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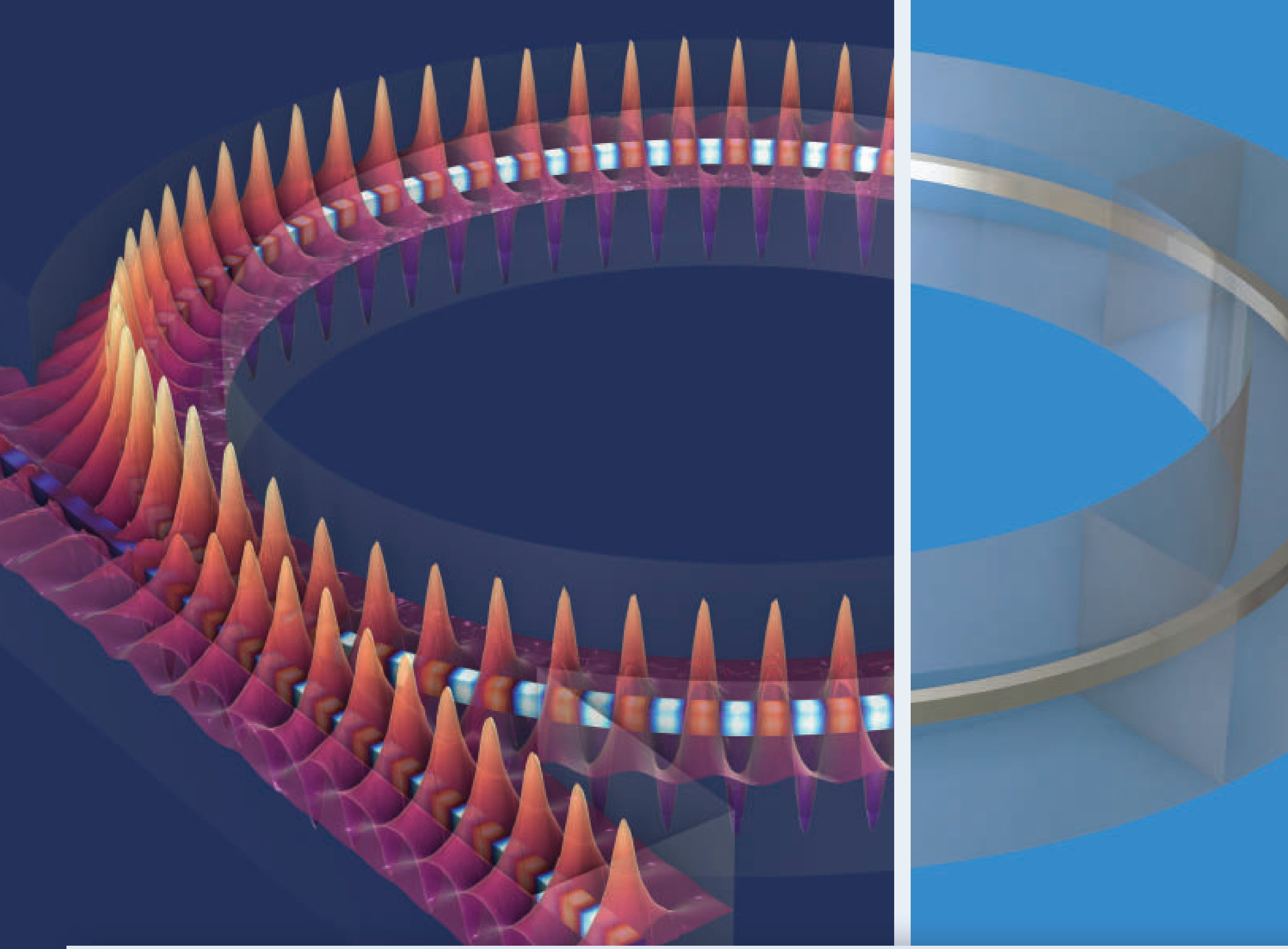


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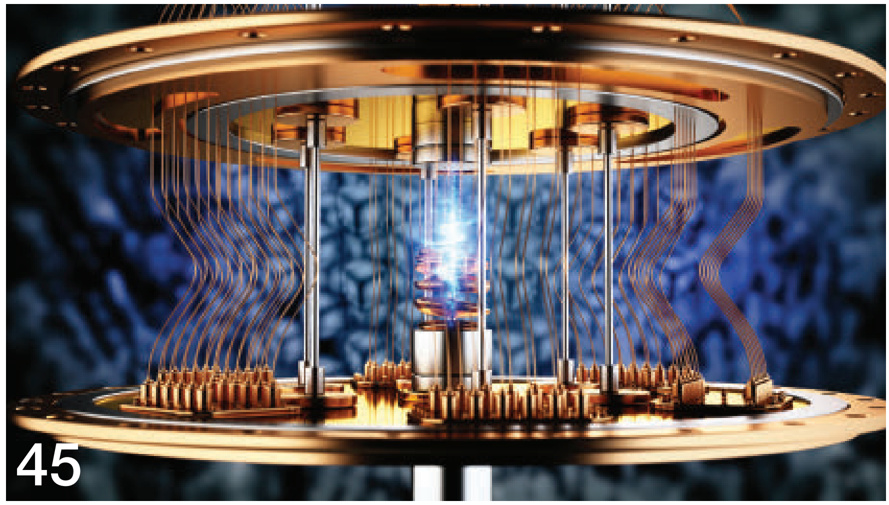
August 2025 volume 59 issue 8



Features

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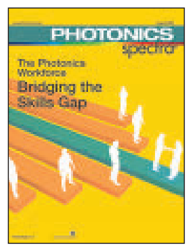
Columns

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



The Cover

Aspects of the training required for peripheral disciplines, such as electrical engineering, are transferable to photonics engineering. At the same time, photonics presents distinct challenges to members of its workforce. The industry is aiming to bridge the skills gap that characterizes this dynamic. Image courtesy of iStock.com/kentoh. Cover design by Senior Art Director Lisa N. Comstock.

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Editor's Note

Tailoring inroads to the photonics workforce

Contributing editor James Schlett, who authors *Photonics Spectra*'s annual industry workforce feature, is as adept as any writer at the "show, don't tell" approach to reporting. Schlett's years covering this topic also make him well-versed in isolating the industry-specific challenges, nuances, and opportunities that abound in growing the optics and photonics workforce. There are plenty of each.

Yet Schlett's journalistic capabilities, and the insights he has collected from years spent peeling back the layers of this industry's workforce dynamics, are not required to discern one of the most glaring needs in resolving present and future personnel shortages. The inroads to a career in optics and photonics are out there, but rising professionals need guidance to pursue them.

A profusion of high-level conversations during the past few years, and likely longer, has focused on this problem and the elusive nature of its clear-cut solutions. The need to better market the industry to raise awareness of its career opportunities has become the prevailing takeaway. Many of these conversations break out from topical panel discussions, forums, conference keynotes, and — perhaps most indicative of the severity of this issue — unprompted gatherings of industry changemakers. This suggests that any shortcomings related to marketing the industry affect prospective members of the workforce rather than those who are already part of it.

In response, the tremendous work of institutions of higher learning and government- and industry-funded initiatives to increase awareness of a sustainable and fulfilling career in optics and photonics is increasingly targeted. These efforts today are precisely aimed at distinct populations of prospective technicians and engineers, spanning the middle school, high school, and college talent pools.

As is true of the issue of workforce demand in the broadest sense, there is nuance to outreach and awareness, too. The optics and photonics field is far-reaching and expansive. Opportunities for prospective members of the workforce — to innovate, achieve financial stability, and give back to their communities — are available. In fact, they are available in numerous disciplines and subdisciplines — from optics technician to fiber optics technician, and from integrated photonics engineer to quantum engineer.

The challenge, beyond helping prospective members of the workforce find industry inroads, is guiding them to the right opportunities that align both with available prospects and with the unique skill sets and interests of each individual.

