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February 2025

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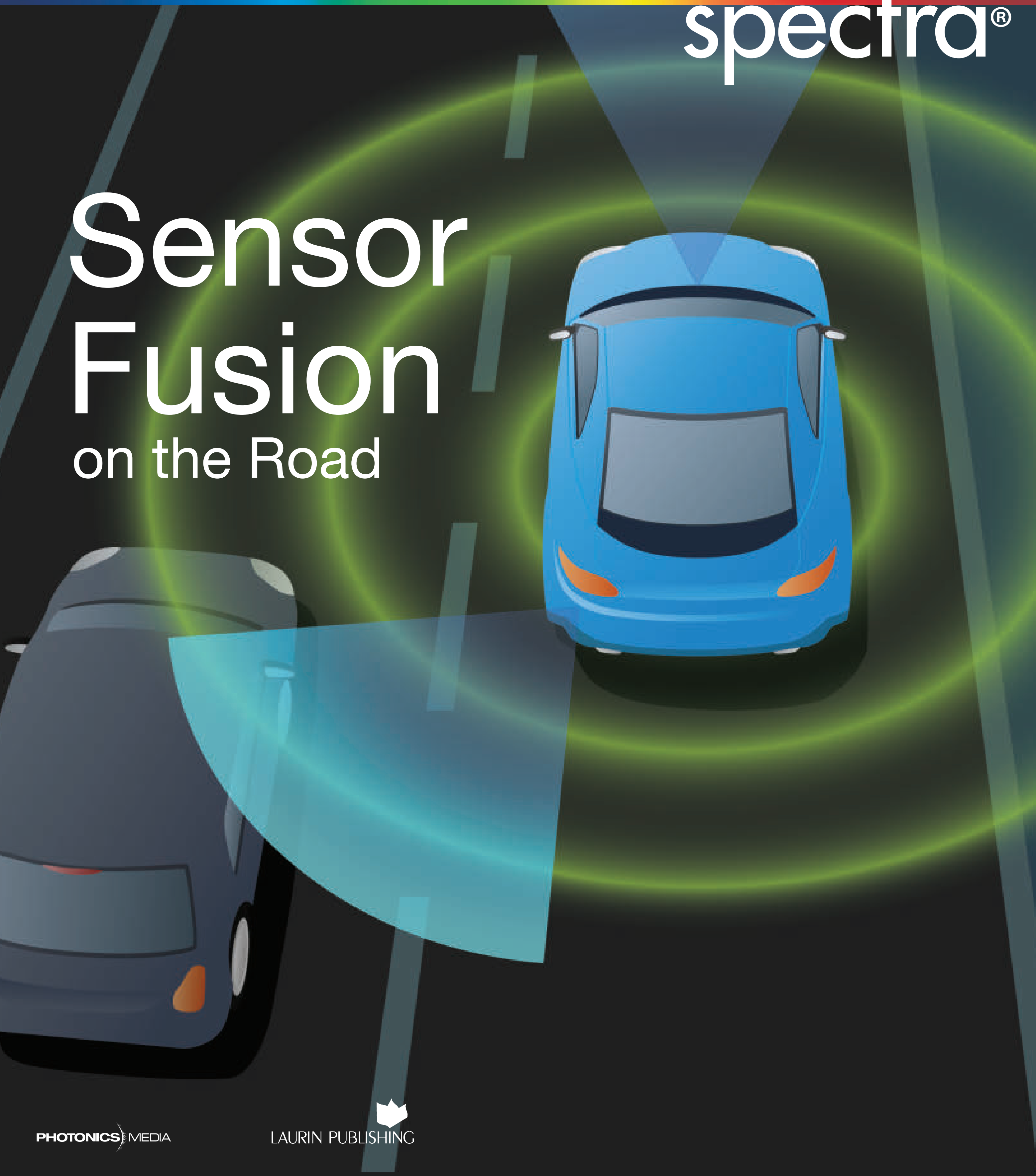

Sensor Fusion on the Road

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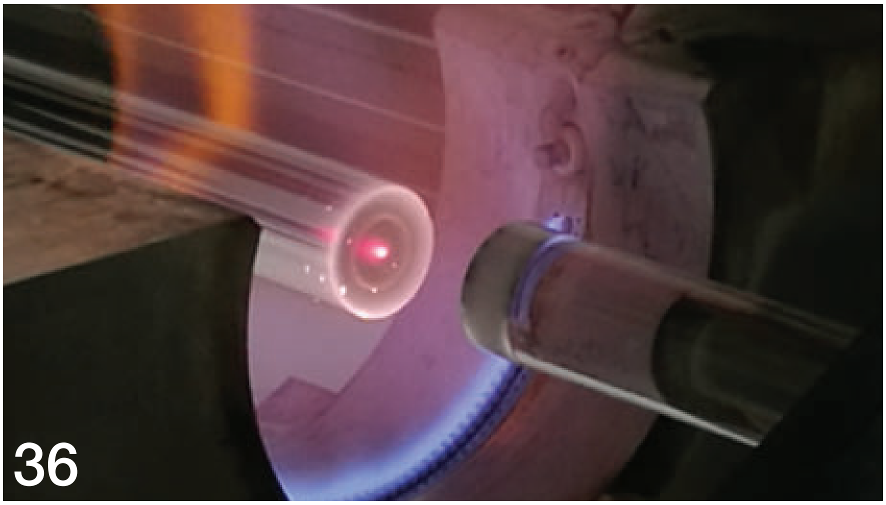
Inside This Issue

February 2025 volume 59 issue 2

Features



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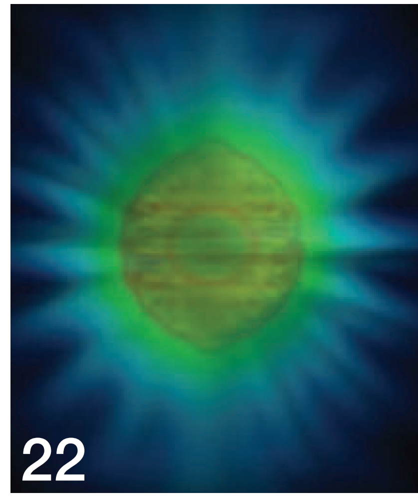
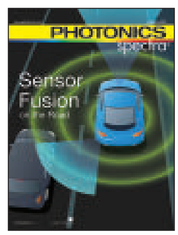
Columns





The Cover

Two ranging modalities, lidar and radar, are combined in a single package based on silicon photonics technology. This sensor fusion concept offers to drive performance and increase safety on roadways. Cover design by Senior Art Director Lisa N. Comstock.

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

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Editor's Note

Complementary combinations

By its definition, the notion of “sensor fusion” allows for the possibility of combining data from one sensing modality with virtually any other. Motion tracking provides a classic trimodal sensor fusion: The fusion of accelerometric, magnetometric, and gyroscopic data delivers precise information relative to location. In this case, the differences in the measurables that each individual sensing modality tracks are quite subtle.

At the same time, the modalities themselves are highly complementary. In combination, data obtained via each type of sensor delivers the utmost precision in determining orientation.

Sensor fusion can be far less nuanced, at least in terms of the sensors used. In 1997, for example, a paper published by a group from the National Institute of Standards and Technology (NIST) “describes a real-time hierarchical system that combines (fuses) data from vision and touch sensors to simplify and improve the operation of a coordinate measuring machine (CMM) used for dimensional inspection tasks”[1]. Even the paper’s title characterizes this as a unique combination, owing to its reliance on sensory processing techniques rather than traditional performance measurements to optimize CMM accuracy.

On a scale with “ubiquitous” and “totally unusual” at either end, the fusion of lidar and radar falls somewhere in the middle. In automotive applications, particularly as autonomous mobility pushes toward the mainstream, the use of the two ranging techniques in tandem is already commonplace. Lidars and radars are also commercially relevant systems. And given their capabilities, both support similar applications.

On the other hand (look no further than in past editions of this magazine for proof), it is easy to articulate lidar’s fundamental advantages by making direct, one-to-one comparisons to radar’s shortcomings. And vice versa.

As the authors from Silicon Austria Labs write in this edition’s cover story, the differences between lidar and radar open opportunities for their fusion, in both the logical settings and more novel use cases. In the authors’ work, high-resolution lidar systems and application-durable radar systems operate simultaneously to benefit safety and performance on the roadways as well as in emergency search and rescue.

The two technologies that so easily contrast are, in fact, complementary. It is something many end users likely already know.

One additional quality puts the concept of sensor fusion in a class with many other dynamic processes: its potential to benefit from photonics technology. To this end, as part of the Horizon project CoRaLi-DAR, the Silicon Austria Labs team is developing a lidar-radar sensor fusion using an innovative platform based on electro-photonic integrated circuits.

jake.saltzman@photonics.com

1. M. Nashman et al. (1997). A unique sensor fusion system for coordinate measuring machine tasks. *SPIE Internat’l Symp. on Intelligent Systems & Advc. Manufact*. Session: *Sensor Fusion & Decentralized Control in Autonomous Robotic Systems*.

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Contributors

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Thomas Achleitner is a business development manager at EV Group, focused on nanoimprint lithography and wafer-level optics for a variety of applications. Page 50.

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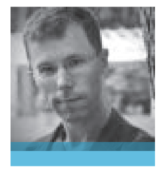
Stephan Prinz is senior product manager at DELO Industrial Adhesives. He is in charge of the company's strategic development in optics and photonics, covering applications including imaging and sensing, automotive lighting, photonic integrated circuits, and AR. Page 50.

Ken Barat
Ken Barat is a certified laser safety officer with 30 years of experience addressing laser safety for end users internationally. He has written 11 texts on the subject and espouses the motto "safety through cooperation." Page 55.



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

Tommaso Cassese
Tommaso Cassese is senior scientist — integrated photonic technologies at Silicon Austria Labs GmbH, a research center focused on electronic-based systems. Since 2023, he has served as the technical coordinator for the Horizon project CoRaLi-DAR. Page 30.

Mark Ventura
Mark Ventura cofounded Optotune in 2008 and serves as vice president of sales and marketing for the company, with additional focus on product management. Page 46.

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Norberto Ramirez Martinez is a researcher in product development at Coractive, focused on the fabrication of optical fibers for 1-µm, 1.5-µm, and 2-µm applications. He holds a Ph.D. (optoelectronics) from the University of Southampton. Page 36.

Tomas Zvolensky
Tomas Zvolensky is marketing manager at Optotune (Slovakia). He has more than 15 years of experience working throughout deep technology. Page 46.

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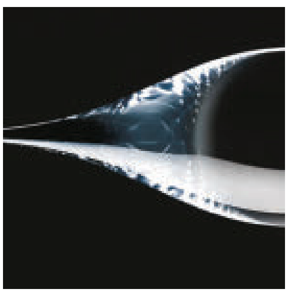
Fused Silica Step Index Fibers: Advanced Preform and Fiber Metrology



This webinar discusses advanced preform and fiber measurement techniques for specialty fibers, with a focus on fibers produced using the plasma outside deposition (POD) process. Key analytical techniques, such as refractive index profile analysis, as well as focal ratio degradation, characterization of attenuation, and metrological challenges that arise during product characterization, will also be discussed. Participants will gain insights into state-of-the-art measurement technologies and methods for the precise development and implementation of specialty fibers for advanced applications. The presentation will provide a comprehensive understanding of the metrology required to evaluate and improve the performance and quality of specialty fiber preforms.
Presented by Heraeus Conamic.
To view, visit **www.photonics.com/w1089**.

Heraeus Conamic

Design Considerations for Automated Manufacturing of Optical Assemblies

As the demand for efficient production of optical systems grows in industries ranging from aerospace and defense to medical imaging, the automation of optical assembly processes becomes increasingly critical. This webinar discusses strategies for optimizing optical assembly designs for automated manufacturing, providing an in-depth exploration of how the latest innovations in optical design, materials selection, and component placement are transforming assembly methods. Zach Klassen discusses how effective optical design software can simulate and predict the performance of manufactured optical assemblies, allowing for adjustments that maximize alignment and tolerances before production begins. Whether focused on stand-alone assemblies or the integration of optical components into larger systems, this webinar is a gateway to mastering the complexities inherent in optical assembly automation.
Presented by Benchmark.
To view, visit **www.photonics.com/w1145**.

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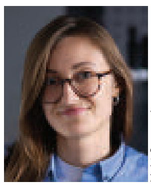
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Ocean Optics
Guenther.

The editors of *Photonics Spectra* magazine invite all guests to attend the Spectroscopy Summit — a virtual event highlighting emerging trends and future directions in spectroscopy components, methodologies, and applications. The event premiers on March 12, and all summit presentations will remain accessible on demand following the conclusion of the event.

With topics spanning the evolution of ultrafast spectroscopy, machine learning for Raman sensing, and practical breakthroughs — including broadband reflection spectroscopy for glucose analysis — professionals from Light Conversion, University of Montréal, Ocean Optics, and more will share insights into fundamental research and real-world deployments.

Registration is free and offers access to expert-led sessions designed to expand and elevate spectroscopy. Attendees can network, exchange ideas in a summit chat box, and help drive innovation across the field.

Website

For more information and to register online, visit www.photonics.com/SS2025.

Machine Learning for Raman Sensing
Jean-François Masson, University of Montréal

Precision in Time: The Evolution of Ultrafast Spectroscopy
Greta Bučytė, Light Conversion

Sweet Insight: Broadband Reflection Spectroscopy for Glucose Analysis
Derek Guenther, Ocean Optics

Upcoming Summits

Infrared Imaging — *April 16*

Microscopy — *May 14*

Laser Optics — *June 11*

Optical Design — *August 13*

Micromachining — *September 17*

Quantum — *November 19*

Register today at
www.photonics.com/SS2025.

OFC to Celebrate the International Year of Quantum in Its 50th Year

The 50th iteration of the Optical Fiber Communication Conference and Exhibition (OFC) will take place this year at San Fransisco's Moscone Center, moving north from its longtime residence in San Diego. From March 30 to April 3, the conference is expected to host more than 13,500 participants from more than 80 countries while featuring more than 600 exhibiting global companies.

The live event's multitude of highlights and displays will revolve around three exhibition hall theaters, showcasing expert presentations on hot topics such as market watches and data center hyper-scaling. As a hallmark of OFC, showcases will place an additional focus on how the latest technology innovations are being used at the conference itself.

Image courtesy of Optica.

As it hits the 50-year milestone, OFC will recognize the yearlong celebration of the International Year of Quantum Science and Technology, according to Nicolas Fontaine of Nokia Bell Labs, Fotini Karinou of Microsoft, and Elaine Wong of the University of Melbourne, who are chairing this year's event. The chairs said that this recognition will culminate with a "symposium showcasing groundbreaking advancements, including innovative architectures and enabling technologies that are shaping the future of quantum communication and photonics for quantum computing."

Complementing this celebration of quantum, a plenary session on April 1 will feature three industry leaders, beginning with Kei May Lau, professor at the Hong Kong University of Science and Technology, who will speak on the practicality of shifting from III-V bonding to direct epitaxy for silicon photonics. Bryan Robinson, leader of the Optical and Quantum Communications Group at MIT's Lincoln Laboratory, will discuss space-based optical communications. Pradeep Sindhu, corporate vice president of silicon at Microsoft and inventor of the data processing unit, will discuss the conflict between data center scaling and increasing interface speeds.

Accompanying the exhibit, OFC's five-day technical conference will feature 17 live demonstrations, along with several tutorials, more than 45 short courses, five symposia and special sessions, 10 industry panels, 12 interactive workshops, and more than 650 technical presentations. A quantum track will comprise sessions and presentations focusing on quantum key distribution, entangled photon sources, and a multitude of systems and components. Additional topics will range from technological explorations into fiber sensing and its applications, generative AI and large language models in network operations, and the development of materials for high-speed transceivers. Integrated photonic optical processors — particularly those for use in AI training, integrating sensing and communications, free space communications, and optical materials innovation (thin-film lithium niobate) — will also feature as the themes of numerous submitted papers and presentations.

Featured events include the Open Networking Summit, which will determine which path should be taken with optical networks on the way toward 6G, and the thought- and crowd-provoking rump session on March 31 that will probe the question, "If a Global Disaster Struck and all the Optical Infrastructure Was Wiped Out, Would You Rebuild with Today's Mainstream Technologies?" The organizers of this highly anticipated session include Antonio Tartaglia, photonics expert at Ericsson; Roy Rubenstein, consultant at LightCounting LLC; and Dirk Van Den Borne, director of systems engineering at Juniper Networks.

OFC 2025 will run from March 30 to April 3. For more information and to register, visit www.ofcconference.org.

Industry News

AIM Photonics, Cornell to lead DOD-funded QUPICS project

In collaboration with academic and commercial partners from across the Northeastern U.S., AIM Photonics and Cornell University's School of Electrical and Computer Engineering will lead research efforts on the Quantum Ultra-Broadband Photonic Integrated Circuits and Systems (QUPICS) project. The project, supported by approximately $8.5 million in anticipated funding and run through the Northeast Regional Defense Technology Hub (NORDTECH), will focus primarily on the development of an accessible 300-mm foundry fabrication platform for quantum photonic technologies extending from optical wavelengths in the UV through the IR.

Integrated systems in the UV-IR broad wavelength range enable a variety of photonics-heavy quantum systems and applications, such as sensing, networking, next-generation computing, navigation, secure communications, and drug discovery. The QUPICS team includes experts from the Air Force Research Laboratory in Rome, N.Y.; Columbia University; NIST-Gaithersburg; Rochester Institute of Technology; Quantinuum; TOPTICA Photonics Inc.; Xanadu; and Yale University. The collaborative team will address the foundry gap of tuning across the UV-IR spectrum of broadband for experimental use in electro-optic devices with multi-metal layer electrical functionality and laser capabilities into a single broadly available chip-based system. In future iterations, the QUPICS platform will be available for multi-project wafer runs for joint development opportunities.

AIM Photonics

Funded by the Department of Defense (DOD), the Quantum Ultra-Broadband Photonic Integrated Circuits and Systems (QUPICS) project aims to develop an accessible 300-mm foundry fabrication platform for quantum photonic technologies.

"QUPICS has the unique promise to deliver a mature and broadly accessible fabrication platform supporting atomic and photonic quantum systems, which we will develop and leverage for the trapped-ion systems we are working on at Cornell," said Karan Mehta, assistant professor of electrical and computer engineering at Cornell University, and QUPICS co-principal investigator. The project is also expected to enhance AIM Photonics' research in silicon photonics by extending the institute's current capabilities in prototyping and deployment of quantum systems, which are specifically tailored to the requirement of QUPICS.

Successive build offerings and process design kits will facilitate experiments in QUPICS devices throughout the program. The multi-project wafer runs will be offered outside the project team to help research groups at national labs, government agencies, and a range of commercial organizations pursing quantum computing, communication, sensing, and related photonics applications.

QUPICS is among four major NORDTECH projects recently selected for funding by the Department of Defense (DOD) that aim to significantly boost microelectronics manufacturing capabilities in the U.S.

European Union launches Lasers4MaaS laser welding project

Funded by a European Union HORIZON grant, a project targeting the integration of advanced laser welding technologies with digital platforms to enable flexible, scalable, and sustainable production solutions has debuted as an international consortium. The Lasers4MaaS (Laser-as-a-Service) project aims to increase the technological readiness level (TRL) from TRL 4 to TRL 6.

Coordinated by the WMG, the Laser Beam Welding Group at the University of Warwick, Lasers4MaaS will address the pressing need for sustainable and efficient manufacturing solutions. Key innovations include the deployment of dynamic beam shaping, AI-driven manufacturing, digital manufacturing platforms, and sustainable and decentralized manufacturing, which offer benefits such as enhanced flexibility and precision, seamless data integration for real-time monitoring, quality control, and predictive maintenance.

"The deployment of dynamic beam shaping within laser welding has an immense potential for servitization," said Pasquale Franciosa, Lasers4MaaS project coordinator and head of the Laser Beam Welding Group. "Manufacturers will be able to build products on-demand, without the need of re-investment in new equipment, thereby enabling rapid repurposing."

The project brings together academics from the University of Stuttgart IFSW, TU Wien, University of Leiden, and industry experts from Civan Advanced Technologies Ltd., United Kingdom Atomic Energy Authority, ECOR International SpA, IL Sentiero International Campus srl, Officine Metallurgiche Cornaglia SpA, FFT Produktionssysteme GmbH & Co. KG, Futurice GmbH, and the European Photonics Industry Consortium (EPIC). The project is also supported by an industrial advisory board. As of press time, the project is seeking and accepting new members.

U.S. Senate introduces Quantum Initiative Reauthorization Act

The U.S. Senate introduced the National Quantum Initiative Reauthorization Act, a bill that would authorize $2.7 billion in federal funding to accelerate quantum R&D at federal science agencies for the next five years. The act provides a significant expansion of the program's national infrastructure and extends its duration from the original 2029 deadline to December 2034.

The bill would refocus the National Quantum Initiative (NQI) from basic research to practical applications and establish up to three National Institute of Science and Technology (NIST) quantum centers focusing on quantum sensing, measurement, and engineering. It would also create five new National Science Foundation Multidisciplinary Centers for Quantum Research and Education, a quantum workforce coordination hub, and quantum testbeds at the National Science Foundation's Technology, Innovations, and Partnerships Directorate. The

This month in history

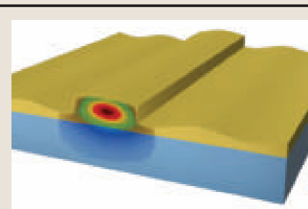
What were you working on five, 10, 20, or even 30 years ago? *Photonics Spectra* editors have perused past February issues and unearthed the following:

1995

Researchers at the University of California, Berkley built microscopic versions of beam-steering mirrors for use in fiber optic systems. The system fitted within a 0.04-sq-in. area and was part of a larger micro-optical bench that included an optical fiber, semiconductor laser diode, and a glass bead to act as a laser focusing lens.

2005

A research group from Intel reported a silicon Raman laser that overcame silicon's indirect bandgap by integrating it on a single CMOS chip and extending the pulse lengths of the laser's optical pumping. The laser was based on a rib waveguide with a reverse bias applied across a horizontal PIN junction.



2015

A team from the University of Minnesota created a microchip that generated both light waves and ultrahigh-frequency sound waves, achieving acousto-optic coupling and modulation above 10 GHz. The chip featured a silicon base coated with a layer of aluminum nitride that conducted an electrical charge.

2020

Researchers at Nanyang Technological University demonstrated tunable, controllable amplified spontaneous emission in a colloidal semiconductor device via electric field-induced charging. The work was completed in an effort to open avenues for achieving electrically pumped colloidal quantum dot lasers.

legislation would additionally authorize NASA quantum R&D activities, including quantum satellite communications as well as quantum sensing research initiatives.

Further, the act requires the White House Office of Science and Technology Policy to develop an international quantum cooperation strategy to coordinate R&D activities with allied nations and directs the Secretary of Commerce to submit a plan to strengthen quantum supply chain resilience. Per the bill, each agency would need to develop metrics for monitoring and evaluating advancements in quantum information science and progress toward practical quantum applications and report to Congress. The bill additionally directs the Government Accountability Office to conduct a study on reducing red tape and paperwork burden related to private sector and academic participation in NQI activities and centers.

Created in 2018, the NQI coordinates quantum research and development to advance the economic and national security of the U.S. The original five-year authorization was signed into law in December 2018, and authorization for certain R&D activities expired on Sept. 30, 2023. The authorization for the entire NQI expires on Dec. 21, 2029.

EU to establish pilot line for photonic integrated circuits

Europe's Chips Joint Undertaking (Chips JU), the European public-private partnership that supports research, development, and innovation in semiconductor technologies, is in negotiations with the PIXEurope consortium to establish the Advanced Photonic Integrated Circuits Pilot Line for Europe. The pilot line, expected to be established in the Netherlands, will be jointly funded by the European Union, through the Horizon Europe and Digital Europe Programmes, participating states, and private organizations.

PIXEurope's PIC pilot line will bring together Europe's top research organiza-

People in the News


SCHOTT AG
Torsten Derr.

SCHOTT AG appointed **Torsten Derr** CEO. Derr, who served as CEO of SGL Carbon since 2020, succeeds **Frank Heinricht**, who has retired. Derr began his career at Bayer AG as an R&D manager for plastics. He then joined specialty chemicals company LANXESS AG, where he held various leadership roles, including head of commercial and supply chain excellence and CCO. In 2016, Derr moved to the company's subsidiary, Saltigo, where he managed the fine chemicals business until joining SGL Carbon. Per his appointment, Derr will also serve as chairman of the supervisory board for SCHOTT Pharma.


Lumicell
Howard Hechler.

Lumicell Inc., a developer of fluorescence-guided imaging technologies for cancerous tissue detection during surgery, appointed **Howard Hechler** CEO. Hechler joined Lumicell as senior vice president of corporate development and strategy before being promoted to president.

Scintil Photonics, a PICs developer, appointed **Matt Crowley** CEO, replacing company founder **Sylvie Menezo** who was appointed CTO. Crowley joins Scintil from Qualcomm, for which he served as senior director of business development. Crowley was previously appointed senior strategic advisor of Sheba Microsystems in June 2024.


Basler AG
Ines Brückel.

Basler AG appointed **Ines Brückel** CFO. Deputy CEO **Hardy Mehl**, currently CFO/COO, will assume responsibility for sales and marketing and communications, continuing to oversee operations and investor relations. Brückel previously worked for auditing firm KPMG and held leading positions in the finance departments of large international technology companies.

MKS Instruments added **Wissam Jabre**, executive vice president and CFO of Western Digital Corporation, to its board of directors. Jabre previously served as senior vice president and CFO of Dialog Semiconductor from 2016 until it was acquired by Renesas Electronics in August 2021. Prior to that, he held senior finance roles at Advanced Micro Devices, Freescale Semiconductor, and Motorola. He began his career with Schlumberger, where he held engineering and finance roles.

POET Technologies, a developer and designer of PICs, appointed **Bob Tirva** to its board of directors and audit committee, expanding the board to six members. Tirva brings more than 30 years of executive experience in the technology industry, having held various management positions at IBM, Broadcom Corporation, Dropbox, and Intermedia Cloud Communications Inc. He serves on the board of Skyworks Aeronautics.


Light Trace Photonics
Steve Kitson.

Integrated photonics technology developer Light Trace Photonics named **Steve Kitson** to chair the company's board. Kitson currently chairs the boards of LumOptica, Actuation Lab, and Impulsonics. He was previously CEO and cofounder of Folium Optics Limited.


flō Optics
Guy Menchik.

Optical coatings company flō Optics appointed **Guy Menchik** vice president of its incubation lab. Before joining flō, Menchik served initially as CTO and then vice president of R&D at Stratasys.

The OIF Forum's members elected the 2024 to 2025 board of directors and officers. **Mike Klempa** of Alphawave Semi and **David Stauffer** of Kandou Bus were elected to the board, and **Ian Betty** of Ciena, **Mike Li** of Intel, and **Cathy Liu** of Broadcom tions to set up the world's first open-access PIC ecosystem, the Chips JU said in a statement. According to the government of the Netherlands, Eindhoven and Enschede are potential future locations for the planned production facilities. A total of €380 million (approximately $405 million) has been allocated for the project, with €133 million expected to be invested in the Netherlands.

