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October 2024

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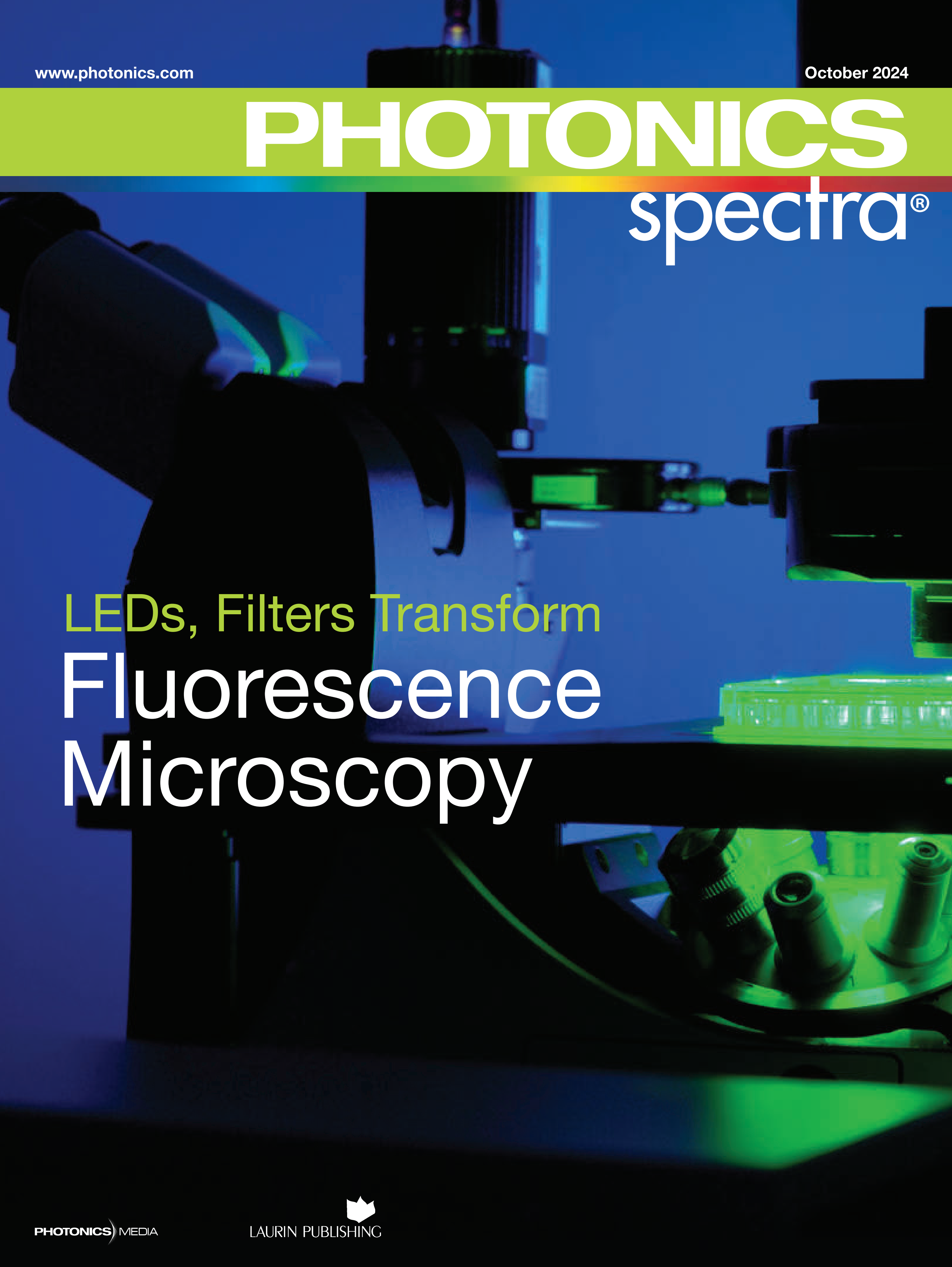

LEDs, Filters Transform
Fluorescence Microscopy

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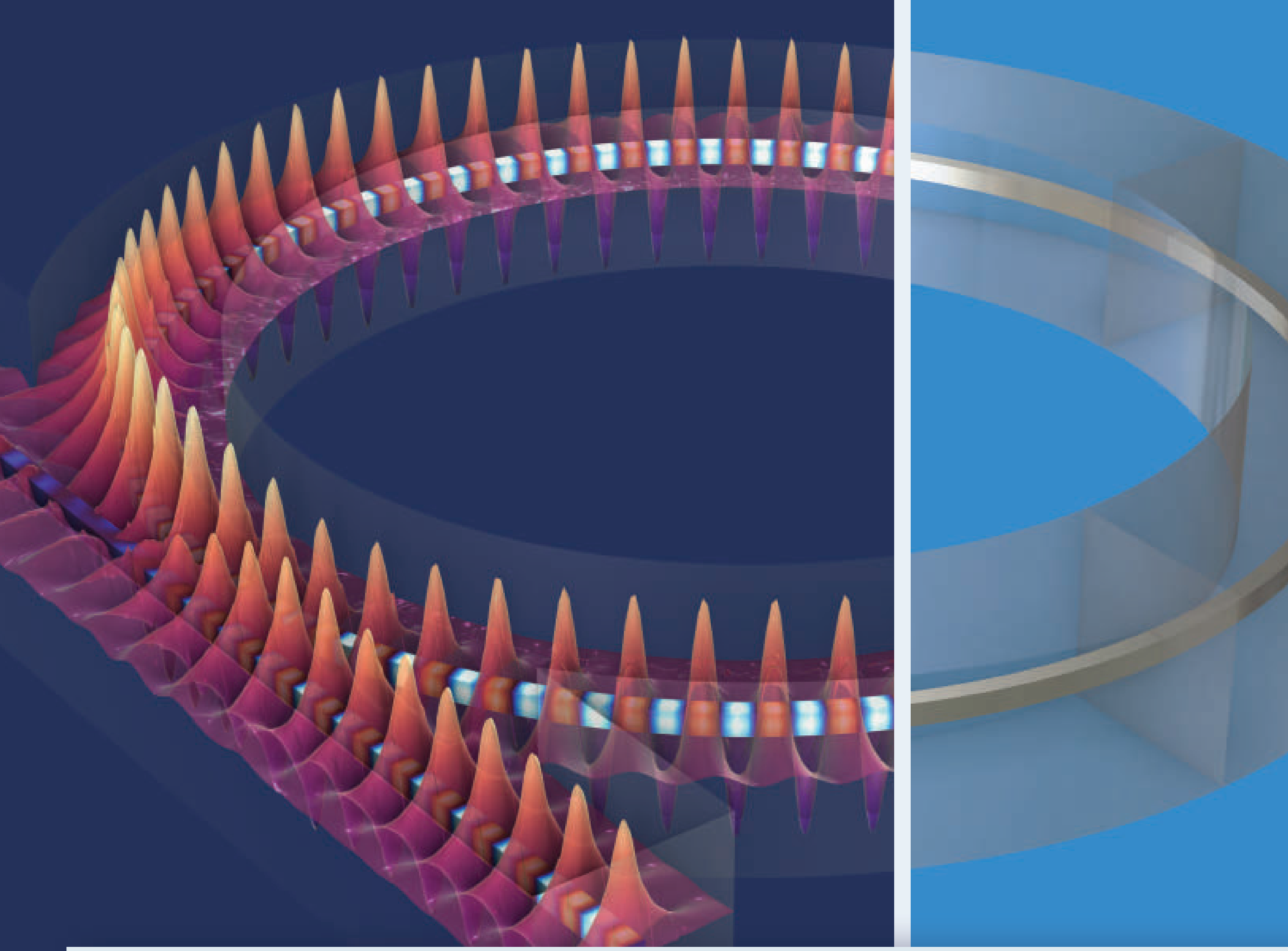
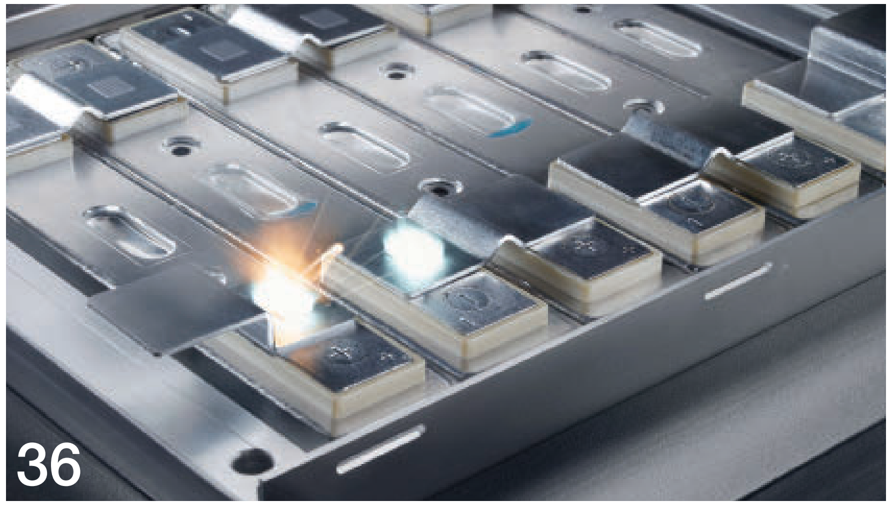
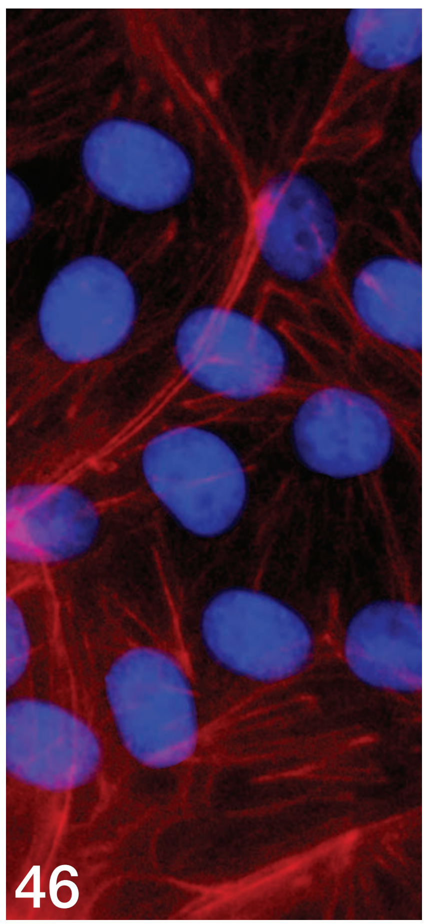


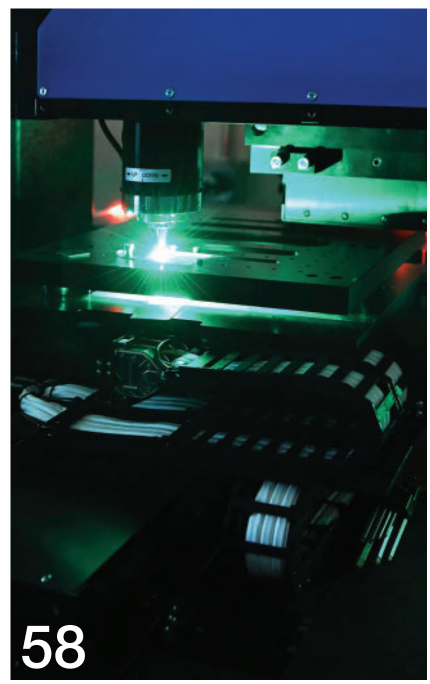
Inside This Issue

October 2024 volume 58 issue 10

Features







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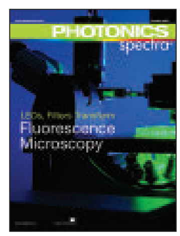
PHOTONICS: The technology of generating and harnessing light and other forms of radiant energy whose quantum unit is the photon. The range of applications of photonics extends from energy generation to detection to communications and information processing.

Columns



The Cover

Fluorescence microscopy methods have proved to be exceptional for live-cell imaging. The combination of LEDs and multi-bandpass filters are increasing durability and versatility for the imagers used in the systems that facilitate these applications. Cover design by Senior Art Director Lisa N. Comstock. Image courtesy of iStock.com/JuPanula.

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Editor's Note

Introducing 'Photonics Spectra Now'

Blink and you may have missed a spirited start to fall 2024 at *Photonics Spectra*. Following September's addition of four acclaimed industry leaders to the *Photonics Spectra* Editorial Advisory Board, the "All Things Photonics" podcast debuted its landmark 10th season on October 1. The upcoming annual *BioPhotonics* Conference features presentations from luminary figures in biomedical optics, imaging, and diagnostics as part of a dynamic program that runs Oct. 15 to 17.

Longtime readers of the magazine know that summer's segue into fall is the dawn of one of the busiest stretches of the year. Along with a brisk chill, photonics is "in the air," signaling our arrival into the final quarter of 2024.

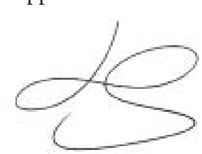
Here, of course, photonics is always in the air. Starting this fall, it is also *on* the air.

"Photonics Spectra Now" (PSN), a weekly broadcast spanning the top news and interest stories in the optical sciences, is the latest addition to the Photonics Media program lineup. Airing on Thursdays and available on Photonics.com, PSN dives into the most important headlines to deliver need-to-know information on the business and research advancements that are making waves each week. Its host, Joe Kuczynski, senior editor and broadcast veteran, works in close collaboration with members of the news team to share the most prominent stories with our readers.

The addition of a news broadcast fundamentally enhances the quality and range of coverage that online and print readers already expect from Photonics.com and our magazine offerings (of note to readers of this magazine: PSN also offers coverage of breaking news in the biophotonics and machine vision sectors). And, as industry news so often extends to events and awards, PSN delivers show previews and onsite coverage from industry events this fall — and will continue to do so well into the future.

As the flagship video offering from Photonics Media, PSN will also set the standard for an increased video presence across platforms. Notably, this includes the "All Things Photonics" podcast. From its audio-only origins in 2020 to an audio/video production two years later, season 10 of the podcast will feature a polished, updated look. A complete schedule for the remainder of season 10 of the "All Things Photonics" podcast is available at Photonics.com.

As for this issue, instrumentation in microscopy takes center stage in the cover story from Delta Optical Thin Film's Poul Svensgaard on page 46. Raman spectroscopy pioneer Jürgen Popp (whose insights also feature in this month's *BioPhotonics* Conference); contributing editor Marie Freebody; and Joe Kuczynski himself also appear as feature authors.



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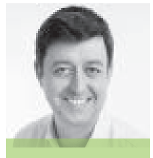

Paul Cain

Paul Cain, strategy director at FlexEnable, has 20 years of experience in flexible and organic electronics, both in technical and strategic roles. He has a Ph.D. in physics from the University of Cambridge and an MBA from London Business School. Page 42.

Jürgen Popp

Jürgen Popp is a professor of physical chemistry at the University of Jena and scientific director of the Leibniz Institute of Photonic Technology. Popp has been working on using Raman spectroscopy for medical diagnoses for more than 20 years. Page 52.

Marie Freebody

Contributing editor Marie Freebody is a freelance science and technology journalist with a master's degree in physics from the University of Surrey in England. Page 58.

Anja Silge

Anja Silge is a scientist at the Leibniz Institute of Photonic Technology. She specializes in applied bio-spectroscopy, enabling the analysis of patient samples in modular diagnostic systems. Her objective is to find answers to pressing diagnostic questions. Page 52.

Joe Kuczynski

After more than 16 years of covering local news on television as a video journalist, reporter, and producer, Joe Kuczynski joined Photonics Media as a senior editor in 2024. Joe leads the video department and performs editorial duties in support of *Photonics Spectra*. Page 36.

Poul Svensgaard

Poul Svensgaard, CEO of Delta Optical Thin Film, has more than 30 years of managerial experience within high-tech companies, including in optical filter technology with Delta Optical Thin Film. Page 46.

Jérémy Picot-Clémente

Jérémy Picot-Clémente works at the European Photonics Industry Consortium (EPIC), where he oversees developments in optics, micro-optics, and all related technologies and applications. He has a strong interest in photonics technologies as they apply to AR/VR, lidar, 3D sensing, and imaging devices. Page 64.

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Photonics Spectra Webinars

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How to Improve Laser Applications Using Freeform Optics

Freeform optics enable the optimization of laser applications but are often regarded as difficult to design and use in optical systems, expensive, and limited in optical performance. As a result, they occupy a small niche in the photonics industry. This webinar discusses easy, cost-effective ways to design, manufacture, and integrate solutions for fused silica freeform optics to enhance laser systems and applications. Stephen Kidd shares examples of some of the most prevalent and important laser applications, including coherent beam combing for laser-induced fusion as well as blue laser beam shaping for lithium-ion battery welding and other electric vehicle components.
Presented by PowerPhotonic.
To view, visit **www.photonics.com/w1044**.

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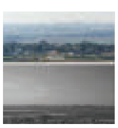


Peter Kunert of MKS Ophir IR Optics discusses the advantages of SWIR lenses and their pivotal role in air, land, and maritime imaging in challenging conditions, such as haze, smoke, and fog. Incorporating SWIR and NIR into electro-optical (EO) systems significantly enhances image clarity and performance. SWIR lenses excel in long-range daytime observation, glass transmission, and laser spot detection for designators, making them an ideal solution for defense and homeland security applications. This presentation shares how SWIR technology can transform an EO system and improve operational efficiency.
Presented by MKS Ophir Optics.
To view, visit **www.photonics.com/w1042**.

mks
Ophir

How Motion Control Enables Modern Datacom Technologies

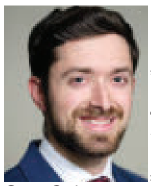
With the growth of AI and high-performance computing, modern data centers must find ways to support a rising demand for transferring massive amounts of data. To keep pace, there is no technology more foundational than optical transceivers. In this webinar, Justin Bressi explores macro trends pushing innovation in this space and the technologies that are enabling the next generation of optical transceivers, including silicon photonics, PICs, and co-packaged optics. He discusses common precision alignment-related challenges that arise when manufacturing and testing these devices, as well as methods and technologies to overcome them.
Presented by Aerotech.
To view, visit **www.photonics.com/w967**.

AEROTECH

PHOTONICS spectra SUMMIT

Sensors and Detectors Summit


Hamamatsu Corporation
Albert Tu.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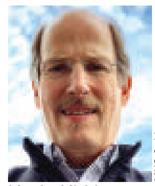
MKS Ophir
Kevin Kirkham.


Balluff
Rob Kline.


Baumer
Mike Nagle.

The editors of *Photonics Spectra* magazine invite you to the Sensors and Detectors Summit, a one-day virtual event exploring practical applications and emerging innovations in sensor and detector technology. The event takes place on Nov. 13, and all presentations will remain accessible on demand following the event.

Attendees will gain an understanding of how these technologies are enhancing energy measurement in laser systems, improving quality control in manufacturing, and advancing infrared detection. Experts from Hamamatsu Corporation, MKS Ophir, Balluff, Baumer, and VIGO Photonics will present actionable insights and strategies for optimizing sensor and detector performance across various industries.

Registration is free and opens the door to expert-led sessions spanning topics in industrial, environmental, and nonvisible inspections. Connect with industry professionals, exchange ideas, and explore new opportunities to advance your expertise.

Website

For more information and to register, visit **www.photonics.com/SD2024**.

Infrared Insights: Understanding the Deployment of NIR/MIR Detectors
Albert Tu and Gary Spingarn, Hamamatsu Corporation

Type II Superlattice Detectors and Their Place in MWIR and LWIR Gas Sensing
Jędrzej Mijas, VIGO Photonics

Pyroelectric Detectors, Insight to Energy
Kevin Kirkham, MKS Ophir

Enhancing Quality and Uptime with IO-Link Vision Sensors and Condition Monitoring
Rob Kline, Balluff

Inspect the Invisible
Mike Nagle, Baumer

Upcoming Summits

Polymer Optics — *December 4*

Hyperspectral Imaging — *January 15, 2025*

Integrated Photonics — *February 12, 2025*

Spectroscopy — *March 12, 2025*

Infrared Imaging — *April 16, 2025*

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Industry News

Industry prepares for Photonics West 2025

In 2024, SPIE Photonics West welcomed more than 24,000 technical professionals to San Francisco, along with more than 1500 exhibitors. The premier event for the optics and photonics industry aims to reach similar heights next year, as it makes its yearly return to the Moscone Center from Jan. 25 to 30.

Continuing with the previous year's run, the conference will feature the 2024 newcomer Quantum West Expo and the established BiOS Expo and Photonics West Exhibition. Plenary presentations, networking events, educational courses, conferences, and industry highlights will feature in the program, including landmark events such as the 2025 Prism Awards and the SPIE Startup Challenge.

Four technical symposia will host more than 4300 expert-led oral and paper presentations in more than 100 conferences. LASE will be offering 19 distinct conferences with tracks including laser sources, nonlinear optics and beam guiding, micro/nano applications, and macro applications.

As last year, the BiOS expo will kick off the conference on Jan. 25 with leaders in the fields of biomedical optics and instruments displaying new products and innovations as part of the world's largest showcase of biophotonics companies.

The self-titled flagship Photonics West Exhibition will run from Jan. 28 to 30. Companies from all over the photonics space, including optics, imaging, and lasers, will offer an inside look into their products and services portfolios. Live demonstrations, company-led presentations, and product releases are planned for the three-day expo.

The SPIE Photonics West conference and exhibition will be held Jan. 25 to 30, 2025, at the Moscone Center in San Francisco. The conference will host the Quantum West Expo, BiOS Expo, and Photonics West Exhibition along with the co-located SPIE AR/VR/MR show.

The 17th annual Prism Awards will feature again during the conference's run. Winners will be announced during a gala presentation on the evening of Wednesday, Jan. 29. The annual awards recognize the most innovative products on the market across the wide range of optics and photonics applications.

Registration to attend Photonics West is open now. Registration for the conference includes full access to the SPIE AR/VR/MR show, co-located with Photonics West and offering its own exhibition running Jan. 28 to 29.

Additional details regarding registration, accommodations, programs, and other SPIE trade shows can be found at www.spie.org/conferences-and-exhibitions/photonics-west.

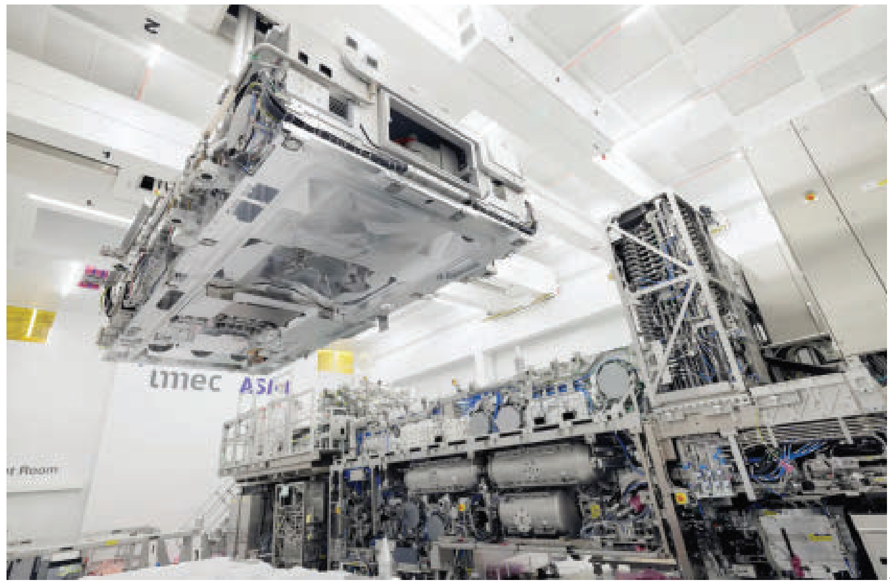
Joint imec-ASML lithography lab reports breakthroughs

In a series of advancements, imec and ASML demonstrated the utility of the 0.55 numerical aperture (NA) extreme-ultraviolet (EUV) scanner in the newly opened joint ASML-imec High NA EUV Lithography Lab in Veldhoven, Netherlands. imec reported that it successfully patterned single-exposure random logic structures with 9.5-nm dense metal lines, corresponding to a 19-nm pitch, achieving sub-20-nm tip-to-tip dimensions. The R&D center additionally reported printing random vias with a 30-nm center-to-center distance, 2D features at a P22-nm pitch, and dynamic random access memory (DRAM)-specific layout at P32 nm.

The results, imec said, were printed after single exposure, using materials and baseline processes that were optimized for high NA EUV in the framework of imec's Advanced Patterning Program.

Following the lab's opening, customers now have access to the TWINSCAN EXE:5000 high NA EUV scanner to develop private high NA EUV use cases leveraging the customer's own design rules and layouts.

"The results showcase the unique potential for high NA EUV to enable single-print imaging of aggressively scaled 2D features, improving design flexibility as well as reducing patterning cost and complexity," said Steven Scheer, senior vice president of compute technologies and systems/compute system scaling at imec. "Looking ahead, we expect to pro-



imec

The 9.5-nm random logic structure (19-nm pitch) after pattern transfer.

This month in history

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

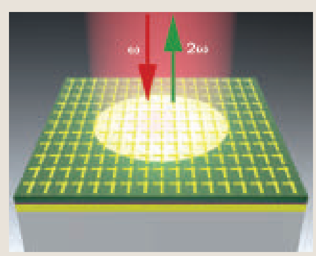
1994

Researchers from the Institute for Polymers and Organic Solids at the University of California at Santa Barbara created an optical image processor that could correlate two 5000-pixel images in <160 fs. The researchers employed a polymer called poly(1,6-heptadiester) to achieve this.

2004

Scientists at the University of Sydney and Macquarie University developed the first photonic crystal fiber dye laser. The laser's gain was great enough that it essentially operated without mirrors and its spectral characteristics were effectively independent of dye concentration and fiber length.

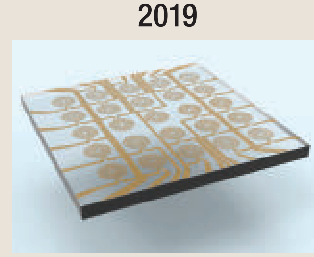
2014



Investigators from the Technical University of Munich and University of Texas at Austin created a metamirror nanostructure that produced nonlinear effects 1 million times greater than traditional macroscale nonlinear crystals. The researchers said that the technology could enable miniaturized laser systems and enhance chemical sensing.

2019

Scientists from the Institut de la Vision teamed up with a group from the Institute of Photonic Sciences (ICFO) to develop a dynamically tunable lens that can achieve almost any complex optical function. The lens, called Smartlens, is able to manipulate light without mechanical movement.



vide valuable insights to our patterning ecosystem partners, supporting them in further maturing high NA EUV-specific materials and equipment.”

The successful patterning of designs that integrate the storage node landing pad with the bit line periphery for DRAM — beyond logic structures — underscores the potential of high NA technology to replace the need of several mask layers by a single exposure, imec said.

PsiQuantum to build utility-scale quantum computer in Chicago

Under a partnership with the state of Illinois, Cook County, and Chicago, PsiQuantum will build a utility-scale fault-tolerant quantum computer at the former U.S. Steel South Works property in Chicago. Under the agreement, PsiQuantum will anchor the newly established Illinois Quantum and Microelectronics Park (IQMP). The facility aims to catalyze the state’s growing quantum ecosystem.

The utility-scale system is expected to consist of 1 million qubits, with a modular architecture able to use existing cryogenic cooling technologies. PsiQuantum uses a fusion-based architecture for its quantum computing approach, leveraging infrastructure in the semiconductor manufacturing industry to fabricate and test its photonic devices.

PsiQuantum will be the anchor tenant of the site with its Quantum Computer Operations Center spanning over 300,000 sq ft and additional acreage for future expansion. The operations are expected to create at least 150 jobs in mechanical, optical, and electrical engineering; software development; and technical lab work over the next five years. Additionally, Illinois has allocated $500 million of its 2025 state budget to the development of the IQMP, including $200 million for the build-out of a cryogenic plant to serve the cooling needs for PsiQuantum and other potential users.

Lamar Johnson Collaborative

A rendering of the Illinois Quantum and Microelectronics Park (IQMP), which is set to house PsiQuantum’s 300,000-sq-ft Quantum Computer Operations Center.

PsiQuantum also agreed with the state, Cook County, and Chicago to a package of incentives, totaling more than $500 million over 30 years, to enable the company to rapidly move toward the build-out and commissioning of the Quantum Computing Operations Center. Additionally, the recently announced Quantum Proving Ground Initiative in partnership with DARPA is set to provide $280 million to the IQMP and support the development and validation of utility-scale quantum computing technologies and systems.

The project is the second of its kind, after the company announced plans to build a utility-scale quantum computer in Australia earlier this year. Among PsiQuantum’s partnerships are several with various U.S. government agencies, including DARPA, through its US2QC program, and the U.S. Department of Energy, among others.

Report urges European photonics investment amid China’s progress

A study published by the European technology platform Photonics21 shows China’s substantial growth in the photonics industry, prompting calls from European Union (EU) photonics experts for increased funding to close a gap in market share. During the past two decades, China’s global market share has increased from 10% to >30%, eclipsing both the U.S. and Europe, each with 15% market share respectively, the report said. Photonics production in China is expected to reach €315 billion (approximately $342 billion) in 2025, the report said.

The study, Political Steering Processes in China in Core Segments of the Photonics Industry, was conducted by international management consultancy EAC. The report notes the role played by industrial development plans and unique regional clusters in China’s growing market dominance.

Lutz Aschke, president of Photonics21, said that while Europe currently holds the second position in the global photonics industry, a lack of significant investment means that Europe faces the threat of losing ground in the photonics technology sector, with implications for its technological independence.

"We need to implement a European strategy on critical materials and components for key industries and technologies to secure a resilient photonics supply chain in Europe. Specifically, research and development activities, as well as the production of photonic components in Europe that are critical to the industry supply chain, should be strengthened," Aschke said.

The EAC report shows that China's photonics industry clusters are enabling regional strategies and market demands to drive the photonics boom. China's financial backbone, the study said, consists of local governments, investment institutions, and enterprises. These entities are set to exceed national contributions with around €5 billion for photonics innovations over the next few years. The research shows that public funds account for only 20% to 30% of this regional revenue. The remaining 70% to 80% is composed of funds from investment institutions and enterprises.

These clusters are based in eight different cities in major industrial areas across China, each with its own focus and strategy. In Suzhou, China, for example, a 10 billion RMB (approximately €1.4 billion) photonics industry fund aims to establish the Suzhou Taihu Photonics Center to fuel scientific innovation through collaborative research. Beijing, for its part, plans an approximately €30 million optoelectronics fund.

The research shows that a significant part of China's success lies in a series of proactive industrial development plans, including Made in China 2025, the 14th Five-Year Plan and Beyond, and the National Science and Technology Plan. While the U.S. passed its CHIPS and Science Act in 2022, China's National Integrated Circuit Industry Investment Fund (ICF) had been operating for more than seven years. According to EAC, 2024 marked the start of Phase III of the ICF, which has a budget of €39 billion. Integrated photonics is one of the technologies funded in the third phase of the ICF.

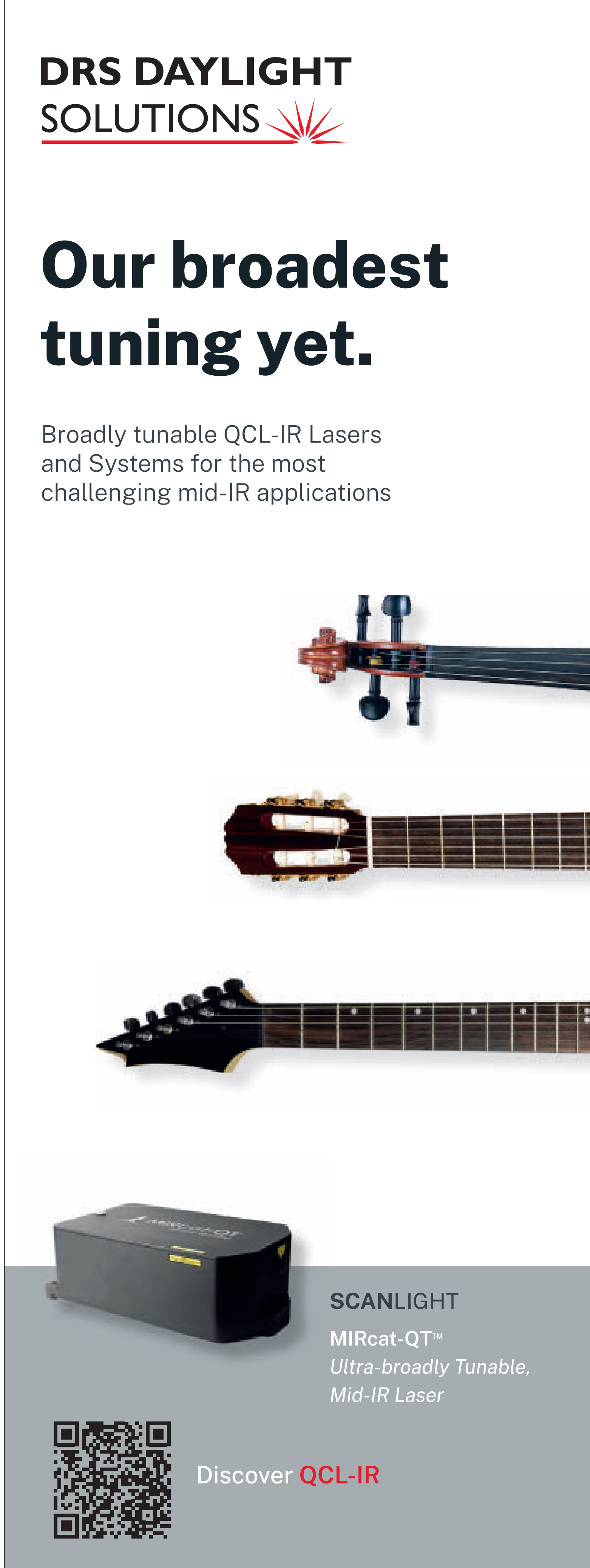
Sivers Semiconductors to spin off photonics business

Sivers Semiconductors plans to merge its Sivers Photonics Ltd. subsidiary with byNordic Acquisition Corporation, a publicly traded special-purpose acquisition company (SPAC). The proposed transaction would create a stand-alone, publicly traded photonics company.