Schlett is not the only contributor to this month's edition to elucidate this point. Another happens to soon be advancing into the workforce himself. Jasper Stackawitz, recipient of the 2025 Teddi C. Laurin Scholarship, speaks with *Photonics Spectra* about his journey and plans for a career involving photonics on page 54.

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Andreas Thoss
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In the September issue of
Photonics Spectra...

- **Precision Optics Manufacturing**
- **Aspheric Optics**
- **Lab-on-a-Chip Systems Design**
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Practical Aberration Correction Using Freeform Optics — Pushing the Boundaries of Laser System Performance

Nonchromatic aberrations in laser systems can be compensated using a single, custom-manufactured freeform optical element, without the requirement for rotational symmetry. These components then require high tolerance positioning and permanent fixturing. Optical aberrations in the laser system come from a variety of sources and affect the extent to which the actual output spot deviates from that of the design intent of the system. To compensate for aberrations, it is vital to make appropriate measurements of the aberrations, and then ideally represent them as Zernike coefficients. Then, it is possible to design a freeform surface using refractive principles as a freeform aberration compensator. If the freeform surface can be designed and manufactured with a fast turnaround, the aberration compensator can be regarded as an "in-build" manufacturing solution. By making the freeform in fused silica using a precision direct-write laser machining process, aberration compensators will have extremely low scatter and low loss. These fused silica freeform aberration compensators can therefore be used in either extreme high-power applications or extremely sensitive low-light applications. Presented by PowerPhotonic.
To view, visit **www.photonics.com/w1159**.

PowerPhotonic
Enhancing Beam Performance

Optimization of LED Illumination for Hyperspectral Imaging Applications

Hyperspectral systems provide powerful spectral insight at production-line speeds. Inline versions typically use a line-scan camera coupled with a wavelength-dispersing element, and the resulting data cube reveals spatial and spectral information across UV to mid-infrared wavelengths, with increasing interest in the SWIR. Among other requirements, the light source must deliver high radiant intensity over the relevant spectral range while maintaining exceptional stability. This webinar introduces key principles of inline hyperspectral imaging, with a focus on the often-overlooked design and integration of illumination. The webinar will reveal how optimized, performance-driven LED illumination strategies can improve results and unlock capabilities to give solutions an edge in the market. Presented by Innovations in Optics Inc.
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INNOVATIONS IN OPTICS

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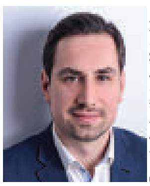
SUMMIT

Micromachining Summit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The editors of *Photonics Spectra* magazine invite you to the Micromachining Summit — a one-day virtual event showcasing ultraprecise, reliable, and scalable micromachining solutions across industries and application areas, including medical devices, electronics, and semiconductors.

The summit takes place on Sept. 17, and all presentations will be available on demand after the premiere.

Join presenters from the Fraunhofer Institute for Material and Beam Technology IWS, MKS Ophir, DataRay Inc., Novanta, Cailabs, and SCANLAB as leading experts share the latest developments in micromachining. Featured topics include real-time adaptive process control, industrial laser beam shaping, and precision drilling techniques for electronics and semiconductor manufacturing.

Registration is free and includes access to all sessions, networking opportunities, and actionable insights to enhance your design capabilities and improve product performance.

Website

To learn more about the program and to register, visit **www.photonics.com/MMS2025.**

DLIP on Freeform Surfaces: Structure Homogeneity via Acoustic-Based Process Control
Christoph Zwahr, Fraunhofer Institute for Material and Beam Technology IWS

Sharpening Precision: Laser Beam Profiling for High-Accuracy Micromachining
Logan Hatanaka, DataRay Inc.

How to Ensure Laser Accuracy for Precise Micromachining
John McCauley, MKS Ophir

Precision Laser Drilling for Electronics and Semiconductors
Matthew Tedford, Novanta

Implementing Beam Shaping for Industrial Microprocessing: Challenges and Solutions
Gwenn Pallier, Cailabs

Recent Advancements in Laser Drilling
Mara Lisa Heinlein, SCANLAB

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In Uncertain Times, LASER World of PHOTONICS Brings Good News from the Community

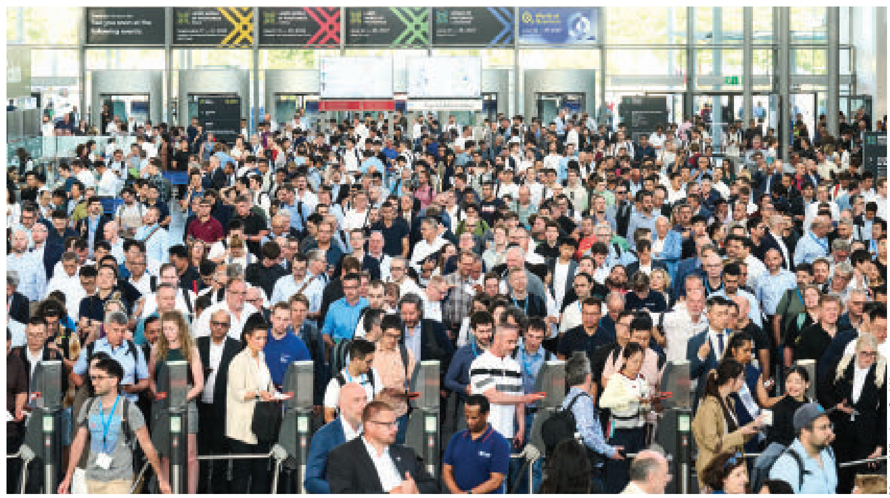
BY ANDREAS THOSS
CONTRIBUTING EDITOR

There's no doubt that the world is in turmoil. High tariffs are threatening global trade, missiles are flying through the air, and climate change is no longer a looming threat — it is our daily reality.

Amid this global backdrop, the vibrancy of LASER World of PHOTONICS felt surprising, even uplifting. From show organizers, exhibitors, and perhaps most noticeably from the community, the mood in the halls was upbeat, despite the fact that many companies are facing severe challenges.

We are living in the century of light. The industrial manifestation of photonics is clearly on the rise. As a major photonics trade show, LASER 2025 grew by 10% compared to 2023. A total of 1398 exhibitors from 41 countries showcased the full spectrum of photonics technologies to ~44,000 visitors. The co-located events — automatica, the World of QUANTUM, and the World of Photonics Congress — were thriving as well. Almost every exhibitor with whom I spoke reported high booth traffic and strong leads.

Against what felt like all odds, the show was a complete success.



Messe München GmbH

LASER World of PHOTONICS 2025 — co-located with the World of QUANTUM, the World of Photonics Congress, and automatica events — posted record numbers with 1398 exhibitors and 44,000 visitors.

A wonderful world

In the lead-up to the week of the trade show, on Friday, June 20, the eyes of the photonics world focused intently on Ditzingen, Germany, the site of the Berthold Leibinger Zukunftspreis (Future Prize) and Innovationspreis (Innovation Prize) ceremony. At TRUMPF's headquarters, Peter Leibinger, chairman of the Supervisory Board of TRUMPF SE, welcomed more than 600 invited guests. Berthold Leibinger, Peter's father, transformed TRUMPF into a global leader in industrial laser technology. With his foundation, he sought to honor outstanding achievements in both basic and applied laser research.

Sobering news, though, cast a shadow over this year's ceremony: TRUMPF recently announced significant layoffs. And, of course, the global backdrop remains grim. "Shall we celebrate in these times?" Peter Leibinger asked the audience. His answer was a thoughtful and heartfelt "yes."

He reminded us that international exchange has never been more essential. It is precisely in difficult times such as these, he said, that we must honor scientific excellence. And above all, Peter Leibinger affirmed his deep appreciation for this world, calling it "wunderbar" (marvelous).