Coordinated by the Institute of Photonic Sciences, the 20-member consortium includes participants from Spain, Ireland, the Netherlands, Finland, Belgium, Portugal, Poland, Austria, Italy, France, and the U.K.

The PIC pilot line is the fifth pilot line set to be implemented in Europe by the Chips JU to strengthen the continent's semiconductor ecosystem. Aligned with the goals of the Chips for Europe Initiative, the PIC pilot line is expected to collaborate closely with the other four Chips JU pilot lines, design platforms, and competence centers. The NanoIC pilot line, led by imec, was announced in 2024.

The Chips JU will proceed with the negotiations with the consortium to finalize the hosting agreements, joint procurement agreements, and related grant agreements.

were reelected. **Nathan Tracy** of TE Connectivity will continue to serve as president, **Jeff Hutchins** of Ranovus will serve as secretary and treasurer, and **Dave Brown** of Nokia will continue to serve as director of communications. **Sam Kocsis** of Amphenol Corporation was elected technical committee vice chair, **Karl Bois** of NVIDIA was reelected as technical committee chair, and **Tom Issenhuth** of Huawei Technologies was reelected as market awareness and education committee co-chair.

TRUMPF Inc. promoted **Claudio Santopietro** to head of Smart Factory consulting and automation; **Kevin Cuseo** to head of software sales; **Julian Schorpp** to product manager for automated bend products; and **Adam Simons** to head of additive manufacturing in North America.

Test and measurement company Rohde & Schwarz appointed **Markus Fischer** president and COO. Fischer joined Rohde & Schwarz in 2011 as head of corporate material sourcing at its Munich headquarters, and most recently served as the company's executive vice president of operations.

Exosens named **Laurent Sfaxi** director of investor relations. Sfaxi has more than 20 years of experience in the field of financial communications and investor relations, having most recently held the same role at Deezer. The appointment follows Exosens' initial public offering last year.

Laser welding company Evosys named **Marie Schafnitzl** head of finance and **Oliver Brandmayer** technical director.

Modular camera solutions developer Photonfocus AG named **Marco Reiter-Waßmann** general manager. Reiter-Waßmann has a background in the vision industry, in the areas of project management and sales.

Optimax names Joseph Spilman CEO

Global optics manufacturer and solutions provider Optimax named Joseph Spilman CEO. Spilman will take over from outgoing CEO Rick Plympton, who is retiring.

In a corresponding move, the company named Peter Kupinski president, taking over from Spilman.

Spilman has worked in the optics and photonics industry for 20 years. His previous roles include director of sales and marketing at Optimax, serving on the executive team at ArmorLine Corp., and roles supporting NIR and IR laser optics applications for II-VI Inc. (Coherent).

Kupinski has served as Optimax's COO and director of engineering. He has worked with Optimax for 13 years, with previous positions with Sony, Kodak, and the Laboratory for Laser Energetics at the University of Rochester.

According to the company, Spilman and Kupinski will split duties — with Spilman focusing on market strategy and Kupinski on operations.

Plympton, as well as company founder Mike Mandina, who retired in 2021, will assume the title of corporate fellow.

Joseph Spilman, CEO of Optimax.

Coherent, SkyWater, and X-Fab to receive CHIPS Act funding

The U.S. Department of Commerce signed three separate preliminary memoranda of terms under the CHIPS and Science Act to provide up to $33 million in proposed direct funding to Coherent, up to $16 million to SkyWater Technology Foundry, and up to $50 million to X-Fab.

The proposed investment in Coherent would support the modernization and expansion of a state-of-the-art manufacturing cleanroom in Coherent's existing 700,000-sq-ft facility in Sherman, Texas, to establish a 150-mm indium phosphide (InP) manufacturing line by adding advanced wafer fabrication equipment to produce InP devices at scale. InP optoelectronic devices are widely used in applications, such as data communications and telecommunications transceivers, including for AI infrastructure applications, advanced sensing for consumer electronics, and medical and automotive applications. The increased production of Coherent's InP devices would allow the U.S. to advance supply chain resiliency and technological leadership and create approximately 70 jobs.

The proposed investment in SkyWater would support the modernization of its

Briefs

The U.S. Department of Commerce signed two preliminary memoranda of terms under the CHIPS and Science Act to provide **Corning** up to $32 million in proposed direct funding, and **Powerex**, a designer and packager of systems, up to $3 million in proposed direct funding. The funding would allow Corning to increase the production of its High Purity Fused Silica and EXTREME ULE Glass for deep-UV and extreme-UV lithography machines and photomasks. Powerex plans to modernize and expand its production and semiconductor power module packaging facility in Youngwood, Penn.

ZEISS acquired the lithography division of **Beyond Gravity**, a provider of special actuators and complex mechatronic modules. ZEISS plans to integrate the Coswig site into **Carl Zeiss SMT GmbH** and will rebrand the Zürich site to **Carl Zeiss SMT Switzerland AG**. The move expands the ZEISS semiconductor manufacturing technology segment's production and R&D capacities to meet the global demand for semiconductor manufacturing systems, according to the company.

Electro Optic Systems (**EOS**), a developer of remote weapon systems, entered into a binding agreement to divest its naval satellite communications subsidiary, **EM Solutions**, to **Cohort PLC**, a defense technology group. The transaction carries an implied enterprise value of AUD $144 million ($93.6 million). According to EOS, the proposed deal aligns with its transformation strategy to focus on its core product offerings in the areas of remote weapon systems, high-energy laser weapons, and space control.

Medical device company **PhotoniCare** secured $4.6 million in funding and formed a manufacturing partnership with **Gentex Corporation** to produce its OtoSight Middle Ear Scope. The company also finalized the relocation of its headquarters from Champaign, Ill., to Grand Rapids, Mich. Using OCT high-resolution depth imaging, PhotoniCare's device helps to determine the presence or absence of fluid in the middle ear and to characterize the fluid type, even in the presence of significant ear wax. According to the company, the device is the first FDA-cleared device for middle ear visualization and boasts 90.6% accuracy in the detection of middle ear effusion. The funding, led by Gentex, is the first close in an expected $9 million round.

RAITH, a developer of maskless nanofabrication and characterization systems and solutions, acquired **Xnovo**, an imaging solutions company. The company stated that the acquisition will enable it to provide its customers with more solutions in the fields of failure analysis and metrology.

The **Innovative Optical and Wireless Network Global Forum** (**IOWN**) entered into a collaboration with the **Telecom Infra Project** to advance the development of optical technologies, principles, existing facility in Bloomington, Minn., to improve the quality of production and wafer services by replacing equipment, upgrading the facility's cleanroom, space, and IT systems, and increase overall production capacity of 90- and 130-nm wafers by ~30%. The facility offers customers in the aerospace and defense, automotive, biomedical, and industrial markets the ability to prototype and scale to volume production-differentiated technology.

SkyWater is a Department of Defense Trusted Foundry. As a result of proposed CHIPS funding, the company would be able to improve productivity and enhance operational sustainability to support Department of Defense missions as well as grow its commercial business. In addition, the State of Minnesota's Forward Fund would provide $19 million in dedicated funding to support this proposed project.

The proposed investment in X-Fab would support the expansion and modernization of X-Fab's silicon carbide foundry facility, the only high-volume silicon carbide foundry in the U.S. Silicon carbide technology is vital to the global decarbonization efforts in the automotive and industrial sectors and offers multiple advantages compared with conventional silicon-based technologies for high-power applications.

The proposed CHIPS funding would serve to bolster supply resiliency for critical infrastructure markets that were adversely affected by foundry capacity shortages and supply chain disruptions during the COVID-19 pandemic.

Lightwave Logic makes executive leadership changes

Lightwave Logic, a developer of electro-optic polymer technology, named Yves LeMaitre CEO and Thomas Zelibor president. The company announced that Michael Lebby retired as chairman and CEO in a corresponding move.

The company board also appointed Ronald Bucchi, who had served as the lead independent director, as nonexecutive independent chairman.

LeMaitre joined the company's board of directors in August 2024. The photonics industry veteran has more than 30 years of experience working in optical networks and AI/data centers, as well as in global technology, corporate strategy, and marketing. LeMaitre led IPG Photonics' Optical Coherent Division and advised and oversaw its divestiture to Lumentum in 2022. For 10 years, he held roles of increasing responsibility, including chief strategy officer of Lumentum.

Zelibor served as CEO of Lightwave Logic between 2011 and 2017, and as chair from 2011 to 2022. He also served as the CEO of Flatirons Solutions and the not-for-profit U.S. Space Foundation. As the U.S. Navy's chief information officer, Zelibor oversaw a multibillion-dollar annual budget, delivering increased growth and efficiency while directing IT policy, Navy space, processes, and cyber security strategy. He continues to serve as a director for public and private companies.

Lightwave Logic appointed Thomas Connelly Jr., former CEO of the Ameri-

approaches, and designs. The initiative is designed to accelerate the innovation of energy-efficient, low-latency network infrastructure, supporting the next generation of data-driven and communication-intensive applications.

Quantum computing company **IonQ** is developing PICs and chip-scale ion trap technology for trapped ion quantum computing in partnership with **imec**. By moving traditional bulk optical components into integrated photonic devices, IonQ aims to reduce overall hardware system size and cost, increase qubit count, and improve system performance and robustness. IonQ and imec have worked to prototype photonic and ion trap technologies since 2021, and the expanded engagement aims to develop advanced trap fabrication processes that will allow much richer trap and device functionality.

Industrial cleaning laser systems developer **Laser Photonics Corporation** will transition to an operational holding company with wholly owned subsidiaries under the name **LASE Holdings**. LASE Holdings will be based out of a corporate office in Lake Mary, Fla. The projected subsidiaries under LASE Holdings are **Laser Photonics**, **CMS Laser**, **Control Micro Systems**, **LP Semiconductor**, **3D AXS**, and **LP Media Group**. Control Micro Systems was acquired by the company for $1.05 million last year.

Semiconductor company **Aeluma Inc.** was awarded a contract by NASA to develop quantum dot PICs on silicon, to enhance optical performance in challenging environments for a range of aerospace functions by delivering high-precision, low-power solutions essential for space missions and autonomous systems.

PICs designer and developer **POET Technologies Inc.** intends to expand its optical engine production capacity in Malaysia. The company signed a binding memorandum of understanding with **Quanzhou Sanan Optical Communication Technology Co. Ltd.** (**SAIC**) to transfer to POET its 24.8% stake in the joint venture **Super Photonics Xiamen** (**SPX**), along with all the production equipment previously leased by SAIC to SPX. POET is negotiating with several contract manufacturers in Malaysia to become the focal point for POET's wafer-scale assembly of optical engines.

Quantum information company **Infleqtion** received $11 million in funding from the U.S. Department of Defense under the Accelerate the Procurement and Fielding of Innovative Technologies program to support the development of Tiqker, Infleqtion's rack-mounted optical clock. Tiqker will support a range of defense areas and applications, such as assured communications, GPS-denied navigation, anti-spoof timing, and synchronization for emerging technologies. The project has received a total of $22 million to date.

can Chemical Society, to its board of directors in 2023. The company said at the time that the move was expected to aid Lightwave in expanding its initial business focus from data centers and AI clusters connectivity to include other markets, which were to include materials and organics as well as quantum/optical computing, aerospace, defense, and storage.

Lebby joined the Lightwave Logic board in 2015. He had served in the company's CEO position since his appointment in 2017.

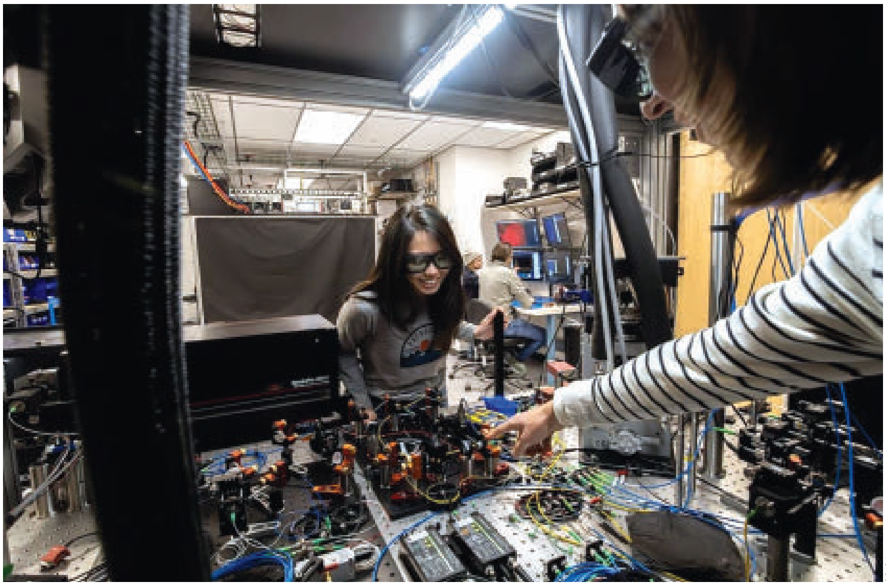
Lightsynq emerges from stealth with $18M in funding

Lightsynq, a startup developing optical interconnect technology, raised approximately $18 million in a series A funding round. Lightsynq is developing optical quantum interconnects that enable hardware providers to link quantum processors. The company was founded by former Harvard quantum networking experts and research leads from Amazon Web Services Center for Quantum Networking.

Lightsynq plans to use the funds to build prototypes of its quantum interconnects, which it said it will use to help leading quantum computing companies scale to multimodule systems. Lightsynq's quantum interconnect technology is based on color centers in diamond photonics devices, combining a quantum networking platform with scalable photonic fabrication. The solution, the company said, will provide a pathway to foundry-scale production of quantum interconnects, enabling more usable qubits across networks and accelerating wider industrial and commercial applications.

The round saw participation from longtime collaborator Element Six, a provider of synthetic diamond material solutions. Element Six has collaborated with Lightsynq cofounder and CEO Mihir Bhaskar's team since 2015, it said.

According to Lightsynq, the company's architecture is broadly compatible with leading quantum computing modalities and leverages integrated diamond photonic circuits to link multiple limited-scale devices into a modular, full-scale quantum computer, similar to the methods used to build current high-performance computing systems.


Lightsynq

Lightsynq's quantum interconnect lab at its headquarters in Boston. The company uses cryogenic and optical test and measurement systems to validate the performance of its interconnect technology.

One of the biggest challenges in connecting quantum computers is the network loss associated with extracting quantum information out of computing modules, Lightsynq said in a blog post. The only known solution for building loss-tolerant connections, the company said, is quantum memories.

Lightsynq's quantum memories are created by embedding silicon atoms into diamond to form silicon vacancy color centers, which serve as two-qubit registers that are fully controllable using microwave pulses. Lightsynq places these color centers in optical cavities to achieve high-fidelity, high-efficiency interactions between single photons and the color center's electron qubit. The implementation of quantum interconnects in a diamond-based photonic integrated circuit enables scaling to many parallel memory registers in a single, compact chip.

"We can perform universal quantum logic operations on our quantum memory register, enabling in-memory Bell-state measurements for entanglement swapping — a step [that] other technologies often struggle with due to inherent inefficiencies when using linear optics for Bell-state measurements," Lightsynq said in a blog post.

$627.4M — predicted size of the global quantum cascade laser market by 2033, according to Future Market Insights

Ayar Labs secures $155M from investors including AMD, NVIDIA

Optical interconnect solutions company Ayar Labs secured $155 million in financing for the high-volume manufacturing of its optical input/output (I/O) technology, as the company prepares its optical solution for high-volume manufacturing aligned to customer road maps. Participating investors in the latest round include AMD Ventures, Intel Capital, and NVIDIA.

The financing brings Ayar Lab's total funding to $370 million and raises its valuation to more than $1 billion.

"We believe optical I/O is on the cusp of revolutionizing the future of AI infrastructure, and we recognize the significant growth potential of in-package optical interconnects," said Jordan Katz, partner at Advent Global Opportunities, who will join Ayar Labs' board of directors per the funding round. Mark Wade, CEO and cofounder of Ayar Labs, said, "The leading GPU providers, AMD and NVIDIA, and semiconductor foundries — GlobalFoundries, Intel Foundry, and TSMC — combined with the backing of Advent, Light Street, and our other investors, underscores the potential of our optical I/O technology to redefine the future of AI infrastructure."

The funding announcement comes less than a year after Ayar's commercial release of its SuperNova 16-wavelength light source. According to the company, the product enables 16 Tbps of bidirectional bandwidth and 64× the wavelengths compared with CWDM4 multiwavelength pluggable optics.

Sivers Semiconductors halts plan to spin off photonics business

The board of Sivers Semiconductors has paused its discussions related to a proposed business combination. The planned merger was between Sivers subsidiary Sivers Photonics and byNordic, a special purpose acquisition company (SPAC).

"While we agree with byNordic's thesis that our photonics business is highly undervalued in Sivers' current market capitalization with its critical positioning in the upcoming AI data centers, the capital markets for successfully executing SPAC mergers remain challenging," said Bami Bastani, chairman of the board of directors of Sivers Semiconductors AB.

"Consequently, we have elected to put our pencils down on this opportunity."

According to the company, the decision was made after a thorough evaluation as well as feedback from Sivers' financial advisors, noting U.S. market conditions surrounding the small-cap companies and the performance of SPACs in the current market environment. Sivers Photonics is a supplier of semiconductor photonic devices with a particular focus on indium phosphide laser sources. The company develops customizable lasers aimed at high-growth AI infrastructure and sensing applications for data centers, consumer health care, and automotive lidar.

Sivers Semiconductors comprises two wholly owned subsidiaries addressing two different markets: wireless and photonics. The company supplies integrated chips and modules critical for high-performance gigabit wireless and optical networks. Its solutions find application in telecommunications, aerospace, satellite communications, optical networking, and sensing. The company recently appointed semiconductor industry veteran Vickram Vathulya president and CEO.

Lightmatter follows up 2024 Funding with Amkor, ASE collaborations

Photonic supercomputing company Lightmatter established strategic partnerships with semiconductor packaging and testing companies Amkor Technology and Advanced Semiconductor Engineering (ASE). The collaborations aim to advance Lightmatter's Passage platform and follow the company's $400 million funding round announced in late 2024.

The partnership with Amkor involves Lightmatter's 3D-stacked photonic engine along with Amkor's advanced multi-die packaging expertise to create a 3D-packaged chip complex to meet the interconnect scaling and power demands of modern AI workloads. The collaboration targets unprecedented silicon density and bandwidth within a single package, paving the way for next-generation computing advancements, such as artificial general intelligence, Lightmatter said.

Lightmatter's 3D-stacked photonics engine enables input/output to be placed over the entire chip surface area, dramatically increasing the bandwidth and freeing chip shoreline for other needs, including memory expansion. By partnering with ASE, Lightmatter will deliver a photonics-optimized 3D-packaging solution that empowers its customers to massively expand high-speed connectivity to their chips and rapidly scale the production and deployment of the most advanced generative AI superclusters, the company said.

The joint effort between Lightmatter and ASE also addresses the need to directly incorporate pluggable fiber attachment points for all-optical interconnect scaling at very high fiber density in a reliable and serviceable manner.

AeroVironment to acquire BlueHalo in $4.1B transaction

Uncrewed aerial vehicle designer and manufacturer AeroVironment will acquire fellow U.S.-based defense technology company BlueHalo in an all-stock transaction valued at $4.1 billion. The deal, expected to close in the first half of this year, combines complementary capabilities and expands AeroVironment's global footprint, the company said.

With BlueHalo's portfolio, AeroVironment said, it will enter into segments that will significantly increase the company's total addressable market, including counter-uncrewed aircraft systems, directed energy, electronic warfare, and cyber and space technologies. The combined company will benefit from greater resources, enabling faster innovation and more efficient deployment of critical defense systems.

Additionally, the combination will expand global reach, enabling the distribution of BlueHalo's solutions to AeroVironment's larger international customer base.

Following the completion of the transaction, Wahid Nawabi, AeroVironment's president, CEO, and chair, will assume the same positions at the combined company. Jonathan Moneymaker, CEO of BlueHalo, will serve as a strategic advisor to Nawabi and the combined company's management team.

Akhetonics raises $6.3M for all-optical digital processor

Akhetonics raised €6 million ($6.3 million) in funding, which the company said it plans to use to deliver its first-generation hardware to pilot customers. The German startup is developing a full-stack processor that combines photonic hardware and components, software tools, and an in-house design automation tool. The solution's low latency and deterministic execution, coupled with immunity to electromagnetic interference, make it useful for customers in the aviation, defense, and networking sectors, according to the company.

"Many companies that claim to use optical computing actually take a hybrid approach, incorporating electronics in their processing," said Michael Kissner, CEO of Akhetonics. "In contrast, we are shipping a completely new, all-optical, general-purpose processor.

"This not only enables higher performance at lower power but also offers real-time processing that is simply not possible with electronics or [optoelectronic] hybrids."

Akhetonics is part of the GATEPOST (Graphene-Based All-Optical Technology Platform for Secure Internet of Things) consortium, which includes HP Enterprise, imec, Enlightra, and Fraunhofer HHI. With the GATEPOST project, Akhetonics said, it is planning to combine graphene with standard CMOS processes to realize efficient nonlinear light interactions with ultrafast response times.

PhotonixFAB partners X-Fab, SMART Photonics deepen collaboration

X-Fab Silicon Foundries SE, an analog/mixed-signal and specialty foundry, and SMART Photonics, an indium phosphide (InP) integrated photonics foundry, partnered to integrate X-Fab's silicon photonics platform with SMART Photonics' InP chiplets by using micro-transfer printing for heterogeneous integration. The collaborators expect the combination to enable capabilities for datacom and telecom applications.

InP technology supports modulator bandwidths exceeding 120 GHz, making it suitable for next-generation multi-terabit telecom and datacom standards. In contrast, commercially available silicon photonics technologies hit a performance ceiling at ~70 GHz. The newly formed collaboration aims to deliver scalable, high-volume solutions that combine the best of both InP and silicon photonics technologies.

The companies specifically expect the combination to enable improved system performance while reducing integration costs through relaxed photonics packaging requirements. X-Fab said that the micro-transfer printing technology, which has been licensed from X-Celeprint, enables a broad degree of freedom for the system and product designers by providing flexible integration of various material system chiplets into the product design.

This collaboration additionally builds on the PhotonixFAB European Union funding project. The initiative aims to provide a path to scalable high-volume manufacturing for silicon-on-insulator and silicon nitride silicon photonics as well as micro-transfer printing-ready InP chiplets and micro-transfer printing of chiplets. X-FAB heads the public/private PhotonixFAB consortium, and SMART Photonics is a participating partner on the project.

X-FAB

Rudi De Winter, CEO of X-FAB **(left)** and Johan Feenstra, CEO of SMART Photonics.

From the current collaboration, the companies anticipate industrial prototyping to be underway by 2026.

3D-printing consortium seeks to speed industrial adoption

TRUMPF, Renishaw, Ansys, EOS, and Nikon SLM are among the founding members of a consortium seeking to address manufacturers' challenges in the adoption and scaling of 3D-printing technology for industrial use. Citing 3D printing's ongoing transition from a niche innovation to a high-volume manufacturing method, the companies comprising the Leading Minds consortium additionally include HP, Materialise, and Stratasys.

The Leading Minds consortium has identified its first initiative as the development of a common language framework for 3D printing. The consortium members said that the collective effort is about not only enhancing 3D printing but also taking practical, actionable steps to reshape the manufacturing landscape to be more innovative, sustainable, and capable of meeting the evolving needs of advanced manufacturing. The primary objective of the Leading Minds consortium is to broadly increase awareness of 3D printing's capabilities across more industries and eliminate hurdles that manufacturers face.

Despite its promise, many manufacturing companies still encounter barriers to 3D-printing adoption. In 2023, B2B International surveyed companies in the U.S., Germany, and Japan. According to the survey, the companies recognize 3D printing as a key trend in manufacturing, but 98% of the companies reported experiencing challenges and barriers to adopting 3D printing, such as a lack of expertise, perceived high costs, and sometimes complex integration with established processes. And currently, many companies and technologies operate using different terminology for similar concepts, making it difficult to collaborate effectively, the consortium members said.

Materialise

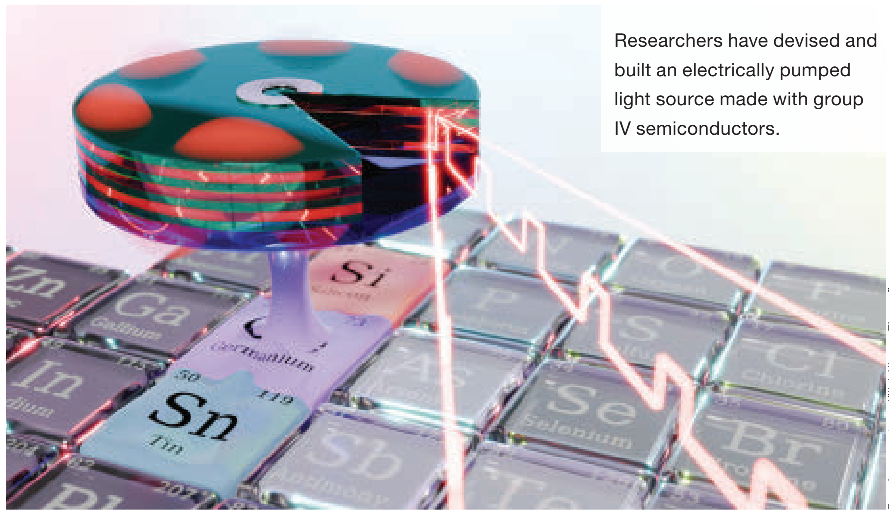
The Leading Minds consortium, consisting of Ansys, EOS, HP, Materialise, Nikon SLM, Renishaw, Stratasys, and TRUMPF, is addressing the common challenges experienced by manufacturers that have so far hindered the adoption of additive manufacturing technologies in production processes.

To resolve this bottleneck, the consortium plans to develop a common language framework to facilitate a clearer understanding of 3D printing's capabilities.

International team grows electrically pumped laser on silicon wafer

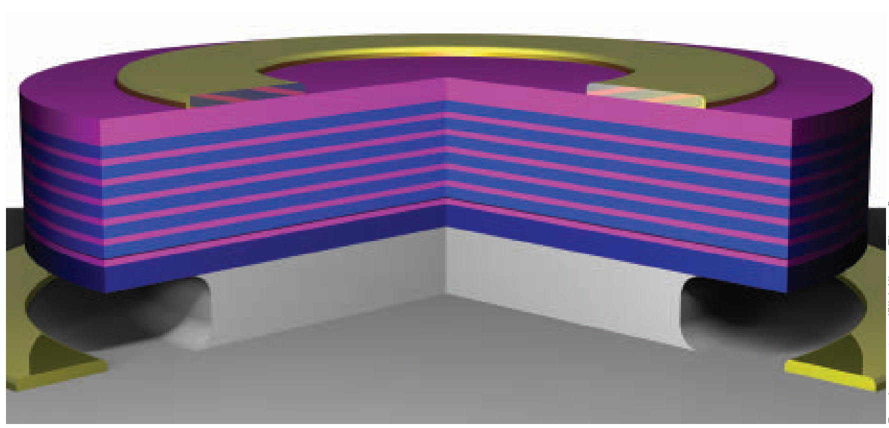
JÜLICH, Germany — An international research team has developed an electrically pumped continuous-wave semiconductor laser suitable for seamless silicon integration. According to the researchers, the laser is the first of its kind to be directly grown on a silicon wafer, and the device opens possibilities for on-chip integrated photonics.

