There is also a need for more efficient single-photon sources with improved miniaturization. More advanced optical detectors are also required, according to the institute, along with better cryogenic compatibility, lower loss reduction, and greater modulation for sources and detectors.

Fortunately, supply issues in these areas are not currently expected in Europe. This is a testament to its development and supply of high-quality laser sources and photonics systems for quantum technology. Europe serves as much as 80% of the current global market for quantum needs, according to estimates.

However, greater EU sovereignty for photonics components, improved high-end foundry fabrication, and more assembly lines for PICs are necessary growth steps. In addition, moving from small volume with high cost to larger volumes with low cost necessitates a stable, long-term market with greater capital investment from governments and European contracts. As R&D efforts continue in these areas, integrated photonics will drive innovations to redefine quantum computing, heralding an era of technology that will reshape industries and society.

ivan.nikitski@epic-photonics.com

Product News

Video Measuring System

The NEXIV VMF-K series from **Nikon Corporation** is a video measuring system that automatically measures the dimensions of electronic components, including semiconductor devices. The series uses a confocal optical system that can take micron-level measurements of 2D and 3D objects. The NEXIV VMF-K series also features an LED confocal light source, SEMI S2/S8 compliance, and 30× and 45× magnification.
sales.nm-us@nikon.com

Quantum Cascade Lasers

Boston Electronics' quantum cascade lasers can be used for spectroscopy applications such as gas spectroscopy. The lasers have TEM00 beams collimated to <6 mrad and are spectrally monochromatic with a bandwidth of a few megahertz. The quantum cascade lasers feature continuous-wave operation with >5-mW power, a hermetic package with internal collimation and chip-temp-stabilizing Peltier cooling, and target frequencies of 1030 cm^{-1}, 1046 cm^{-1}, 1103 cm^{-1}, and 1900 cm^{-1}.
boselec@boselec.com

Bidirectional Optical Transceiver

The 100G QSFP28 ZR4 BiDi from **NEC Corporation** is a single-fiber bidirectional optical transceiver for data center applications. The transceiver extends transmission distances up to 80 km using a direct detection method rather than a coherent method and incorporates a high-output laser on the transmitting side and an optical semiconductor amplifier on the receiving side to provide a link budget of 30 dB. The 100G QSFP28 ZR4 BiDi features a bit rate of 103 Gbps over Ethernet and 111.8 Gbps over OTU4 signal, an optical interface of 4 × 25.78 Gbps, and a power consumption of 5.5 W or less.
info@necam.com

Compact Fiber Laser

The ARM FL from **Coherent** is a compact adjustable ring mode fiber laser for industrial laser applications. The laser's internal active power control and back reflection insensitivity help to bring consistent welding results and maximized yield, and an updated high-performance controller enables faster process monitoring solutions. The ARM FL is compatible with the company's process heads and features the option to be connected to multiple scanner units.
info@coherent.com

Coherent-Lite DSP

The Aquila from **Marvell Technology** is a coherent-lite digital signal processor (DSP) made for 1.6-Tbps coherent optical transceiver modules operating at O-band wavelengths. The DSP comes in a pluggable module form factor with 400 Gbps/lane 16-QAM signaling. The Aquila was developed for distributed campus data center interconnects spanning up to 20 km with high bandwidth and low latency.
info@marvell.com

Miniature Hexapod

The HexGen HEX150-125HL from **Aerotech Inc.** is a miniature hexapod for applications including silicon-photonic device manufacturing and inspection, optics alignment, photonics device manipulation, optical wafer probing, and electro-optics testing. The compact hexapod uses a six degree-of-freedom precision positioning system along with a peak-to-peak repeatability over a large travel range. The HexGen HEX150-125HL features a 150-mm base diameter, a nominal height of 125 mm, a maximum speed of 30 mm/s, and a turning speed of 30°/s.
amcgrath@aerotech.com