The evening unfolded as a joyful celebration of light and science; a gathering of more than 600 laser enthusiasts shared inspiration, purpose, and a bit of much-needed optimism. It served as a strong inspiration for the forthcoming week, as the photonics world traveled to Munich.

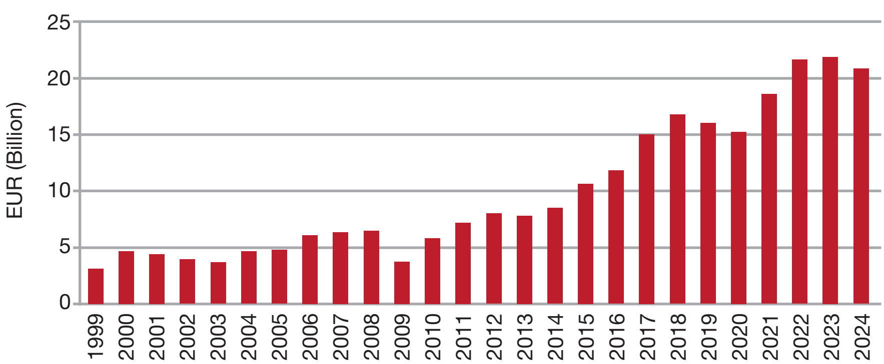
A visit to the future of ultrafast lasers

Like Photonics West in January, LASER World of PHOTONICS in Munich kicked off on a Tuesday, leaving Monday free for a visit to one of the city's many photonics hotspots. Munich is home to world-class research centers, including the famed Max Planck Institute of Quantum Optics in Garching, Germany. This year, though, I opted to visit a company that has been on my wish list for years: TRUMPF Scientific Lasers.

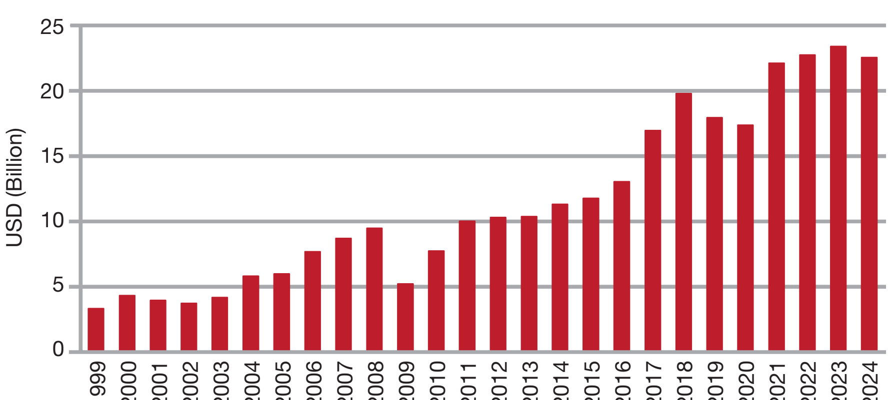
Among the companies in the industrial laser ecosystem, this spinoff has a unique advantage: It can draw from the full TRUMPF portfolio and change (or add)

TRUMPF

Tom Metzger, CEO of TRUMPF Scientific Lasers, presents a 10-J, 100-Hz amplifier head based on multiple ytterbium-doped YAG (Yb:YAG) slabs developed by colleagues at TRUMPF Laser SE. The TRUMPF Scientific Lasers team plans to adapt the system for ytterbium glass (Yb:glass) operation.



Source: Optech Consulting — April 15, 2025



Source: Optech Consulting — April 15, 2025

The global market for laser materials processing systems. While projections for 2025 show a decline in the global market for laser materials processing, the overall market trend for laser materials processing systems remains positive, advancing at a solid compound annual growth rate of 7% to 7.5%. This was explained by Arnold Mayer during his overview of observations and data at LASER Munich during the 17th Laser Marketplace forum. Conversion rate on April 15, 2025: €5B = $5.67B.

whatever its experts deem necessary to create lasers with extreme specifications tailored to specific scientific pursuits.

"We often sell lasers that don't exist," CEO Tom Metzger said regarding the team's daily mission. The results are high-performance systems that deliver ultrashort pulses at high repetition rates, offering tens of thousands of hours of uptime.

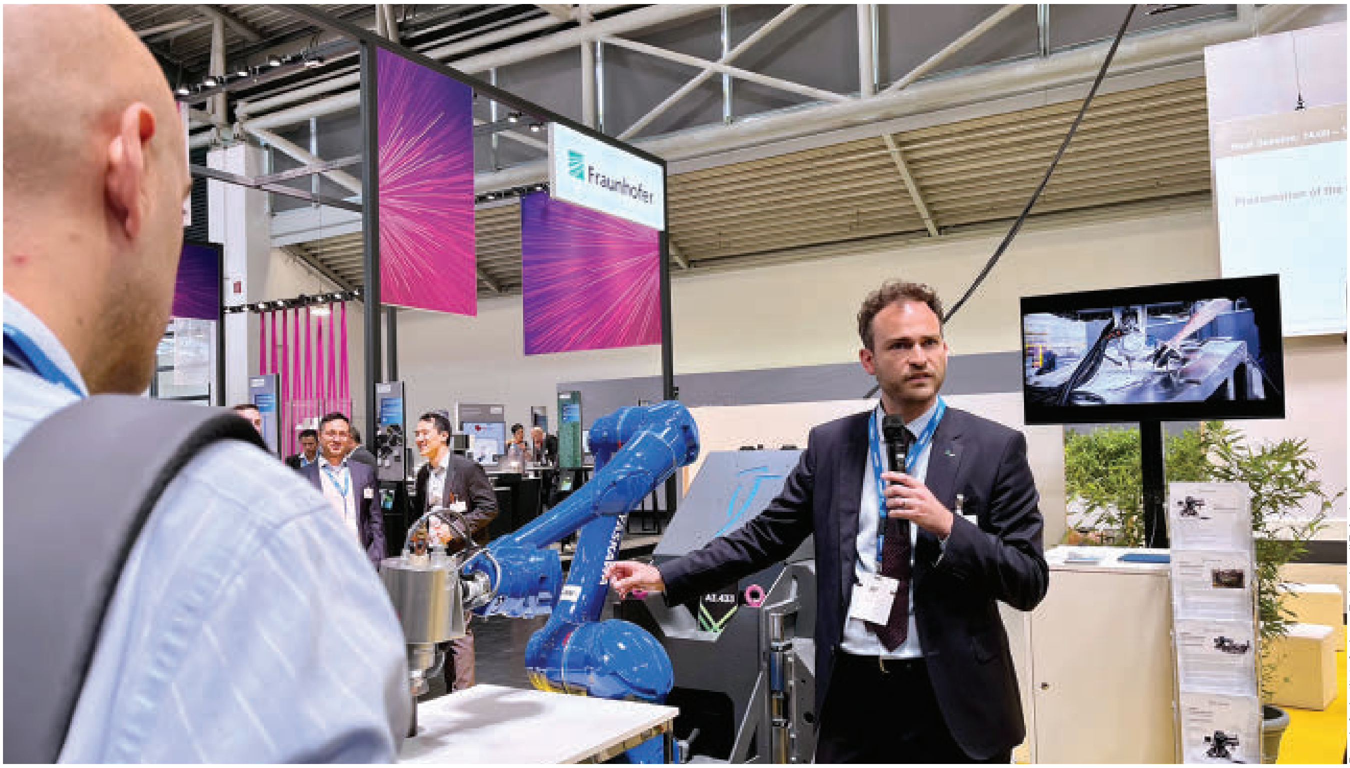
Most of TRUMPF Scientific Lasers' systems are based on ytterbium-doped YAG (Yb:YAG), a material that is favored for its diode-pumping efficiency. The drawback, of course, is Yb:YAG's relatively narrow bandwidth. To achieve pulse durations that are 50 fs or less, the company uses nonlinear devices for spectral broadening, resulting in minimal loss due to the use of a Herriott cell. One such cell, stretching an impressive 12 m, dominates a large part of the lab. It is clear that this approach has practical limits.