The laser addresses the lack of an efficient, electrically pumped light source using only group IV semiconductors. Monolithic integration of optically active components on silicon chips has traditionally been completed with III-V materials, which are difficult and expensive to integrate with silicon. Developed by scientists from Forschungszentrum Jülich (FZJ), the University of Stuttgart, and the Leibniz Institute for High Performance Microelectronics (IHP), along with researchers from CEA-Leti, the laser is composed exclusively of elements from the fourth group of the periodic table — the silicon group. Specifically, the device is built from stacked ultrathin layers of silicon germanium-tin and germanium-tin.



Researchers have devised and built an electrically pumped light source made with group IV semiconductors.

Forschungszentrum Jülich/Jhonny Tiscareño



Forschungszentrum Jülich/Jhonny Tiscareño

A schematic view of the newly developed germanium-tin laser.

In an optically pumped laser, an external light source is required to generate the lasing light, while the electrical pumped laser generates light when an electrical current is passing through the diode. Electrically pumped lasers are usually more energy efficient, because they directly convert electricity into laser light.

Additionally, the laser developed by the researchers is compatible with the conventional CMOS technology for chip fabrication and is therefore suitable for seamless integration into existing silicon manufacturing processes. As a result, the resarchers said, it could therefore be seen as the last missing piece in the silicon photonics toolbox.

According to Dan Buca of FZJ's Peter Grünberg Institute, the development has been one of the main goals of his group's exploration of germanium-tin alloys, work that has been ongoing for almost a decade. Unlike previous germanium-tin lasers that relied on high-energy optical pumping, the developed laser operates with a low current injection of just 5 mA at 2 V, comparable to the energy consumption of a light-emitting diode.

With its advanced multiquantum well structure and ring geometry, the laser minimizes power consumption and heat generation, enabling stable operation up to 90 K or −183.15 °C.

Grown on standard silicon wafers like those used for silicon transistors, the device represents the first truly usable group IV laser, though the researchers said that additional optimizations are needed to further reduce the lasing threshold and achieve room temperature operation. However, the success of earlier optically pumped germanium-tin lasers, which have evolved from cryogenic to room temperature operation in only a few years, suggests a clear path forward.

The research was published in *Nature Communications* (www.doi.org/10.1038/s41467-024-54873-z).

Study finds laser light can cast a shadow

OTTAWA, Ontario — Researchers at the University of Ottawa demonstrated that a laser beam under certain conditions can act as an opaque object and cast a visible shadow. The finding challenges the traditional understanding of shadows and opens possibilities for technologies that could use a laser beam to control another laser beam.

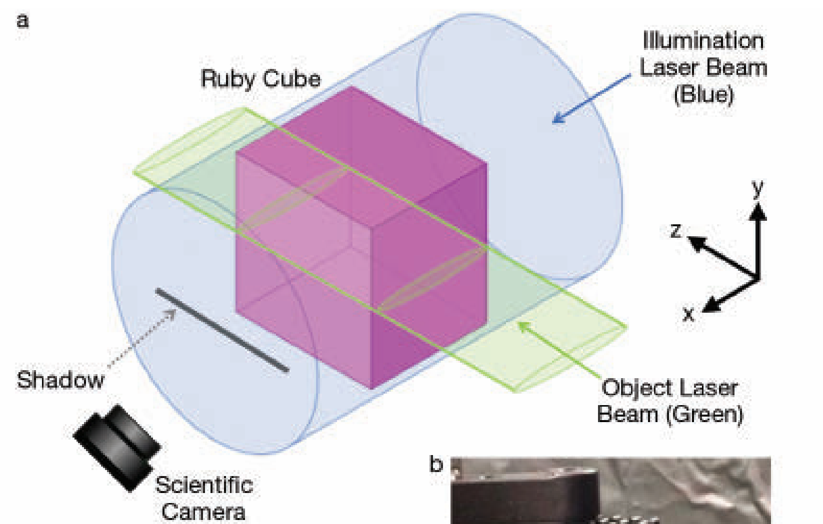
The team's experimental setup involved shining a green laser beam through a ruby crystal while illuminating it from the side with blue light. This arrangement created a shadow on a surface, visible to the naked eye. The effect occurs due to a phenomenon called reverse saturation of absorption in the ruby crystal, which allows the green laser to block the passage of blue light, resulting in a dark region that follows the contours of the laser beam.

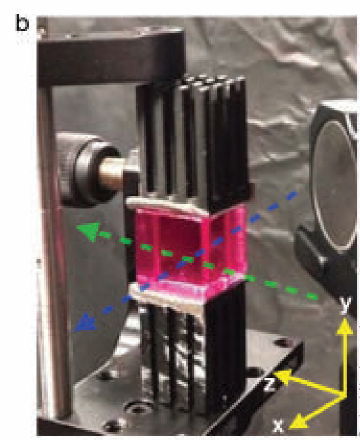
"What's particularly fascinating is how closely this laser shadow behaves like a traditional shadow," said associate physics professor Jeff Lundeen. "It follows the shape of the 'object' — in this case, our laser beam — and even conforms to the contours of surfaces it falls on, just like [how] the shadow of a tree branch would."

The researchers developed a theoretical model to predict the shadow's contrast, which closely matched their experimental data. They found that the shadow's darkness increased proportionally with the power of the green laser beam, reaching a maximum contrast of 22% — comparable to a typical shadow on a sunny day.

The laser shadow effect itself is a consequence of optical nonlinear absorption in the ruby. The effect occurs because the green laser increases the optical absorption of the blue illuminating laser beam, creating a matching region in the illuminating light with lower optical intensity. The result is a darker area that appears as a shadow of the green laser beam.

"Our understanding of shadows has developed hand-in-hand with our understanding of light and optics," said Raphael Abrahao of Brookhaven National Laboratory (formerly of the University of Ottawa). According to Abrahao, the findings could benefit applications such as optical switching as well as devices in which light controls the presence of another light, and technologies such as high-power lasers that require precise control of light transmission.





Raphael Abrahao et al.

A high-power green laser is directed through a ruby cube and illuminated with a blue laser from the side **(a)**. The green laser increases the optical absorption of the blue illuminating beam, creating a matching region in the illuminating light and a darker area that appears as a shadow of the green beam.

Raphael Abrahao et al.

Researchers showed that a laser beam can sometimes act as a solid object and cast a shadow that is visible to the naked eye. The shadow appears as the horizontal line traversing the blue background.

From a technological perspective, the researchers said the effect demonstrates that the intensity of a transmitted laser beam can be controlled by applying another laser. Next, they plan to investigate other materials and laser wavelengths that can produce similar effects.

The research was published in *Optica* (www.doi.org/10.1364/OPTICA.534596).

Theory posits the physical shape of a single photon

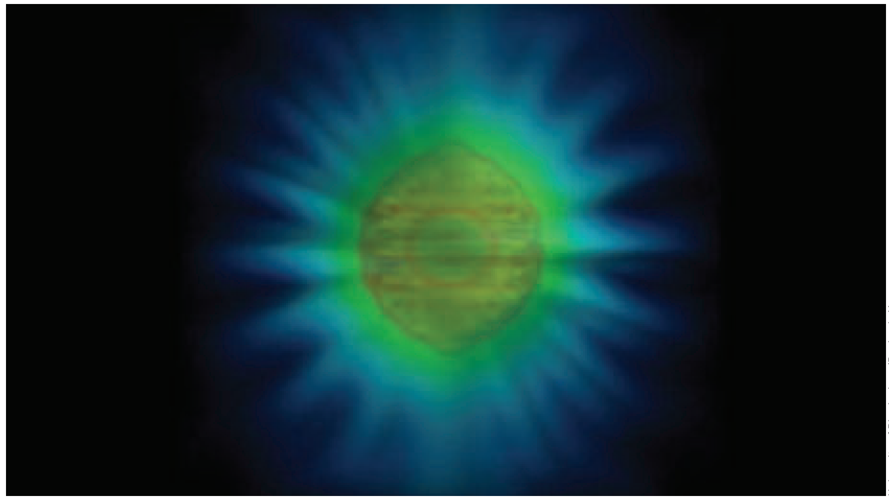
BIRMINGHAM, England — A theory that explores the nature of photons in unprecedented detail aims to show how they are emitted by atoms or molecules and subsequently shaped by their environment. University of Birmingham researchers proposed the theory, which considers the way that light and matter interact at the quantum level and allows researchers to define the precise shape of a single photon, the scientists said.

The nature of this interaction leads to infinite possibilities for light to exist and propagate through its surrounding environment. However, this limitless possibility makes the interactions exceptionally difficult to model. This is a challenge that quantum physicists have been working on for decades. By grouping these possibilities into distinct sets, the researchers created a model that describes not only the interactions between the photon and the emitter but also how the energy from that interaction travels into the distant far field.

At the same time, they used their calculations to produce a visualization of the photon itself.

"Almost as a by-product of the model, we were able to produce this image of a photon, something that hasn't been seen before in physics," said Benjamin Yuen, a professor in the University of Birmingham's School of Physics and Astronomy and first author on the study.

The work opens avenues of research in quantum physics and materials science. By precisely defining how a photon interacts with matter and other elements of its environment, scientists can design new nanophotonic technologies that could change secure communications, pathogen detection, and the control of chemical reactions at a molecular level.



University of Birmingham/Benjamin Yuen

The shape of a single photon, according to a theory presented by researchers at the University of Birmingham.

"The geometry and optical properties of the environment has profound consequences for how photons are emitted, including defining the photon's shape, color, and even how likely it is to exist," said co-author and University of Birmingham professor Angela Demetriadou.

"This work helps us to increase our understanding of the energy exchange between light and matter, and secondly to better understand how light radiates into its nearby and distant surroundings," Yuen said.

"[A lot] of this information had previously been thought of as just 'noise' — but there's so much information within it that we can now make sense of and make use of. By understanding this, we set the foundations to be able to engineer light-matter interactions for future applications, such as better sensors, improved photovoltaic energy cells, or quantum computing."

The research was published in *Physical Review Letters* (www.doi.org/10.1103/PhysRevLett.133.203604).

Waveguiding method is a lightguide through scattering materials

GLASGOW, Scotland — An approach to guiding light based on the process of diffusion can enhance light transmission by orders of magnitude, even along curved trajectories. The diffusion waveguiding approach could be used in future medical imaging technologies. It could also be adapted to guide heat, instead of light, and to confine particles, such as neutrons, instead of light waves.

Developed by researchers at the University of Glasgow, in collaboration with researchers at the University of Arizona, the waveguiding mechanism shows that photon density can propagate as a guided mode along a core structure embedded in a scattering, opaque material. It guides the flow of energy by transporting light through a solid core of weakly scattering material that is encased within a uniform, strongly scattering medium. The contrast between the scattering properties of the two materials causes the light to remain confined to the core and enables the light waves to be guided with a high degree of precision.

Similarly to fiber optic cable, the waveguiding mechanism transports light through a core. In fiber optics, the core is surrounded by a cladding material with a lower refractive index, which allows the light to travel long distances with minimal loss. In the proposed waveguiding mechanism, a thin cylindrical element inside strongly scattering material guides the energy flow.

The researchers used a 3D printer to build highly scattering, opaque, white resin structures with a low-scattering core. When the researchers directed light through the structures, they found that 100× more light was transmitted through structures with a low-scattering core than through structures without such a core. They demonstrated this effect in both straight and curved structures.

Next, the researchers developed a model to describe the physical processes of diffusion that underpin the new approach to waveguiding. Their equations supported the existence of guided modes, and the presence of guided modes was also demonstrated in Monte Carlo numerical simulations.

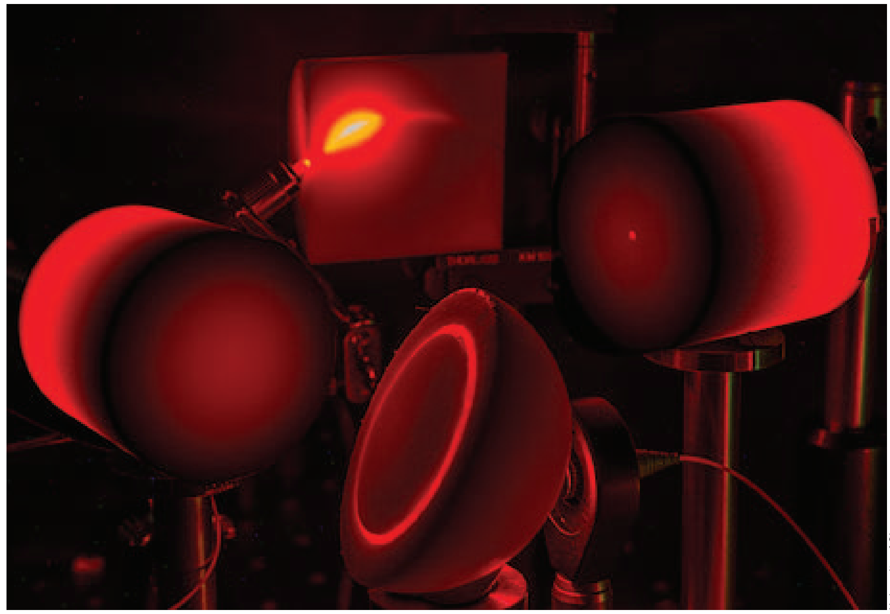
The team further found that the equations that governed the propagation of the photon density also applied to the transport of other forms of energy. The technique could, therefore, provide an effective means to guide not only electromagnetic waves but also particles, giving it a wider use beyond moving light.

“We’re still learning new tricks about light, in this case, by a process that we were surprised to discover has more in common with our understanding of the way heat travels than light,” professor Daniele Faccio said. “That means that we can expect to use this technique to find new ways to see inside opaque biological tissue using light, but also … apply it to guide more than just photons.” For example, the diffusion-based approach could be used to transport heat energy through systems that need to be cooled, such as data center computer networks, or to transport particles such as the neutrons used in nuclear power plants.

The researchers’ inspiration for the diffusion waveguiding method came from “having their heads in the clouds,” so to speak. The team knew that cumulus clouds are often bright white at their highest point and dark gray at their lowest, because sunlight is scattered through the water droplets contained in the cloud. The light in the cloud decays exponentially as it scatters through the cloud, making the lower part appear darker. Light is reflected at the top of the cloud, making the upper portion of the cloud appear white.

The guiding and transport of electromagnetic waves underlies many technologies, from long-distance optical fiber communications to on-chip optical processors. The results of the research could offer insights into how to control and harness photon density modes to access locations deep within the body for deep-tissue imaging. It is also possible to clear thin channels using spatially shaped beams in scattering fluids or in fog with light filaments from high-power lasers, with applications, for example, in free-space telecommunications.

The research was published in *Nature Physics* (www.doi.org/10.1038/s41567-024-02665-z).



University of Glasgow

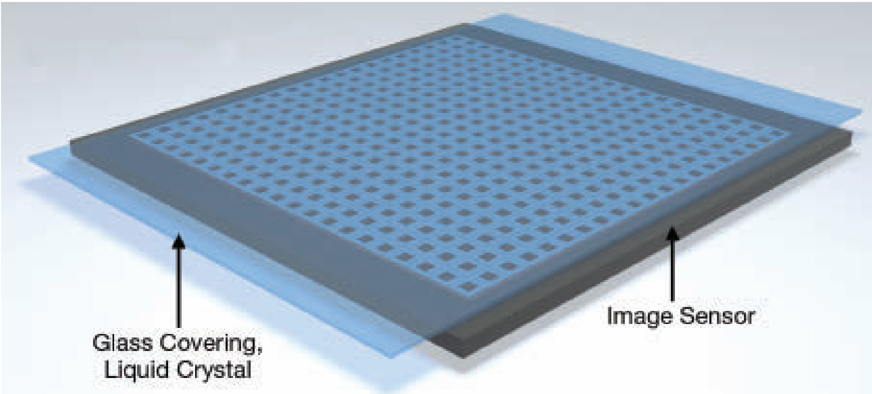
A method of waveguiding based on diffusion allows light waves to be guided around curved paths tunneled through opaque materials that would typically scatter the light.

Compact device combines light sensing and modulation capabilities

GRENOBLE, France — A device developed by researchers at CEA-Leti combines the ability to sense light and modulate it accordingly by pairing a liquid crystal cell and a CMOS image sensor into a single device. According to the researchers, as this device enables these capabilities simultaneously in a single package, it could have diverse benefits across a range of sectors. In addition to improving biomedical imaging resolution and depth, the technology could enable earlier detection of diseases and support noninvasive therapies. In industry, it could improve laser beam quality and efficiency.

The compact system provides intrinsic optical alignment and compactness and is easy to scale up, facilitating the use of digital optical phase conjugation techniques in applications such as microscopy and medical imaging. According to Arnaud Verdant, a CEA-Leti research engineer in mixed-signal integrated circuit design and lead author of a paper introducing the development, the device provides significant advantages compared with competing systems requiring separate components. Verdant said that he expects its benefits to boost deployment in more complex and larger optical systems.

In a paper presented at the 2024 IEEE International Electron Devices Meeting, the researchers said that their device represents the first solid-state instrument integrating a liquid crystal-based spatial light modulator hybridized with a custom lock-in CMOS image sensor. The integrated phase modulator and sensor embeds a 58- × 60-pixel array, where each pixel both senses and modulates light phases.



CEA-Leti

Researchers fabricated a 58- × 60-pixel array in which each 70- × 70-μm pixel has its own circuit to measure the incident light phase and modulate it via applying an electric field to the liquid-crystal layer. The array could help enable earlier detection of diseases and support noninvasive therapies.

The device relies on the key advantage of digital optical phase conjugation to dynamically compensate for optical wavefront distortions. This improves performance in a variety of photonic applications and corrects optical aberrations in imaging systems. By precisely controlling laser beams, it improves the resolution and penetration depth of optical imaging techniques for biomedical applications.

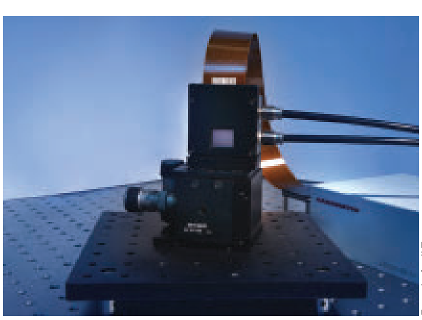
Standard digital optical phase conjugation systems rely on separated cameras and light-wavefront modulators, but bandwidth is limited by the data processing and transfer between these devices. If the system senses and controls the light-phase modulation locally in each pixel, the bandwidth no longer depends on the number of pixels and is only limited by the liquid crystal response time. This feature is a major benefit in fast-decorrelating, scattering media, such as living tissues.

"Wavefront shaping techniques can overcome these scattering effects and achieve focused light delivery. In the future, this will make it possible to envision applications such as photodynamic therapy, where light focusing selectively activates photosensitive drugs within tumors," Verdant said.

Beam-shaping method optimizes 3D-printing process

AACHEN, Germany — Studies have demonstrated that beam shaping in laser powder bed fusion (LPBF) can improve the efficiency and productivity of this additive manufacturing process. A collaboration between the Fraunhofer Institute for Laser Technology ILT (Fraunhofer ILT) and RWTH Aachen University yielded an approach to beam shaping that serves to individually optimize LPBF processes. Customized beam profiles improve component quality, reduce material losses, and enable previously impossible scaling of the buildup rate of the single beam process.

With the system currently under construction, liquid crystal on silicon-spatial light modulators (LCoS-SLMs) can be used to generate almost any beam profile in the laser powder bed fusion (LPBF) process by selectively bending the phase front of the laser beam.


Fraunhofer ILT

Fraunhofer ILT and the chair of technology of optical systems at RWTH Aachen University are collaborating to create a state-of-the-art test system enabling flexible investigation of complex laser beam profiles in power classes of up to 2 kW. Such an innovation could be used to customize solutions for industrial partners. This platform is designed to integrate LPBF processes more efficiently and robustly into industrial production so that they can meet its growing demands.

Currently, laser powers of around 300 to 400 W are common in many LPBF processes. However, the standard Gaussian laser beam they use has significant disadvantages: The high concentration of power in the beam center leads to local overheating and undesirable material evaporation as well as process instability, both of which can impair component quality due to spatter and pores. These issues significantly limit the scalability of the process, meaning that the laser power available in LPBF systems — often up to 1 kW — cannot be used for most materials.

"One way to speed up the process is to use several lasers and optical systems in parallel," said Marvin Kippels, a Ph.D. student in the Laser Powder Bed Fusion Department at Fraunhofer ILT. "However, the costs scale at least proportionally to the number of systems installed."

In addition, these systems cannot always be used homogeneously in real applications, which means that productivity cannot be increased proportionally to the increase in power. Therefore, a promising approach is to increase the productivity of the single beam process, which can also be transferred to multibeam systems.

Previous studies have shown that even simple beam shapes with rectangular, ring-shaped, or a combination of two Gaussian distributions produce promising results for both component quality and process speed. What has been unexplored, however, is the potential for more complex beam shapes in this context — a result of the lack of a necessary system technology for such investigation.

"The interaction of [the] laser beam and material in the process is so complex due to its dynamics that simulations can only provide indications of the actual melt pool behavior," said Kippels, who is currently setting up a new type of system that uses liquid crystal on silicon-spatial light modulators (LCoS-SLMs). This will enable researchers to investigate almost any beam profile in the LPBF process.

With laser power of up to 2 kW, the innovative system is a platform for testing new beam shapes at high power levels in the LPBF process, which allows the suitable system technology to be identified for an individual LPBF task.

Currently, system technology is often promoted as able to produce specific beam shapes, such as ring or top hat profiles. However, the choice of these beam shapes is not based on an in-depth understanding of the underlying process mechanisms, which is reflected in the sometimes-contradictory literature on the subject. Only by fundamentally understanding the processes can researchers specifically define which adjustments achieve a defined target, such as a certain melt track geometry. This means that a beam shape must be developed and optimized for the application, which can then ideally be implemented in the company without needing LCoS-SLM technology.

Due to the ongoing research platform, industrial customers and project partners of Fraunhofer ILT can already benefit from unprecedented flexibility in researching the laser-beam tool. "We are still at the very beginning, but we can already see the enormous potential that beam shaping can offer for the LPBF process," Kippels said.

"There is no one perfect beam shape; every application has its own requirements. Thanks to our flexible beam shaping, we can find the ideal distribution for each process, [and] the best process parameters for the task in question."

Fraunhofer ILT presented the developed test system at Formnext 2024.

Micro-LEDs show potential for neuromorphic computing

BRAUNSCHWEIG, Germany — It is expected that approximately a third of the world's electrical energy will be used for supercomputers and their cooling in 10 years. In response, a research group at Technische Universität Braunschweig's Nitride Technology Center is using a neuron network of microscopic LEDs to make future computers more powerful and energy efficient. The work extends the utility of LEDs, and specifically micro-LEDs, to a highly sophisticated application area, using the displays to effectively develop computer architectures.

Along with collaborators from Ostfalia University of Applied Sciences and ams OSRAM, the scientists aim to miniaturize and scale the energy-efficient micro-LEDs in a way that makes a neuromorphic computer possible.

"Our optical neuromorphic computing mimics the functioning of biological neural networks, such as those in the human brain, by using electronic circuits or photonic components," said professor Andreas Waag from the Institute of Semiconductor Technology at Technische Universität Braunschweig.

"This avoids the weaknesses of conventional digital computer technology, which lead to immense energy demands in massively parallel information processing for AI applications," said professor Christian Werner from Ostfalia University of Applied Sciences.

Gallium nitride is the semiconductor of choice for micro-LED technology and is increasingly used in power electronics because it offers higher power density and better efficiency than traditional silicon semiconductors. However, unlike silicon, gallium nitride is optically active, making it the basic building block for blue LEDs.

In the current work, the researchers are combining gallium nitride components with conventional silicon microelectronics to open highly integrated arrays with hundreds of thousands of micro-LEDs. "The special properties of gallium nitride are ideal for micro-LEDs with dimensions of 1 µm and smaller," Waag said.

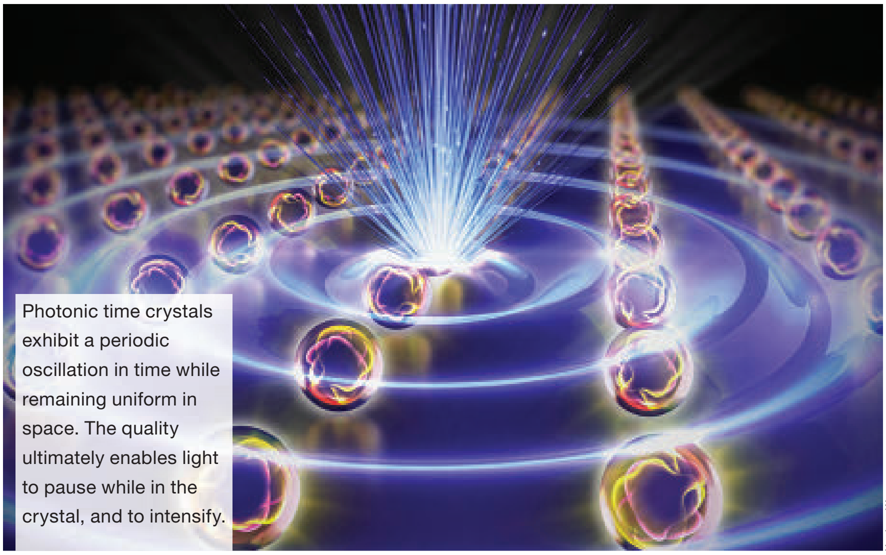
The research group sees great potential in gallium nitride-based micro-LED technology for reducing the power consumption caused by AI systems by a factor of 10,000. The micro-LEDs perform the task that would otherwise be performed by silicon transistors. Parallel in-memory processing combined with efficient photon production and detection creates a hardware that physically maps the different levels of neural networks and enables parallel information flow.

Much research is needed before an artificial brain based on this technology can become a reality, though the work already points to the potential for enormous energy savings, the researchers said. The Nitride Technology Center research group previously developed a macroscopic optical micro-LED demonstrator with 1000 neurons. The demonstrator passed a standard AI pattern recognition test in which it identified numbers from zero to nine written in a jumbled fashion — some of which are difficult for a human to decipher.

The research was published in the *Journal of Physics: Photonics* (www.doi.org/10.1088/2515-7647/ad8615).

Time crystals amplify light exponentially for lasing, sensing

ESPOO, Finland — A practical approach to creating photonic time crystals at optical frequencies, developed by an international research team, could lay the groundwork for faster, more compact lasers, sensors, and other optical devices. The development team comprising scientists from Aalto University, the University of Eastern Finland, Karlsruhe Institute of Technology, and Harbin Engineering University previously demonstrated photonic time crystals at microwave frequencies. However, designing the crystals at optical frequencies has remained a challenge for the researchers, due to the need for a fast, large-amplitude variation of properties in the material platforms for these crystals.



