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December 2024

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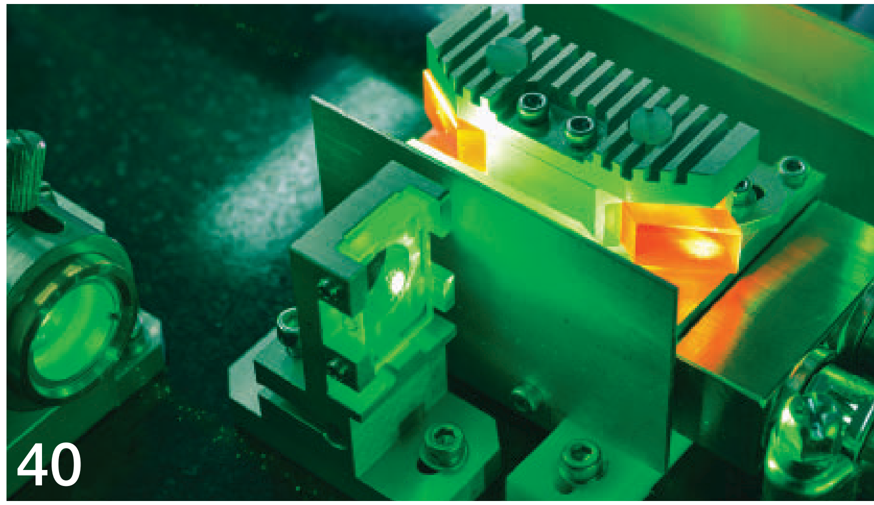
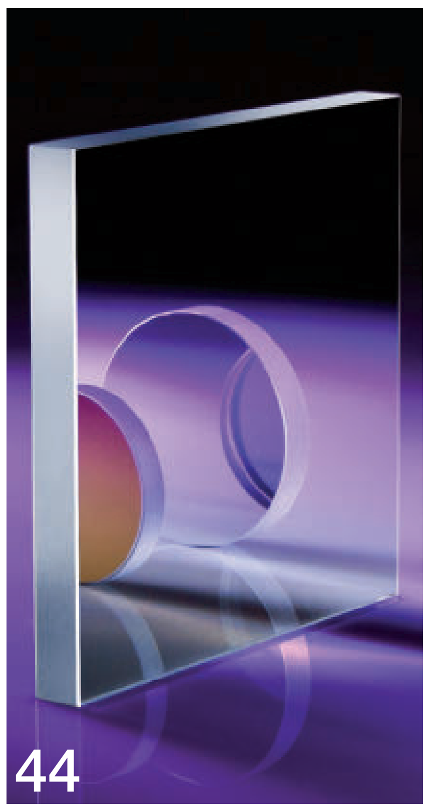
Inside This Issue

December 2024 volume 58 issue 12

Features





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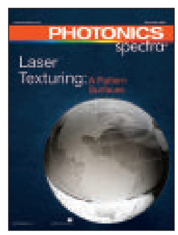
Departments

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

Columns



The Cover

From glass, to metal, to a range of composites, laser texturing is etching its mark in manufacturing as well as the fabrication of intricate designs. Image courtesy of iStock.com/Catshila. Cover design by Senior Art Director Lisa N. Comstock.

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Editor's Note

A familiar theme comes back into focus

Roel Baets' plenary presentation at Photonics West in January reiterated a common call from the global integrated photonics ecosystem: the need for a robust PICs supply chain. Widely considered a necessity to drive sustained growth in this technology space, the PICs sector has been adamant about its supply chain ambitions, particularly as it relates to manufacturing and packaging. Baets isolated many of the underlying factors that he and other experts have used to provide evidence for the importance of establishing a dedicated PICs supply chain.

Baets wasn't prognosticating outcomes for 2024 in his plenary. But the number of collaborations in integrated photonics and its subfields that industry and R&D launched this year make Baets look like a skilled forecaster. Newly formed collaborations spanning national, regional, and the global integrated photonics ecosystem emphasize that decision-makers in the photonics industry view cooperation as critical to overcoming the bottlenecks that lead to congested supply chains.

Collaboration is only one effect. And from a macro perspective, we will remember 2024 in photonics not for collaboration, but instead for the return of supply chain concerns. If not for 2020 and the pandemic, 2024 would be a leading candidate to earn the "Year of the Supply Chain" label.

There are certain differentiators between the pandemic-era shutdowns of four and five years ago and now. For one, today's supply chain complications are occurring on the heels of the aforementioned global shutdown, as well as the subsequent recovery operation. This sense of déjà vu may not offer a solution, but it does serve as a reminder that industry will seek, identify, and implement creative strategies to achieve an effective workaround. The current state of geopolitics, as it relates to global supply chains, represents a further contrast between then and now. Import and export restrictions are familiar hurdles to a streamlined flow of materials and components. The ongoing war in Ukraine, intensified scrutiny from the U.S. of Chinese silicon photonics, and the time that it takes for reshoring efforts to become fully functional have thrust supply chains into the spotlight, and with a new set of wrinkles.

Integrated photonics growth is an obvious area of worry amid these woes. Quantum is another technology space to monitor: In quantum photonics alone, many protocols and standards are still undeveloped. This creates the possibility for a frightening scenario: As quantum R&D advances, the inability to reliably procure the materials and components that are paramount to its advancement will severely hinder quantum's breakout moment.

Like Baets' start to the year, these end-of-year observations are not prognostications. Rather, they are reminders of how looking to the past offers meaningful perspectives for the future.

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Contributors

Achin Bhowmik
Achin Bhowmik, Ph.D., is CTO and executive vice president of engineering at Starkey and an adjunct professor at Stanford. He is a Fellow of the Society for Information Display (SID) and served as the president of SID. Page 54.

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. Pages 34 and 44.

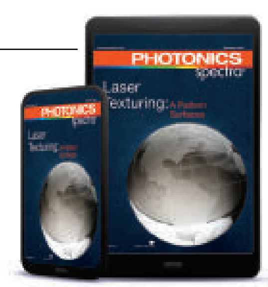
Joe Kuczynski
After more than 16 years of covering local news on television as a video journalist, reporter, and producer, Joe Kuczynski joined Photonics Media as a senior editor in 2024. Kuczynski leads the video department and performs editorial duties in support of *Photonics Spectra*. Page 40.

Mark Naples
Mark Naples is managing director at Umicore Coating Services. He has nearly two decades of experience working across the optics, sensing, and imaging industries. Page 49.

In the January 2025 issue of
Photonics Spectra...

- **PICs Supply Chain**
- **Nonvisible Imaging**
- **Silicon Photonics**
- **Micro-Optics**
- **Laser Microprocessing**
- **Optical Materials**

You'll also find all the news that affects your industry, from tech trends and market reports to the latest products and media.



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Photonics Spectra Webinars

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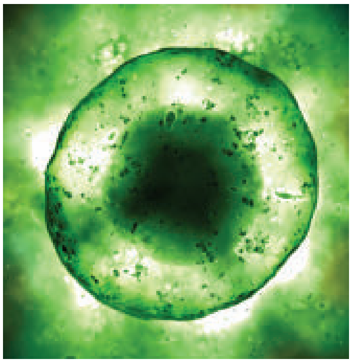
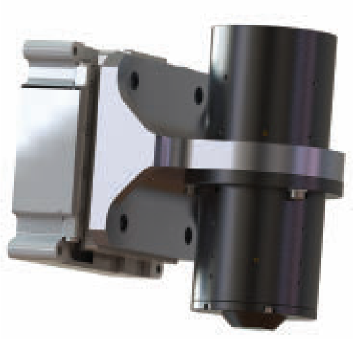
Multiplex Imaging: Camera, Lights, Optics, Action!



EXCELITAS TECHNOLOGIES

Multiplex imaging, either multicolor fluorescence or multispectral absorption and reflection imaging, is rapidly gaining popularity in the life sciences and medical arenas. Imaging samples at a variety of wavelengths, in live or fixed samples, provides a depth of information that was never possible to attain using conventional microscopy. This webinar discusses the options and requirements for performing multiplex imaging, from the illumination to the detection and the optics in between to navigate the light to and from the sample.
Presented by Excelitas Technologies Corp.
To view, visit **www.photonics.com/w1092.**

Accelerating Life Sciences Imaging Instrument Development with Unrivaled Performance and Speed



IDEX HEALTH & SCIENCE

Developing a high-performance fluorescence microscope is a challenging task, in which all subsystems must work in harmony. In this webinar, Joseph Mulley and James Feeks of IDEX Health & Science introduce key system architecture decision points and discuss their pros and cons. By considering the effect of each decision on the system, it is possible to design a more cohesive microscope that achieves a desired performance. The Melles Griot XPLAN CCG Lens Series and Dover Motion DOF-5 precision z-stage are introduced, with an explanation of how the components can enable a high-performance breadboard microscope under an accelerated timeline.
Presented by IDEX Health & Science.
To view, visit **www.photonics.com/w1102.**

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The editors of *Photonics Spectra* magazine invite you to the Hyperspectral Imaging Summit, a one-day virtual event premiering on Jan. 15, 2025. This summit explores breakthrough applications of hyperspectral imaging. All presentations will be available on demand following the premiere.

Industry experts from imec, ProPhotonix, EVK, Norsk Elektro Optikk, and ImagoAI will share actionable insights, with a focus on AI-enhanced imaging. Sessions include an examination of how AI-driven hyperspectral imaging enhances contaminant detection in grains; strategies for optimizing data output in industrial applications; advancements in on-chip spectral imaging; and methods for overcoming optical challenges in LED sources.

Registration for the summit is free and provides access to leading-edge knowledge that aims to boost understanding and applications of hyperspectral imaging. Join the conversation with industry leaders and discover how this technology can transform your work, and drive innovation in your field.

Website

For more information and to register, visit **www.photonics.com/HIS2025**.

Quantification of Mycotoxin Levels in Grains Using Hyperspectral Imaging & AI
Shweta Gupta and Abhishek Goyal, ImagoAI

Maximizing Output from Hyperspectral Data for Industrial Applications
Matthias Kerschhaggl, EVK

Addressing Complex Optical and Spectral Challenges of LED Light Sources in Hyperspectral Machine Vision
Matthew Branch, ProPhotonix Ltd.

On-Chip Spectral Imaging: New Developments Toward Commoditizing Spectral Imaging
Wouter Charle, imec

Upcoming Summits

Integrated Photonics — *February 12, 2025*

Spectroscopy — *March 12, 2025*

Infrared Imaging — *April 16, 2025*

Microscopy — *May 14, 2025*

Laser Optics — *June 11, 2025*

Photonics West Gears up for 2025 Showcase

San Francisco's Moscone Center will play host once again to the optics and photonics industries' premiere event from Jan. 25 to 30, 2025. Photonics West 2025 will feature more than 5000 technical presentations, and show organizers are expected to welcome more than 1500 exhibiting companies from around the world. Visitors will be able to explore the long-standing BiOS Expo and Photonics West Exhibition as well as the Quantum West Expo, which was introduced in 2024.

Photonics West 2025 will offer 100 conferences across the BiOS, LASE, OPTO, and Quantum West symposia. Program highlights include the annual BiOS Hot Topics plenary, which will feature a session on sensing in the surgical field through vision and robotics by Imperial College London's Daniel Elson. The University of Ottawa's Paul Corkum headlines the OPTO symposium with a presentation focusing on the importance of plasma in the generation of both attosecond and terahertz pulses.

Additional plenaries and keynotes will explore technologies in imaging, sensing, materials, and more. LASE symposium plenaries and Hot Topics sessions will feature Constantin Häfner from the Fraunhofer Institute for Laser Technology ILT and Aiko Narazaki from the National Institute of Advanced Industrial Science and Technology. Häfner will discuss the field of laser inertial fusion energy's recent boost and how it is affecting both the private and research sectors as well as how its acceleration to practicality will affect the wider photonics market. Narazaki's session will cover data-driven laser processing using high-speed data acquisition and AI data optimization for higher throughput and quality.

Quantum West will offer seven tracks: Quantum Information Systems; Quantum Communications; Quantum Computing and Simulation; Quantum Sensing, Imaging, and Timing Systems; Enabling Materials, Devices, and Techniques; Quantum Biology; and Complex Light and Optical Forces. Additionally, the Quantum West Business Summit will run from Jan. 27 to 29. Panelists and speakers include Peter Knight of Imperial College London, who will discuss the current and future state of quantum technology from the perspectives of both government and industry. Knight will be joined by top industry figures, including COO of Google Quantum AI, Charina Chou, who will serve on a panel discussing how quantum is transforming computational paradigms, and Roman Orus, chief scientific officer of Multiverse Computing.

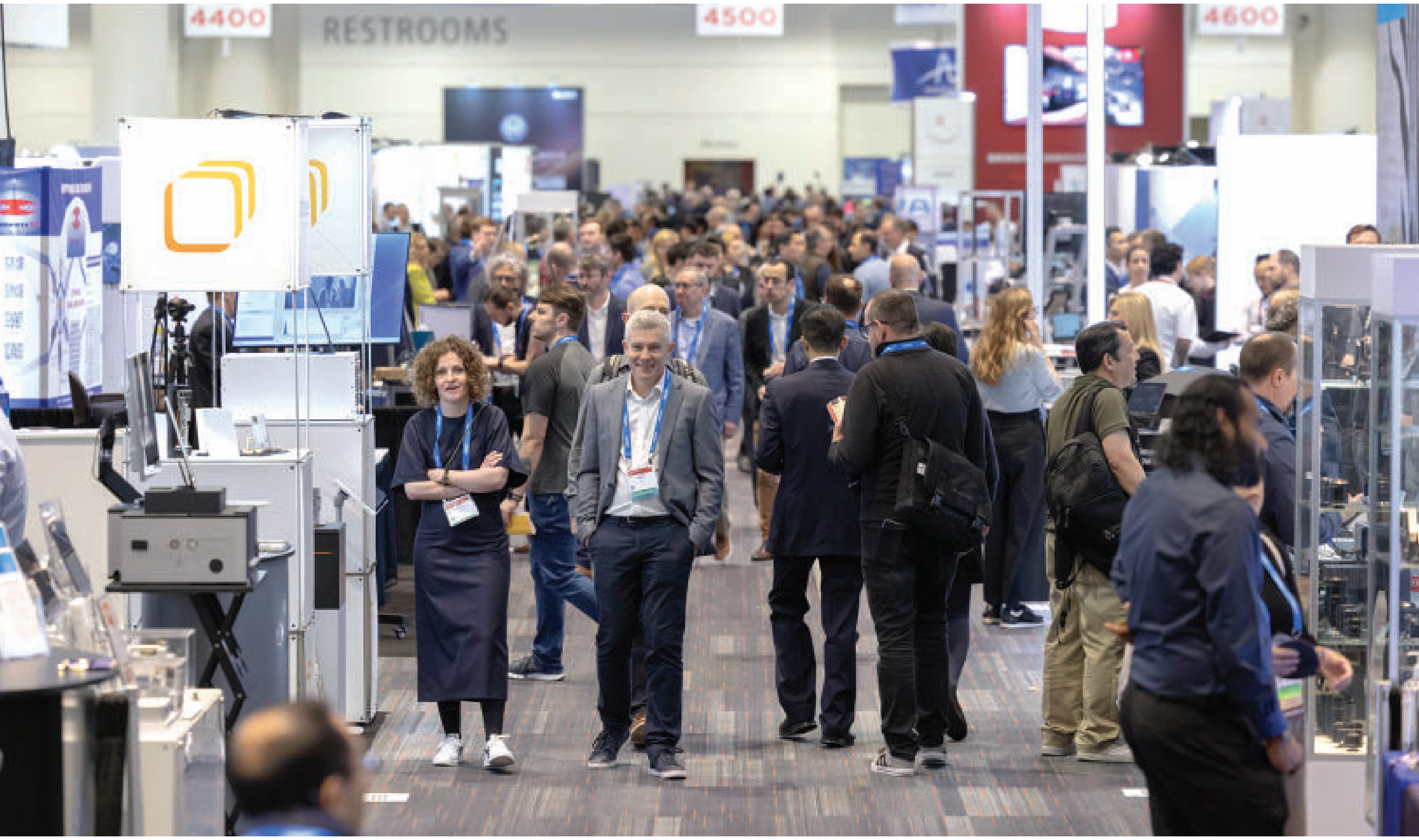
Following the BiOS exhibition, which runs from Jan. 25 to 26, the Photonics West Exhibition kicks off on Jan. 28 and runs through Jan. 30. The expo will offer product demos and product releases, with industry events scheduled for all three exhibition days. Photonics West company announcements are available to view before, during, and after the show via SPIE.org.

The 17th annual Prism Awards ceremony will be held on Jan. 29 during a gala event to honor the best new optics and photonics products on the market. The Catalyst Award will also see a second iteration. The award recognizes for-profit companies with specific socially or environmentally focused programs that have had a significant positive effect within their workplace, on society, or on the environment.

The annual SPIE Startup Challenge, in which participating companies vie for sponsored prizes and the attention of potential investors, will also return on Jan. 28. Companies will compete and present their business and financial cases to a panel of industry judges that includes venture capitalists and business development experts.

For more information and to register to attend Photonics West 2025, visit www.spie.org/photonics-west.

Images courtesy of SPIE.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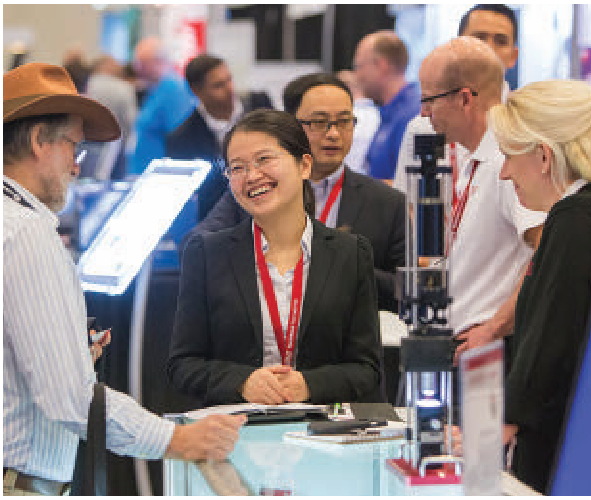


Industry News

Synopsys to sell Optical Solutions Group to Keysight

Synopsys will sell its Optical Solutions Group to Keysight Technologies, a provider of design, emulation, and test solutions. The sale is subject to customary closing conditions, including the successful closing of Synopsys' proposed $35 billion acquisition of Ansys, which is pending regulatory approvals and expected to close in the first half of 2025. Financial terms of the Keysight deal were not disclosed.

Synopsys' Optical Solutions Group provides design tools and services to model all aspects of light propagation for high-accuracy optical product simulations and visualizations. This includes products such as imaging systems design software, illumination design software, and a virtual prototyping platform for imaging systems. The acquisition broadens Keysight's design engineering software portfolio and builds on its core positions in radio frequency/microwave electronic design automation and physics-based, computer-aided engineering capabilities.

Synopsys will sell its Optical Solutions Group to Keysight. The deal, for which financial terms were not announced, is contingent upon Synopsys' close of its acquisition of Ansys.

Intel reorganizes, core photonics unit moves under new division

Intel will incorporate its integrated photonics solutions (IPS) business into its Data Center and Artificial Intelligence division. The decision represents one of several moves targeting strategic changes and reorganization that the company said it will initiate to support both near- and long-term profitability. The company also said that it plans to establish Intel Foundry as an independent subsidiary that is to operate inside of Intel.

With the release of its second quarter results, Intel said that it would pursue cost reduction measures to realize $10 billion in savings, including a 15% headcount reduction. In a message shared with employees, Intel CEO Pat Gelsinger outlined many additional forthcoming moves. Gelsinger also said that the company is now more than halfway to its workforce reduction target of approximately 15,000 employees.

Intel's IPS business develops light generation, amplification, detection, modulation, CMOS interface circuits, and package integration technologies. Earlier this year, the company introduced an integrated optical compute interconnect chiplet, co-packaged with an Intel CPU, that runs live data. In a separate move last fall, the company sold its silicon photonics-based pluggable optical transceiver product lines to Jabil in a transaction that enveloped the R&D of future generations of such modules.

According to Gelsinger, using a subsidiary structure for the foundry business will provide external foundry customers with clearer separation and independence from the rest of Intel, enable flexibility to evaluate independent sources of funding, and optimize the capital structure of each business to maximize growth. Intel also implemented an internal foundry operating model earlier this year, creating a foundry relationship between its Intel Products business and its Intel Foundry business.

Intel recently increased its capacity in Europe through its fab in Ireland, which will remain its lead European hub for the foreseeable future, the company said. Intel will pause projects in Poland and Germany for two years based on anticipated market demand but said that it will not be making changes to its U.S. manufacturing operations. It will move forward with projects in Arizona, Oregon, New Mexico, and Ohio.

Microsoft partners post quantum milestones

In collaboration with Microsoft, quantum computing developer Quantinuum has demonstrated 12 logical qubits on the newly updated 56-qubit System Model H2 quantum computer — representing a 3× advancement compared with the four logical qubits, which the companies announced in April.

"This represents the largest number of entangled logical qubits, with the highest fidelity, on record," Microsoft said in a blog post. Logical qubits combine multiple physical qubits together to protect against noise and maintain coherence for long-running computations.

Microsoft also used Quantinuum's System Model H1 quantum computer to run what the collaborating companies claim is the first chemistry simulation using reliable logical qubits combined with AI and high-performance computing to produce results within chemical accuracy. Additionally, the companies completed the integration of Quantinuum's InQuanto computational quantum chemistry software package with Microsoft's Azure Quantum Elements, making it available to customers through private preview.

Microsoft also established a partnership with Atom Computing to integrate and advance the company's neutral atom hardware into the Azure Quantum Compute platform. The collaboration diversifies the qubit architecture accessible through Azure Quantum.

Atom Computing is building second-generation systems with more than 1200 physical qubits and plans to increase the physical qubit count tenfold with each new hardware generation. Atom Computing's approach combines essential capabilities for expanding quantum error correction, including large numbers of high-fidelity qubits, all-to-all qubit connectivity, long coherence times, and mid-circuit measurements with qubit reset and reuse.

This month in history

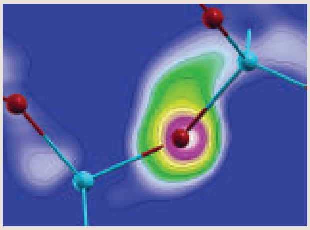
What were you working on five, 10, 20, or even 30 years ago? *Photonics Spectra* editors have perused past December issues and unearthed the following:

1994

Researchers at the Los Alamos National Laboratory developed an inexpensive manufacturing technique to produce flat-panel displays with true blue color. It included using cerium-doped material to produce blue light in electroluminescent displays, with a focus on using metallo-organic chemical vapor deposition to prepare crystalline thin films below 600 °C.

2004

Scientists with the U.S. Geological Survey and NASA used remote sensing to track the growth of a volcano dome around Mount Saint Helens. The team used airborne lidar systems along with photogrammetry measurements to create a digital elevation model of the volcano.



2014

A team at the Vienna University of Technology studied the further usage of a phenomenon in which quartz glass can take on metallic properties if subjected to ultrafast laser pulses. Further testing involved using different materials to induce the effect more efficiently.

2019

A research team led by Google AI Quantum (Google Quantum AI) demonstrated that a quantum computer can outperform a classical computer at certain tasks. The quantum computer, which consisted of 53 qubits, was tested against a computer from the Oak Ridge National Laboratory with more than 4600 compute nodes. The test showed a 1.5 trillion-times improvement in computation speeds.

NUBURU secures $65 million, including $50M in equity credit

Industrial blue laser developer NUBURU Inc. secured a comprehensive funding program of approximately $65 million. The funding comprises $15 million of direct investment and an additional $50 million equity line of credit provided through hedge fund Liqueous LP.

The deal between NUBURU and the Delaware-based hedge fund includes an immediate capital infusion of $3 million, along with further weekly installments of $1.25 million for a total of $10 million.

In November 2023, NUBURU entered into a bridge loan agreement with a principal amount totaling $5.5 million, two months before receiving a deficiency notice from the New York Stock Exchange indicating that the company was not in compliance with continued listing standards. In February, the company engaged financial advisor Northland Capital Markets and said it would evaluate options including a sale, merger, and divestiture. NUBURU additionally received a $3 million investment in the company's common stock from strategic investors in April, before receiving notice in July that the New York Stock Exchange had withdrawn its delisting determination and would lift the trading suspension on NUBURU common stock.

The company said that the newly announced funding will go toward its goal of long-term, sustainable growth along with putting it in the position to achieve commercialization and expand its intellectual property portfolio. NUBURU showed a net operating loss of more than $20 million for the year ending Dec. 31, 2023, according to its most recent annual report.

Briefs

The **U.K. Government** acquired **Coherent**'s semiconductor factory for an undisclosed amount. The newly rebranded **Octric Semiconductors UK**, which has the capability to manufacture gallium arsenide semiconductors, will be used to boost the U.K.'s defensive industrial capacity and exports.