Sivers and byNordic have entered a nonbinding letter of intent for the transaction. Once the merger is finalized, the newly formed company plans to establish headquarters in Silicon Valley with manufacturing operations in the U.K.

Sivers Photonics is a supplier of semiconductor photonic devices with a 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.

"With the attractive opportunity for silicon photonics in AI infrastructure and the emerging demand for photonic biometric sensors, we feel now is the right time to shine a light on this



business unit as a stand-alone entity to gain access to the U.S. capital markets and create an opportunity for our shareholders to participate in its potential future success," said Bami Bastani, chairman of Sivers Semiconductors.

Sivers Semiconductors is comprised of 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 named Vickram Vathulya president and CEO in July.

Corning, Lumen strike supply agreement

Lumen Technologies entered into an agreement with Corning Inc. for a substantial supply of next-generation optical cable, representing 10% of Corning's global fiber capacity for each of the next two years. The fiber-dense cable is expected to more than double Lumen's intercity fiber miles in the U.S., offering capacity for AI-related cloud data centers and high-bandwidth applications.

The agreement marks Lumen's largest cable purchase and will equip the networking solutions provider to meet the network infrastructure needs of major data center operators, including Microsoft, which announced in July that it is investing with Lumen to support the rising demand on its data centers.

"The rise of AI is driving technology companies to quickly secure fiber and bandwidth before their competition," said Kate Johnson, president and CEO of Lumen Technologies. The agreement with Corning, she said, grants Lumen status as a preferred partner.

"This marks the first outside-plant deployment of Corning's new gen-AI fiber and cable system, which will enable Lumen to fit anywhere from two to four times the amount of fiber into their existing conduit," said Wendell Weeks, chairman and CEO of Corning.

People in the News


SCHOTT AG
Knöbel.

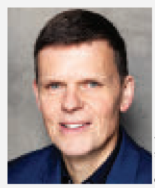
SCHOTT AG appointed **Marcus Knöbel** CFO. Knöbel suceeds **Jens Schulte**. He previously served as SCHOTT's executive vice president of its advanced optics business unit.


Intel
Chandrasekaran.

Intel appointed **Naga Chandrasekaran** chief global operations officer, executive vice president and general manager of Intel Foundry Manufacturing and Supply Chain organization. The Intel Foundry business encompasses Intel's technology development, global manufacturing, and foundry customer service and ecosystem operations. Chandrasekaran is joining Intel from Micron, where he served as senior vice president for technology development. In the new roles, Chandrasekaran will be a member of Intel's executive leadership team and report to CEO **Pat Gelsinger**.

QuEra, a neutral-atom quantum computing company, appointed **Andy Ory** acting CEO. This followed **Alex Keesling**'s transition to a role leading production and technology development. Ory is a member of QuEra's board of directors and cofounded and led several companies, including Acme Packet, which was acquired by Oracle, and 128 Technology, which was acquired by Juniper Networks.

Lidar technology developer Scantinel appointed **Frank Lindenberg** chairman of its advisory board.


Scantinel
Lindenberg.

Lindenberg brings more than 30 years of experience in the automotive industry to Scantinel. He most recently served on the board of directors of electric car manufacturer Lucid and as CFO and head of corporate strategy at Mercedes-Benz AG.

Swave Photonics, a developer of holographic display technology, named **Joel Kollin** director of optical architecture. Kollin spent more than a decade at Microsoft as a principal optical architect. He holds more than 60 U.S. patents, with several pending, and dozens of international patents for technologies relevant to Swave Photonics.

Optica added 95 senior members for 2024, recognizing their experience and professional accomplishments in optics and photonics. To qualify for Optica Senior Membership, individuals must have at least 10 years of significant professional experience in the field, five years of active Optica membership, and two endorsement statements from current Optica members. A complete list of Optica's 2024 senior members is available at www.optica.org.

SPIE named 107 senior members for 2024, from academia, industry, and government, and hailing from 22 countries. SPIE senior members are society members of distinction who are recognized for their professional experience and technical accomplishments, their active involvement with the optics community and with SPIE, and for significant performance that sets them apart from their peers. A complete list of SPIE senior members is available at www.spie.org.

Lumentum named **Matthew Sysak** CTO for Lumentum's cloud and networking platform. Sysak most recently served as vice president of laser and platform engineering at Ayar Labs, and previously served in a variety of leadership roles at Intel.


ESPROS Photonics
ESPROS Photonics founder Beat De Coi **(left)** and CEO Achim Ott.

ESPROS Photonics, a manufacturer of sensor and camera chips for time-of-flight sensing technology, appointed **Achim Ott** CEO. Ott succeeds company founder **Beat De Coi**, who held the role for 19 years. Ott most recently served as vice president of robotics for Hamilton Bonaduz AG, having previously held senior leadership roles at TRUMPF, including as CEO of TRUMPF Grüsch AG. De Coi continues to serve as chairman of the company's board.

Quandela, Welinq partner on quantum photonic computing

Quantum computing company Quandela partnered with quantum networking company Welinq to develop custom quantum interconnects. The collaborators aim to establish clusters of interconnected and error-corrected photonic quantum computers by combining Welinq's full-stack quantum interconnects technology with Quandela's photonic quantum computing processors.

The result, the partners said, will be the ability to provide custom quantum that supports fault-tolerant computing and the expansion of comprehensive quantum networks that connect numerous chips.

For Quandela, the partnership serves to lay the groundwork for error-corrected photonic quantum computing. To achieve the promised benefits of quantum computing, the company said, quantum processing units (QPUs) will need to execute algorithms across vast numbers of qubits, making error correction a foundational necessity. Photonic QPUs offer advantages due to their inherent modularity.

This modularity lends itself to scalability because additional qubits can be seamlessly integrated into the system. Scaling to numerous qubits will involve the interconnection of multiple independent photonic QPUs.

Full-stack quantum interconnects based on efficient quantum memories are crucial for linking multiple QPUs regardless of the qubit modality. These interconnects enhance the overall computational power by allowing quantum information to be transferred between different processors with high fidelity and low latency.

Welinq's interconnect technology, said company CEO and cofounder Tom Darras, natively offers compatibility with all existing QPU architectures. Darras said that he expects the collaboration to provide both an opportunity for Welinq to push the boundaries of its interconnect technology as well as to demonstrate its efficacy in providing scalability and error correction for quantum computing.

Quandela

Tom Darras **(left)**, CEO and cofounder of Welinq and Niccolo Somaschi, CEO and cofounder of Quandela.

TRUMPF and SiMa.ai partner on AI lasers

TRUMPF and machine learning system-on-chip developer SiMa.ai established a partnership to equip TRUMPF laser systems with AI technology. The agreement will focus on the acceleration of complex materials processing, and will include systems for welding, cutting, and marking, as well as powder metal 3D printers.

"Many of the processes we perform are difficult to capture with sensors and difficult to evaluate with traditional machine vision methods, especially for image data, because there are no 'clear edges' to detect — melting edges are fluid, and defects are often detected only during the process, especially during welding," said Jonas Zöller, head of R&D software development business center systems at TRUMPF. "This is why we need AI extensions to our current sensor methods."

Per the collaboration, SiMa.ai's compact AI chips will be integrated directly into the laser systems. AI-optimized sensor technology will monitor the quality of the laser welding process in real time and evaluate more than 3000 images/s.

According to Zöller, following the establishment of live-quality assessment capabilities, the collaborators are aiming to develop "healing strategies" — if it is known that something is incorrect, operators will be able to adjust parameters to try to repair the affected sector. The third stage would entail live adjustments of the laser system's parameters, he said.

"However, this is viewed critically by industrial customers today because, depending on the system, we are in qualified processes," Zöller said. "There, parameter changes are subject to documentation and approval. That's why this step is the last on the agenda."

Electric vehicle production is one application that is expected to benefit from the capabilities afforded by AI-enhanced laser systems. In this application, real-time quality inspection during laser welding is expected to replace separate and complex testing procedures. Once the AI capabilities are fully realized, battery manufacturers will be able to increase the quality of their production in real time and reduce rejection rates, which could ultimately lead to lower costs for consumers.

In addition to TRUMPF, SiMa.ai previously entered into partnerships with companies including e-con Systems and Lanner Electronics, targeting edge- and AI-supported capabilities for multiple applications.

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

Harald Kröger **(right)**, SiMa.ai's head of sales and president of its automotive business, and Richard Bannmüller, CTO of TRUMPF Laser Technology, in front of TRUMPF's TruLaser Cell 8030. The laser system is among those set to receive AI integration for process monitoring.

TRUMPF

TroGroup acquires Luxinar

Austria-based TroGroup acquired Luxinar Ltd., the U.K.-based manufacturer of CO_2 and ultrashort-pulse laser sources. The acquisition adds to TroGroup's existing portfolio of laser companies, following its 2022 acquisition of InnoLas Photonics. TroGroup subsequently merged InnoLas with U.S. subsidiary Iradion Laser Inc. following the acquisition.

"Effective immediately, Iradion can offer its customers a complete portfolio in the field of CO_2 laser sources, encompassing a variety of lasers with different technologies, power levels, wavelengths, and pulse durations," said TroGroup CEO Bernd Badurek.

Luxinar's catalog of laser sources spans offerings with power levels of up to 1000 W, and the company has been active in this laser technology area for more than 25 years. The company has sales subsidiaries in Germany, Italy, the U.S., China, and South Korea and serves customers in the semiconductor, electronics manufacturing, packaging and textile, automotive, and medical technology industries, among other industrial sectors.

TroGroup's development of a laser sources business sector began with its acquisition of Iradion Laser and continued with its purchase of InnoLas. At the beginning of 2023, TroGroup's laser sources business was organizationally separated from its sister company, Trotec, and has since operated under the name Iradion.

With the acquisition of Luxinar, the division significantly increases its revenue and workforce. The laser sources now included in Iradion's portfolio enable applications such as marking, engraving, cutting, drilling, and joining on a variety of materials, including technical ceramics, glass, textile, paper, metal, plastic, and rubber.

Luxinar employs around 200 staff at six locations worldwide.

Torrent Photonics acquires Knight Optical

Torrent Holdings LLC, parent company of imaging and sensing solutions provider Torrent Photonics, acquired Knight Optical, a manufacturer and provider of scientific optical components and subassemblies based in the U.K. The acquisition of Knight Optical strengthens Torrent Photonics' market position in photonic and optoelectrical components, particularly in the scientific, defense, medical, pharmaceutical, and optoelectronics industries, the company said.

According to Torrent CEO John Dougherty, the addition of Knight Optical's online catalog will allow the company to accelerate prototyping for key customers and expand services and sales. For Knight Optical, access to Torrent's custom capabilities for OEM and high-volume customers will help to support customer needs through volume manufacturing. Knight Optical will add many of Torrent Photonics' standard products to its catalog and will continue to operate from its offices in Kent, England.

Torrent Photonics, formerly Salvo Technologies prior to 2024, made numerous acquisitions before the corporate rebranding, including of Flash Photonics, Pixelteq, Arrow Thin Films, Spectrecology, Kreischer, and Graflex, in a three-year period dating to 2020.

11% — estimated compound annual growth rate of the global near-infrared fluorescence imaging system market by 2031, according to Transparency Market Research

Optimax launches dedicated space systems business

Rochester, N.Y.-based optics manufacturer Optimax launched Starris: Optimax Space Systems, a business operating under the Optimax corporate structure. Starris will focus on the development of space-qualified optical payloads, enabling customers to enter the space economy quickly and with low risk, the parent company said. Optimax said that Starris will develop payloads from idea to launch-ready status in less than one year, for Earth observing, space infrastructure, resource exploitation, space manufacturing, and defense.

"The global space economy is at an inflection point, poised to nearly triple by 2025, reaching a staggering $1.8 trillion," said Joe Spilman, CEO of Optimax. "To accelerate our pace, the industry must shift to a new norm where risk, cost, and time to orbit are significantly minimized."

The official unit launch took place in August at the Small Satellite Conference, held in Utah. Optimax named Kevin Kearney director and CTO of Starris.

Starris is powered by 30 years of space-qualified and precision optics from the parent company, which enabled a variety of space-flight missions, including NASA Mars Rovers and commercial space ventures. The business will support the integration of space-rated optics, sensors, and electronics into digital cameras and instruments using pre-engineered modular systems, tailored for aggressive design cycles and rapid deployment. Development will be bolstered by Optimax's existing testing and manufacturing ecosystem, which supports the transition from prototype to production, and radiation-tolerant design for temperature, vacuum, shock, and vibration.

Additionally, Starris technology features in collaborations with space-rated suppliers, including sensors by Teledyne Space Imaging, with which Starris has partnered to develop space cameras for small satellites and lunar missions. This collaboration will focus on applications that include Earth observation, space navigation, in-orbit servicing, in situ resource utilization, in-orbit manufacturing, and space domain awareness.

Koito deals to acquire longtime partner Cepton

Publicly traded lidar company Cepton signed a definitive agreement to be acquired by automotive Tier 1 supplier and longtime collaborator Koito. Per the agreement, Koito will acquire all outstanding capital stock for $3.17 per share in an all-cash transaction. Following the transaction's close, Cepton will operate as a privately held indirect subsidiary of Koito in the U.S.

"Our partnership with Koito will provide us with unique access to a broader range of opportunities and resources and help us stay resilient to industry challenges in a way no other lidar company can," said Cepton cofounder and CEO Jun Pei. "This will position us as a leading automotive lidar company for years to come, as Cepton continues to execute current automotive programs and actively manage future OEM initiatives."

The acquisition complements Koito's existing sensor technology portfolio, while providing Cepton with greater financial stability and scalability to commercialize its lidar technology. Cepton and Koito have partnered since 2017 to industrialize high-performance lidar solutions for mass-market automotive, smart infrastructure, and industrial applications.

According to Cepton, its directional lidar technology, targeting the automotive lidar and advanced driver-assistance systems market(s), reportedly takes up 75% less space and consumes <50% power compared with similarly performing scanning systems. The systems do not require active cooling to maintain performance and feature proprietary custom system-on-chip technology for back-end point cloud processing.

Founded in 2016 by technologists from Stanford University, Cepton went public in 2021 through a merger with a special-purpose acquisition company (SPAC), which at the time valued the company at an enterprise value of approximately $1.5 billion on a cash-free, debt-free basis.

The transaction is expected to close in the first quarter of 2025.

Briefs

IDEX Corp. entered into an agreement to acquire **Mott Corporation**, a designer and manufacturer of sintered porous material structures and flow control solutions, and its subsidiaries for a cash consideration of $1 billion. The acquisition expands IDEX's applied materials science technologies portfolio and expands market opportunities in semiconductor wafer fab equipment, medical technologies, space and defense, and water purification industries.

Novanta is relocating from its founding premises to a 70,000-sq-ft facility in Stockport, England. The new location quadruples the previous facility's capacity.

The U.K. is funding five quantum hubs with £100 million ($128 million) to support the development of practical applications for quantum technologies in areas such as medical scanning, secure communications, and next-generation positioning systems. The hubs will be led by leading universities that will work closely with industrial partners.

The **Mahr Group**, an industrial technologies business, acquired **OptoSurf GmbH**, a developer of optical surface measuring devices. The acquisition expands the Mahr Group's portfolio in optical surface metrology. According to Mahr Group CEO Manuel Hüsken, OptoSurf's scattered light technology is complementary to its existing portfolio and will provide its customers with greater functionalities and application potential in surface analysis.

Photonic chip foundry **LioniX International** secured approval for €1.5 million ($1.6 million) in short-term bridge financing. The funds, LioniX said, will be used to bolster the foundry's financial position as well as to enable LioniX to further develop its TriPleX waveguide photonic integrated circuit platform.

POET Technologies, a developer of optical technologies for data center, telecommunication, and AI markets, expanded its partnership with **Luxshare Technology** to provide more optical module products targeted at AI network equipment and AI service providers. The companies will produce additional types of optical transceiver modules that will include POET's transmit and receive optical engines for Luxshare's 400G and 800G pluggable transceivers for single-mode fiber applications. The optical modules will be manufactured and sold globally by Luxshare.

NLM Photonics received a $1.8 million contract from the U.S. Air Force to fund a 21-month project with **AIM Photonics**. The project aims to offer modulator components in AIM Photonics' process

NIST updates UV calibration system

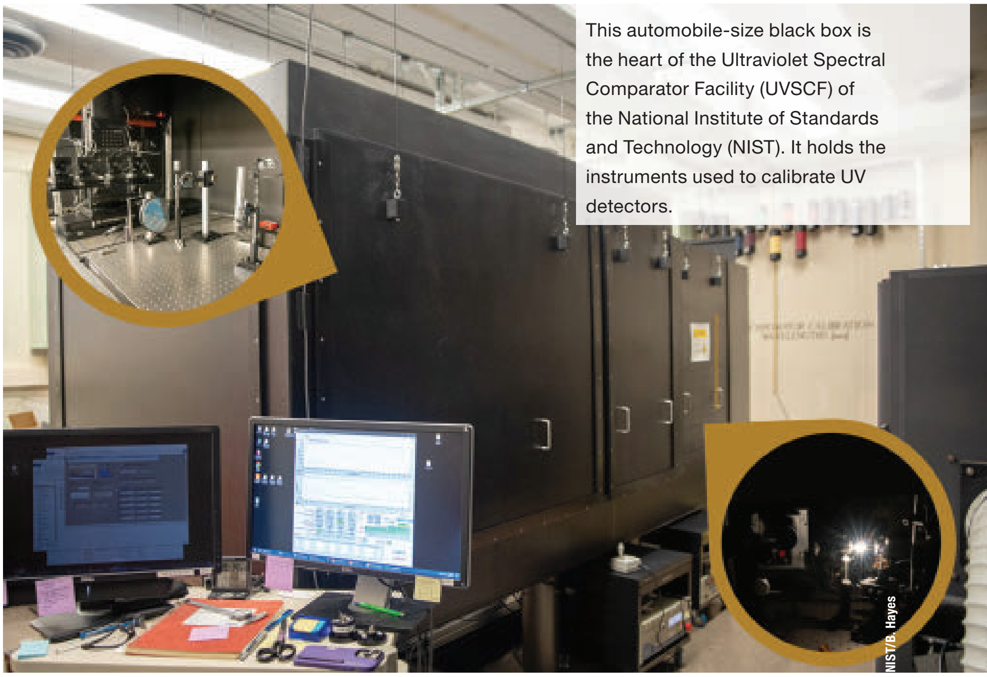
The National Institute of Standards and Technology (NIST) updated its ultraviolet (UV) calibration facility to ensure accurate calibration of UV detectors. The Ultraviolet Spectral Comparator Facility (UVSCF) measures and calibrates UV detection equipment delivered by industry.

The germicidal properties of UV light make it useful in sanitation and disinfection, especially in health care settings. It is also used to combat microbial contamination in water and for curing epoxy. Organizations that use UV light, from the military and research institutions to universities and industrial manufacturers, use calibrated UV detectors to check that UV light sources are emitting the right amount and intensity of light.

NIST's calibration system accommodates all three categories of UV light — that is, UVA, UVB, and UVC — each spanning distinct wavelengths. The update specifically emphasizes UVC

17.4%

— predicted compound annual growth rate of the global quantum dot market by 2029, according to Mordor Intelligence



This automobile-size black box is the heart of the Ultraviolet Spectral Comparator Facility (UVSCF) of the National Institute of Standards and Technology (NIST). It holds the instruments used to calibrate UV detectors.

NIST/B. Hayes

design kits for silicon-organic hybrid devices on the institute's 300-mm silicon photonics platform. These devices focus on low-power, high-bandwidth electro-optic (EO) modulation for data communications, radio frequency photonics, sensing, and other applications using silicon-organic hybrid EO modulators. NLM will perform process development and optimization, and work with the AIM Photonics' test, assembly, and packaging facility for wafer-scale passive and die-level, high-speed device testing.

Lumileds LLC, a manufacturer of LEDs for automotive and illumination markets, completed the $238 million sale of its lamps and accessories business to **First Brands Group LLC**, an automotive parts manufacturer. According to Lumileds CEO Steve Barlow, the sale will allow Lumileds to focus on its core LED business. The acquisition includes automotive lamp factories in China, Germany, and Poland. Lumileds retains its factories and sites in the Netherlands, the U.S., Malaysia, Singapore, Germany, and Jiaxing, China.

Optical computing technology developer **Light-Solver** will receive more than $13.5 million in funding after being selected for the European Innovation Council (EIC) Accelerator Program. The company, which has developed a laser-based high-performance computing paradigm, said that it will use financing to advance the commercialization of its platform and accelerate its growth in the high-performance computing (HPC) sector.

Augmented reality technology company **OQmented** partnered with laser chip developer **Brilliance** to advance laser beam scanning technology applications. The collaboration aims to integrate Brilliance's laser chips with OQmented light engines, both of which are assembled at the wafer level. The strategy for their combination is expected to provide significant cost savings compared with conventional processes.

Halo Industries, a developer of laser manufacturing technology for the semiconductor industry, raised up to $80 million in a series B funding round. The company said that it plans to use the funds to scale the commercialization and reach of its technology targeted for silicon carbide substrate production.

Laird Thermal Systems, a developer and manufacturer of thermal management solutions, acquired **Tark Inc.**, a supplier of pumps and cooling solutions for the medical and industrial x-ray tube and computed tomography industry. The company said that the acquisition adds complementary technologies and capabilities to its portfolio while enhancing its global market position.

light, which spans a wavelength range of 200 to 300 nm.

NIST has maintained a UV calibration facility since the late 1980s, but by the mid-2010s, the facility was no longer able to meet the needs of emerging technologies, such as UV disinfection, because it was not optimized for that particular wavelength range. The upgrade was spurred in part by the increased adoption of these technologies in the wake of the COVID-19 pandemic, NIST said.

IonQ is contracted to build networked quantum computer

Through a competitive solicitation with the Applied Research Laboratory for Intelligence and Security (ARLIS), quantum computing company IonQ won a contract to design a networked quantum computing system for the Department of Defense (DOD). The first phase of the project — awarded at $5.7 million — will focus on the design phase of the quantum system.

Future phases of the project, which have yet to be awarded, include the construction, delivery, and maintenance of these systems.

Through this project, ARLIS will conduct hands-on research into the cybersecurity of multiparty quantum computation, including blind quantum computing protocols — a process where quantum computers remain “blind” to what information is being processed through them. This effort is funded by an award from the Secretary of the Air Force Concepts, Development, and Management Office.

ARLIS is the DOD’s principal university-affiliated research center for intelligence and security, and the contract extends the reach of IonQ technology to yet another U.S. federal agency. Agencies such as the U.S. Air Force Research Lab (AFRL) have previously announced deals with IonQ to use the company’s systems for quantum networking research and application development.

The contract is the latest in a series of federal government investments in projects using IonQ’s systems. Earlier this year, the Department of Energy funded research at Oak Ridge National Laboratory to explore how quantum technology can modernize the power grid. In 2023, IonQ announced a $25.5 million deal with the AFRL to deploy two barium-based trapped ion quantum computing systems for quantum networking research and application development.

In addition to the collaborations and investments, IonQ also works with enterprise customers to incorporate quantum solutions into several industries. IonQ customers include Airbus and Hyundai Motor.

Project DIPOOL yields updated laser blanking system

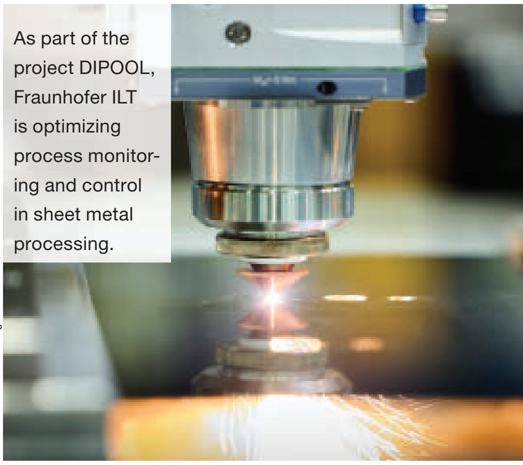
As part of the joint project DIPOOL (Digital Process Online Optimizer for Intelligent Laser Machines), the Fraunhofer Institute for Laser Technology ILT (Fraunhofer ILT) and its project partners are developing solutions to improve the efficiency and safety of laser cutting and welding processes. Funded by the German Federal Ministry of Education and Research, DIPOOL seeks to use AI and minimally invasive laser modulation to optimize process monitoring and control in sheet metal processing, with a particular focus on thin sheet metal and laser blanking.

"These technologies make it possible to detect process deviations in real time and make immediate adjustments to sustainably increase production reliability and speed," said Frank Schneider, DIPOOL project manager and cutting group leader at Fraunhofer ILT.

The functional principle of the monitoring system is based on a minimally invasive laser modulation pattern (MILM). Minimal disturbances are imposed on the machining process, to which the process continuously responds with particularly characteristic, condition-dependent signals. AI can effectively analyze these patterns.

Automatic-Systeme Dreher, Fraunhofer ILT, and a pilot customer have cooperated on building an industrial-scale laser blanking demonstrator system and integrating system monitoring with AI and MILM. For this pilot customer, the Aachen-based institute has been developing the process over many years.

The system, which will be used to process cold-rolled strip products, among other items, is designed to maximize process reliability when processing coils. The AI-based systems analyze the process signals in real time and detect even the smallest deviations before they lead to problems. MILM ensures that the cutting process remains continuously stable, an advantage that minimizes scrap rates and increases overall system productivity.



As part of the project DIPOOL, Fraunhofer ILT is optimizing process monitoring and control in sheet metal processing.

Fraunhofer ILT/Ralf Baumgarten

"The new concept of overlapping work areas of two processing heads with continuous belt transport in the system enables maximum flexibility and resource-efficient production," said Hasan Sarac, managing director of Automatic-Systeme Dreher. "This means that each laser can process exactly what is required."

Graphene deploys as a powerful gas sensor emission source

AACHEN, Germany — Using graphene as an emission source, scientists at the research institute AMO GmbH, in collaboration with university researchers, developed a MIR emitter for integrated photonic gas sensors. Applications in environmental monitoring, industrial process control, medical diagnostics, and other areas require compact, reliable gas sensors to monitor air quality in real time. The graphene IR emitters, which could be used for a distributed network of sensors, offer a potential solution for gas sensor systems across various industries.

Traditional gas sensing methods are based on the chemical reaction of the targeted gas to the sensor material. The reaction of the gas affects the sensor, which can lead to the need for frequent calibration, drift, performance degradation, and a limited sensor lifetime. Absorption spectroscopy, in contrast, works by characterizing the absorption wavelengths of gases, such as greenhouse gases, and providing a spectral fingerprint that can be used to determine the composition of the gas. This method provides high specificity, minimal drift, and long-term stability without chemically altering the sensor.

Photonic integrated circuits (PICs) can be used to shrink spectroscopy equipment to the size of a chip, creating a compact, cost-efficient optical gas sensor system. However, PIC-based gas sensors still require light coupling from external sources and coupling to detectors in and out of the waveguides. Integrating light sources and detectors directly on the wafer could enable spectroscopic gas sensing in a highly compact format.

The researchers integrated the graphene-based emitter with photonic waveguides that couple directly into silicon waveguides operating in the region relevant for gas sensing. The integration of these components at wafer level could reduce the size and cost, improve the mechanical stability, and potentially enhance the performance of environmental sensors.

The researchers operated the emitter for ~1 h under ambient conditions, demonstrating MIR emission into the waveguide and out of a grating coupler. They detected emissions in the spectral range of 3 to 5 µm.

Graphene was selected as the active material for the thermal MIR emitter because the material can reach the temperatures necessary for thermal emission, and its emissivity is comparable to that of other very thin emitters. These properties make it a viable candidate as a source for MIR emission; monolayers of graphene are so thin that the entire emitting volume can be placed closest to the waveguide, generating ideal near-field coupling of the emission directly into the waveguide mode. In addition, monolayer graphene causes minimal distortion to the waveguide mode, which lessens the mismatch between the mode in the emitter region and outside this region.

Based on thermal simulations, the researchers predict emitter temperatures could reach the range of 500 to 900 K, which is comparable to other nanoscale emitters. They estimate emission coupling efficiencies into the waveguide of up to 68%, which compares favorably with other nanoscale emitters.

Although the PIC used in the experiment was primarily characterized for a 4.2-µm wavelength targeting CO_2 detection, the integrated graphene thermal emitters radiate in a broad gas absorption fingerprint wavelength range of 3 to 10 µm.

Combined with integrated graphene MIR photodetectors, the graphene MIR emitters could enable fully integrated photonic sensors, where the evanescent fields of the waveguides could interact directly with the gaseous environment, enabling their broad application for gas and environmental sensing.

The research was published in *ACS Photonics* (www.doi.org/10.1021/acsphotonics.3c01892).

Transparency gains characterize Fraunhofer OLED microdisplays

DRESDEN, Germany — Building on results that yielded OLED microdisplays with 20% transparency, researchers working as part of the Fraunhofer Society's HOT project (High-performance transparent and flexible micro-electronics for photonic and optical applications) demonstrated 45% transparency in a CMOS OLED microdisplay. The results represent a significant increase in the transparency of commercial versions of these displays.

Transparent electronics have found use in ultrathin layers for touch display and as transparent films with printed antennas for mobile communications.

As of yet, however, OLED displays have not been used for this purpose.

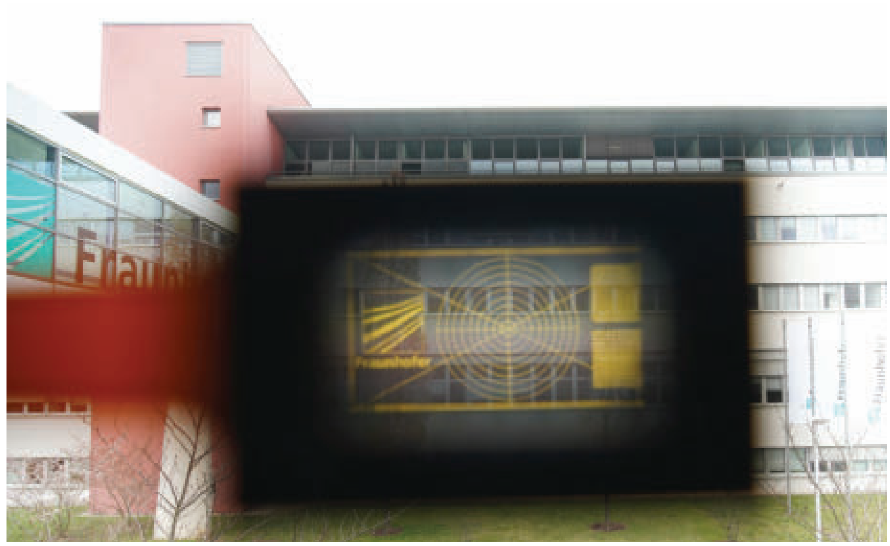
Two fundamental methods can achieve semitransparency in optical systems. The first, the pixel approach, involves creating transparent areas between individual pixels. The second method is the cluster approach, in which several pixels are grouped into a larger, nontransparent cluster to produce larger transparent areas in between these clusters.

Both approaches are relevant for different applications in practice. The pixel approach is suitable, for example, for image overlay within a complex optical system, where the image is inserted between other image planes. The cluster approach is particularly suitable for augmented reality applications, such as in data glasses, where the pixel clusters are combined into a uniform virtual image using a micro-optic over each cluster. The transparent areas between the clusters remain unaffected by the optics, allowing a clear view of the real environment.