For this reason, the team is exploring ytterbium glass (Yb:glass), which offers a broader amplification bandwidth. Metzger sees this material solution as a potential game-changer for diode-pumped high-energy lasers, especially for future laser fusion applications.

"Lasers for fusion must be diode-pumped," Metzger said. "We're thinking about those components and doing simulations, but a full-scale power station would require a dedicated factory for the respective laser modules."

State of the laser market

The trade show was huge, which reflects the state of the laser industry quite well. On one hand, lasers have matured, particularly in materials processing. The laser source itself is now largely a commodity, and machines that deliver quality that is



Fraunhofer Institute for Laser Technology ILT, Aachen

Carlo Holly, professor at RWTH Aachen University and department head at the Fraunhofer Institute for Laser Technology ILT.

“good enough” are sold primarily based on price. But this does not mean that the major laser manufacturers have paused innovation. On the contrary, they continue to push boundaries, using technological differentiation to stand out in an increasingly competitive field.

At the same time, lasers are moving into new applications across sectors, driving both consolidation among major players and a wave of innovation from startups. This dynamic was clearly visible in the halls of the show: Large companies with expansive booths presented industrial systems for applications such as battery welding and displays manufacturing. Smaller firms — their booths often grouped by region or theme — showcased a myriad of exciting new technologies. One entire hall was devoted to quantum technologies. Another dedicated area featured integrated photonics. Additional areas showcased medTECH, robotics (within the automatica halls), and many more applications.

But how is the market evolving overall? This is a difficult question to answer, especially in such a fragmented field.

For laser materials processing, one reliable source of insight at the show is the Laser Marketplace forum. This session is a staple of each LASER Munich show, organized by Arnold Mayer, president of Optech Consulting. A seasoned market analyst, Mayer estimated the global market for laser systems in materials processing at $23 billion for 2024, a value that has decreased by 4% since 2023. However, during the past decade, the industry has maintained a healthy compound annual growth rate of 7.5%, according to Mayer. For 2025, he forecasts modest single-digit growth, driven by rising unit sales despite ongoing price erosion.

To dig deeper, I had the chance to moderate a Marketplace panel with executives from three top laser firms. In my 40-min conversation with Thomas Fehn of TRUMPF, Sanjai Parthasarathi of Coherent, and Trevor Ness of IPG Photonics, several takeaways emerged:

1. **Lasers are mature** — especially fiber lasers. Low-cost continuous-wave fiber lasers start at $1/W, enabling applications on a mass scale.
2. **Bigger is still better** — high-power lasers that operate at up to 50 kW are beginning to replace plasma cutters, offering higher precision and efficiency for cutting thick materials.
3. **Commoditization is accelerating** — particularly due to China’s rapid adoption and intense domestic competition. But the leading players are responding with flexible, regionalized (“local-for-local”) manufacturing strategies and smart technologies.

Despite global uncertainty, one thing is clear: The laser industry is evolving rapidly. Those who adapt and innovate will be the ones shaping its future.

AI and laser-based manufacturing

What’s the major news takeaway from the show? I asked myself and others, and there isn’t just one. A single headline does not sufficiently capture the diversity of the technologies that were on display. But one trend clearly stood out as increasingly relevant in photonics: the application of AI.

AI is making its way into photonics in several influential ways. First, it supports complex, multiparameter problems using machine learning — for example, in optical design or the alignment of intricate laser systems, such as those used in secondary sources. Second, AI tools are already being integrated into daily production. Here, AI serves to optimize cutting trajectories, improve sorting algorithms, or even suggest ideal laser parameters via AI-driven assistants. Third, AI is now used in quality control to classify “good” and “bad” laser welds in real time based on image data.

Of the many people and firms bringing AI to (laser) production, it is important to mention Carlo Holly, professor at RWTH Aachen University and department head at the Fraunhofer Institute for Laser Technology ILT. Holly leads several projects on AI in laser-based manufacturing and has developed a four-step framework for implementation. The process starts with data acquisition. Multiple sensors monitor both the machine and the workpiece during processing. The next step is process understanding — analyzing the captured data to simulate how the process behaves. Once the simulation reliably matches real-world data, it can be used for prediction. Finally, this enables adaptive control, where the system adjusts itself in real time for optimal performance.

The multistep process is best illustrated with an example. Consider that some laser welding systems already record images of each weld seam. A computer, trained on thousands of labeled images, detects flaws such as spatter or pores and classifies parts accordingly. This covers steps one and two of Holly’s model. If the manufacturer can model how laser parameters affect seam quality (step three), they can begin to close the control loop, automatically adjusting laser settings to improve results (step four).

Holly envisions reducing the need for large training data sets using smarter learning techniques. This could lead to self-learning machines capable of achieving first-time-right production.

Valuable connections

It was an amazing week, full of reconnecting with old contacts and an overwhelming number of chances to make new ones. The quality of networking events has further improved. I suppose that this is due to the amazing number of breakfasts, morning runs, luncheons, and, last but not least, booth parties. Thousands of drinks were handed out (standards set by TOPTICA Photonics), while others got physicists dancing (HÜBNER Photonics). I enjoyed a wonderful evening at Menlo’s off-site event and connected with many people at the exhibitor reception.

Again, it is impossible to attend all these networking events. But, returning to Peter Leibinger’s words, it has never been more important to foster international exchange than it is today. LASER World of PHOTONICS was successful (by the numbers) and almost everyone with whom I spoke confirmed successful traffic at the booths and great leads to take home. I hope this quickly turns into good business. I look forward to discussing it and seeing you all again at LASER 2027!

th@thoss-media.de

QED Technologies acquires Dutch United Instruments

Precision optics manufacturing solutions company QED Technologies acquired Dutch United Instruments (DUI), a Netherlands-based metrology company. This acquisition of the former Demcon subsidiary adds DUI's Nanomefos metrology platform to QED's portfolio and establishes a European headquarters for the company.

Nanomefos' capabilities for rapid, nanometer-accurate measurement of complex surfaces complement QED's existing technologies, including magnetorheological finishing and subaperture stitching interferometry. The addition of a noncontact, ultraprecise metrology platform for freeform and aspheric optics complements QED's existing expertise in optical manufacturing and supports its long-term growth strategy, the company said.

DUI was founded as a spinoff of the Dutch research institute TNO. DUI and its customers will now have access to QED's global service and support infrastructure. Through its network of field service engineers, applications experts, and regional offices, QED will provide Nanomefos users with timely and reliable support, the company said. QED's global distribution channels are also expected to make Nanomefos available to a wider customer base.

In May, QED revealed plans to invest \$18.7 million to expand its operations in Rochester, N.Y. The expansion aims to help the company meet growing fabrication demand for precision optics technologies in the semiconductor, defense, and aerospace industries.

The Rochester project, which is expected to be completed by the end of the year, will add up to 20,000 sq ft to QED's existing University Avenue facility and establish an R&D center. The expansion is also expected to lead to the creation of up to 72 new jobs over the next five years.

This month in history

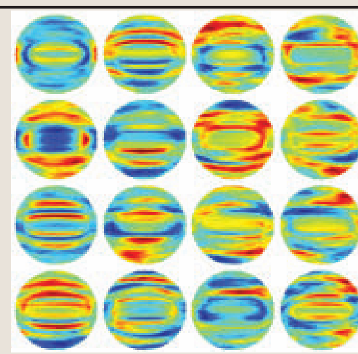
What were you working on five, 10, 20, or even 30 years ago? *Photonics Spectra* editors have perused past August issues and unearthed the following:

1995

Researchers at Hughes Research Laboratories developed an optical approach to sonar techniques that allowed the inspection of welds during manufacturing. Called compensated laser ultrasonic evaluation, the technique used lasers to "ping" a part, generating ultrasonic waves, while a second probe beam remotely sensed the vibrations using an optical compensator and a detector.