Photonic time crystals exhibit a periodic oscillation in time while remaining uniform in space. The quality ultimately enables light to pause while in the crystal, and to intensify.

Xuchen Wang

Unlike traditional crystals, which have spatially repeating structures, photonic time crystals are uniform in space but exhibit a periodic oscillation in time. This temporal oscillation creates a momentum bandgap in the crystal, an unusual state during which light pauses inside the crystal while its intensity grows exponentially over time. The momentum bandgaps in photonic time crystals can lead to exotic light-matter interactions.

To achieve a momentum bandgap that is large enough to noticeably amplify light, the material platforms for photonic time crystals require substantial modulation strength. The modulation strength in most material platforms, by contrast, tends to be low.

The researchers devised a way to expand the momentum bandgaps in photonic time crystals through resonances. By introducing temporal variations in a resonant material, the team expanded the momentum bandgap in the material and produced a modulation strength in reach with known low-loss materials and realistic laser pump powers. The resonance came from an intrinsic material resonance or by using a material that was spatially constructed to support a structural resonance. Rather than seeking out new materials with improved nonlinear characteristics, the researchers capitalized on artificial composites that could support high-quality resonances.

The team then validated its concept for resonant photonic time crystals for bulk materials and optical metasurfaces through theoretical models and electromagnetic simulations.

From the work, momentum bandgap size can be enhanced considerably by exploiting the structural resonances in the metasurfaces of photonic time crystals. The researchers achieved a momentum bandgap size that was 350× wider than the same metasurface operating far away from the structural resonances, with a modulation strength as small as 1%. In principle, a stronger resonance has the potential to decrease the required modulation strength even further, the team said.

Potential uses for photonic time crystals include applications in communications, imaging, and sensing. For example, light amplification with photonic time crystals could enhance nanosensing applications. "Imagine we want to detect the presence of a small particle, such as a virus, pollutant, or biomarker for diseases like cancer," Aalto University professor Viktar Asadchy said. "When excited, the particle would emit a tiny amount of light at a specific wavelength. A photonic time crystal can capture this light and automatically amplify it, enabling more efficient detection with existing equipment."

Further, it could lead to the design of more complex photonic time and space-time crystals. The team's geometry does not require the emitter to be immersed inside a solid material, and it could be used to amplify the spontaneous emission of light from emitters near the structure.

This approach to creating photonic time crystals could also be used to design lenses. Although the photonic time crystals developed by the team operate in the IR spectrum, the crystals can be implemented for the visible spectrum using other materials.

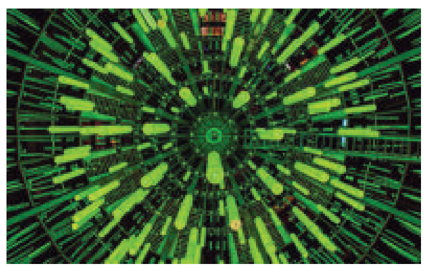
"This work could lead to the first experimental realization of photonic time crystals, propelling them into practical applications and potentially transforming industries," Asadchy said.

"From high-efficiency light amplifiers and advanced sensors to innovative laser technologies, this research challenges the boundaries of how we can control the light-matter interaction."

The research was published in *Nature Photonics* (www.doi.org/10.1038/s41566-024-01563-3).

Perovskite efficiency study targets increasingly effective devices

RALEIGH, N.C. — North Carolina State University (NC State) researchers developed and demonstrated a technique to engineer layered hybrid perovskites (LHPs) down to the atomic level, which dictates how the materials convert electrical charge into light. The technique opens the door to engineering materials tailored for use in next-generation printed LEDs and lasers, and holds promise for engineering other materials, including for use in photovoltaic devices.


North Carolina State University/Thomas Bormans

A discovery into the engineering of layered hybrid perovskites (LHPs) could lead to the development of materials for use in next-generation printed LEDs and lasers as well as photovoltaic applications.

LHPs consist of thin sheets of perovskite semiconductor material that are separated from each other by thin organic "spacer" layers. LHPs can be laid down as thin films consisting of multiple sheets of perovskite and organic spacer layers. These materials are desirable because they can efficiently convert electrical charge into light, making them promising for use in next-generation LEDs, lasers, and photonic integrated circuits.

The researchers' first task in the work was to obtain an understanding of how LHPs are formed. This started with quantum wells — sheets of semiconductor material sandwiched between spacer layers that make up LHPs. These are made by nanoplatelets, which are perovskite materials sheets that form on top of the solution that is used to create LHPs.

Measured in atoms, the researchers identified that the size distribution of quantum wells determined the value of LHPs' energy conversion efficiency.

"A quantum well that is two atoms thick has higher energy than a quantum well that is five atoms thick," said Kenan Gundogdu, a professor of physics at NC State. "And in order to get energy to flow efficiently, you want to have quantum wells that are three and four atoms thick between the quantum wells that are two and five atoms thick." This creates a gradual slope of energy flow.

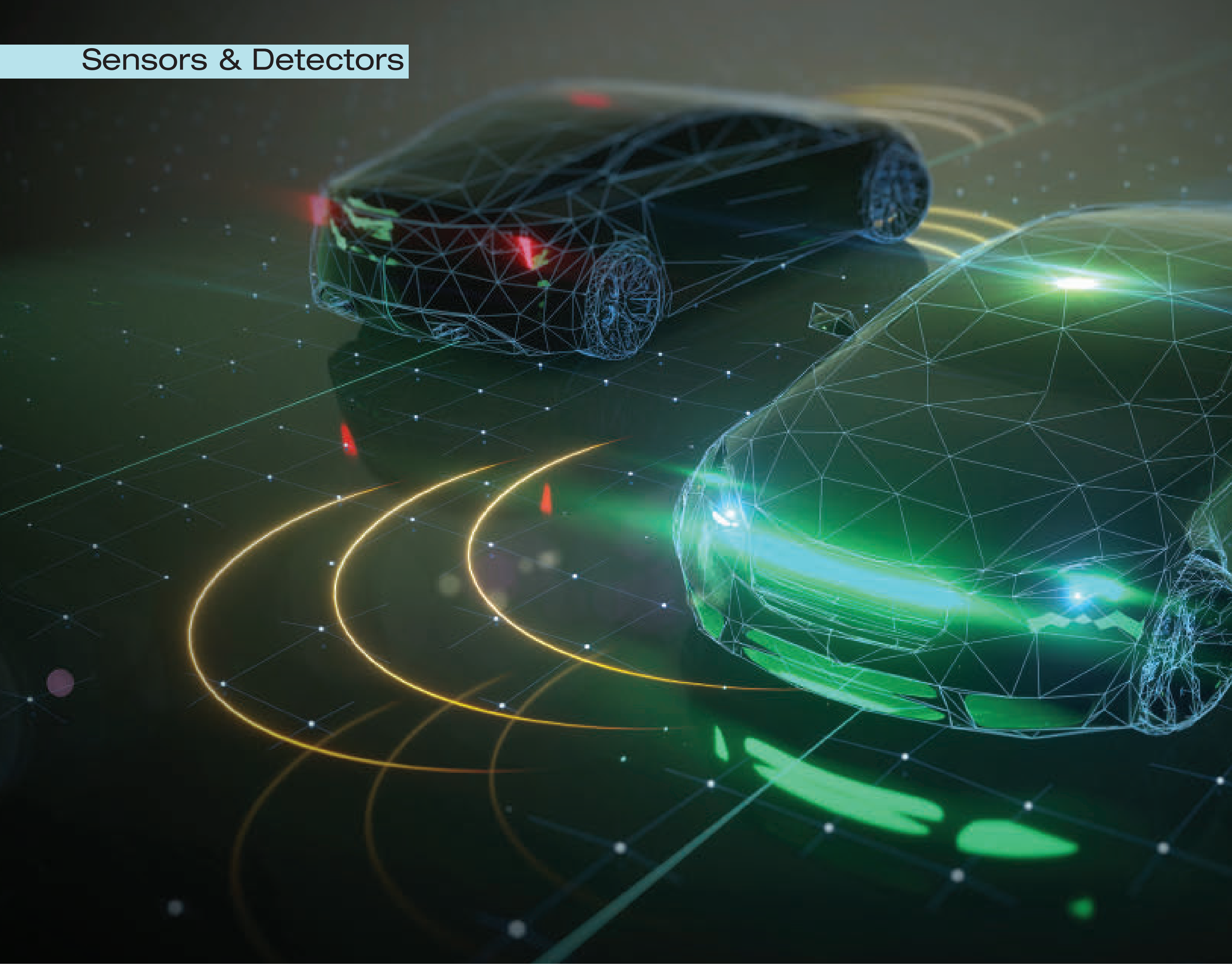
Nanoplatelets, in turn, dictate how many atoms thick a quantum well is, but it is not always exact. They act as templates for the material that will eventually form beneath them, according to Aram Amassian, a professor of materials science and engineering at NC State. This means if the nanoplatelet is one atom thick, then the quantum well will be one atom thick. But nanoplatelets tend to keep growing, meaning the corresponding quantum well will also continue to grow.

The discovery of the nanoplatelets' function answered the researchers' question pertaining to the inconsistencies in reading the thickness of each quantum well; the researchers used both x-ray diffraction and optical spectroscopy to measure the quantum wells, but each method yielded opposing answers. In the work, the researchers found that these results were a result of diffraction detecting the stacking of sheets, and therefore not detecting nanoplatelets, whereas optical spectroscopy only yielded the detection of the isolated sheets.

The discovery further led to the researchers' understanding of how to stop the growth of the nanoplatelets in a controlled setting. This allowed the researchers to engineer quantum wells to have a desired gradual slope of energy flow.

"By controlling the size and arrangement of the quantum wells, we can achieve excellent energy cascades, which means the material is highly efficient and fast at funneling charges and energy for the purposes of laser and LED applications," Amassian said.

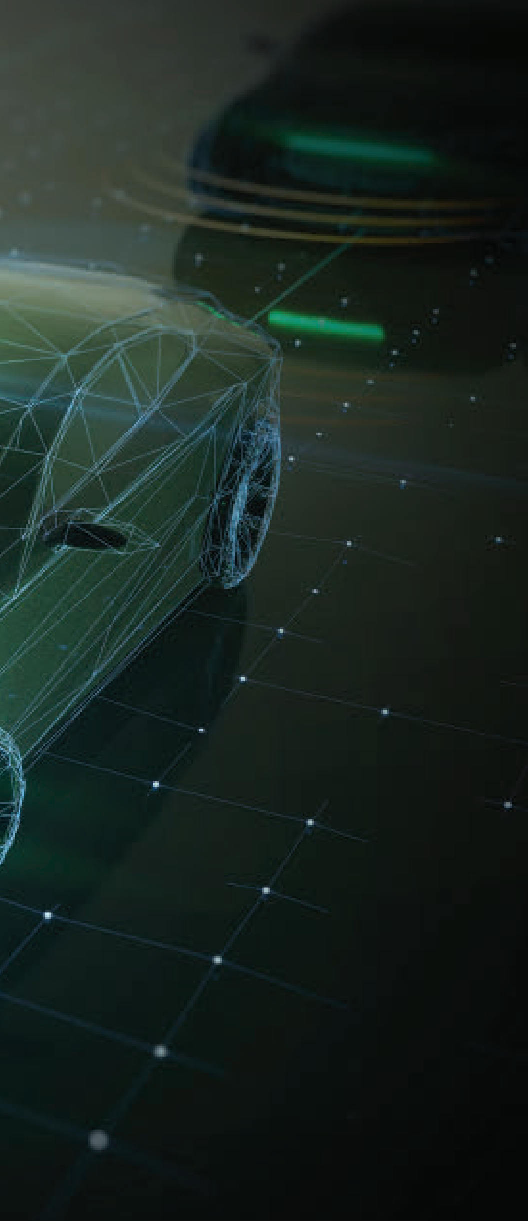
The research was published in *Matter* (www.doi.org/10.1016/j.matt.2024.09.010).



Silicon Photonics

Brings a Collaborative Lidar-Radar Relationship into View

Image on this page, courtesy of iStock.com/Just_Super.
All other images courtesy of Silicon Austria Labs.



Lidar and radar offer distinct, though complementary, capabilities. An integrated approach is maximizing the benefits of both modalities in a single package.

BY TOMMASO CASSESE
AND ION VORNICU
SILICON AUSTRIA LABS

For decades, end users and systems designers have valued radar technology for its reliability. Especially in adverse weather conditions in which sensors based on other modalities are apt to fail, radar is a dependable technique offering broad application potential.

As a result of this robustness and widespread applicability, radar today is established as a standard sensing system in several high-growth technology sectors. The automotive industry, for example, has been a key driver of radar sensor miniaturization and overall performance improvements. The commercialization of radar for passenger vehicles predates the turn of the century, and radar sensors are also now commonly deployed in advanced driver-assistance systems, including for adaptive cruise control, autonomous emergency braking, and blind-spot assist.

However, increasingly complex urban driving scenarios are intensifying the demands on sensor technology. Situations involving turn-across-path or junction crossings with pedestrians and cyclists pose particular challenges, and scenarios such as these now verge on being included in crash test ratings. Sensors that are capable of tracking multiple, smaller, and more agile objects simultaneously are therefore required to make timely, accurate identifications in critical situations.

While the current class of standard commercially available radar sensors excels in detecting single large objects, such as cars, they struggle to distinguish between multiple objects that are close together.

High-resolution radar, often referred to as imaging radar, addresses this limitation. This technology uses multiple transmit (TX) and receive (RX) channels to offer object separation that is comparable to that achieved via classical lidar. However, these systems require a much larger front-facing area due to the increased number of antennas. Furthermore, multiple-input multiple-output radar reduces the footprint of the antennas by implementing virtual channels with improved aperture.

Considering that acquiring better resolution requires more complex processing, R&D projects are exploring the integration of radar with camera sensors. These efforts aim to further enhance radar's capabilities at a time when manufacturers are progressing toward higher levels of vehicle automation.

Starting with Level 3 — Conditional Driving Automation, lidar sensors are now expected to play an increasingly important role in the next stages of growth in autonomous mobility. Lidar can serve as a safety backup and validation technology, offering capabilities that overlap with cameras, such as optical texture detection.

The high-resolution specialist

Lidars are complex systems, mainly built by components on the TX and RX sides. Typically, the TX side houses a laser along with its controller and a laser projection system, and the RX side consists of a light signal detector unit with signal readout and a data processing unit. Unlike camera imaging, lidar is independent of environmental brightness, due to its generation and use of a light source. By emitting laser pulses and measuring the time that it takes for them to return after hitting an object, lidar produces a detailed

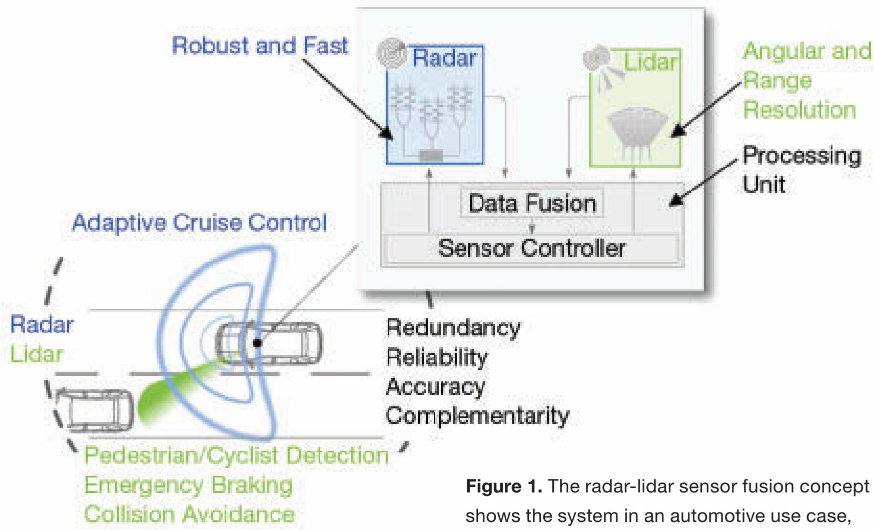


Figure 1. The radar-lidar sensor fusion concept shows the system in an automotive use case, with a processing unit enabling the distinct performance advantages of the complementary sensing modalities.

point cloud that accurately represents the surrounding environment. This is crucial for applications such as autonomous driving, in which understanding the exact position and shape of objects is paramount for safe navigation.

Though the distance detection capabilities that lidar offers are comparable to that of radar, and although lidar excels in spatial accuracy, the technology presents several drawbacks. One significant challenge is its performance in adverse weather conditions such as fog, rain, and dust. In such conditions, the combination of accurate velocity measurements and reliable object detection offered by radar is a crucial complement to the strengths of lidar.

The case for a sensor fusion

The integration of lidar and radar into a single module offers a powerful combination of capabilities that neither technology can provide alone. This fusion of high-resolution data from lidar with the all-weather performance of radar creates a comprehensive sensing system with several important advantages, especially for automotive applications. One specific example, urban traffic management, benefits from the accurate detection and classification of a diverse array of closely spaced objects — something that is essential for both safety and efficiency.

Radar can additionally be used to identify regions of interest within a frame, allowing lidar to then be deployed to focus its scanning on these areas. This targeted approach reduces the volume of point cloud data that is generated, thereby minimizing storage requirements and simplifying data processing and analysis. This efficiency is necessary in settings with limited computational resources, or for real-time data processing, such as in autonomous vehicles.

Additionally, the integration of radar's detection capabilities with lidar's scanning precision reduces the time required for data collection per frame. In applications such as search and rescue, for example, this efficiency is paramount. Quick and accurate scanning of a map of an affected area can be the determining factor of a successful search and rescue effort to locate survivors.

Lidar fundamentals

Different solutions have been proposed for lidar sensors, many of which are already on the market. The primary differentiator between lidar systems is the measurement principle; depending on the measurement mechanism, lidar systems are mainly based on time-of-flight (ToF) — either direct or indirect — or frequency-modulation continuous wave (FMCW) engines.

ToF sensors measure the time required for a light pulse to travel from the transmitter to the object and back to the receiver. Direct ToF sensors typically require higher power, short pulses, and fast electronics such as picosecond time-to-digital converters. This class of sensor currently dominates the lidar market.

Indirect ToF sensors are based on amplitude-modulated continuous wave (AMCW)-based sensing mechanisms; these systems emit a continuous signal, the power of which is amplitude-modulated. Demodulating the backscattered signal, these sensors calculate the distance to the object based on the phase shift of the received signal. The advantages in this case are that the receiver does not require very fast electronics, and it features a smaller pixel pitch, reaching a higher resolution than the direct ToF sensor. Nevertheless, the backscattered signal has quite low power when received by the sensor, impairing the depth accuracy, especially above the medium range.

FMCW lidar sensors deliver intrinsic amplification connected to the use of homodyne reception; for example, the received signal beats with the local oscillator, and both are generated by the same laser source. This process puts FMCW lidar into favor in cases of high losses due to absorption and/or long-range application. Broadly, this class of lidar sensors offers the potential to overcome ToF and AMCW limitations. Additionally, FMCW has an intrinsic immunity to sun radiation and other incoherent radiations.

From the imaging standpoint, the laser projection system found in lidar systems is based either on scanning or flash, or a combination of both mechanisms. Scanning systems are either implemented with conventional mechanical parts, microelectromechanical system (MEMS) devices, or solid-state solutions, such as programmable VCSEL arrays or optical phase arrays (OPAs).

In the most advanced mechanical scanning systems, the laser source is fixed, while a mirror is continuously rotating, featuring a wide horizontal field-of-view (FOV), typically 360°. The vertical FOV is typically smaller than the horizontal and it is implemented in a flash manner. The reduced FOV comes mostly from a practical point of view — automotive applications do not typically require >30°. However, the mechanical scanning is quite bulky, and it cannot be scaled cost-wise because ~70% of the lidar cost is due to the macromechanical system. A MEMS mirror solution could overcome this scalability bottleneck, though such a solution would be limited in horizontal resolution. And additional dimension considerations, such as eye safety and miniaturization, must be accounted for.

Silicon photonics: The fusion enabler

Given these performance advantages and drawbacks, an ideal lidar system will combine solid-state (for miniaturization) and scanning (for eye safety) with flash (multiple channels for increased frame rate). On top of this, it is known that the 1550-nm wavelength is more eye-friendly at the same optical power and emission conditions.

Additionally, an FMCW engine can operate with less optical power than a ToF engine due to the advantages of coherent detection. An additional benefit of using the 1550-nm option comes from the possibility to use (integrate) components developed for telecommunications applications into the lidar system. This can highly reduce the development time and improve yield.

Given the need for discrete components to enable this miniaturization, advancements in PICs are very promising for the integration of FMCW lidar. Recent developments in electro-photonic integrated circuits (EPIC) technologies specifically offer an ideal platform. The lidars can be truly miniaturized, because the electronic and photonic components can be monolithically integrated on the same chip.

A major leap in the EPIC FMCW lidar system concept beyond the monolithic integration potential is the replacement of the lenses; these components are the primary component-level limitation to the miniaturization of ToF-lidar systems. Various integrated photonics platforms have been proposed as suitable for integrating not only beam forming and steering devices, such as OPAs employing electro-optical or thermo-optical effect to control the beam direction, but also for integrating the full lidar system. This is possible because the multiple components needed for an FMCW lidar sensor have already been developed in integrated photonics platforms for telecommunications applications, and primarily at 1550 nm. These components can now be repurposed for the disruptive application of lidar without the need for further reconceptualization.

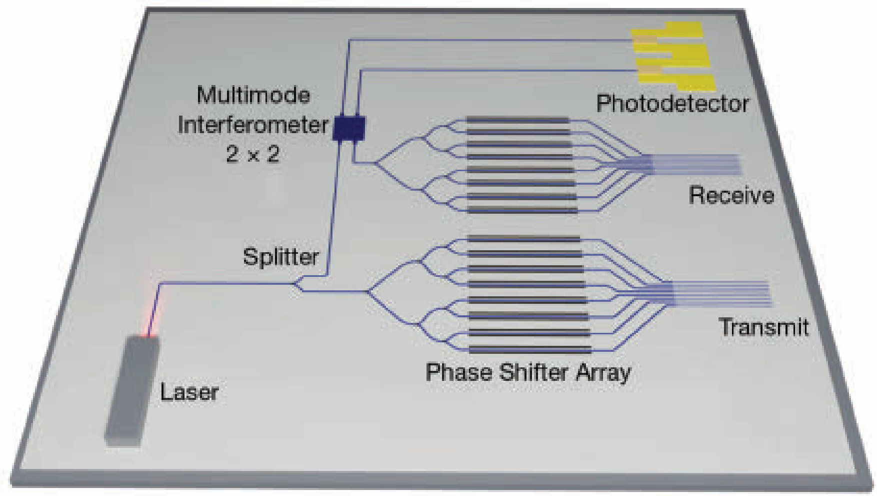


Figure 2. The schematic of a lidar PIC shows the individual components, or elements, including the photodetector; transmit and receive (TX and RX) paths; phase shifter array; laser source; and beamsplitter. A multimode interferometer is used as a coupling mechanism.

The future: Opportunities and challenges

A fully integrated radar-lidar sensor could greatly enhance the capabilities of autonomous vehicles, environmental monitoring, and other critical applications, providing reliable, high-quality data in the most challenging conditions (Figure 1).

As it relates to the advantages of an integrated photonics-enabled radar-lidar sensor fusion, miniaturization is the

Given the need for discrete components to enable this miniaturization, advancements in PICs are very promising for the integration of frequency-modulation continuous wave lidar.

obvious benefit. By integrating all components onto a single chip, an ultimate sensor fusion between lidar and radar sensors can be achieved, using an approach that can drastically reduce the amount of data sent to the central processing unit of an autonomous car.

Still, a number of challenges persist, particularly in materials integration, sensor placement, and range performance. And, downstream from system design considerations, the final placement strategies for radar and lidar sensors must be carefully considered in regard to application. Co-assembling these two types of sensors may present performance disadvantages since each has different operational requirements. Lidar sensors are highly sensitive to dirt and debris on the emitter, making it necessary to place them under surfaces that are actively cleaned, such as windshields and back and side windows. Radar sensors can be placed with fewer limitations.

Another core challenge is the need to develop a lidar PIC with low propagation loss, compatibility with high optical power, efficient optical phase shifters to control the OPA(s), integrated light sources, and detectors. Single integrated photonics platforms do not currently offer all the required capabilities. Achieving optimal performance will likely require co-integrating a mix of materials on the same chip.

The range limitation of PIC-based lidar sensors is another design demand. To achieve performance comparable to radar, with ranges exceeding 200 m, a large receiver surface is needed. This requirement makes lidar PICs more susceptible to defects on the wafer, potentially lowering overall yield and increasing final product costs beginning in the design and fabrication stages. In this context, the use of micro-optics may be explored as a potential solution to enhance performance.

Further, the control of the lidar PIC requires dedicated electronics. Ideally, these can be co-integrated with photonics: With the OPA deployed both on the TX and RX paths, many individual antennas are required for high resolution and efficiency. Each antenna needs a dedicated optical phase shifter for beam steering, which in turn requires a dedicated driver. Depending on the shifter technology, the driver must output tens of milliamperes. The development of an efficient and reliable bank of drivers is a major undertaking.

A simple block diagram of the silicon photonics-based lidar system proposed within the CoRaLi-DAR consortium resembles that which is shown in Figure 2. A tunable laser generates the light signal, and its output wavelength is controlled to vertically steer the OPA output beam. The same laser output is also frequency-modulated according to the FMCW approach. Part of the laser output power is emitted from the chip through the OPA, which controls emission direction, and the remaining portion is kept on-chip and used as a local oscillator in the homodyne detection scheme. Here, the eventual backscattered light is collected by a receiver OPA and sent together with the local oscillator to the balanced photodetector integrated on-chip.