Scientists developed the technology for transparent microdisplays to support both techniques, and the OLED-on-silicon technology specifically uses a silicon backplane that contains the entire active-matrix drive electronics for the pixels. The organic frontplane is monolithically integrated on the topmost metallization layer, which simultaneously serves as the drive contact for the OLED. The second connection of the OLED is formed by a semitransparent top electrode shared by all pixels.

The pixel circuitry is based on silicon CMOS technology and requires several metal layers to connect the transistors embedded in the substrate. These metal connections are made of aluminum or copper. Additionally, the optical structure of the OLED requires a highly reflective bottom electrode to ensure high optical efficiency upwards. These two aspects result in the pixels themselves not being transparent.

"A transparent microdisplay, however, can be realized through a spatially distributed design of this basic pixel structure, creating transparent areas between the pixels and minimizing column and row wiring," said Philipp Wartenberg, group leader of integrated circuit and system design at the Fraunhofer Institute for Photonic Microsystems IPMS (Fraunhofer IPMS). "Further optimization of the OLED layers, for example, by avoiding OLED layers in the transparent areas, introducing antireflective coatings, and redesigning the wiring also contributes to increasing transparency."



Fraunhofer IPMS

Fraunhofer scientists presented a transparent OLED microdisplay device at the 2024 International Meeting on Information Display in South Korea. The demonstration supports broadening the adoption of OLED technology for commercial and consumer applications.

The researchers presented a microdisplay at the International Meeting on Information Display 2024, showcasing the cluster approach with a new augmented reality optic based on a microlens array. The optics were designed to enable a setup close to the eye, with a similar distance to the eye as regular corrective glasses.

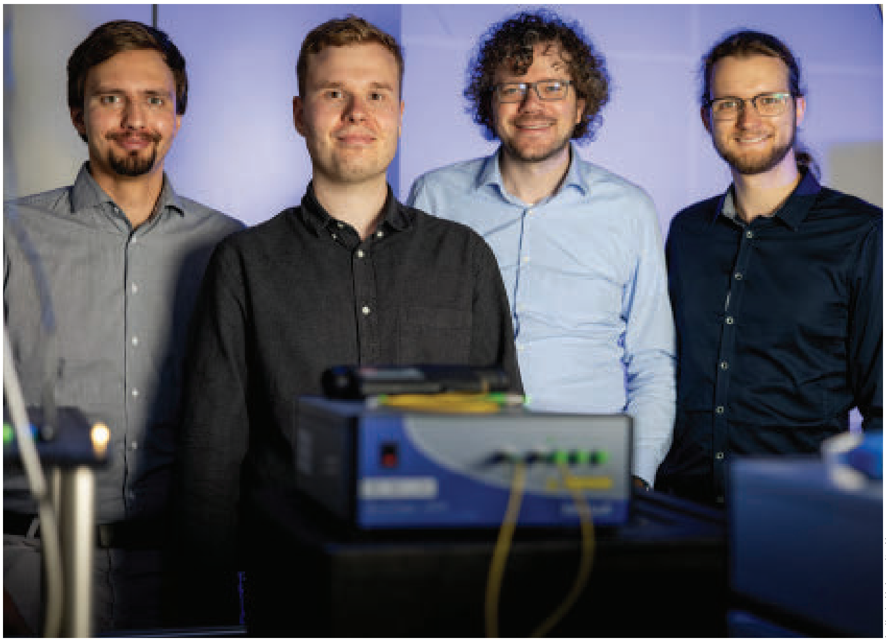
Method combines the powers of conventional and quantum internet

HANNOVER, Germany — While the co-integration of quantum frequency-entangled photons with coherent information transmission can be achieved via spectral multiplexing, more resource-efficient approaches are required to accommodate the next generation of telecommunications technology, including the quantum internet.

In recent work, researchers from Leibniz University Hannover sent entangled photons and laser pulses of the same color over a single optical fiber. According to the researchers, this is the first time the feat has been achieved.

"To make the quantum internet a reality, we need to transmit entangled photons via fiber optic networks," said Michael Kues, head of the Institute of Photonics and board member of the PhoenixD Cluster of Excellence at Leibniz University Hannover. "We also want to continue using optical fibers for conventional data transmission. Our research is an important step to combine the conventional internet with the quantum internet."

As part of the research, team members developed a new transmitter-receiver concept, aiming to transmit entangled photons over an optical fiber. In their experiment, they demonstrated that the entanglement of photons is maintained even when they are sent together with a



(From left) Jan Heine, Philip Rübeling, Michael Kues, and Robert Johanning. The researchers developed a concept to enable the cohabitation of quantum and conventional internet signals in the same optical fiber without the need of multiplexing.

laser pulse. The concept leverages the serrodyne technique, which applies a linear temporal phase ramp to translate the spectrum of an optical pulse via electro-optical phase modulation, leading to very different dynamics for entangled and coherent photons. This in turn enables the temporal multiplexing of the respective signals.

"We can change the color of a laser pulse with a high-speed electrical signal so that it matches the color of the entangled photons," said Philip Rübeling, a doctoral student researching the quantum internet at the Institute of Photonics. "This effect enables us to combine laser pulses and entangled photons of the same color in an optical fiber and separate them again."

This effect could function to integrate the conventional internet with the quantum internet.

Until now, the team said, it has not been possible to use both transmission methods per color in an optical fiber. "The entangled photons block a data channel in the optical fiber, preventing its use for conventional data transmission," said Jan Heine, a doctoral student in Kues' group.

With the concept demonstrated in the experiment, the photons can now be sent in the same color channel as the laser light: This implies that all color channels could still be used for conventional data transmission.

The research was published in *Science Advances* (www.doi.org/10.1126/sciadv.adn8907).

Stacked transition metal dichalcogenide material layers show optoelectrical qualities

QUÉBEC CITY — Researchers at the Institut national de la recherche scientifique (INRS), in collaboration with a team at the Université de Picardie Jules Verne (UPJV, France) developed a material growth method that bypasses traditional challenges associated with the material molybdenum disulfide (MoS_2), and that could unlock innovations in optoelectronics and renewable energies technology. The method to grow films of MoS_2, which is a transition metal dichalcogenide, uses a vertically layered structure.

MoS_2 can strongly absorb light and transform it into electrical charges with high electron mobility, giving it the capacity for rapid signal transmission. This combination makes it particularly appealing for the development of optoelectronic applications, such as photodetectors, photonic switches, next-generation solar cells, and LEDs. Yet while MoS_2 has been used since the 1970s and '80s as a solid lubricant in the aerospace industry and for high-performance mechanics, for example, the material has attracted a great deal of interest from the scientific communities because of its properties as a 2D semiconductor material.

"By proposing a new way of growing MoS_2 films with a vertically layered structure, we are paving the way for the synthesis of MoS_2 that is labeled as '3D' but has exceptional '2D' behavior," said Driss Mouloua, a postdoctoral researcher at Commissariat à l'énergie atomique in France.

MoS_2's distinct properties depend on the way that the monolayers of this material are arranged in the films. Over time, scientists have developed manufacturing strategies to obtain two to five horizontally layered monolayers to take advantage of MoS_2's optoelectronic properties.

In the study, the researchers synthesized relatively thick MoS_2 films that are made up of vertically aligned MoS_2 layers. To achieve this, they used an approach based on pulsed-laser deposition (PLD).

The result is films that achieve an optoelectronic behavior that resembles that of ultrathin 2D MoS_2, and which are ~100-nm thick — equivalent to ~200 atomic monolayers of MoS_2.

In their observations, the researchers found that layers arranged more vertically enabled better photodetection performance in the PLD-MoS_2 films. The vertical MoS_2 monolayers interact individually with light, thereby enhancing their capacity to absorb light and achieve a swift vertical transfer of the photocharges along the MoS_2 layers in this structure. Moreover, these 3D PLD-MoS_2 films can be scaled up to the wafer level while circumventing the difficulties associated with the synthesis of only a few horizontal monolayers.

With this breakthrough, said lead researcher My Ali El Khakani of INRS, a better understanding of quantum confinement phenomena can be cultivated. The work also supports improvements in the design of new optoelectronic devices based on 2D materials, such as MoS_2 and tungsten disulfide.

The research was published in *Advanced Optical Materials* (www.doi.org/10.1002/adom.202302966).

OptoGPT enhances optical components in the design phase

ANN ARBOR, Mich. — An algorithm developed at the University of Michigan is expected to streamline the design process for optical components, including solar cells, smart windows, and telescopes. The resource, called OptoGPT, harnesses the transformer neural networks that power large language models to work backward from desired optical properties to the material structure that can provide them.

Specifically, the algorithm designs optical multilayer film structures — stacked thin layers of different materials — that can serve a variety of purposes. Well-designed multilayer structures can maximize light absorption in a solar cell or optimize reflection in a telescope. They can also improve semiconductor manufacturing with extreme-ultraviolet light and be used in smart windows that become more transparent or more reflective, depending on temperature, and enable buildings to better regulate heat.

OptoGPT produces designs for multilayer film structures within 0.1 s. In addition, its designs contain six fewer layers on average compared with previous models, meaning that the designs that are developed using the model are easier to manufacture.

"Designing these structures usually requires extensive training and expertise as identifying the best combination of materials, and the thickness of each layer, is not an easy task," said L. Jay Guo, professor of electrical and computer engineering at the University of Michigan and corresponding author of the study describing OptoGPT.

To automate the design process for optical structures, the research team tailored a transformer architecture for its own purposes. This uses the same machine learning framework that is used in large language models, such as OpenAI's ChatGPT and Google's Bard. "In a sense, we created artificial sentences to fit the existing model structure," Guo said.

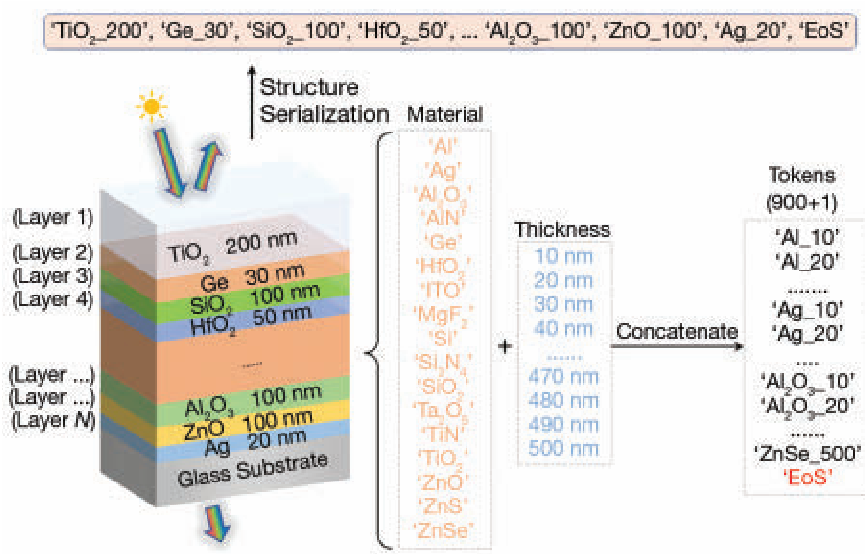
The model treats materials at a certain thickness as words, and encodes their associated optical properties as inputs. Seeking out correlations between these words, the model predicts the next word to create a phrase — in this case, a design for an optical multilayer film structure — that achieves the desired property, such as high reflection.

Similar to how large language models are able to respond to any text-based question, OptoGPT is trained on a large amount of data and is able to respond well to general optical design tasks across the field. Researchers tested the new model's performance using a data set containing 1000 known design structures that included their material composition, thickness, and optical properties. When comparing OptoGPT's designs to the validation set, the difference between the two was only 2.58%. This value is lower than the closest optical properties in the training data set, at 2.96%.

If researchers are focused on a task, for example, designing a high-efficiency coating for radiative cooling, they can use local optimization — adjusting variables within bounds to achieve the best possible outcome — to further fine-tune the thickness to improve accuracy. During testing, the researchers found that fine-tuning improves accuracy by 24%, reducing the difference between the validation data set and OptoGPT responses to 1.92%.

Taking analysis a step further, the researchers used a statistical technique to map out associations that OptoGPT makes.

"The high-dimensional data structure of neural networks is a hidden space, too abstract to understand. We tried to poke a hole in the black box to see what was going on," Guo said.



Michigan Engineering/L. Jay Guo Laboratory

The schematic shows the process of OptoGPT, an algorithm developed at the University of Michigan that projects to enhance optical component design. The process combines an undetermined layer's possible materials and thicknesses into a format that can be run through the program to choose the best possible combination.

When mapped in a 2D space, materials cluster by type, such as by metals and dielectric materials, which are electrically insulating but can support an internal electric field. All dielectrics, including semiconductors, converge upon a central point as the thickness approaches 10 nm. From an optics perspective, the pattern makes sense because light behaves similarly regardless of material as such small thicknesses are approached. This quality helps further validate OptoGPT's accuracy.

Known as an inverse design algorithm because it starts with the desired effect and works backward to a material design, OptoGPT offers more flexibility than previous inverse design algorithm approaches, which were developed for specific tasks.

The research was published in *Opto-Electronic Advances* (www.doi.org/10.29026/oea.2024.240062).

Magnetic field illuminates path to solar panel efficiency uptick

SYDNEY — Singlet fission and triplet fusion are related photophysical processes with potential applications in photovoltaics, photocatalysis, optical and magnetic resonance imaging, and advanced manufacturing. When applied to photovoltaics, singlet fission and triplet fusion can increase the efficiency of solar cells appreciably, according to a research team at the University of New South Wales (UNSW).

The team is investigating how to integrate singlet fission with existing silicon-based solar technology. Singlet fission would enable solar cells to retain more of the energy they receive from the sun, pushing them beyond their current efficiency limits.

The efficiency of a solar panel is represented by the fraction of energy supplied by the sun that can be converted into electricity. Existing solar cells work by absorbing photons that are used by the system's electrical conductors to generate energy.

"As part of this process, a lot of this light is lost as heat, which is why solar panels don't run at full efficiency," said professor Tim Schmidt, head of UNSW's School of Chemistry. Although each color of light produces a different energy level, the amount of energy that is supplied to the cell does not change, regardless of the color of the incoming light. The excess energy is turned into heat.

"If you absorb a red photon then there's a bit of heat," Schmidt said. "With blue photons, there's lots of heat."

Introducing singlet fission into a silicon solar panel enables a molecular layer to supply additional current to the panel.

According to University of New South Wales (UNSW) professor Tim Schmidt, recent findings could lead to a prototype of a solar cell operating above the theoretical capacity for silicon-based solar cells.

UNSW

Singlet fission produces two molecular excitations from one photon, causing the photon to split in two. A solar-powered system can use each half of the photon individually to ensure that more of the high-energy portion of the spectrum is used to produce solar power, resulting in less energy emitting as heat.

The researchers explored the process of singlet fission using magnetic fields to interrogate the process. "The magnetic fields manipulate the wavelengths of emitted light to reveal the way that singlet fission occurs, and that hasn't been done before," Schmidt said.

To better understand the dynamics underlying the process of singlet fission, the researchers analyzed the time-resolved emission of a liquid singlet fission chromophore at room temperature. They observed that the chromophore had three spectral components. Two of the components corresponded to the bright singlet and excimer states. A third component became more prominent during triplet fusion.

Through their magnetic field experiments, the researchers gained further insight into the spectral components generated by a triplet pair. They showed that the spectrum is enhanced by magnetic fields, confirming its origins in the recombination of weakly coupled triplet pairs. The spectrum could thus be attributed to a strongly coupled triplet pair state, the team said.

The experimental results indicate that there is a spectrally observable emissive intermediate in singlet fission, both in concentrated solutions and the solid state, and that this is distinct from the unstructured, red-shifted excimer emission.

"From this firm scientific understanding of singlet fission, we can now make a prototype of an improved silicon solar cell and then work with our industrial partners to commercialize the technology," professor Ned Ekins-Daukes said.

Silicon, the material that most photovoltaic solar panels are made from, is inexpensive but has almost reached its performance limit for producing solar power. According to Ekins-Daukes, UNSW industry collaborator LONGi achieved 27.3% efficiency earlier this year. The absolute stands at 29.4%, he said.

"We're confident we can get silicon solar cells to an efficiency above 30%," Schmidt said.

The research was published in *Nature Chemistry* (www.doi.org/10.1038/s41557-024-01591-0).

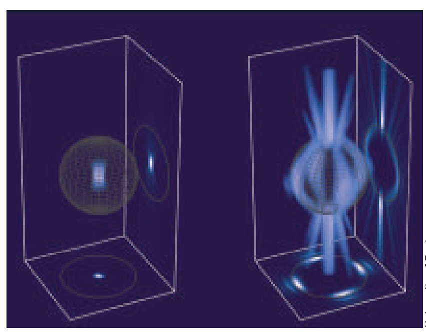
Customized optical trapping spans three dimensions

EXETER, England — In optical tweezing, the smaller the volume of light that confines a microparticle, the more tightly the particle can be trapped. Maximizing the stiffness of the optical trap can lead to more precise measurements at the nanoscale and more photon-efficient tweezing of objects.

Building on conventional optical tweezing techniques, a University of Exeter-led team, including researchers at the University of Glasgow and the Vienna University of Technology, devised an approach to optimize particle trapping through customization. The researchers tailored the shape of the light fields in the optical trap to suit the specific particle, with the aim of optimizing trapping stiffness in all three dimensions.

The team focused on optimizing the trapping of larger particles, which include many types of biological cells. When a particle is large, most of the light from optical tweezing is concentrated near the particle's center. However, light interacts more strongly with the surface of a particle than with its center — a phenomenon that affects the ability of larger particles to make the most of the light coming from the tweezers.

"We hypothesized that, if instead of being concentrated in the middle of the particle, the light enveloped it, that would confine the particle more strongly, giving it a sort of a tight hug," said professor David Phillips.


University of Exeter

Light intensity in conventional optical tweezers **(left)** and a custom-tailored optical trap. Projections show cross sections through the middle of the particle, which is 6 μm in diameter.

Determining the shape of light that would yield the strongest confinement was challenging both computationally and experimentally.

"There is no one-size-fits all solution here," researcher Une Butaite said. "For best performance, every different particle requires a custom suit of light, if you will."

Typically, the spatial shape of the laser beam in an optical tweezer is created using a Gaussian beam profile. While Gaussian beams are versatile and straightforward to create, they usually do not have the optimal shape of light field needed to tightly trap a microparticle — especially a larger particle whose size is greater than the trapping wavelength.

The researchers designed trapping beams using a strategy that allowed all three dimensions to be considered simultaneously, in terms of both stiffness enhancement and trap stability.

Still, a particle is not completely immobilized by optical tweezers. "It is experiencing thermal motion of the molecules surrounding it," Butaite said. "A bit like a boat in a lake rocked about by the wind and the waves but prevented from drifting away by the anchor, a particle in optical tweezers is constantly jiggling about, but its motion is confined to a certain volume."

The researchers estimate that custom-tailored trap shapes could confine microsphere motion to a volume of up to 200× smaller than a Gaussian trap of equivalent power.

The researchers found the implementation of such highly optimized trapping fields to be extremely sensitive to precise experimental conditions. To validate their approach experimentally, they developed a real-time optimization routine that iteratively adapts the trapping field to the shape of the particle in situ.

Then, using a strategy inspired by wavefront-shaping methodology, they passively suppressed the Brownian fluctuations of microspheres in every direction concurrently, demonstrating order-of-magnitude reductions in their confinement volumes.

The work of the Exeter-led researchers could set scientists on a path toward reaching the limits of optical control when using optical tweezers to manipulate nano- and micromaterials.

The research was published in *Science Advances* (www.doi.org/10.1126/sciadv.adi7792).

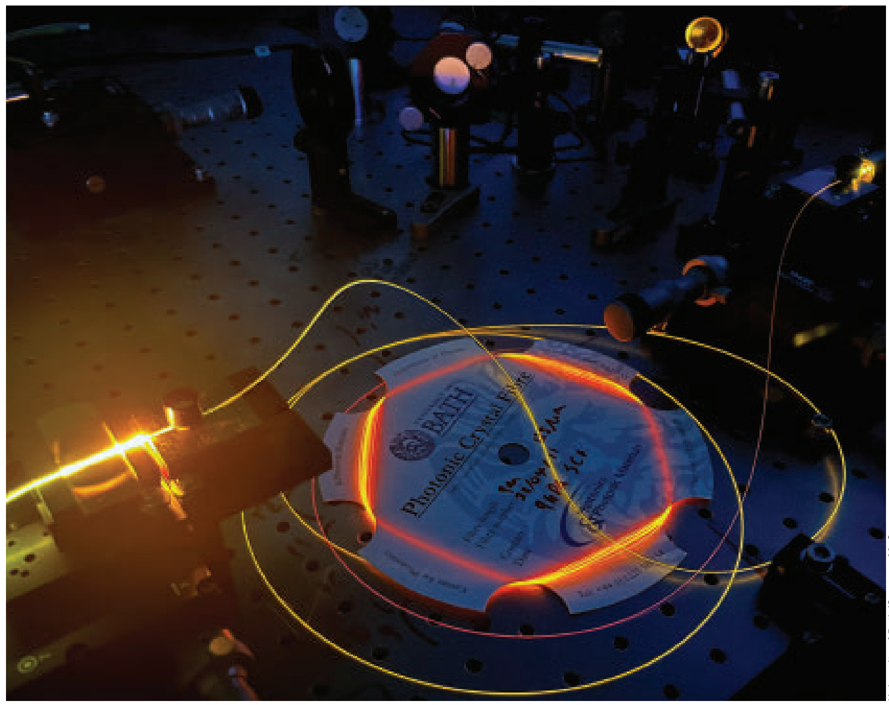
Specialty fibers rise to the challenge of quantum data transfer

BATH, England — Quantum technologies promise unparalleled computational power, leading to the development of medicines and unbreakable cryptographic techniques for secure communications. But achieving seamless, low-loss integration between quantum network components and optical fibers for quantum data transmission is a formidable challenge.

To support efficient data transfer between quantum computers in the future, researchers at the University of Bath are developing optical fibers that, among other features, enable the researchers to manipulate the properties of the light inside the fiber and create entangled pairs of photons. Central to the design of the fibers is a microstructured core. This microstructure consists of a complex pattern of air pockets running along the entire length of the fiber. Unlike traditional optical fibers, in which light is guided in a silica core through total internal reflection, the guidance properties of the Bath fibers are dictated and can be tailored by the design of the microstructured glass cladding that surrounds the core. The structure of the cladding depends on the guidance mechanism. The fiber core can be either solid or hollow.

In addition to the creation of photon pairs, said researcher Cameron McGarry, the pattern of the air pockets allows the researchers to change the color of photons and/or trap individual atoms inside the fibers.

The microstructured fibers provide a wide range of functionality. For example, the nonlinearity of solid core photonic crystal fibers could allow photon pairs to be generated directly inside optical fibers that could then be seamlessly spliced into conventional solid-core networks. Correlated photon-pair generation would enable the resource states required for many photonic implementations of quantum technology, including entangled pairs and the single photons that can be derived from them.



University of Bath/Cameron McGarry

Optical fibers developed by University of Bath researchers have microstructured glass cladding surrounding their core to tailor their functionality.

Further, the loss of quantum information as it travels over a distance could be reduced by transmitting it across mid- to long-range distances with hollow core fiber, which offers fast, low-latency data transfer. Coupling losses could be mitigated by integrating atomic vapors for storage and switching within the core of a hollow core fiber.

The optical nonlinearity of solid core and gas-filled hollow core fibers could also provide a valuable medium for quantum frequency conversion between the operating wavelengths of existing quantum photonic material architectures. The creation of photonic links between different wavelength bands is a key requirement for compatibility between processing nodes and memory technologies in future quantum networks.

"The conventional optical fibers that are the workhorse of our telecommunications networks of today transmit light at wavelengths that are entirely governed by the losses of silica glass," said researcher Kristina Rusimova. "However, these wavelengths are not compatible with the operational wavelengths of the single-photon sources, qubits, and active optical components that are required for light-based quantum technologies."

The researchers are also investigating how specialty optical fibers could be used to implement quantum computation at the nodes of a network by acting as sources of entangled single photons, quantum wavelength converters, low-loss switches, and vessels for application in or with quantum memories.

The research was published in *APL Quantum* (www.doi.org/10.1063/5.0211055).

Nanofabrication in bulk silicon advances 3D integrated photonics

ANKARA, Turkey — Using spatially modulated laser beams and anisotropic seeding, researchers at Bilkent University demonstrated a way to control nanofabrication deep inside silicon bulk material, rather than only on the surface of a silicon chip. This approach surpasses the feature-size limitations of current lithographic techniques, enabling the fabrication of silicon structures with feature sizes ranging from 80 to 120 nm. The method could advance the development of 3D nanophotonics, micro- and nano-fluidics, and integrated photonic systems for the NIR to MIR regime.

Silicon is a foundational material in modern electronics, photovoltaics, and photonics. However, this material has traditionally been limited to surface-level nanofabrication. Existing lithographic techniques either cannot penetrate the silicon wafer surface without causing alterations or are limited by the micron-scale resolution of laser lithography within silicon.

The researchers sought to fabricate structures inside silicon that were <1 µm, using a method that offered subwavelength and multidimensional control. They based their method on 3D nonlinear laser nanolithography and near- and far-field seeding effects.

"Our approach is based on localizing the energy of the laser pulse within a semiconductor material to an extremely small volume, such that one can exploit emergent field enhancement effects analogous to those in plasmonics," said professor Onur Tokel, who led the work. "This leads to subwavelength and multidimensional control directly inside the material."

The team used spatially modulated pulses corresponding to how a Bessel beam functions, and holographic projection techniques to create the beam. The nondiffracting nature of this type of laser beam suppresses the effects of optical scattering and enables precise energy localization. This leads to a high temperature and a pressure value strong enough to modify the silicon material at a small volume. The realization of energy concentration at the nanoscale allows nano-voids to be created within the irradiated volumes.

The resulting field enhancement sustains itself through a seeding-type mechanism. After small, localized voids inside the wafer are created, a seeding effect causes preformed, subsurface nano-voids to establish strong field enhancement around their immediate neighborhood.

According to the researchers, this effect is analogous to the hot spots observed in plasmonics but is achieved deep inside the wafer.

Simply, the researchers said, the initial nanostructures that are created support fabrication of subsequent nanostructures. Laser polarization provides additional control over the alignment and symmetry of the nanostructures. This enables diverse nanoarrays to be formed with a high degree of precision.

The anisotropic feedback from the preformed subsurface structures enabled the researchers to establish control of the nanofabrication capability inside the silicon. "This capability allows us to guide the alignment and symmetry of the nanostructures at the nanoscale," said researcher Asgari Sabet.

The team demonstrated large-area volumetric nanostructuring with feature sizes beyond the diffraction limit and multidimensional confinement. The buried nanostructures had feature sizes down to 100 ± 20 nm, which is an order-of-magnitude improvement over the state-of-the-art.

"We believe the emerging design freedom, in arguably the most important technological material, will find exciting applications in electronics and photonics," said Tokel. The work will enable the fabrication of nanophotonic elements buried in silicon with high diffraction efficiency and spectral control, he said.

"The beyond-diffraction-limit features and multidimensional control imply future advances, such as metasurfaces, metamaterials, photonic crystals, numerous information processing applications, and even 3D integrated electronic-photonic systems," he said.

The research was published in *Nature Communications* (www.doi.org/10.1038/s41467-024-49303-z).

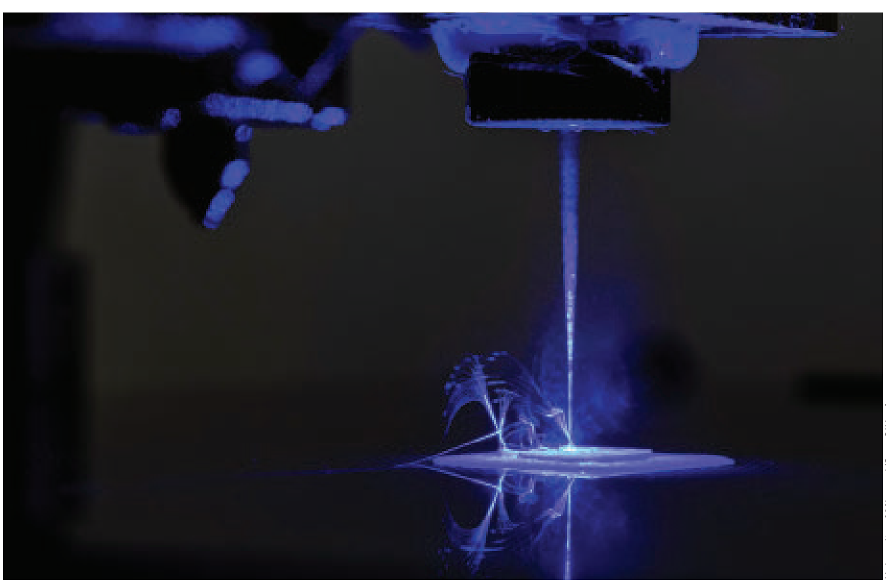
3D-printing technique streamlines multi-materials prototyping

COLUMBIA, Mo. — Researchers at the University of Missouri developed a laser 3D-printing process that they believe opens the door to more simplified manufacturing of multi-material, multilayered sensors, circuit boards, and even textiles with electronic components. Called the freeform multi-material assembly process, the technique allows complex devices to be crafted from multiple materials — including plastics, metals, and semiconductors — using a single machine.

By printing sensors embedded within a structure, the machine can make objects capable of sensing environmental conditions, such as temperature and pressure. For example, researchers could create a discrete, natural-looking structure, such as a rock or a seashell, that could help take field measurements.

Currently, manufacturing a multilayered structure, such as a printed circuit board, can be costly and time-consuming, and it can generate waste that is harmful to the environment. The researchers' aim is to reduce costs, time, and waste associated with prototyping new devices.

A laser 3D-printing method enables fast prototyping of complex devices using multiple materials but only one machine.


University of Missouri/Sam O'Keefe

According to doctoral student Bujingda Zheng, the technique itself emulates nature. "For example, electrical eels have bones and muscles that enable them to move. They also have specialized cells that can discharge up to 500 V to deter predators. These biological observations have inspired researchers to develop new methods for fabricating 3D structures with multifunctional applications, but other emerging methods have limitations."

Specifically, other techniques fall short when it comes to how versatile the material can be and how precisely smaller components can be placed inside larger 3D structures, according to the researchers.

For the method, the researchers devised a machine that features three different nozzles: One adds ink-like material, another uses a laser to carve shapes and materials, and the third adds additional functional materials to enhance the product's capabilities. Next, the machine begins to create a basic structure with regular 3D-printing filament, and then it switches to laser operation to convert some parts into a special material called laser-induced graphene. Finally, more materials are added to enhance the functional abilities of the final product.

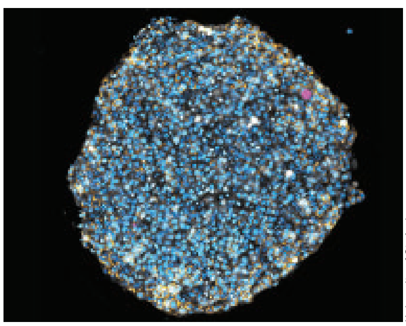
"This opens the possibility for entirely new markets," said Jian Lin, an associate professor of mechanical and aerospace engineering. Lin expects far-reaching effects on wearable sensors, customizable robots, and medical devices, among other areas.

Funded by the National Science Foundation (NSF)'s Advanced Manufacturing program, the researchers are exploring commercialization options with help from the NSF Innovation Corps program.

"Currently, we believe it would be of interest to other researchers, but we believe it will ultimately benefit businesses," Lin said. "It will shorten fabrication time for device prototyping by allowing companies to make prototypes in-house."

The research was published in *Nature Communications* (www.doi.org/10.1038/s41467-024-48919-5).

Squishy lasers reveal the secrets of cell growth


University of St. Andrews

Researchers from the University of St. Andrews and the University of Cologne developed deformable microlasers capable of measuring force at the cellular level. This advancement could lead to a greater understanding of the mechanisms behind cell growth.

ST. ANDREWS, Scotland — Researchers at the University of St. Andrews and the University of Cologne developed a class of lasers that they describe as "squishy." The devices could help solve the biological mysteries behind the development of embryos and cancerous tumors by enabling users to precisely measure the forces exerted by biological cells.

"Embryos and tumors both start with just a few cells," said professor Malte Gather, from the University of St. Andrews. "It is still very challenging to understand how they expand, contract, squeeze, and fold as they develop. Being able to measure biological forces in real time could be transformative. It could hold the key to understanding the exact mechanics behind how embryos develop, whether successfully or unsuccessfully, and how cancer grows."

According to Marcel Schubert, a professor at the University of Cologne, the microlasers are droplets of oil doped with fluorescent dye. The properties of these squishy microlasers allow them to be injected directly into embryos or mixed into artificial tumors.

"As the biological forces get to work, the microlasers are squished and deformed by the cells around them. The laser light changes its color in response and reveals the force that's acting upon it," Schubert said.