2005

Researchers from the University of Tokushima and Hokkaido University used fingernails as a medium for 3D optical data storage. They employed a femtosecond laser to write data and a fluorescence microscope to read the stored data at a density of 2 Gb/cm^3, which is concentrated enough to store >0.5 Mb within a space measuring 0.5 cm on a side and 0.1 mm deep.

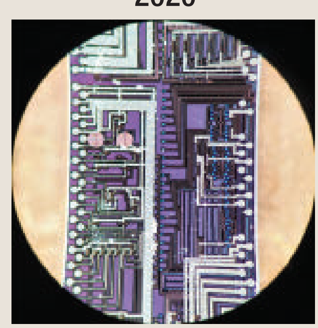


2015

Korea Advanced Institute of Science and Technology (KAIST) scientists developed a quantitative phase imaging unit to convert standard optical microscopes into holographic microscopes. The conversion was paired with machine-learning software to help hospitals and the food industry screen for bacteria in real time.

2020

Physicists at the University of Bristol developed an integrated photon source to deliver large-scale quantum photonics. To produce high-quality photons, the researchers exploited a dual-mode pump-delayed excitation technique to engineer the emission of spectrally pure photon pairs through intermodal spontaneous four-wave mixing in low-loss spiraled multimode waveguides.



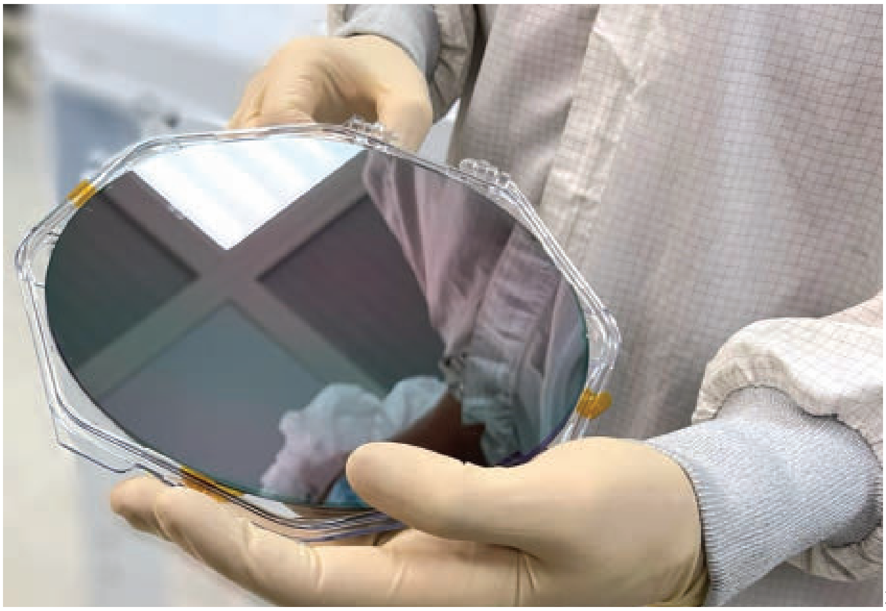
Partners lay groundwork for scalable quantum integrated photonics

Aeluma, in collaboration with Thorlabs Crytalline Solutions, demonstrated wafer-scale integration of the nonlinear optical material aluminum gallium arsenide (AlGaAs) onto CMOS silicon photonics-standard 200-mm-diameter wafers. According to Aeluma, this demonstration and method could accelerate the commercial-scale adoption of quantum computing and communications.

The nonlinear optical material enables entangled photon pair generation and modulation — key building blocks for quantum photonic systems. According to the collaborators, AlGaAs offers significantly improved efficiency for next-generation quantum photonic circuits compared with other materials such as silicon nitride and lithium niobate.

"Quantum integrated photonics requires different materials to control quantum states. High-performance materials — including aluminum gallium arsenide, lithium niobate, or barium titanate — are not traditionally compatible with large-scale, 200-mm and 300-mm silicon photonics," said Jonathan Klamkin, CEO and director of Aeluma. "Therefore, scalable heterogeneous integration techniques are needed to bring these materials together."

According to Garrett Cole, manager of Thorlabs Crystalline Solutions at the time of the collaboration, the partners aim to combine the core strengths of the companies' respective teams, which are both based in Santa Barbara, Calif. Aeluma produces high-quality epitaxial compound semiconductors at wafer sizes up to 300 mm. Thorlabs Crystalline Solutions develops direct bonding processes for novel III-V-based compound-semiconductor-on-insulator materials, including AlGaAs.


Aeluma

A 200-mm wafer manufacturing method developed by Aeluma and Thorlabs Crystalline Solutions could facilitate the scalable fabrication of quantum photonic circuits on silicon.

"Our aim was to bring these capabilities together to demonstrate high-performance compound semiconductor-on-insulator wafers at commercially relevant scales," Cole said. "There have been several demonstrations of smaller R&D-level solutions, but this is the first, to our knowledge, of a demonstration that is truly scalable."

According to the companies, the work provides opportunities for quantum systems developers by delivering the desired performance alongside an inherently mature manufacturing process. More broadly, it showcases the potential to integrate mature III-V materials, which, Cole said, is particularly compelling given their high-performance properties for both quantum and classical applications.

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

IonQ extends acquisition spree with plans to buy Oxford Ionics

IonQ entered into a definitive agreement to acquire Oxford Ionics, a trapped-ion quantum computing technology company, in a cash and stock deal valued at more than $1.08 billion. The deal will bring together IonQ's quantum compute, application, and networking stack with Oxford Ionics' ion-trap technology manufactured on standard semiconductor chips.

The combined company expects to build systems with 256 physical qubits at accuracies of 99.99% by 2026 and advance to more than 10,000 physical qubits with logical accuracies of 99.99999% by 2027. It also anticipates reaching 2 million physical qubits in its quantum computers by 2030, enabling logical qubit accuracies exceeding 99.9999999999%.

The combined entity plans to expand its workforce in Oxford, England. Per the deal, Oxford Ionics founders Chris Ballance and Tom Harty are expected to remain with IonQ.

The acquisition is the latest in a series of purchases by IonQ, which entered into agreements in May to acquire quantum interconnect developers Lightsynq Technologies and Capella Space, a provider of space-based sensing and communications. Earlier this year, the company acquired ID Quantique, a developer of technologies that span quantum networking and quantum-safe communication, as well as high-performance single-photon detectors used for quantum memories and quantum computers. IonQ acquired Qubitekk last year, adding quantum networking hardware and security capabilities.

Glass Imaging raises $20M to expand AI imaging tech

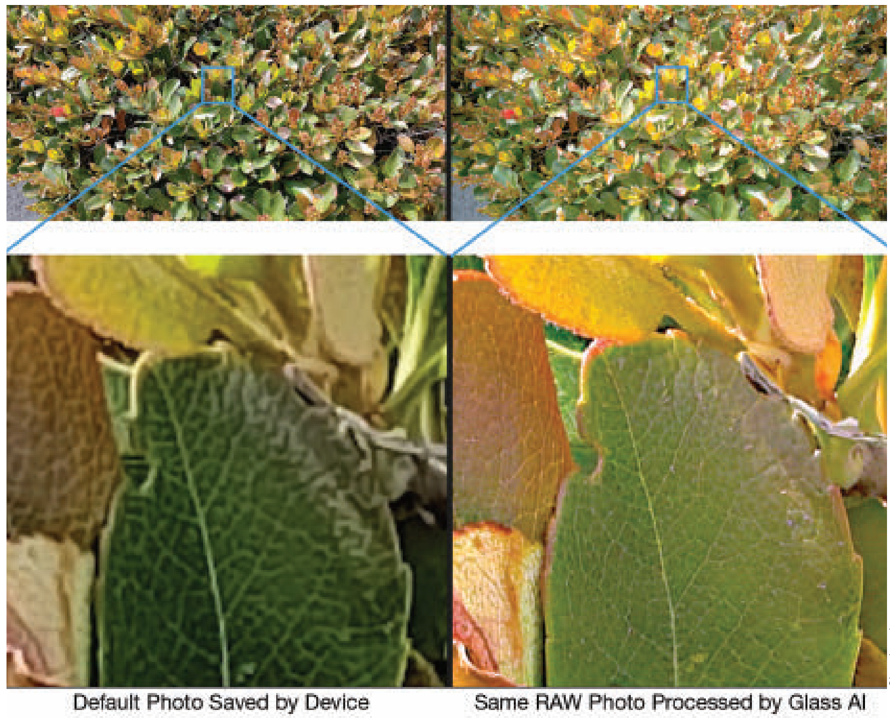
Glass Imaging, a developer of AI-enhanced imaging technology, secured $20 million in a series A funding round. The company plans to use the funds to refine and implement its proprietary GlassAI technologies across a range of platforms, including smartphones, drones, and wearables.