The **U.S. Government** awarded **Intel Corporation** up to $3 billion to support the manufacturing of microelectronics and ensure access to a domestic supply chain of advanced semiconductors for national security. The funding was issued under the CHIPS and Science Act for a capability known as the Secure Enclave. The Secure Enclave program builds on previous projects between Intel and the Department of Defense, focused on microelectronic prototypes.

HyperLight Corporation, a provider of thin-film lithium niobate (TFLN) photonic integrated circuits received $37 million in series B funding to accelerate product development and boost production. The company's technology platform, based on TFLN, supports applications in optical communications, lidar, and sensing. HyperLight, founded in 2018, released a set of TFLN-based electro-optical modulators earlier this year, and has participated in research collaborations with MIT and Freedom Photonics, among others.

Trapped ion-based quantum computing company **IonQ** reported its demonstration of remote ion-ion entanglement, entangling two trapped ion qubits from separate trap wells by using entangled photons. The undertaking was enabled with a system to collect photons from two trap wells and route them to a single detection hub. The company sees the development as a next step forward in scaling its quantum systems and developing photonic interconnects. In a separate development, the company signed a $54.5 million contract with the U.S. Air Force Research Lab. The focus of the partnership is to design, develop, and deliver technology and hardware that enables the scaling, networking, and deployability of quantum systems.

Infleqtion, a neutral atom quantum technology company, signed a licensing agreement with **Thorlabs** to commercialize Infleqtion's integrated optical fiber collimation package. The agreement will allow researchers and product development teams to have more access to collimation capabilities.

Physik Instrumente (**PI**) opened a €20 million ($22.3 million) production facility in Eschbach, Germany. The facility expands PI's global production capacity by 6500 sq m for high-precision positioning technology and piezo applications. The company has stated that it has further developments planned for its facilities in Germany, the U.S., China, and Japan.

ZEISS opened its ZEISS Microscopy semiconductor applications lab in Dresden, Germany. The facility is located within the ZEISS Innovation Hub, which opened in May. The company said that the lab will address increased automation of microscopy workflows and techniques to help the semiconductor industry accelerate root cause analysis and pathfinding for challenges in microelectronics.

Jabil Inc. acquired **Mikros Technologies LLC**, a manufacturer of liquid cooling solutions for thermal management. The acquisition will provide Jabil with capabilities for helping its customers manage thermal requirements of its current and next-generation products. The company also said that Mikros' technologies and capabilities will complement Jabil's portfolio of data center lifecycle solutions, semiconductor test equipment solutions, and energy and transportation solutions.

Aeluma Inc., a developer of optoelectronics for sensing and communications, received $11.7 million in funding from the Defense Advanced Research Projects Agency (DARPA) to develop heterogeneous integration technology compatible with leading edge and future advanced-node semiconductors with potential applications in AI, mobile devices, and 5G/6G wireless communication.

Ephos, a producer of glass-based photonic integrated circuits, expanded its operations and closed an $8.5 million funding round. Per the expansion, the company opened a research and manufacturing facility in Milan. The site provides the capacity and resources necessary to scale the company's proprietary chip manufacturing technology as it expands its partnerships across the quantum technologies industry.

ZEISS plans for 2025 CEO transition

Andreas Pecher **(left)** will serve as president and CEO of Carl Zeiss AG effective, April 1, 2025. He will succeed Karl Lamprecht **(right)**.

Carl Zeiss AG

The supervisory board of Carl Zeiss AG appointed Andreas Pecher president and CEO of the company. The appointment will be effective April 1, 2025, and follows current CEO Karl Lamprecht's decision to not seek a contract extension.

Pecher joined ZEISS in 2013 and has been a member of the executive board, responsible for the ZEISS Semiconductor Manufacturing Technology (SMT) segment since 2022. He joined the company as head of strategic business development for SMT and has held management roles including head of the Semiconductor Mask Solutions and the Semiconductor Manufacturing Optics strategic business units.

Lamprecht has served as CEO of ZEISS since April 2020, having joined the company in 2005 as head of strategic business development for the SMT segment. He assumed responsibility for the entire segment as a member of the executive board of Carl Zeiss AG in 2018. In addition to serving as a member of the supervisory board of Carl Zeiss Meditec AG, Lamprecht also serves on the supervisory board of Körber AG and as chairman of the University Council of Aalen University.

Frank Rohmund succeeds Pecher as a member of the executive board and head of the SMT segment, effective Jan. 1, 2025. Rohmund currently heads the Semiconductor Manufacturing Optics strategic business unit. The board also extended the contracts of Susan-Stefanie Breitkopf and Sven Hermann by five years.

Radiant Opto-Electronics Corporation acquires NIL Technology

Taiwanese display manufacturer Radiant Opto-Electronics Corporation (ROE) reached an agreement to acquire NIL Technology (NILT). ROE and NILT are active collaborators, and the acquisition follows ROE's investment into the meta-optics technology company earlier this year.

The acquisition is subject to governmental approval and is expected to close in the first quarter of 2025. Per the deal, NILT will continue its operation unaffected, the company said, and will continue to support customers with design, prototyping, and mass production. The company is a developer of meta-optics technology and nanoimprint lithography (NIL)-based production processes. According to the company, its NIL-based manufacturing allows for high-volume production as well as greater precision and versatility in the creation of nanostructures for higher performance meta-optics. NILT raised $31 million earlier this year.

ROE, founded in 1995, is a manufacturer of backlight modules. In recent years, the company has updated and expanded its production capabilities and has established a complete molding and forming plant to expand its offerings. The addition of NILT is poised to strengthen ROE's position in advanced optics by adding meta-optics for imaging and 3D sensing as well as waveguide technologies for AR and VR applications.

ROE previously acquired Nanocomp Oy, a provider of micro- and nanostructured films, in a deal last year.

15.5%

— the expected compound annual growth rate of the global hyperspectral imaging systems market by 2032, according to IMARC Group

People in the News

Optica's membership elected **Turan Erdogan** vice president and **Christine Hendon** director-at-large. Erdogan serves as president of Plymouth Grating Laboratory Inc. and previously served as site leader of Melles Griot and CTO and vice president of business development for the IDEX Optics & Photonics platform. Hendon is an associate professor of electrical engineering and vice dean of diversity and strategic partnerships within the engineering school at Columbia University. Her research contributions include optical systems and methods to extract architectural information and identify structural substrates within tissue.

Hamamatsu Photonics' board of directors has made nominations for the company's directors and audit and supervisory board members as well as executive officers. Three directors and two audit and supervisory board members have been appointed along with five executive officers. This comes with the retirement of three current directors and two audit and supervisory board members as well as the promotion of four executive officers. New directors include **Ken Nozaki**, **Naofumi Toriyama**, and **Takaaki Kimura**; new audit and supervisory board members include **Shoji Nakano** and **Seidai Hirai**; and new executive officers include **Hiroshige Takada**, **Takashi Ogasawara**, **Kazuo Ueno**, **Toshimichi Ishizuka**, and **Naoki Uchiyama**.


TOPTICA Photonics

(From left) TOPTICA COO Mathias Schindler, CSO Thomas Renner, founder and CTO Wilhelm Kaenders, and CFO Fabian Uhl.

TOPTICA Photonics promoted **Mathias Schindler** to COO and **Fabian Uhl** to CFO. Schindler joined TOPTICA in 2016 as vice president of production and logistics before serving as the company's executive vice president. Uhl began his tenure at TOPTICA in 2019 as vice president of finance and controlling with previous experience as treasurer of Proteros USE Inc. and vice president of finance and administration at Proteros Biostructures GmbH.

LightPath Technologies Inc. named **Steven Garcia** general manager of the company's production facility in Orlando, Fla. Garcia brings more than two decades of expertise in domestic and international manufacturing to LightPath, most recently serving as director of operations at HT Global Circuits.

Intevac Inc., a supplier of thin-film processing systems, appointed **Kevin Barber** board chairman, succeeding **David S. Dury**, who has served as board chairman since 2017 and will remain on the board until the annual meeting of stockholders in 2025. Barber joined the board of directors in 2018 with previous experience as senior vice president and general manager of Synaptics' mobile division.

Iridex Corporation, a provider of laser-based medical systems, appointed **Patrick Mercer** to the role of CEO. **David Bruce**, the company's prior CEO, is transitioning from the company, and **Scott**

Lynred acquires New Imaging Technologies

Infrared sensor developer Lynred acquired New Imaging Technologies (NIT), a Paris-based developer of shortwave infrared (SWIR) imaging modules and sensors. In a strategic move to consolidate its leadership in IR sensors, Lynred said, the deal will expand its product portfolio to include large-format shortwave sensors with small pixel pitch.

In addition to NIT's SWIR products, the deal includes NIT's portfolio of wide dynamic range patents.

The transaction is expected to close later this year.

The acquisition will enable Lynred to further support its customers' needs in application areas such as AI, deep learning, and multispectral imaging. According to Lynred, NIT is the only Europe-based company to manufacture and market a SWIR HD 1080p array and associated module at a pixel size of 8 µm, which Lynred said is a key asset for several applications that it now aims to leverage.

"The global market for SWIR infrared imaging for machine vision is growing fast, as well as for defense applications, such as laser detection and in new space," said Hervé Bouaziz, executive president at Lynred, who joined the company with CEO Xavier Caillouet earlier this year.

In parallel to the acquisition, Lynred said that it is investing in its ongoing Campus project, which includes the construction of cleanroom spaces that will double Lynred's current capacity.

9.5% — the predicted compound annual growth rate of the global lidar market by 2030, according to Grand View Research

Shuda was appointed executive chairman of the company's board of directors. Mercer previously served as Iridex's COO and will retain the position of president.

PHIX

(Bottom row) PHIX CTO Jeroen Duis **(left)** and sales director Marcel van Veen with members of the PHIX sales team.

PHIX, a photonic integrated circuit assembly services company, transitioned **Jeroen Duis** to the role of CTO and named **Marcel van Veen** sales director. Duis previously served as PHIX's CCO along with a stint as a business developer for SMART Photonics.

Advanced materials solutions company Materion Corporation appointed **Jason Moore** president of precision optics. Moore most recently served as vice president and general manager of the industrial business unit for TE Connectivity in Zürich.

iPronics

iPronics CEO Christian Dupont **(left)** and founder and CTO Daniel Pérez-López.

iPronics, a reconfigurable photonics deep tech company, appointed **Christian Dupont** CEO. Dupont brings more than 30 years of experience in high-tech business and developing strategy, having previously served as the wireless general manager for Texas Instruments as well as CEO of several optical microelectromechanical systems (MEMS) startups. iPronics is the developer of an optical networking engine for data center management.

Edge computer developer Lattice Semiconductor named **Ford Tamer** CEO. Tamer replaces **Esam Elashmawi**, who served as interim CEO since June and will continue to serve as the company's chief strategy and marketing officer. Most recently, Tamer served as president and CEO of electro-optics solutions company Inphi for more than nine years.

Optical solutions provider Apollo Optical Systems named **Gregory French** a senior business development manager. Prior to joining Apollo, French worked for Optimax in roles ranging from manufacturing engineering to sales and account management.

Morphotonics

Hugo da Silva.

Nanoimprint technology developer Morphotonics appointed **Hugo da Silva** CEO. Da Silva has more than 20 years of experience in advanced materials, manufacturing, and commercialization. He most recently served as vice president of strategy and corporate development at additive manufacturing company Stratasys.

Photonic chiptech foundry New Origin named **Twan Korthorst** CEO. Korthorst, an integrated photonics industry veteran who has more than 25 years of combined experience in integrated photonics, microfluidics, and MEMS, most recently served as executive director of photonic solutions at Synopsys.

Polar Light, Finetech partner on micro-LED tech

Semiconductor equipment solutions provider Finetech and micro-LED developer Polar Light Technologies partnered to advance micro-LED technologies for next-generation AR and head-up and head-mounted display applications. The collaboration focuses on connecting micro-LEDs to silicon substrates.

The fabrication method developed by Polar Light, in which LEDs are built from the bottom up, avoids the surface damage seen in traditional top-down methods, resulting in better optical performance, according to the companies. The pyramidal shape of these LEDs enables smaller size, higher brightness, and greater emission efficiency, the companies said.

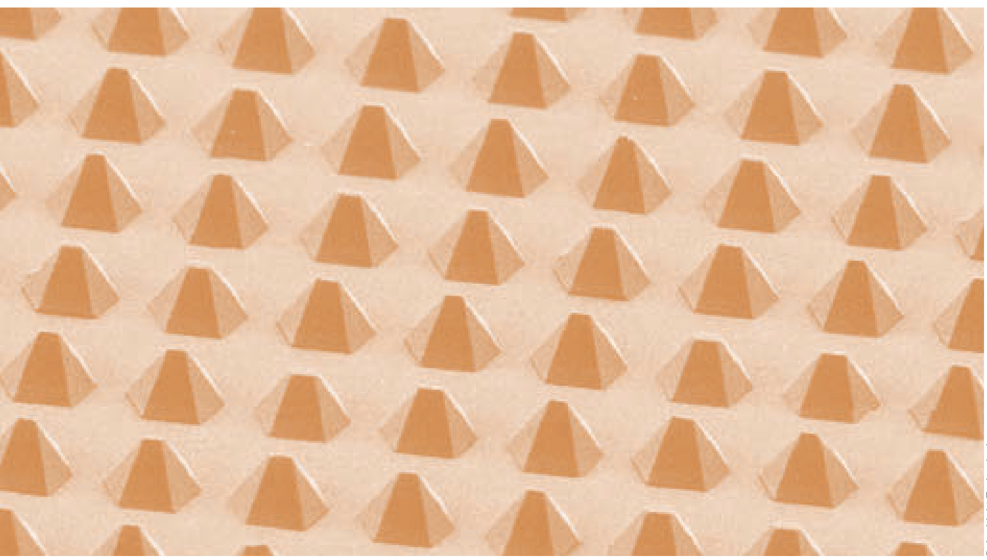
Specifically, the partnership aims to advance novel gallium nitride (GaN) pyramidal micro-LEDs that are directly bonded to indium pads on a silicon chip. Due to the differences in how silicon carbide and silicon expand with heat, heat cannot be used during the bonding process. Finetech and Polar Light developed a cold compression bonding method for aligning and bonding micro-LED arrays using an automated FINEPLACER femto 2 submicron die bonder. The companies reported an 85% success rate in early trials, which they said shows its potential for large-scale manufacturing.

Polar Light's approach to making display front panels uses a bottom-up fabrication method using atomic layer regrowth. The company grows GaN micro-LEDs on a silicon carbide substrate in a method that produces micro-LEDs as small as 300 nm without the damage that traditional top-down fabrication methods may cause. As a result, the devices have nearly perfect surfaces, which is crucial for optical properties.

The micro-LED displays developed through this process can fit the resolution of a full TV screen into an area <5 sq mm, with about 1000 × 1000 connection points spaced just 5 µm apart. Polar Light's design also significantly reduces energy use, making these micro-LEDs efficient for next-generation micro displays.

Compared with regular LEDs, the companies said, the pyramidal micro-LEDs improve AR system efficiency by 50 to 200× as a result of better internal and external quantum efficiencies and enhanced light use. Further, by minimizing internal electric field interference and optimizing the interaction between charge carriers in the quantum wells, the developed micro-LEDs produce more light with sharper, more narrow emission.

Polar Light's bottom-up fabrication process for pyramidal micro-LEDs uses a cold compression bonding method developed with Finetech.



Polar Light Technologies

PhotonDelta debuts integrated photonics-themed engineering contest

Netherlands-based photonic chip industry accelerator PhotonDelta launched a Global Photonics Engineering Contest to stimulate the creation of new applications for photonic chips. Rolled out in collaboration with Wevolver, a knowledge and community platform for engineers, the competition invites engineers to use the characteristics of photonic integrated chips (PICs) to innovate in fields such as health care, autonomous vehicles, AI, and agriculture by enabling advanced sensors for earlier diagnostics, safer infrastructure, and more efficient food production.

The goal of the contest, PhotonDelta said, is to discover future applications in segments that are yet to be invented. The winner will receive €50,000 worth of services to develop their concept as well as global exposure at an industry event. Participants will also have the chance to secure a loan of up to €2 million from PhotonDelta if selected by the accelerator.

Contest entries will be judged on the

$21.7B — the estimated size of the global tunable lasers market by 2029, according to Mordor Intelligence level of innovation, technical and commercial feasibility, and how effectively the design addresses current industry challenges. Participants are required to submit detailed descriptions of their projects, including team information and supporting visuals or videos.

The contest is backed by a €60 million ($65.7 million) fund from PhotonDelta. The event is supported by industry members SMART Photonics, LioniX International, Bright Photonics, Epiphany, and PHIX Photonics Assembly.

The contest was officially launched at PIC Summit 2024 in Eindhoven, Netherlands. Submissions will remain open until March 3, 2025, with PhotonDelta announcing the winner and runners-up the following month.

Ansys, TSMC, Microsoft boost high-speed optical data transfer

TSMC and simulation software developer Ansys completed a pilot with Microsoft that speeds the simulation and analysis of silicon photonic components. According to the collaborators, the successful pilot achieved >10× increased speed of Ansys' Lumerical FDTD (finite-difference time-domain) photonics simulation software via Microsoft's Azure NC A100v4-series virtual machines.

With NVIDIA accelerated computing running on Azure AI infrastructure to power the virtual machines, the collaborators said that the machines executed the simulations and identified optimal resources that balance cost with performance.

The overall result, they said, is seamless deployment, graphical interface access, scaling of distributed simulations, and post processing for large data sets in cloud environments.

According to Stefan Rusu, head of silicon photonics system design at TSMC, the size and complexity of the company's multiphysics silicon solutions make it a challenge to simulate all possible parameter combinations. The collaboration, he said, delivers accurate solutions in a fraction of the time.

The companies see the pilot as a solution to the design and fabrication of silicon photonic integrated circuits (PICs). The silicon PIC workflow is susceptible to minor missteps that may cause continuity challenges within chips, which can result in added cost and timeline setbacks of up to several months.

According to the collaborators, deploying Lumerical FDTD on the cloud enables designers to identify optimal chip designs to account for the multiphysics challenges related to combining photonic circuits with electronic circuits.

Partners bring hybrid solutions supply chain into focus

Three photonic integrated circuit (PIC) developers partnered to simplify and enhance heterogenous integration through micro-transfer printing (MTP). The collaboration, the companies said, aims to close existing gaps in the PIC value chain and offer faster transitions from R&D to mass production.

The collaboration brings together Ligentec, a developer and provider of silicon nitride (SiN) PICs; X-Celeprint, an MTP technology developer; and X-FAB, a specialty foundry for analog mixed-signal application-specific integrated circuits, microelectromechanical systems (MEMS), microsystems, and photonics.

"After years of intensive R&D, we are seeing significant uptake and interest in micro-transfer printing," said Kyle Benkendorfer, CEO of X-Celeprint. "The technology readiness level in photonics integration has reached the stage to bring it to the market, offering customers a powerful solution to overcome the challenges of hybrid PICs."

Per the collaboration, Ligentec will integrate photodetectors onto its SiN platform using MTP technology. This will be offered as an additional module to their regular multi-project wafer runs, providing an entry point for customers. X-Celeprint will contribute its expertise in process development, with X-FAB targeting scale-up from prototyping to volume production.

In this announcement, the partners identified the advancement of PIC technology toward chiplets, and specifically the desire to achieve hybrid solutions. Currently, they said, the industry lacks an integrated supply chain to streamline the path from development to production.

European initiative's quantum sensors to deliver climate insights

A research project launched by the European Commission with support from the European Union's Quantum Flagship initiative is developing quantum-enabled space-based sensors that aim to provide a sharper view of environmental changes on Earth. The project will use the technique of cold atom interferometry as the technological basis for sensors that are expected to aid in the monitoring of glaciers, sea level rises, and variations in groundwater levels.

The €17 million ($18.9 million) project, called CARIOQA-PMP (Cold Atom Rubidium Interferometer in Orbit for Quantum Accelerometry — Pathfinder Mission Preparation), will ultimately support the development of a quantum

Briefs

Amkor Technology Inc., an outsourced semiconductor assembly and test service provider, signed a memorandum of understanding with **TSMC**. Under the agreement, TSMC will contract turnkey packaging and test services from Amkor in its planned facility in Peoria, Arizona, outside Phoenix. TSMC will leverage these services to support its customers, particularly those using TSMC's wafer fabrication facilities in Phoenix. The companies will jointly define the specific packaging technologies, such as TSMC's integrated fan-out and chip-on-wafer-on-substrate that will be employed to address common customers' needs.

Telecommunications company **Softbank** and integrated photonics developer **NewPhotonics Ltd.** entered into a joint R&D collaboration to advance photonics technologies for linear-drive pluggable optics, co-packaged optics, and all-optics switch fabric. The technologies support SoftBank in AI data center and mobile fronthaul infrastructure with NewPhotonics' patented technologies, coupled with its photonic integrated circuits for all-optics communication and optical fabric switching. The technology will address power consumption and capacity bottlenecks in AI cluster workloads based on high-speed optical communication and optical switching technology, the collaborators said.

Lightwave Logic Inc. entered into a collaboration with **Polariton Technologies**, a manufacturer of plasmonic photonic integrated circuits, to demonstrate a packaged device with >110 GHz superhigh bandwidth packaged electro-optic polymer modulators. The demonstration uses Polariton's plasmonic modulator device design, and the packaged device contains a plasmonic modulator using electro-optic polymer material and platform chips that have demonstrated 400 Gbps.

Medical imaging company **SpectraWAVE Inc.** raised $50 million in series B funding to support commercial expansion and product additions for the company's HyperVue imaging system. HyperVue technology combines DeepOCT and NIR spectroscopy into an AI-driven workflow and image analysis offering. The platform was developed for intravascular imaging applications, including coronary stenting procedures, plaque morphology, and future adverse event risk.

Marvel Fusion closed a €62.8 million ($70.3 million) financing round that will enable the company to continue demonstrating its fusion concept at existing laser facilities and achieve full proof of technology at its Colorado facility by 2027. Marvel said that it was also selected by the European Innovation Council and SME's Executive Agency for its accelerator program, which entails a €2.5 million grant to scale fuel target production along with an equity investment of up to €15 million.

OpenLight, a photonic application-specific integrated circuit chip designer and manufacturer, entered into a strategic partnership with **Epiphany**, a fabless photonic design house. The partnership aims to advance the photonic integrated circuit design ecosystem: Per the collaboration, Epiphany will gain access to OpenLight's open heterogeneously integrated III-V-based process design kit.

accelerator that will allow scientists to see a complete gravity map of Earth in a much higher resolution.

Materials on Earth, such as rocks, minerals, and water, have different densities from place to place. Earth's gravity field is affected by the mass of these materials. The more mass in an area, the stronger the gravitational pull in that location. When large masses move or change, such as ice melting and flowing into the ocean or when groundwater is depleted, it changes local gravity.

Traditional gravity mapping can detect these differences, which can in turn yield insights on the location of underground water, how much ice is melting in the polar regions, or the location of natural resources.

From outer space, however, the picture of gravity is somewhat unclear. Using traditional gravimeters, weak gravitational signals from Earth pose a challenge to those attempting to measure fine-scale variations across different regions.

Cold atom interferometry relies on the principles of quantum mechanics to examine and exploit the wave-like behavior of atoms at extremely low temperatures. When atoms are cooled to near absolute zero, they move almost in slow motion, allowing for extremely precise measurements with lasers.

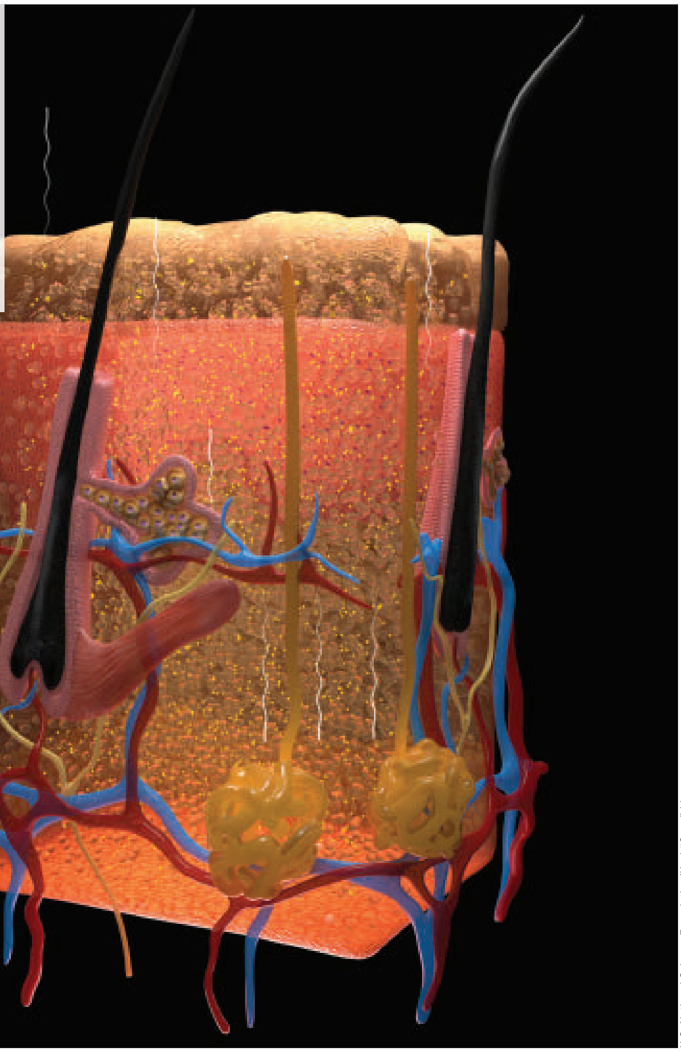
The European Commission project comes in two parallel parts: CARIOQA-PMP and CARIOQA-PHA (phase A). CARIOQA-PMP is focused on developing quantum accelerometry technology for use in space within the next decade. It will lay the groundwork for the Quantum Pathfinder Mission, with CARIOQA-PHA continuing the effort to demonstrate the feasibility of a Quantum Space Gravimetry Pathfinder Mission, through which the European Union is aiming to enable the deployment of quantum gravimeters and accelerometers in space.