Line-Scan Imagers

The GLT5008BSI and GLT5016BSI from **Gpixel** are back-side illuminated time delay and integration line-scan imagers for semiconductor inspection and life sciences applications. The GLT5008BSI has a horizontal resolution of 8K pixels and is available in speeds of 500 kHz and 1 MHz with a dynamic range of 65.8 dB in 12-bit mode and 61.5 dB in 10-bit mode, while the GLT5016BSI has a horizontal resolution of 16K pixels and operates at a maximum line rate of 500 kHz. Both imagers feature dual-band architecture providing high dynamic range (256 and 32 stages each), a peak quantum efficiency of >92% at 440 nm, and high-speed readout capabilities.
info@gpixel.com

DBR Laser

Modulight's 632.8-nm distributed Bragg reflector (DBR) semiconductor laser is designed to

replace traditional helium neon lasers across a range of applications. The laser features a power output of up to 25 mW and single-frequency operation with a linewidth of <10 MHz. The DBR laser is available on the company's ML6600 platform with packages including 14-pin butterfly and TO-can.
sales@modulight.com

Microscope and Measurement System

The O-INSPECT duo from **ZEISS** is a system that combines a microscope and measurement technology for the measurement and inspection of large workpieces, such as circuit boards and fuel cells, to smaller components. The solution uses an integrated pallet system, allowing measurements and inspections to be prepared and then carried out on the system as well as an optional vibration isolation for precision in environments with floor vibrations. The ZEISS O-INSPECT duo features an adjustable ring light and a 5-MP color camera. It is compatible with ZEISS software CALYPSO for measurement applications and ZEISS ZEN core for microscopic analyses.
info.metrology.de@zeiss.com

Stepper Motor

The ASA86 from **Nanotec** is a UL/CSA-certified stepper motor for automation applications in

harsh environments. The motor comes in a built-in encoder in an incremental version with a resolution of 4096 counts per revolution/16,384 pulses per revolution and a multiturn version with an SSI of 16-bit multiturn/17-bit singleturn. The ASA86 features an 86-mm flange and a holding torque of up to 933 Ncm (newton centimeters).
info@nanotec.de

UV Laser Marking System

The 7920 from **Videojet Technologies** is a UV laser marking system for coding operations in the consumer-packaged goods, parts marking, and pharmaceutical industries. The system's compact design and beam turning units allow for a 360° rotation, and it comes with IP54 environmental protection and an optional IP65 rating to help enable reliable operation in a range of conditions. The 7920 features advanced cellular and Wi-Fi connectivity options for secure remote interface control and analytical capabilities, integration into production and control networks using EtherNet/IP and ProfiNet protocols, and marking speeds up to 2000 characters/s.
vti.domesticcs@videojet.com

3D Sensor

The ECCO X 100 from **SmartRay** is a 3D sensor for automated inspection. Providing inspection at a metrology-grade level, the sensor comes in a 450-nm blue and 660-nm red laser version that can be used in multisensor setups. The ECCO X 100 features up to a 40-kHz scan rate, 4096 3D points per profile, four connector options, and a compact design.
info@smartray.com

SWIR LEDs

The OCI-490 series from **EPIGAP OSA Photonics GmbH** is a series of SWIR LEDs for sorting and quality control tasks in pharmaceutical, medical, defense, and agricultural industries, among others. The SWIR wavelengths in the high-power LEDs' packages allow imaging through dust, fog, and smoke, enhancing visibility in harsh environments such as extreme heat,

humidity, and vibration. The OCI-490 series features a wavelength range from >1720 to 2300 nm with a 1-A and 41-mW optical output.
sales@epigap-osa.de

Dual Laser System

The RenAM 500D from **Renishaw** is a dual laser additive manufacturing machine fitted with the company's TEMPUS technology that allows the laser to fire while the recoater is moving, saving up to 9 s per build layer. The machine's dual 500-W lasers can access the entire build platform. The system is fully compatible with Renishaw's AM software suite, including Renishaw Central and QuantAM.
usa@renishaw.com