Glass Imaging uses AI to extract the full image quality potential on current and future cameras by reversing lens aberrations and sensor imperfections while reducing noise; this delivers fine texture and real image content recovery that outperforms traditional image signal processing pipelines.

Glass Imaging is currently developing licensable intellectual property, including GlassAI, across novel camera architectures and software-based solutions. By exploiting the power of the edge AI chips in today's devices, the company says its GlassAI software can be tailored to any current or new camera to deliver photo quality that far exceeds what is typically provided by OEMs. Glass Imaging is also using this technology to enable a new class of optical hardware designs that overcome the limitations of traditional camera architectures.

Founded by Ziv Attar and Tom Bishop, former Apple engineers who led the team behind the iPhone's Portrait Mode, Glass Imaging previously raised a $9.3 million extended seed funding round in 2024. The financing followed an initial seed investment in 2021.

The current funding was led by Insight Partners, with participation from repeat investors Google Ventures, Future Ventures, and Abstract Ventures.



Two photos captured by a midrange Android smartphone. An unprocessed image taken by the smartphone **(left)**. An image captured with the same hardware but processed by Glass Imaging's AI software **(right)**.

VLC Photonics secures $6.1M for PIC design and testing

VLC Photonics secured funding to advance PIC design and testing, with a focus on research, upgraded infrastructure, and industry collaborations aimed at accelerating commercialization and innovation in optical communications, signal processing, and sensing. VLC, a Hitachi High-Tech group company, provides engineering services for photonic integrated circuits.

The company was selected to receive a €5.4 million ($6.1 million) grant as an associate partner under the Important Project of Common European Interest on Microelectronics and Communication Technologies.

The company said that it will reinforce its capabilities for modeling, simulation, and design of III-V epitaxies, fabrication processes, and advanced photonic components — including lasers, modulators, and filters — for process design kits in silicon, silicon nitride, indium phosphide, and other emerging materials. Simultaneously, VLC Photonics will scale up its back-end capabilities for chip- and wafer-level testing at multiple wavelengths and very high speeds, while also expanding into thermal reliability testing.

The funding was awarded by the Spanish Ministry of Industry and Tourism under the second call of the Strategic Project for Economic Recovery and Transformation in Microelectronics and Semiconductors. VLC has secured additional funding from the Hitachi High-Tech Group to complement the grant.

$28.3B

— the estimated value of the global thin-film photovoltaics market by 2032, according to S&S Insider

Thales launches fusion company GenF with 10-year road map

High-powered laser company Thales inaugurated a standalone company, GenF, that aims to develop an energy source based on inertial confinement nuclear fusion. The company, which officially launched in January, has signed a first contract worth several million euros to develop its fusion laser.

The company's formation stems from the TARANIS project, which Thales and its partners — CEA, the Centre national de la recherche scientifique (CNRS), and École Polytechnique — submitted to the French government in response to a call for projects on innovative nuclear reactors. The project aims to demonstrate the feasibility of designing a first inertial confinement nuclear fusion reactor. The project was selected in February 2024 and provided with a budget of €18.5 million ($20.7 million) for its initial development phase.

GenF currently brings together around 10 scientists, engineers, and industrial experts, and involves about 40 people from the collaborating entities. The company is headquartered in Bordeaux, France, a region that already combines many areas of expertise in nuclear fusion, including the Centre Lasers Intenses et Applications at the University of Bordeaux and the Centre d'Études Scientifiques et Techniques d'Aquitaine.

GenF will progress through three development phases. By 2027, it plans a first phase of modeling and simulation, calibrated through experiments on existing facilities such as the Laser Mégajoule. Between 2027 and 2035, a second phase will focus on the maturation of fusion technologies, such as multiple laser synchronization, the production of cryogenic targets, and the development of new materials for the reactor wall. In 2035, a third phase could lead to the scale-up of the reactor, with the construction of a first prototype.

$219.9B — the expected value of the global liquid crystal display market by 2034, according to Market Research Future

CCRAFT launches to commercialize photonic chips

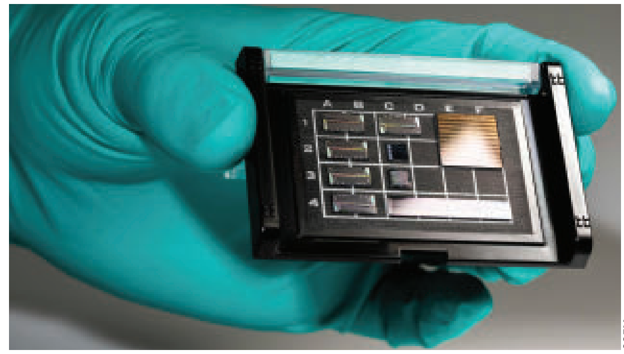
The Centre Suisse d'Electronique et de Microtechnique (CSEM) has spun off CCRAFT, a company working to commercialize the production of photonic chips. Registered in April, CCRAFT has been developing its technology at CSEM for six years. During the past four years, the team has delivered photonic chips through a precommercial offering at CSEM, using a 150-mm pilot production line.

The company said that it plans to install additional production lines in Neuchâtel, Switzerland, to deliver 12 million chips per year by 2030 and capture up to 30% of the worldwide market.

"By leveraging CSEM's infrastructure and years of know-how and also Horizon Europe projects, CCRAFT can accelerate the time to production and could become the first company in the world offering industrial production of components essential to high-performance optical information processing," said Bahaa Roustom, vice president of marketing and business development at CSEM. "This is a real opportunity for Switzerland and Europe to regain some sovereignty in an essential communication and computing technology."

Most existing platforms, such as silicon photonics or indium phosphide, cannot deliver the leap in performance that the market needs, CSEM said in a release.

"[Thin-film lithium niobate (TFLN)] combines several key advantages: high electro-optic efficiency, low optical losses, a wide transparency window, optical nonlinearities, and compatibility with microelectronic systems," said Hamed Sattari, founder and CEO of CCRAFT. "CCRAFT offers both monolithic chips, built entirely on a TFLN substrate, and hybrid designs that combine TFLN with silicon for easier integration."


CSEM

CCRAFT's thin-film lithium niobate (TFLN) technology combines more than 10 core process steps to deliver dozens of integrated optical components on an area no larger than a fingertip.

People in the News

Jenoptik named **Gregg Borek** interim president of JENOPTIK Optical Systems LLC. Borek has served as vice president of microoptics for JENOPTIK Optical Systems and general manager of the Huntsville, Ala., facility for more than 15 years. Prior to joining Jenoptik, he was director of engineering at MEMS Optical for 13 years. After Jenoptik acquired the company in 2006, Borek served as president and CEO for four years.


Jenoptik

Gregg Borek.