Consortium partners include the French Space Agency, the German Aerospace Center, Airbus Defence and Space in France and Germany, Exail, TELETEL, Leonardo, GMV, and additional European laboratories and universities.

$25B — the expected size of the global optical transceiver market by 2029, according to MarketsandMarkets



Food dye curbs light scattering for living tissue imaging



An illustration of skin tissues rendered transparent following saturation by food dye tartrazine (FD&C Yellow 5) dye, including the paths of photons reflecting off undyed tissues.

U.S. National Science Foundation/Keyi "Onyx" Li

STANFORD, Calif. — The structure of biological tissues causes light to scatter during optical imaging, making tissue imaging difficult using this class of techniques. Also, each biomaterial comprising the tissue, whether a fat, protein, or other biomolecule type, has a different refractive index. The variety of refractive indices causes light to scatter as it passes through the tissue, making the tissue appear opaque. Tissue additionally absorbs light, which limits penetration depth.

Researchers at Stanford University developed a method that uses biocompatible, food-safe yellow dye to make living tissues transparent to visible light without increasing light absorption. The optical imaging approach could serve as the foundation for a straightforward, noninvasive way to help medical personnel diagnose a range of conditions, from injuries and internal disorders to cancer.

The researchers surmised that dyes that strongly absorb light could also be effective at directing light uniformly through different refractive indices. Using the Lorentz oscillator model for the dielectric properties of tissue components and absorbing molecules, they predicted that dye molecules with sharp absorption resonances in the near-UV spectrum (300 to 400 nm) and blue region of the visible spectrum (400 to 500 nm) could raise the real part of the refractive index of an aqueous medium at longer wavelengths when dissolved in water. As a result, the water-soluble dyes could effectively reduce the refractive index contrast between water and lipids, enabling optical transparency of live biological tissues.

The team found that the FDA-approved food dye tartrazine, or FD&C Yellow 5, could match refractive indices and prevent light from scattering when it was dissolved into water and then absorbed into tissues. By tuning the refractive index of the surrounding medium to match that of the cells, this dye made living tissues transparent.

The researchers conducted experiments in tissue-mimicking scattering hydrogels and ex vivo biological tissues. These tests confirmed the mechanism underlying the team's observations and showed the achievable spatial resolution down to the micrometer level. They also performed tests on slices of chicken breast and on live mice.

In the research, the team applied two long-standing optical concepts to its research — Kramers-Kronig relations, which are mathematical formulas, and Lorentz oscillation, a phenomenon in which electrons and atoms resonate within molecules as photons pass through. So far, these tools have not been applied to biomedical research explictly as the team used them. In the work, the researchers found these concepts to be valuable to predict how a given dye can raise the refractive index of biological fluids to match surrounding fats and proteins.

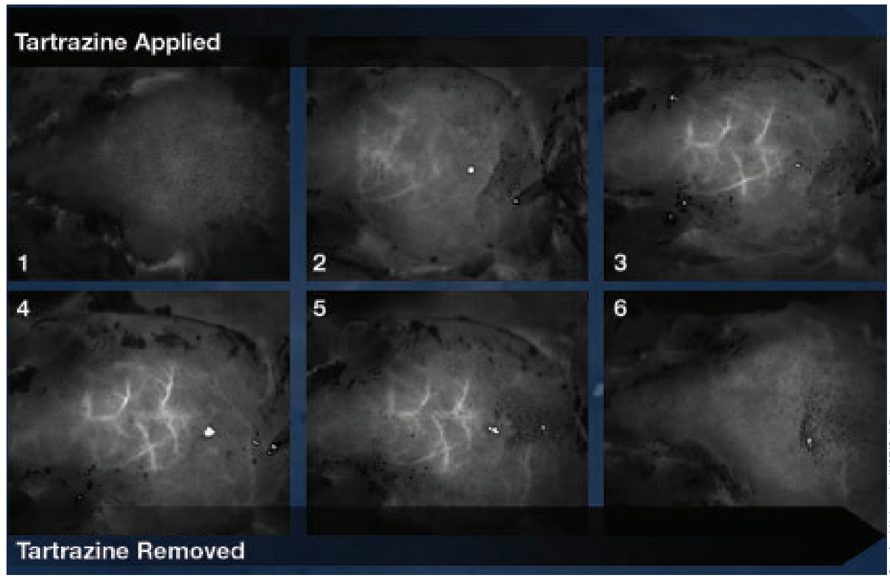
The researchers hope their approach will launch a field of study to match dyes to biological tissues based on optical properties.

"As an optics person, I'm amazed at how they got so much from exploiting the Kramers-Kronig relationship," said Adam Wax, program officer at the U.S. National Science Foundation. "Every optics student learns about them, but this team has used the equations to figure out how a strongly absorbing dye can make skin transparent."

This optical bioimaging approach offers a way to visualize the structure and activity of deep tissues and organs in vivo in a safe, temporary, noninvasive manner that could be used for a range of medical applications.

"Looking forward, this technology could make veins more visible for the drawing of blood, make laser-based tattoo removal more straightforward, or assist in the early detection and treatment of cancer," said Guosong Hong, a U.S. National Science Foundation CAREER grantee. "For example, certain therapies use lasers to eliminate cancerous and precancerous cells, but are limited to areas near the skin's surface. This technique may be able to improve that light penetration."

The results suggest that the search for high-performance optical clearing agents should focus on strongly absorbing molecules.



Stanford University/NSF/Gail Rupert

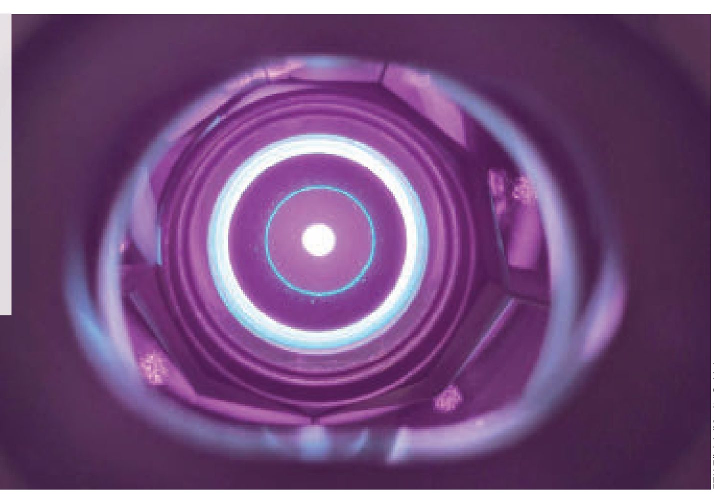
Time-lapse images of blood vessels in the brain just beneath the skull of a sedated mouse, revealed without any surgery, incisions, or damaging the mouse's bone or skin.

The research was published in *Science* (www.doi.org/10.1126/science.adr7935).

Keller-led team posts an ultrashort-pulse record

ZÜRICH — Researchers at ETH Zürich developed a laser that can produce extremely short pulses with peak powers of up to 100 MW and 550 W of average power. The researchers, led by Ursula Keller, a professor at the Institute for Quantum Electronics, report that the achievement marks a record — surpassing the previous reported maximum by >50% — and that the demonstrated pulses are the strongest ever created by a laser oscillator.

In demonstration, the pulses, lasting <1 ps, exited the laser in a regular sequence at a high rate of 5 million pulses per second.



The interior of the record-breaking thin-disk pulsed laser. The laser has an average power of 550 W and reached a peak power of 100 MW.

ETH Zürich/Moritz Seidel

The pulsed laser geometry includes an array of mirrors that send light through the laser's disk several times and a central semiconductor mirror with a thin sapphire window to automatically create the laser pulses.

"Pulses with powers comparable to the ones we have now could, up to now, only be achieved by sending weaker laser pulses through several separate amplifiers outside the laser," said Moritz Seidel, a Ph.D. student in Keller's research group. "The disadvantage of this is that the amplification also leads to more noise, corresponding to fluctuations in the power, which causes problems particularly in precision measurements." To create the high power directly using the laser oscillator, the researchers had to attach a thin sapphire window to the semiconductor layer of the semiconductor saturable absorber mirror (SESAM), which improved its properties.

According to Keller, the team expects to soon be able to shorten the pulses to a few cycles for the creation of attosecond pulses. The pulses could be used in new frequency comb designs in the UV to x-ray regime, which could lead to more precise clocks. Terahertz radiation can also be created with the laser, the researchers said, and used to test materials.

For the past 25 years, Keller has been working on the advancement of short-pulsed disk lasers, in which the laser material consists of a thin disk (100 µm thick) of a crystal containing ytterbium atoms. According to Seidel, the recent achievement was based on two factors. The first was an arrangement of mirrors that send the light inside the laser through the disk several times before it leaves the laser through an outcoupling mirror. "This arrangement allows us to amplify the light extremely without the laser becoming instable," Seidel said.

The second factor was the addition of a mirror acting as the "centerpiece" of the pulsed laser, and which was fabricated from semiconductor material. The reflectivity of this SESAM depends on the strength of the light hitting it. The researchers used SESAM to make the laser automatically produce pulses by reflecting high-intensity light, which had already made many passes through an amplifying disk.

"All in all, one can say that with our pulsed lasers we have shown that laser oscillators are a good alternative to amplifier-based laser systems and that they enable new and better measurement," Keller said.

The research was published in *Optica* (www.doi.org/10.1364/OPTICA.529185).

Spectroscopic headset could reveal stroke risk

PASADENA, Calif. — A stroke occurs when blood flow to the brain is interrupted — usually due to a blocked or damaged blood vessel — and brain tissue is damaged. According to the World Stroke Organization, there are 12.2 million new strokes per year around the world, with 101 million people living with long-term health effects.

Yet despite the danger that stroke presents to large segments of the population, clinicians have historically been at a disadvantage in successfully identifying those who are at grave risk of having a stroke.

A team from Caltech and Keck School of Medicine of the University of Southern California have created a headset based on relatively basic laser and detector technology that could be fitted on patients to dramatically change the health trajectory of those at risk. The scientists devised a way to monitor patients noninvasively by using a technique called speckle contrast optical spectroscopy, which measures the decrease in light intensity from where light enters the skull to where it is collected, as well as the degree of speckle. This determines the volume and flow of blood in the brain's blood vessels.

Using this technique in a study group, the team demonstrated that blood flow can serve as a guide for potential stroke risk prior to the onset of a catastrophic event among those likely to experience one.

For the study, the team chose 50 participants aged 18 to 65. The group was screened through the Cleveland Stroke Risk Calculator, which provides a preliminary stroke risk assessment based on indicators such as family history and general health. Subjects were asked to hold their breath, which alters blood flow and dilates blood vessels in healthy patients.

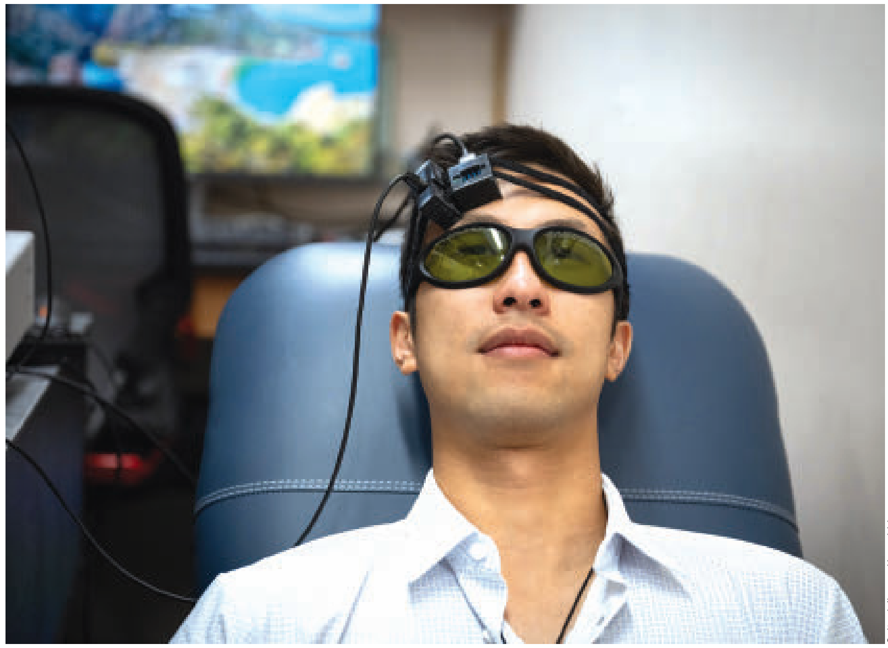
In their research, the team described the headset of relatively simple construction, containing a single-mode continuous-wave laser diode (at 785 nm) in a 3D-printed mount on the participants' foreheads. The mount was positioned 5 mm from the skin. A USB-board camera with a sensor was mounted on the other side of the forehead, collecting at a rate of 60 fps. Measurements were then taken before, during, and after each of the participants completed the breath-holding exercises.

Results indicated that the headset showed marked differences between low-risk and high-risk subjects; namely, those in the lower-risk category experienced higher blood flow, due to an inability of their blood vessels to fully dilate.

Simon Mahler, who is a postdoctoral scholar in the lab of Changhuei Yang and a co-author on the paper, said that the group now hopes to use the device to track several hundred patients over a five-year span. This would serve to make their data more robust, possibly aided by machine learning.

"Once we collect data from a larger cohort of subjects in future studies, we would like to apply machine learning techniques to further improve our results and potentially extract and identify new features," he said. Yang also said that there is potential for the headset for applications beyond stroke. "This instrumentation can also be used for traumatic brain injury detection, which is another project we are currently working on," he said.

The research was published in *Biomedical Optics Express* (www.doi.org/10.1364/BOE.534796).


Caltech/Lance Hayashida

Researcher Yu Xi Huang, wearing the speckle contrast optical spectroscopy device, which can assess stroke risk.

Douglas Farmer, Senior Editor
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Printing method delivers quantum dots for ultra-HD displays

DAEGU, South Korea — Advancements in wearable, mobile, and Internet of Things technologies are driving the demand for high-definition displays. Efficient, ultrahigh-definition displays can enhance the immersive experience of AR/VR applications and make AR, VR, and wearable technologies more comfortable to use.

Researchers at Daegu Gyeongbuk Institute of Science and Technology (DGIST), Ulsan National Institute of Science and Technology (UNIST), and the Institute for Basic Science (IBS, South Korea) developed a technique to create ultrahigh-definition screens for emerging display technologies. The researchers used the technique, called double-layer dry transfer printing, to build highly efficient LEDs with quantum dots.

As light-emitting materials for displays, quantum dots offer many advantages, including a high photoluminescence quantum yield, wide color range, and high color purity. But the development of a quantum dot patterning process for high-definition pixels and efficient quantum light emitting diodes (QLEDs) is still in the early stages. Conventional dry transfer printing, in which quantum dot ink is applied to a substrate, can be used to make ultrahigh-definition pixels. However, this method is avoided for actual display production because of its low luminescence efficiency of <5%.

Using the double-layer dry transfer printing technique, the light-emitting and electron-transferring layers of the device can be transferred onto a substrate simultaneously. This reduces interfacial resistance in the device, which facilitates electron injection and the control of leakage charge transport during the fabrication process.

"By using double-layer dry transfer printing technology to reduce interfacial resistance and facilitate electron injection, we have fabricated light-emitting devices that are simultaneously ultrahigh-definition and high efficiency," professor Jiwoong Yang said. "The light-emitting devices with double-layer thin films fabricated using this technology exhibited high [external quantum efficiency] of up to 23.3%, similar to the maximum theoretical efficiency of quantum dot light-emitting devices, which is a very significant result."

Surface engineering viscoelastic stamps enabled the researchers to use the double-layer transfer printing technique to create RGB pixelated patterns with 2565 pixels/in. and patterns of monochromic quantum dots with ~20,526 pixels/in.

The researchers used the quantum dot/zinc oxide (QD/ZnO) thin film to create ultrahigh-definition patterns of QDs of up to 25,526 pixels/in. and achieved an 8- × 8-cm area through repeated printing. They demonstrated highly efficient, wearable QLEDs made with the double-layer dry transfer printing technique. This confirmed the feasibility of using the technique to mass-produce the devices for commercialization, according to the researchers.

The research was published in *Nature Photonics* (www.doi.org/10.1038/s41566-024-01496-x).

Silicon photonic modulator streamlines atom interferometry

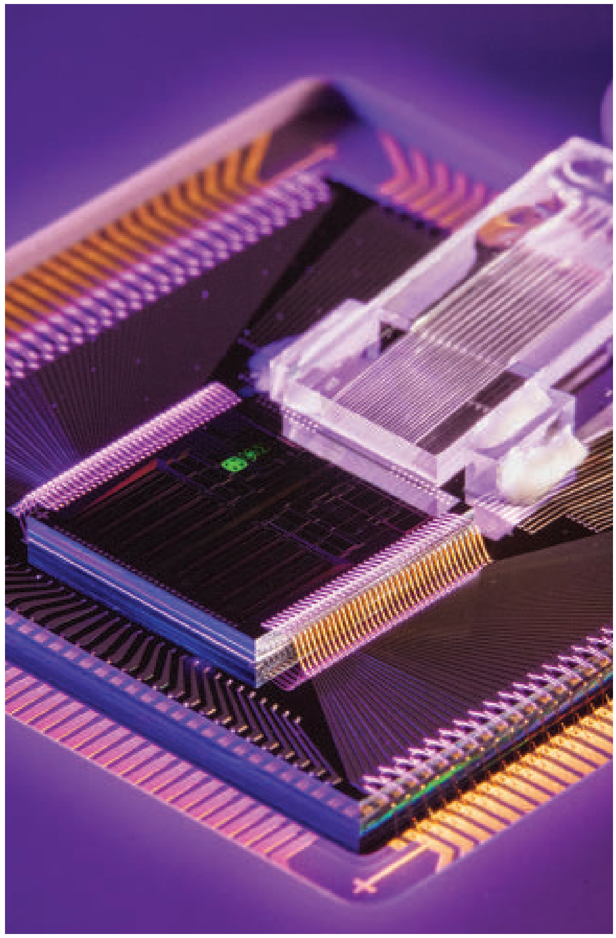
ALBUQUERQUE, N.M. — The development of a motion sensor that provides the necessary levels of precision for use as an alternative to global positioning satellites is ongoing, but such a physical device has historically been considered too large and too costly for practical use. Amid advancements to shrink the size and cost of this technology, researchers at Sandia National Laboratories reported the use of silicon photonic microchip components to perform a quantum sensing technique called atom interferometry — a precise solution to measure acceleration. According to the researchers, their advancement is the first time the technique has been achieved in this way and marks a milestone in the development of a quantum compass for navigation when GPS signals are unavailable.

"By harnessing the principles of quantum mechanics, these advanced sensors provide unparalleled accuracy in measuring acceleration and angular velocity, enabling precise navigation even in GPS-denied areas," said Sandia scientist Jongmin Lee.

Typically, an atom interferometer is a sensor system that fills a small room. A complete quantum compass — more precisely called a quantum inertial measurement unit — would require six atom interferometers.

But Lee and his team have been finding ways to reduce its size, weight, and power needs. They have already replaced a large, power-hungry vacuum pump with an avocado-size vacuum chamber and consolidated several components usually delicately arranged across an optical table into a single, rigid apparatus.

The newly developed high-performance silicon photonic modulator is the centerpiece of a laser system on a microchip. Rugged enough to handle heavy vibrations, it would replace a conventional laser system that is typically the size of a refrigerator.



Sandia National Laboratories/Craig Fritz

A four-channel, silicon photonic single-sideband modulator chip **(green)** inside packaging that incorporates optical fibers, wire bonds, and ceramic pins.

Lasers perform several jobs in an atom interferometer, and the Sandia team uses four modulators to shift the frequency of a single laser to perform different functions. However, modulators often create unwanted echoes called sidebands that must be mitigated.

Sandia's suppressed-carrier, single-sideband modulator reduces these sidebands by an unprecedented 47.8 dB — a measure often used to describe sound intensity but also applicable to light intensity — resulting in a nearly 100,000-fold drop.

"We have drastically improved the performance compared to what's out there," said Sandia scientist Ashok Kodigala.

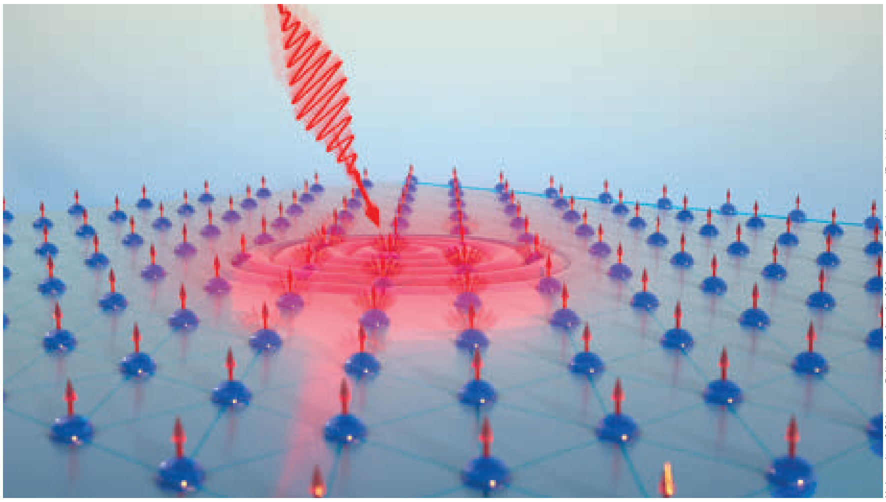
Cost has also been a major obstacle to deploying quantum navigation devices. Every atom interferometer needs a laser system, and laser systems need modulators. "Just one full-size single-sideband modulator, a commercially available one, is more than $10,000," Lee said.

Miniaturizing bulky, expensive components into silicon photonic chips helps drive down these costs. "We can make hundreds of modulators on a single 8-in. wafer and even more on a 12-in. wafer," Kodigala said.

And, because these modulators can be manufactured using the same process as virtually all computer chips: "This sophisticated four-channel component, including additional custom features, can be mass-produced at a much lower cost compared to today's commercial alternatives, enabling the production of quantum inertial measurement units at a reduced cost," Lee said.

The research was published in *Science Advances* (www.doi.org/10.1126/sciadv.ade4454).

Insulator material boosts optical memory device efficiency



University of Chicago, Pritzker School of Molecular Engineering/Peter Allen

Researchers in the Yang Lab at the University of Chicago's Pritzker School of Molecular Engineering made unexpected progress toward developing a new optical memory that can quickly and energy-efficiently store and access computational data.

CHICAGO — A material that is known for its potential as a magnetic topological insulator (MTI) could be put to different use. While investigating $MnBi_2Te_4$, a material composed of manganese, bismuth, and tellurium, a University of Chicago research team observed that the material's magnetic properties changed quickly — and easily — in response to light. From this response, the team inferred that a laser could be used to encode information within the magnetic states of the material to optically store computational data.

Using advanced spectroscopy techniques, the researchers further showed how the electrons in $MnBi_2Te_4$ compete between two opposing states — a topological state useful for encoding quantum information and a light-sensitive state useful for building energy-efficient devices that could be used for optical storage.

The team originally set out to explore $MnBi_2Te_4$'s capabilities as an MTI. Scientists believe that the material should be able to host a quantum phenomenon known as "electron freeways," in which an electric current flows in a 2D stream along the edges of the MTI. However, the material has been challenging to work with experimentally.

"Our initial goal was to understand why it has been so hard to get these topological properties in $MnBi_2Te_4$," professor Shuolong Yang said. "Why is the predicted physics not there?"

The researchers visualized the behavior of the electrons within $MnBi_2Te_4$ in real time on ultrafast timescales. They combined time- and angle-resolved photoemission spectroscopy with time-resolved magneto-optical Kerr effect measurements, working with researchers at the University of Florida to observe the electromagnetism at the surface of the material.

"This combination of techniques gave us direct information on not only how electrons were moving, but how their properties were coupled to light," Yang said.

The results of the analysis revealed why $MnBi_2Te_4$ did not show the behavior that is desired in topological materials: A quasi-2D electronic state in the material was competing with the topological state for electrons.