The innovation allows researchers to measure and monitor biological forces in real time, he said. Another advantage of the squishy lasers is that they are demonstrated to work in thick biological tissue.

The commercial viability of the technology is another benefit. The oil and fluorescent dye that were used to create the microlasers are made from nontoxic materials that are readily available on the market.

The researchers tested their method on fly larvae to see how they developed, and in artificial tumors made from tumor cells, so-called tumor spheroids. “We measured the 3D distribution of forces within tumor spheroids and made high-resolution long-term force measurements within the fruit fly larvae,” Gather said.

Members of the team are currently seeking funding to adapt the method for clinical trials. The team aims to ultimately extend its application to larger cell systems.

The research was published in *Light: Science & Applications* (www.doi.org/10.1038/s41377-024-01471-9).

Microlaser bandage measures glucose without drawing blood

SINGAPORE — Researchers at Nanyang Technological University (NTU) developed a wearable sensor based on microlasers to measure biomarkers found in sweat. The bandage-like device could provide a way to monitor blood sugar levels noninvasively.

Human sweat contains biomarkers such as glucose, lactate, and urea that indicate various health conditions and can be collected in a noninvasive and painless manner, making it ideal for daily monitoring, the researchers said.

People with diabetes typically use an invasive finger prick test to self-monitor blood glucose levels. Alternatively, sensor-based monitoring devices exist, though these can be expensive and rigid, and must be attached to a patient’s skin over prolonged periods of time.

By encapsulating a microlaser in liquid crystal droplets and embedding the liquid within a soft hydrogel film, the NTU team created a compact and flexible light-based sensing device — similar to a bandage — that can provide highly accurate biomarker readings within minutes.

The NTU researchers customized their microlasers to pick up lactate, glucose, and urea. A different colored liquid crystal dot on the device distinguishes each biomarker. When sweat interacts with the bandage device, the amount of light emitted by the microlasers fluctuates based on the concentration of biomarkers present. To read the biomarker levels, users shine a light source on the device. The light emitted from the microlaser sensors is analyzed and translated using a mobile application.

NTU

The bandage-like device developed by Nanyang Technological University (NTU) researchers is comprised of microlaser sensors embedded in liquid crystal droplets. The sensors are customized to pick up three different types of biomarkers. A different colored liquid crystal dot on the bandage distinguishes each biomarker.

In experiments, the bandage device successfully picked up tiny fluctuations of glucose, lactate, and urea levels in sweat, down to 0.001 mm. The figure represents a value that is 100× better than current similar technology, according to the researchers.

“Our device is capable of detecting both the high and low range of biomarkers levels,” said Nie Ningyuan, first author of the study and a Ph.D. candidate at NTU. “This is particularly beneficial for patients with diabetes as current similar health monitoring devices focus on tracking only high glucose levels, but not abnormal or low glucose levels, which may indicate other health complications. In comparison, our device will provide a clearer picture of the user’s health condition with a variety of readings captured.”

The team now plans to fine-tune the microlaser sensors to detect a wider variety of substances, including drugs and chemicals that are found in sweat.

The research was published in *Analytical Chemistry* (www.doi.org/10.1021/acs.analchem.4c00979).

Method tracks fast-moving objects, supports autonomous applications

BEIJING — Researchers at Tsinghua University developed a 3D method that can be used to track fast-moving objects at high speeds. The tracking approach, which is designed to be deployed and operate in real time, is based on single-pixel imaging. The developers of the technique believe that it could be used to improve autonomous driving, industrial inspection, and security surveillance systems, among other applications that require imaging and tracking.

According to research team and project leader Zihan Geng, the approach does not require reconstructing the object’s image to calculate its position. This, Geng said, significantly reduces data storage and computational costs.

“Specifically, acquiring a 3D coordinate requires only six bytes of storage space and 2.4 µs of computation time,” Geng said.

“By reducing computational costs and improving efficiency, it could lower the cost of equipment needed for high-speed tracking, making the technology more accessible and enabling new applications."

The researchers demonstrated a tracking speed >200× faster than traditional video-based methods. Further, the method does not require any prior motion information and can be performed with minimal computational resources.

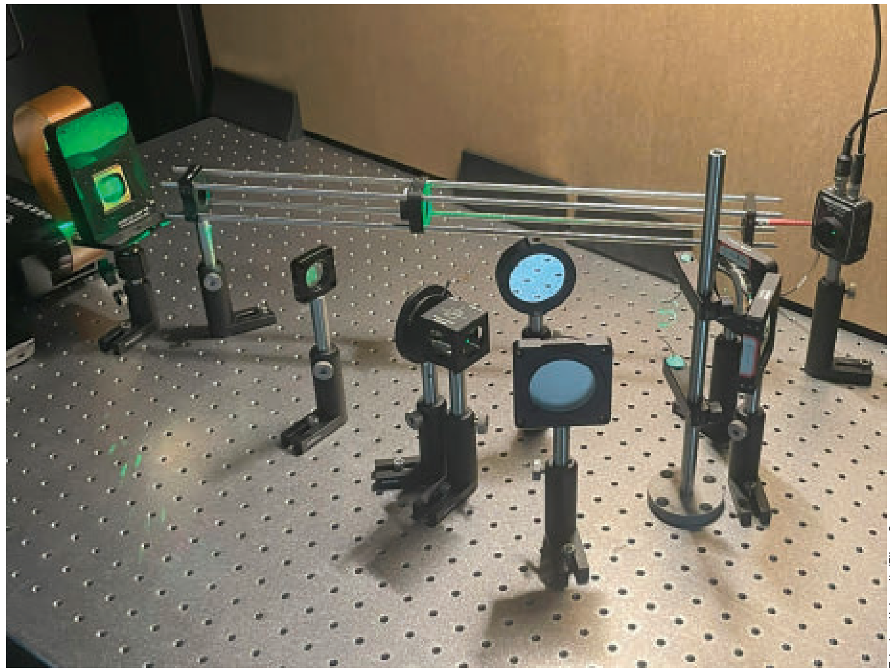
Single-pixel imaging is a computational approach that acquires measurements using a single detector, rather than the traditional array of pixels. It typically involves illuminating a scene with a sequence of patterns and then measuring the corresponding intensity values with a single-pixel detector. To create a more practical single-pixel imaging system for object tracking, the researchers implemented non-orthogonal projection, which is more efficient than the orthogonal method typically used. This involves projecting geometric light patterns onto two non-orthogonal planes, which creates 3D coordinates used to calculate the object's position. Non-orthogonal projection also reduces the overall system size, making it easier to implement.

After validating their method using simulations, the researchers conducted experiments using a single-pixel imaging setup that included a 532-nm laser for active illumination, a digital micromirror device (DMD) with a 20-kHz modulation rate to create the light patterns, and two single-pixel detectors to collect the light signals. To test the tracking ability, they allowed a metal sphere with a central hole to move down a wire under gravity while being illuminated with light patterns. They used the detectors' signals to calculate the object's 3D position and then used coordinate system rotation to obtain the calculated motion trajectory of the object.

With this approach, they achieved a tracking rate of 6667 Hz with the DMD at a modulation rate of 20 kHz.

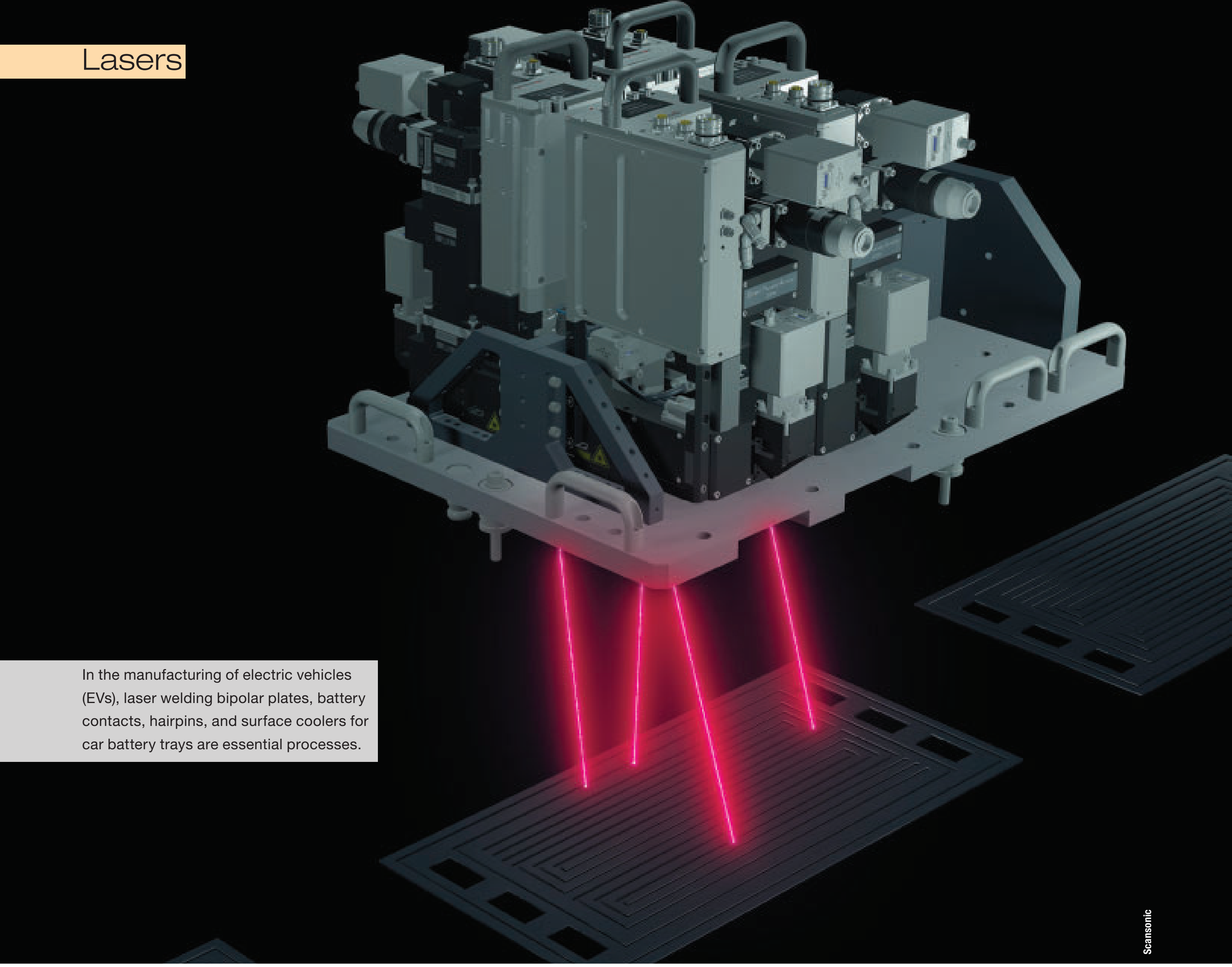
The researchers said that the primary challenge with this technology is that it can currently only be used to track a single object. Beyond autonomous applications, according to Geng, the developed high-speed localization technique can be used in scientific research, such as in insect flight trajectory studies.

The research was published in *Optics Letters* (www.doi.org/10.1364/OL.521176).



Tsinghua University/Zihan Geng

The optics setup used by the researchers to test their experiments, which achieved a tracking rate of 6667 Hz with a digital micromirror device (DMD) at a modulation rate of 20 kHz.



In the manufacturing of electric vehicles (EVs), laser welding bipolar plates, battery contacts, hairpins, and surface coolers for car battery trays are essential processes.

Electric Vehicles Drive the Need for Advancement in Laser Welding

Electric vehicle production requires engineers to complete several crucial manufacturing processes. Laser welding is essential to achieving target outcomes at high throughputs.

BY JOE KUCZYNSKI
SENIOR EDITOR

Propelled by legislation that aims to accelerate the adoption of electric vehicles (EVs), automakers around the world are facing growing pressures to ramp up production. Japan, Canada, and the U.K. are among the world powers that have already enacted policies that will require all new cars on the market to be electric by 2035. In the U.S., individual states are at various stages of implementing EV mandates, further signaling a forthcoming wave of e-mobility technologies.

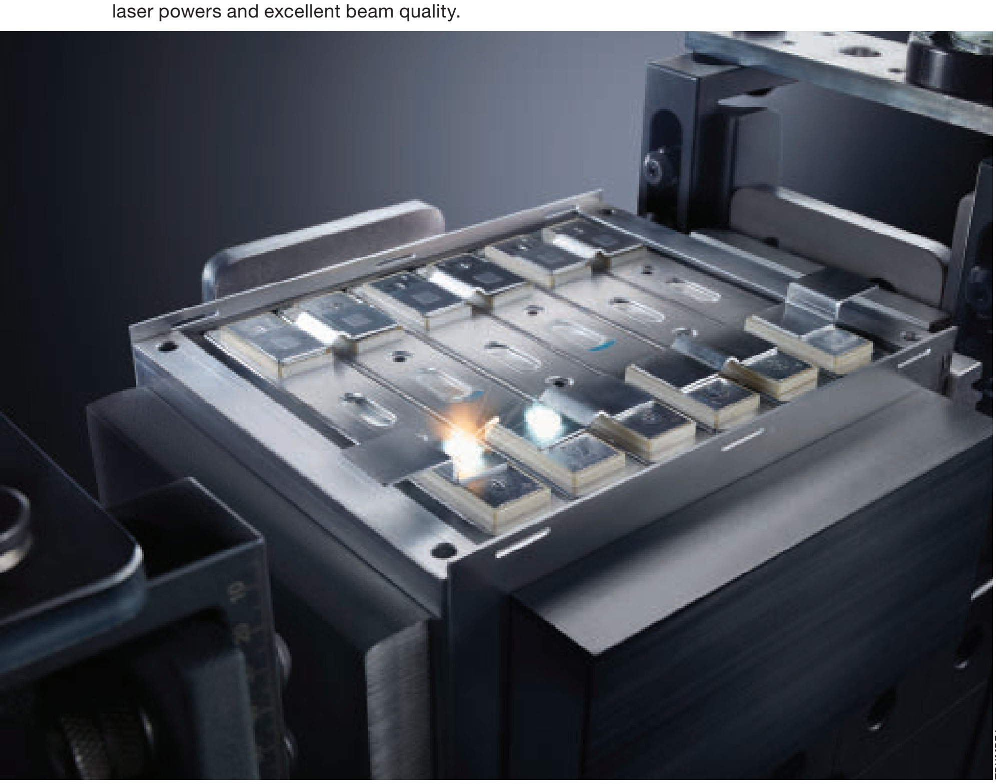
Although early adopters have many options for this next-generation technology, not all consumers are prepared to make the change to EVs. Concerns over battery life, a lack of established charging infrastructure, and a basic unfamiliarity are among the factors that bind many would-be buyers of EVs to gas-powered vehicles.

These considerations fail to address the ultimate concern facing consumers. If EVs are to win over skeptics, champions of the technology must convince drivers that EVs will meet affordable cost targets.

For EV manufacturers, laser welding is a vital practice, enabling the joining of dissimilar materials, facilitating the processing of lighter parts, and adding levels of precision necessary for various distinct production steps. In addition to being a high-quality method to produce these vehicles, laser welding also helps to lower costs by eliminating waste and improving vehicle efficiency. Current welding capabilities enable fabricators to bypass the use of filler materials that certain applications require and to use fewer materials overall as a result.

With these advantages, however, some companies, at various positions in the EV manufacturing production chain, demand more from the systems that enable these critical manufacturing process steps. The properties of the materials used in vehicle production call for light and high-quality welds, and the need to produce them at high volume is driving laser manufacturers to refine efforts to improve commercial laser welding systems.

Electric vehicles (EVs) and power storage use thick copper bus bars. The development and processing of these components requires high laser powers and excellent beam quality.



TRUMPF Inc.

Applications within the application

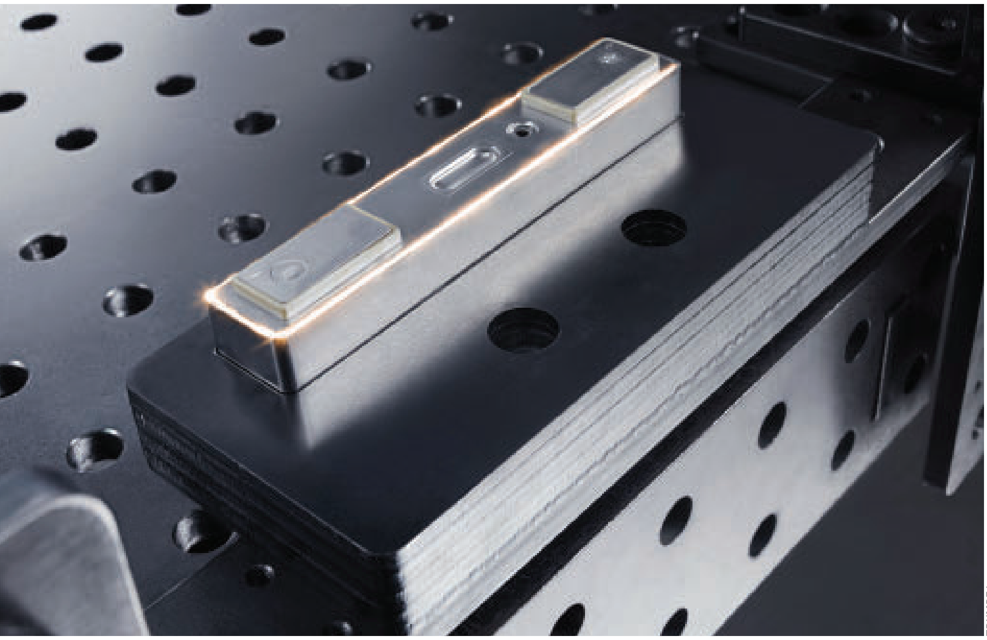
Though iterations of the current common laser welding systems have been in place for roughly a decade, laser welding has progressively improved in terms of both speed and quality. Recently, a shift in commodity weight shares — namely, higher usage of aluminum and copper — has expanded opportunities for laser welding, especially in the EV space.

Fundamentally, this shift and the opportunities it establishes underscores the thousands of laser welds that are at the heart of every battery pack that is used to power an EV.

One application, joining cells to bus bars, is vital to meeting the stringent electrical requirements for consumer EVs. A poor connection can hinder the effective performance and reliability of the vehicle as well as the safety of its passengers. Battery modules are produced by joining battery cells and welding them using high-conductivity bus bars. Laser welding ensures that manufacturers can fabricate these joints in a consistent and high-quality manner.

The cell structures of these batteries comprise three layers: anode, separator, and cathode foils. Lasers are an established solution for cutting these foils, which play a vital role in keeping electrodes separate and mitigating the risk of a short circuit. The same benefits that lasers deliver to bus bar joining — high speed, contact-free operation, and high precision — also transfer to this application. Additional benefits include flexible pattern cutting and improved edge quality.

From cutting separator foils with a dust and chemical-free process to ablating battery casings, bus bar, and hairpin coatings in a quick and clean process, lasers are indispensable in e-mobility production as it relates to the processing of batteries and their materials. Still, laser welding extends to additional processes in the manufacturing process chain; while battery production is a leading application



TRUMPF Inc.

Sealing the prismatic battery housing requires spatter-free welding, process stability, and a weld that is media-tight without pores, cracks, or unwanted seam buckling **(left)**. To produce prismatic battery cells, manufacturers may deploy lasers operating in the IR and/or visible bands **(below)**.

TRUMPF Inc.

for laser welding, manufacturers demand exceptional joint quality with high throughput and a high yield of parts. Laser welding meets these requirements as a highly repeatable noncontact process for creating mechanically strong joints.

The marriage of e-mobility and lasers

Markus Kogel-Hollacher, head of R&D projects at Precitec Group, a developer and manufacturer of system technology for laser material processing and sensors for quality control, leaves little to the imagination in his assessment of the relationship between e-mobility and laser sources. "There is no e-mobility without lasers," Kogel-Hollacher said. From cell to car, welding with high-power lasers has proved its importance in the production of batteries for EVs.

The broad efficacy of the technique stems from several distinct advantages. One, the utility that laser welding offers in making EVs lighter in weight contributes to finished-vehicle efficiency by optimizing miles per charge. Laser welding enables manufacturers to shift from bolted constructions to welded ones that provide the necessary degrees of strength at a much lighter weight. Laser welding also enables the joining of materials that could not be welded by more conventional methods. Current manufacturing practices rely on laser welding to join disparate and dissimilar materials, including aluminum, copper, high-strength steel, and fiber-reinforced materials.

To quantify the success that laser welding has had in both the automotive and e-mobility sectors, consider its influence on productivity and quality. EV manufactures that performed laser welds in 2017, for example, typically used machines that achieved a rate of 60 mm/s for can-cap welding on prismatic battery cells, according to estimates from laser manufacturer TRUMPF Inc. Since then, the speed has more than octupled, the company said, with current laser welding machines on the market reaching up to 500 mm/s.

Considering the number of welds in each battery pack, increasing weld speeds can eliminate both common and persistent bottlenecks in assembly line processes. Today's more advanced lasers can also "weld on the fly" — a process in which robots weld battery packs in one continuous motion. This cuts the cycle time by anywhere from 20% to 40%.

Such a considerable increase in speed, in a relatively short period, may suggest a loss to the overall quality of the weld. However, according to data from Travis Stempky, head of laser applications for TRUMPF Inc., welds that current market models perform have an improved yield rate of 99% or higher since 2017.

This twofold improvement is crucial to manufacturers achieving and sustaining cost savings.

"If you combine this productivity improvement and quality improvement, we can calculate cost savings," said Pierson Cheng, battery industry manager for TRUMPF Inc. According to Cheng, new laser welding systems allow parts to be mass produced, including batteries and cars, at a consistent pace. This meets the need of manufacturers to produce high volumes of vehicles quickly without sacrificing quality.

Waste reduction, achieved by a more efficient use of materials, is an additional consideration, both for production and quality as well as cost savings. Cutting down on scrap material saves manufacturers money and reduces their reliance on other industries that may otherwise be called upon to provide these materials.

Pravin Sievi, senior product manager for remote laser processing systems at Scansonic, said that the performance advantages that current laser welding delivers to manufacturing processes are dynamic. This, he said, makes it difficult to regard advanced processes now used in manufacturing settings as conventional welding, or welding in a traditional sense.

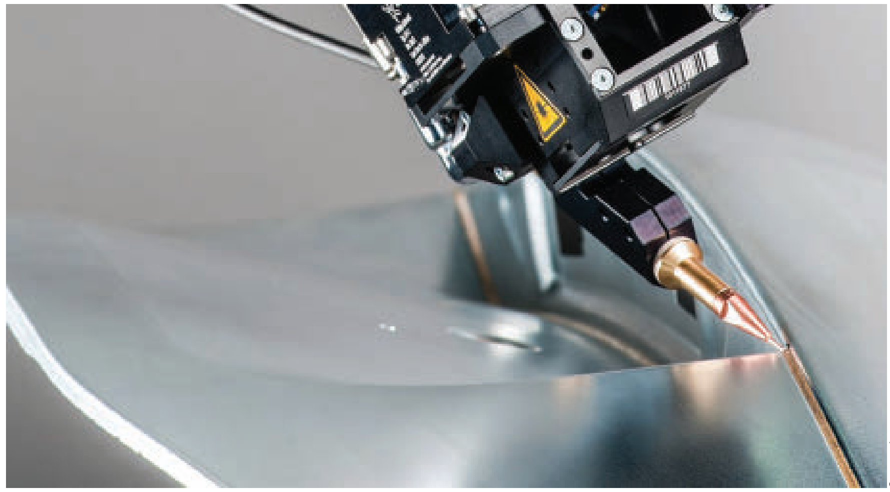
"In batteries, most used alloys do not develop a crystalline joint after solidifying," Sievi said. "Due to the dissimilar materials, we are not 'welding' anymore, but rather it is solidifying inside something that resembles a Ziploc bag. To be able to make the Ziploc, we are melting a lot less material, with very small focus diameters. And it is holding in this kind of manner."

Systems and solutions

For battery manufacturers, high-powered IR lasers, with powers ranging from 3 to 8 kW and beam parameter product values in the range of 2 to 4 mm mrad are popular choices. EV manufacturers commonly pair these lasers with added beam optimization mechanisms to deliver the power and speed necessary for EV production.

Manufacturers also opt for visible sources, especially for electronic welding. Specifically for this application, engineers favor green lasers. These lasers can reach power levels comparable to those of their IR counterparts while minimizing spatter and achieving consistent weld penetration. More broadly, green and blue lasers have proved to be suitable for welding dissimilar materials, such as aluminum and copper, because the absorptivity of the shorter wavelength results in cleaner welds.

Lasers operating in both the IR and visible are used to produce prismatic battery cells. Lasers for this application generate 40 battery cells per minute. This compares to eight parts per minute earlier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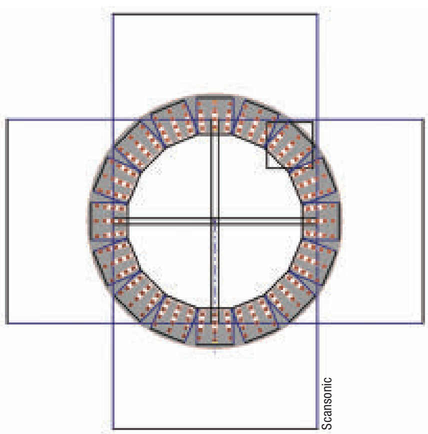
Scansonic

Laser sources used to alter material properties are widely used in and for laser welding to optimize the process itself as well as ensure target outcomes for welds **(above)**. Using the example of a stator with hairpins, 16 fields of view and four scan fields are created. The hairpins can be manufactured in this way in one work step **(left)**.

this decade, as estimated by laser maker TRUMPF Inc.

And, using single mode lasers, Sievi said, manufacturers are commonly working with a mode field of, for example, 15 µm with a focus diameter of 60 to 70 µm. These small beams deliver the advantage of a reduced heat affected zone.

Such precision requires advanced optics and devices that can scan, drive, and position items for welding while working in synchronization with the laser source on a microsecond timescale. Communication between the lasers and welding optics ensures consistency and quality on the mass scale needed to support volume manufacturing.

Elsewhere, ultrashort-pulse and CO_2 lasers have proved to be ideal options for battery cell shaping and electronic component refinement. Multiple laser companies have developed these solutions, and now offer lasers in these classes to meet the rising demands that they are seeing from automakers.

Laser surface structuring is a promising technology for improving the lifetime and performance of battery electrodes. With great precision, noncontact processes, and speed, it is a viable candidate for large-scale battery production. Luxinar, a developer of CO_2 laser sources of up to 1000 W as well as ultrashort-pulse laser sources, expects these lasers to play a large role in the future of battery development.

"Battery technology today is all about increasing power density, and laser processes are being developed to advance this," said Yannick Galais, sales director with Luxinar.

"At high power densities during fast charging or discharging processes, lithium separation is currently an issue. Femtosecond laser surface structuring uses ultrashort pulses of laser light to introduce micropores into the active layer of the battery electrodes, thus mitigating the problem."

Pushing for laser welding

In addition to the unparalleled efficiency gains, several other drivers are facilitating the use of laser processes in e-mobility. According to Stempky, none is more prolific than the push for high-quality and consistent welds, which are persistent needs for manufacturers.

"As we are going to higher and higher volumes, How do we increase the yield rate [with] less scrap rate, [and] How do we ensure that we are getting good quality without testing every single weld that we are [performing], are questions we must ask," Stempky said. "The laser is a tool that is very repeatable."

Repeatability is especially important because the production volumes that consumer demand places on manufacturers are driving the need for increased laser welding. Simultaneously, new designs often lean heavily on laser welding to perform necessary operations that cannot be completed by other means. "One example is the foil welding from the batteries themselves," Cheng said. "Traditionally, these are an ultrasonically welded part. But there is a limitation to the thickness of that foil stack with ultrasonic welding."

"So, as companies want to make more compact battery cells and make each battery itself a little bit higher charge rate, they want to go [with] more foil stacks and lasers, allowing them to go to a higher foil stack welding."

Automation and AI

Major technological advancements have made laser welding more powerful, more precise, and more adaptable in the last five years.

Still, according to Stempky, improving laser welding's prospects for automation, rather than improvements to strength, are likely to characterize the future direction of this laser process.

"The future is all related to quality monitoring," Stempky said. "The tech has come very far but how do we use it for an in-line look at quality? How do we use lasers to detect flaws in our welds and use automation and AI to adjust on the fly?"

According to Stempky, the quality of the weld is measured through weld depth, weld interface width, and electrical conductivity through the joint. AI, he said, can help to assess these measures quickly and accurately. And, according to Stempky, lasers and automation go hand-in-hand because of the sheer precision of the types of processes in which they are used. Soon, AI may be able to assist in not only detecting flaws and defects but also programming lasers to correct them in real time. Already, AI can detect a weld that does not meet quality standards, alerting to a technician that a correction is needed.

"While the focus today is on improving energy density, reducing cost, and developing alternative chemistries, automation and AI will be playing a significant role in the production of EVs, particularly in laser technologies, which are vital for precision manufacturing," Galais said.

AI-driven process control could improve laser cutting of complex geometries in battery electrodes, ensuring high precision and minimal waste by adjusting parameters in real time. This ensures optimal quality and reduces errors or defects, which is particularly important when dealing with high-volume battery production.

AI systems could also monitor laser machinery in real time, predicting when maintenance is needed to prevent downtime. This keeps the production line moving efficiently, especially in large-scale battery manufacturing for EVs.

According to Galais, "In [the] near future, we could envisage that AI models could analyze data from production to improve how lasers interact with different materials, adjusting cutting paths or parameters dynamically. This would lead to higher efficiency, reduced energy consumption, and better material utilization."

Limitless laser welding

As demand pushes the production of EVs, laser welding continues to play an integral part in manufacturing. For numerous applications, including many outside the realm of battery assembly and EV production, it is likely that laser welding will either remain or become an optimal process.

In fact, it is likely that many laser-based and laser-enabled manufacturing processes will outlast the e-mobility era. If the necessary infrastructures do not progress at the same rate as EV production, manufacturers may consider allocating time and resources for the development of hydrogen-powered or fuel cell-powered automobiles. Regardless of the power source, laser welding is bound to play a critical role.

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Merging the Virtual and Real Worlds Through Ambient Dimming Technologies

BY PAUL CAIN
FLEXENABLE

Visibility is critical when it comes to developing see-through augmented reality (AR) optics. Users must be able to clearly see the real world in harmony with the superimposed virtual one on their smart glasses. These two elements of the view should be balanced, with one almost indistinguishable from the other.

Arguably one of the biggest hurdles to achieving this is the constant change of real-world environments and lighting conditions that users will encounter, especially when considering long-term wear. Even the simple act of moving from one room to another will introduce a whole new set of variables, making it more difficult to balance the virtual image against the real world. If a headset is used in a completely dark room, then it will be easy to see a virtual image projected by a light engine and associated optics. The same is also likely to be true in a typical office environment.

However, in much brighter ambient conditions, it can be difficult to see virtual objects in front of the real world; they may appear washed out (low contrast) with darker colors that are almost impossible to reproduce correctly. This happens because the light engine can only add photons on top of the view of the real world — it cannot subtract them. Increasing the brightness of the image is one way to improve this contrast issue with smart glasses. But, this cannot compensate for darker colors and hinders the device's battery life and generates uncomfortable heat from power consumption — already a major constraint for untethered headsets.

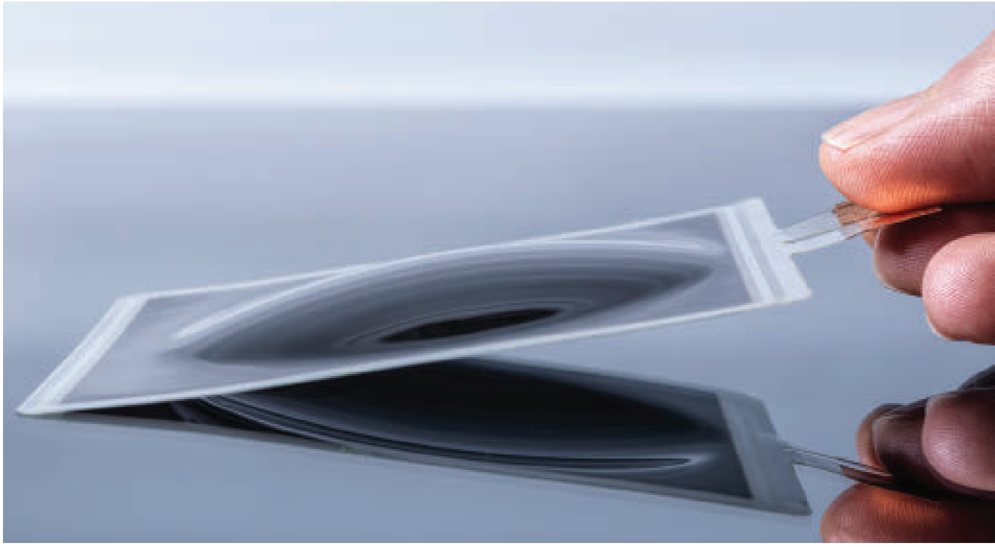
AR device manufacturers are using technology to tackle this from the other side: Their aim is to darken the real world by controlling the amount of ambient light passing through the lenses. This enhances the visibility of virtual images in all environments and can even give them a sense of "solidness" as they reduce the observed luminance of real-world objects.