Laser Line Scanner

The Eyeonic Trace from **SiLC Technologies** is a Class 1 laser line scanner and all-in-one inspection and measurement tool for objects in motion, including on an assembly line or being scanned by a robotic arm. The scanner uses the company's Eyeonic Vision Sensor with an integrated silicon photonics chip containing low-loss waveguides, coherent detection, semiconductor optical amplifiers, and other photonic functions. The Eyeonic Trace also features a 72° field of view and a form factor of 200 × 135 × 75 mm.
contact@silc.com

Inverted Microscope System

The IXplore IX85 from **Evident** is an automated inverted microscope system for life sciences research applications. The microscope system's built-in optics provide consistent lighting across the entire field of view, allowing users to collect large, uniform images. It uses silicone gel pad technology that moves with the objective, eliminating the need to wipe or replace oil as a sample is navigated. The IXplore IX85 features a 26.5-mm field number, automated acquisition features, task management software, an automatic correction collar, and advanced real-time image processing and analysis.
kristopher.lee@evidentscientific.com

Alpha-Beta Goniometers

The AK150-10-15 Series from **Optimal Engineering Systems** (**OES**) are dual-axis alpha-beta goniometers for applications such as examining cutting edges of medical instruments, estimating hyperspectral bidirectional reflectance, measuring radiation patterns of LEDs, directing lasers, and manufacturing quartz oscillator plates using quartz cutting x-rays. The series has four motor options, including stepper motors and three-phase brushless direct current servo motors. The AK150-10-15 Series features ±10° of travel on the alpha axis, ±15° of travel on the beta axis, a 120- × 120-mm table, and end-of-travel limit switches and preloaded crossed roller guides on each axis.
sales@oesincorp.com

High-Density Fiber Switch

The ECS5550 series from **Edgecore Networks** are 1/2.5/10 Gigabit Ethernet devices designed for carrier, enterprise, and small data center applications. The series enables expanded services from residential to business users through networks, Layer 2 virtual private networks, and advanced OAM features while supporting IPv6 adoption. The ECS5550 series supports ITU-T G.8032 Ethernet ring protection switching with sub-50-ms convergence time for Layer 2 ring protection and features 100 GbE uplinks.
sales@edge-core.com

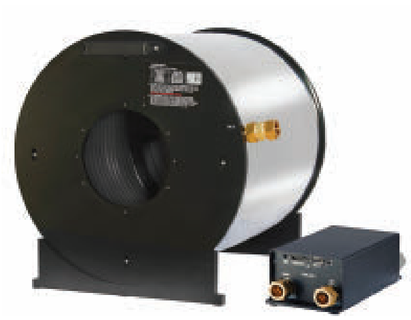
Personalization CO_2 Lenses

Laser Research Optics' line of direct field-replacement CO_2 laser lenses and mirrors are designed for laser engravers for personalized work. The lenses and mirrors come in 1- and 1.5-in. diameter sizes, are fully OEM compatible with 25- to 250-W engraving lasers, are optimized for 10.6 µm, and are available with focal lengths from 2- to 7.5-in. × 0.5-in. increments.
sales@laserresearch.net

Stereo Camera

The 3DPIXA pro dual 200 µm from **Chromasens** combines line-scan imaging technology with 3D stereo computation for the inspection and scanning of large, complex, or irregularly shaped objects to identify flaws. The camera

simultaneously captures 2D color images along with a height map or 3D point cloud and can detect overlapped or nonaligned parts, as it displays different colors on the depth map based on height differences. With line-rate speeds of 29.7 kHz and an optical resolution of 200 µm/pixel, the 3DPIXA pro dual 200 µm features a 1400-mm field of view, a trilinear CCD line RGB sensor with 10- × 10-µm pixels, an IP50 rating, and a 220.3- × 463- × 98.5-mm housing.
sales@chromasens.de