Theoretical modeling was able to capture the initial quenching of a surface-rooted exchange gap within a factor of two, but overestimated the bulk demagnetization by one order of magnitude. This explained the sizable gap in the quasi-2D electronic state and the nonzero residual magnetization in even-layer $MnBi_2Te_4$. At the same time, it revealed the potential for efficient, light-induced demagnetization that would enable magnetism and topological orders to be manipulated for future topotronics.

"There [are] completely different [types] of surface electrons that replace the original topological surface electrons," Yang said. "But it turns out that this quasi-2D state actually has a different, very useful property."

The second electronic state showed a tight coupling between magnetism and external photons. This condition is not useful for sensitive quantum data. However, it is essential for efficient optical memory.

To further explore the potential application of $MnBi_2Te_4$ for optically controlled magnetic memory, Yang's group will use a laser to manipulate the material's properties. Yang believes that a better understanding of the balance between the two electron states on the surface of $MnBi_2Te_4$ could improve the material's ability as an MTI and make it more effective for quantum data storage. "Perhaps we could learn to tune the balance between the original, theoretically predicted state and this new quasi-2D electronic state," he said. "This might be possible by controlling our synthesis conditions."

The research results could lead to advancements in optical memory. The team believes that an optical memory using $MnBi_2Te_4$ could be orders of magnitude more efficient than today's electronic memory devices.

The research was published in *Science Advances* (www.science.org/doi/10.1126/sciadv.adn5696).

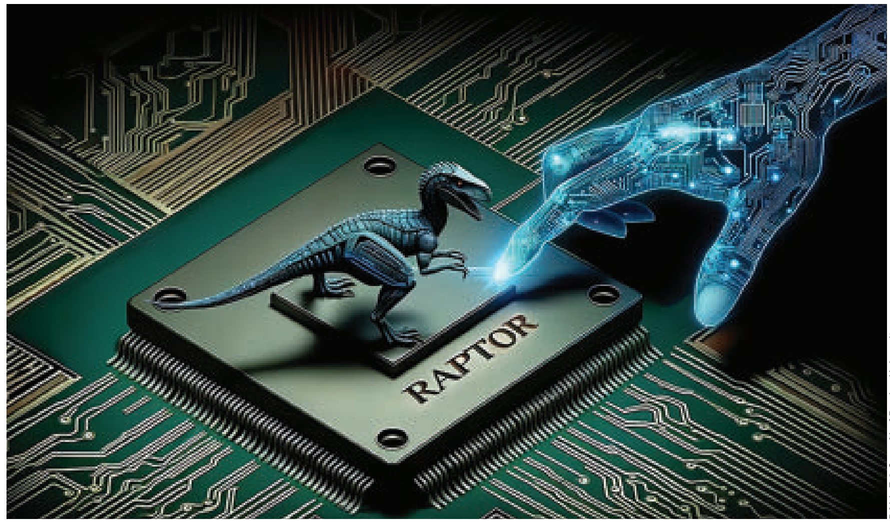
Deep learning-based method guards against chip tampering

WEST LAFAYETTE, Ind. — The $75 billion counterfeit chip market jeopardizes the safety and security of multiple sectors that depend on semiconductor technologies, including aviation, communication, quantum computing, artificial intelligence, and finance. A counterfeit detection method for semiconductor devices could help global chip makers and users evade the risks introduced by the surge in counterfeit chips emerging in the market.

The optical counterfeit detection method from Purdue University uses deep learning to identify tampering in semiconductor chips. The technology, called residual attention-based processing of tampered optical responses (RAPTOR), detects adversarial tampering, such as malicious package abrasions, compromised thermal treatment, and adversarial tearing.

According to professor Alexander Kildishev, who led the research, several techniques have been developed to verify semiconductor authenticity and detect counterfeit chips. "These techniques largely leverage physical security tags baked into the chip functionality or packaging," he said. "Central to many of these methods are physical unclonable functions (PUFs), which are unique physical systems that are difficult for adversaries to replicate either because of economic constraints or inherent physical properties."

Experts consider optical PUFs, which capitalize on the distinct optical responses of random media, to be especially promising for identifying counterfeit chips. However, achieving scalability and maintaining accurate discrimination between adversarial tampering and natural degradation pose significant challenges.



DALL-E 3 OpenAI of Purdue University

Purdue University engineers developed the optical counterfeit detection method RAPTOR. It uses deep learning to identify adversarial tampering in chips used in semiconductor devices.

The deep learning-based approach from the Purdue team identifies adversarial tampering to an optical PUF based on randomly patterned arrays of gold nanoparticles, which are used to construct a distance matrix. The researchers imaged the arrays using dark-field microscopy — according to researcher Yuheng Chen, a technique that can integrate seamlessly into any phase of the semiconductor fabrication process pipeline — and extracted the positions and radii of individual particle patterns using semantic segmentation and labeled clustering. The nanoparticles then underwent a treatment that typified either natural degradation or adversarial tampering. After exposing the nanoparticles to the treatment, the researchers remeasured the nanoparticle positions and radii and compared the post-tampered distance matrix to the pre-tampered distance matrix.

"The gold nanoparticles are randomly and uniformly distributed on the chip sample substrate, but their radii are normally distributed," Chen said. "An original database of randomly positioned dark-field images is created through dark-field microscopy characterization."

Test results indicate that RAPTOR can authenticate PUFs built on random arrays of gold nanoparticles faster and more accurately than classical distance matrix metric methods. However, more work is required in material development to ensure that the methods used in RAPTOR can recognize unforeseen types of tampering and natural degradation.

The team is planning to collaborate with chip-packaging researchers to further develop the nanoparticle embedding process and streamline the authentication steps. Purdue has applied for patents to protect the intellectual property.

The research was published in *Advanced Photonics* (www.doi.org/10.1117/1.AP.6.5.056002).

Method measures trapped qubits while keeping others safe, close

WATERLOO, Ontario — Quantum information is often difficult to protect during experiments. Protecting qubits from accidental measurements is essential for controlled quantum operations, especially during state-destroying measurements or resets on adjacent qubits in protocols such as quantum error correction.

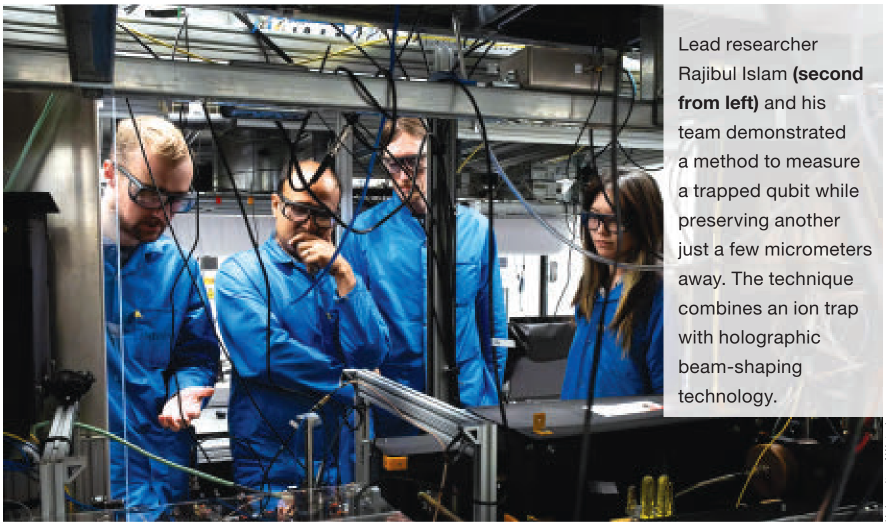
Although current methods to preserve atomic qubits against disturbances exist, these techniques can waste coherence time and extra qubits. They may also introduce errors.

Researchers from the University of Waterloo demonstrated a method to measure and reset a trapped ion qubit to a known state without disturbing neighboring qubits just a few micrometers away. The distance is smaller than the width of a human hair, which is ~100 µm thick. According to lead researcher Rajibul Islam, the researchers combined an ion trap with holographic beam-shaping technology, precisely controlling laser light to overcome the bottleneck.

The researchers said that the demonstration has the potential to influence future research in advancing quantum processors, enhancing speed and capabilities for tasks such as quantum simulations in machines that already exist today, and in implementing error correction.

The researchers used quantum theory to calculate how well light can be controlled and demonstrated that the error is in fact lower than originally conceived. Focusing on destructive qubit manipulation, which destroys the state of a qubit, the researchers used mid-circuit measurement to measure the state of qubits in a chain — a challenging process due to the proximity of the ions. Next, a laser beam was directed to manipulate the target qubit in a chain of qubits. The researchers ensured that laser light did not affect nearby ions just a few micrometers away, requiring extreme precision to minimize a range of interfering effects known as crosstalk.

"Trapped ion qubits are measured by using laser beams tuned to specific atomic



Lead researcher Rajibul Islam **(second from left)** and his team demonstrated a method to measure a trapped qubit while preserving another just a few micrometers away. The technique combines an ion trap with holographic beam-shaping technology.

University of Waterloo

transitions," Islam said. "The target ion scatters photons in all directions during this process. Even with perfect control over light, there is still a risk that these scattered photons could disturb the quantum states of nearby qubits, which limits how well we can protect them."

The researchers achieved >99.9% fidelity in preserving an asset ion-qubit while a neighboring process qubit is reset, and >99.6% preservation fidelity while applying a detection beam on the same neighboring qubit for 11 µs, which is the shortest measurement duration that was demonstrated by a separate research group.

The process of measuring a qubit without disturbing others is so fragile that, in other experiments, scientists are required to move the other qubits many hundreds of micrometers away to protect them. The process of moving qubits adds delay and noise to experiments.

"What we realized [was] that for all practical levels of errors, it's how well you can control this light and how much intensity you can suppress at the surrounding qubit — the bottleneck in all these measurements," Islam said.

The researchers said that the approach, using mid-circuit measurements and resets with controlled light, can be combined with other strategies. These include moving the important qubits away from the active ones or hiding quantum information in states that the measurement laser does not affect, to further reduce errors.

The research was published in *Nature Communications* (www. doi.org/10.1038/ s41467-024-50864-2).

Light source aims to build on Nobel Prize-winning technology

EDINBURGH, Scotland — Researchers at Heriot-Watt University are developing a light source for extremely fast laser pulses that will enable scientists to observe some of the fastest processes in the natural world as they occur. The source will capture natural processes such as light absorption in photosynthesis in attoseconds. The project supporting the work, FASTER (Flexible Attosecond Soliton Transients for Extreme Resolution) will debut next year and build on the extreme-ultraviolet attosecond technology that received the Nobel Prize in physics in 2023.

"My aim is to create laser pulses with similar extremely short duration to conventional attosecond science sources, but at the same ultraviolet and visible wavelengths as we get from the sun," said Christian Brahms, lead researcher on the work. Bringing attosecond resolution to ultrafast spectroscopy experiments in the UV, visible, and IR will enable scientists to study ultrafast dynamics entirely with nonionizing radiation, as well as without the need for strong field excitation or probing.

Ultrabroadband optical attosecond spectroscopy will be enabled by soliton self-compression. The researchers will create the optical attosecond pulses required for the source by building on the results of the recent High-Energy Soliton (HISOL) project. This effort combines the high damage threshold and far-UV transparency of gas media; the long interaction lengths enabled by waveguides; the guidance of high-energy laser pulses in large-core hollow capillary fibers; and the nonlinear evolution of ultrafast laser pulses in the higher-order-soliton regime. Using tailored soliton dynamics in hollow-core waveguides, the FASTER team will convert femtosecond pulses to attosecond pulses that will then be used on various samples to perform experiments that will use ultrabroadband optical attosecond pump probe and 2D spectroscopy.

While current attosecond technology, including the 2023 Nobel Prize-winning breakthrough, can create extremely short pulses of light at UV or x-ray wavelengths, it is limited when it comes to natural phenomena. FASTER will allow scientists to take "freeze-frame" images of very fast microscopic processes in molecules and materials. "This will fill in attosecond technology's blind spots and directly relate our knowledge of ultrafast processes to other areas, like photochemistry or materials science," Brahms said.

"Many of the most important breakthroughs in the history of science have been enabled by observing nature at scales far beyond the limits of human perception," he said. "That's exactly what we'll be working on — pushing far beyond the limits of conventional laser sources to bring fundamental science into focus."

Research on HISOL was published in *APL Photonics* (www.doi.org/10.1063/5.0206108).

Laser-Textured Components

Pervade Consumer and Industrial Markets

BY MARIE FREEBODY
CONTRIBUTING EDITOR

The range of benefits that laser texturing technologies offer, which span those in the critical areas of precision, performance, and efficiency, are direct drivers to the expansion of laser texturing's application into multiple industries. At the same time, the evolution of laser texturing-based technologies suggests that these technologies hold great promise to continue to spur innovation and improve the performance of many widely used materials, components, devices, and finished products.

By definition, laser texturing is the process of changing the surface properties of a material through laser light at a specific wavelength and intensity. Unlike chemical or mechanical methods, laser texturing enables noncontact, highly precise patterns and modifications of a material's surface with no tool wear or variance of process quality over time.

Image this page courtesy of GF Machining Advanced Solutions.

From improved grips and adhesives to aesthetically pleasing cell phone frames and light displays, laser texturing is essential for the fabrication of devices used in numerous markets.

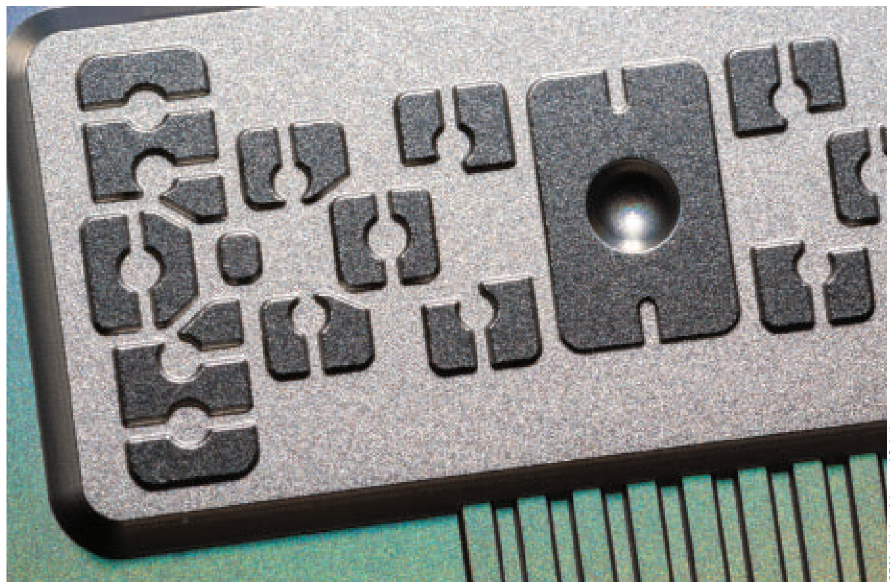
In this way, laser texturing falls somewhere between laser marking and cutting processes: Unlike laser marking, texturing involves some amount of material removal, but not full removal, as in laser cutting. Physical modifications are typically in the micrometer and submicrometer range(s).

Plastics, composites, and glasses

Essentially, any material that can absorb laser radiation at a specific wavelength can be treated via laser texturing. This includes polymers, composites, and glasses. Changing the topography of the surface of the material can create or affect specific effects that improve necessary performance and application qualities, such as friction, adhesion, and wetting as well as optical characteristics. Changes that are induced via texturing may also influence the way the material interacts with any surrounding fluid, air, or biological condition.

Certain laser parameters must be optimized, in addition to those with the material. These parameters include laser power, fluence, pulse duration, wavelength, and scanning speed — each of which must be optimized based on the properties of the material in use. For example, UV nanosecond-pulsed laser sources are generally used for plastics, ceramics, and glass due to the high photon energy.

Femtosecond (fs) pulsed lasers have the added advantage of multiphoton absorption mechanisms, which grants these sources widespread use in texturing materials that are typically transparent to the laser wavelength. “Even with infrared fs laser pulses, it is possible to achieve the antifogging effect on glass by introducing tiny ablation spots that are barely visible for the naked eye,” said Bogusz Stepak, R&D director of laser microprocessing at Fluence.



GF Machining Advanced Solutions

Beyond low roughness average values, laser micromachining offers precise control over surface finishes. Laser texturing exists between the techniques of laser marking and laser cutting: It offers some amount of material removal, like in marking, though not full removal, as in cuttng.

The viability to use femtosecond lasers to texture numerous types of materials makes these sources enabling technologies for a range of applications even beyond industrial. “High-performance, high-reliability fs lasers make it possible to perform laser surface modification of transparent brittle materials, such as sapphire and glass, a variety of ceramic compositions, and some types of polymers used in medical applications,” said Mark Keirstead, N.A. sales manager at GF Machining Advanced Solutions. Nonmetals, such as polymers, absorb long wavelengths and reflect shorter wavelengths, and the opposite is true of metals. This means that short-wavelength lasers are needed to process metals and longer-wavelength lasers are needed for nonmetals.

Femtosecond lasing enables an exception to this letter of this rule, because these lasers can be used to process all solid materials, even in the infrared. The ultrashort pulses provide the possibility of high-speed patterning of the surface with periodic structures that are comparable in size with the laser wavelength — and up to 10× smaller.

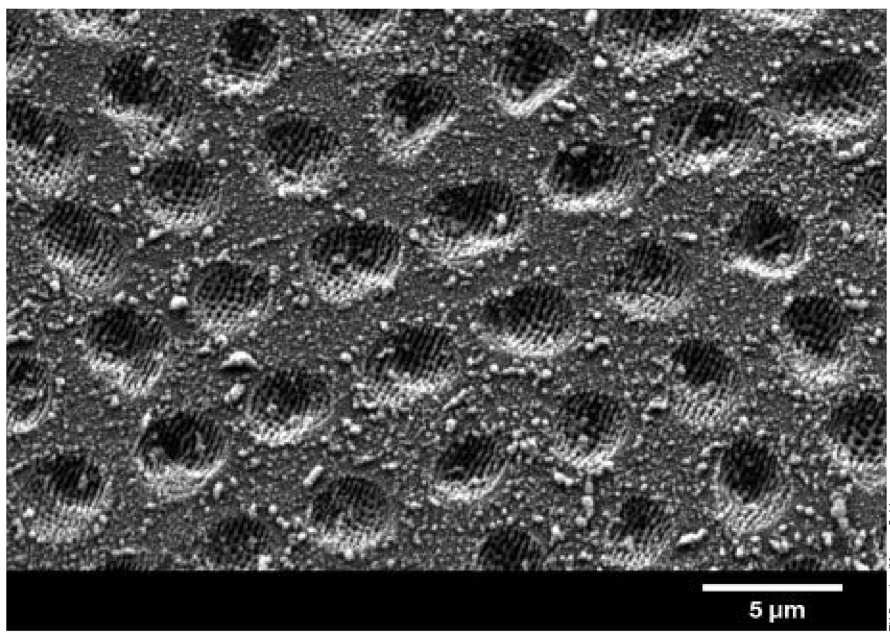
Among commonly used industrial lasers, CO_2 lasers have the longest wavelength, which makes them preferred sources for processing many polymers and composites. “These laser sources are typically paired with galvanometer scan heads to quickly sweep the focused beam across the surface of the material. Two-axis scan heads can process simple planes while three-axis heads can process complex 3D geometry,” said Justin Conroy, global application engineering manager at Novanta.

Elsewhere in the realm of industrial lasers, both metals and nonmetals benefit

GF Machining Advanced Solutions

The centerpiece features a brass dial, engraved and decorated with a femtosecond laser for superior quality and aesthetics **(left)**. The stainless steel exterior showcases five-axis capabilities, with deep engravings in white and blue, complemented by laser brushing to integrate the bezel with the outer cylindrical surface.

An image of a glass substrate processed using direct laser interference processing (DLIP) with a spatial period of 4 μm **(below)**.



TU Dresden/Marcos Soldera

from the flexibility and high efficiency provided by fiber lasers. At Allied Scientific Pro, for example, the process of laser texturing metals, such as aluminium, uses high average power pulsed master oscillator power amplifier fiber lasers.

"We use a 300-W average power, between 100 and 350 ns of pulse width and pulse frequency in the kilohertz range," said Yuhao Qiu, photonics specialist at Allied Scientific Pro. "For optics, the main [parts are] mirrors and an f-theta lens."

Although optimized laser parameters depend entirely on application, material, and desired outcome, processing methods are typically very similar, and require only subtle adjustments to laser power, speed of marking, and pulse control. Common methods include direct laser interference patterning (DLIP) and direct laser writing. The exact method required further depends on the resolution or feature size that is needed.

Laser-patterning ceramics

Laser patterning involves the creation of specific geometric patterns on the surface of a material. It is commonly used to create microchannels, grids, and other intricate designs, with applications in opto- and microfluidics, sensor fabrication, and electronic device manufacturing. With ceramics, laser patterning can create microchannels on the material surface to enhance heat dissipation in electronic devices. A recurring challenge in laser processing ceramic materials involves results than can appear visually misleading: Some laser sources can pattern ceramic surfaces so they appear suitable upon visual inspection, but may weaken the tensile strength of the material. Defining the optimal laser parameters without causing any change in the tensile strength of the finished part is imperative for medical implants and aerospace and defense applications, among others.

For the most common applications of laser patterning, laser-textured surfaces can improve light extraction, enhance signal transmission, and enable precise control of optical properties. This is useful in the fabrication of microelectromechanical systems (MEMS), photonic devices, and sensors.

A wood handle is laser textured to improve handgrip qualities.

Fluence

"In ceramics, laser texturing can enhance mechanical properties, alter electrical conductivity, or improve surface wettability," said Ilya Noskov, technical marketing manager in the Laser Marking Technologies Division at Keyence. As it relates to medical implants, laser texturing is used to increase the chances to achieve a positive outcome in osseointegrations. In aerospace and defense, laser texturing is necessary for surface modifications of electronics for better performance and improved wear resistance of components, Noskov said.

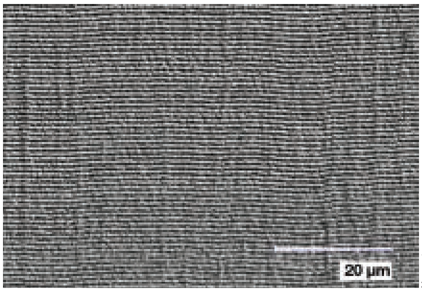
Direct laser interference patterning-glass

Direct laser interference patterning involves the use of two or more coherent laser beams that intersect on the material's surface to create an interference pattern. This pattern can produce periodic structures with high precision and uniformity. The method is suitable for creating large-area textures and is commonly used in the fabrication of diffraction gratings, photonic crystals, and antireflective surfaces.

"In DLIP, several laser beams that are obtained from a single laser source are recombined at the material surface, creating an interference pattern with different geometries like lines or dots," said Andrés Lasagni, a professor at Technische Universität Dresden, Germany, where he also serves as chair of laser-based manufacturing. "The material is then locally modified by melting or ablating at the interference maxima positions."

DLIP is highly effective for modifying the surface of glass materials used in display technologies. By creating precise patterns on the glass surface, laser texturing can enhance light extraction and improve display brightness. This makes it ideal for use in the production of OLED and liquid crystal displays, where it is important to achieve high-resolution patterns that enhance the overall visual performance.

The effectiveness of DLIP extends to modern advancements in automotive lighting using LEDs. For automotive lighting applications, LEDs demand optical components that appropriately disperse LED light for safety as well as for branding and design purposes. Plastic covers, which have micro-optic surface structures that have been transferred from a glass mold to the plastic part, disperse light evenly. The micro-optic features are laser-machined into the glass mold using femtosecond lasers, which are capable



Novanta

A depiction of laser-induced periodic surface structures on stainless steel, induced by an infrared femtosecond laser. The processing throughput for the depicted sequence is 22.8 cm^2/s at 60 W average power.

of processing the small geometries with sharp edges and no burr or slag.

Direct laser writing composites

Direct laser writing is a technique in which a focused laser beam is used to write patterns directly onto the surface of a material. This process involves the selective removal or modification of material to create the desired texture.

As in DLIP, direct laser writing is particularly useful to make high-resolution patterns and involves combining two or more distinct phases to precisely modify the composite's surface without affecting its bulk properties. In aerospace applications, for example, the technology is used to create microstructures on composite surfaces to improve aerodynamic performance and reduce drag. Additionally, direct laser writing can be used to fabricate complex conductive patterns on composite materials for electronic applications.

Direct laser writing is limited to the diffraction limit when focusing the laser beam, which means typical feature sizes range from ~10 to 50 µm. On the contrary, DLIP enables resolutions even better than 1 µm.

Again, laser texturing composite materials brings together considerations to both practicality and design aesthetics for numerous applications.

"In composites, laser texturing can tailor surface properties to improve bonding with other materials, reduce friction, or enhance aesthetic appeal," Noskov said. "Applications include automotive parts (improved bonding with coatings), sports equipment (enhanced grip), and aerospace structures (optimized surface characteristics)," he said.