Types of dimming

Global dimming is the simplest approach to control the external light sources, dimming the real world by the same degree at the same time, much like a pair of light-sensitive sunglasses. This allows virtual objects to be seen more clearly with higher contrast, because the dimming only affects the real world and not the virtual object. Another use of this dimming technology, if it can dim sufficiently, is to allow the AR headset to be used in a virtual reality (VR) mode, in which the user's view of the real world is removed, for example, when static video content is viewed in a sort of virtual cinema.

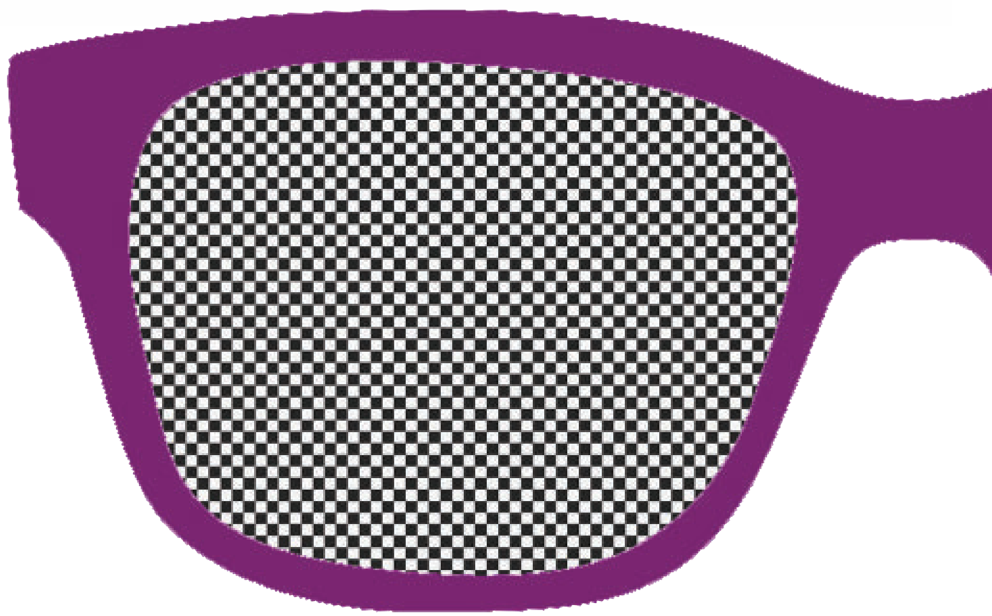
While global dimming can be useful, there may be situations in which one must see the virtual object clearly, without compromising and/or dimming the view of the real world. An example occurs when one is guided by an AR headset during work, where both the real-world and virtual instructions must be clear and uncompromised. Another example takes place in precision tasks such as surgery, during which high luminance is required

A biaxially curved liquid crystal dimming cell enables dimming films to fit snugly against other curved optical surfaces.



 All images courtesy of FlexEnable.

Designers benefit from flexible liquid crystal cells as new form factors become a reality, due to curvable dimming cells **(above)**.



Pixelated dimming divides a set dimming area into an array of pixels **(right)**. The lens provides an example of pixelation.

to "stop down" the human eye, decreasing the pupil size to increase depth of focus.

Another approach, pixelated dimming, divides the same dimming area into an array of pixels, each individually controllable in its level of dimming, essentially a grid of miniature "shutters." The advantage of pixelated dimming is that it allows much more granular control over real-world lighting levels by dimming only the specific pixels "behind" virtual objects.

In this approach, the size of these dimming pixels does not need to be as small as the pixels that form the virtual image (from the light engine). Indeed, there would be no point: Eyes are unable to focus on these dimming pixels.

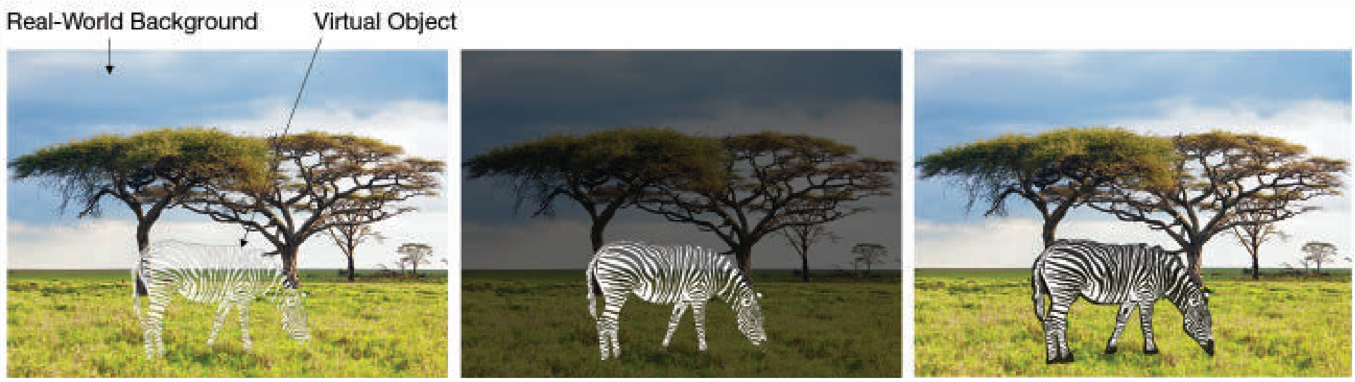
Instead, the dimming pixels are intended to provide dark zones on which the high-resolution virtual image can be overlaid. An important requirement for spatial dimming is that the dimming levels on each pixel must be rapidly adjusted, because any movement of the head would require the dimming zones as well as the virtual image to be repositioned in the field of view.

Dimming technologies

Several dimming technologies exist, some suited to both global and pixelated dimming, others only suited to global dimming.

One approach is to use the same dimming technologies used in liquid crystal displays (LCDs); an LCD is effectively a dimmer with a backlight behind it. This provides the advantages of being highly optimized for performance, and with an established, robust supply chain. The primary drawback is its limited transmission: Because the LCD mechanism requires polarizers, then at least half of the light is lost. The maximum transmission possible is typically <45%. This may be undesirable or even unacceptable in dimly lit environments.

A second approach is to use electrochromic dimming, whereby a material undergoes a reversible chemical reaction under an applied voltage, resulting in a color change. This has the advantage of not requiring polarizers (higher transmission) as well as bistability. However, it is inherently a slow switching process, occurring in seconds or longer. As such,



No Dimming
The zebra is barely visible against the bright background, and the dark regions appear transparent.

Global Dimming
With the background luminance reduced, the zebra is more clearly visible, but the real-world view is compromised.

Pixelated Dimming
The zebra is clearly visible with no compromise to the real-world view; the zebra's black stripes appear darker than for the global dimming case, because the eye is "light adjusted."

Pixelated dimming, one of three types of dimming, allows much more granular control over real-world lighting levels by dimming only the specific pixels 'behind' virtual objects.

it can be used for only global and not pixelated dimming.

A third approach is to use a different kind of liquid crystal that does not require polarizers, known as dye-doped guest-host liquid crystals (GHLCs). These have a dye mixed in with the liquid crystal, and the dye has very different absorption properties in different directions. When the liquid crystal molecules change orientation under applied voltage, they cause the dye to also change orientation, and therefore change the level of dimming seen through the film. This polarizer-free approach can therefore have a high transmission (e.g., 80%) but switches up to 1000× faster than electrochromic (i.e., 10 ms) and is color neutral.

Importantly, among the three approaches only GHLCs can achieve the transmission and switching speeds that are needed for high-transmission pixelated dimming. Still, all three variants are likely to be used in devices, at least in the short term, depending on initial product requirements.

Commercial integrated dimming devices

The location of dimming modules within the optical system in a headset depends on the product's optical architecture and the type of dimmer used. In certain cases, it may be laminated directly to a lens, and in others, it may sit farther back in the stack, for example, on the outer visor. This is dependent on the mechanical and optical properties of the dimmer. To produce a final product that is more like traditional glasses, any dimming must be tightly integrated and conformed to existing surfaces to minimize volume.

Dimming is just one of many areas in which optical performance is improving, yet all these performance enhancements must be achieved and incorporated while continuing to reduce the size and weight of headsets.

The first generation of products with dimming capabilities arrived on the market by 2022, targeting both consumer and enterprise customers. The Air 2 Pro and Ultra AR glasses, from XREAL, feature global electrochromic dimming to three preset levels. This tints the entire field of view and is controlled by the user through a physical button on the side of the device. Similarly, Viture's One XR glasses also include global dimming controlled by a physical button. And Magic Leap's Magic Leap 2 can perform both global and pixelated dimming, where the application determines the amount and type of dimming employed. The responses to dimming advancements for see-through AR have been very positive, and this technology is now considered a must-have for future iterations.

While some headsets will initially incorporate global dimming, many now expect pixelated dimming to be needed for optimal performance. Dimming is just one of many areas in which optical performance is improving, yet all these performance enhancements must be achieved and incorporated while continuing to reduce the size and weight of headsets. They must resemble a regular pair of glasses to ensure that they are comfortable, appealing to wear, and functional for all-day use. This requires additional optics to be not only thin and light but also ideally shaped to conform to commonly curved fixed optical surfaces in the headset to minimize volume.

Flexible cells for next-generation AR

Future generations of AR glasses will aim to be indistinguishable from a pair of ordinary vision-correction glasses. For dimming, this means future technology must adhere to a set of standards. The tech must first be extremely thin and lightweight as well as curved to match the surfaces of fixed optics. The screens will be pixelated to greatly enhance the visual experience. There must be high transmission, with low haze, so that the environment is clearly visible. And the technology must be fast-switching and low-power to cope with dynamic and demanding applications.

This means that cells must be built on plastic films instead of glass to meet these size and flexibility requirements. This is more easily completed for global dimmers, but to be pixelated, transistors must be included to control the individual pixels. Finally, to become high-transmission and fast-switching while also being low-power, dye-doped GHLC modes are needed.

Building pixelated dimmers on plastic requires transistors to be manufactured directly onto optically clear plastic films with well-controlled optical properties suitable for use with liquid crystals.

This is where organic transistors come into play. Organic thin-film transistors (OTFTs) use a class of organic semiconductor materials in place of silicon. While organic transistors are well-known for their flexibility, it is less well-known that the manufacturing process to make these transistors is undertaken at much lower temperatures than that which silicon requires: $<$100 °C, compared with $>$300 °C for silicon. This is fundamental to the ability to build transistors directly onto optically ideal plastics without damaging the flexible film.

Further, the same manufacturing techniques that can be used to build OTFTs can also be used to fabricate complete liquid crystal cells on ultrathin plastic films. Using triacetyl cellulose, a recyclable, biodegradable plastic with excellent optical properties, has proved to be effective for this fabrication. This film is widely available and usually supplied with a thickness of only a few tens of microns, meaning complete dimming cells can be as little as 100-µm thick, making their weight only a fraction of a gram.

Also, because of their thinness and the low temperature properties of the substrate, the dimming films can be 3D (biaxially) curved. This enables them to fit snugly against other curved optical surfaces, minimizing the volume of a device. This combination makes pixelated liquid crystal cells far simpler to integrate into optical stacks and devices that approach the look of regular glasses.

Looking ahead, designers will benefit from flexible liquid crystal cells as new form factors become a possibility due to curvable dimming cells that can be more easily integrated without compromising design. Manufacturers will be able to produce lightweight, comfortable devices. And for their part, developers will be able to take advantage of high-resolution, fast-switching dimmers, providing for experiences far in advance of current models of smart glasses.

As for customers and end users, both will benefit from the cumulative effects of these advantages with the ability to use all-day wearable devices that seamlessly blend into their everyday lives.

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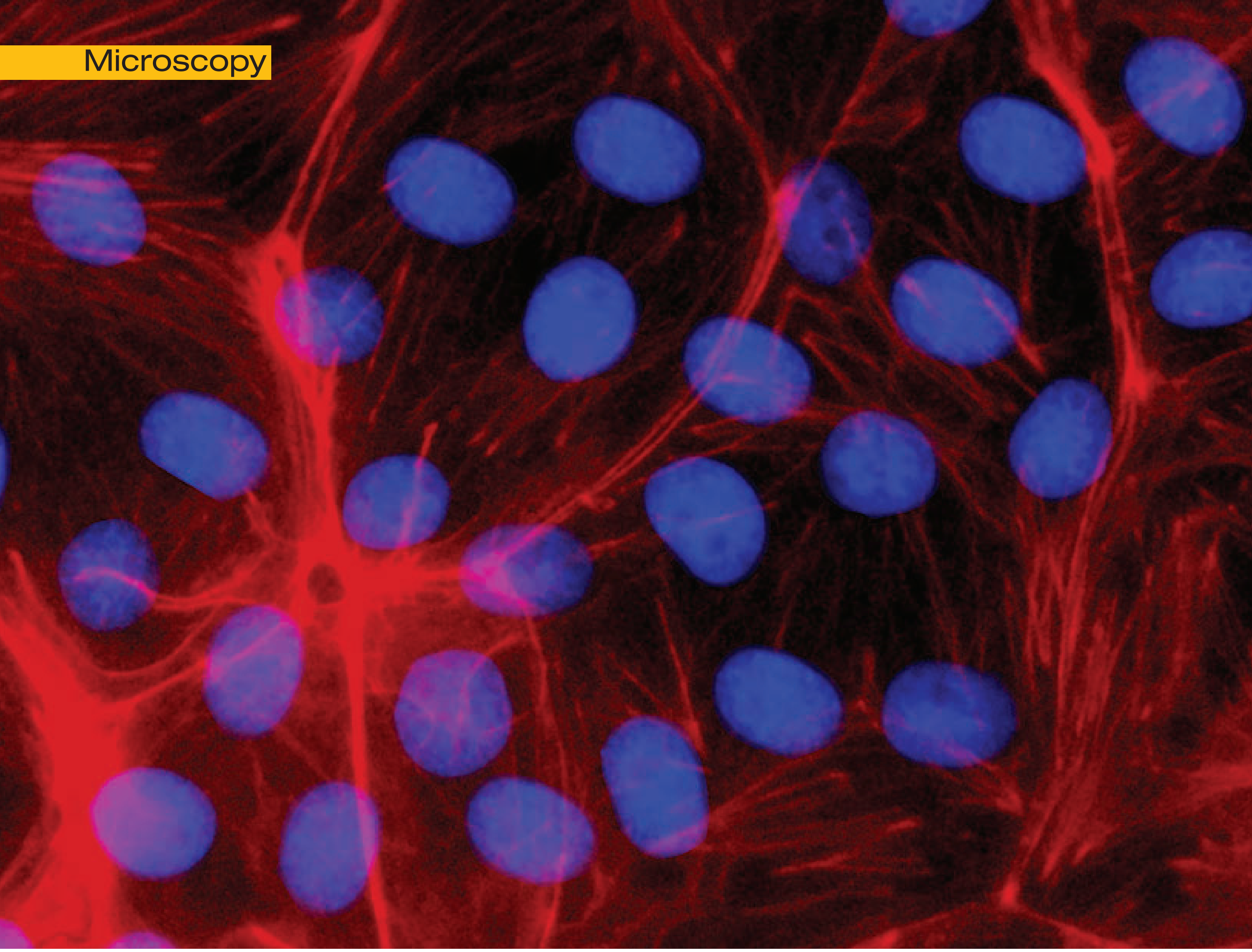


LEDs and Multi-Bandpass Filters Work in Tandem to Transform Fluorescence Instrumentation

All images courtesy of **Delta Optical Thin Film**.

The technological arcs of a familiar light source and a common component have intersected. Their combination is elevating the potential for advanced designs in fluorescence.

BY POUL SVENSGAARD
DELTA OPTICAL THIN FILM

Fluorescence stands as a cornerstone technology in the realm of bioanalysis. Fluorescence is one of the most sensitive spectroscopic quantification techniques, and fluorescence microscopy methods, including wide-field and confocal microscopy, enable users to identify the locations and movements of certain molecules. This technique finds wide application in live-cell imaging as a result. These technologies, as well as flow cytometry, enable scientists, medical professionals, and biotechnology companies to obtain accurate results, often in rapid time frames.

Instruments that are used to perform fluorescence-based analysis range from compact, purpose-built, single-wavelength devices to large, multispectral instruments. End users and systems designers alike place a premium on the versatility and durability of these instruments. Members of both populations seek devices that can serve multiple purposes — either directly or through reconfiguration.

Especially from the perspective of an end user, this flexibility can reduce capital expenditure by minimizing the need for multiple pieces of equipment.

Meanwhile, for instrument developers, a product portfolio centered around a common instrument design architecture can facilitate a more efficient, streamlined device production process.

Advanced analyses, such as those that are performed on biological reactions occurring in real time, often require the use of fluorescence instruments that are capable of simultaneously emitting and detecting multiple wavelengths. This technical requirement builds on ease-of-use concerns: Users in R&D, clinical, and industrial settings favor instruments that combine the simplicity, cost efficiency, and robustness of basic devices with the versatility of more advanced systems.

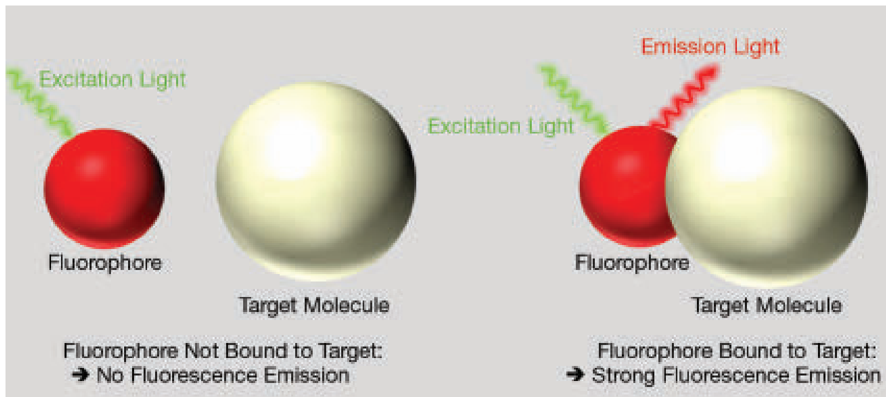


Figure 1. When a fluorophore is "free" **(left)**, it does not emit fluorescent light upon excitation. A fluorophore that is bound to the target molecule emits strong fluorescence upon excitation.

To provide solutions that can deliver these coveted qualities, systems designers reap the benefits of multiple-wavelength light sources and optical filters. The availability of LEDs at various wavelengths, paired with custom-designed multi-bandpass optical filters, is vital to the creation of durable, and sometimes novel, fluorescence instruments.

Fluorescence basics

Enhancing contrast for specifically targeted molecules is a fundamental deployment of fluorescence-based analysis. This approach uses fluorophores that emit bright light at one wavelength when exposed to the light of another wavelength. Typically, the fluorophore must be modified to bind to, or react with, the specific target molecule. As shown in Figure 1, fluorescence emission is greatly enhanced when the fluorophore binds to the target. By exposing the sample to light at the appropriate excitation wavelength, it is possible to use the emitted light intensity to obtain a direct measure of the concentration of the sample molecule.

One common fluorescence technique uses nucleic acid amplification, whereby viral RNA strands are extracted from saliva and amplified to form viral DNA strands. These strands are then tagged with a fluorophore that binds only to the viral RNA. Emission at a specific wavelength then offers a straightforward indicator of the presence of a virus. This application was in the spotlight as a tool for the detection of COVID-19.

Further, complex reactions — those involving two or more target molecular groups — can be explored using multiple fluorophores, with each fluorophore targeting a specific molecular group. In these reactions, variations in the intensity of emitted wavelengths from different fluorophores correspond to changes in the concentrations of reactants and products as the reactions occur.

Instrument considerations

The combination of distinct optical components in a single device or apparatus is a principal consideration insofar as it relates to fluorescence instrumentation. Figure 2 shows a schematic setup of a commonly used arrangement for measur-

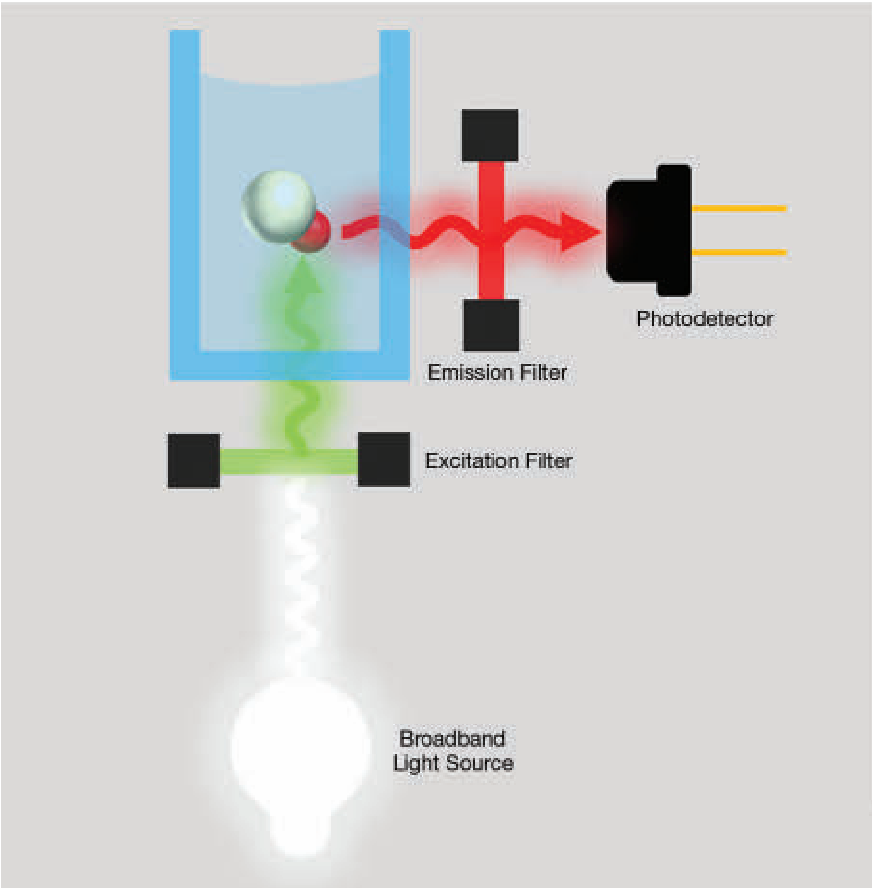


Figure 2. A simple 90° configuration used to enable fluorescence measurement **(above)**.

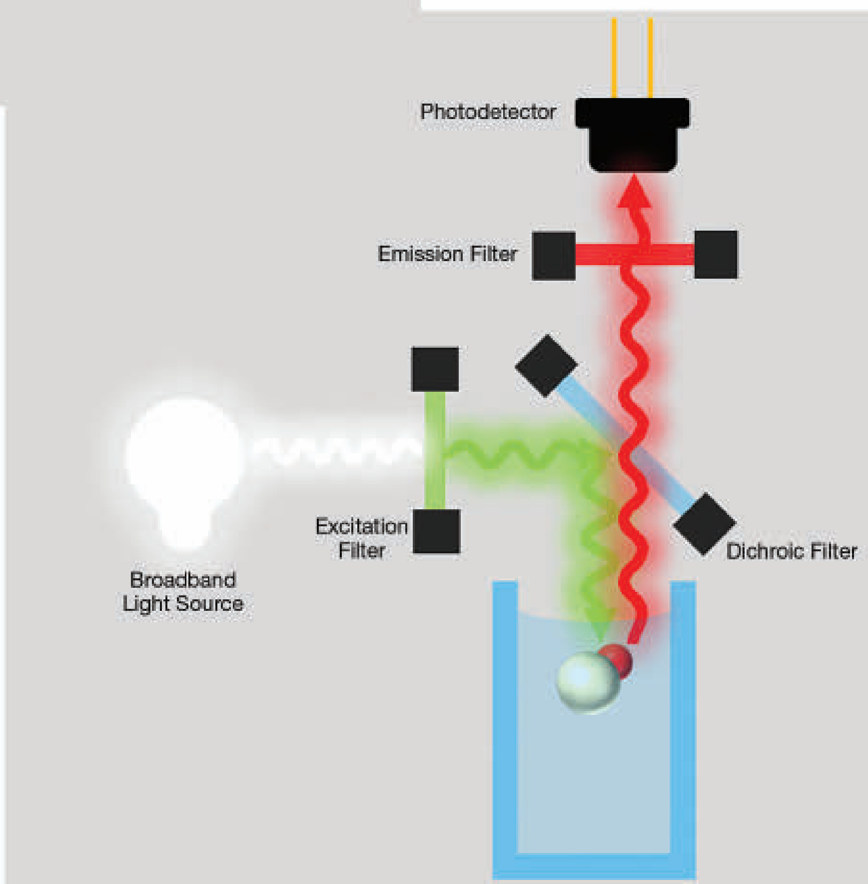
Figure 3. A fluorescence measurement configuration incorporating a dichroic filter **(right)**. Such a setup enables a user to perform reflective measurement.

ing fluorescence from a sample. This arrangement comprises a broadband light source, excitation filter, emission filter, and photodetector. The 90° configuration minimizes the direct light from the source reaching the detector. The excitation and emission filters are selected such that their passbands — the range of frequencies that can pass through — correspond to the peak absorption and emission wavelengths of the fluorophore, respectively. Since fluorophores absorb at shorter wavelengths and emit at longer wavelengths, it is especially important that the excitation filter provides deep-blocking at long wavelengths and that the emission filter provides deep-blocking at short wavelengths.

For reflective measurements, it is common to incorporate a dichroic mirror — itself functioning as a filter — into the device configuration (Figure 3). Typically positioned at a 45° angle of incidence, the dichroic mirror reflects the excitation wavelength while transmitting the emission wavelength. It is also common to combine the excitation, dichroic mirror, and emission filter in a cube to save space and simplify system alignment. Since the dichroic mirror functions as an emission filter, the need for out-of-band blocking by the emission filter in front of the detector can often be reduced when compared with the 90° setup.

Multiple-wavelength advantage

Different fluorophores emit at distinct wavelengths, which enables the use of fluorophores to label specific targets with different colors. Therefore, the selection of fluorophores with minimal spectral overlap streamlines the identification of different targets within the sample. This



specificity is crucial to accurately identify and quantify individual components in complex samples, such as in flow cytometry, in which multiple fluorophores are often used to characterize different cell populations based on surface markers or intracellular molecules.

The simultaneous detection of multiple molecules through the incorporation of multiple fluorophores is referred to as multiplexed detection. This technology enables the analysis of several parameters or interactions in complex biological systems simultaneously. For example, in immunofluorescence assays, multiplexing facilitates the detection of multiple proteins or cellular structures within a single experiment. This can ultimately yield richer data and reduce experiment time.

Using multiple fluorophores further allows users to probe dynamic processes and functional interactions within biological or chemical systems. By monitoring the fluorescence signals of different fluorophores over time or under varying experimental conditions, researchers can elucidate temporal dynamics, spatial organization, and/or functional relationships between molecules or cellular components. This capability is particularly valuable in studies in which the simultaneous visualization of multiple targets provides insights into the underlying mechanisms of biological or biochemical processes.

Instrumentation for multiple wavelengths

To ensure that an instrument can accommodate excitation and detection at various wavelengths, both the excitation and emission filters must be interchangeable (Figure 4a-c). The architecture(s) of such a system vary; in basic setups, the excitation and/or emission filters are manually exchanged (Figure 4a). A design alternative that may often be more friendly to the end user is to mount the filters in a motorized rotational filter, to in turn provide an alternative to the manual filter swap (Figure 4b).

In still more sophisticated instruments, both the excitation and emission wavelengths can be adjusted to the exact desired value using scanning grating monochromators (Figure 4c). The tunability of the monochromator can also be achieved by adjusting a pair of linear variable filters relative to one another.

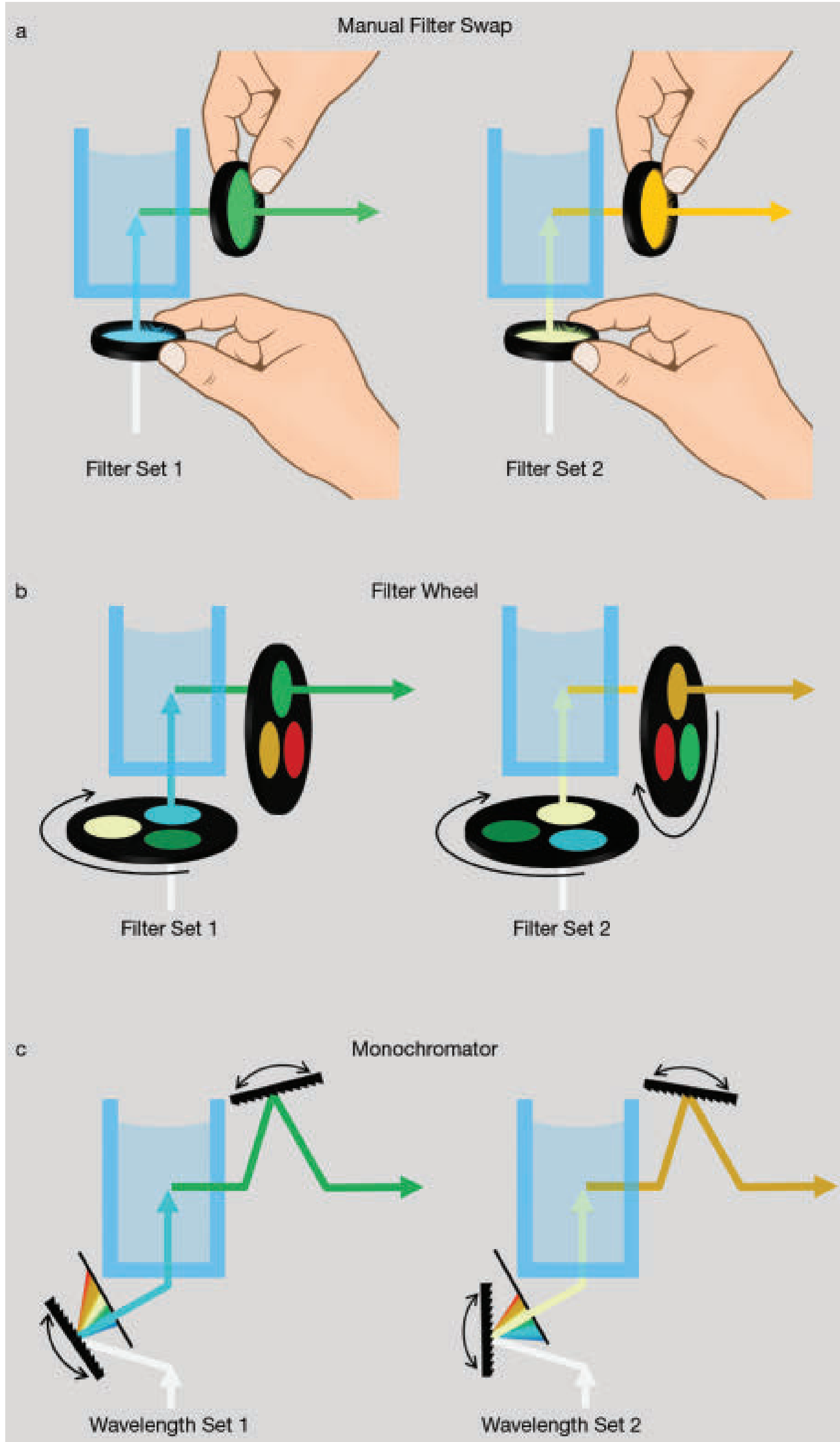


Figure 4. Fluorescence instrumentation accommodating multiple excitation and emission wavelengths: swapping a filter manually **(a)**; changing a filter via filter wheels **(b)**; selecting wavelengths using monochromators **(c)**.