Meet the authors

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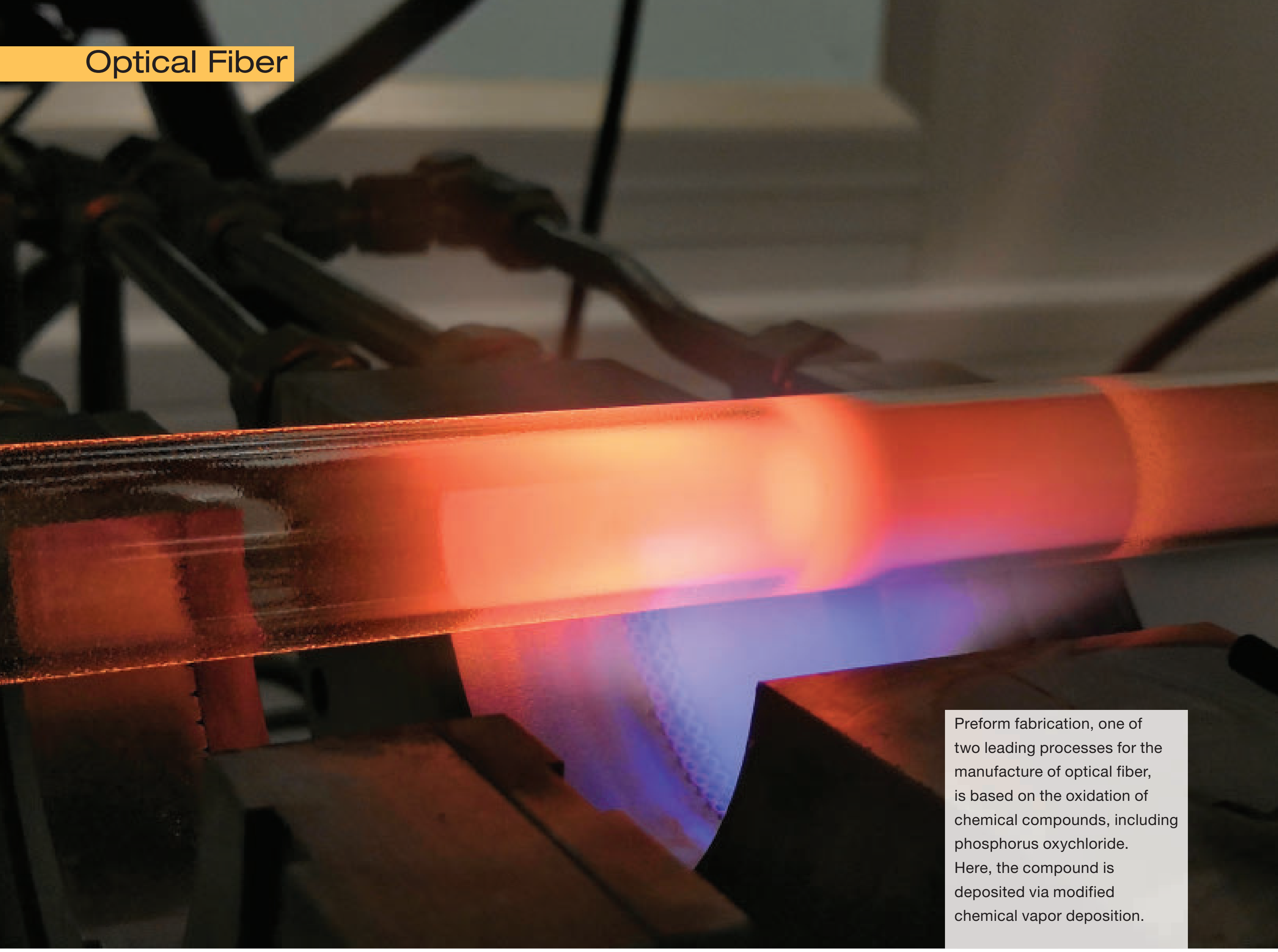


Preform fabrication, one of two leading processes for the manufacture of optical fiber, is based on the oxidation of chemical compounds, including phosphorus oxychloride. Here, the compound is deposited via modified chemical vapor deposition.

Thulium-Doped Fibers Lead a Charge to the 2-µm Band

Emissions in the eye-safe region between 1.7 and 2.2 µm are providing end users with precision and command over a range of applications.

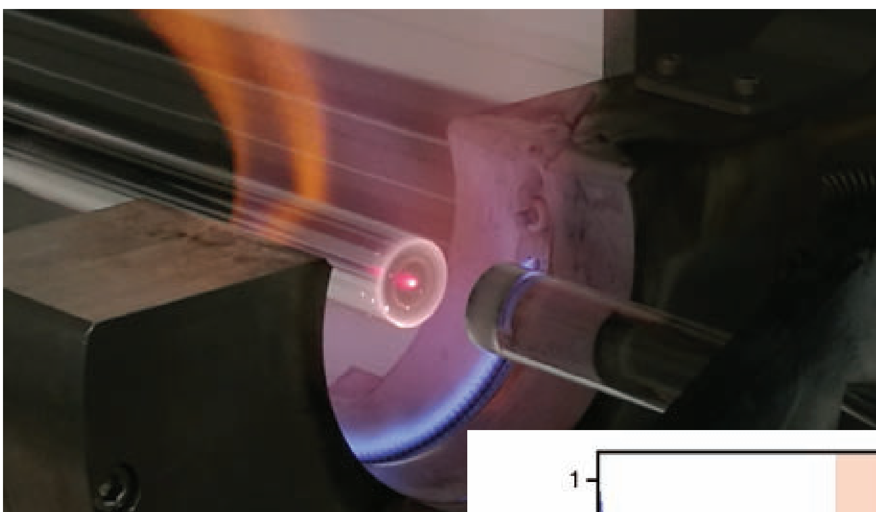
All images courtesy of Coractive Inc.

BY NORBERTO RAMIREZ MARTINEZ
CORACTIVE INC.

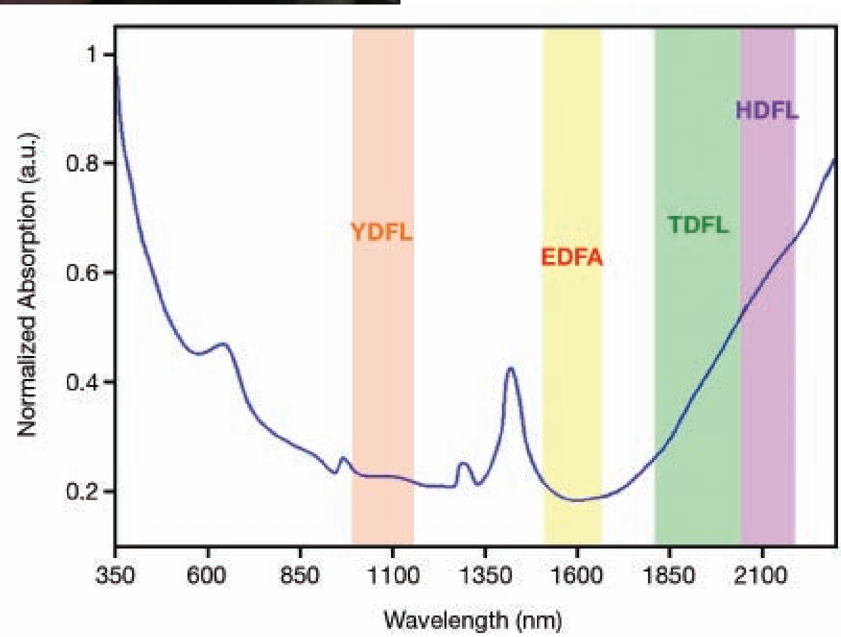
Optical fibers are well known and widely used as the transmission medium for optical communications. Due to the rapid increase of technology and service demand that has characterized modern optical data and telecommunications, optical fibers are necessary to use as optical amplifiers for long-haul transmission.

The most suitable example of this evolution was the development of the erbium-doped fiber amplifier. This device consists of a laser-active gain medium that enables the amplification of optical signals of 1.55 µm. Similarly, ytterbium-doped fibers (YDFs) are now an established solution supporting the growth of manufacturing and materials processing, owing to their suitability for high-power generation with a superior beam quality and thermal management.

As laser technology continues to mature, the development of thulium-doped fibers (TDFs) is undergoing an exponential increase in terms of both development and application. Compared with previous solutions, these fibers offer a much higher transmission capability in free space and a much larger nonlinear and fiber damage threshold (versus YDFs), and they have shown exceptional advantages in medical applications and a range of sensing and detection techniques.



Preform fabrication is performed to achieve a modified core to cladding ratio in the finished fiber **(above)**.



Hydroxyl group absorption and laser emission opportunities band in silica fibers **(right)**. EDFA: erbium-doped fiber amplifier; HDFL: holmium-doped fiber laser; TDFL: thulium-doped fiber laser; YDFL: ytterbium-doped fiber laser.

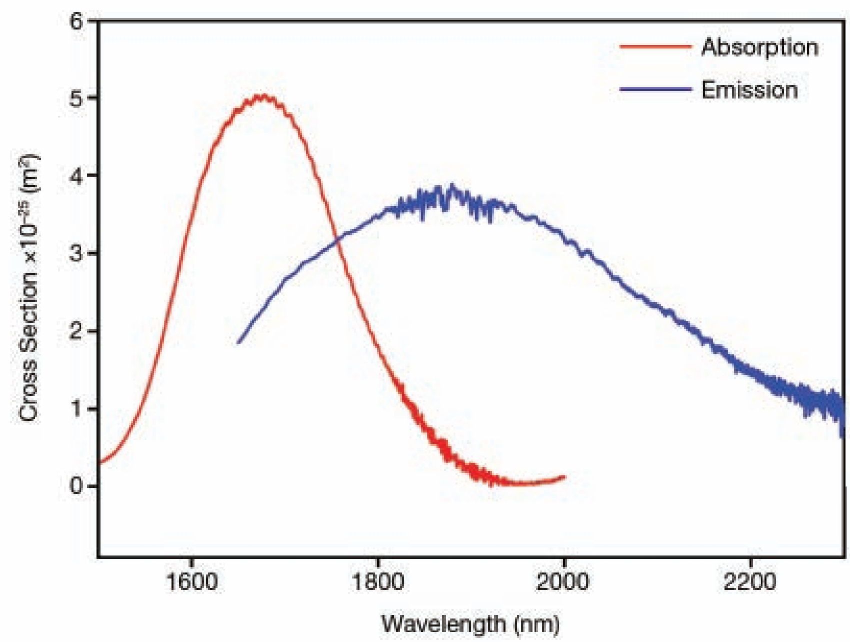
Manufacture of optical fibers

Rare-earth-doped silica fiber fabrication has played an important role in optical communications and high-power fiber laser applications. The current competitive landscape of new fiber compositions and fiber designs has overtaken the standard fabrication techniques, leading companies to be active in the manufacture of specialized optical fibers. Many industry leaders have developed and are deploying innovative fabrication methods so that customers can become and remain leaders in their markets.

The main target for the incorporation of rare-earth ions into silica glass is multifaceted. The aim is to tailor the absorption and emission spectra, influence excited state properties, and improve glass-forming characteristics. Therefore, the addition of rare-earth dopants to the silica matrix is essential for the development of fiber laser technologies.

Industry uses two main manufacturing processes to create an optical fiber: preform fabrication and fiber drawing. Preform fabrication is based on the oxidation of chemical compounds such as silicon tetrachloride, germanium tetrachloride, and/or phosphorus oxychloride that pass through a rotating high-purity silica substrate tube and are exposed to an external energy source to produce soot particles. These particles are deposited on the inside tube wall, then collapsed into a solid rod, called preform. The preform is then heated in a fiber drawing tower to a temperature just above the softening mark until the far end of the preform falls, thereby relying on the effects of gravity to form the optical fiber.

Adjusting the optical components of the setup configuration can broadly address most unwanted effects in a rare-earth-doped fiber laser system, such as thermal management problems and nonlinear effects. It is also possible to reduce these adverse effects by modifying the core design and selecting the proper glass host material and rare-earth concentration.



The graph shows the absorption-emission cross section of thulium-doped fibers. Thulium exhibits a wide emission wavelength range and multiple transition lines. It is possible to pump silica-based thulium-doped fibers (TDFs) with 79x-nm high-power diodes to achieve a "hidden" feature that can generate a maximum laser efficiency of 80% and correspond to a quantum efficiency of 200%.

Thulium fiber facts

Thulium is the second-least abundant lanthanide, and has traditionally been widely studied for generating laser emissions in the eye-safe region between 1.7 and 2.2 µm. The first report of this type of laser was in 1967 by a team led by H.W. Gandy. The laser emitted at 1900 nm. It was not until the 1980s that significant work on thulium-doped fiber lasers emerged in R&D.

It is widely regarded that the best method to pump an active medium is to choose a pump wavelength that is close to the target wavelength due to the reduced quantum defect. To enter the 2-µm region, TDF lasers can be addressed by either high-power diodes at 79x nm, or by fiber laser pump sources at 1.55 µm. To achieve the ~1.55-µm pump, an erbium-doped fiber or ytterbium-erbium-co-doped fibers and additional high-power diodes (0.98 µm and 1.45 µm, respectively) must be added into the dynamic of the laser system.

Fortunately, since thulium exhibits a wide emission wavelength range and multiple transition lines, it is possible to pump silica-based TDFs with 79x-nm high-power diodes and benefit from a "hidden" feature that can generate a maximum laser efficiency of 80%, corresponding to a quantum efficiency of 200%. This well-known cross-relaxation process is one of the most beneficial mechanisms in operating with thulium fibers, enabling the generation of two excited ions for one pump photon when pumped by 79x-nm diodes. When the thulium concentration in a gain material exceeds ~2wt%, quantum efficiencies >100% in the 2-µm lasing transition can be reached.

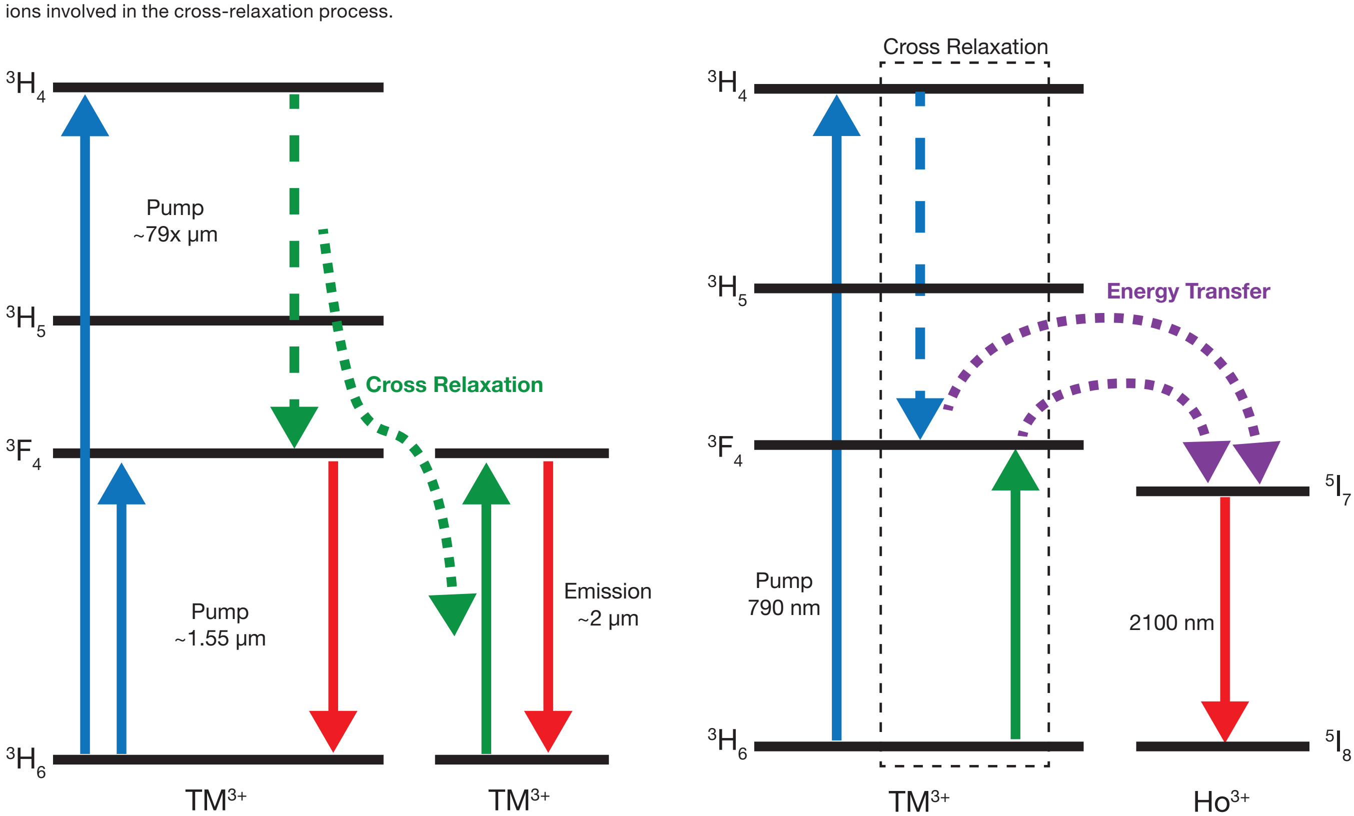
It is worth mentioning that when the thulium concentration in a system is significantly low, the large interionic distance prevents any ion-ion interactions. These interactions are more likely to happen upon an increase to the thulium concentration and a reduction to the distance between ions.

The innovation and adaptation of companies to meet demands is enabling TDFs to approach the well-established YDFs operating in the 1-µm region. In many cases, they are reaching laser efficiencies of ~70% by possessing better eye safety, relaxed nonlinear limits, and the flexibility to work in continuous wave, nanosecond, picosecond, and femtosecond laser regimes. At the same time, this significant growth of the thulium fiber lasers has opened opportunities for R&D to continue its search of more efficient laser solutions across cutting-edge applications and emerging markets.

Medical applications

The widely recognized origin of the use of lasers in health care applications traces back 50 years, where an argon laser beam was pointed at the bladder wall for an experiment. Advancements in scientific research have enabled modern laser technologies to find use in minimally invasive surgeries as well as in urology procedures. These and many other applications achieve the required high levels of precision and efficiency. As a result, they are leading to opportunities for laser-based innovation for established and emerging medical markets.

The simplified thulium (Tm) energy level diagram shows the two-for-one cross-relaxation process **(left)**. Charting the thulium-to-holmium (Ho) energy transfer process **(right)**. The $^3F_4$ manifold describes an upper laser level in ions of thulium ions involved in the cross-relaxation process.



Two significant aspects of 2-µm laser sources render it a suitable candidate for clear-cut surgical applications: the high absorption in water in combination with the penetration depth that leads to a minimal damage around the exposed area, and the coagulation effect caused by the 2-µm radiation that helps mitigate unnecessary bleeding during the intervention.

Comparison of Holmium:YAG and Thulium (Tm) Fiber Lasers

	Holium: YAG Laser	Thulium Fiber Laser
Power Supply	High Amperage	Standard
Pump	Flashlamp	Diode
Gain Medium	YAG Crystal + Ho^{3+}	Silica Fiber + Tm^{3+}
Wavelength	2120 nm	1940 nm
Cooling System	Water Cooling	Air Cooling
Delivery Fiber	≥200 µm	≥100 µm
Operation Mode	Pulsed	Continuous Wave/Pulsed
Pulse Energy	0.2 to 6 J	0.025 to 6 J
Pulse Width	50 to 1300 µs	200 to 12,000 µs
Pulse Profile	Irregular	Symmetric
Penetration Depth	~0.3 mm	~0.08 mm

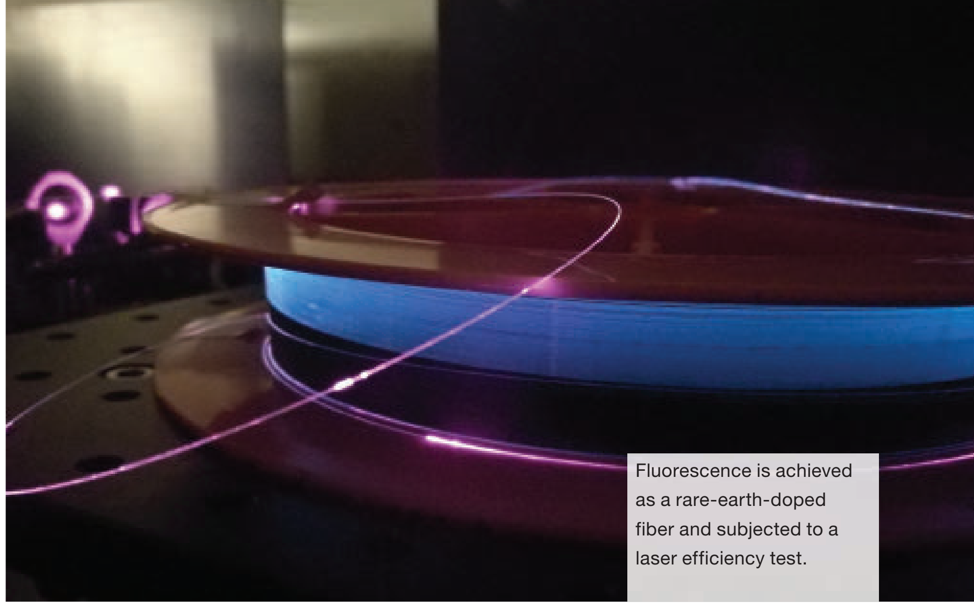
The Holmium:YAG (Ho:YAG) laser is the most commonly used laser in urology due to its multipurpose ability to achieve desired cutting and tissue coagulation. Despite this ubiquity, however, common diodes for its main absorption band at 1.9 µm do not exist. Therefore, these lasers are typically flashlamp-pumped — and generate considerable heat waste because the pumping of the laser crystal is not effective. On the other hand, TDF lasers can be pumped using commercial diodes, which offers several advantages compared with flashlamps because they can operate at a lower power and less robust laser configurations (see table).

Since the water absorption coefficient determines the level of absorption of an infrared radiation source, users can localize the most efficient wavelength for stone ablation and retropulsion, for example, as well as for other clinical applications. The energy of TDF lasers has a water absorption coefficient ~4× higher than the Ho:YAG laser energy, which is clinically advantageous because it leads to a more efficient intervention while minimizing photothermal damage to surrounding tissue.

TDF lasers and their holmium-doped fiber laser counterparts have experienced significant improvements in the longer side of the NIR region. This progress for both sources has arrived at a point at which holmium-doped fiber lasers are now the favored option for operation at longer wavelengths (>2.1 µm). As mentioned, these holmium laser systems do not have absorption bands where high-power diodes are available.

As an alternative, TDF lasers operating at ~1.95 µm are traditionally used for pumping holmium-doped fiber lasers. Therefore, the overall optical-to-optical conversion efficiency of the holmium laser system depends on the efficiency of TDF lasers. This dynamic brings additional challenges to fabrication processes due to the need for an all-glass fiber structure with a fluorine-doped cladding for low-loss pump guidance. Low-index polymer(s) used in standard double clad fibers will incur a strong absorption in the 2-µm wavelength region.

Co-doping silica fibers with thulium



Fluorescence is achieved as a rare-earth-doped fiber and subjected to a laser efficiency test.

and holmium can be considered as an alternative to the in-band pumping scheme. The 79x-nm pump can be used to excite thulium ions and promote the two-for-one cross-relaxation process, followed by a dominant donor-acceptor energy transfer mechanism from thulium to holmium. Laser sources based on thulium:holmium co-doped silica fibers have been reported with slope efficiencies of up to 56%.

Room for future innovation

In addition to 2-µm medical applications, 2-µm laser systems are also promising options for the permissible power transmission in free space that can achieve several orders of magnitude greater than at 1 µm. This potential is allowing thulium technology to rapidly mature and achieve improvements in different fiber laser regimes. For example, pulsed laser systems may be used either for lidar, or for conversion into the mid- and far-infrared, remote sensing, and spectroscopy. Despite the application potential, it is still the power scaling of continuous-wave thulium fiber lasers that offers the most evidence for the improvements to the fiber technology.

Not long ago, it was expected that 100-W class, 2-µm mid-infrared fiber lasers would overthrow the use of YDFs for certain applications. Now, with the constant improvement to TDF laser technology, offering eye safety from 1.7 to 2.2 µm — and the ability to convert available diode sources into emission features for numerous applications — this idea has become a reality.

Meet the author

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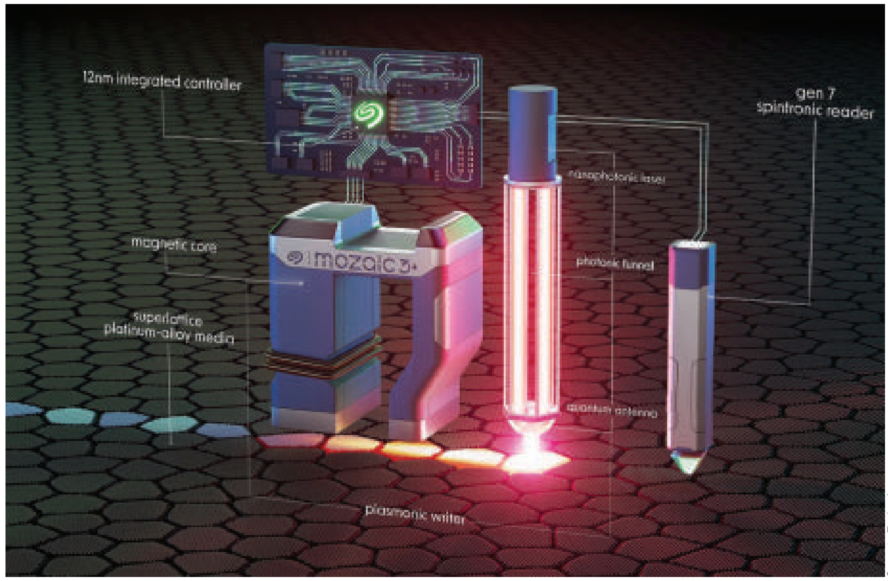
Low-Power Lasers

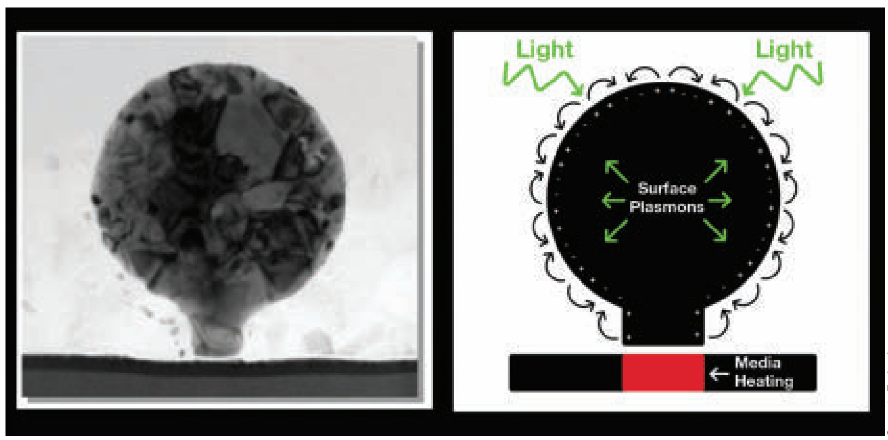
Heat Up Data Storage

From heat-assisted magnetic recording to magnetic random-access memory, low-power lasers are boosting data capabilities for AI and beyond.

BY JAMES SCHLETT
CONTRIBUTING EDITOR



Seagate Technology



Seagate Technology

Seagate Technology's heat-assisted magnetic recording (HAMR) hard disk drives (HDDs) include a plasmonic writer with a precision-engineered laser that heats and writes the media to >800 °F and cools it down in <2 ns.

Last spring, electronics giant Toshiba announced its plans to ship its first test sample hard disk drives (HDDs) using heat-assisted magnetic recording (HAMR) technology. Toshiba, at the time of the announcement, said that it is targeting 2025 for the shipment.

The decision as well as the technological advancement represent an emerging movement in the data storage and photonics industries. Toshiba's debut of its HAMR HDDs, with 28 to 30 Tb of storage, follows Seagate Technology's rollout of similar technology in 2017, following 15 years of research.