High-Power Laser Sensor

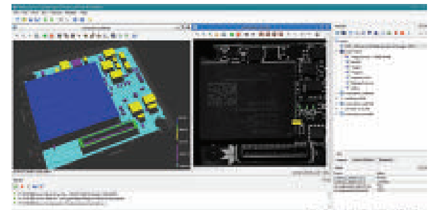
The Ophir 150K-W from **MKS Instruments** is a calorimetric laser sensor for measuring high power levels from 10 to 150 kW. The water-cooled sensor measures laser powers over a spectral range of 900 to 1100 nm and a low back reflection of <0.5%. The Ophir 150K-W incorporates a beam dump and measurement unit and is equipped with an RS232 interface and a smart connector interface that operates with the company's Centauri, StarBright, StarLite, and other Ophir smart displays.
sales@newport.com

Linear Servo Motor

The GVCM-032-038-02M from **Moticont** is a linear voice coil servo motor for applications including medical devices, laser machining and drilling, scanners, laser beam steering and filtering, optical focusing, testing, sorting, and assembly. The motor has a 25.4-mm stroke with a built-in shaft and bearing and is 31.8 mm in diameter. The GVCM-032-038-02M also features a continuous high-force-to-size ratio of 8.3 N, 26.1 N of peak force at a 10% duty cycle, an M2.2X0.45 × 0.2 threaded shaft, and a combined length with a coil end of 47.63 mm.
moticont@moticont.com

3D Measurement Software

The Z-Trak 3D Apps Studio from **Teledyne DALSA** is a suite of software tools developed for in-line 3D machine vision applications, such as measurement and inspection. Designed to work with the company's Z-Trak family of laser profilers, the software suite is capable of



handling 3D scans of objects with varied surface types, sizes, and geometric features. The Z-Trak 3D Apps Studio features tools for measuring object thickness, inspecting glue-beads, weld seams, and identifying defects on flat, inclined, and curved surfaces on machined, assembled, or extruded parts as well as anchoring and data enhancement features such as reflection.
tdi_sales.americas@teledyne.com

SF6 OGI Camera

LightPath Technologies' SF6 optical gas imaging (OGI) camera can detect fugitive ammonia and sulfur hexafluoride (SF6) emissions for industrial and manufacturing applications. The camera images gases that are invisible to the naked eye by detecting the infrared energy absorbed or emitted by the gases. The SF6 optical gas imaging camera features the company's non-germanium BlackDiamond BD6 lens.
sales@lightpath.com

MARCH

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

International Laser Safety Conference
(March 3-6) Orlando, Fla.
Contact The Laser Institute, +1 407-380-1553; www.ilsc.ngo.

LASER World of PHOTONICS China
(March 11-13) Shanghai.
Contact Messe München GmbH, +49-89-949-11468, **info@world-of-photonics.com**; www.world-of-photonics.com/en/china.

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

Image Sensors Europe
(March 18-19) London.
Contact Image Sensors Europe, +1 330-762-7441; www.image-sensors.com/image-sensors-europe.

W3 + Fair WETZLAR
(March 19-20) Wetzlar, Germany.
Contact FLEET Events GmbH, **w3plus@fleet-events.de**; www.w3-fair.com/en/wetzlar.

SEMI MEMS & Sensors Technical Congress (MSTC)
(March 26-27) Atlanta.
Contact SEMI, **mfabiano@semi.org**; www.semi.org/en/connect/events/mems-and-sensors-technical-congress-mstc.

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

APRIL

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

SPIE Optics + Optoelectronics
(April 7-11) Prague.
Contact SPIE, +1 360-676-3290, **customerservice@spie.org**; https://spie.org/conferences-and-exhibitions/optics-and-optoelectronics.

AeroDef Manufacturing
(April 8-10) Detroit.
Contact SME, +1 800-733-4763, **aerodef@xpressreg.net**; www.aerodefevent.com.