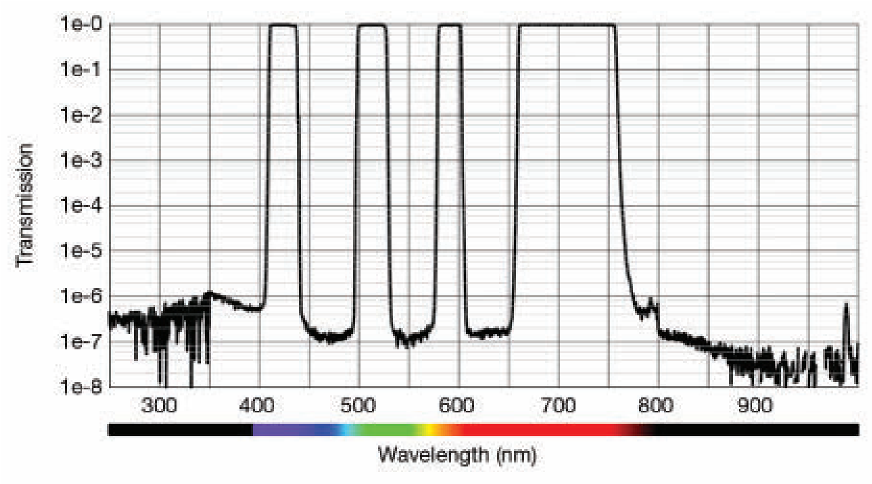
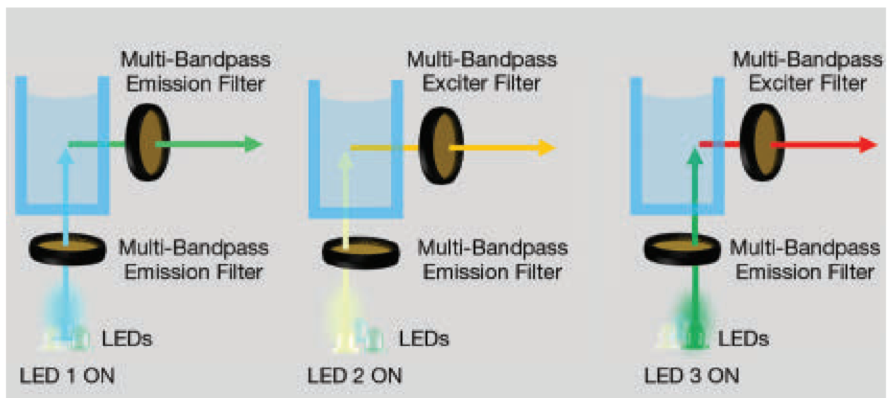


Figure 5. An example of a quad-bandpass filter, manufactured on a single substrate, in application **(left)**.

Figure 6. The multiwavelength fluorescence instrument uses three LEDs, sequentially turned on, plus a triple-bandpass exciter filter and a triple-bandpass emission filter **(below)**.



As possible solutions to accommodate excitation and detection at various wavelengths, all three options are plagued by a common consideration: the time required to switch from one filter wavelength to another. When analyzing numerous samples, the time that allots between wavelength change(s) serves to decrease laboratory throughput. This becomes highly problematic if biological samples degrade over time. In real-time experiments in which multiple fluorophores are active simultaneously, measurements are also ideally conducted simultaneously, or at the frame rate of the detector/camera system.

Scanning monochromators, which function by rotating a diffraction grating with a motor, typically enable a transition from one wavelength to another in a few seconds, whereas manually swapping filters might take several minutes. A motorized filter wheel can typically switch between neighboring filters in ~50 ms.

However, for instruments used in clinical settings, scanning monochromators and filter wheel solutions are often too large and/or expensive. These components are also often sensitive to environmental factors, such as vibration and temperature. Also, scanning grating monochromators typically provide narrower bandpass and higher loss than filters. Simple instruments, using fixed filters, are preferred for such applications.

LED technology road map

The availability of powerful LEDs emitting at any wavelength reflects substantial progress over the lifetime, or technology arc, of this technology. In the 1960s, the first commercial visible LEDs emitted a dim red light. These LEDs were used as indicator lights in small electrical equipment and were not of sufficient brightness to use in or with lighting applications. The introduction of LEDs based on AlGaAs, in 1987, enabled the development of red LEDs that achieved brightness levels that made them ubiquitous for lighting applications, such as in traffic lights and car brake lights.

Creating high-brightness blue and green LEDs posed significant challenges, delaying their market introduction until the early 2000s. These LEDs are typically fabricated using indium gallium nitride (InGaN). The adjustment of the composition of alloy(s) — and applications, as a result — is fundamental to the production of composition enabling a wide range of colors and applications. Multiple wavelength LEDs retain the inherent benefits of LED technology, such as high-power efficiency compared with alternative and traditional light sources, as well as a longer operational life.

However, LEDs are sensitive to temperature changes, which influence their emitted spectrum and power. Additionally, variations in the production process can lead to variability in peak wavelength. And, high-brightness LEDs tend to carry high upfront costs compared with halogen lights. This potential drawback is frequently offset by LEDs' long-term benefits, such as lower energy consumption, longer lifespan, and reduced maintenance costs upon implementation.

With high-brightness LEDs now available at a range of visible wavelengths, it is possible to find an LED that matches the absorption peak of almost any fluorophore. LEDs emit light in a relatively narrow spectral band, minimizing the amount of out-of-band ambient light. This characteristic can, in some cases, relax requirements for out-of-band blocking compared with solutions that use broadband halogen sources.

It is currently common to combine an excitation filter with an LED, as well as beam combiners that enable a user to combine beams from different LED sources in one excitation beam. Alternatively, users may select an LED that can emit several colors, with a multi-bandpass filter positioned in front of the source. Furthermore, LEDs can switch on and off in nanoseconds, making them ideal for multiplexed fluorescence and other applications where fluorophores must be excited at different frequencies.

Multi-bandpass filters

In their earliest iteration, optical filters used for fluorescence spectroscopy were comprised of colored glass or polymers. More advanced interference filters in use today can be optimized to match the exact absorption and emission spectra of certain fluorophores.

As an alternative to color filters, early interference filters were manufactured using thermal evaporation that resulted in soft coatings that were not durable and required sealing. The fabrication process for these filters itself necessitated the deposition of thin layers of dielectric materials with different refractive indices and thicknesses on a glass substrate. The key advantages of these filters were their customizability for specific applications as well as superior performance in terms of in-band transmission, out-of-band blocking, and edge steepness. The introduction of ion-assisted deposition (IAD) and plasma IAD (PIAD) enabled high-volume manufacturing of durable hard coatings with high performance. Today, PIAD is the preferred technology for many fluorescence filters.

More complex filter designs require a greater number of dielectric layers. The manufacturing of complex optical filters, such as multi-bandpass filters, requires significantly more material to be deposited than simpler single bandpass filters. Although the PIAD process can be used, it requires opening the vacuum chamber to add more coating material, which is detrimental to both final cost and final performance. The introduction of magnetron sputtering has enabled the deposition of large amounts of material required for multi-bandpass filters in a single coating run, making this technique the preferred technology for more complex filters.

Figure 5 shows the performance of an advanced filter manufactured using magnetron sputtering — namely, a quad-bandpass filter on a single substrate. The filter exhibits nearly 100% transmission in four distinct bands and out-of-band blocking of OD6.

Dynamic combination

Combining the performance advantages of powerful LEDs at any wavelength and custom-designed multi-bandpass filters, Figure 6 shows a three-wavelength version of one possible system design. This design uses an array of LEDs that are turned on one at a time to excite specific fluorophores. A single multi-bandpass excitation filter, with center wavelengths matching those of the LEDs, is used to filter the excitation light. On the emission side, a multi-bandpass emission filter, with center wavelengths matching the emission peaks of the fluorophores, selects the appropriate emission wavelength for detection.

There are several benefits to this type of design. The LEDs can be switched on and off very quickly, allowing fluorescence from multiple fluorophores in the sample solution to be measured almost simultaneously. Further, the instrument has no moving parts, making it extremely stable in various environmental conditions. Also, with both LEDs and filters having long lifetimes, the instrument itself is also very durable. And the use of LEDs as the light source — and the absence of motor drives — results in low power consumption, making the instrument more sustainable than alternative instruments. Finally, the ruggedness and low power consumption also enable the creation of hand-held and battery-operated instruments.

Meet the author

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Raman spectroscopy could soon aid traditional blood diagnostics at the patient's bedside.

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Raman Spectroscopy

for Point-of-Care Blood Testing

For clinicians and patients to benefit from rapid Raman-based point-of-care analysis, a system must analyze small amounts of fluid with specificity, using AI tools to include important data in the diagnostic process.

BY ANJA SILGE AND JÜRGEN POPP
LEIBNIZ INSTITUTE OF PHOTONIC TECHNOLOGY

Raman spectroscopy offers new possibilities for blood diagnostics, which is crucial for making timely decisions in the intensive care unit (ICU). Progressions in clinical knowledge and well-defined objectives of a technology's use guide developers toward inventive technical opportunities in a clinical setting. This synergy enables the translation of insights from both fields into groundbreaking diagnostic processes. By merging clinical expertise with the latest instrumentation, developers can create more accurate and efficient diagnostic tools. A continuous sample-to-answer approach with a Raman spectroscopic readout is particularly well suited for this task, because it measures a blood sample's components, and after proper sample preparation, puts the right biological targets in the laser focus.

Infections — many of which manifest in the blood — frequently lead to critical and life-threatening conditions in the ICU. Clinicians may see patients with very similar symptoms that actually have varying illnesses. As a result, two key strands of information must be tracked and incorporated into a diagnosis in a timely and effective manner. The first of these strands includes the cause of the symptoms, which can be determined by identifying whether the infection is viral or bacterial. This distinction is crucial, leading to the use of distinct therapeutic approaches.

For bacterial infections, it is essential to know the most effective antibiotic and its concentration, because this will influence the treatment. It is therefore crucial to have access to advanced tests that are precise, sensitive, and quick to prevent the unnecessary, inappropriate, or ineffective use of antibiotics. With growing trends in antibiotic resistance, it is vital to provide this treatment only when necessary[1].

The second strand of information includes the distinct clinical phenotypes and host-response patterns of the patient, which require individual therapeutic approaches for each condition. Substantial advancements in basic science, in combination with extensive clinical or epidemiological studies, have increased the medical community's knowledge of life-threatening organ dysfunction caused by a dysregulated host response to infection. This condition is known as sepsis. The advanced knowledge about sepsis must be translated into new diagnostic processes to accelerate therapeutic interventions and improve patient outcomes. Critical information must be captured to intervene safely and reliably at the right place and time[1].

Now, the task at hand for developers is to connect clinical diagnostic gaps using intelligent solutions. The aim is to adapt the advantages of new technologies, such as Raman-based in vitro diagnostics, to the latest medical findings. What does it mean for a developer when a clinician requests information on the clinical phenotype behind symptoms and the appropriate antibiotic in a timely manner? To be fast, the information must be obtained from easily accessible patient material, such as biofluid that may have already been collected. The processing of patient material should be achievable in no more than a few straightforward steps. Furthermore, this process needs to be automated.

It is necessary to extract information from small sample volumes to operate on-chip Raman spectroscopy, which entails reading data from miniature devices[2]. The second panel of Figure 1 depicts designs of such a sample container with multiple sampling units in the size of a microscope slide and a miniaturized Raman instrument as developed at the Leibniz Institute of Photonic Technology eV (Leibniz-IPHT). This enables the instruments to be positioned near the patient's bedside, and, if properly implemented, testing can be completed robotically.

Blood diagnostics are an important and objective source of information about an infection and the immune response, and they are easily accessible in clinical settings. Blood circulates continuously, and the analysis of its components by Raman spectroscopy offers immediate insights into a person's health and medical conditions. As a result, blood cells are easily obtained for diagnosis and contain important information about the patient's immune response. In the ICU, it is of paramount importance to test bacteria that can affect the entire body, which are identifiable in the blood. Blood cultures are essential in this context; the bacteria are grown in a culture medium inoculated with the patient's blood to test them against various concentrations of antibiotics[1].

Raman-based diagnosis

Raman spectroscopic diagnostics offer a straightforward, objective, and label-free approach to sampling small volumes of biological material. Raman microspectroscopy is a technique that allows for the analysis of small samples at a microscopic level. Using lasers with high precision enables the analysis of the molecular

The technological developments in clinical Raman spectroscopy have been oriented toward unmet clinical needs and the challenges in obtaining therapy-relevant information.

composition of any biological structures, such as blood cells at a resolution of a few micrometers, which converts the data into diagnostic information directly. Since a few microliters of blood contain thousands of cells, a representative cell population can be measured. Collecting such a small volume is minimally invasive for patients, because it does not require significant discomfort or inconvenience during extraction.

Figure 1 outlines the overall goals of developers in the field of clinical Raman spectroscopy. The first stage is to translate the knowledge about Raman spectroscopic applications into diagnostic concepts. Practitioners of clinical Raman spectroscopy have established approaches for comprehensively investigating cell samples. The pre-analytics stage, which encompasses comprehensive and expedient sample preparation, reveals all pertinent phenotypic data. All technological necessities for sample presentation for subsequent Raman microscopic analysis are considered.

Researchers from Leibniz-IPHT, the Jena University Hospital in Germany (the Center for Sepsis Control and Care, Department of Anesthesiology and Intensive Care Medicine, Institute for Clinical Chemistry and Laboratory Diagnostics), as well as the internal medicine department of the National and Kapodistrian University of Athens in Greece and the clinical research center of the Copenhagen University Hospital in Denmark have demonstrated that the spectral patterns of white blood cells can indicate various subtypes and activation states[3]. This analysis has considerable potential because it facilitates the acquisition of crucial, unbiased information about infections and immune responses through the direct sampling of blood cells without the need for labeling or additional processing.

On this basis, it is essential that physicians conduct multicenter trials to fully understand the value of the technology and the improvement in patients' outcomes. This will help them to identify the ranges in Raman data derived from normal and affected populations, and to determine the diagnostic sensitivity/specificity across different studies. To achieve this, it is crucial that technology is translated into user-friendly instruments and that comprehensive sample-to-answer workflows are developed.

Data analysis

Experimental research carried out with partners from Leibniz IPHT and Jena University Hospital has demonstrated that machine learning can distinguish between various infections caused by bacteria, viruses, or fungi using the Raman signatures of white blood cells[4,5]. The sample's Raman data is computationally associated with all essential metadata, including biological and technological data. This integration ensures that the data is accurately transformed into useful diagnostic information with respect to all technological pitfalls[6]. The development of diagnostic tests for critically ill patients has demonstrated that the Raman signatures of blood cells can provide crucial details for the identification and classification of various medical conditions, including sepsis, which is essential for the selection of appropriate treatment[3,7].

Another crucial aspect of blood diagnostics is the processing of blood cultures. As previously discussed, bacterial bloodstream infections are highly dangerous due to their rapid spread throughout the body. The most critical information for clinicians is the selection of the most effective antibiotic in the appropriate concentration to fight these bacteria. This assertion can be most effectively conveyed through phenotypic resistance tests. This entails testing the isolated bacteria from the blood against specific antibiotic concentrations, thereby initiating the implementation of a targeted antibiotic therapy.

To conduct these tests, standardized bacterial suspensions with a culture density of 108 colony-forming units (CFU)/mL are required. This culture density is achieved within a standardized blood culture through a 12-h incubation period. The bacteria must then be dispersed over several test units to grow against various antibiotics for at least 12 more hours. The “yes/no” statement regarding growth is converted into an antibiogram (an overall profile of antimicrobial susceptibility), which assists the clinician in determining the most appropriate treatment[1].

Methods that could perform these phenotypic resistance tests on early micropopulations, distributed over a relevant antibiotic test panel, would provide significant advancement. Raman spectroscopic resistance testing can play an important role in accelerating this process. Firstly, the cell populations required for Raman testing can be significantly reduced. For Raman-based antibiotic sensitivity testing, a few hundred cells in the laser focus are sufficient[2,8]. Researchers are currently trying to distribute this number of cells evenly in each test unit and to get them effectively into the laser spot. The aim is to reduce the number of CFU/mL from 105 to 103. This will result in a significant reduction in the cultivation time. For the resistance test, the bacteria only need to be exposed to the antibiotic for 90 to 120 min. Specific changes in the spectrum captured with Raman instrumentation can reveal whether a bacterium is resistant or sensitive[2,8].

This rapid turnaround time allows for the identification of antibiotic resistance patterns in a timelier manner, thereby enabling health care providers to make more-informed decisions about treatment options for patients. Additionally, the reduced sample size needed for Raman spectroscopic resistance testing means that resources can be conserved. The goal is to make it easier to scale up testing in settings with limited resources.

Commercialization

The second panel in Figure 1 visualizes the system development stage. The team, led by Jürgen Popp, professor of physical chemistry at the University of Jena and scientific director of Leibniz IPHT, is working together with the University Hospital of Jena to develop diagnostic concepts and translate them into technological solutions that enable the handling of small sample volumes and cell populations to produce statistically significant and reliable measurements.

Startups that are active in the fields of biotechnology, medical technology, and/or in vitro diagnostics are expected to bring these technological approaches to the market. This also involves reducing the necessary sample volume and pre-cultivation durations. Small and portable Raman microscopes, designed to measure cell characteristics essential for diagnosis, can effectively analyze these cartridge and chip systems. A data analysis protocol has been developed and published by photonic data scientists to establish standardized procedures for processing Raman spectral data in a manner that is consistent and reliable[6].

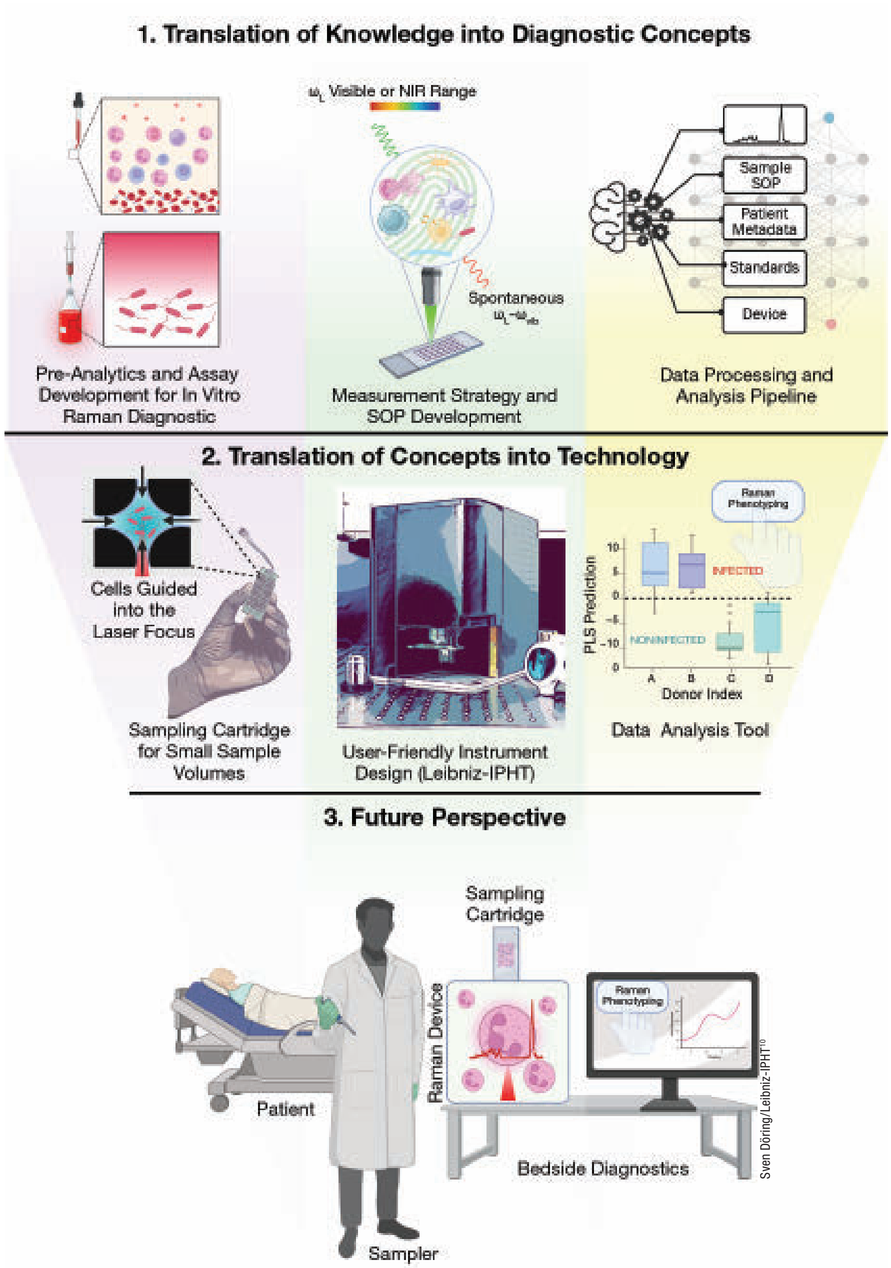

Figure 1. The mission of developers in the field of clinical Raman spectroscopy.


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Decisions must be made quickly at the point of care in the intensive care unit (ICU).

In a specific example, company Biophotonics Diagnostics GmbH converted this methodology into user-friendly software called RAMANMETRIX, which was designed to overcome challenges faced during the analysis of Raman spectra by using a graphical user interface, a complete workflow for the relevant data[9].

Elsewhere, the technological developments in clinical Raman spectroscopy have been oriented toward unmet clinical needs and the challenges in obtaining therapy-relevant information. Future advancements in blood diagnostics should be able to reach the patient's bedside for direct testing and analysis. Efforts should include simple and time-saving sample handling, the development of robust and user-friendly instruments, and the creation of analysis software for the targeted evaluation of all therapy-relevant information.

It is of paramount importance for spectroscopists and clinicians to identify sample materials containing time-critical and therapy-relevant information with minimal preparation. The implementation of appropriate technological solutions in hardware and software that are currently in development will enable the use of photonic diagnostic solutions in the presence of the patient, creating new opportunities. In the future, machine learning and AI systems will be used to extract information from combined data collection approaches.

This integration will connect data from various near-patient measurement systems, enhancing the speed and efficiency of diagnostic processes. The globally unique infrastructure at the Leibniz Center for Photonics in Infection Research (LPI) as an open-user one-stop agency is a model for how to accelerate the development of market-ready light-based diagnostic procedures and novel therapeutic approaches for the treatment of infectious diseases.

Meet the authors

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Jürgen Popp, professor of physical chemistry at the University of Jena and scientific director of the Leibniz Institute of Photonic Technology (IPHT) has been working on using Raman spectroscopy for medical diagnoses for more than 20 years. Popp is spokesperson of the Leibniz Center for Photonics in Infection Research (LPI); email: juergen.popp@leibniz-ipht.de.

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Figure 1 Attribution: Illustration created with BioRender.com; photo of the sampling cartridge and Raman instrument courtesy of Sven Döring/Leibniz-IPHT.

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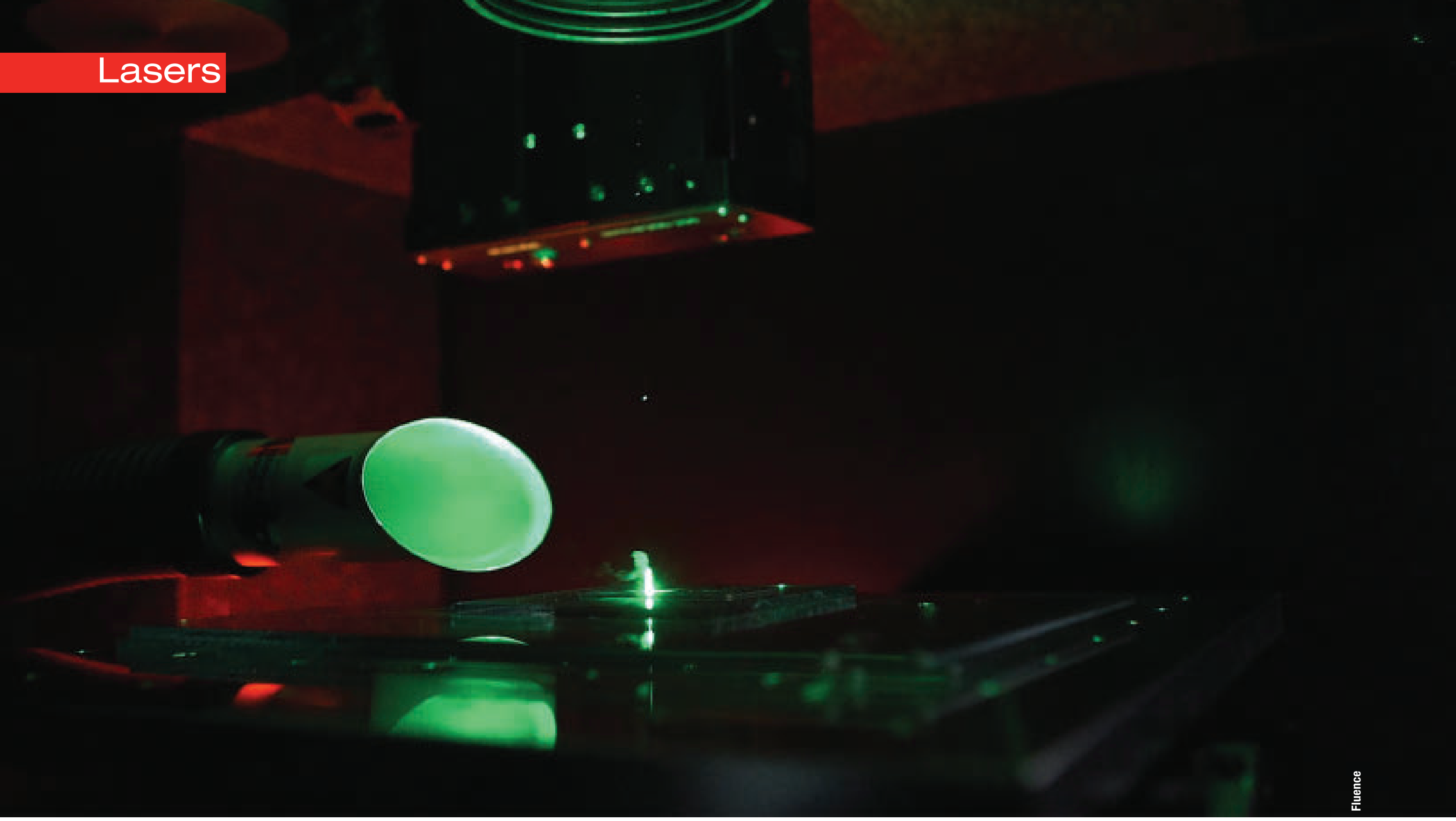


Motion Control

Upholds Micromachining's Dynamic Role in Complex Manufacturing

Advancements in automated motion control are helping high-volume manufacturing processes meet the demands of the consumer electronics and semiconductor industries.

BY MARIE FREEBODY
CONTRIBUTING EDITOR

Laser micromachining has proved to be revolutionary in modern manufacturing, enabling the creation of intricate features at the micro- and nanoscale. Laser micromachining and microprocessing envelop various similar, yet distinct, processes. These include laser patterning and texturing, engraving, scribing, and cutting. Engineers in a range of industries have relied on these and other similar processes for decades.

Today, the semiconductor and consumer electronics industries provide the powerful tailwinds driving progress in this technology area. Advanced manufacturing can be qualified by the high-tech innovations that the industries that power the market are delivering. It is also characterized by the sophistication of the processes and components that enable their manufacture.

In either case, laser micromachining and microprocessing are not the only technologies behind this trend: Another, motion control, is central to the success of laser-based manufacturing. Motion control is essential for advanced manufacturing applications, facilitating the degrees of system precision and efficiency that are necessary for high-volume production as well as the tight part tolerances that are required in precise machining.

If there is a hierarchy for motion control, commoditized capabilities exist at the lower end as typically inexpensive and ubiquitous solutions. At the higher end, a push for automation to reach new levels of precision is driving growth and development of new product solutions.

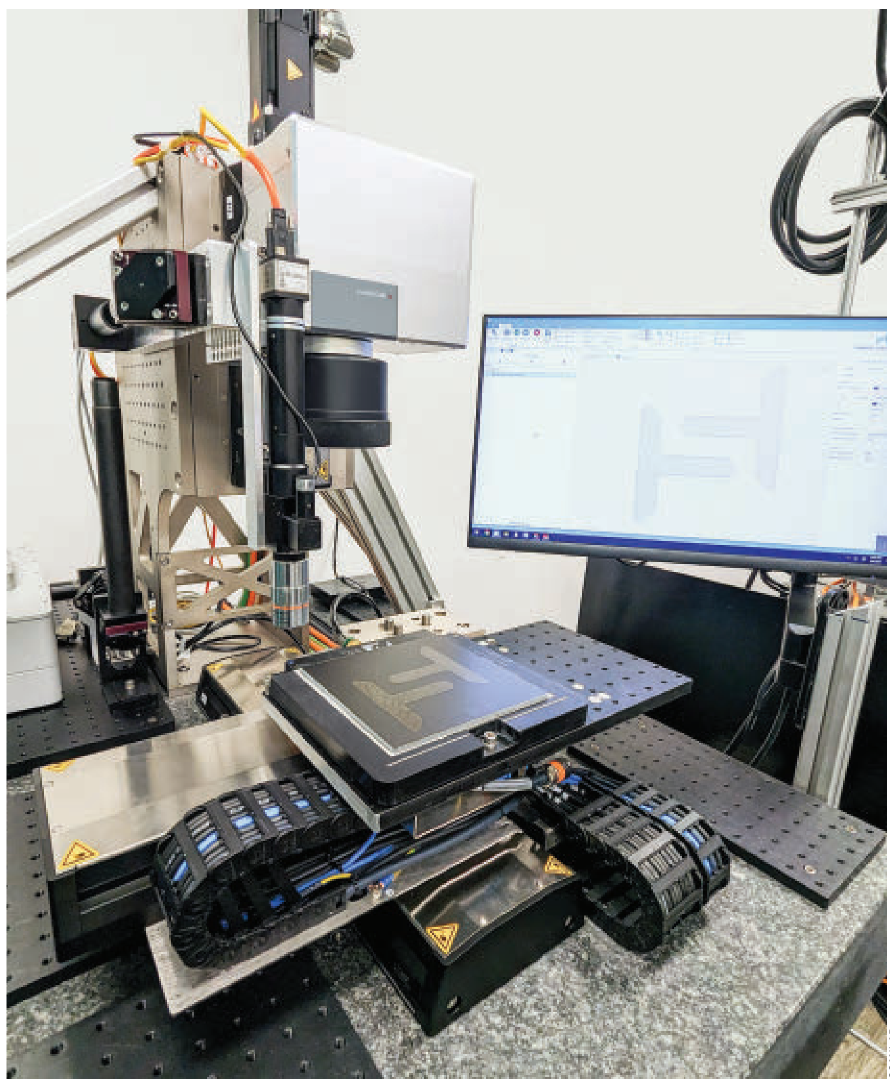
"Market development in electronics and semiconductor environments is expected to continue to move fast," said Amanda Dobbins, director of business development at SCANLAB GmbH, a developer of laser scan systems used in a range of laser-based manufacturing applications. "Continuous evolution on the product side will require more precision and throughput in manufacturing and processing technologies. Also, the demand for advanced scanning solutions will push R&D for laser systems."

As demand increases for higher throughput and tighter part tolerances, the approach to controlling laser positioning systems has become more stringent. This is evident in applications that require high-speed methods, such as laser scan heads that are used to control beam position.

"For the customers I work with, accuracy is typically the number one driver when it comes to considerations for a micromachining system," said Matthew Tedford, photonics central applications manager of precision medicine and manufacturing at Novanta. "From my experience, the demand has been typically for 10 µm (±3σ) or better for a system-level accuracy spec. More recently, I've seen applications start to push this to about 5 µm (±3σ) or better."

Priority considerations

According to Jeff Hansen, senior principal applications engineer at MKS/Newport, the evolution of motion control technology has reached a point at which



SCANLAB partners with Turner Laser Systems for application development and scan system integration. A challenge involves the integration of real-time control capability with the interface to effectively combine the movements of a stage and the scan system.

SCANLAB

the technological capabilities necessary for many widespread applications are now available to a broad customer base. The technology itself has undergone rapid advancement. This, Hansen said, is crucial to remain competitive as well as to meet the continuously growing demands of industry.

"Initially, the cost of implementing motion control systems was a major concern," Hansen said. "Over time, as technology has advanced and become more accessible, the cost factor has become more manageable, allowing for broader adoption."

In the past, stage manufacturers provided not only the control for the stage but also the control for the galvanometer — typically a scan head. Although pairing the galvanometer with the stage increases throughput, the approach also increases system costs.

Industry has taken steps to address the dynamic, with the aim to streamline the motion control aspect of a system to ultimately enable improved accuracy and features through the laser micromachining process. In 2007, precision motion and automation firm Aerotech unveiled a coordinated stages and galvanometer solution. The company now markets a line of controller products that alleviates challenges posed by non-coordinated control elements.

Innovation has continued. Earlier this year, SCANLAB, in partnership with ACS Motion Control, announced a solution that combines a 2D scan head with an xy positioning stage in which the scanner and stages are continuously moving during operation.

Novanta has also developed and introduced an approach — one that places priority on reducing the hardware and software needed to enable a coordinated system to become operational.

The focus on this consideration aligns with what manufacturers are coveting: streamlined solutions delivering high throughputs.

"Manufacturers ideally would like to have 'lights out' factories, and the only way to get to this is through motion control and automation," Tedford said. "I expect this will lead to different and potentially novel ways to use existing technologies."