With Toshiba and Seagate expecting to be working toward mass-producing HAMR HDDs with 32 Tb of storage capacity by next year, industry analysts predict that more than half of all drives shipped in 2027 will be using this next-generation, large-capacity magnetic recording technology. And HAMR's share of the HDD market could be even greater if this technology is incorporated into drives made by Western Digital — which said in mid-2023 that it was at least one-and-a-half years from achieving volume production of this technology.

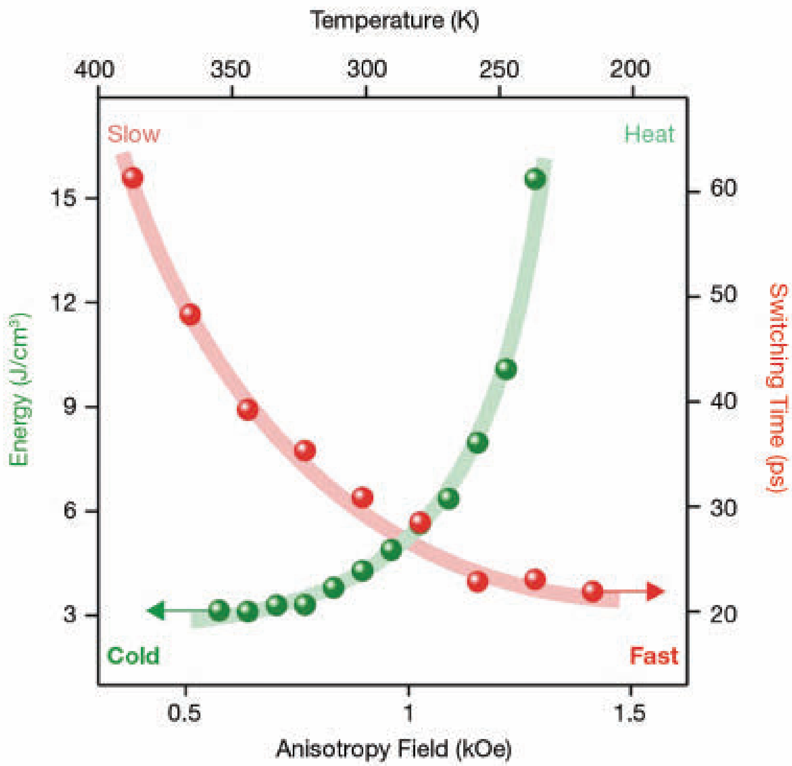
Despite the magnetic foundation of HDDs, these developments signal a growing opportunity for low-power lasers, which serve as the heat source for HAMR. For example, Seagate's HAMR HDDs use a low-power NIR Fabry-Pérot laser. The use of lasers for the flipping, or "switching," of data bits represents a shift from the industry-standard, perpendicular magnetic recording. In this legacy mechanism, a recording head's write pole creates a perpendicular magnetic field to switch the recording media.

HAMR

HAMR was conceptually proposed in the 1990s, and in 2002, Seagate began to strive for its commercialization. In HAMR, the laser function helps drive an increase in the areal density, which is the number of data bits per unit area on a disk platter. One challenge associated with increasing areal density is that if the bits are too close together, they can affect each other's magnetic direction. HAMR systems use a laser to rapidly heat the magnetic media to enable the recording head to switch bits in the higher magnetic energy (coercivity) materials.

"A Fabry-Pérot laser is coupled into a waveguide, which provides the proper phase and intensity distribution to excite a plasmonic resonance on the near-field transducer," said Ed Gage, vice president of Seagate Research Group. Fundamentally, the low-power sources offer an assist in this technology. "The electrons in the metallic peg at the bottom of the transducer move in a way to excite an electric field in the recording media. The media is made of a poor metallic conductor, so the media get[s] very hot very quickly [and] then [it] cools down very quickly as well."

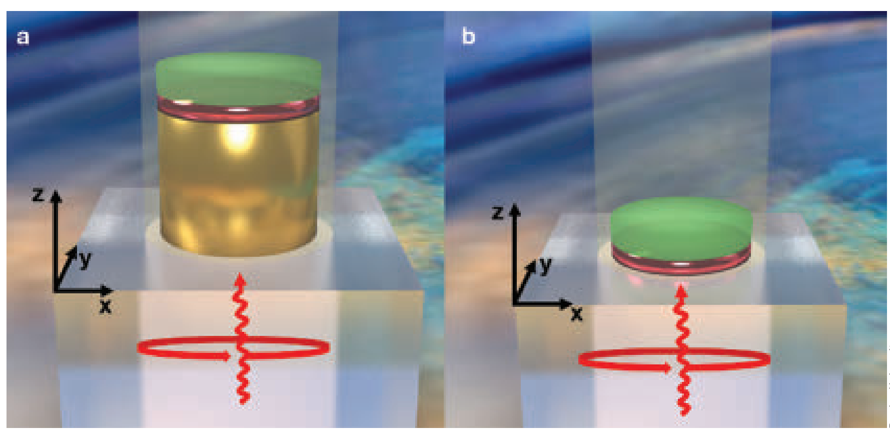
According to Seagate, the typical recording power from the laser is on the order of 10 mW. For HAMR, the laser power must be high enough to raise the recording medium close to its Curie temperature, which is nearly 500 °C in iron-platinum (FePt)-ordered alloys, said Ernesto Marinero, a professor of materials



University of Bialystok

In 2024, researchers in Poland and the Netherlands demonstrated cold all-optical toggle switching of magnetization **(left)**. The green dots show minimum heat load accompanying the switching as functions of temperature. The red dots show corresponding switching time as a function of temperature.

Purdue University researchers proposed CMOS-compatible plasmonic materials for on-chip magnetization reversal in nanomagnets. A nanodisk includes a plasmonic antenna **(below left, yellow)**; a thin magnetic layer **(burgundy)**; and a capping layer **(green)**. A nanomagnet and capping layer, without the plasmonic antenna, shows circularly polarized light **(below right, right-pointed arrow)**. The curled arrow shows incidence direction.



Purdue University

engineering at Purdue University. "The laser power must be sufficient to provide the power density at the near-field transducer to raise the medium temperature in the vicinity of the Curie temperature, but also to compensate for reflectivity losses and coupling efficiency of all the optical components involved in guiding light from the laser to the near-field transducer," he said.

According to Gage, the lasers in Seagate's HAMR HDD account for <1% of the drive's power consumption, resulting in a significantly lower storage per power (Tb/W) rate compared with competing technologies. For HAMR, said Richard Evans, a professor of physics at the University of York, the laser spot is tiny (~100 nm). This makes the local heating especially strong.

Gage said that laser efficiency improvements could further reduce the power and heat generated in the recording head, and that Seagate is evaluating advancements in other low-power laser diode technologies. Single-mode VCSEL technology would also be of interest, though, in this case, with an increase in available laser power, he said.

Marinero said that the path to further reducing laser power in the future hinges on improvements to losses of the optics guiding the laser beam to the near-field transducer. Laser power reduction could also involve lowering the recording medium's Curie temperature. However, the relationship between the Curie temperature and the medium's structural and magnetic properties would present a challenge.

The combination of HAMR and bit-patterned media (BPM), which involves lithographically defined "magnetic islands" of bits, could present an option to boost storage capacity of 50 Tb or greater. In 2012, for example, Marinero was part of the team of researchers at Western Digital that used direct electron-beam lithography to fabricate 1 Teradot/in.[2] cobalt-chrome-platinum alloy BPM disks, on which magnetic recording was performed.

"This technology is currently [on] the [shelf] for future solutions once the limits of HAMR-alone magnetic recording are reached and the cost of BPM mass production is attractive to the market," Marinero said.

Cold magnetic storage

Lower laser energy consumption in writing data can also be used through all-optical magnetic switching with femtosecond laser pulses. Last year, researchers from the University of Bialystok (Poland) and Radboud University's (Netherlands) Institute for Molecules and Materials demonstrated laser-induced toggle switching without relying on heat. For this "cold" magnetic storage, the researchers used a commercial ultrafast system with high energy per pulse.

While noncommercial, all-optical switching of metallic systems has been demonstrated, its minimum heat load, or volume energy needed for the switching, was ~1500 J/cm^3. Previously, switching without such heat seemed unrealistic, said Andrzej Stupakiewicz, a physics professor at the University of Bialystok. According to Stupakiewicz, the researchers' approach from the 2024 work considerably outperformed existing alternatives, both in the speed of the write-read magnetic recording event and in a negligible heat load.

At Purdue, researchers are also examining "cold" recording as it relates to all-optical magnetic switching and using femtosecond laser pulses in their efforts. Marinero said researchers at the university have conducted modeling studies that validate these ultrafast lasers (in combination with surface plasmons) to generate intense opto-magnetic fields. Such studies support an approach that would drastically reduce the laser energy required for writing data, he said. However, the commercialization of such technology is years away, though it could accelerate as HAMR reaches its technical limits.

As for potential application areas, Stupakiewicz said prime opportunities for cold magnetic storage are emerging in superconducting electronics, quantum compute, and AI, because applications in these domains face energy consumption challenges. Traditional metallic technologies also lack the speed and frequency for CPU or storage due to material cooling delays for equilibrium thermodynamics after switching bit states.

Single-pulse toggle switching

The International Data Agency estimates global data to swell to 163 Zb (zettabytes) by 2025, compared with 16.1 Zb in 2015. Currently, the data storage industry is facing pressures to not only lower energy consumption through the deployment of low-power lasers but also to increase data speeds. Cognitive systems, such as machine learning and AI, and the continued expansion of mobile and real-time data and embedded systems and Internet of Things, are among the drivers behind this rise in demand.

Femtosecond lasers are positioned to meet these data storage requirements, particularly through single-pulse all-optical switching of magnetization. While femtosecond lasers may seem like high-power options, their requisite energy power in single-pulse switching magnetization over individual magnetic bits is much less than the power found in existing technologies, such as hard drives and/or flash memory (10 nJ), said Chuangtang Wang, a physics research fellow at the University of Michigan.

"Femtosecond laser switching of magnetization requires the laser-heating of materials to near Curie temperature (above 1000 K for ferromagnetic Co/Pt [cobalt/platinum] multilayer) in tens or hundreds of femtoseconds. Therefore, high-pulse energy is needed, [typically on the] order of several mJ/cm^2 (mW over focused laser spot)," Wang said. "Therefore, an optical parametric amplifier laser is typically used so the frequency is on the order of kilohertz."

To date, single-pulse toggle switching is achieved with ferrimagnets, which have low anisotropy. This limits their applicability to magnetic data storage due to thermal instability. In contrast, ultrafast magnetic switching has been demonstrated with ferromagnets that have high anisotropy. But this requires multiple pulses.

According to Evans, the current need is for high anisotropy materials, such as FePt, that are switchable by all-optical means. As it relates to FePt, single-shot switching has yet to be achieved — and this is necessary for it to work as a technology, he said.

"The solution lies in advanced/composite materials and greater physical understanding of all the mechanisms at play — for example, ultrafast currents and magnons as well as angular momentum transfer," Evans said. In 2014, Evans was part of a team that developed a synthetic ferrimagnet that sandwiched two ferromagnetic materials and a nonmagnetic spacer layer. Single-pulse magnetic switching was achieved with this synthetic ferrimagnet. Since then, synthetic ferrimagnets have been fabricated, but Evans said challenges remain in engineering a strong antiferromagnet coupling between layers.

Opto-magnetic random-access memory

All-optical switching schemes in synthetic ferrimagnetic multilayers are also creating opportunities for femtosecond lasers in magnetic random-access memory (MRAM), following a demonstration by researchers at Eindhoven University of Technology in 2017. Previously, magnetic memory writing could only be achieved by electrical means.

"Opto-MRAM introduces lasers into this process to manipulate the magnetic states. Instead of using electrical currents, ultrafast laser pulses induce magnetic switching via all-optical switching," said Luding Wang, an assistant professor at Tohoku University.

"This allows for [the] magnetic switching process to overcome the traditional spin precession process. A femtosecond laser interacts with atoms at nonequilibrium thermal states, allowing for efficient spin transfer faster in picosecond compared to traditional MRAM," Wang said.

For opto-MRAM, the laser's typical pulse duration is 100 fs and wavelengths are in the visible or NIR spectra (around 800 to 1000 nm). It uses extremely low energy, on the order of picojoules per pulse.

"Femtosecond lasers offer energy savings because they can switch magnetic states using ultrashort pulses of light with minimal power consumption," Wang said. "These savings are especially important for data centers and high-performance computing systems, where energy efficiency directly impacts operational costs and environmental footprint.

"As demand for faster, more energy-efficient memory grows, opto-MRAM and similar technologies will become more attractive."

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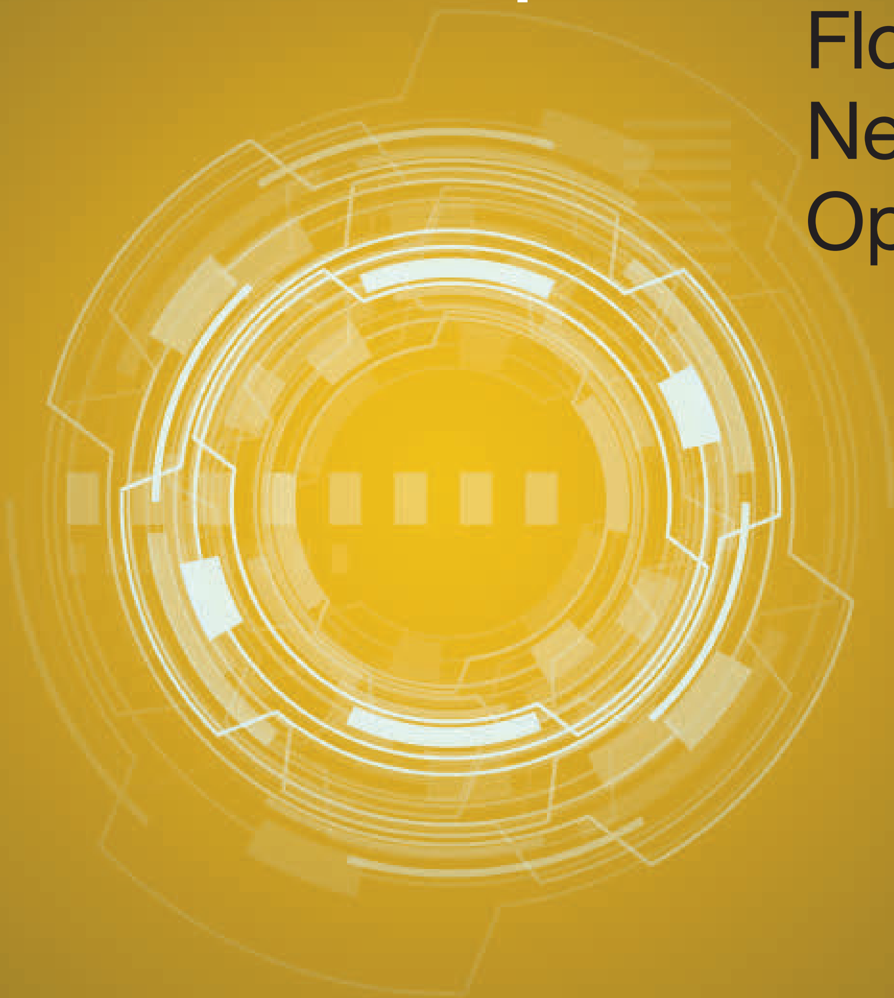
Sharper, Faster, and Smarter: Liquid Lenses Flourish as Next-Generation Optics



Vision systems often face limitations related to wear and misalignment. Liquid optics provides a solution with unmatched flexibility, speed, and precision.

BY TOMAS ZVOLENSKY AND
MARK VENTURA, OPTOTUNE

The remarkable capabilities of human vision serve as a powerful inspiration to developers of advanced optical systems. Despite its seemingly uncomplicated design, comprising a single lens and offering about ~1 MP of resolution per eye, human vision achieves exceptional performance. For this reason, designers and engineers strive to replicate and even surpass its capabilities.

Yet while the capabilities of human vision provide a dynamic reference, creating vision systems that deliver high magnification, small pixel sizes, and low f-numbers — especially in low-light conditions — poses substantial challenges. These factors tend to reduce the depth of field, necessitating precise focusing solutions. Traditional mechanical lenses often suffer from misalignment and wear over time, making them less reliable for high-speed, high-frequency applications.

Liquid lenses offer a compelling solution to overcome these bottlenecks. Drawing on the dynamic focusing capabilities of the human eye, these lenses, constructed with a polymer membrane encasing optical fluid, adjust focus rapidly through a voice coil actuator (Figure 1). This mechanism pumps liquid in or out, altering the lens shape from convex to concave to achieve focus adjustments within milliseconds. Moreover, this technology enables reliable, precise focusing without mechanical wear and tear, and guaranteed performance for a billion refocus cycles and beyond.

Precision and focusing speed

Liquid lenses are integral elements of various vision systems, including those that are used in established applications in microscopy, industrial code readers, and even consumer electronics, such as smartphones. Also, these lenses excel in applications that require rapid refocusing, such as inspection systems for integrated circuits, connectors, and other small components. Optimal performance is typically achieved when liquid lenses are incorporated into the lens stack, ideally behind the aperture stop to maximize low f-number performance and large image circles. Liquid lenses are available in numerous configurations, covering a wide range of sensor formats and focal lengths, between 5 and 300 mm, and magnifications from 0.15× to 6×.

Delivering a current, often using inexpensive voice coil motor driver integrated circuits, with interfaces such as I2C, is used to obtain control over liquid lenses. Advanced control systems with Ethernet, USB, or analog interfaces are also available, and these options facilitate integration into various applications. Closed-loop autofocus systems can achieve focus within a few hundred milliseconds, and sensors with phase detection autofocus enable even faster, single-step focusing.

Expanding FOV: Fast steering mirrors

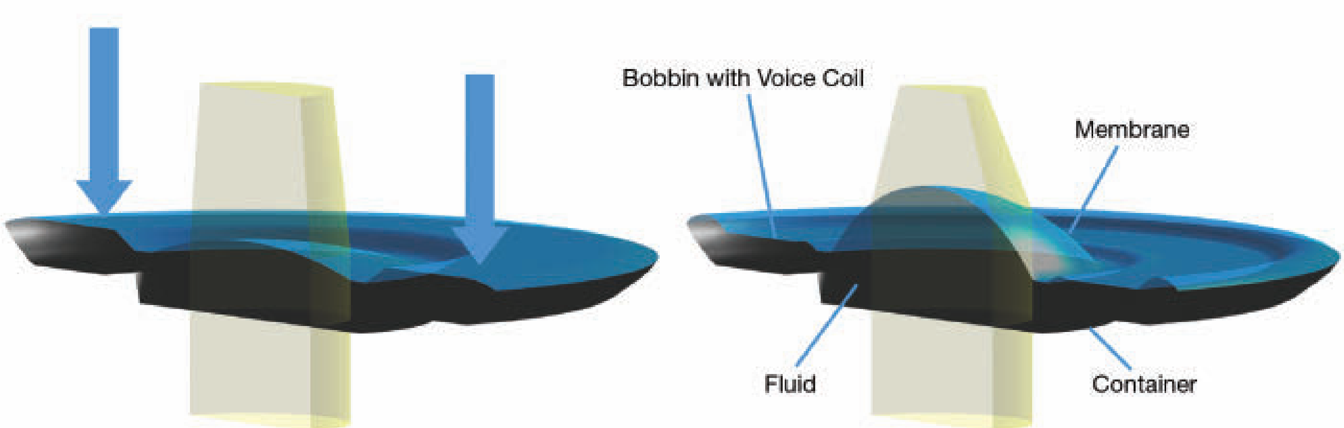
Conventional methods for expanding the field of view (FOV), such as short focal length lenses or large image sensor systems, are often restricted by resolution, cost, and reliability. Mechanical scanning can be slow and prone to failure. Optical zoom systems are typically bulky and compromise optical quality.

Fast steering mirrors offer a solution, enabling the rapid scanning of high-resolution images across large fields of view. These mirrors can tilt along two axes, providing an expanded FOV of up to 100°. They are also more compact than traditional galvanometer mirrors and larger than microelectromechanical systems (MEMS)-based scanners, which enables these components to strike a balance between size and performance.

Fast steering mirrors typically have a clear aperture of 15 mm, or ~0.59 in. This value is much larger than MEMS-based scanners, and, due to the single point of rotation, they are still more compact than a pair of galvanometer mirrors. The point of rotation can be placed either on the mirror surface, avoiding image shifting, or in the center of mass, to make the unit resistant to shock or vibration. The mirror is current-controlled and includes an optical feedback system for high repeatability. Small steps of 0.1° take 3 ms, and large steps of 20° settle in 13 ms.

In a typical setup, a 3-MP camera with a 75-mm (~2.95-in.) lens can achieve an angular field of view of about 4° × 5°. The mirror can expand the field ~350× to cover a total of 70° × 100° at a resolution

Figure 1. The anatomy of liquid lenses **(left)** and actuation principle.



Opening image courtesy of iStock.com/tein-studio.
All other images courtesy of Optotune.

Figure 2. A gigapixel imaging kit, comprising a wide-angle camera and a narrow-angle camera, which uses the liquid lens for focusing and a fast steering mirror to expand the field of view to 100°.

of >1 GP. With performant hardware, and assuming an image overlap of ~20%, the time to acquire such an image stack is in the order of 10 s. Figure 2 shows a gigapixel imaging kit, comprising a wide-angle camera and a narrow-angle camera, which uses a liquid lens and a fast steering mirror.

Applications of fast steering mirrors include surveillance, in which high resolution is necessary for face or object recognition, as well as iris recognition, code reading over large areas, and high-magnification imaging including on drones. In infrastructure inspection, for example, the 2D mirror is faster, lighter, and more compact than mechanical gimbals that have historically been used for these types of applications.

Medical imaging is among the additional application areas that use fast steering mirrors. These components can further enhance medical imaging by allowing for the rapid scanning of tissues in systems such as optical coherence tomography. This in turn can lead clinicians to make faster and more accurate diagnoses.

Pixel shifters enhance resolution

Pixel shifting enables cameras to achieve higher resolution without the need for smaller, noisier pixels, which are also apt to demand more expensive optics. This technique uses small, controlled movements to oversample an image, effectively increasing its resolution. In this way, pixel shifting is comparable to the functionality of the microsaccades of the human eye.

Pixel shifters are particularly useful in thermal cameras, in which pixel sizes are difficult to reduce to <15 µm. By shifting the image in small increments, pixel shifters can double the effective resolution to provide clearer, more detailed images (Figure 3, top). As such, this technology is beneficial for applications such as display inspection, microscopy, and slow-moving object surveillance, in which high resolution is critical.

A glass window, which serves to move the image in small, precise increments, is typical of most pixel shifting. This method can significantly enhance the resolution of color, monochrome, and thermal imagers. However, it requires synchronization with the camera's frame rate and increases computational demands. It is therefore best suited for applications in which the need for high resolution outweighs the need for rapid frame rates.

Application considerations

The integration of liquid optics offers particular promise for quality control and inspection processes in the realm of industrial automation. Since liquid lenses rapidly adjust focus and adapt to varying object heights and distances, these optics are invaluable in environments where speed and precision are paramount.

In assembly lines, where components of varied sizes and shapes must be inspected, liquid lenses can instantly switch between focal points. This ensures that every item is examined with the level of clarity necessary to meet stringent requirements for accuracy and reduce the likelihood of unnoticed defects. Moreover, the application of fast steering mirrors in machine vision systems enables quick scanning of large areas. This quality is critical to accelerate processes such as wafer inspection in semiconductor manufacturing in which the slightest imperfection can lead to costly failures.

Liquid lenses also swiftly alter focal lengths. This enables the creation of more versatile and portable imaging devices and offers advantages in the medical sector. For example, liquid lenses are used in advanced retinal imaging systems, allowing ophthalmologists to perform more detailed and rapid eye examinations. The adaptability of these lenses can further lead to the development of hand-held diagnostic tools that could be used in remote or under-resourced areas, providing high-quality medical imaging without the need for bulky equipment.

The European Union Commission-funded project iToBoS (Intelligent Total Body Scanner for Early Detection of Melanoma) is one example of how liquid lenses were used in a device that improves the early detection of melanoma. This project's aim is to develop an AI diagnostic platform for the early detection of melanoma based on a total body scanner that is powered with high-resolution cameras equipped with liquid lenses.

Liquid lenses are viable in the consumer electronics industry, too, particu-

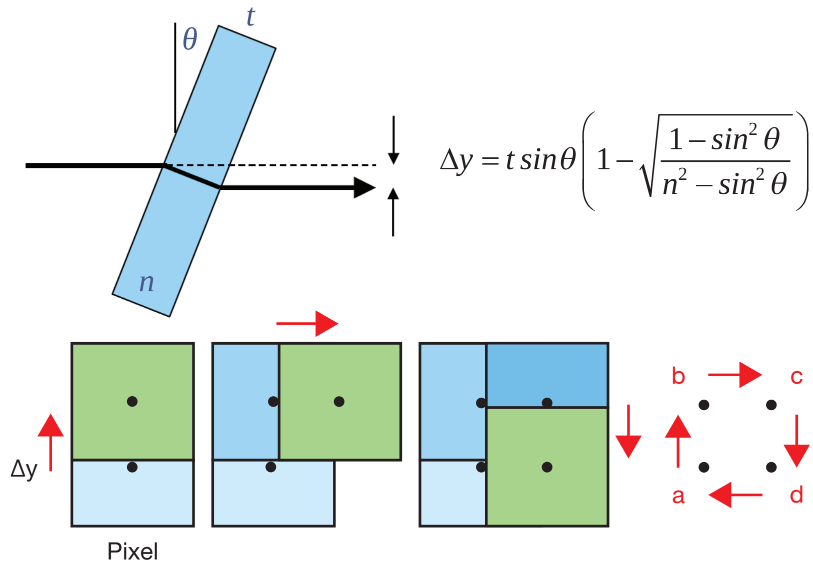


Figure 3. The working principle of pixel shifters: The tilt angle of a glass window is accurately controlled along the x and y axes **(top left)** such that the image is shifted by half a pixel, or a full pixel, in the case of color cameras with a Bayer pattern.

larly in augmented reality (AR) headsets. They enable cameras to achieve quick and precise autofocus, which is crucial for capturing high-quality images and videos in varying environments. As AR technology evolves, the need for compact, responsive optical components will grow. Liquid lenses and fast steering mirrors could be used to achieve lightweight, high-performance AR glasses that provide users with a seamless blend of digital and real-world visuals. These technologies could also lead to more immersive virtual reality (VR) experiences by enabling headsets to offer dynamic focusing and wider fields of view, enhancing the realism of virtual environments.

And in defense and security, liquid optics are positioned to play an essential role in improving surveillance systems and targeting mechanisms. Quickly adjusting focus or expanding the FOV offers significant benefits in rapid response scenarios, such as in drones used for reconnaissance missions. Fast steering mirrors can be used in advanced imaging systems to provide a broader situational awareness, enabling the detection and tracking of objects across large areas with high precision. These technologies could also enhance the capabilities of night vision and thermal imaging equipment, providing clearer images under challenging conditions and improving the effectiveness of security operations.