Laser ablation of polymers

Laser ablation involves using the energy from the laser to remove material from a surface by vaporization or sublimation. This technique is highly precise and can be used to create complex 3D textures. For example, rubber shoe soles are textured to improve grip performance, and plastic cell phone frames are textured to alter aesthetics for a more premium or metallic look without adding weight.

Laser ablation is also effective for materials that are difficult to machine using other traditional methods. It is widely used in applications such as medical device manufacturing — specifically to improve the adhesion of coatings in packaging and controlled fluid flow in microfluidic devices — and aerospace component fabrication, and also in materials research. The laser texturing of polymers can improve surface properties such as wettability and adhesion as well as optical characteristics.

A material's absorption for a specific wavelength is key to achieving an efficient process without charring, while the correct output power is needed to achieve the process speed needed. CO_2 lasers meet these demands for polymers, effectively interacting with the surface and enabling high control of laser pulsing for varying surface properties.

"Oftentimes the texture consistency requires very good power stability from the laser source to get acceptable results, as in the case of roughing surfaces for consistent glue adhesion," Novanta's Conroy said. Novanta's ti100-HS CO_2 laser model is used for high-end texturing and additive manufacturing applications, he said.

Another consideration is that the approach to processing differs for thermoplastics compared with thermoset plastics; thermosets are more likely to chemically degrade and char, and thus more process parameters may be needed. In addition, a pulsed laser with high-energy pulses may be required to quickly ablate the material without degradation.

"UV and deep-UV fs lasers can perform ablation and selectively activate the polymer surface to make it more hydrophilic without damage to volume," Stepak said. "And, both chemical and geometrical modification can be achieved at the same time with the highest precision even for medical-grade polymers."

Future challenges

Laser texturing hard and brittle nonmetal materials requires a high-quality machine capable of processing homogenous surfaces on oftentimes complex shapes. Further, the various approaches to laser texturing often require a seamless pattern projected onto a highly contoured 3D part. For the most part, five-axis control within the laser machine is required. This in turn means that sophisticated software is needed to ensure that the application is performed correctly.

"If the part surface is not a flat plane, then it can be difficult for more basic laser systems to focus the beam consistently on it," Conroy said. "More complex multi-axis scan heads or multi-axis part handling equipment is needed to keep the surface at the focus point of the laser beam at all times."

To address this set of requirements, several European-level projects are focusing on implementing high-power short and ultrashort laser sources combined with new optical concepts and advanced sensors. The goal of these efforts is to distribute laser energy more efficiently across the material's surface to prevent heat accumulation that could damage the material's intrinsic properties, while also enhancing productivity.

"The aim is to efficiently distribute this energy to avoid heat damage and boost productivity," said Lasagni, who is also the coordinator of the CLASCO (Climate Neutral and Digitized Laser-Based Surface Functionalization or Parts with Complex Geometry) project.

At the same time, the emergence of new polymers and ceramic materials is placing correspondingly new demands on the performance capabilities of laser systems. Because new materials have novel absorption curves, and absorption curves are unique to materials, the determination of new laser wavelengths, to better absorb new material types, is a constant undertaking.

These challenges have not diminished the need for a non-damaging green solution that eliminates the multiple steps required in a chemical etch process. Laser texturing continues to displace chemical etching processes in existing as well as new application areas.

"With femtosecond lasers, patterning or surface functionalization can be performed on any material. The latest studies show the possibility of achieving durable functional surfaces such as antifog without using chemicals and multiple processing steps," Stepak said.

"This is truly green technology. Modern femtosecond lasers provide power levels that will enable the manufacturing of a new generation of functional surfaces on the mass scale."

The ongoing investigation to use laser surface texturing to modify the thermal properties of materials further supports laser texturing's robust and enduring application potential. Thermal management is a critical challenge across industries, and laser surface modification is a promising technology to solve this problem. Features created via surface ablation can alter a material's surface area or emissivity and improve heat transfer efficiency.

"Ultrafast lasers have become increasingly popular in these surface texturing applications," said Mark Turner, CEO and founder of Turner Laser Systems. "In addition to being able to delicately ablate the surface into a different texture, they also offer the ability to modify the surface into highly periodic nanostructured patterns through a mechanism known as laser-induced periodic surface structures (LIPSS)."

Other applications of LIPSS include altering optical properties, wetting properties, friction, wear, de-icing and controlling bacterial growth.

"With higher power levels available and the cost per watt of ultrafast lasers decreasing, commercial viability has significantly improved, opening up more applications," Turner said. Still, according to Turner, motion control over complex-shaped parts remains a challenging task in the engineering domain.

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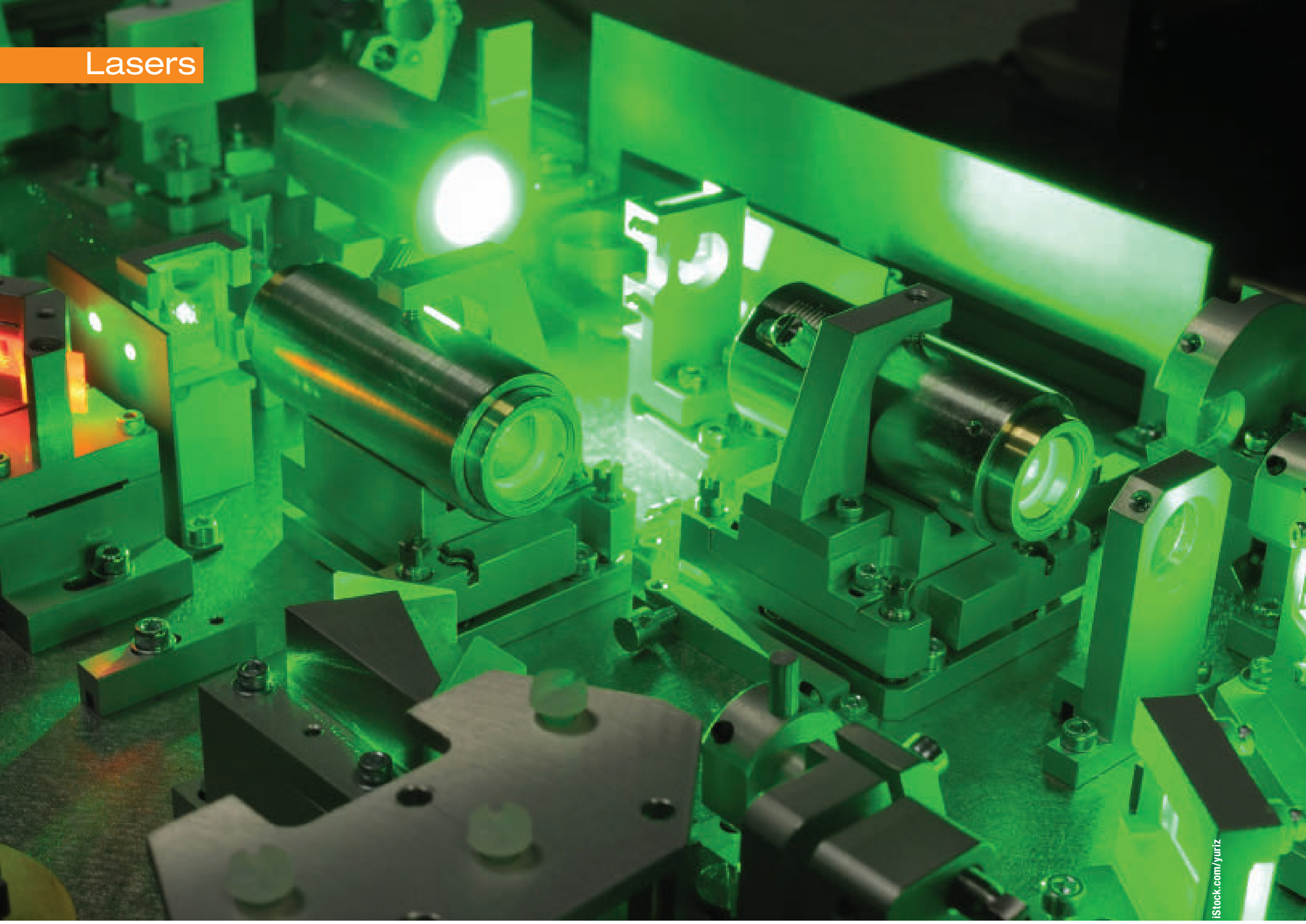


A Quantum Tool Set Could Reshape Laser Beam Profiling

Existing beam-profiling practices may not be well suited for emerging classes of extremely small and powerful lasers. A quantum 'tool set' is poised to offer a solution.

BY JOE KUCZYNSKI
SENIOR EDITOR

With applications for lasers constantly expanding, the need to precisely monitor the lasing process to ensure optimal and repeatable performance places stringent requirements on beam-profiling mechanisms. Industry widely agrees on many of the standards that govern effective beam profiling as well as the parameters — such as power, shape, and energy — for which data is needed to determine the utility of the laser.

Similarly, in the context of profiling and measuring a beam, industry has also reached an understanding of which qualities are changeable and which are not. With these factors in mind, operators select the precise time to measure a beam in-process, gather data, and sort it in a way that yields information on the most meaningful parameters. This information enables users to calculate more than the physical parameter of the beam: It can also be used to deliver insights into how to best use the laser.

Still, current beam-profiling and measurement practices often rely on equipment that is big and bulky, which may present a bottleneck for many high-power and on-chip lasers. To acquire the full picture, a tool set based on quantum mechanics is needed to provide a more complete understanding of lasers on the extreme ends of the spectrum.

A whetstone to an axe

Beam profiling, by its simplest definition, describes the process of finding and analyzing the spatial intensity distribution of a beam. Laser beam profiling is not a new practice, and the fact that evaluating different parameters provides insights of varying significance to a given application is hardly novel.

In many ways, the laws of physics, and even logic, can be applied to determine how and why a beam behaves. Consider for example that a polarization parallel to a laser cut leaves a smoother surface than an angled approach.

For this reason, beam profiling has historically been the means by which users gather spatial intensity distribution, polarization, and other data and tune their lasers accordingly, much as a logger may use a whetstone on an axe. According to Asger Jensen, senior market development manager at NKT Photonics, the quality of the beam profile has a direct tie to the overall efficiency of a given process. Sophisticated applications, such as those in the quantum realm, increasingly necessitate the use of specialty laser systems, including high-power fiber lasers.

"At a very high power, you do get distorted beam profiles even in fibers, and so of course beam profiling is an important part of what we do," Jensen said.

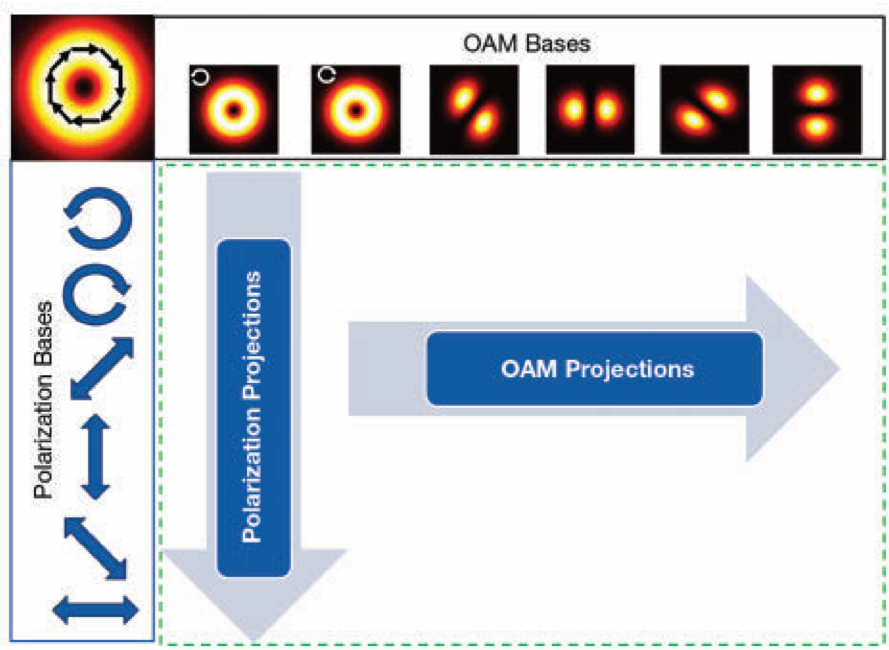
Currently, high-power fiber lasers such as these are used in quantum optical computing, among other applications. These lasers are frequency-converted to achieve wavelengths that are appropriate for the application. According to Jensen, the quality of the beam profile dictates the efficiency of this process.

Photonic integrated circuits (PICs) create additional challenges. Just as very high-powered lasers typically generate too much heat to be successfully profiled, the extremely small size of on-chip lasers often makes these sources too small to measure.

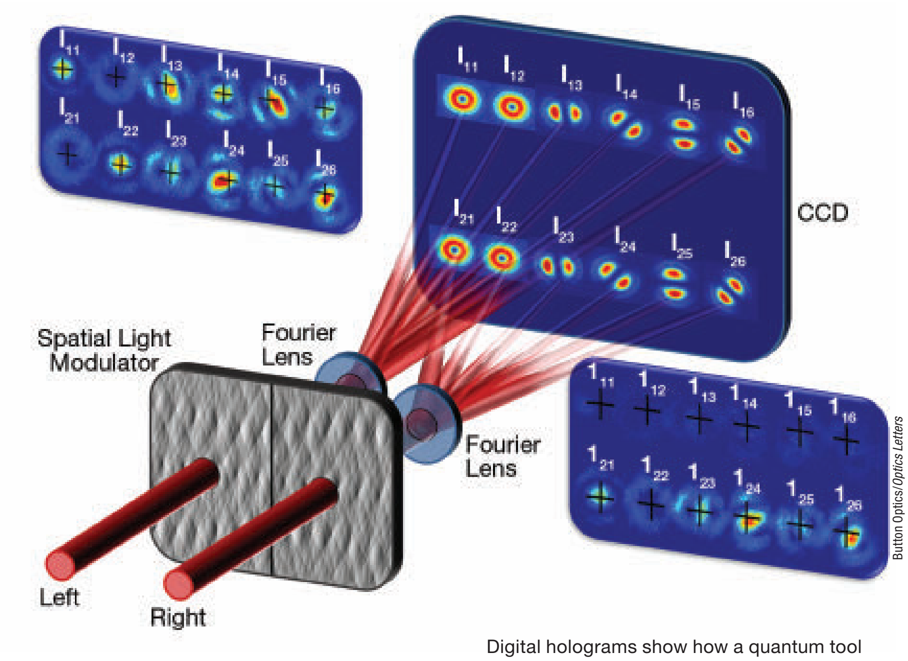
"When you bring a laser on-chip, that's really challenging as is," said Klea Dhimitri, quantum technology lead for Hamamatsu Photonics. While fabrication and integration may eventually give way to considerations about optimizing the performance of the laser, many companies and institutions remain focused on laser on-chip integration.

Still, Dhimitri said, learning and optimizing the properties of an on-chip laser will undoubtedly help users in the future. And this is especially true regarding applications for which on-chip lasers are not yet known. "For quantum computers, whether it be modulators or bringing detectors on-chip, it's the holy grail," Dhimitri said.

With very high-power models on one side of the scale and on-chip lasers on the other, most users operate in the space



A quantum tool set is poised to enable users to completely profile a beam, building on and enhancing the functionality of existing beam measurement methods. The tool set-based method involves several measurements — six different spatial patterns and six different polarization states — resulting in 36 individual measurements. OAM: orbital angular momentum.



Digital holograms show how a quantum tool set can be used to profile beams. This allows the user to reconstruct the complete picture of the beam.

Establishing a tool set to profile multiple degrees of freedom simultaneously is especially valuable now, in an age in which optics, such as metasurfaces, are increasingly prevalent, even in industry.

between the two. And in many cases, these users do not require expanding profiling techniques. "The middle ground is like going to the department store: If you're looking for a medium, there are lots of things on the rack," said Andrew Forbes, a professor at the University of the Witwatersrand in South Africa. "But, if you're looking for extra-extra-small or extra-extra-large, you're going to have a problem.

"I don't know if there is an answer to this question, in terms of looking at far ends of the spectrum for beam profiling," Forbes said.

The need for new measurement

According to Forbes, the evolution of new and sophisticated lasers is bringing with it beams with degrees of freedom that are mixed together, as opposed to scalar beams with a single polarization. In applications using these beams, statistical tools may not suffice to achieve optimal profiles or measurements.

Quantum mechanics, Forbes said, offers the right machinery that may be used to extract new information.

Forbes is turning to a reconceptualized approach to laser beam profiling that uses what he calls a quantum "tool set." In situations in which beams are constantly changing polarizations, such as when a horizontally polarized beam is joined with a vertically polarized beam, more than conventional beam profiling is needed to evaluate the beam with accuracy. "This beam is very hard to analyze with standard profiling techniques because it doesn't capture the kind of salient property of this beam," Forbes said. "Intensity is certainly one part of the equation, but how the polarization looks is actually the critical part of the equation. And this is called vectorial light."

Vectoral beams are used in industrial applications to drill smaller holes, make cleaner cuts, and ablate surfaces with better performance than with classic systems. The principal challenge in measuring and profiling these beams involves the pattern of light, or the intensity. According to Forbes, the pattern of two different lights used in a spectral beam, each with different polarizations, as well as their degrees of freedom, will look one way on camera. However, those images will not at all reflect the laser beam itself, which will appear to be in more of a quantum state with countless polarizations.

Ultimately, images of vectorial light produced by one camera may not paint an accurate picture.

Though the beam in this situation is not in a true quantum state, quantum tools could potentially be applied to the beam to offer the same data set provided by current iterations of beam profiling — plus additional information that could include the multitude of variations on polarization that would be critically important to modern applications, Forbes said.

"It's kind of a modern manifestation of the old laser beam shaping," Forbes said. "Previously, when we shaped light, we only shaped light in its amplitude, like what it looks like on the camera. We ignored polarization."

Another example involves adding a doughnut beam — a beam carrying orbital angular momentum — with a Gaussian beam. Such a combination provides every possible polarization embedded inside it, Forbes said.

Establishing a tool set to profile multiple degrees of freedom simultaneously is especially valuable now, in an age in which optics, such as metasurfaces, are increasingly prevalent, even in industry.

"Together with the ability to create, we need the ability to detect. And that's where the modern profiling tools must come in," Forbes said. He said that a full field analysis, complete with new layers of data, provided at the same precise time, will be key to unlocking the full potential of today's lasers.

Rethinking benchmarks

A solution without a problem is a common occurrence, both with new and established technologies. Companies such as Button Optics, a spinout of the Structured

Light Lab at the University of the Witwatersrand, use many standard beam-profiling practices. At the same time, the company is working to create novel structured light vector beams, thereby creating demand for an approach to beam profiling that extends beyond these established techniques.

Bertus Jordaan, an R&D scientist with Button Optics, said that his group is focusing on the generation and detection of new laser types and that new detection practices will rely on quantum inspired practices.

Further, Jordaan said, such new detection processes, with a quantum inspired tool set, are poised to support applications beyond standard profiling.

"Wavefront sensing and getting phase information that is more than the amplitude, along with the amplitude, can tell you a lot," Jordaan said. "And this could support applications even in ophthalmology and astronomy, if you want to really understand what's going on in your telescopes."

The critical technology to consider is wavefront sensing, Jordaan said.

"If you have the full field information, phase and amplitude together, then you can predict everything from the beam. And wavefront sensing is doing that. Now, we can combine some of the aspects of that together with the vector analysis to really give a full perspective."

According to Jordaan, many companies and researchers are now tasked with simultaneously analyzing multiple degrees of freedom. This analysis, along with the intensity profile and the polarization profile, can reconstruct the state of new, complex beams by running a modal analysis and a polarization analysis at the same time.

Though developing the process needed to support the quantum tool set for beam profiling is still in the works, it must meet certain benchmarks to become a new standard, even for sophisticated beam measurements; it must be widely recognized by the international photonics community, and it must be affordable enough to permeate all the fields using these lasers and beams. Perhaps most critically, it must deliver on its promise to accurately reconstruct new types of laser beams.

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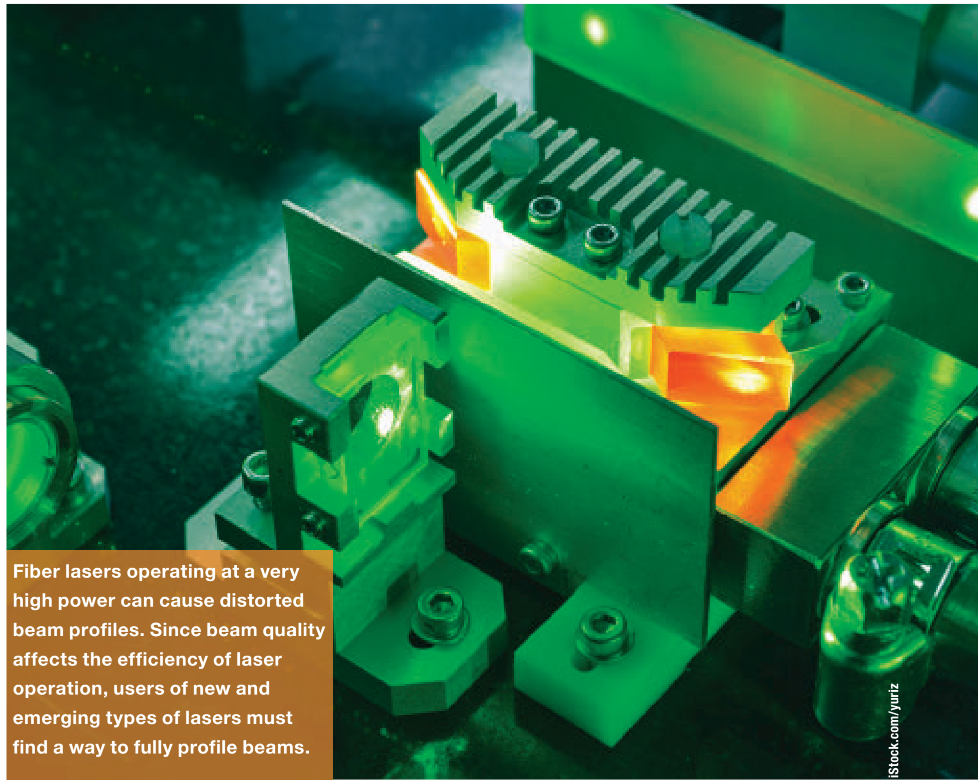

Fiber lasers operating at a very high power can cause distorted beam profiles. Since beam quality affects the efficiency of laser operation, users of new and emerging types of lasers must find a way to fully profile beams.

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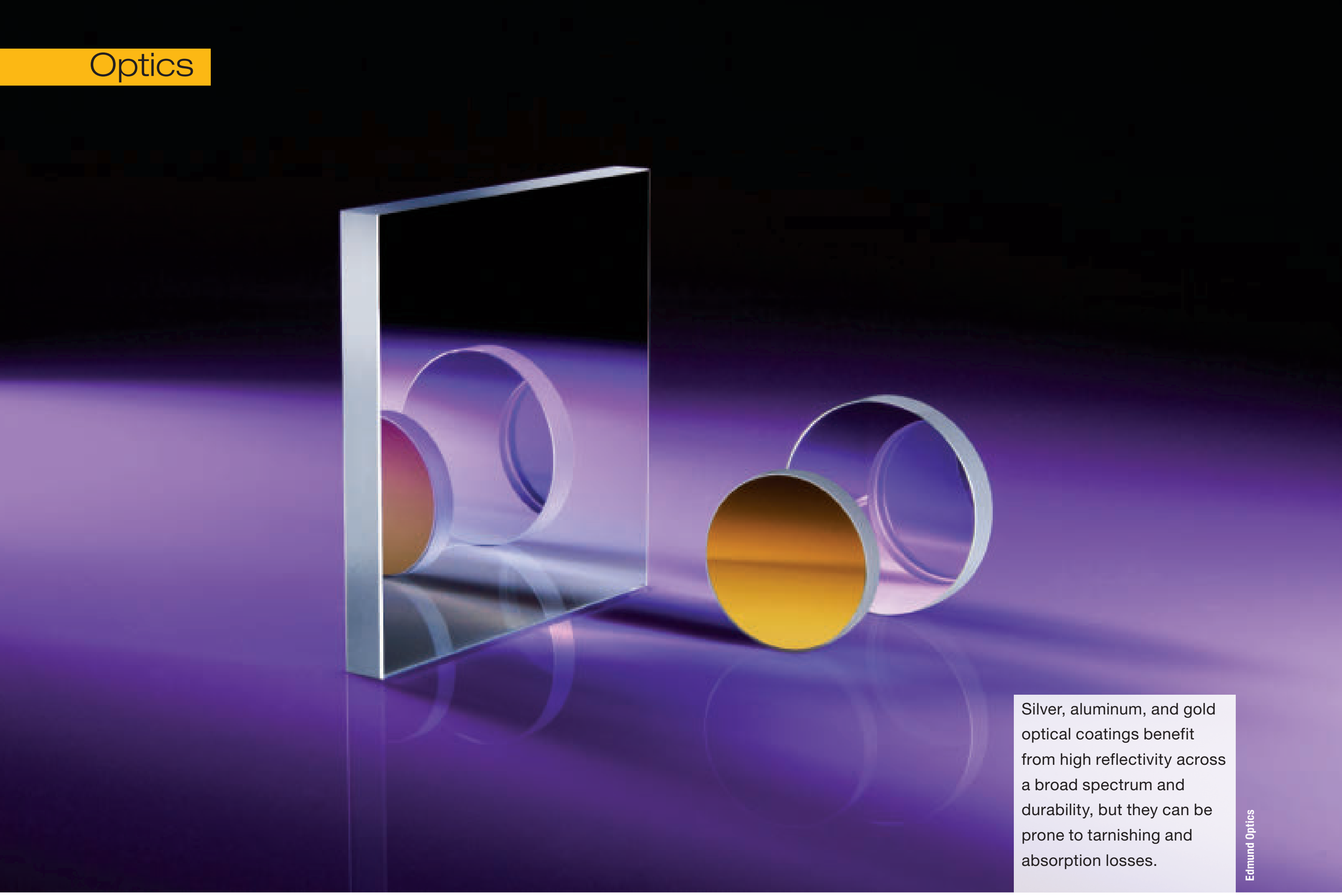


Silver, aluminum, and gold optical coatings benefit from high reflectivity across a broad spectrum and durability, but they can be prone to tarnishing and absorption losses.