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

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

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

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

MAY

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

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.

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

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.

PAPERS

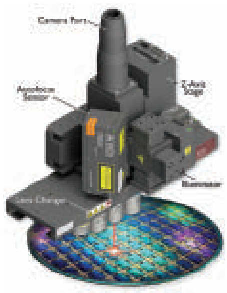
SPIE Optifab
(Oct. 20-23) Rochester, N.Y.
Deadline: Abstracts, May 7
Contact SPIE, +1 360 676 3290, **customerservice@spie.org**; www.spie.org/conferences-and-exhibitions/optifab.

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.

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

Photonics Showcase

PFA-LN Dynamic Adaptive Aufofocus



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

WDI Wise Device Inc.
(905) 415-2734
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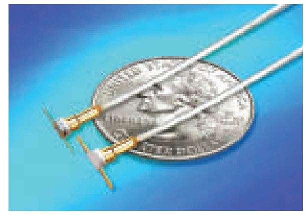
Compact InGaAs Photodiode



Fermionics Opto-Technology introduces high-speed, low-dark-current, low-capacitance indium gallium arsenide FD80 Series photodiodes with space-saving surface-mount packaging. Ultracompact ceramic fiber pigtail photodiodes are specially designed for extremely tight spaces and ideal for high-speed communication systems. The planar-passivated device with 80-µm active area on a horizontal- or vertical-mount S8 ceramic package can be coupled directly to a single- or multimode pigtail fiber.

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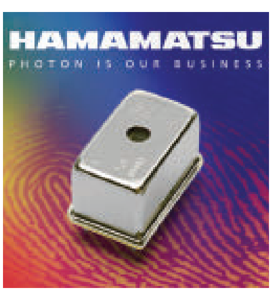

Hamamatsu's C16767MA ultra-compact spectrometer head is equipped with an image sensor with enhanced UV resistance that supports high UV sensitivity and a spectral response range of 190 to 440 nm. Ideally suited for integration into mobile measurement equipment, the C16767MA can easily integrate into devices for water quality analysis and semiconductor process monitoring for example. Enhance your device with this lineup of mini-spectrometers.

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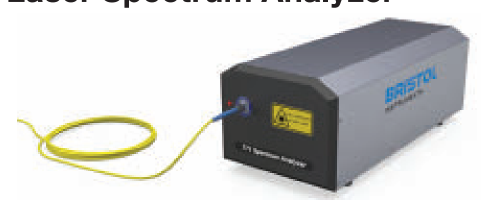
771 Laser Spectrum Analyzer



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

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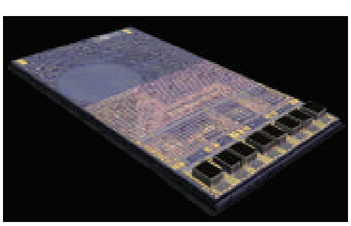

POET Teralight powers AI with 1.6T speeds in 2xFR4 and DR8 configurations to support the industry's leading pluggable transceivers. Teralight removes wire bonds and active alignments of components, creating an elegant architecture that can reach 3.2T. Teralight is a system-on-chip with integrated drivers, EML lasers, multiplexer (if needed), MPDs and thermistor. Its power efficiency and low cost puts it at the forefront of optical-engine design.

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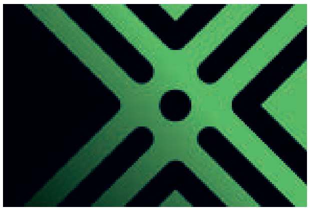

The latest trends and innovations in photonics will be the focus of the next Laser World of Photonics, June 24–27, 2025 at Messe München. The world's leading platform for the laser and photonics industry covers the entire market–from optoelectronics and laser manufacturing to imaging, sensors and biophotonics. It also offers a comprehensive supporting program with application-oriented presentations, awards, start-up programs, guided tours, special shows and much more. The co-located World of Photonics Congress as well as the trade fairs World of Quantum and automatica provide added value. More information and tickets.