Paradigm shift across industries

As liquid optics technologies continue to advance, their broader implications across various industries are increasingly apparent. By offering unmatched flexibility, speed, and precision, these technologies are enhancing current applications and paving the way for future innovations.

Even beyond imaging applications, liquid lenses and 2D mirrors are also applied in several laser-based applications. These include 3D marking, laser-based welding and/or cleaning, cosmetic treatment, and beam stabilization for terrestrial and satellite free-space communication.

Meet the authors

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UV-Curable Polymers Enable Robust Wafer-Level Micro-Optics Fabrication

BY THOMAS ACHLEITNER AND ANDREA KNEIDINGER, EV GROUP (EVG), AND STEPHAN PRINZ, DELO INDUSTRIAL ADHESIVES

Polymer refractive microlenses are the core technology in many micro-optical modules, which themselves are critical enabling technologies for an expanse of optoelectronic systems, including those found in cars, smartphones, and wearables. Microlenses in ambient light sensors, diffractive optical elements for structured light generation, and high-precision surface relief gratings in diffractive waveguides — which enable emerging technologies such as 3D sensing and augmented reality glasses — are just some of the functionalities that these refractive optics enable. In the automotive sector specifically, this class of micro-optical modules is used in ultracompact microlens-enabled projector beam headlights and other lighting features, both functional and cosmetic, that can be found virtually anywhere in the car.

The current rise of polymer refractive microlenses points to a broader trend that is underway, with implications for fabrication technologies. Unquestionably, the increased adoption of micro-optical components and devices is necessitating robust and economic manufacturing. Today's production requirements for hundreds of thousands or even millions of pieces each year command new and innovative solutions.

One such approach is UV lens molding. Unlike generic injection molding, used mainly for macroscopic elements, the UV lens molding process meets the stringent requirements of micro-optics manufacturing, specifically as it relates to alignment precision. Lens molding uses transparent working stamps to replicate defined lens shapes into UV-curable polymers — essentially, adhesive resins — directly deposited onto substrates, such as glass or silicone. To deposit the polymer, puddle or droplet dispensing is used. Subsequently, the working stamp, on a rigid backplane, is brought into contact with the substrate using a linear force. The rigidity of the backplane enables high alignment accuracies. The polymer is UV-cured to form a solid lens with glass-like properties.

Upon completion of this process, the working stamp is released and reused for the next batch of imprints. The imprinted wafer, which may contain up to thousands of optical elements, can now be further processed.

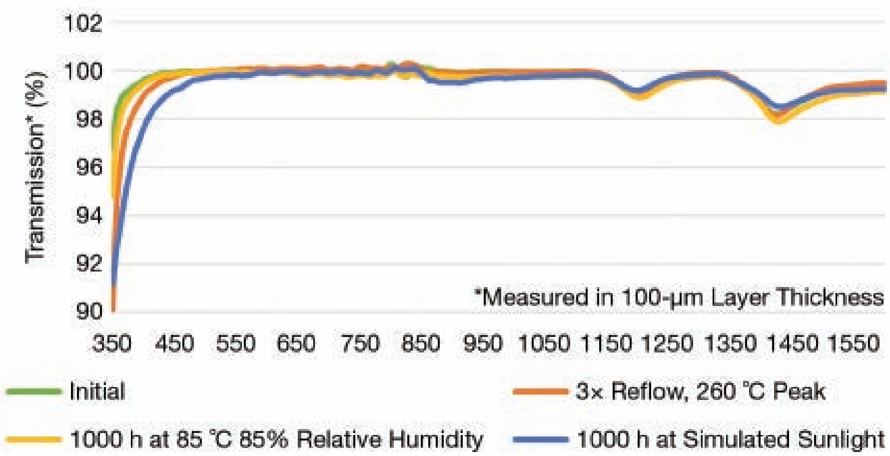

Figure 1. Transmission values at ~100% over the entire visible spectral range with no scattering were achieved, indicating that the resin was optically clear. Optical stability was maintained, even after challenging reliability tests, such as reflow soldering or '85/85' storage.

And, because the stamp structure is replicated in a single step directly into the material with UV-curing instead of heat, the lens molding and nanoimprint lithography (NIL) methods are significantly more sustainable than other lithography or replication technologies. Also, alternative lithography methods are limited in their ability to be used to manufacture complex optical structures at the wafer level. NIL and lens molding are insensitive to shape and complexity, rendering them suitable for high-volume production of almost any optical system.

The combination of NIL and lens molding not only enables miniaturization, but it also allows for monolithic integration and dense wafer-level packaging, which pushes this miniaturization toward new standards. NIL enables fabricators to create multifunctional optical systems, with the ability to combine polymers, each with different functionalities, in

 All images courtesy of DELO Industrial Adhesives.

subsequent steps that must be completed during the imprinting stage.

Micro-optics application trends

UV lens molding is finding widespread application in direct imprint processes, replacing the traditional etching processes that previously dominated in these use cases. The UV approach is more efficient and sustainable in many instances and, in sectors including automotive (microlens arrays), UV lens molding comes with a higher reliability standard than legacy and/or alternative methods.

Additionally, as ongoing efforts in miniaturization often come with their own set(s) of strict criteria for any technical polymer that may be used in the assembly of ultrafine components, lens molding has become a mainstay in applications combining UV-curing and micro-optics fabrication. And with increasing market penetration now calling for higher production volumes, and an increasing degree of automation as a result, capacity is more efficiently upscaled with larger wafers with more units per hour rather than lengthening production lines and adding machinery.

In this context, a recent study led by DELO and partner EV Group (EVG) aimed to determine how UV-curable polymers can augment the manufacture of wafer-level micro-optics. As is well understood in the semiconductor industry, increasing wafer sizes can be challenging. This study demonstrated possibilities for settings beyond the controlled laboratory environment, in real-life production sites with state-of-the-art machinery and materials.

Study parameters

The collaborators used the EVG7300 multifunctional UV lithography system, which features an alignment accuracy of 300 nm and allows for easy production scaling with wafer sizes ranging from 150 to 300 mm. The machine enables nanoimprinting capabilities, including conformal printing, automated low-force stamp detachment, and fast curing times

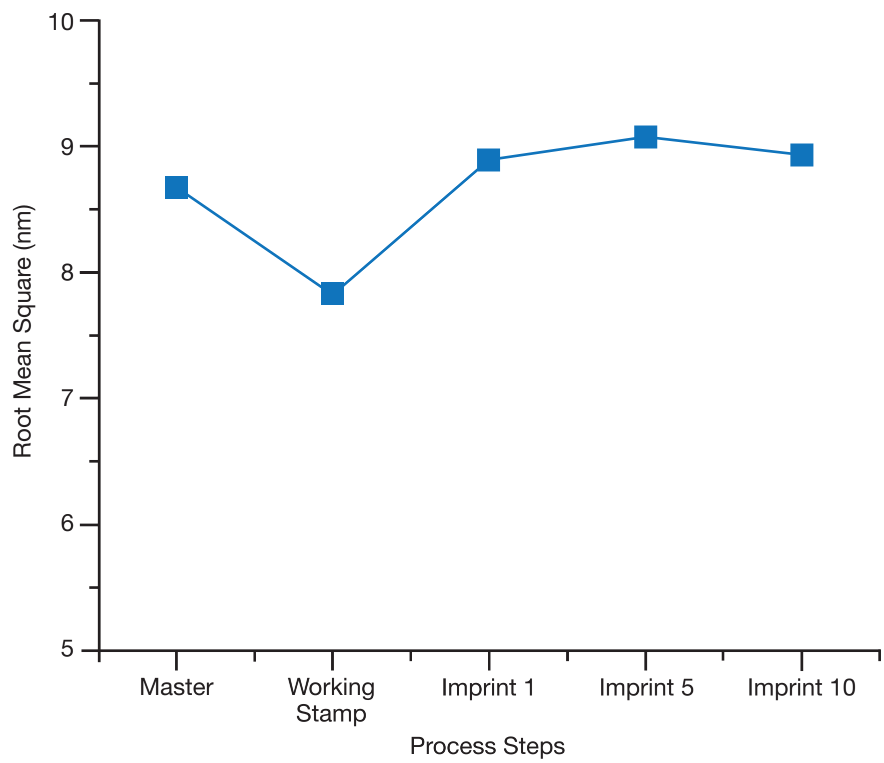

Figure 2. Obtained via white light interferometric measurement, the chart data shows lens roughness values, from the surface of the master via the working stamp to final imprints. Five lenses from each step were measured: center, left, right, top, and bottom. The chart shows the average values.

Table 1.
Working Stamp Properties

Chemical basis	Solvent-free
Index of refraction (at 589 nm) — liquid	1.34
Viscosity (10/s)	200 to 500 mPas
Typical irradiation time (LED 365 nm, 340 mW/cm^2) — O_2-free	200 s
Index of refraction (at 589 nm) — cured	1.35
Transmission	100%
Young's modulus	130 MPa
Shore hardness	5 MPa
Volume shrinkage	4 to 5 vol%
Contact angle (H_2O)	109°

Table 2.
Lens Material Properties

Chemical basis	Modified epoxy resin, solvent-free
Typical irradiation time (LED 365 nm, 200 mW/cm^2)	60 s
Color	Colorless, transparent
Index of refraction (at 589 nm)	1.50
Abbe number	53
Viscosity (10/s)	300 mPas
Compression shear strength	Glass/Glass: >20 MPa Polycarbonate/Polycarbonate: 16 MPa
Young's modulus	2150 MPa
Shore hardness	D 81
Glass transition temperature	120 °C
Volume shrinkage	2.4 vol%

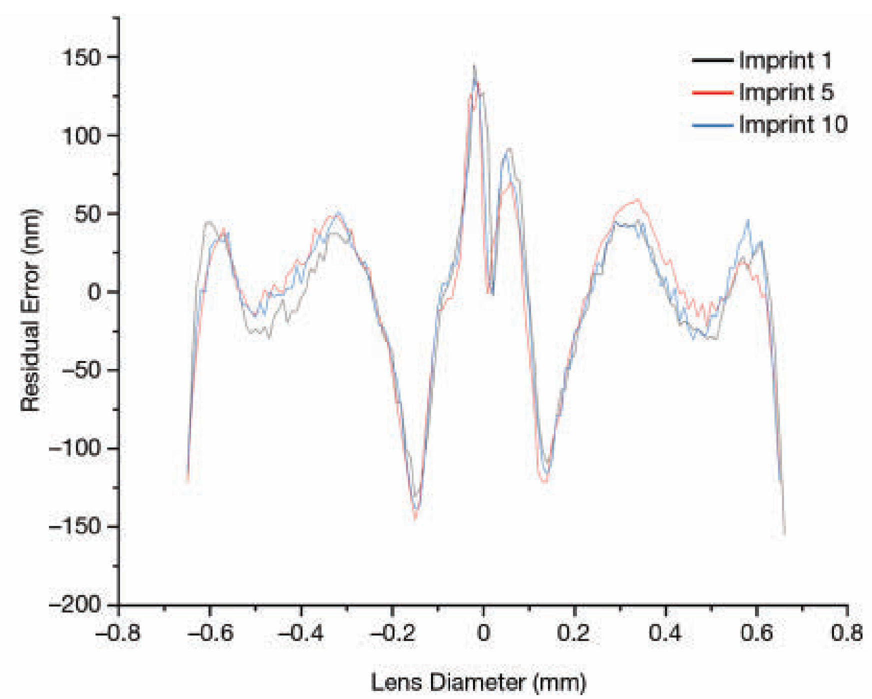

Figure 3. Residual error plots of 1st, 5th, and 10th imprints were compared, demonstrating that the imprint process itself was stable.

when paired with a high-performance curing lamp emitting at intensities >500 mW/cm^2.

Through the course of the study, the collaborators achieved the simultaneous production of working stamps and imprints. This eliminated the need for multiple tools and allowed the study participants to bypass removal of the wafer from the system environment. The degree of automation at which stamps and substrates were handled could be customized per the user's preferences with a selection of either manual, semiautomated, or fully automated modes.

The properties of the resin used for the study posed an additional consideration. Indeed, the properties of a resin used in a particular imprinting process can determine both the success of the imprinting process itself and the overall performance of the resulting optical element. The resin used in this case was a fast-curing epoxy-based polymer that can be universally used for lens molding in single lenses or microlens arrays as well as for the replication of nanostructured diffractive optical elements. When stamped, it showed minimal interaction with the stamp and low detachment force. These results indicate a long stamp service life and easily automated separation. A very low rate of volume shrinkage at 2.4% allowed for the exact reproduction of master geometries and smooth optical surfaces throughout the lens-molding process.

This resin additionally showed transmission values at ~100% over the entire visible spectral range with no scattering, indicating that it was optically clear. Optical stability was maintained, even after challenging reliability tests, which included a 3× reflow test, according to the JEDEC (Joint Electron Device Engineering Council) standard J-STD-020D.1, with a peak temperature of 260 °C, after 1000 h of storage at 85 °C and 85% humidity, and after 1000 h of storage at 125 °C under simulated sunlight (Figure 1).

Finally, the resin takes on compression shear values of >15 MPa on substrates, such as glass and polycarbonate, without any pretreatment or primer.

Study tests and results

A fully populated master with test lenses was used for replication tests. Standard glass with a thickness of 500 µm and an 8-in. diameter was used as the substrate; this glass is commonly used in wafer-level optics. After replicating the working stamp from the master, 10 wafers were imprinted with the material combination to undergo examination (Tables 1 and 2).

The first test examined optical quality. In this test, lenses were evaluated for cracks, bubbles, and shrinkage. No bubbles, cracks, or shrinkage were observed in/on the imprinted lens. The surface of the molded lenses did not change across all replication steps from master to final imprint. No uncured material or residue was observed on either lens, indicating completed curing. After undergoing measurement for volumetric shape fidelity, using a white light interferometer, results continued to show no cracks, bubbles, or shrinkage.

The measurement results indicate that the selected resin is suited for wafer-level optics applications, without creating any visible deformation, residue, or defects on the molded lens. Additionally, it can be fully cured without any further shrinkage.

A second test examined roughness. Ideally, the surface of a fully cured lens must demonstrate low surface roughness to achieve optimal performance across multiple end applications. How lens surface roughness changes over the course of wafer-level optics processes — from master to final imprint — is a crucial parameter.

Lens roughness in this study was measured using a white light interferometer. Five lenses from each step were measured: center, left, right, top, and bottom (Figure 2). The average roughness ($RMS_{surface}$) of the lens surfaces is <10 nm, representing a common requirement for optical active surfaces. The average surface roughness showed almost no change from master to imprints, and over multiple imprints. This indicator of process stability reflects how lenses molded with the resin showed constant surface roughness over the whole imprint series on a low absolute level. The material cured evenly, fully replicating the surface shape of the master, without adding additional defects or deformities. The curing and detachment of the material did not influence the surface quality of the wafer stamp mold, as seen in the stable roughness values of the imprint series.

A third test examined replicability by comparing the measured profile of the molded lens to the initial lens design equation. This comparison of the profile to the equation resulted in a residual error plot.

The principal parameters that derived from this residual error plot are peak-to-valley (PV) and root mean square (RMS). Here, PV is the difference in height between the highest and lowest points in the residual error plot, and it represents a worst-case scenario for the surface in this test. $RMS_{residual}$ error is a method for describing the average deviation of the surface figure from the desired surface and describes the overall surface variation.

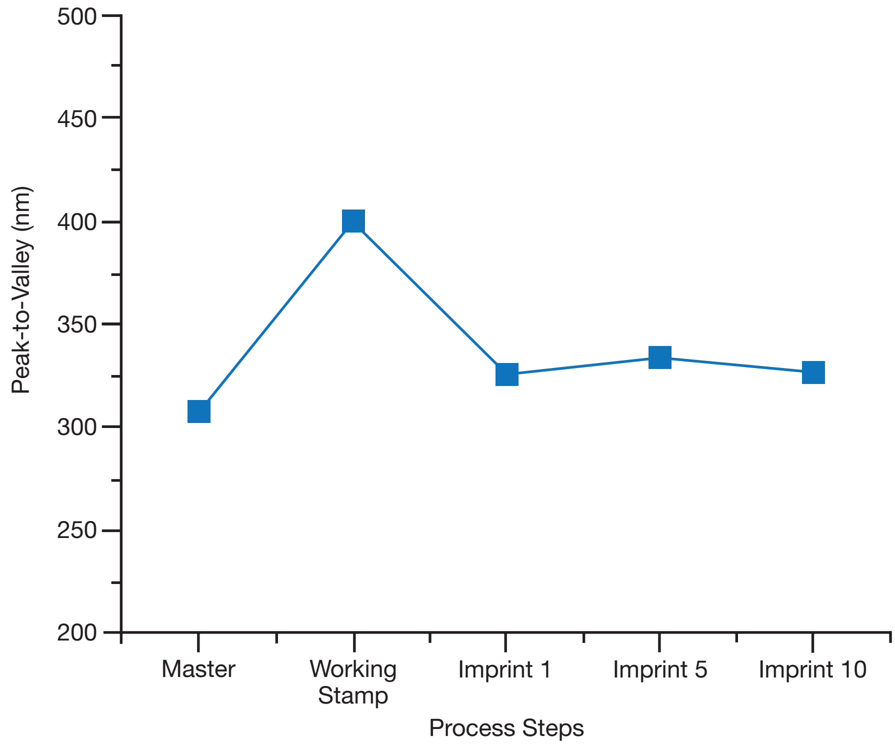

Figure 4. The charts show the precise peak-to-valley (PV) **(a)** and root mean square residual error ($RMS_{residual}$ error) **(b)** values calculated from the residual error plots. A comparison of the residual error plots from the 1st and 10th imprint shows almost no difference in the shape of the profile (Figure 3), indicating no significant change in the molded lenses between the start and the end of the automatic molding process.

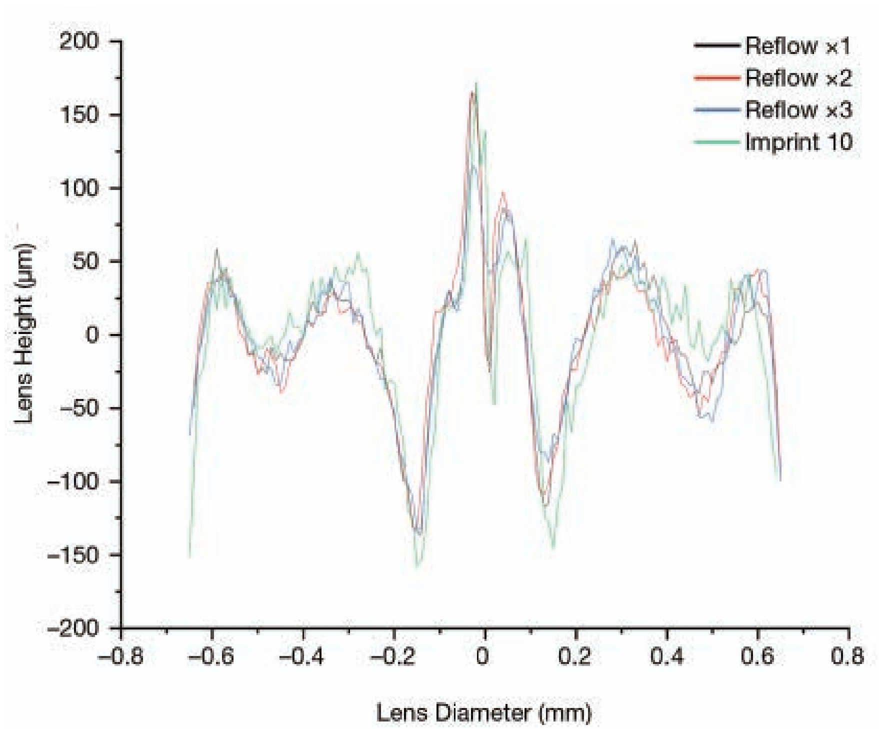

Figure 5. The chart shows residual error plots of the lenses following the reflow process, indicating no significant change in the molded lenses.

In testing the replicability of the lens profiles, the molded lenses were measured with an industry-standard tactile profilometer and analyzed for shape PV stability. Five lenses were measured from each step (master, working stamp, and imprint 3× (up to the 10th)): center, left, right, top, and bottom.

The measured profiles were overlaid and compared with the profiles from the metal master and wafer stamp. Each of the measured profiles showed a very uniform shape without any discrepancies. The lens profiles resulting from the imprint series with the adhesive used could be perfectly laid over each other. The study participants further observed no change in shape between the 1st and 10th imprint, which indicated a stable process and no deformations in the stamp mold.

In determining the residual error plots of the master, stamp, and imprint, each was calculated and compared by overlaying the plots. The resulting data shows that the plots are almost identical. This points to high fidelity in the replication throughout the entire process, resulting in favorable correlation to the above overlaid raw lens profiles.

Additionally, the residual error plots of the 1st, 5th, and 10th imprints were compared to see whether the imprint process itself was stable (Figure 3).

A comparison of the residual error plots from the 1st and 10th imprint showed almost no difference in the shape of the profile, indicating no significant change in the molded lenses between the start and the end of the automatic molding process, underlining their favorable reproducibility.

The increase and subsequent reduction of the PV and $RMS_{residual}$ error value from the master over the working stamp to the imprint is due to the reversed polarity of the molded cavity and change in residual error. The precise PV and $RMS_{residual}$ error values, calculated from the residual error plots, can be seen in Figure 4. Additionally, it is shown that the average absolute PV value of the imprint series with the resin used is as low as 330 nm with a stable $RMS_{residual}$ error of ~55 nm, which is close to the value of the master. The minimal deviation observed is a result of material shrinkage. This offset can be easily considered in the master design and therefore compensated for.

Both the PV and the $RMS_{residual}$ error values remain on a constant level over all imprints. The deviation range of the PV is well below 100 nm, and the $RMS_{residual}$ error is <10 nm. Both minimum deviation ranges are an indicator for a stable and reproducible process.

A fourth test examined reliability, in which wafers were subjected to a reflow process three times, in accordance with JEDEC standard J-STD-020D.1, at a peak temperature of 260 °C. Visually and optically, the lenses showed no changes after the reflow process compared to the imprint series. No yellowing or cracking of the lenses was visible even after three administered rounds of reflow.

A profilometer was used again to measure the lens shapes after reflowing via the same procedure previously described. Figure 5 shows the overlaid error plots of the measured lenses after the reflow process, compared to the profiles after 10 imprints. The shape of the lenses is almost identical between the reflow steps and imprints. No deformation or deviation from the original shape is observed. Also, no significant change in height or diameter of the lenses is seen. Overall, the lenses showed high stability during the reflow process.

Consistent quality

The detailed analysis of the imprinted lenses molded with the chosen resin shows consistently high-quality lens shapes with consistently low surface roughness throughout the process chain. The lenses are not influenced in their shape by the reflow process in any significant manner. Additionally, the imprinted lenses show no measurable changes in transmission or mechanical behavior upon exposure to an additional reflow process. This demonstrates that the optics manufactured by lens molding are suitable for demanding packaging applications in optoelectronics, even satisfying typical automotive standards.

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Advancing Laser Safety with Updates to Standard Operating Procedures

BY KEN BARAT
LASER SAFETY SOLUTIONS

It is unlikely that anyone who has read the Z136.1: Safe Use of Lasers Standard, or any of the application standards stemming from it, is unfamiliar with standard operating procedure (SOP). By definition, SOP is a formal written description of the safety and administrative procedures to be followed in performing a specific task. In laser safety, SOP typically applies to the laser system operation and alignment.

Unlike the fluorescent bulb, for example, SOP has not evolved over the years even as it is foundational to laser safety. And while it may be logical that the essence of SOP be unchanged, there are nuances to consider, as is true of other laser safety procedural elements. Knowing when an SOP is required is critical to understanding the function and interpretation of the SOP itself. Z136.1 and Z136.9, for example, share requirements. SOP for a Class 3B laser is considered a "should," and it is considered a "shall" for a Class 4 laser. For Z136.3 and Z136.8, it is a "shall" for Class 3B and Class 4 lasers.

SOP ins and outs

SOPs are a widespread requirement across laser systems, but the content of these procedures is inconsistent. Further, few individual standards offer SOP templates; within the ANSI Z136.1-2022: Safe Use of Lasers, for example, only the research-specific standard, Z136.8, provides templates. This means that guidelines interpreted as standard are apt to vary depending on the author of the set of guidelines.

As a result of this flexibility, any operational instruction would qualify as an SOP, essentially by default. The consensus of laser safety officers (LSOs) is that an SOP must address the hazards

Standards and Standard Operating Procedure

Z136.1 Safe Use of Lasers-2022

Per Section 4.4.3.1 Standard Operating Procedures (Class 3B or 4), the laser safety officer (LSO) should require and approve written standard operating procedures (SOPs) for maintenance and service procedures for Class 3B lasers or laser systems. The LSO shall require and approve written SOPs for Class 4 lasers or laser systems. These written SOPs shall be maintained with the laser equipment for reference by the operator and maintenance or service personnel.

Z136.3-2018, Medical Policies & Procedures

Per Section 4.2.1 Policies and Procedures (Class 3B and Class 4) the health care framework shall establish policies and procedures. The LSO shall require approved guidelines for issued Class 3B and Class 4 health care laser systems. These established regulations shall be maintained and be readily available to users. The LSO shall further require that safety protocols exist for servicing the health care laser systems. Manufacturers and service agents assume responsibility for safety when servicing the equipment.

Z136.8 Safe Use of Lasers in Research, Development, and Testing

Section 4.3.3 Standard Operating Procedures (Class 3B and Class 4) says that the LSO shall require and approve written standard operating, maintenance, and service procedures for Class 3B and Class 4 lasers or laser systems. These procedures shall be accessible in the laser control area, either by hard copy or in an electronic format, for reference by the system users, maintenance staff, and service personnel. Continuous-wave visible lasers at or below 15 mW are exempt from this requirement.

Z136.9-2013 Safe Use of Lasers in Manufacturing Environment

Section 4.4.3.1 Standard Operating Procedures (Class 3B or Class 4) requires the LSO to have and approve written SOPs for operation, maintenance, and service of Class 3B lasers or laser systems. The LSO shall further require and approve written SOPs for Class 4 lasers or laser systems. These written SOPs shall be maintained with the laser equipment for reference by the operator and maintenance or service personnel.

and the measures that users must take to protect themselves and the equipment. Once procedures are established, the signatures of all who will be working under it are required.

In this context, the SOP should be viewed as a contract between the user/operator and the safety department. Still, certain inherent variables must be considered. SOPs can range from a single page to as many as 40 pages. Further, some SOPs are formatted as risk assessment documents. With so much room for interpretation, one must address several questions before developing an SOP.

Generating an SOP

An approved SOP can be likened to a driver's license: Once granted, all items, such as hand signals, for example, are rarely or never considered again. Many SOP documents spend their existence on a shelf and are not used as a reference.

The laser or laser system operator or user is the best person to write the SOP. For this reason, some institutions have created an electronic template for the user to complete. Other companies enlist the LSO to write the SOP. But this can be problematic if the LSO is unfamiliar with all the details of the required work. A meeting between the LSO and operator is a practical solution for bridging these knowledge gaps. These meetings provide an exchange of information on what work will be performed and any existing or assumed safety concerns as well as any recommendations.