Adapting Metallic Coatings for Dynamic Applications

BY MARIE FREEBODY
CONTRIBUTING EDITOR

As with all products for which a variety of options is available to consumers, and for which application ultimately determines consumer selection, each type of metallic coating offers its own unique set of benefits and shortcomings. By carefully selecting the proper material(s) — whether aluminum, silver, nickel, or gold — as well as the necessary enhancements, manufacturers can expand the range of applications for mirrors from high-precision scientific instruments to commercial products and beyond.

Fundamentally, coatings enable manufacturers to differentiate products based on performance metrics, such as reflectivity, wavelength selectivity, and environmental resistance. They also extend the lifespan of mirror components, reducing the need for frequent replacements and lowering the overall cost of ownership. As a result, the evolution of

Advancements in nanotechnology, plus chemical modifications and overcoat fabrication, are extending the utility of mirror coatings into specialized applications.

metallic coatings, broadly speaking, has revolutionized the design and application of mirrors, providing greater control of critical parameters and metrics.

And as industries such as telecommunications, aerospace and defense, and medical imaging evolve, demand for highly specialized optical coatings is poised to continue to increase. Today, to engineer coatings to meet specific optical requirements is a decisive factor in determining the utility of products and the success of the manufacturers that bring them to market.

Reflectivity and metallic coatings

Reflectivity is a defining parameter for mirrors, and as it relates to the mirror coating, this quality depends significantly on the metal used for the coating. The coating process involves depositing a thin metal layer onto a substrate — typically glass or plastic — via methods such as physical vapor deposition or chemical vapor deposition. Beyond the distinct properties that different metals offer or achieve (sidebar), different enhancements can be made that influence the performance of the coating following the deposition stage.

"Metallic mirror coatings, such as silver, aluminum, and gold, offer high reflectivity across a broad spectrum, especially in the visible and near-infrared ranges, making them suitable for various optical applications," said Tyler Christy, a thin-film manufacturing engineer at Edmund Optics.

"These coatings are durable and versatile, [and] applicable to different substrates. However, they can be prone to tarnishing, exhibit some absorption losses, and may suffer from surface roughness, which affects performance." Metallic mirrors also have a tendency to absorb and are often susceptible to pinholing. These imperfections may stem from fabrication processes, material properties, substrate quality, or a combination of factors. Since these imperfections can leave small voids in the coating, they are apt to degrade the quality of the mirror and limit performance.

"Typically, the reflectance requirement and target wavelength will dictate the type of metallic mirror coating, as well as any changes or enhancements needed for optimal performance," said Kelley Plats, business development manager at North American Coating Laboratories (NACL). "While most mirrors work well in various applications, they can be limited to wavelength."

"For example, gold is an excellent reflector in the infrared spectrum but does not perform as well in the low-visible and ultraviolet wavelengths. Gold is also delicate and requires a protective layer to ensure it is not scratched," Plats said.

"Aluminum is an amazing visible reflector and is relatively simple to use in most applications; however, if you need a high reflector, it will need to be enhanced using other dielectric materials. Silver has excellent reflective properties; however, it tarnishes easily."

Advancements in metallic coatings

Customers' needs for higher performance and resilience, as well as supply chain issues, especially in recent years, are the core drivers behind this current state of innovation in metallic coatings. Materials shortages have plagued procurement and lead times for coating developers, who have also contested with discontinuations of critical materials.

According to Christy, developers have had to explore alternate suppliers, consider different materials, and/or modify coating formulations to adapt to supply chain challenges. One such adaptation is the increased integration of nanotechnology, which has enabled the use of thinner, more efficient coatings that improve reflectivity while minimizing material usage. For example, nanoparticles of metals, such as aluminum and/or silver, are being engineered to increase the uniformity of coatings, enhancing reflectivity at specific wavelengths. Another advancement is a multilayered approach: Engineers or fabricators layer different metals to harness the strengths of each. For example, silver can be layered with aluminum to increase reflectivity in the UV range while maintaining the superior visible-light reflectivity of silver.

Additionally, researchers are exploring organic-inorganic hybrid coatings that combine the flexibility of organic materials with the robustness of inorganic compounds. This combination can yield coatings that offer advantages both for their reflectivity and durability.

In terms of fabrication, Christy believes that the future now centers increasingly around advancements in precision deposition technologies, such as atomic layer deposition and advanced sputtering, which are currently focused on reactive processes. These techniques offer finer control over coating thicknesses and compositions, resulting in highly customized coatings for specific wavelengths and applications. Innovations such as low-emissivity windows (either polymer or, more commonly, glass) and the use of thin metallic coatings in biomedical surface activation have illuminated the expanding applications of these coatings, but the fundamental manufacturing processes have largely remained consistent.

"The ongoing emphasis on precision will continue to enhance the performance, reflectivity, and durability of metallic mirror coatings, supporting further innovations across various fields," Christy said.

Also, Christy said, manufacturers use simulation software to optimize coating designs before fabrication. The careful selection of substrate and adequate preparation also hold a direct line to improving adhesion and surface quality.

Complex shapes and space applications

The range of market-available solutions that optics companies (for example, Edmund and Altechna) offer is evident in more than just a variance of materials. The various shapes and forms of consumer optics that these and other companies offer include prisms, parabolic off-axis mirrors, cylindrical and spherical mirrors, and computer numerical control (CNC)-machined custom-designed parts.

Use cases for complex-shaped optics are evolving steadily, and this flexibility in shape is helping to supplant conventional monolithic glass bank primary mirrors in telescope imaging systems. Historically, these components imposed limitations on both the maximum size and coating options — with primary mirrors constructed of lightweight hexagonal segments. Since each segment is relatively easy to manufacture and can be coated using standard-size equipment, size limitations are removed and many more coating options become available. Ground-based examples include the Hobby-Eberly (11 m) and Keck (10 m) telescopes. Perhaps the most notable system is the recently launched James Webb Space Telescope. It features 18 gold-coated hexagonal mirrors arranged in a honeycomb pattern, effectively creating a singular and massively powerful primary mirror.

Within industry, one of the niche areas of focus currently at coatings developer and manufacturer AccuCoat Inc. is extending capability to uniformly coat polygons in aluminum, gold, and silver. Polygons are used in and for UPC (universal product code) barcode readers. In this application, a rapidly spinning polygon located in front of a red laser ensures that a barcode can be read from any direction.

The challenge in coating a polygon is to coat all the outside edges uniformly.

While continually rotating the polygon on its own axis, and inside of a chamber, AccuCoat overcame the challenge of balancing the speed of rotation in relation to deposition rate to maintain uniformity across each face of the part.

For AccuCoat, this achievement is tied directly to a common customer demand.

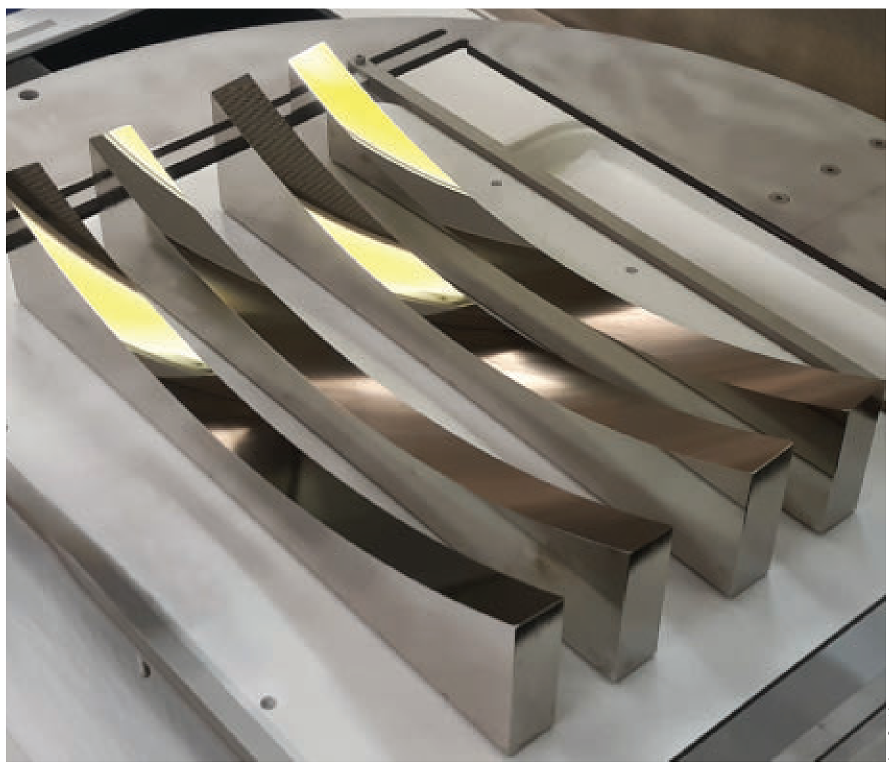
"Many times, customers want <1% change in uniformity of reflectivity from surface to surface," said Patrick Iulianello, AccuCoat's vice president of operations and cofounder.

"During deposition, generally the face that is orientated toward the deposition at the bottom of the chamber is the face that gets coated, so when you continually rotate a spinner/polygon, you have to control speed, orientation, and deposition rate to achieve the proper total deposition for reflectivity."

Dielectric overcoats

Dielectric overcoats, which consist of nonmetallic materials, such as magnesium fluoride and silicon dioxide, serve as protective and performance-enhancing layers for metallic mirrors. These coatings are applied over the metal to prevent tarnishing and oxidation. Both are common issues with metallic coating materials, including silver and aluminum.

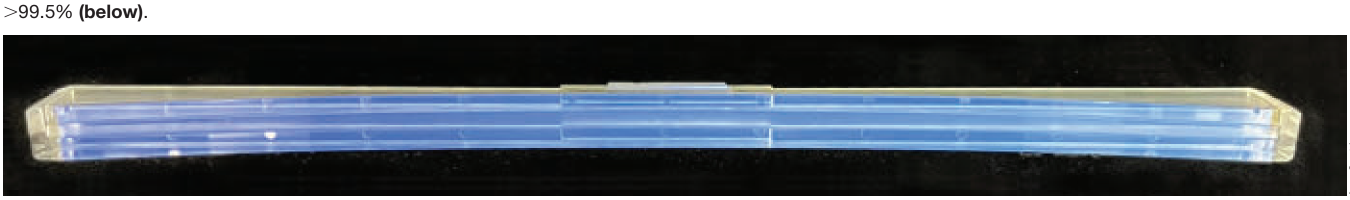
More than just a protective layer, dielectric overcoats also increase reflectivity by minimizing surface losses. "Dielectric materials give metals a boost



AccuCoat Inc.

These diamond-turned aluminum parabolic mirrors are coated with a protective aluminum coating for a typical visible (400 to 700 nm) operating wavelength **(right)**.

A dielectric mirror for 405 to 415 nm on polymer. This molded parabolic mirror has 15 layers of material and reflectivity of >99.5% **(below)**.



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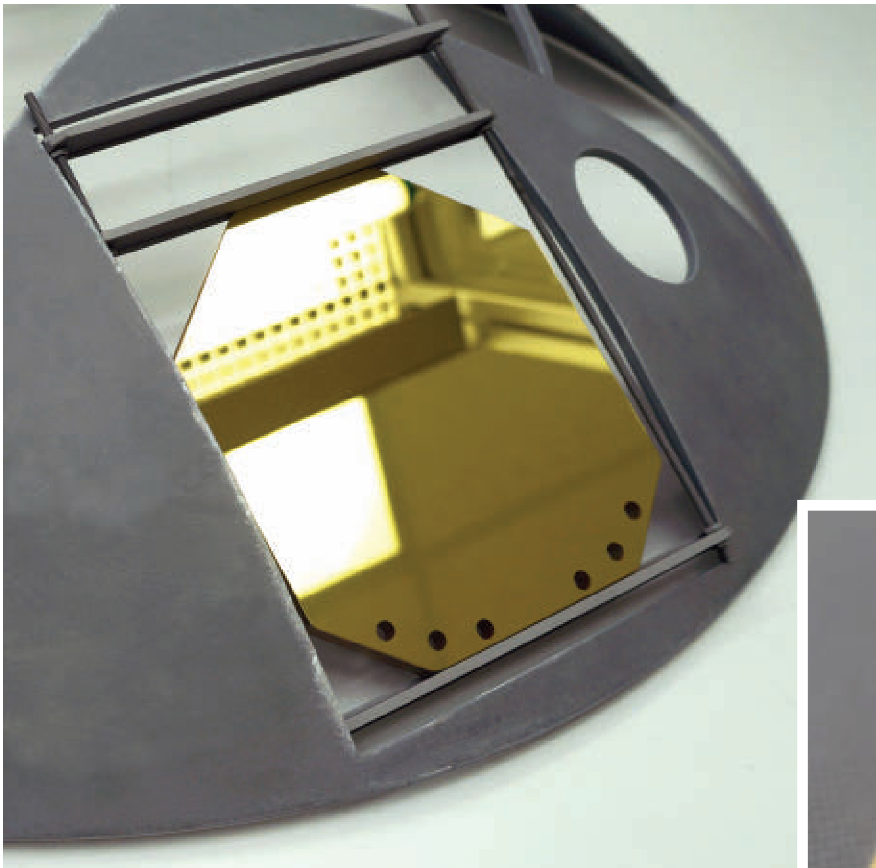

AccuCoat Inc.

A gold-coated material in a custom tooling for correct alignment and optimal coating uniformity **(left)**. The coated part **(with drilled holes)** is a nonstandard shape.

Gold, shown here protected on polycarbonate, is an excellent reflector in the infrared spectrum **(below)**. The material does not perform as well in the low-visible and UV wavelengths.

NACL

in performance: They allow a coating designer or engineer the ability to specifically target reflectance at a specific wavelength," said NACL's Plats. "They can also increase the overall durability of the coating on the lens, which extends the life of the lens and enhances the performance of the complete system."

Dielectric coatings are particularly useful in applications with high laser-induced damage threshold exposure. Evaporated Coatings Inc. (ECI), for example, manufactures highly reflective low-loss dielectric laser optical coatings with up to 99.9% reflection that can be optimized for use from 248 to 2500 nm for laser line wavelengths or multiband applications.

Also, overcoat dielectric layers of alternating high/low refractive index can enhance the reflectivity of less expensive metals while simultaneously enhancing durability. ECI's coatings can be deposited onto various types of optical materials, including glass substrates, fiber optic devices, and crystals and semiconductor materials.

Chemically, the key to fabricating an effective mirror coating lies in understanding the interaction between the metal and the surrounding environment. For example, adding a layer of magnesium fluoride on top of aluminum prevents oxidation and improves the reflection of UV light. The thickness and composition of the coating are carefully controlled to minimize absorption and scattering, thereby preserving reflectivity. Similarly, chromium or silicon dioxide overcoats are commonly applied to protect silver mirrors, preventing tarnishing while also enhancing durability.

"In applications where high reflectivity in the infrared is crucial, a metal like gold may be chosen for its superior IR reflectivity," Christy said. "For applications needing high UV reflectivity, aluminum would be the metal of choice and additional layers may be added to enhance performance. The coating's material, thickness, and protective measures are adjusted based on the application's operating environment, wavelength range, and performance requirements."

Chemical tweaks in high-precision applications may also involve doping the metallic coatings with small amounts of other elements to modify the refractive index or improve the adhesion of the metal to the substrate. For example, adding titanium or chromium to aluminum can improve the mirror's adherence to the substrate, making it more durable under mechanical stress.

Dielectric coatings can also be fine-tuned to reflect specific wavelengths while allowing others to pass through for optical applications, where controlling the reflection and transmission of light is critical. This property is especially useful in beamsplitters, antireflective coatings, and laser mirrors, in which precise control over reflectivity is required.

Still, dielectric coatings are unsuitable in certain situations. Vilnius, Lithuania-based EKSMA Optics emphasizes that although dielectric metallic coatings provide greater reflection across the operating bandwidth, they alter the polarization state of an incident beam. This quality makes them inappropriate for polarization-sensitive applications. The company offers variously sized round, rectangular, and spherical mirrors coated with gold, silver, or aluminum.

Pricing pressures

Even as consumers frequently opt for advanced multilayer dielectric coatings for high-performance applications, the effectiveness of metallic coatings alone often suffices in applications that require broad-spectrum reflectivity and durability. "Metallic mirrors are a [cost-effective] alternative to dielectric mirrors with high reflectivity," said Audrius Jakštas, sales technical director at EKSMA Optics. "For example, when the customer needs a mirror for a broadband wavelength range and there are no requirements for high reflectivity (>98% to 99%), then a metallic mirror is a good alternative."

Reflectivity and operational wavelength typically guide materials selection for coatings. But the rising costs of precious metals are increasingly influencing the direction of the industry. For example, gold coatings can be up to 10× that of aluminum and certain other materials. Though materials with lower levels of purity may be usable substitutes, a less pure material may hinder durability, reflectivity, or other factors. Such a degradation may not be acceptable for a customer or its application.

"We typically use '5 nines' (99.999%) pure gold, silver, and aluminum to give the best-performing product to our customers," AccuCoat's Iulianello said. "At this purity, you are procuring the material at [the] market price of the day, and today that is around $2400/oz (28.35 g) and typically, we can use about 2 to 4 g per coating run."

Of course, these values are evolving, as are the factors that are apt to influence these values. Supply chain considerations, plus increased demand for specialized coatings amid the development of materials and methods, are ensuring a forthcoming dynamic wave of progress in mirror optics and coatings.

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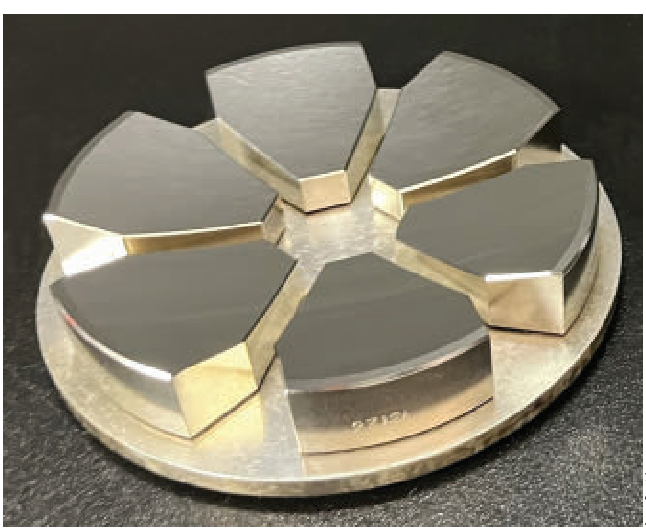
Metallic Coating Materials

Aluminum: Aluminum is known for its high reflectivity across a broad spectrum of wavelengths and is particularly useful in UV, visible, and infrared applications. Its reflectivity ranges between 85% and 95% in the visible spectrum and can reach 90% in the UV. Due to its versatility and cost-effectiveness, aluminum is often used in telescopes, laser optics, and solar panels. Aluminum's susceptibility to oxidation requires it to be used with protective coatings to preserve its reflective properties.



AccuCoat Inc.

Segmented diamond-turned aluminum mirrors coated with a protective silver coating, with reflectivity >97% over a wide wavelength range.

Silver: Silver boasts the highest reflectivity in the visible range, exceeding 97%, which makes it ideal for use in high-performance mirrors, such as those used in imaging, solar energy collection, and other applications. Silver tarnishes quickly when exposed to sulfur or oxygen, limiting its application in harsh environments unless adequately protected by overcoats. Recent advancements in protective coatings and dielectric layers have helped mitigate silver's tendency to degrade, allowing for extended use in challenging environments.

Nickel: Nickel is primarily valued for its durability and resistance to corrosion: It finds application in demanding environments in which mechanical stress, heat, and oxidation are concerns, such as in military optics and aerospace. Nickel's lower reflectivity compared with aluminum and silver limits its use in applications in which brightness and optical precision are paramount.

Gold: Gold excels in the infrared spectrum, with reflectivity reaching up to 98%. It is widely valued for infrared telescopes, thermal imaging systems, and applications in which heat must be efficiently reflected. Gold also has excellent resistance to oxidation and corrosion, which enhances its longevity. The material's high cost often restricts its use to specialized and high-budget applications.

Undetected leaks can lead to environmental dangers and costly losses for companies. Laser absorption spectroscopy (LAS) can help detect these leaks quickly to limit the harm.

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Advancing Spectroscopy Solutions Help Clear the Air

As infrared detectors simplify emissions tracking processes, laser absorption spectroscopy is helping to address an escalating methane problem.

BY MARK NAPLES
UMICORE COATING SERVICES

Ensuring that air quality is safe for humans and other forms of life is one of the most pressing challenges facing the world today. The average person will inhale ~79,250,000 gallons of air in their lifetime. Simply walking a city street, a person will likely inhale millions of potentially harmful particles, potentially with each lungful of air.

Although the toxicity of the air around us has been a known issue for centuries, global energy demands are growing, and the effect of air pollution on the environment and public health is reaching a crisis point. Across the energy sector, businesses are grappling to reduce pollution stemming from their operations. Governments around the world are enacting increasingly strict legislation. As these regulations mount, the need for technology that can monitor the air is more important than ever.

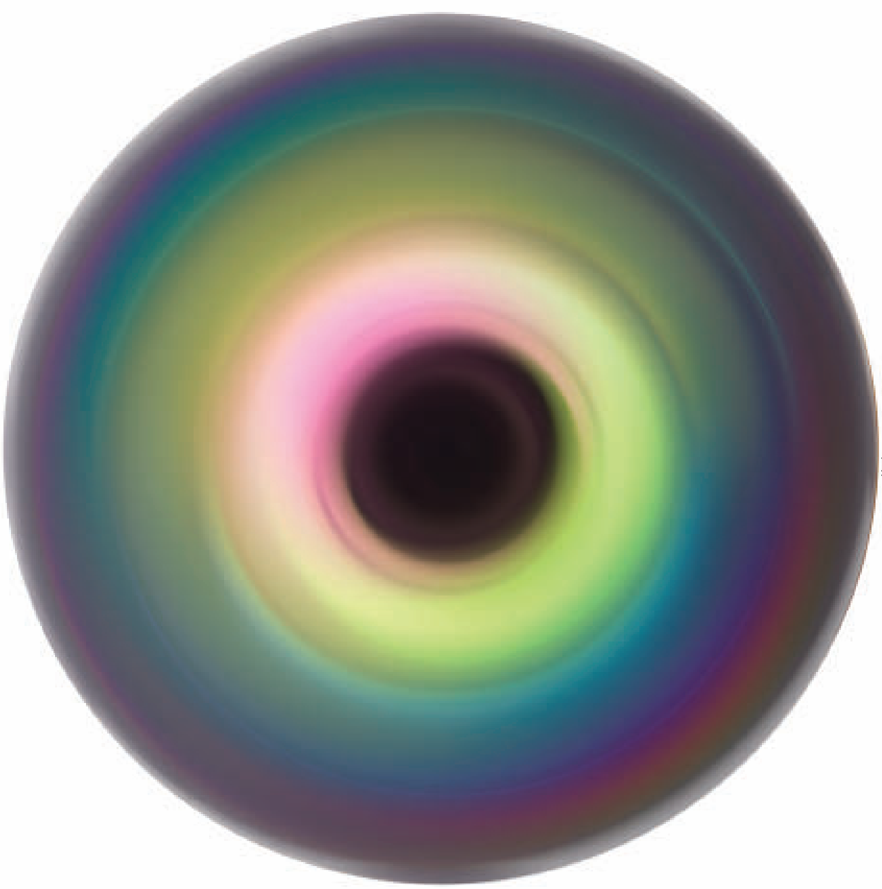
Demand is also increasing for high-performance photonics systems that enable detections of trace amounts of gases. Certain tools, such as the technique of laser absorption spectroscopy (LAS), are essential to improve data collection efforts, thereby helping businesses to identify leaks and maintain regulatory compliance. Combined with advancements in connected sensor networks, photonics techniques, especially those in the IR, are apt to provide industries with the tools needed to begin investing in a more sustainable future.