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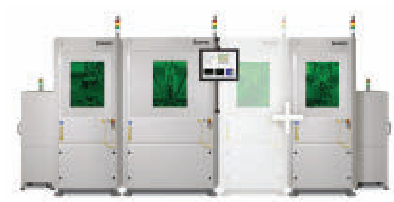
Photonics Assembly and Test



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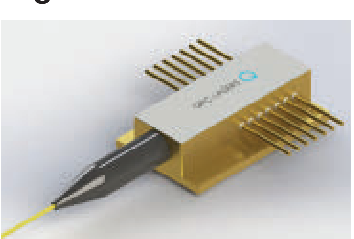

QPC Lasers offers the world's highest power narrow-linewidth diodes for sensing applications, including the detection of methane at 1.65 µm. They have powers beyond 500 mW and can be frequency modulated. They are packaged in thermoelectrically cooled PM single-mode fiber-coupled butterflies and free space configurations. Other applications include wind lidar and free space communications.

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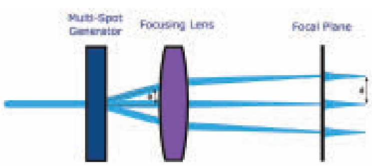

Transforms a single mode input beam into a multi spot array in the focal plane of a lens — these are available as custom designs for specific input wavelength, number of output spots and spot separation. The freeform grating structure design allows for much higher diffraction efficiencies. Multi-Spot Generators are important in applications such as the surface micro-structuring of metal to produce hydrophobic surfaces, using a femtosecond laser.

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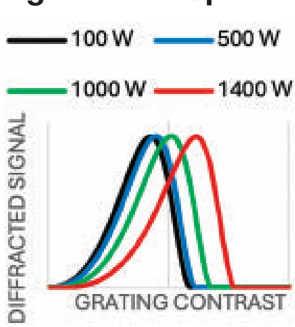

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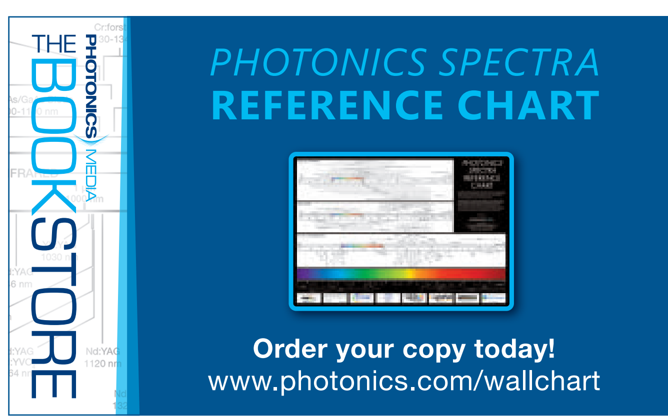

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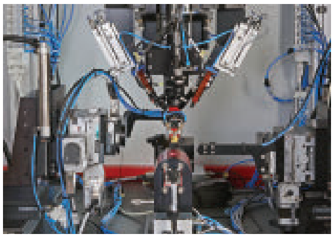

The NanoGlue, NanoWeld, and NanoSolder series are partly or fully automated production stations for demanding alignment and low-shift assembly procedures in opto-electronics industry. The linear axes work with 5-nm resolution, and angular rotation resolution is below 0.0005°. Long travel ranges facilitate the loading and unloading procedures while the modular architecture allows for fast and reliable customization. Visit us at OFC in San Francisco (April 1-3), booth #5439.