Knowing when an SOP is required is critical to understanding the function and interpretation of the SOP itself.

SOP contents

Genericism is a common flaw in the creation of an SOP: Making the document completely generic by only containing fundamentally good practices — for example, removing reflective sources (i.e., jewelry and ID badges) and ensuring that all optics are secure — does not reflect procedure-specific controls, which are a critical safety element.

In some cases, SOPs consist of questions that help the LSO determine hazard evaluation elements and drive the user to examine use operation conditions. Questions regarding the presence or absence of unattended work, illumination level(s), and the potential for beams to be present outside of the laser control area all qualify as examples of potential hazards to both the operator and those around the laser system. Upon the completion of this step, the focus should shift to risk mitigation.

Other times, SOPs more closely resemble work operation instructions than standards. These so-called Operational Work Instructs may function as an SOP with the inclusion of certain safety steps. Also, formats of SOPs may vary. It is common in medical settings, for example, for an SOP to resemble an operational check-list. This same approach can be used in manufacturing or fabrication situations. This includes the use of Class 4 hand-held units such as those found in many laser welding and cleaning operations.

Reviewing the SOP

Standards regard the SOP as a reference document for users and operators to review (sidebar). Traditionally, this would be a paper document in a binder. Now, users may simply use a QR code to access it on a smart device. This approach works well in cleanrooms and/or other settings in which a binder is impractical.

With the availability of the SOP, there is an inherent question as to how often staff members will review it. It is often safe to assume that staff rarely reference the traditional SOP, so a safe plan of action (SPA) approach — which in many ways is the laser safety version of a construction tailgate meeting — is a strong option. With an SPA, staff meet at least once a day to review the work to be completed and agree on the control measures needed for safe and efficient operation. I first encountered this approach at the National Ignition Facility, which led to more than 5 million working hours without a lost time event.

Revisiting the SOP

All SOPs must be reviewed and renewed. Most commonly, companies and/or organizations review their SOPs annually. But even when there is little expectation of change, SOPs must be reviewed, even if it is only to update the user list. A control may have been developed or training requirements may have changed. With each revision, staff members must sign off on the updated SOP. Staff members whose training has lapsed are one of the most common deficiencies found in SOP audits.

From the perspective of the LSO, who relies on users to modify their SOP if there is an ensuing change that will influence user safety, fighting complacency is an ongoing challenge that is paramount to ensure staff safety.

So, what does all this mean? The SOP is a fundamental laser safety document. But it is also one that I would say is stuck in the past and needs to evolve. The nature of this evolution should depend on the environment in which the SOP is used. One size, as many have learned, does not fit all applications.

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From the perspective of the LSO, who relies on users to modify their SOP if there is an ensuing change that will influence user safety, fighting complacency is an ongoing challenge that is paramount to ensure staff safety.

LASER-TEC College Profile

Pasadena City College
Pasadena, California

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

Pasadena City College's (PCC's) curriculum in optical and laser technology (LaserTech) provides students with the applied skills required to work with precision optics, lasers, detectors, electronics, and nanotechnology. Local industrial partners and national laboratories have supported the creation of these courses to ensure that PCC LaserTech students learn relevant laboratory techniques and technologies. Companies interested in PCC LaserTech graduates develop and apply cutting-edge technologies and come from sectors such as aerospace, advanced manufacturing, biomedicine, entertainment, remote sensing, defense, and more.

PCC offers programs of study in many fundamental and in-demand technical disciplines, including geographical information systems, computer and information technology, and biotechnology. By enrolling in the PCC LaserTech program, students learn skills via a comprehensive Associate of Science (AS) in Laser Technology, or via a Certificate of Achievement in Laser Technology that consists of four focused, hands-on courses. The AS program can be completed in as few as 21 months and has no prerequisites to begin studies. Its laboratory-oriented optics courses have been developed since 2007, with more than 150 student graduates working in the field to apply the hands-on skills they learned in the laboratory classroom.

Program description

The program focuses on the application, manufacture, inspection, and test of precision optical elements and systems to established standards. Courses are taught in a laboratory setting, where students are evaluated by their ability to document industry-quality laboratory reports that demonstrate their mastery of the techniques or instrumentation being studied, not by homework assignments. PCC LaserTech courses start with the fundamentals of light and progress to the use of optical devices, from lenses, mirrors, and prisms to lasers, fibers, and cameras.

Further study instructs students on how these devices are fabricated and tested to the highest industrial standards. This includes essential topics such as maintaining cleanroom cleanliness, drafting and interpreting properly toleranced drawings, and inspecting hardware to specifications. Finally, advanced optical measurement technologies are covered so students can learn how to test and troubleshoot optical assemblies and instruments.

Graduates of PCC's AS degree in Laser Technology have the skills to:

- Demonstrate applied comprehension of basic optical physics, including imaging, refraction, polarization, interference, and diffraction.
- Maintain, clean, and safely handle optical components, such as lenses, mirrors, and diffraction gratings in a cleanroom environment.
- Trace the path of light through basic optical assemblies and systems, locating stops and pupils.
- Understand the internal components and assembly of optical and electronic devices, including laser systems, detectors, and optical displays.
- Safely operate and maintain laser systems.
- Comfortably configure and articulate optomechanical and optical hardware in a safe manner on a laboratory breadboard or in a clean flow hood.
- Write and interpret optics drawings to the ISO 10110, 12123, 9211, and 9022 international standards and via various American military specifications.
- Demonstrate a basic knowledge of electronics that includes both analog and digital components as well as common circuit architectures.
- Communicate technical concepts and document procedures, techniques, and measured results via written or oral formats.

How to recruit from this college

Companies interested in recruiting students from PCC should contact our laser technology professor to present your company and its employment opportunities. The next PCC student cohort is expected to graduate with AS degrees in Laser Technology in June 2025.

Contact information

Brian Monacelli, Ph.D.
bmonacelli@pasadena.edu
1570 E. Colorado Blvd.
Pasadena, CA 91106

Program websites

www.pasadena.edu/academics/divisions/natural-sciences/areas-of-study/laser-technology

www.pasadena.edu/academics/degrees-and-certificates/certificates-of-achievement/laser-technology.php

Laser Sensor
The Ophir 20 K-W High Power Laser Sensor from **MKS Instruments** is a compact, water-cooled thermal sensor for measuring high-power lasers. The sensor measures powers from 100 W to 20 kW over the spectral range of 800 to 2000 nm and 10.6 µm. A deflecting cone and annular absorber enable the sensor to withstand high power densities up to 10 kW/cm^2 while delivering a 3.5-s response time. In use, the sensor features an interlock output that shuts down the laser to protect it from overheating, an over-temperature sensor that triggers an LED indicator, an audible alarm, and an M8 3-connector interlock.
sales@newport.com

Imaging Colorimeter
The ProMetric I16-G-SC from **Radiant Vision Systems** is an imaging colorimeter with an integrated spectrometer for the inspection of high-volume manufacturing of displays, illuminated components, light sources, and surfaces. The colorimeter can perform subpixel-level measurements of luminance and chromaticity and is controlled via a single software platform. The ProMetric I16-G-SC features a scientific-grade 16.1-MP image sensor, the CAS 125 spectroradiometer from Instrument Systems GmbH, and can be used to make pixel-level measurements of LCDs, OLEDs, micro-LEDs, and other display types.
marketing@radiantvs.com

InGaAs APDs
The C30645 and C30662 from **Excelitas Technologies** are large-area indium gallium arsenide (InGaAs) avalanche photodiodes (APDs) suitable for use in eye-safe laser range-finding and lidar systems. The APDs provide large quantum efficiency, high responsivity, and low noise in the spectral range between 1000 and 1700 nm. The C30645 and C30662 are supplied in a hermetically sealed TO-18 package, on a ceramic carrier, or in a ceramic surface mount package.
photonics@excelitas.com

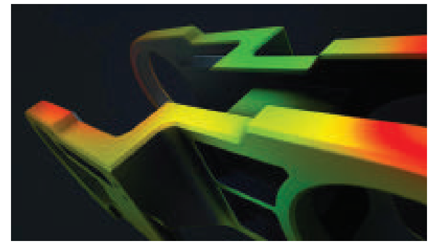
Distributed-Feedback Laser Modules
The LXM-U and LXM-S from **TeraXion** are narrow linewidth distributed-feedback laser modules for distributed acoustic sensing systems and for frequency-modulated continuous wave lidar and Doppler lidar, respectively. The LXM-U is available with >60-mW optical power and a typical instantaneous linewidth of 80 Hz. The LXM-S offers >70-mW optical power and features an intrinsic linewidth of <25 kHz.
info@teraxion.com

Industrial Fiber Laser
The Corona AFX-2000 from **nLIGHT** is a laser with beam-shaping technology for use in laser powder bed fusion processes for metal additive manufacturing. The 2-kW laser is available in nLIGHT's integrated multilaser subsystem modulus platform.
sales@nlight.net

Fiber-Coupled LED Source
The NewDEL Model X3312 from **LumeDEL** is a fiber-coupled LED source for applications in spectroscopy as a replacement for halogen lamps. The LED source employs a phosphor-coated UV-LED to emit a broad spectrum from 330 to 1100 nm, whose peak can be blocked by a longpass filter that only passes VIS-NIR light, providing a continuous and balanced spectrum without peaks. The NewDEL Model X3312 is fully integrated and incorporates its own driver and microcontroller circuitry.
info@lumedel.com

Sapphire Aspheric Lenses
Edmund Optics' line of sapphire aspheric lenses is designed for high-power laser and materials processing applications. The lenses deliver diffraction-limited performance with a 50% reduction in thermally induced focal shift. Edmund Optics' line of sapphire aspheric lenses is also designed and coated at 1064 nm and features 3× faster thermal focal shift rise times.
sales@edmundoptics.com

Metrology Software
ZEISS INSPECT from **ZEISS Industrial Quality Solutions** facilitates the inspection of optical 3D and x-ray data and includes functions that support automated processes. ZEISS INSPECT features the ability for customization due to apps available through the ZEISS Quality Software Store and its built-in Python interface.
info.metrology.de@zeiss.com



UV Spherical Detectors
The RCH-XXXs series spherical UV detectors from **Gigahertz-Optik** are designed for the measurement of effective spherical ultraviolet germicidal irradiance applied in air and water sterilization applications. The detectors can be used in combination with any Gigahertz-Optik filter radiometer and are configured based on the particular light source employed. The RCH-XXXs detectors are additionally designed to withstand and remain stable in high-intensity UV and heat environments with its sensitive components being encapsulated upstream from the irradiation zone.
info-us@gigahertz-optik.com

Fiber Laser
The ARM FL20D from **Coherent** is a fiber laser designed for welding applications such as electric vehicle drivetrain and body-in-white in automotive, aerospace, and energy storage. The laser incorporates a center beam and two coaxial ring beams, all with independent control, for control over the welding process, especially for use with challenging materials, such as cast aluminum. The ARM FL20D features a power output of 20 kW.
info@coherent.com

Monochrome/IR CMOS Image Sensor
The OV0TA1B from **OMNIVISION** is a monochrome/IR CMOS image sensor for AI-based human presence detection, facial authentication, and always-on technology. The sensor's 2-µm pixel is based on PureCel pixel technology for high-performance sensitivity and modulation transfer function. The OV0TA1B features 440 × 360 resolution at 30 fps, a power output of 2.58 mW at 3 fps, and a 1/15.8-in. optical format.
sales@ovt.com

CMOS Image Sensor
The GSPRINT5514BSI from **Gpixel** is a backside illuminated CMOS image sensor that is intended for use in a range of machine vision

applications. The sensor achieves 86% quantum efficiency at 510 nm and 17% at 200 nm for UV applications and offers dual-gain high dynamic range readout, maximizing 15 ke– full well capacity with a minimum <2.0 e- noise to achieve a dynamic range of 78.3 dB. The GSPRINT5514BSI features 4608 × 3072 pixels at 5.5 µm per square, a 4/3 aspect ratio 4K sensor compatible with APS-C optics, 10-bit output at a frame rate of 670 fps, and a 12-bit mode for an output of 350 fps.
info@gpixel.com

Pulsed Laser Diode

The 1550UA Series from **Laser Components** comprises pulsed laser diodes for defense, aerospace, and automotive lidar applications such as time-of-flight as well as laser range finding systems. The series offers a hermetically sealed metal housing featuring thermal stability, overdrive capabilities, and chip alignment. The 1550UA Series is also capable of operating at −45 to 85 °C and is available in a TO-56 package.
info@laser-components.com

Inertial Navigation System

The INS-DM-FI from **Inertial Labs** is a GPS-aided inertial navigation system designed for land, marine, and aerial platforms. The system is designed using fiber optic gyroscope technology and microelectromechanical systems accelerometers incorporated into an inertial measurement unit with an optional embedded air data computer available for implementation. The INS-DM-FI supports embedded multi-constellation GNSS receivers, including NovAtel OEM7, u-blox F9, and Septentrio mosaic-H series, which are capable of processing GPS, GLONASS, GALILEO, QZSS, and BEIDOU signals. The product additionally features anti-jamming and spoofing mitigation for enhanced security and precision.
info@inertiallabs.com

Active Alignment Adhesive

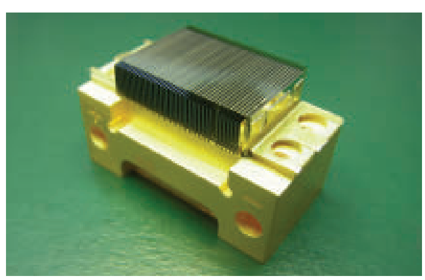
The PHOTOBOND OB4210 from **DELO** is a transparent active alignment adhesive suitable for applications such as the alignment of lens systems and optics in matrix LEDs, microlens arrays, and digital light-processing headlamp systems. The adhesive has a high compression shear strength of 35 MPa on polycarbonate and a low viscosity of 3000 mPa-s. The PHOTOBOND OB4210 retains its transparency after a typical 500-h storage period at +140 °C and its exposure time required to cure the adhesive can be reduced to 1.5 s at high UV intensities.
info@delo.us

Native Processing Unit

The Q.ANT NPU from **Q.ANT** is a photonics-based native processing unit (NPU) designed for compute-intensive applications such as AI inference, machine learning, and physics simulations. The Q.ANT NPU is built on the company's light-empowered native arithmetic (LENA) compute architecture. The NPU can train and achieve accurate recognition with only 0.1 million parameters and 0.2 million operations, perform a simple 8-bit multiplication with a single optical element, and control light at chip level due to the LENA platform.
info@qant.de

Microlenses

The Crocodile Series from **OPT Machine Vision** is a series of microlenses for industrial applications such as close-range inspection tasks. The lenses combine optical imaging technology with long working distances to deliver a higher image quality. The Crocodile Series features clear imaging over a working distance range of 47 to 412 mm, a magnification range of 0.07× to 0.9×, a field-of-view resolution of 145 lp/mm, and support for camera sensors up to 1.2 in.
optmv@optmv.com



High-Density Laser Diode

Hamamatsu Photonics' high-density laser diode module can act as a pump source for 1-kJ lasers used in fusion research. The module uses special mounting jigs and an improved high-melting-point solder joining technique and heat sink structure compared with the company's other laser diode modules for its mounting technology. This allows the suppression of the leakage current and increased cooling efficiency, which contributes to an output density for the laser diode module of 23 kW/cm^2.
photonics@hamamatsu.com

Oscilloscope

The R&S RTB 2 from **Rohde & Schwarz** is an entry-level oscilloscope for metrology applications. The oscilloscope includes an integrated arbitrary waveform generator that allows users

to simulate circuit stimuli or emulate missing components. The generator is capable of generating signals up to 25 MHz and pattern speeds of up to 50 Mbits/s, while supporting imported waveforms from CSV files or oscilloscope captures with the ability to add noise for simulating real-world conditions. The R&S RTB 2 allows up to 160 Mpoints in segmented mode, enabling users to capture more data for in-depth troubleshooting.
info@rohde-schwarz.com

Micro Thermoelectric Coolers

OptoTEC MBX Series micro thermoelectric coolers from **Laird Thermal Systems** are designed for space-constrained optoelectronic applications. The series offers configurations designed for integration into transistor outline can, transmitter optical subassembly, and butterfly packages and includes models as small as 1.5 × 1.1 × 0.65 mm. The OptoTEC MBX Series features high heat pumping densities up to 43 W/cm^2 with temperature differentials of up to 82 °C at an ambient of 50 °C as well as solder constructions supporting reflow temperatures of up to 280 °C and wire-bondable attachments.
info@lairdthermal.com

Character Recognition Sensor

The DCR 1048i OCV from **Leuze** is an optical character verification (OCV) sensor for applications in print quality verification. The sensor can read 1D or 2D codes within one application and check quality using the OCV process, making it possible to determine whether printed information is present, complete, and legible.
info@leuze.de

Cryo-Stage

The CMS196V4 cryo-stage from **Linkam Scientific Instruments** supports cryo-correlative light and electron microscopy, and the ability to investigate samples at cryogenic temperatures down to less than −195 °C. The stage's user interface includes a touch panel and joystick, alongside an encoded and motorized xy stage that allows high-precision automated mapping of sample grids. The CMS196V4 also features different sample holders and interface options for its interchangeable optical bridge for imaging, as well as a cordless magnetic heated lid, auto-fill dewar with drip-feed, and an objective lens heater for greater drift performance.
info@linkam.co.uk

FEBRUARY

Biophysical Society Annual Meetings
(Feb. 15-19) Los Angeles.
Contact the Biophysical Society, +1 240-290-5600, **society@biophysics.org**; www.biophysics.org/2025meeting.

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

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

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.

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

PAPERS

European Conferences on Biomedical Optics
(June 22-26) Munich.
Deadline: Abstracts, Feb. 18
Contact Optica, +1 202-223-8130, **info@optica.org**; www.optica.org/events/topical_meetings/european_conferences_biomedical_optics.

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.

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.

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.

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.

Photonics North
(May 20-22) Ottawa, Ontario.
Contact Photonics North, +1 418-522-8182, **pn.info@conferium.com**; www.photonicsnorth.com/en.

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

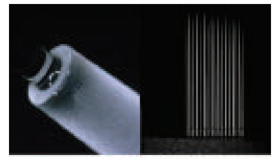
Photonics Showcase

Specialty Preform & Fiber Equipment

From preform creation to final fiber, Nextrom covers every step of specialty fiber manufacturing. OFC 12 MCVD (Modified chemical vapor deposition) and OFC 11 PCVD (plasma chemical vapor deposition) systems produce high-purity preforms with precise doping profiles. Glass-working and collapsing lathes for preform refinement. Finally, the OFC 20 SF draw tower and proof-tester ensure top-quality specialty fibers — multimode, hollow core, and more.

Rosendahl Nextrom
+358950251
office.finland@rosendahlnextrom.com
rosendahlnextrom.com/fiber

The NYFORS SMARTSPLICER



NYFORS

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

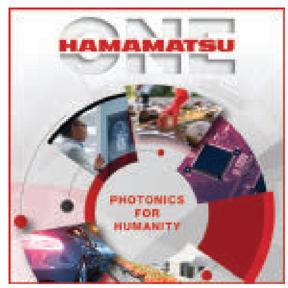
NYFORS **+46 8712-1021**
sales@nyfors.com **www.nyfors.com**

Handheld Laser Welding Helmet

The Panoramaxx laser safety helmets are a ground-breaking innovation in the field of laser protection for welders and offer a unique combination of safety, comfort, and field of vision. Three versions of the helmets will be offered by Laservision including two featuring auto-darkening technology. With this unique hybrid solution one helmet can be used for all welding work. A third version without ADF is designed specifically for laser welding.

Laservision USA **(800) 393-5565**
sales@lasersafety.com **www.lasersafety.com**

Photonics for Humanity



Hamamatsu's Photonics for Humanity series shines a light on the breakthroughs and applications shaping a more sustainable, connected world. Our experts share their insights on how light-based technologies are solving critical challenges and creating a brighter future. Explore the ways photonics is advancing fields like LiDAR and water and soil analysis, and its role in enabling quantum technologies.

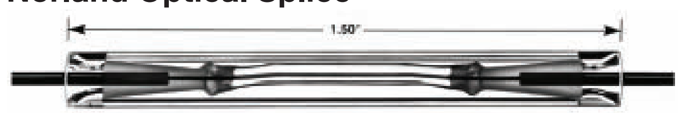
Hamamatsu Corporation
(908) 231-0960
photonics@hamamatsu.com
bit.ly/4j3JYIs

Fiber Focusers and Accessories

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

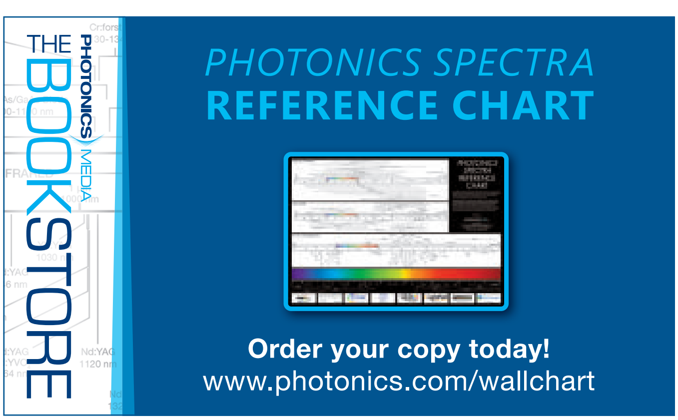
Micro Laser Systems Inc. **(714) 898-6001**
info@microlaser.com **www.microlaser.com**

Norland Optical Splice



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

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



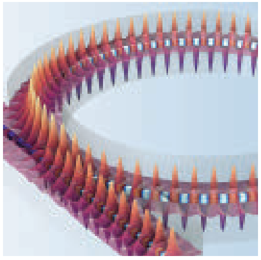
SIRRUS™ PVD Platform

Alluxa's innovative, next-generation SIRRUS™ plasma physical vapor deposition (PVD) platform offers full spectral coverage from ultraviolet (200 µm) to infrared (14 µm). The proprietary process enables optical filters with the steepest edges, highest transmission, and deepest blocking available while maintaining high performance, precision wavelength control, and extremely uniform coatings.

Alluxa Inc. **(855) 425-5862**
info@alluxa.com **www.alluxa.com**

Photonics Showcase

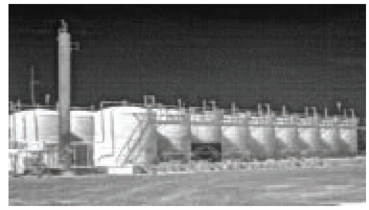
Multiphysics Modeling and Simulation



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

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

Uncooled Optical Gas Imaging



LightPath Technologies OGI (Optical Gas Imaging) camera provides a low cost, effective solution to visualize Methane and VOC's (volatile organic compounds). Traditionally only cooled sensors have been utilized, this has been a road-block to mass deployment due to cost. Our high-sensitivity uncooled LWIR camera provides a unique cost effective path to mass deployment and remote monitor-ing for gas detection and additional applications.

LightPath Technologies **(724) 272-3067**
rschutte@lightpath.com **www.lightpath.com/optical gasimagingoilandgas**

New! Z-axis piezo for IX85

The Nano-ZL-IX5 series nanopositioning systems are compatible with Evident IX85 and FLUOVIEW microscopes. The Z-axis piezo fits directly to the IX5-SSA microscope stage while maintaining the sample plane distance. Travel ranges up to 500 µm with sub-nanometer resolution under closed loop control. Accommodates incubators, multiwell plates, petri dishes, and 75mm slides, making it a versatile addition to your microscope.

Mad City Labs Inc. **(608) 298-0855**
sales@madcitylabs.com **www.madcitylabs.com/ nanozlix5series.html**

Hyperfine One Spectrometer

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

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

Custom Precision Optics & Assemblies

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

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

Mid-Infrared LED 2 to 6 µm

If you need a reliable broadband, incoherent, and cost-effective light source for gas sensing, nanoplus of-fers mid-infrared LEDs from 1750 nm to 6500 nm. These LEDs operate in continuous wave mode and allow you to specify target wavelengths for your application. Our mid-infrared LEDs are available on various submounts, de-signed for optimal temperature control and user convenience.

nanoplus Nanosystems and Technologies GmbH
004936935050000
sales@nanoplus.com **www.nanoplus.com**

PCM2X-271, Fastest Colorimeter Ever

The PCM2X-271, a cutting edge colorimeter using two different types of amplifiers to achieve the best of both worlds. Highest sensitivity for ultra-low luminance levels and high-speed sampling rate for improved signal to noise ratio when performing flicker mea-surements. Not just for Y, but also for X and Z. Whether you work in the automotive industry, in the AV Broadcast market or electronic manufacturing – this colorimeter optimizes processes and guaran-tees maximum efficiency.

Admesy BV **+31 475 600 232**
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A drone's guiding light

Celestial navigation is a dying art in our world. Sure, summer camp counselors might instruct their younger adventurers that they can locate north by correctly identifying the North Star, Polaris, while on a nighttime hike in the woods. But let's be honest — no kid forcibly enrolled in this excursion is willingly taking woodland strolls at night for fear of a rogue bear or an encounter with something more supernatural that could be hiding in the shadows.

The stars used to be the primary source of navigation. From sailing to the New World to traveling across great swaths of indistinguishable terrain, if an intrepid adventurer, merchant, or refugee found themselves off track or misdirected with a map, they could always count on the night sky to guide them to their destination.

GPS has made this tactic obsolete, however, due to its relative accuracy and availability. That said, with recent advancements in jamming technology disrupting radio frequency global navigation satellite system (GNSS) signals in drones, researchers are once again looking up to the stars for tried-and-true navigation.

Case in point: Remote sensing engineers from the University of South Australia have combined celestial navigation with vision-based technology to provide an alternative means of nighttime navigation in environments where GNSS signals can be made unavailable. The celestial navigation system can be integrated into standard drones, offering a dependable and accurate backup.

The payload, which consists of a Raspberry Pi 5 and an Alvium 1800 U-240 monochrome sensor fitted with a 6-mm f/1.4 wide-angle lens, relies on an algorithm that uses visual data from stars and processes it through standard autopilot systems. This differs from other traditional star-based navigation systems, which can be too heavy, complex, or expensive to implement on a regular basis, due to the extra features that are required, such as stabilization hardware.

During tests, the engineers were able to attach the payload into the shoulder of an autopiloted fixed-wing uncrewed aerial vehicle capturing images at a rate of 10 Hz. And while the team conducted the tests on a moonless night where the stars would be at their brightest, advantage or not, the drone demonstrated accurate positioning within 4 km during the designated flight time.

The engineers believe that this type of system will find its optimal deployments with drones flying over oceans, or for militaristic applications where their presence would be considered hostile. And just as the investigators' titles suggest, they also believe the payload could be used for applications such as environmental monitoring and remote sensing.

It probably won't be used to help campers return to their cabins, so for now, kids will just have to pay attention when the counselor points out Polaris in the sky, and not mistake a celestial-guided drone for a shooting star whizzing through the heavens.

The research was published in *Drones* (www.doi.org/10.3390/drones8110652).

Drone image courtesy of iStock.com/Chesky_W.
Background image courtesy of iStock.com/Oscar Gutierrez Zozulia.


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