IPG Photonics appointed **Mira Sahney** senior vice president of global laser systems, a newly created position. Most recently, Sahney served as president of the Pelvic Health Operating Unit at Medtronic. She also served as president and CEO of Hyalex Orthopaedics, a medical device company.

Kopin Corp. announced that its CFO, **Rich Sneider**, will retire. The company has launched a search for his replacement. Sneider is expected to continue in his current role until a successor is appointed.

Photronics announced that **Frank Lee** has stepped down from his role as CEO but will remain chairman and president of Photronics' PDMC subsidiary in Taiwan and continue to focus on the company's operations in Asia. He will also remain a member of Photronics' board. **George Macricostas**, who was appointed executive chairman earlier this year, has assumed the role of CEO.

Scintil Photonics, a producer of laser-integrated photonics technology, appointed **Jim Theodoras** vice president of product development. Theodoras most recently served as vice president of engineering at QXP Technologies and brings more than 35 years of industry experience in electronics and optics, including roles at Texas Instruments, Cisco, and ADVA Optical Networking. The appointment comes as Scintil prepares for commercial product launch.


Scintil Photonics

Jim Theodoras.

Abhishek Khandelwal, senior vice president and CFO of IDEX Corp., has resigned, the company disclosed in a regulatory filing. IDEX appointed **Akhil Mahendra** interim CFO. Mahendra has been with the company for approximately two years, serving as its vice president of corporate development.

Inertial fusion energy startup Xcimer Energy Inc. named **Silvia De Dea** head of materials and process engineering. De Dea brings experience in scaling complex hardware systems for extreme-UV lithography, analytical instrumentation, and advanced materials R&D. Xcimer also announced the formation of a 10-member science and technology advisory board. **Mike Campbell** — former associate director for lasers at Lawrence Livermore National Laboratory, key originator of the National Ignition Facility, and former director of the University of Rochester's Laboratory for Laser Energetics — will serve as chairman of the advisory board.

Lightwave Logic Inc. appointed **Robert Blum** senior vice president of sales and marketing. Blum most recently served as the head of product line management in the photonics platforms business at Applied Materials. Prior to Applied Materials, he was the head of silicon photonics strategy at Intel Corp.

Optical fiber measurement instrument manufacturer Arden Photonics appointed **Ray Pini** as the company's U.S. business development manager. Pini brings more than 25 years of experience in business development and customer support.

SurFunction acquires Surcoatec, diversifies surface tech offerings

SurFunction GmbH, a laser-based surface enhancement company, acquired Surcoatec GmbH, a surface coating technology company. The deal forms a combined company specializing in intelligent surface solutions by bringing together SurFunction's laser-based surface enhancement capabilities — specifically in industrialized direct laser interference patterning (DLIP) — with Surcoatec's expertise in vacuum-based thin-film technology.

According to SurFunction, the integration of Surcoatec's thin-film expertise — including physical vapor deposition and plasma-enhanced chemical vapor deposition coatings — will enable the combined company to create DLIP-structured, functionalized surfaces with precisely coordinated coating systems. These reproducible, scalable, and industrially viable solutions, the company said, support a range of applications such as medical technology, optics, and aerospace.

In mobility and mechanical engineering, for example, hybrid functional surfaces could find application as components in drive, pump, and sealing systems. The micro- and nanostructuring of surfaces additionally offers a pathway to develop antibacterial, anti-adhesive, and/or color-coded instruments to meet biocompatibility, hygiene, and documentation standards, according to SurFunction. Surfaces that are structured to control physical, chemical, and/or biological properties — for example, to minimize friction, reduce germs, and/or control adhesion — support their use for this application.

Surcoatec also brings intellectual property to SurFunction. This includes patented processes for multifunctional layer systems and adaptive hard coatings.

20.9%

— the projected compound annual growth rate of the global lidar market between 2025 and 2034, according to Precedence Research

Briefs

MKS Instruments Inc. dropped the "Instruments" portion of its name, and will now go by "**MKS Inc.**" According to CEO John T.C. Lee, the change better reflects the company's scope of business, which is no longer limited to industrial instruments. The company will continue to trade under the "MKSI" ticker symbol.

AMD acquired silicon photonics startup **Enosemi** to scale its ability to support and develop co-packaged optics solutions across next-generation AI systems. Enosemi, which emerged from stealth in 2023, has existing 1.6 Tbit/s photonic chiplets and design intellectual property. The company uses a 300-mm-wafer manufacturing process, and released a portfolio of high-speed intellectual property in the GlobalFoundries Fotonix IP platform last year. The financial terms of the acquisition were not disclosed.

TNO, a Netherlands-based scientific research organization, plans to develop a manufacturing line for photonic chips in collaboration with **Photonic Integration Technology Center**, **Eindhoven University of Technology**, and the **University of Twente**. The initiative will enable the industrial-scale production of indium phosphide-based chips and the transition from 4-in. to 6-in. wafers, which will make production more efficient, TNO said. The chips will be produced at the High Tech Campus in Eindhoven, a €153 million ($177 million) photonic chip pilot plant.

Qualcomm reached an agreement to acquire data communications company **Alphawave Semi** in a deal worth $2.4 billion. Alphawave Semi develops and provides high-speed wired connectivity and compute technologies delivering custom intellectual property, silicon, connectivity products, and chiplets. The acquisition aims to accelerate and provide key assets for Qualcomm's expansion into data centers, Qualcomm said. The transaction is expected to close in early 2026.

VIGO Photonics, a developer of mid-infrared detectors and semiconductor materials, signed a letter of intent to acquire the assets of a U.S.-based manufacturer of infrared detectors. The company selling the assets operates globally in the industrial, scientific, and defense sectors. According to VIGO, the acquisition aligns with its current strategy, which includes expanding the company's presence in the American market. VIGO has obtained all required certifications necessary to sell to the U.S. Department of Defense and other government agencies.

LaCroix Precision Optics is expanding its manufacturing operations in Batesville, Ark., with a $13.8 million investment to support a 10-year military contract. The expansion will add new equipment and 18,750 sq ft of manufacturing space. According to Kirk Warden, president of LaCroix Precision Optics, the expansion is expected to create 107 jobs over the next five years. Construction on the expansion is underway, with operations expected to begin in December.

Thorlabs opened a 100,000-sq-ft facility in Newton, N.J., the site of the company's corporate headquarters. Thorlabs will use the facility as its North American distribution center, which will house the company's Advanced Systems Technology business unit and corporate quality and compliance teams.

HUBER+SUHNER, a fiber optic cable manufacturer, opened a manufacturing site in Pisary, Poland. The manufacturing site will be used for large-scale production of optical circuit switches for AI and hyperscale data centers. Production capacity is expected to increase at least fivefold over the next two years.

Optics11, a startup building advanced fiber optic sensing solutions, secured a €17 million ($19 million) funding round. According to company CEO Paul Heiden, the funding allows the company to rapidly scale its suite of fiber optic solutions and offer a proactive defense to energy and maritime operators.

Integrated photonics and quantum optics technology company **Quantum Computing Inc.** opened its quantum photonic chip foundry in Tempe, Ariz. The company said that the facility represents a milestone in its road map to meet growing global demand for thin-film lithium niobate photonic chips

DARPA program sets distance record for power beaming

In a series of tests, the Persistent Optical Wireless Energy Relay (POWER) program achieved several records for transmitting power over distance. The team recorded >800 W of power delivered during a 30-s transmission from a laser 8.6 km away. Over the course of the test campaign, >1 MJ of energy was transmitted.

Previously, the greatest reported distance records for an appreciable amount of optical power (>1 µW) were 230 W of average power at 1.7 km for 25 s and a lesser (but undisclosed) amount of power at 3.7 km.

The DARPA-led team brought together industry and government, including the U.S. Naval Research Laboratory and the High Energy Laser Systems Test Facility (HELSTF) at the U.S. Army's White Sands Missile Range.