A clear set of challenges

The colorless and odorless nature of many gases causes many gas leaks to go undetected. The vastness of the networks of pipelines and storage infrastructure that most businesses in the oil, gas, and other relevant sectors operate further challenge these companies and their employees to identify and act on leaks. This increases the risk of serious workplace incidents that can lead to injury and/or death.

At the same time, these undetected emissions also present a problem for the well-being of the environment, with methane, in particular, recognized as a significant contributor to poor air quality. Largely, the intense heat-trapping potential that methane possesses is a cause for this threat. Although methane lasts for much less time in the atmosphere than other greenhouse gases, including carbon dioxide — around 12 years as opposed to hundreds — it possesses a much higher potential for global warming. Since preindustrial times, the concentration of methane in the atmosphere has risen by ~2.5×, reaching a record high in 2019.

As it relates to detection, challenges range from logistical to technical. For example, a lack of concrete and up-to-date data on the scale of air contamination from energy sector emissions is likely to limit the effectiveness and accuracy of preventative actions. Targeting the best places for investments and/or regulations



Accurate measurements obtained via on-the-ground detection will be instrumental to setting and meeting global targets on emissions reduction and supporting the energy sector in mitigating its massive environmental impact.

Coated filters are essential in a variety of applications, including those supporting clean air quality measures and those targeting greenhouse gas reductions.

becomes challenging when the global map of emissions is inaccurate.

As a result, increasing the quality of data, especially that which companies themselves gather, is imperative. Accurate measurements obtained via on-the-ground detection will be instrumental to setting and meeting global targets on emissions reduction and supporting the energy sector in mitigating its massive environmental impact.

Still, these solutions must also account for the number of sources, especially in the energy sector, where gas emissions occur. Super-emitting events, such as pipeline or storage tank failures, can lead to 10,000 kg or more of methane escaping in only 1 h[1]. Flaring and venting represent other common sources of methane, with some businesses often burning off large quantities of gas if they believe they cannot sell the gas for sufficient profit. And smaller-scale emissions, such as valve leaks, are often more difficult to track; much of the monitoring technology in use today is incapable of providing sufficient information about these types of leaks, which is due in part to the frequency of smaller-scale leaks. Satellite monitoring can routinely capture super-emitting events, whereas lower profile events require a more localized network of on-the-ground solutions.

Finally, the atmospheres in the energy sector can also present a problem for detection. Extreme temperatures and high humidity can influence sensor accuracy, as can oxygen-rich or oxygen-deficient atmospheres. Such conditions may contribute to sensor poison, contamination, or corrosion. Also, the presence of ambient moisture may result in lasting leaks in undersea pipelines, or in particularly humid environments that are inherently difficult to detect. Similarly, accidental leaks experienced during fossil fuel production and transport often represent an area of oversight, since these leaks are difficult to account for.

Infrared detection

From electrochemical sensors to flame-ionized detectors, industry currently benefits from a plethora of available choices when it comes to mitigating emissions. Combining devices and methods ranging from point detectors to drones ensures that businesses have access to a suite of low-cost, high-performance monitoring systems.

Amid these choices, the most effective solutions are in the IR.

Gas detection technology can broadly be split into two categories — point detectors and area detectors — with point detection being increasingly deployed by industry. Point detectors use a single detector location in which the detected source, such as a gas cloud, interacts with the sensor. In addition to IR point sensor solutions, catalytic, solid-state, and electrochemical point sensing also find use in gas sensing deployments.

Fundamentally, optical gas detection equipment is used to measure the amount of light at specific wavelengths — namely, the wavelength where hydrocarbon molecules absorb light, and wavelengths where no absorption takes place. IR laser absorption spectroscopy (IR-LAS) exploits this methodology,

Valve leaks are difficult to locate, because current monitoring systems fall short of providing the data needed to find and respond to these leaks. Recent improvements in the cost and scalability of laser absorption spectroscopy (LAS) could provide a solution.

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passing IR beams through a sampling chamber containing a filter that blocks any light from undesired wavelengths from reaching a detector. Passing the light through the sample gas causes the wavelength's intensity to reduce, and the other wavelength is unaffected. Comparing the ratio of the two signals yields information on the gas concentration that is present.

This technology enables rapid, accurate detection and quantification of gases in the atmosphere in the parts-per-billion range. Further, other types of sensors may require the target gas to be present in concentrations below the lower explosive limit. IR sensors effectively measure concentrations of any strength, without requiring oxygen or external gases.

Enhancing potential

Recent advancements in LAS have raised its potential as a potent tool for gas detection. Newer iterations of instruments feature a laser diode mounted on a thermoelectric (or Peltier) cooler, which enables the laser's wavelength to be tuned to match the specific absorption wavelengths of select molecules. Exploiting the high-frequency resolution of the diode sources results in enhanced sensitivity. This means that the detectors register the interaction between gas molecules and light on the order of parts per billion. Compared with other sensors, these detectors provide faster, more accurate results.

IR technology is also much more flexible than alternative solutions. Catalytic, electrochemical, and semiconductor sensors require gases to be present in concentrations below the lower explosive limit. Also, users can deploy current instruments and devices in a range of challenging environments commonly encountered across oil and gas infrastructure. These include oxygen-rich and/or oxygen-deficient locations. Such devices require little sensor calibration and are functionally immune to sensor poison, contamination, and corrosion.

Sensor fusion offers another range of benefits: Users may choose to combine real-time measurements from IR gas detectors with systems, including GPSs and geographic information systems, to expand functionality. This results in an interconnected detector network that provides immediate insights into where leaks occur, to facilitate the chance to perform quick and effective maintenance.

Coating technology

Thin-film technology helps unlock the optimal performance in optical systems. The sophistication of this technology is also rapidly increasing, owing to heightened demand for advanced IR detectors.

The performance (and ultimately the function) of thin films relies on how electromagnetic radiation interacts at different wavelengths with a deposited functional layer. Multiple alternating layers are used to create a filter, and these layers are made up of high- and low-refractive index material on a glass substrate. Controlling the deposition of these coatings enables the precise tailoring of thin-film properties, and experts in this technology are capable of deposition ranging from a fraction of a nanometer to several micrometers in thickness.

Using LAS devices alongside IR filters, operators can ensure an ideal signal-to-noise ratio and high selectivity for the wavelength being used. This grants these coated filters use in a range of applications, supporting air quality and greenhouse gas reduction targets.

Improving understanding

Importantly, the use and increased adoption of LAS underscores a technological shift. Even more importantly, this shift does not have to come at a great cost to oil and gas producers. Data published by the International Energy Agency last year, for example, estimates that ~80 million tons of methane emissions could be prevented by deploying technologies that exist today at no cost to businesses.

In fact, in many cases, action on methane could even prove to be profitable. Improving leak detection enables immediate repair work, which itself results in less wasted gas, which could be resold.

The favorable changes in cost and scalability of LAS technology are helping to address these issues. As these devices become increasingly cost-effective and convenient, mass IR sensing deployment at a hyperlocal level is no longer a pipe dream.

Meet the author

Mark Naples is managing director at Umicore Coating Services. He has nearly two decades of experience working across the optics, sensing, and imaging industries; email: coatingservices@umicore.com.

References

1. Wood Mackenzie (Nov. 2023). Mission invisible: tackling the oil and gas industry's methane challenge, https://www.woodmac.com/horizons/oil-and-gas-methane-challenge.

Thin-film technology helps unlock the optimal performance in optical systems. The sophistication of this technology is also rapidly increasing, owing to heightened demand for advanced IR detectors.

The Evolution of Displays: From Visual Interface to Interactive Technology

BY ACHIN BHOWMIK
SOCIETY FOR INFORMATION DISPLAY (SID)

The technical and commercial breakthroughs that have characterized progress in visual display technologies during the past six-plus decades have revolutionized the viewing experience. These advancements have also served to redefine our relationships with technologies, and in doing so, they have significantly influenced our societal dynamics.

Beginning with the explosion of early televisions based on cathode-ray tubes (CRTs) in the mid-20th century, then evolving into today's sophisticated liquid crystal displays (LCDs) and organic light-emitting diode (OLED) screens, each innovation along the way has reshaped entertainment, education, and communication. The Society for Information Display (SID) has been an active champion for these and other advancements, pushing for innovation, collaboration, and fostering ideals that aim to set the pace for what once seemed to be impossible in display technology.

A look into past, present, and future trends in display technology innovations illuminates their pivotal role in shaping the frontiers of human-technology interfaces and interactions. Perhaps on a microscale, such investigation also unveils how advancements in display technology are enabling continual streams of consumer devices that themselves play a leading role in such interactions.

A historical overview

In many ways, the history of display technology mirrors the story of modern innovation. The era began with CRTs, which were pivotal in bringing television to the masses. This technology, based on electron beams illuminating phosphor dots inside vacuum tubes, dominated for decades and ultimately became a cultural mainstay. Distinct advancements from the 1950s to the 1970s spanned the advent and improvement of color broadcasting as well as major improvements to picture quality and television set design.

The introduction of LCDs dawned a new era in the late 1970s. Using liquid crystals to modulate light, LCDs marked a shift from bulky CRTs and yielded thinner, lighter, and more energy-efficient screens. LCDs also emerged as a baseline component in everything from digital watches and calculators to monitors and televisions in this era.

In the 1990s, plasma display panels marked another major leap in display technology. Offering superior color accuracy and wider viewing angles, plasma screens accelerated the transition to larger flat-panel televisions. This shift changed home entertainment and public display environments, such as airports and shopping centers. The eventual decline in plasma displays occurred in parallel to continued advancements in LCD technology. Superior energy efficiency, thinner profiles, lighter weights, and better overall performance — at a lower cost — were the most notable areas of improvements to LCDs toward the end of the 20th century.

Now, the 21st century is ushering in its own revolution, characterized by LEDs and OLEDs. LEDs, known for their low energy consumption and long lifespan, are dominant in various applications, including lighting and digital signage. OLED technology, featuring self-illuminating pixels, offers unparalleled contrast ratios, color accuracy, and design flexibility for devices. Ultrathin, flexible, and curved displays, aiming to redefine the aesthetics and functionality of electronic devices, are an ongoing area of technological progress.

Societal influence and new devices

Display technologies are among the direct drivers of the ever-changing societal dynamics. In the entertainment arena, they have transformed cinematic and television experiences. High-definition and ultrahigh-definition displays are now standard, dramatically enhancing visual quality and viewer immersion. This technological evolution has also led to the rise of streaming services and on-demand content, vastly reshaping the media landscape.

In the sphere of personal computing and mobile devices, compact and efficient displays have catalyzed a digital revolution. Smartphones, tablets, and ultralight laptops reshaped communication, work, and leisure, fostering a globally interconnected digital ecosystem, spanning both professional and personal interactions.

The next wave is already emerging, with the rise of virtual reality (VR) and augmented reality (AR) devices. Unsurprisingly, LCD and OLED technologies are pivotal enablers of these systems, providing high-resolution, low-latency, and energy-efficient display capabilities that enhance the immersive and interactive experience. Indeed, the permeation of cutting-edge displays extends to a full range of sectors, enveloping industry, education, the life sciences, and more.

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The evolution of the television during the past half-century illustrates the progress in display technologies.

In health care, for example, high-resolution displays enhance medical imaging and diagnostic capabilities, improving patient care and enabling better treatment. Advanced display technologies provide clearer, more detailed visualizations, aiding more accurate diagnoses and precise surgical procedures. And they improve medical training through effective simulation-based learning to elevate the standards of medical practice and care.

The education sector also benefits from interactive and digital displays. Traditional learning environments have evolved to incorporate digital whiteboards, tablets, VR, and AR, making education more accessible and compelling by supporting previously unattainable levels of interactivity and interconnectedness.

Future of display technologies

The future of display technologies holds boundless possibilities. Emerging micro-LED technology offers numerous benefits compared with existing devices, producing superior brightness, contrast, pixel density, and color accuracy. These displays also boast higher energy efficiency and longer lifespans. With continued progress in manufacturing capabilities, especially in scalability, micro-LEDs are poised to revolutionize applications ranging from lightweight eye-worn displays to large-scale digital signage and television screens. This is expected to provide more immersive and visually stunning experiences.

Innovations in flexible, transparent, and 3D displays are meanwhile establishing paradigms in design, as well as in functionality. The integration of artificial intelligence (AI) in display technologies and systems promises to yield more adaptive, responsive, and immersive user experiences. This integration signifies a move toward visual interfaces that not only continue to present information, but that also understand and interact with their environments and users no matter the setting.

The role of SID

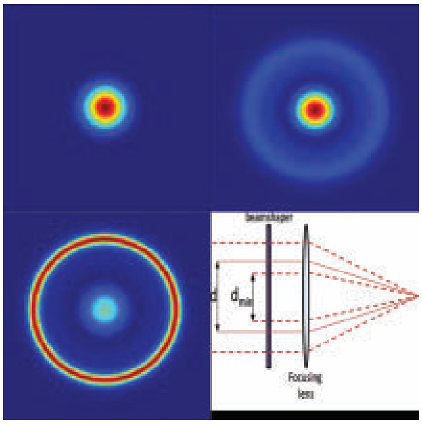
The journey from CRTs to OLEDs to micro-LEDs, and possibilities for the future that these advancements foreshadow, illustrate a vibrant field. Still, these advancements neither take place nor offer their maximum benefits in a vacuum.

As a hub for professionals in academia, industry, and R&D, SID fosters ongoing innovation for the display technologies community. Through its conferences, publications, and collaborative projects, SID advocates for imaging and display technology innovation, sets industry standards, and fosters a culture of knowledge sharing and collaboration.

Moreover, the organization is committed to the education and training of skilled professionals. This begins by preparing specialists to tackle emerging challenges and opportunities in this dynamic field of human-technology interfaces.

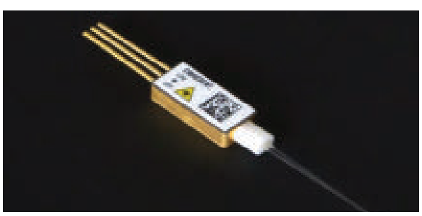
president@SID.org

Product News



Beam Shaper

The Variable Beam Shaper from **PowerPhotonic** is designed for applications in laser welding, additive manufacturing, and laser surface treatment. The shaper enables a single-mode, Gaussian laser beam to be focused into one of three different output profiles: a Gaussian, a flat top circular, or a ring-shaped spot. The Variable Beam Shaper is made from fused silica with low-loss and low-scatter surfaces, which allow high-power handling from continuous-wave or pulsed lasers in the femtosecond-picosecond-nanosecond regime.
sales@powerphotonic.com



Micro-Pump Laser

Coherent's uncooled dual-chip 980-nm micro-pump laser can be used for coherent transceivers in data center interconnects and in compact single-channel and bidirectional amplifiers for metro and long-haul networks. The laser offers an output power of 2 × 400 mW with a power consumption of <2 W in environments where temperatures can range from −20 to 85 °C. The micro-pump laser is also equipped with an internal fiber grating for wavelength stabilization combined with a reduced-clad, bend-insensitive 80-µm single-mode fiber that can support a 5-mm bending radius.
info@coherent.com

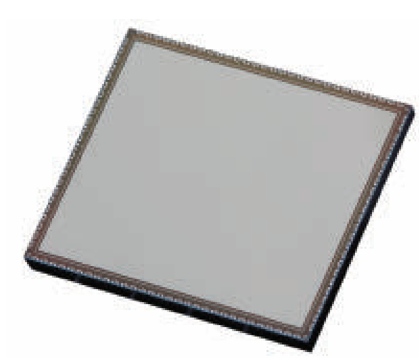
UVC Line Light

The COBRA Slim UVC from **ProPhotonix** is a UVC LED line light for applications including surface inspection, machine vision, pharmaceutical and medical package inspection, food and beverage inspection, and currency and document verification, sterilization, and disinfection.

The light can be implemented into tight spaces with both convection and fan-cooled variants and strobing capabilities. The COBRA Slim UVC delivers up to 61 mW/cm^2 of uniform light at UVC wavelengths of 265 nm and 275 nm as well as a UVB wavelength of 310 nm.
sales@prophotonix.com

Linear Stages

The V-574 family from **PI** (**Physik Instrumente**) is a series of linear positioning stages for applications such as optics inspection, metrology, photonics, interferometry, and semiconductor test equipment. The stages are equipped with crossed-roller bearings and three-phase ironless, cog-free linear motors that transfer their force directly and without friction to the motion platform. Products in the V-574 family achieve velocities of up to 1 m/s, 1 g acceleration, and come in travel ranges of 60 mm, 130 mm, and 230 mm.
info@pi-usa.us



SWIR Sensor

Emberion Oy's SWIR sensor combines Emberion's quantum dot sensor technology and wafer-level packaging for applications such as automotive, consumer electronics, AR/VR, and drone sensing. The sensor is packaged with up to 100 imagers on a single 8-in. wafer, is suitable for outdoor environments, and covers a range between 400 and 2000 nm.
sales@emberion.com

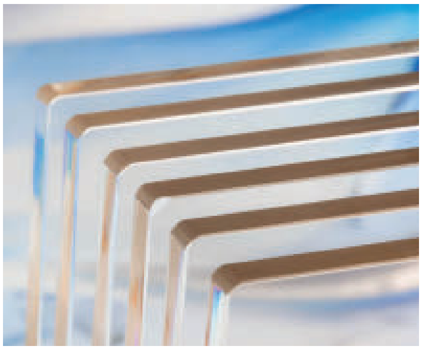
sCMOS Camera

The Marana 4.2B-6 from **Oxford Instruments Andor** is a back-illuminated scientific CMOS (sCMOS) camera for applications in the physical sciences and astronomy. The camera uses a low-noise mode that reduces read noise to 1 e-, as well as a high-speed mode for fast imaging applications, such as quantum computing and fast spectroscopy. Its long exposure mode suppresses the effect of amplifier glow, and its global clear mode purges charge from all rows of the sensor simultaneously at the exposure start. The Marana 4.2B-6 also features 4.2-MP resolution, −45 °C vacuum cooling, two-lane CoaXPress connection, and 135 fps of high-speed operation.
r.finlay@andor.com

EUV Source

The EQS-10 from **Energetiq Technology** is an electrodeless Z-Pinch extreme-ultraviolet (EUV) light source for applications including EUV metrology, resist development, and defect inspection. Designed with solid-state switching technology, the light source delivers up to 4× the energy per pulse with an operating

frequency of up to 5 kHz. The EQS-10 also features the company's direct fueling system, which can reduce gas consumption by up to 60%.
info@energetiq.com



Chip Development Glass

The EXTREME ULE Glass from **Corning Incorporated** is a materials solution for improving photomasks in semiconductor chip manufacturing. The glass can withstand high-intensity extreme-ultraviolet (EUV) lithography, including high numerical aperture EUV. The EXTREME ULE Glass uses Corning's titania-silicate glass material with near-zero expansion characteristics.
specialtymaterials@corning.com

Metrology System

The Swift PRO EDGE from **Vision Engineering** is a metrology system for inspection and shop floor measurement applications. The system takes measurements from sub-millimeters up to 200 mm with a magnification range of 0.7× to 4.5×. The Swift PRO EDGE features a 6.5× zoom for the measurement of various part sizes as well as quick lens changes for different measuring tasks and edge detection capabilities.
info@visioneng.com

Raman Pump Module

The 1948RUB from **3SP Technologies** is a Raman pump module that provides up to 700-mW output power to improve the optical signal-to-noise ratio at the receiver side. The module uses a laser chip that allows for a power consumption of 11 W at a chip temperature of 35 °C and a case temperature of 70 °C. The 1948RUB's chip

also allows for a reduced power consumption of 2 W at 500 mW and 3 W at 600 mW.
customerservice@3sptechnologies.com

Compact Optical Transceiver

The P16548-01AT from **Hamamatsu Photonics** is a compact optical transceiver for spatial light transmission, enabling cable-free optical data communication. The transceiver supports full-duplex bidirectional communication up to 1.25 Gbps over spatial distances up to 100 mm and maintains consistent performance during communication between a stationary object and those rotating 360°. The P16548-01AT can be used for data communication equipment with rotating mechanisms, such as robotic manipulator arms and omni-directional cameras.
photonics@hamamatsu.com

Laser Scanner

The Artec Point from **Artec 3D** is a target-based laser scanner for industrial metrology applications. Verified in an ISO-certified lab against VDI/VDE 2634 and JJF 1951 standards, the

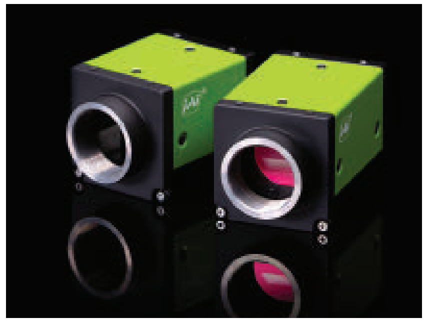
scanner has a lightweight chassis for maneuverability in tight spaces for measuring difficult-to-access areas and features full integration with the company's Artec Studio 3D scanning software. The Artec Point captures objects of different sizes and finishes, including dark, shiny surfaces and deep holes, at speeds of up to 120 fps or 2.8 million measurements per second.
support@artec3d.com

MWIR Sensor

The Sparrow HD from **SemiConductor Devices** (**SCD**) is a high-definition midwave infrared sensor module for defense and homeland security applications. The module incorporates interfaces such as MIPI CSI for integration with edge AI processors and is available in either a high operating temperature XBn configuration operating at 150 °K or a high operating temperature full-midwave configuration. The Sparrow HD features a 5-µm pixel pitch, 90° vertical or horizontal orientations, and optional video engine and image processing capabilities.
marketing@scd.co.il

Quantum SWIR Camera

The Q.Fly from **Quantum Solutions** in collaboration with TOPODRONE is a quantum dot SWIR camera designed for unmanned aerial vehicle drone platforms. The camera uses a built-in Linux computer for facilitating camera control, along with a built-in 16-MP RGB camera and optional thermal imager. The Q.Fly quantum dot sensor has a resolution of 640 × 512 pixels with a spectral range of 400 to 1700 nm and features 220-Hz high-speed spectral imaging, a weight of 650 g, and a three-axis gyrostabilized gimbal.
sales@quantum-solutions.com



Line-Scan Cameras

The Sweep Series from **JAI** are compact line-scan cameras for machine vision applications. The 2K cameras come as either 5 GigE or CXP-6 models and color or monochrome models. The 5 GigE models have a size of 44 × 44 × 64 mm and a scan rate of 44 kHz, while the CXP-6 models have a size of 44 × 44 × 54 mm and a scan rate of 172 kHz.
camerasales.emea@jai.com

Microscope Lens

The TITANITE lens from **Schneider-Kreuznach** is a lens for microscopy applications in medical and biological research. The lens is optimized for 5× magnification and enables the analysis of larger samples in a single image. The TITANITE lens features a resolution of up to 2.8-µm pixel size and a large image circle of 82 mm. It is compatible with SONY IMX461, IMX661, and IMX811 sensors.
isales@schneiderkreuznach.com

VIS-NIR Lens Series

The LINOS inspec.x L 5.6/105 VIS-NIR lens series from **Excelitas Technologies** can be used with large-format high-resolution VIS- and NIR-sensitive camera sensors for applications such as machine vision, industrial inspection, and quality control. The series comes with four lenses that can see wavelengths between 400 and 700 nm and between 700 and 1150 nm without a need to refocus. The LINOS inspec.x L 5.6/105 VIS-NIR lens series comes in magnifications from 0.25× to 4×, allowing for a working distance of ~100 to 500 mm.
photonics@excelitas.com

USB3 Extender

Valens Semiconductor's USB3 industrial grade extender can enable industrial-grade USB 3.0 cameras to be extended past the current 5-m limit to distances of up to 100 m over a category 6a cable. The extender supports the transmission of high-speed USB 3.2 Gen1 traffic, alongside USB 2.0, control signals, and 25 W of power.
info@valens.com

Desktop AOI System

The PowerSpector JSAz 550 from **Mek** is a 3D desktop automated optical inspection (AOI) system for the inspection of components such as printed circuit boards. Capable of accommodating boards up to 550 × 550 mm, the system is designed for maximum defect coverage while maintaining short programming times. The PowerSpector JSAz 550 can be equipped with nine cameras and uses selective 3D laser measurement technology to capture height measurements.
info@marantz-electronics.com

Industrial 3D Scanners

The Mini, Pro, and Ultra Industrial Series from **SCAPE Technologies** are series of industrial 3D scanners for applications such as object recognition, quality inspection, gluing, palletizing, and robotic bin picking. The Mini Industrial Series offerings are compact with either a color

or grayscale camera and can be mounted on robots. The Pro Industrial Series offerings are stationary scanners equipped with a color camera that covers scanning areas from small to large. The Ultra Industrial Series offerings are built for medium to large scanning areas and precision applications, such as bin picking.
info@scapetechnologies.com

Nanolithography System

The NanoFrazor from **Heidelberg Instruments** is a nanolithography system for applications in photonics, biomimetic substrates, and local material modification through heat-induced chemical reactions or phase changes. The system can be equipped with 10 parallel patterning cantilevers and includes capabilities for thermal scanning probe lithography, direct laser sublimation, and automation. The NanoFrazor enables patterning of nanostructures with lateral resolutions of 15 nm and vertical resolutions down to 2 nm and features an in situ inspection system that offers closed-loop lithography.
sales@heidelberg-instruments.com

1.6T Transceivers

Eoptolink Technology's OSFP 1.6T DR8/DR8-2 and 2xFR4 transceivers can be used in network applications for AI and machine learning clusters and data centers. The 1.6T OSFP transceivers have eight electrical host interfacing lanes and eight optical lanes operating at 212.5 Gbps with support for transmission distances of up to 2 km without the need to regenerate the forward error correction. The 1.6T 2xFR4 modules are designed with a dual duplex Lucent Connector running with two pairs of fibers only.
sales@eoptolink.com

SWIR Cameras

The CX.SWIR.XC SWIR cameras from **Baumer** are designed for applications in the semiconductor industry with wafer positioning as well as the food industry. The cameras use static and dynamic defect pixel correction firmware to produce an image quality similar to silicon-based sensors as well as an integrated cooling fin for dissipating heat to the outside. The CX.SWIR.XC cameras can acquire wavelengths ranging from 400 to 1700 nm.
sales.us@baumer.com

Line-Scan Cameras

The Linea HS2 family from **Teledyne DALSA** is a family of time delay integration (TDI) line-scan cameras for life sciences applications and the inspection of semiconductor wafers, high-density interconnects, and flat panel displays. Designed for high-speed imaging in low-light conditions, the cameras use back-side illuminated multi-array charge-domain TDI CMOS sensors that allow the cameras to be configured for maximized line rate, dynamic range, or full well. The Linea HS2 family is equipped with dual camera link HS CX4 connectors to active optical cables providing electromagnetic interference immunity and feature a resolution of 16K/5 µm and data transfer speeds of 16 GP/s.
tdi_sales.americas@teledyne.com

Industry Events

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

A3 Business Forum
(Jan. 20-22) Orlando, Fla.
Contact A3, +1 734-994-6088; www.automate.org/events/business-forum-2025.