"Manufacturers ideally would like to have 'lights out' factories, and the only way to get to this is through motion control and automation."

Communication in motion control systems, especially for today's systems that rely on coordinated elements, is necessary to sustain any shift toward automation on the road to the streamlined work environments that manufacturers seek. In motion control systems, control mechanisms and the physical terminals (endpoints) of a given operation must be able to send and obtain information. The communication function between the two elements is enabled by bus protocols.

On the design side, motor designs are also frequent areas of both novel solutions and iterative product improvements. These include direct-drive linear motors as well as piezoelectric actuators. Direct-drive linear motors eliminate the need for mechanical transmission elements, which reduces backlash and increases responsiveness. Piezoelectric actuators meanwhile are known for their high precision and responsiveness and are particularly valuable in applications that require submicron levels of accuracy.

To ensure lasers can be positioned quickly and accurately to meet the demands of modern manufacturing processes, advancements in drive hardware also play a pivotal role.

"Advancements in more powerful embedded controller devices with lower latency bus protocols are enabling higher trajectory rates, which also impacts precision for laser scan head applications," said Bryan Germann, product manager for laser processing products at Aerotech.

The ascent of automation

The advantages to motion control automation are multifaceted: The incorporation of an automation element can significantly enhance both quality and cost-efficiency in manufacturing. This is proved by significant cost savings in areas such as labor, material waste, and energy consumption.

Functions and applications that benefit from motion control automation include semiconductor wafer processing, battery processing, and solar panel processing. "Equipment manufacturers selecting precision motion control equipment require specialized tools to achieve their application objectives," Germann said. "Superior electromechanical design and controller features that enable synchronizing the laser and part motion are extremely enabling for difficult laser applications."

Automation also offers preventative benefits, helping manufacturers avoid human and operational errors that could lead to lower yields.

Automation can also bring advanced functionalities to micromachining workstations. Features such as real-time monitoring, automatic adjustments, and predictive maintenance become possible, leading to more robust and reliable systems.

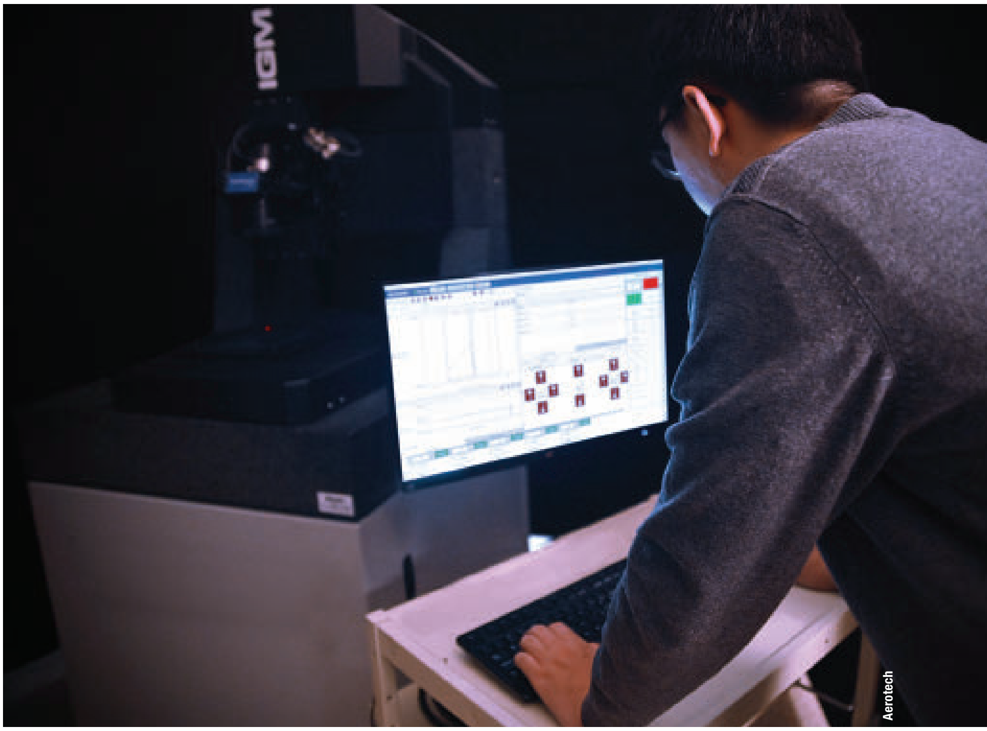
"The ability to quickly and precisely modify laser processes in-line with the help of vision systems, sensors, and other peripheral equipment ensures accuracy throughout the process, and thus higher yields," Dobbins said.

Again, the incorporation of automation ties to the relationship between the operating laser and the scanner.

"The integration of process monitoring to assure highest product quality requires tight synchronization between laser and scanner," Dobbins said. For printed circuit board (PCB) manufacturing, for example, xy tables are commonly used. For drilling the connections between layers of a board, the PCB substrate is positioned beneath a laser scan head. Copper, which is highly reflective in the CO_2 wavelengths (~9.3 to 10.6 µm), can be opened on the PCB using an ultraviolet laser. The PCB is then positioned under a CO_2 laser system to drill through the epoxy laminate material.

"Because the area the scan head can process is smaller than the PCB board, the positioning of the substrate under the scan head is critical," Tedford said.

"And because you don't have the two laser wavelengths going through the same scan head, the motion control stage and machine vision plays a critical role in making sure the substrates are positioned correctly for drilling."



Powerful embedded controller devices with lower latency bus protocols lead to higher trajectory rates, which also influences precision for laser scan head applications, according to Bryan Germann, product manager for laser processing products at Aerotech.

Motion control and software interplay

A motion controller interfaces with physical motion hardware, such as motors, stages, drives, and laser scan heads. To operate effectively, motion controllers require both firmware and software. Firmware, embedded in digital signal processors or field-programmable gate arrays, generates the current signals for servo motors and interfaces with feedback devices, such as encoders, for accurate positioning.

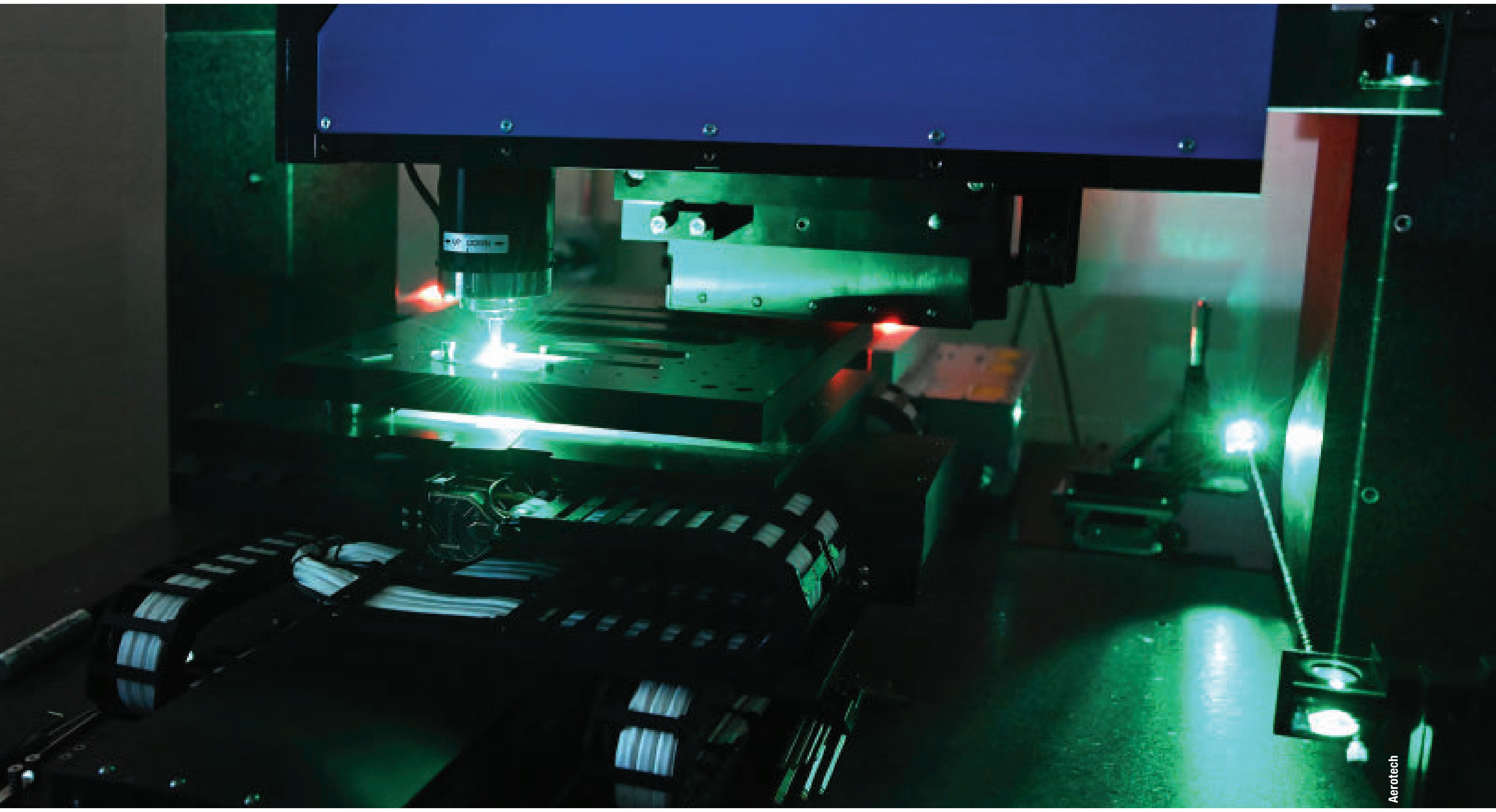
In certain cases, such as very high-speed automation, the motion controller is treated as an independent control system. To ameliorate the burden on the motion controller, automation is carried out on a software layer between the main automated system and the software that drives the galvanometer controller.

"Communication between the [galvanometer] controller and the main programmable logic controller (PLC) is critical for high-speed execution," said Mark Turner, founder and CEO of Turner Laser Systems. "However, in some cases, the amount of control required is too complex and requires the controls algorithms to be done on a software level, not on a motion controller level."

Obtaining the measurements of the position, scale, and skew errors of a part, and then transforming the part in software before uploading it to the motion controller, is one such example, according to Turner.

A challenge is to integrate real-time control with the interface, to combine the movements of a stage and the laser scan system.

"We realized that micromachining today requires more and more precision regarding physical movements and motion control, together with managing the laser power efficiently," Dobbins said. The company uses software to calculate optimum trajectories from specified



Aerotech's 515-nm, five-axis laser micromachining center with drilling operation using a femtosecond laser.

machining patterns and process parameters, she said. The calculation considers the physical limits of the scan head.

"This allows us to achieve optimal processing results with minimum laser-off times," Dobbins said.

The rise of ultrafast lasers

In modern manufacturing, high-peak-power ultrafast lasers have allowed laser micromachining processes to reach new standards for the quality and precision of micro- and nanoscale features. However, the proliferation of these lasers has not bypassed bottlenecks, especially as average powers have increased. Ultrafast lasers, capable of generating multiple wavelengths from a single source, present challenges for optical damage thresholds and supported wavelengths for laser scan heads. This necessitates high-quality optical coatings with high laser-induced damage thresholds (LIDTs) in multiaxial laser scan head products.

According to Turner, a 50- to 100-W ultrafast laser, which needs to be moving very fast or use beamsplitting to reap the benefits from the source, presents a good example.

"Power scaling can often affect the commercial viability as it drives throughput, and thus cost-per-part. So, the motion control is critical for high throughput ultrafast applications," Turner said.

Moreover, flexibility in pulse output methods, such as generating megahertz or even gigahertz repetition rates with burst mode, indicates the importance of high-quality laser-triggering electronics.

"Accurately triggering these pulses with respect to micrometer or submicrometer positioning systems highlights the importance of high-quality laser triggering electronics for scanners," Germann said. "Everything operates faster and on smaller time scales, so there is increased design pressure on control electronics and methods."

Today's control systems achieve precision and accuracy using high-resolution encoders and advanced control algorithms. These systems also typically incorporate real-time compensation mechanisms for various disturbances, which further ensures stable and precise operations.

Increasingly, designers are integrating other types of advanced technologies, such as AI and machine learning algorithms, that aim to dynamically optimize the laser processing parameters. These technologies allow for adaptive control, meaning that the system can adjust in real time to changes in environmental conditions or material properties.

Changes to material properties, particularly amid the wide adoption of ultrafast laser technology, underscores the persistent — and critical — need to optimize the light-matter or light-material interaction.

Position synchronized output (PSO), a function of a control mechanism that coordinates motion with output to the laser, is a favored solution to control this interaction. Aerotech's PSO solution, for example, offers users several operating modes that accommodate the need for pre-

As demand increases for higher throughput and tighter part tolerances, the approach to controlling laser positioning systems has become more stringent.

cision integration with a range of distinct processes.

"Control of the laser-material interaction is crucial, and PSO is an enabling technology for both motion control and ultrafast laser processing," Germann said.

"Functions such as PSO pushed the development of ultrafast lasers toward minimizing the jitter between the triggering signal and the actual pulse coming out of the laser head to increase the processing quality and accuracy," said Bogusz Stępak, director of Fluence's Ultrafast Laser Application Laboratory.

"As a result, the processing time can be shorter, and the sharp corners can be machined with better quality."

Choosing the right platform

Most commercial motion control solutions support the full range of laser micromachining tasks. Physics dictates many considerations pertaining to system setup, including laser wavelengths, beam diameters, and optical configurations needed to achieve the desired spot size, Rayleigh length, and pulse energy.

Still, the optimal solution must address specific application needs, which may include payload, travel, speed, precision, and cost.

"End users can drive their applications to success by having the right skill sets and understanding the capabilities of the tools at their disposal that dictate success," Germann said. "Every application involves a laser and a motion system, [and it is] application requirements, such as feature size and material type, that end up dictating which tools are most appropriate to do the job."

Applications that demand large spot sizes and slower processes, such as welding, do not exclusively necessitate ultrafast lasers. Users can commonly manage these functions with the use of lower dynamic scanners and stages or robots with average accuracy requirements. Conversely, applications involving high-peak-power ultrafast lasers necessitate high LIDT mirrors, high dynamic motors, and complex motion with higher accuracy requirements.

At Fluence's application laboratory, feasibility studies determine the best source and required optics for a given material and process. According to Stępak, these studies can also determine the most efficient delivery of laser energy as well as the scanning strategy to maximize the average laser power while maintaining processing quality.

"In the ultrashort-pulse domain, process optimization is a complex task due to multidimensional parameter space and the high sensitivity of the process performance to the laser parameters," Stępak said. "This will determine whether the beam motion should be implemented by combining the [galvanometer scanner] and linear stages or fixed high-numerical aperture optics."

In some cases, it is beneficial to combine the scanner with a microscope objective for tight laser focusing. Modern lasers often offer more power than that which can be used with a single beam, which means that the main beam can be split into several or multiple spots using beam shapers.

"Femtosecond lasers often provide the highest processing quality and precision due to reduced thermal effects and a melt-free process," Stępak said. Today's class of industrial-grade femtosecond lasers meet the demand of mass production, after available powers increased significantly during the last few years, he said.

mariefreebody@physics.org

Photonics at Its Brightest in Automotive Illumination Systems

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

The automotive industry has traditionally been at the fore of adopting emerging technologies to improve safety, performance, and user experience. In recent years, photonics has solidified its role as a transformative force in automotive lighting; photonics technologies provide significant benefits compared with traditional and legacy lighting systems, ranging from improved efficiency and longevity to overall design flexibility. Among the innovation areas driving these advantages are LEDs, OLEDs, and micro-LEDs as well as microlens arrays (MLAs) and color measurement technology.

LED solutions for automotive projection

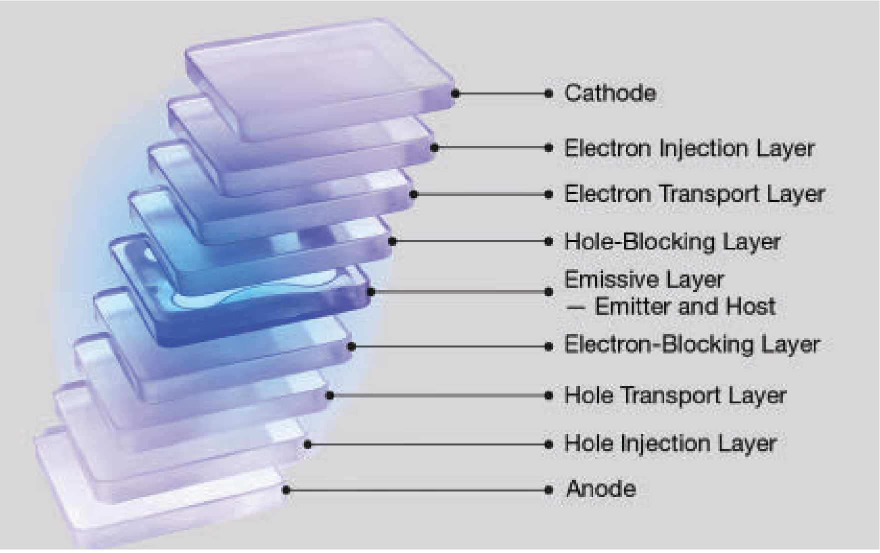
LEDs generate light through electroluminescence, a process that involves the recombination of electrons and electron holes in an inorganic semiconductor. The wavelength of the light produced depends on the energy bandgap of the semiconductors used. The favored semiconductor material may be, for example, gallium arsenide (infrared); aluminum gallium arsenide (red); gallium phosphide (green); or zinc selenide (blue).

A range of LED-enabled technologies is already incorporated into next-generation automotive display applications. California-based Luminus is one such developer of LED technologies, supporting augmented reality (AR) and holographic head-up displays, interior dynamic lighting, rear/side window displays, and dynamic ground projection. The company's portfolio of LED solutions spans platforms (and wavelengths), with LED offerings from approximately 260 to 280 nm, to 610 to 950 nm.

Especially for digital light processing (DLP) applications, Luminus' LED offerings benefit from the etendue — the required phase space of the area and the solid angle that is required to guarantee the loss-free transfer of light from one point to another within the optical system — matching with the DLP panel and system parameters. This allows for peak optical efficiency and maximum performance. The low thermal resistance package, which enables high reliability with passive cooling, is another advantage for DLP applications.

OLED advantages

An OLED functions in the same way as an LED, though, as its name implies, the present semiconductor material is organic. Commonly used materials include Tris-(8-hydroxyquinoline)aluminum, polyfluorene, and triphenylamine.

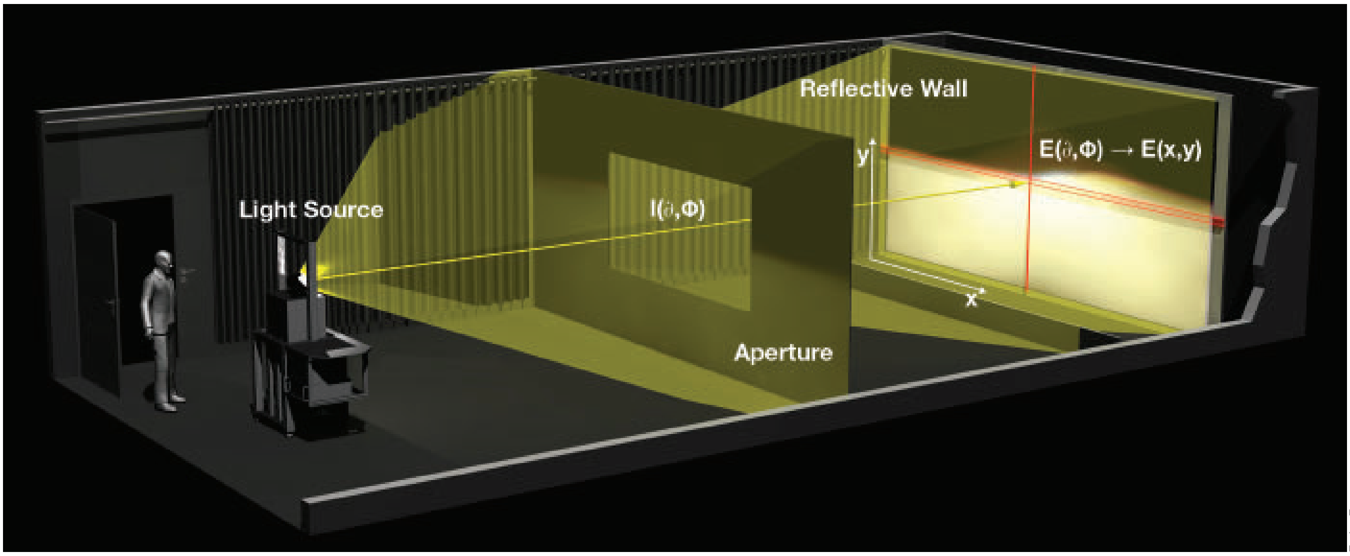


Noctiluca

The subpixel scheme for an OLED display with the separation of individual layers. Blue emitters are necessary for electroluminescent displays as well as certain micro-LED displays that use ultraviolet LEDs as backplanes.

The OLED display stack is made up of thin layers of organic materials, one of which, the emitter, converts electricity into visible light. This emitter and the additional organic materials combine to form a subpixel — the basic building block of an OLED display.

Toruń, Poland-based Noctiluca is a designer and producer of these OLED emitters. In addition to its proprietary technology, Noctiluca markets ready-made product solutions, including compounds that can be combined with a finished OLED stack. This capability enables Noctiluca to select the optimal target material to increase OLED device efficiency for a given partner's technology, while also optimizing the synthetic path and ultimately producing a new



TechnoTeam

TechnoTeam's 'BV ROOM' system returns luminous intensities, illuminances, and/or color coordinates as measurement results. The mechanism can be applied to automotive applications to yield color and light intesity measurments of interior and exterior illuminations.

material for the customer. These materials may also find use beyond the display industry, in light sources.

Also, unlike LEDs, OLEDs can be synthesized from readily available and inexpensive precursors, which makes them inexpensive to produce. In addition, organic semiconductors can be dissolved in solvents, which makes it possible to deposit them onto a variety of substrates using solution-based techniques such as printing and inkjet printing. This quality enables the fabrication of devices with large active areas with more diffuse light sources that can be viewed directly, eliminating the need for shades, diffusers, lenses, shutters, and/or parabolic shells.

Another Polish company active in the field of inorganic semiconductors is QNA Technology. The company specializes in the synthesis of quantum dots, heavy metal-free emitting blue light, and inks based on these dots. These inks include monomer-based ultraviolet (UV)-curable inks. Blue light emitters are essential in displays, particularly electroluminescent displays and in certain micro-LED displays that use ultraviolet LEDs as backplanes.

For automotive lighting applications, QNA offers PureBlue.dots in a colloidal solution consisting of quantum dots that are characterized by a limited toxicity and which can emit blue light in the range of 455 nm. This frequency is safe for the human eye and particularly important for displays. The company's PureBlue.UV ink, one of its monomer-based UV curing inks, supports applications including light conversion or micro-LED fabrication, with the exact composition tailored to customer needs. This ink also contains pure blue quantum dots.

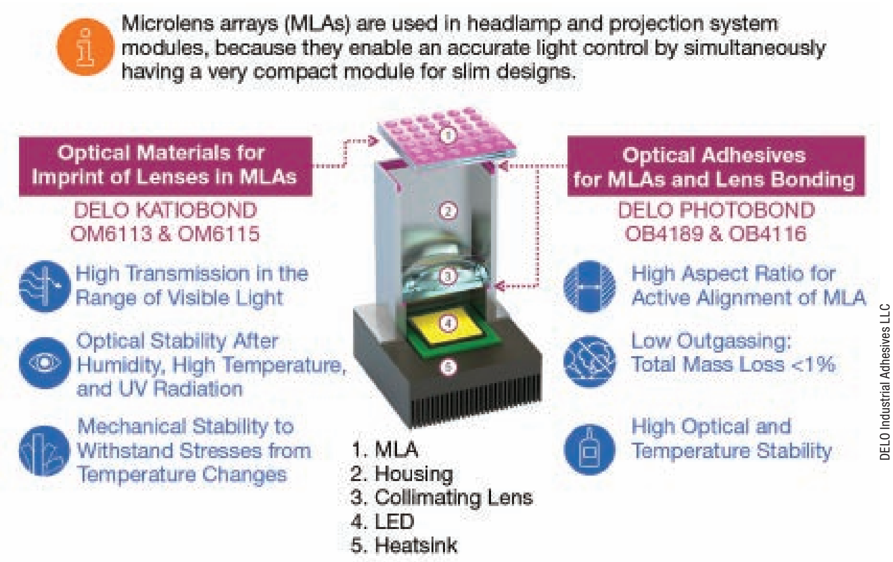
OLEDs are also widely used for displays and lighting systems in dashboard displays, holographic head-up displays, internal lighting, digital rear-view internal mirrors, and external lighting, such as taillights and indicators. Following Audi's unveiling of the 2016 TT RS model, which can be fitted with optional OLED taillights, several subsequent models, including from Audi, adopted OLED lighting panels. Automakers, including BMW, Hongqi, Mercedes, and others have adopted OLED lighting panels in their designs.

Micro-LED applications and integration

Micro-LEDs are typically <100 µm and work much like traditional LEDs, though on a much smaller scale. When an electric current passes through a semiconductor material, it emits light. The core components are a semiconductor material, typically made of gallium nitride (GaN), and a substrate of sapphire, silicon, and/or GaN, on which the micro-LEDs are fabricated.

Micro-LED manufacturing is a highly specialized field that necessitates the development and use of advanced techniques to manage the tiny size and precise placement of each individual micro-LED. The intricate steps involved in micro-LED fabrication are substrate preparation, epitaxial growth, photolithography, etching, metal deposition, passivation, singulation, transfer, bonding, encapsulation, and packaging. Moreover, integrating finished micro-LEDs into existing systems and products also requires careful design and engineering. Ongoing advancements to overcome these fabrication challenges are increasing the viability of micro-LED technology for a wide range of applications, from high-resolution displays to automotive lighting.

These advancements complement the advantages of the technology: Compared



This complete microlens array (MLA)-based projection module includes an LED light source, collimation lens, and an MLA-based projection unit. Optical materials and adhesives are essential for the technical realization of this concept. The arrows in the image indicate the placement of the materials **(left arrow)** and adhesives **(right and bottom arrows)**.

with conventional LEDs or OLEDs, micro-LEDs can achieve higher levels of brightness in a smaller and more energy-efficient package. They also achieve better color accuracy and contrast, a faster response time, and a longer operational lifespan. Due to their size, micro-LEDs can be densely packed, enabling the creation of displays with high pixel densities.

One of the most influential applications of micro-LEDs in the automotive industry is in headlight systems. Traditional halogen and even standard LED headlights face limitations in terms of brightness, energy efficiency, and adaptability. By contrast, micro-LEDs offer adaptive beam control, adjustable dynamic light patterns to suit various driving conditions, and enhanced visibility. Further, micro-LEDs may be organized into arrays in which each LED or LED group can be individually controlled. Such a configuration allows for matrix headlights that can adapt to various driving scenarios as well as automatic switching between high and low beams by detecting the presence of other vehicles.

HELLA, an automotive supplier operating under the umbrella brand FORVIA, and the German luxury car manufacturer Porsche have co-launched a high-resolution headlamp. This solution is based on matrix micro-LED technology. In the forthcoming system from HELLA and the German automaker, the space required for the light module is reduced by up to 75% compared with conventional architectures. Additionally, the system features two high-resolution LED chips, smaller than a fingernail, that are equipped to generate >32,000 pixels per headlamp. The pixels are controlled by one electronic control unit for each headlamp. The system uses Gigabit Multimedia Serial Link (GMSL) interfaces to handle the high data volumes.

To control two light sources per headlamp with one control unit, HELLA has additionally developed algorithms that allow the light distribution to be calculated in real time. The digital headlamp system is debuting in the upcoming Porsche Cayenne models as an optional feature.

Microlens arrays

MLAs consist of multiple microscopic lenses arranged in a precise grid pattern on a single substrate. These lenses focus, collimate, and/or redirect light, providing enhanced control over light distribution. Compared with the projection of light through a single lens, MLAs enable very sharp and controlled projection under shallow angles. There is another added benefit: a lower distance between the light source and the optics. In addition, the high precision and efficiency qualities of MLAs make them ideal for numerous lighting applications in modern vehicles, including headlamps.

The fabrication of MLAs is achieved via a wafer-level imprint process involving first dispensing a UV-curable polymer onto a glass substrate. This is followed by imprinting, UV curing, and dicing of the finished wafer.

The properties of the polymer used are fundamental to the performance of the MLA. The polymer(s) must have high transmission in the visible range and excellent optical stability at elevated temperatures, as well as during UV exposure. Also, they must exhibit low shrinkage in combination with excellent adhesion to glass and simultaneous debonding from stamp materials. And at the same time, the mechanical properties must be suited to withstand stresses from temperature changes and vibration. As a result, adaptations to polymers serve as the nuances to this manufacturing process.

The specially adapted polymers from Germany-based DELO, for example, support the wafer-level imprint process that meet these demanding requirements, and they are effective for multiple applications in the automotive sector. The company's solutions for MLA LED headlamps also address additional considerations. These considerations include MLA-to-housing bonding, active alignment of primary optics, and lens bonding.

MLA deployments enable other innovations. Focuslight Technologies, based in Xi'an, China, is a developer and manufacturer of high-power diode laser components and materials. The company now produces MLAs for ground projection applications and headlamp applications, integrating its solution into commercially available headlamps. The technology is also under investigations as a solution to create very slim headlamps down to a lens height of 10 mm.

Color measurement

Color measurements in the auto sector are necessary to determine values of the luminance and luminous intensity of headlamps, daytime running lights, and other light sources. Glare and ambient light are potentially hazardous occurrences that can be assessed in terms of color.

TechnoTeam, a developer of light and color measurement systems, provides spatially resolved measurement technology in the form of digital camera systems, which allows for complex analyses of lighting situations in relation to luminance, luminous intensity, illuminance, color values, contrasts, and other photometric perception criteria. In automotive applications, these systems are used for the quality assurance of interior lighting in respect to luminance, color, and homogeneity.

Still, this type of objective measurement — of light and color — is even more important for exterior lighting, because exterior lighting must conform to precise specifications as defined by standardization bodies.

Prospects and challenges

Ongoing advancements in the automotive industry will continue to transform photonics' role for this field. Emerging trends promise to revolutionize vehicle illumination systems, enhancing safety, functionality, and user experience.

One such innovation is the advent of AR headlights capable of overlaying critical information directly onto the road, offering drivers real-time navigation guidance and hazard warnings. This improves driver awareness and integrates seamlessly with smart vehicle ecosystems.

Additionally, integrated front lighting systems coupled with lidar are poised to enable obstacle detection and road condition assessments with unparalleled precision. At the same time, vehicle-to-vehicle communication facilitated by light signals will enable efficient data exchange between vehicles for enhanced traffic management and safety protocols.

Despite these advantages, several challenges remain to the widespread adoption of advanced photonics technology solutions in automotive lighting. The complexity of manufacturing micro-LEDs, and the precision engineering and integration requirements of diverse photonics components, for example, require continuous refinement to meet stringent automotive standards for reliability, durability, and regulatory compliance.

Even amid the challenges, the demand for integrated lighting solutions that communicate and interact with other vehicle systems will continue to increase as vehicles become increasingly connected and autonomous. This drives ongoing R&D to ensure the seamless integration of photonics technologies into the broader ecosystem of smart vehicles.

Addressing these challenges will require interindustry collaboration, continued investment in R&D, and advancements in manufacturing processes. By overcoming these obstacles, the automotive industry can unlock the full potential of photonics to create safer, smarter, and more efficient vehicles for the future.