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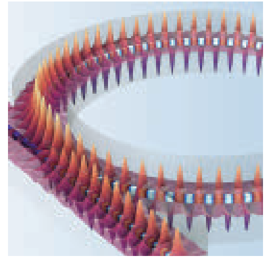

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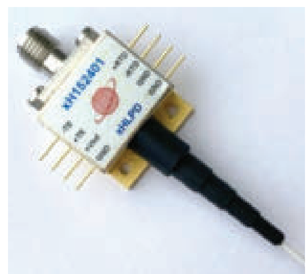

The xHLPD photodiodes provide high power operation up to 10 GHz bandwidth, and deliver up to 4 V peak-to-peak (+16 dBm CW) RF output power with exceptional phase linearity < 5 rad/W. The thermoelectrically cooled modules enable reliable device operation with multiple biasing options. Applications include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

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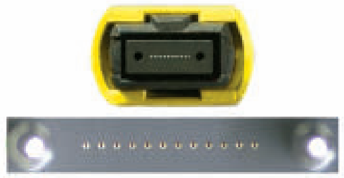

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The humble heart cockle: Nature's fiber optics

The name heart cockle, despite being wonderfully sophomoric, is apt for the Indo-Pacific native clam. The moniker goes beyond the mollusk's heart-like shape: It just can't help but fall head over shell for a certain microscopic alga in its native waters, with which it forms a symbiotic relationship. In return for a home that's safe from most predators, the algae feed the host heart cockle with a sugary byproduct produced via photosynthesis.

Biologists and other experts in the field might take umbrage with this proposition, as photosynthesis generally needs the sun to make the arrangement work. The heart cockle presumably realized this too somewhere down its evolutionary ladder and so has evolved, developing natural skylights in their shells in a more reminiscent pattern than you might have guessed.

Using a laser scanning microscope to study the 3D geometry of heart cockle shells, researchers at Duke University discovered tiny translucent bumps smaller than a grain of sand under each window that function as lenses. These bumps allow sunlight to enter the normally dark space without the need for the clam to open. But when given a closer look, researchers realized that within the bumps, the shell material resembles something familiar: tiny optical fibers.

Most of the heart cockle's shell is made up of a special form of calcium carbonate called aragonite, which has a layered structure, with thin plates of the material stacked in different orientations. And within each window, the material of the shell forms tightly packed, hairlike fibers, rather than plates, all lined up in the direction of incoming light. The fibers specifically filter in blue and red light and appear to block ultraviolet radiation, with the former being most optimal for photosynthesis.

And while this is great for plant life, as the researchers shined light down on the bundled fibers, the shell's cramped fiber arrangement allowed them to see a high-resolution image of whatever appeared on the other side, likening the phenomenon to a TV screen.

The researchers said more work will need to be completed to understand the reason heart cockles have this ability to project images, although it may be safe to assume that it's not to show predators the meat inside. And while the jury is still out on the clams' imaging feat, computer simulations on the layered fibers found that the size, shape, and orientation of the fibers transmit more light into the heart cockles' interior than other possible designs that the creatures could have hypothetically come up with. With this knowledge, researchers believe that they might inspire new designs for fiber optic cables that allow light to travel great distances, even around curves, without escaping and losing signal along the way.

In any case, whether nature's cardiac-shaped mollusk will lead us to improve our communication technologies, the promise of advancements like this would leave anybody happy as a … well … you know.

The research was published in *Nature Communications* (www.doi.org/10.1038/s41467-024-53110-x).

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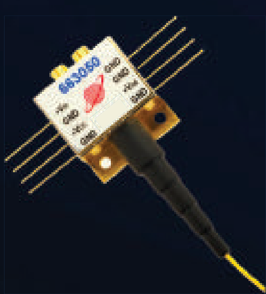
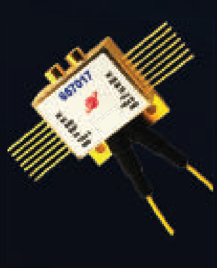
WIDE BANDWIDTH OPTICAL RECEIVERS FOR MAXIMUM NETWORK FLEXIBILITY





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