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

FEBRUARY

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

⭘ SPIE Medical Imaging
(Feb. 16-20) San Diego.
Contact SPIE, +1 360-676-3290, **customer service@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, **semicon korea@semi.org**; www.semiconkorea.org/en.

MARCH

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

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

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

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

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

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

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

APRIL

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

⭘ SPIE Optics + Optoelectronics
(April 7-10) Prague.
Contact SPIE, +1 360-676-3290, **customer service@spie.org**; www.spie.org/conferences-and-exhibitions/optics-and-optoelectronics.

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

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

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

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

MAY

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

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

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

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

PAPERS

11th International Conference on Machine Vision and Machine Learning
(Aug. 17-19) Paris.
Deadline: Abstracts, Jan. 23
Contact International ASET Inc., +1-613-834-9999, **info@mvml.org**; www.mvml.org.

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

⭘ Indicates shows **Photonics Media** will be attending.
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Hamamatsu's newest InAsSb detector module with built-in preamp can detect infrared light simply by connecting to a DC power supply. With back-illumination technology, it's designed for a high-speed response of 10 MHz typical and is available for wavelengths in the 5 µm, 8 µm, and 10 µm bands. Integrate a standard or custom version of this module into your application.

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Ophir® Ariel is an ultra-compact laser power meter for measuring high power industrial lasers up to 8KW. Designed for use in confined, humid, or dusty additive manufacturing, metal cutting, and welding applications, the Ariel power meter is a robust, battery-powered device that requires no water or fan cooling and is small enough to fit in the palm of your hand. New detachable diffuser supports high power density beams.

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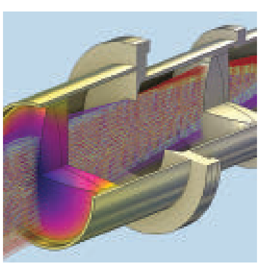
Multiphysics Modeling and Simulation



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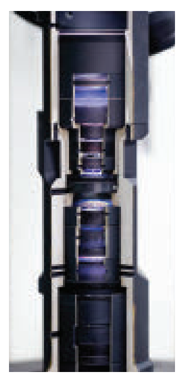
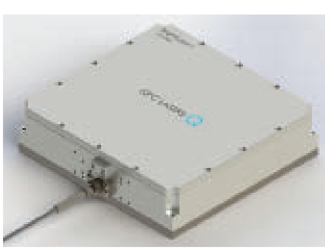
Custom High NA Objective Lens



Hyperion specializes in custom objective lenses engineered for quantum applications. Achieve high NA in a compact design with metrology-backed precision, including 2-5µm decenter & tilt correction per surface and 20µm air gap control between each element. We support extended wavelengths in the UV range (CaF_2, Quartz). Our Active Alignment assembly process ensures unmatched resolution. Enhance your quantum performance with custom engineering.

HYPERION OPTICS USA
(908) 899-1918
rfq-us@hypoptics.com
www.hyperionoptics.com

795-nm Diode Laser for Rb Vapor Pumps



QPC Lasers offers Brightlock® wavelength stabilized laser modules for pumping the D1 line of Rb at 795 nm, which are used for applications such as medical imaging, quantum sensing and computing. Standard products feature powers to 180 W and linewidths below 250 pm, with other specifications on request.

QPC Lasers Inc. **(818) 986-0000**
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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.

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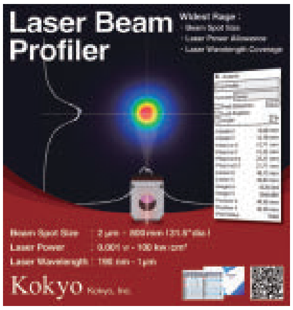
Ultrawide Range Laser Beam Profiler



A full line of our versatile Laser Beam Profilers will make your beam quality control easier. It covers Beam Spot Size from 2 micron (1/10 mils) to 800mm (31.5" dia.) , Laser Power from 0.001W through 100kw/cm^2, and Laser Wavelength 190nm to 1micron, that makes our profiler applicable for majority of industries related to laser such as Processing, Machinery, Inspection, Measurement, Research & Development, and Tele-communication.

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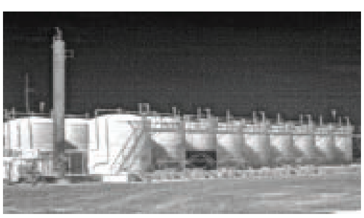
Uncooled Optical Gas Imaging



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

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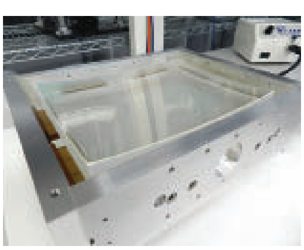
Off-Axis Parabolas



AOS produces off-axis parabolas for the most demanding applications in technology today including high energy lasers, analytic instruments, and satellite imaging. Our special tolerancing system optimizes performance. We manufacture custom components in a variety of materials including silicon carbide, glass, silicon and other advanced ceramics. AOS aspheric optics can be found in high technology companies and laboratories around the globe.

Aperture Optical Sciences Inc. **(860) 316-2589**
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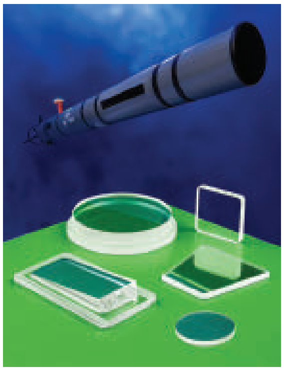
AUV & UUV Sapphire Optics



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.

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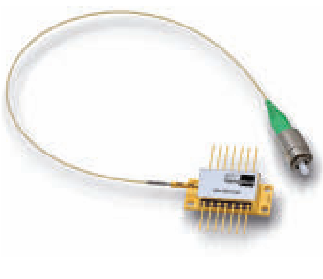

Exciting news for photoacoustic customers! Our nanoplus DFB Interband Cascade Lasers (DFB ICL) at 3345 nm and 4565 nm now offer power outputs up to 40 mW, while maintaining the quality you trust. Additionally, we now provide nanoplus DFB ICLs up to 5500 nm in a fiber-coupled butterfly package for easier handling. Embrace these new options!

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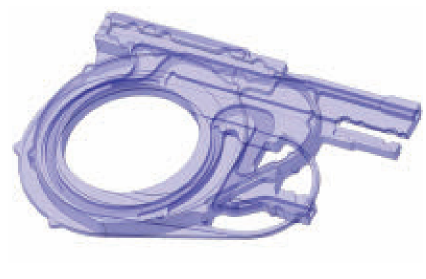

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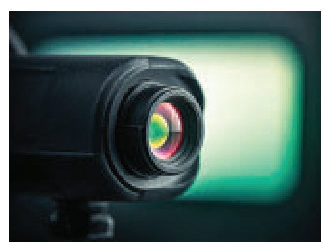

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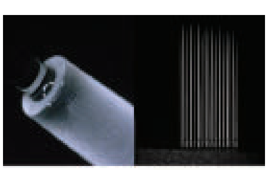
The NYFORS SMARTSPLICER



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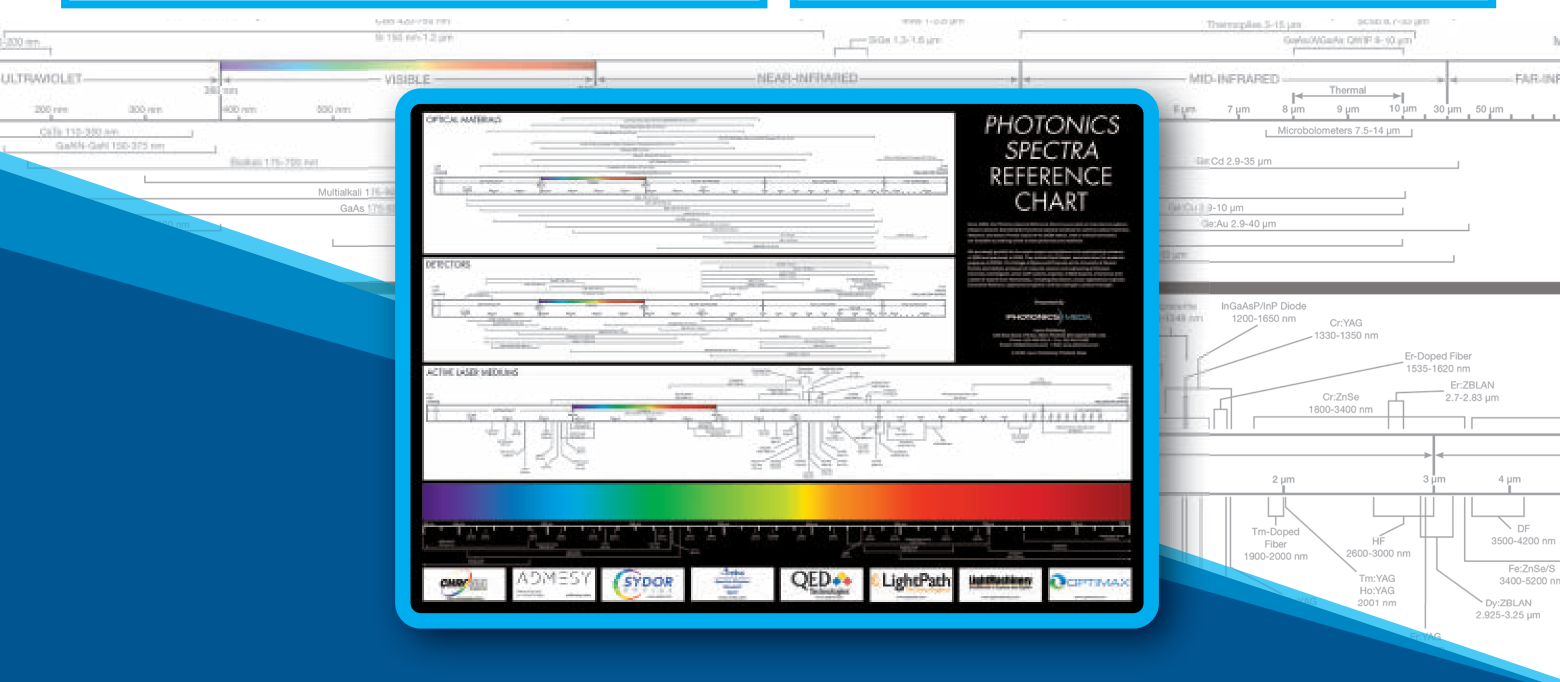

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Feel the burn! See the burn!

Any athlete will tell you that their sport is a numbers game. It's not only adding points on a scoreboard, though. Slight deviations in timing when exiting the starting blocks, for example, can mean the difference between first and second place in a 100-meter dash. And even a miniscule difference in force could turn a three-point shot into a brick. With such a wide margin of failure, it's no wonder why coaches keep preaching the fundamentals.

But sometimes it's the variables we can't see that tip the balance in a competition — a fact that was recognized by researchers at the Universidad de Concepción in Concepción, Chile. Perhaps on a mission to get "swole," the researchers developed a method that combines videos from thermal cameras with AI-based digital processing to enhance weightlifting training.

The hidden variables in question here are the small changes in temperature and body positioning that the method tracks throughout an exercise. The changes in body temperature correlate to muscle activation and areas of strain or fatigue, which can be used to prevent injuries, monitor thermal responses, and quantify physical exercise.

While most current methods use "before-and-after" snapshots to track body temperature, they only offer a limited view of the complex dynamics happening inside the body. Instead, the researchers' method uses data taken from either an inexpensive thermal camera in a smartphone or a high-end thermal device, runs it through data processing algorithms, and then uses Google MediaPipe AI software to identify individuals and their body parts within the images and extract the required information.

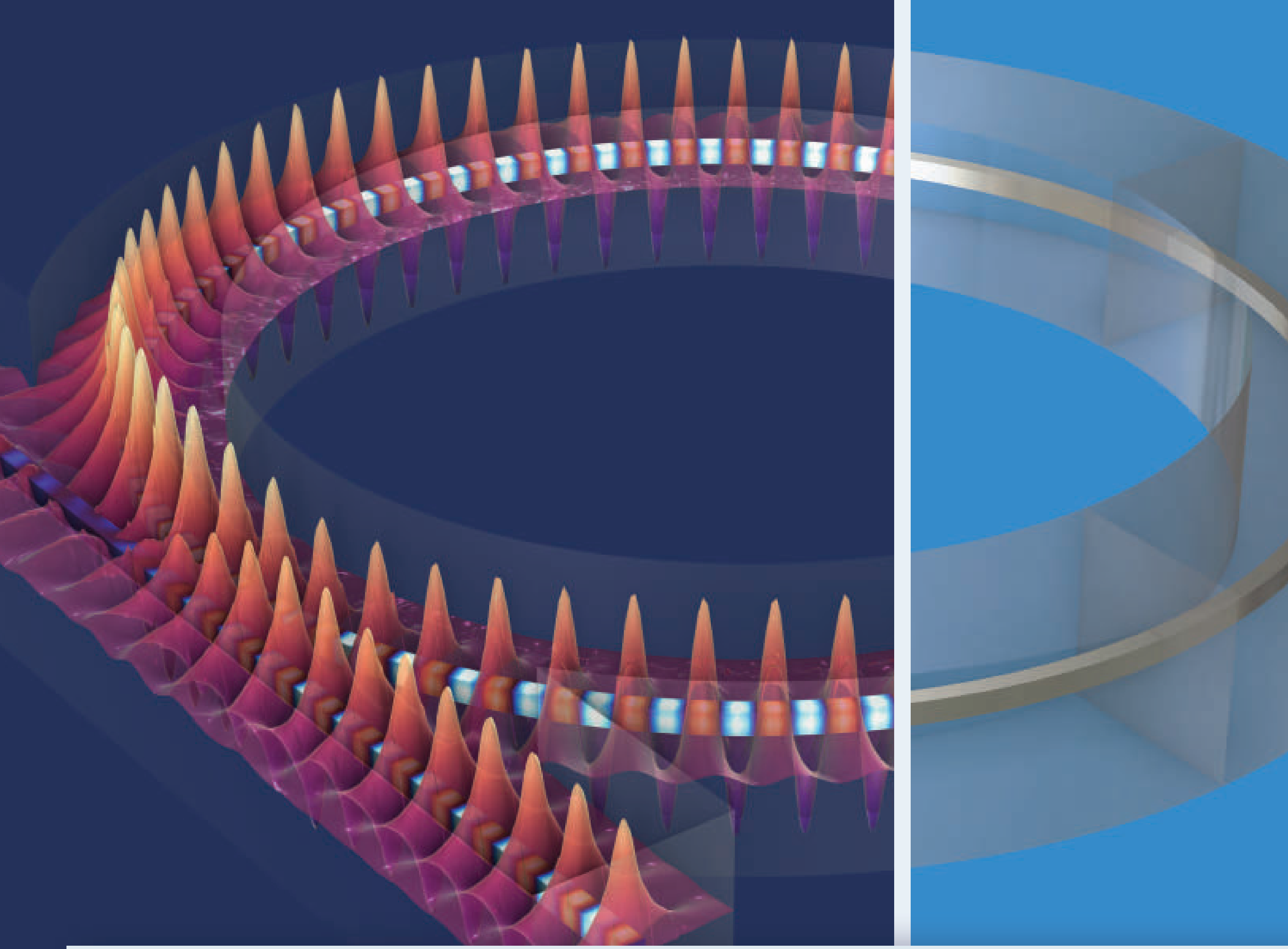
Additional key points, such as the subject's joints and the barbell, were then identified and used to calculate the corresponding angles and create a frame-by-frame graph to track positional and temperature changes throughout the exercise.

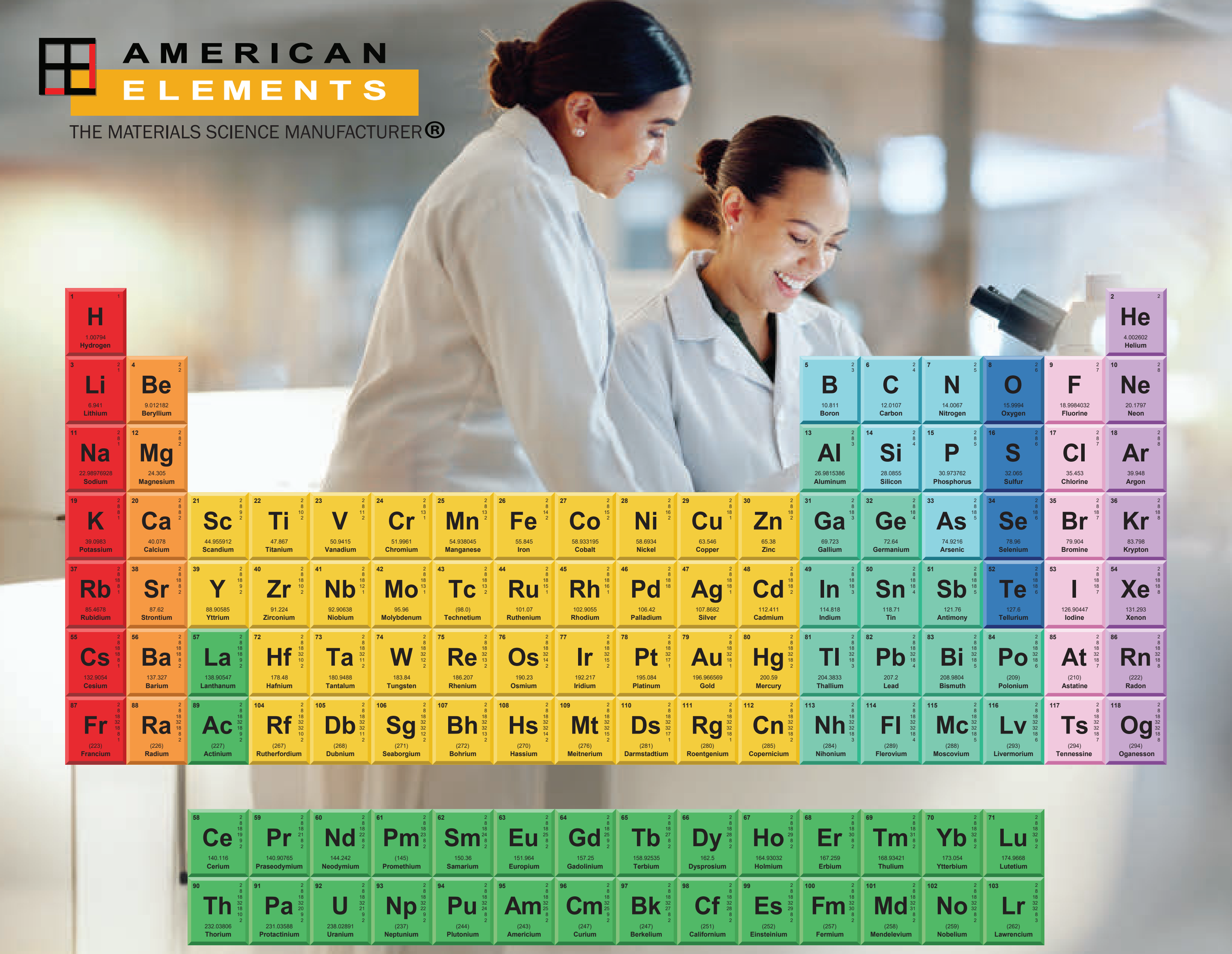
So, can you quantify a heated workout on a budget? Yes, but as predicted, there is a hierarchy of options that unfortunately the inexpensive smartphone app just doesn't top. The researchers found that the process became more complicated with a conventional camera with some movements — such as curling up into a ball or having a weight obscure their body — too difficult for the inexpensive option to precisely capture. So, unfortunately, the method is not quite ready for a mass consumer release.

The researchers, however, are at a stage in which they feel they can branch out into other sports, such as basketball, soccer, and their Paralympic counterparts, as well as refine their algorithm to provide real-time, actionable information to users. In the meantime, gym rats who live in the weight room will have the upper hand in training until further testing is completed; so maybe expect more people to be lifting like Eddie Hall or Brian Shaw next time you head out to pump iron.

The research was published in *Applied Optics* (www.doi.org/10.1364/AO.532763).

Courtesy of iStock.com/SrdicPhoto.





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2025 Industry Events

January

S	M	T	W	T	F	S
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5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
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- A3 Business Forum, Jan. 20-22, Orlando, Fla.
- SPIE BiOS and SPIE Photonics West, Jan. 25-30, San Francisco

February

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- Biophysical Society Annual Meeting, Feb. 15-19, Los Angeles
- SPIE Medical Imaging, Feb. 16-20, San Diego

March

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- Pittcon, March 1-5, Boston
- LASER World of PHOTONICS China, March 11-13, Shanghai
- SPIE Smart Structures + Nondestructive Evaluation, March 17-20, Vancouver, Canada
- Image Sensors Europe, March 18-19, London
- OFC, March 30-April 3, San Francisco

April

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- OFC, March 30-April 3, San Francisco
- PIC International Conference, April 7-9, Brussels
- SPIE Defense + Commercial Sensing, April 13-17, Orlando, Fla.
- Optica Biophotonics Congress: Optics in the Life Sciences, April 20-24, Coronado, Calif.
- OPIE, April 23-25, Yokohama, Japan

All dates accurate as of 11/5/24. For updates and additional shows refer to the Industry Events page each month in *Photonics Spectra*.

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2025 Industry Events

May

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- CLEO, May 4-9, Long Beach, Calif.
- SENSOR + TEST, May 6-8, Nuremburg, Germany
- SID Display Week, May 11-16, San Jose, Calif.
- Automate, May 12-15, Detroit
- Photonics North, May 20-22, Ottawa, Canada

June

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- Optica Quantum 2.0 Conference and Exhibition, June 1-5, San Francisco
- AutoSens USA, June 10-12, Detroit
- LASER World of PHOTONICS Munich, June 24-27, Munich

July

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- Photonics Media *Vision Spectra* Conference, July 15-17, **(Virtual)**
- Microscopy & Microanalysis, July 27-31, Salt Lake City

August

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- SPIE Optics + Photonics, Aug. 3-7, San Diego

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2025 Industry Events

September

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- FABTECH, Sept. 8-11, Chicago
- CIOE, Sept. 10-12, Shenzhen, China
- ECOC, Sept. 28-Oct. 2, Copenhagen, Denmark

October

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28	29	30	1	2	3	4
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12	13	14	15	16	17	18
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- ECOC, Sept. 28-Oct. 2, Copenhagen, Denmark
- SciX, Oct. 5-10, Covington, Ky.
- SEMICON West, Oct, 7-9, Phoenix
- Photonics Media *BioPhotonics* Conference, Oct. 14-16, **(Virtual)**
- SPIE Optifab, Oct. 20-23, Rochester, N.Y.

November

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- Neuroscience, Nov. 15-19, San Diego

December

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14	15	16	17	18	19	20
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- Cell Bio, Dec. 6-10, Philadelphia

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