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epic-photonics.com

Noncontact Sensor

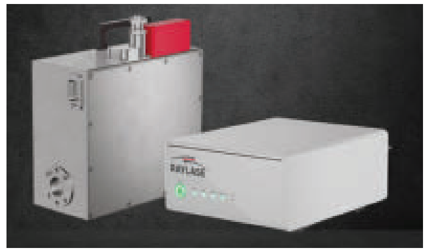
The SM1008S from **Mitutoyo America Corporation** is a noncontact line-laser sensor for surface measurement processes in electrical, electronics, semiconductor, automotive, food, medical device, and pharmaceutical applications. Using the company's optical system alongside traditional sensor technology, the sensor delivers both 2D profile measurements and comprehensive 3D inspections. The SM1008S features an accuracy of 20 µm, a Z repeatability of 0.5 µm, a high-speed profile acquisition of up to 10 kHz, an IP67 protection level, and on-board software with an array of measurement tools.
marketing@mitutoyo.com

Scan Lens

The S4LFT5650-292 from **Sill Optics** is a 650-mm scan lens that can be used in additive manufacturing applications. The highly transmissive fused silica lens was designed for green lasers with a wavelength of 532 nm for processing precious materials such as gold and silver. Due to the shorter wavelength of green lasers, the S4LFT5650-292 achieves focus sizes of 32 to 38.5 µm in a 410- × 410-mm field with an input beam of 20 mm.
ziad.najem@silloptics.com

Distance Measurement Sensor

The RAYDIME METER from **RAYLASE** is an OCT-based distance measurement system designed for prefocusing beam deflection units



in metrology and industrial applications. The system uses a spectral domain OCT in which light interference of different wavelengths is analyzed to obtain distance information. The RAYDIME METER has an accuracy of <10 µm in a field of 500 × 500 mm for accurate z-distance adjustments before laser processing and can capture distance measurements and z-autofocuses in <50 ms.
marketing@raylase.de

Nanopositioning Stages

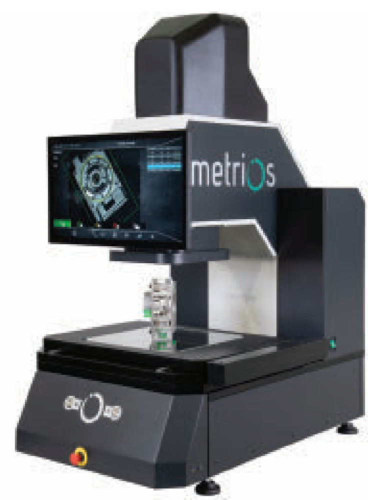
The N-332 family from **Physik Instrumente (PI)** are nanometer-precision linear stages designed for applications in semiconductor technology, fiber optics, microscopy, bio-nanotechnology, metrology, and scientific research in beamlines and laser labs. Configurable to multiaxis setups

of xy, xz, and xyz, the stages have a low profile of 30 mm and a small footprint of 80 × 110 mm and 80 × 160 mm with travel ranges of 1 in. and 2 in., respectively. The N-332 family offerings are brakeless with a high active force of 75 N and a power-off passive holding force of 80 N. They feature V8 piezo-walk technology and availability in configurations suitable for pressures down to 10-9 hPa.
info@pi-usa.us

Tunable Laser Systems

The TLS-Red (shown) and TLS-Blue from **Spectrolight Inc.** are tunable laser systems that combine a supercontinuum laser and a tunable bandpass filter for fields that require precise scanning and fields that require high output, respectively. The TLS-Red can generate

output beams of various wavelengths from approximately 410 to 1700 nm and can control the full width at half maximum of the output beam from 2 to 15 nm as nominal, while the TLS-Blue has the same wavelength range with a fixed full width at half maximum at 10 nm or 20 nm. The picosecond tunable lasers can be used in applications including fluorescence microscopy, time-resolved spectroscopy, machine vision, and hyperspectral imaging.
info@spectrolightinc.com

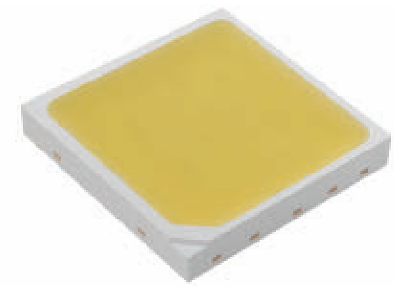


Optical Measuring System

The Metrios 332 from **Metrios** is an optical measuring machine for metrology applications on the shop floor. The system provides a wide measuring range of 300 × 300 mm x-y with a part passage of 200 mm and a part carrying capacity of up to 20 kg on the stage. The Metrios 332 features a wide-field sensor that detects and measures parts placed on the stage, a magnification sensor that can detect points in x-y-z, and a comprehensive lighting system that provides a shield from environmental light and ensures accurate measurement results on difficult-to-detect surfaces.
info@metrios.net

Open Frame Positioning Stage

The SmartStage open frame positioning stage from **Dover Motion** can be used in regular or inverted optical microscopy applications that require an open aperture in life sciences, metrology, and related fields. The stage's controller and encoder are physically integrated inside the stage structure and the stage can be driven by another axis or external source to follow defined motion curves based off the input. The stage features a physically integrated controller, software, and user-definable motion profiles.
sales@dovermotion.com



Mid-Power LEDs

The MP-5050-240E and MP-5050-810E from **Luminus Devices** are mid-power LEDs for outdoor and industrial lighting applications. Delivering an efficacy of 233 lumens/W at 4000K, the LEDs have an L90 rating of more than 36,000 h with availability in both 6 V (240 E) and 24 V (810 E) options. The MP-5050-240E and MP-5050-810E feature a low thermal resistance design for increased thermal dissipation as well as a square light-emitting surface design that offers uniform light distribution for more controlled and directed light beams.
sales@luminus.com

IR Emitting Diode

The TSHF5211 from **Vishay Intertechnology** is an 890-nm high-speed IR emitting diode for optoelectronic applications. The emitting diode has a typical radiant intensity of 235 mW/sr at a 100-mA drive current while offering good spectral matching with silicon photodetectors. The TSHF5211 features a −1 mV/K temperature coefficient of forward voltage, a switching time of 15 ns, a typical forward voltage of 1.5 V, and a ±10° angle of half intensity.
business-americas@vishay.com

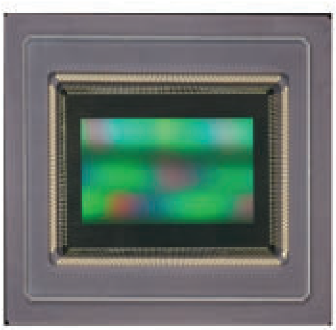
Tunable Light Sources

The Newport TLS260B series from **MKS Instruments Inc.** comprises compact, fully assembled, pre-aligned tunable light sources for spectroscopy, materials research, and sensor and device characterization applications. The

unified light sources allow for the generation and manipulation of monochromatic light using a single instrument, while providing white light or monochromatic light from 300 to 1800 nm with a spectral resolution of 0.5 nm. The Newport TLS260B series features fast scan speeds, increased output power, and dual output port options from the company's integrated CS260B Monochromator.
sales@newport.com

Optical Transceiver

The OSFP 800G DR8 from **Approved Networks** is an 800G transceiver for high-speed data transmission applications, specifically for AI. The OSFP 800G DR8 transceiver provides compatibility for both InfiniBand and Ethernet networks and features data transmission capabilities of up to 500 m and scalability for data centers and broadband networks.
sales@approvednetworks.com



2-MP GSI Sensor

The GSPRINT6502BSI from **Gpixel** is a high-sensitivity 2-MP global shutter image (GSI) sensor for applications including 3D laser profiling and scientific and UV imaging. Using backside illumination, the sensor has a resolution of 2048 × 1152 pixels at 6.5 µm per square with 10-bit output and 32 pairs of sub-low-voltage differential signaling outputs operating at 1.2 Gbps, letting the sensor achieve a frame rate of 1500 fps. The GSPRINT6502BSI features up to eight defined vertically oriented regions of interest, the ability to detect a spectral range from 200 to 1100 nm, an on-chip sequencer, serial peripheral interface control, a phase-locked loop, and both analog and digital temperature sensors.
info@gpixel.com

Multi-Axis Stages

The XYHG series of stages from **Optimal Engineering Systems (OES)** are linear x- and y-axis

plus horizontal goniometer stages for metrology, light measurement, mirror positioning, laser scanning, inspection, tracking, and optical bench applications. The stages are available in stroke lengths for the x-axis and y-axis of 50 to 1000 mm and are integrated with a +/−10°, +/−15°, or +/−45° horizontally mounted goniometer. The XYHG series also features travel lengths of up to 75 mm with a 1-mm per-turn lead screw pitch and travel lengths of >100 mm with a 4-mm per-turn lead screw pitch.
sales@oesincorp.com

Silicon-Based Terahertz Products

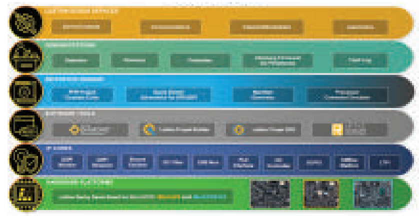
TicWave Solutions GmbH's silicon-based terahertz product line includes terahertz cameras, sources, and imaging systems for applications in research and industry. The terahertz cameras are battery operated and provide high-resolution imaging capabilities in a compact form factor. The compact, hand-held, and battery-operated terahertz sources are available in continuous-wave or diffused illumination with an output of up to 20 mW. The terahertz imaging systems come in comprehensive kits and can be extended with pre-aligned optical rails and cage systems.
ullrich@ticwave-solutions.com

Event-Based Camera

The Triton2 EVS from **LUCID Vision Labs** is an event-based camera that continuously samples incoming light and generates signals when the light level changes. Using Sony's CMOS image sensor technology with Prophesee's event-based Metavision sensing technologies, the camera has a time resolution equivalent of >10,000 fps with a dynamic range of >120 dB.

Product News

The Triton2 EVS features a 0.08 lx low-light cut-off, M12 2.5 GigE power over Ethernet interface, and IP67 protection for applications in industrial environments.
sales@thinklucid.com



Software Solution Stack

The Lattice Sentry (v 4.0) from **Lattice Semiconductor** is a software solution stack that can be used in platform firmware resiliency solution development for communications, computing, industrial, and automotive applications. NIST SP 800-193 compliant, the stack supports multiple QSPI/SPI monitoring with I2C peripheral attack protection demonstration. The Lattice Sentry (v 4.0) also features security protocol and data model (SPDM) and management component transport protocol (MCTP) support for platform management. It offers secure server operations and expanded plug-and-play design tools and reference designs with workspace template and a policy, provisioning, and manifesting generator.
sales@latticesemi.com

Industrial Cameras

The CXP-C3240 and SFP-C3240 from **Imperx** are high-sensitivity cameras that can be used in applications such as automated inspection, surveillance, traffic monitoring, medical imaging, and microscopy. Featuring the Sony Pregius IMX420 7-MP global shutter CMOS image sensor, the cameras have a native resolution of 3200 × 2208 in., a 1.1-in. optical format, and are ruggedized to perform in extreme temperature, vibration, and radiation situations. The CXP-C3240 delivers up to 152.3 fps with dual CXP-6 CoaXPress output, while the SFP-C3240 achieves 129 fps using a 10 GigE Version 2.0 interface via an SFP+ transceiver.
sales@imperx.com

High-Speed Framing Cameras

The SIM-D and SIM-X from **Specialised Imaging Ltd.** are ultrahigh-speed framing cameras designed to capture high-resolution images without creating shading or parallax at up to 1 billion fps. The eight-channel cameras allow interchangeability of filters across all eight channels in hyperspectral imaging applications. The SIM-D can capture two images on each of its eight channels, offering the capacity to capture 16 mono/filtered images, or four mono and four full-color images. The SIM-X, alternatively, captures one high-resolution image per channel, offering the potential to capture eight mono/filtered images.
info@specialised-imaging.com

Line-Scan Cameras

The racer 2 series from **Basler AG** are line-scan cameras that are suited for quality assurance applications. Including a CXP-12 interface, the cameras have resolutions of up to 16K and line rates of up to 200 kHz. The racer 2 series features long cables of up to 40 m with Micro-BNC (HD-BNC) connections, passive cooling fins for applications with lower ambient temperatures, and an active compressed air cooler.
sales.europe@baslerweb.com

Optical Filter

The birefringence-induced phase delay (BIPD) filter from **Specto Photonics** is a compact filter meant for the suppression of strong disturbances caused by excitation light in Brillouin spectroscopy. The filter can operate across a broad range of visible and near-infrared wavelengths with an operating range of 450 to 900 nm and a high rejection capability. The BIPD filter has an insertion loss of <1.5 dB, a free spectral range from 15 to 200 GHz, an extinction ratio of >45 dB, a working temperature range from 15 to 35 °C, and a form factor of 10 × 8 × 17 cm.
info@spectophotonics.com

Rack Scanner

The Ziath DP5 Mirage Rack Reader from **Azenta** is a compact camera-based 2D rack scanner for 2D barcode scanning applications in the life sciences. The scanner has a low profile that allows it to be used in robotic integrations for liquid handling systems and an in-house written software for decoding 2D barcodes with tube-size codes. The Ziath DP5 Mirage Rack Reader features a 208- × 135- × 80-mm form factor, a weight of 1.35 kg, a power consumption of ≤10 W, and a CMOS camera.
salesorders.na@azenta.com

Benchtop Live-Cell Interface

The Pixel Octo system from **CytoTronics** is a semiconductor-to-live-cell interface in an environmentally controlled benchtop system that can be used to deliver live-cell measurements for up to eight 96-well pixel plates simultaneously. The Pixel Octo system features a dedicated incubator to regulate temperature,

CO_2, humidity, and oxygen. The system can be integrated with industry standard robotic and liquid handling platforms, with multiple systems running in parallel for high-throughput applications.

contact@cytotronics.com

Dual-Color Laser System

The FemtoFiber ultra dual-color laser system from **TOPTICA Photonics** is designed for multicolor nonlinear microscopy applications, such as fluorescence lifetime imaging. The system requires no laser wavelength tuning and uses simultaneous nicotinamide adenine dinucleotide plus hydrogen and flavin adenine dinucleotide measurements for metabolic imaging. The FemtoFiber ultra dual-color laser system features two synchronized laser lines, a shared oscillator design for all-optical synchronization, fixed delay between two colors, and a single electronic trigger output as reference for time-correlated single-photon counting systems and gated detection.

sales@toptica.com

Fiber Optic Testing Tools

The FlowScout OPM8 and OLS8 from **AFL** are an optical power meter and optical light source, respectively. The products are designed for use in testing fiber optics in data center fiber

networks, FTTH PON networks, high-power broadband and dense wavelength-division multiplexing systems testing, and multimode and single-mode fiber networks. The OPM8 uses AFL's proprietary Wave ID functionality for accuracy and automatically reports the presence of 270-Hz, 330-Hz, 1-kHz, and 2-kHz fiber-identifying tones. The OLS8 uses AFL's proprietary Wave ID generation for reduced test time and user errors as well as field-replaceable connector adapters for flexibility. Both devices can be integrated into each other for testing purposes.

marketing@aflglobal.com

Industry Events

OCTOBER

○ Neuroscience
(Oct. 5-9) Chicago.
Contact the Society for Neuroscience, +1 202-962-4000, **meetings@sfn.org**; www.sfn.org/meetings/neuroscience-2024.

SEMI MEMS & Sensors Executive Congress (MSEC)
(Oct. 7-9) Bromont, Québec.
Contact SEMI, **mfabiano@semi.org**; www.semi.org/en/connect/events/mems-sensors-executive-congress-msec.

○ AutoSens Europe
(Oct. 8-10) Barcelona, Spain.
Contact Sense Media, +44 (0)208-133-5116, **info@sense-media.com**; www.auto-sens.com/europe.

○ VISION
(Oct. 8-10) Stuttgart, Germany.
Contact Landesmesse Stuttgart GmbH, +49 711-18560-0, **info@messe-stuttgart.de**; www.messe-stuttgart.de/vision/en.

***BioPhotonics* Conference 2024**
(Oct. 15-17) Virtual.
Contact Photonics Media, +1 413-499-0514, **conference@photonics.com**; www.photonics.com/bpc2024.

FABTECH
(Oct. 15-17) Orlando, Fla.
Contact SME, +1 313-425-3000, **information@fabtechexpo.com**; www.fabtechexpo.com.

○ Optica Laser Congress and Exhibition
(Oct. 20-24) Osaka, Japan.
Contact Optica, +1 202-223-8130, **info@optica.org**; www.optica.org/events/congress/laser_congress.

SCIX
(Oct. 20-25) Raleigh, N.C.
Contact FACSS, +1 856-224-4266; www.scixconference.org.

Single-Molecule Sensors and Nanosystems International Conference — S3IC 2024
(Oct. 28-30) Paris.
Contact S3IC 2024 Organizing Committee, +33 1-46-60-89-40, **s3ic2024@premc.org**; www.premc.org/conferences/s3ic-single-molecule-sensors-nanosystems/registration.

○ SPIE PHOTONEX
(Oct. 30-31) Manchester, England.
Contact SPIE, +1 360-676-3290, **customerservice@spie.org**; www.spie.org/conferences-and-exhibitions/photonex.

PAPERS

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

NOVEMBER

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

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

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

DECEMBER

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

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

JANUARY

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

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

FEBRUARY

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

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

MARCH

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

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

APRIL

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

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

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

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.

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

Automate 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.

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

PHOTONICS SHOWCASE

Polarization Analyzer

The polarization analyzer series SK010PA is a compact, comprehensive, universal USB2.0 measurement and test system for free beam applications and laser beam sources with polarization-maintaining fiber optics. Alignments and measurements are performed rapidly. A real-time interactive display shows the state of polarization on a Poincaré sphere as well as the degree of polarization. New: SK010PA-UV+ for 350nm – 450nm! https://www.sukhamburg.com/

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info@sukhamburg.com **www.sukhamburg.com**

Zoom 7000-2 Macro Imaging Lens

Redesigned and optimized for demanding applications in machine vision, industrial imaging, life science and research. This versatile, close-focusing lens delivers excellent image quality across various magnification ranges.

- 18-111mm focal length with manual zoom
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Navitar **(585) 359-4000**
info.navitar@ametek.com **www.navitar.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**

LAMBDA 721 LED Light Source

The Lambda 721 is a new concept for combining up to 7 separate LED cubes with different spectra into a single common output beam. The LED cubes contain the LED, collimating optics, and a filter. These LED cubes are easily exchanged and installed with no tools required. The Lambda 721 is the ideal solution for a wide variety of microscopy applications that require illumination at various wavelengths.

Sutter Instrument **(415) 883-0128**
info@sutter.com **www.sutter.com/imaging/lambda721.html**

Large-Size Switchable Planar Optics

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

BEAM Engineering for Advanced Measurements Co.
(407) 734-5222
www.beamco.com **sales@beamco.com**

Ultima 2Pplus Multiphoton Microscope

The Ultima 2Pplus All-Optical Multiphoton System delivers state-of-the-art flexibility, resolution, imaging depth and speed, so researchers can perform simultaneous in vivo imaging, photostimulation, and ephys protocols with greater efficiency. Recent modular advancements expand Ultima 2Pplus: NeuraLeap simultaneously correlates activity across depths, and NeuraLight 3D Ultra independently images and photostimulates multicellular targets in 3D.

Bruker Fluorescence Microscopy
(520) 741-1044
productinfo@bruker.com
www.bruker.com/fm

Newport™ High-Precision Hexapods

Engineered with six industry-proven, high-performance actuators and innovative joint designs, Newport Hexapods deliver unparalleled rigidity. Whether you require high precision and accuracy, heavy load handling, or vacuum compatibility, Newport Hexapods are the perfect answer to your complex motion challenges.

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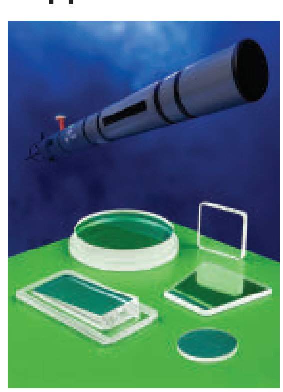
sales@newport.com
www.newport.com/c/hexapods

Sapphire Windows for Deep AUVs



Meller Sapphire Windows feature Mohs 9 hardness which is second only to diamond and can withstand fast moving particles, sand, and deep water pressure to 10,000 psi, depending upon application. Custom manufactured to precise OEM specifications, they can include stepped edges, elliptical edge shaping, holes, slots, and wedges for mounting and feature a smooth flat surface that resists algae growth.

Meller Optics
(800) 821-0180
sales@melleroptics.com
www.melleroptics.com

PHOTONICS SHOWCASE

Miniature Power Components

Pico Electronics, the leader in high reliability, mission critical miniature power components, offers a full line of Converters: 2V — 10,000VDC Output; 1 — 300Watts Transformers and Inductors. Surface mount and thru-hole models. Custom models available. Proudly made in the USA.

Pico Electronics Inc.
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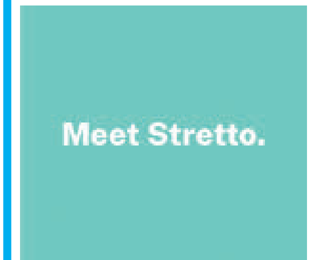
info@picoelectronics.com
www.picoelectronics.com

Meet Stretto



DRS Daylight Solutions introduces Stretto, a family of high-precision tunable lasers. Designed to enable quantum information science applications, Stretto provides wavelengths from UV to infrared, maintaining a common footprint and interface. This simplicity facilitates transition from laboratory experiments to OEM integration without redesign. Leveraging Daylight's military ruggedized designs, Stretto provides performance-at-scale, enabling our customers to succeed in what's next.

DRS Daylight Solutions **(858) 432-7500**
dls-info@drs.com **www.daylightsolutions.com**

Optimize Your Optical System

For optical systems success in medical device and life sciences, Fresnel Technologies (FTI) has the expert guidance in optical design, biocompatible polymer and silicone materials, and testing processes to fit your program. From freeforms and aspheres to micro-optics, our capabilities include catalog and custom polymer optics. Talk through your optical approach with our experts.

Fresnel Technologies Inc. **(817) 926-7474**
info@fresneltech.com **bit.ly/3Z6Ptby**

Enhance Your Analysis

Hamamatsu's new photon counting head, H10682-110W, is engineered for reliability and offers exceptional performance in low-light applications, making it the perfect choice for advanced scientific research and cutting-edge industrial applications. It's integrated with a newly designed condenser lens for high light-collecting efficiency while keeping a thin profile and allows for photon counting measurements by simply connecting a +5 V supply.

Hamamatsu **(908) 231-0960**
photonics@hamamatsu.com **bit.ly/4e2E6FG**

Polarization Analysis

PolSNAP™ — Quantitative polarization data for your free space or fiber-coupled VIS and NIR light sources. PolSNAP software includes real-time reporting of Stokes vector values and degree of polarization along with a visual polarization ellipse and Poincaré sphere. Sampling rate: 2000 samples per second and 4 Stokes vectors per second. Free space aperture: 10 mm, no alignment tools needed.

Hinds Instruments Inc.
(503) 690-2000
sales@hindsinstruments.com
www.hindsinstruments.com

HHV Precision Optical Tools

HHV Ltd.'s optical deposition tools are designed for research and production of precision optical films on lenses, prisms, and domes. Systems incorporate powerful multipocket electron beam sources with ion assistance, substrate heating, and a range of work holders. Computer-controlled deposition processing and optical film monitoring provide repeatable accuracy. Systems range from 500-mm research tools to 1400-mm production systems.

HHV Ltd. **+44 1293 611898**
info@hhvltd.com **www.hhvltd.com**

Digital Delay/Pulse Generator

Given an internal or external trigger, Highland Technology's compact T660 generates up to four precisely timed output pulses that are individually programmable for delay and pulse width. Featuring <35 picoseconds typical jitter, programmable-level trigger input with divide and burst features and trigger enable GATE input, and an advanced Trains/Frames option that includes timing lists and multiple pulses per trigger.

Highland Technology Inc. **(415) 551-1700**
sales@highlandtechnology.com **www.highlandtechnology.com/product/T660**

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PG&O's new capabilities include cost-effective, high-volume, precision optical components up to 100,000 parts per month with timely delivery. The high-quality optical components operate from 0.2 µm - 15 µm. Our recently installed PR Hoffman 5400 double-sided polishing machine provides exceptional surface quality on substrates up to 250 mm diam. and allows us to polish parts in days, rather than weeks. Call us today at 714-540-0126 to learn more.

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info@pgo.com **www.pgo.com**

PHOTONICS SHOWCASE

High-Precision IR Lens Assembly

Hyperion specializes in custom precision IR lens design and prototyping for low-volume production projects. Ranging from 0.8 to 12 microns for infrared applications, we utilize a combination of materials, including Si, ZnS, ZnSe, Ge, chalcogenide, and CaF_2, to meet the specific requirements of each application. Enhance your IR imaging and sensing performance with custom engineering today.

Hyperion Optics USA
(908) 899-1918
rfq-us@hypoptics.com
www.hypoptics.com

HyperFine Spectrometer

The HyperFine series of spectrometers for low-intensity sources are designed for measuring hyperfine spectra and subtle spectral shifts from scattered light or distributed sources. The HyperFine spectrometer from LightMachinery is a compact spectrometer capable of 1-picometer resolution. It is enabled by VIPA etalons produced by LightMachinery's patented fluid jet polishing technology.

LightMachinery Inc. **(613) 749-4895 x114**
info@lightmachinery.com **www.lightmachinery.com**

IR Detection Module NIPM-I-5

The NIPM-I-5 is an infrared detection module designed for differential optical signal detection. The device operates in both balanced and auto-balanced modes. It features two individual detectors based on HgCdTe heterostructures. These IR detectors (signal and reference) are precisely matched to achieve a very high Common Mode Rejection Ratio. The NIPM-I-5 is intended for use in systems where excess radiation noise dominates.

VIGO Photonics S.A. **+48-22-733-54-10**
info@vigophotonics.com **www.vigophotonics.com**

Z-Axis Nanopositioners

Mad City Labs originated low profile Z-axis piezo nanopositioners. They are widely used for optical microscopy techniques such as super resolution microscopy and confocal microscopy. We offer a wide range of designs for compatibility with most microscope models and stages. These piezo Z stages are fully removable from your microscope stage and accommodate a wide range of sample media.

Mad City Labs Inc. **(608) 298-0855**
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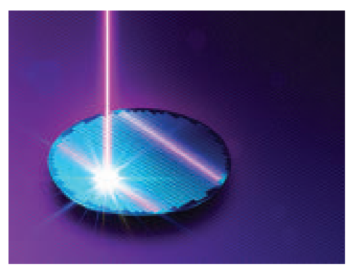
Liquid Crystal Polarization Gratings

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

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

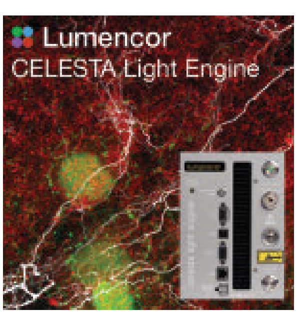
Optical Filters for Semiconductor



Optical filters play a crucial yet often overlooked role in semiconductor manufacturing, where nanoscale precision can make or break a product. At Chroma Technology we understand that the quality of your optical filters directly impacts the accuracy of your inspection processes and ultimately the performance of your semiconductors. We specialize in creating advanced optical filters designed to meet the rigorous demands of semiconductor inspection

Chroma Technology **(802) 428-2644**
sales@chroma.com **bit.ly/3T7KaEW**

CELESTA Light Engine



CELESTA Light Engine houses seven lasers in a turnkey illuminator for fluorescence confocal spinning disk microscopy and spatially resolved transcriptomics. 1000 mW/color from the end of an optical fiber is powerful, intense, quiet, reproducible and consistent. High-end imaging and OEM instrumentation are well supported. Ask about customization.

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www.lumencor.com

Ultrafast Fiber Lasers: <50 fs, 2 W

HÜBNER Photonics proudly announces the next generation of the VALO femtosecond lasers. The new Tidal delivers pulse durations of typically 40 fs at 2 W of output power. Due to the exceptional peak power and the integrated dispersion pre-compensation unit it is an ideal tool for nonlinear applications like high harmonic imaging, broadband terahertz generation, and nonlinear wafer inspection.

HÜBNER Photonics **+46854591230**
sales@hubner-photonics.com **www.hubner-photonics.com**

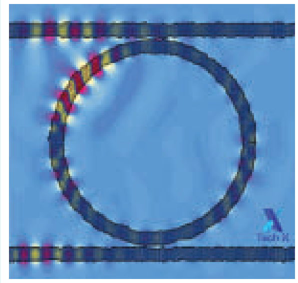
PHOTONICS SHOWCASE

450-nm Blue Diode Laser

The 450nm diode laser emits up to 200W from a single fiber with beam quality of 20mm.mrad. The diode module comes with hermetically sealed package, water cooling baseplate and a high-power SMA connector. Red aiming, thermistor and photodiode are integrated in the package. To drive the diode an appropriate power supply is available. 450nm laser is an ideal light source for processing non-ferrous metals such as gold, copper and copper alloys.

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

Tech-X Corporation XSim



XSim is a powerful GPU-enabled FDTD tool for precise time-dependent EM simulations. With multi-GPU scalability, start on your laptop and seamlessly transition to AWS for faster, cost-effective results. Ideal for photonic integrated circuit designers, convert GDS files to detailed 3D simulations, optimizing performance and ensuring robustness against manufacturing variations. Achieve unmatched accuracy and efficiency.

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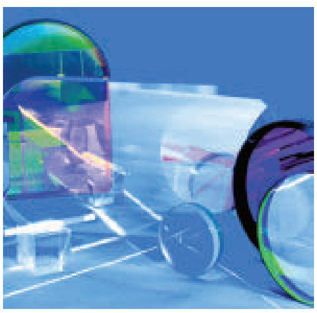
sales@txcorp.com **www.txcorp.com/xsim**

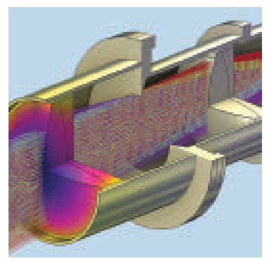
Thin Films and Optical Assembly



The Applied Optics Center has been and continues to be one of the preeminent suppliers of laser blocking and absorbing filters as well as optical assemblies to both the U.S. military and commercial industry. Five 2-meter coating chambers, along with various 1-meter and ½-meter chambers, place AOC in a unique position with regard to coating capacity. A wide variety of coatings on various substrates can be designed.

Applied Optics Center **(972) 629-1701**
info.aoc@optexsys.com **www.optexsys.com/aoc**

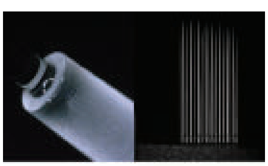
Multiphysics Modeling and Simulation



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**

The NYFORS SMARTSPLICER



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

NYFORS **+46 8712-1021**
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6-Axis Precision Hexapods

PI hexapods are supported by powerful, easy-to-use controllers, along with extensive programming examples and software tools for simulation and workspace verification.

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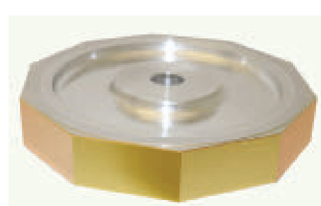

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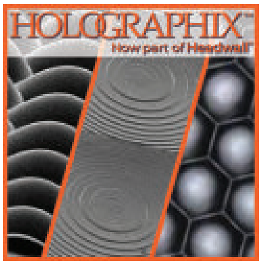

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Lighter Side

There was a little black spot on the sun 400 years ago

Ever since humans figured out how to walk on two legs, we have looked to the cosmos and wondered what celestial objects illuminate our night skies and how we all fit into it.

The Greek polymath Eratosthenes, for example, was the first person to calculate the circumference and axial tilt of Earth. Nicolaus Copernicus created one of the first models of the universe that was sun-centric instead of Earth-centric, and many years later, Edwin Hubble established both the fields of extragalactic astronomy and observational cosmology before his name got plastered onto a space telescope.

While scientists hold these early pioneers in astronomy in high regard, their once earth-shattering observations no longer answer our burning questions about the mysteries of outer space, at least until recently.

An international collaborative group led by Nagoya University in Japan is using sketches of the sun made by fellow space telescope user Johannes Kepler to understand the history of our great heat lamp. Specifically, the team is trying to resolve a controversy regarding the duration of solar cycles at the beginning of the 17th century, which are associated with the transition from regular solar cycles to the Maunder minimum: a unique, grand solar minimum in observational history during which fewer than 50 sunspots occurred within a 28-day period. For those who aren't astronomers, normal cycles with that time span show between 40,000 and 50,000 sunspots.

Johannes Kepler's 1607 sunspot sketches.

The sketches were created in 1607 with the use of a camera obscura, which is the fancy post-Renaissance name for a small hole in a wall that can project the sun's image onto a piece of paper. While the father of modern optics surely started in humble places, Kepler's sketches of the camera obscura image led to the discovery of sunspot clusters on the sun's surface. These areas exhibit such intense magnetic activity that they appear as darker blemishes.

Beauty spots aside, the sketches are important to the researchers, marking some of the earliest datable instrumental records of solar activity in the early 17th century. They even predate telescopic sunspot drawings by about three years. The year that Kepler made his drawings was between solar cycles on the way to the Maunder minimum, which tells researchers how the sunspots' gradual decrease in visibility depends on the solar cycle.

After running their tests, the researchers determined that Kepler's sunspots seemed to appear at the end of the previous solar cycle, suggesting a normal cycle duration and proving a few scientists' theories wrong in the process. The researchers find this fascinating, and not only because a 17th century genius continues to prove people wrong; the results also show that this part of the sun's history could inform us of its future, as well as how solar activity affects Earth.

The research was published in *Astrophysical Journal Letters* (www.doi.org/10.3847/2041-8213/ad57c9).

Courtesy of Nagoya University and iStock.com/sapannpix.