The tests, referred to as the POWER Receiver Array Demo (PRAD), mark an important step toward the POWER program's long-term goal of being able to instantly beam power from a location where it can be easily generated to wherever it's needed, opening new design possibilities for platforms no longer limited by fuel limitations.

To achieve the power and distance records, PRAD used a receiver technology with a compact aperture for the laser beam to shine into, ensuring that minimal light escapes once it has entered the receiver. Inside the receiver, the laser strikes a parabolic mirror that reflects the beam onto dozens of photovoltaic cells to convert the energy back to usable power.

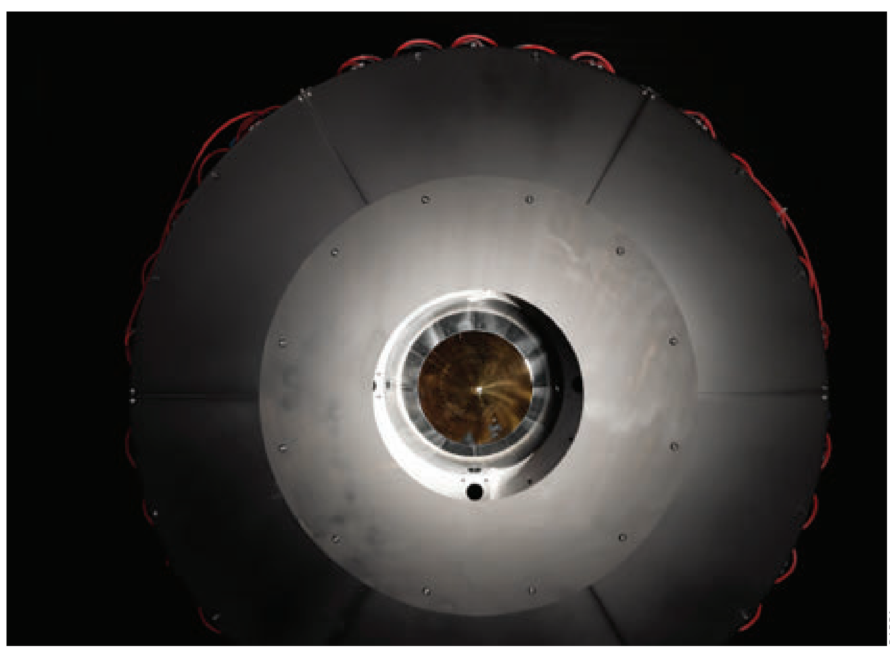
Teravec Technologies, led by principal investigator Raymond Hoheisel, designed the receiver, with support from Packet Digital and the Rochester Institute of Technology. According to the scientists, the technology is scalable to higher power levels and can be integrated into different platforms, such as unmanned aerial vehicles, to support the long-term needs of the POWER program.

For the tests, both the transmitter and receiver were on the ground, which required the beam to go through the thickest part of the atmosphere.

"It's a lot easier to send a power beam directly up or down relative to the ground because there is so much less atmosphere to fight through," said POWER program manager Paul Jaffe. "For PRAD, we wanted to test under the maximum impact of atmospheric effects."

While efficiency was not the focus of the demonstration, the team measured >20% efficiency from the optical power out of the laser to the electrical power out of the receiver at shorter distances. Because the goal of the effort was to rapidly validate the capability of a new design to massively extend potential distance, trade-offs were made to accelerate the design and build of the test receiver, which was completed in about three months.

The POWER program is now aiming to demonstrate the benefits of integrated relays and vertical power transmission and is seeking potential partners to help complete the project's second phase.


DARPA

In the optical power beaming receiver designed for the POWER Receiver Array Demo (PRAD), the laser enters the center aperture, strikes a parabolic mirror, and reflects onto dozens of photovoltaic cells arranged around the inside of the device, which convert the energy back to usable power.

and accelerates the commercialization of its next-generation quantum machines.

Information and telecommunication manufacturer **OKI** established the OKI Berlin Lab R&D center in Berlin. The R&D center will focus on photonics research with European research organizations and photonics clusters, with a focus on Germany.

Guidant Power, a provider of electrical safety, reliability, and training solutions, acquired **Monroe Infrared Technology**, a provider of ground-based inspections and thermography training. According to Guidant Power, the acquisition strengthens its capabilities in infrared thermography, aerial inspections, training services, and infrared technology.

Precision Optics, an optical instrument manufacturer, plans to move its corporate offices from Gardner, Mass., to Littleton, Mass. The facility in Littleton, along with a new facility in Maine, enables access to a broader engineer talent pool to execute the company's ongoing product development pipeline, the company said.

Astrolight, a space communications company, closed a €2.8 million ($3.2 million) seed round. The investment will support the continued development of Astrolight's laser-based, end-to-end communication platform, which securely connects satellites to Earth.

Technology News

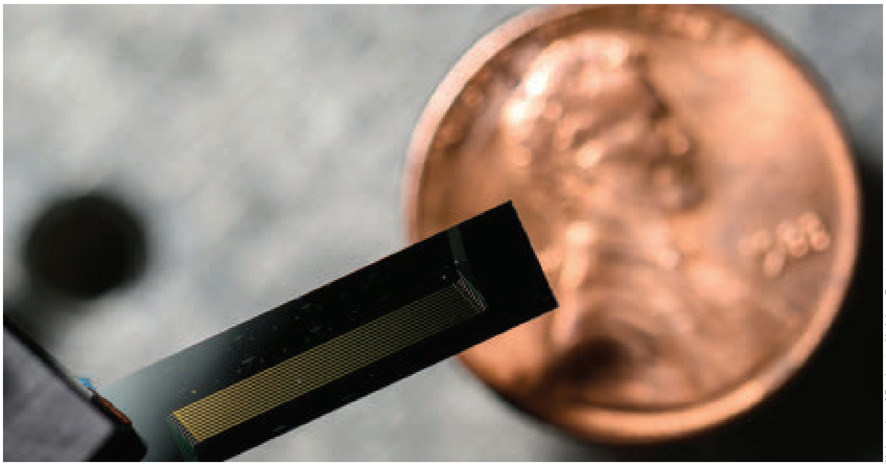
Researchers add ultrafast chip-scale laser to optical metrology toolkit

ROCHESTER, N.Y. — Laser-based measurement techniques can be used to study the physical properties of objects and materials. But current optical metrology methods require bulky and expensive equipment to achieve delicate laser-wave control, hindering the deployment of streamlined, cost-effective systems.

Researchers from the University of Rochester and University of California, Santa Barbara, engineered a laser device smaller than a penny that they believe could power technologies ranging from lidar systems used in self-driving vehicles to gravitational wave detection. They demonstrated that the chip-scale laser can perform extremely fast and accurate measurements by precisely changing its color across a broad spectrum of light at extremely fast rates — ~10 quintillion× per second.

Additionally, the laser is made with a synthetic material, lithium niobate, and leverages the Pockels effect, which changes the refractive index of a material when an electric field is present. In these ways, the laser differs from traditional silicon photonics architecture.

“There are several applications we are aiming for that can already benefit from our designs,” said Shixin Xue, a Ph.D. student at the University of Rochester. “The first is lidar, which is already used in autonomous vehicles, but a more advanced form known as frequency-modulated continuous-wave lidar requires a large tuning range and fast tuning of the laser’s frequency, and that’s what our laser can do.”



University of Rochester/J. Adam Fenster

A chip-scale laser developed by researchers from the University of Rochester and the University of California, Santa Barbara, can be used to conduct extremely fast and accurate measurements by precisely changing its color across a broad spectrum of light at extremely fast rates.

The researchers demonstrated how their laser could be used to drive a lidar system on a spinning disc and identify the letters “U” and “R” made out of LEGO blocks. They said that the miniature demonstration could be scaled up to detect vehicles and obstacles at highway speeds and distances.

The researchers also demonstrated how the chip-scale laser could be used for Pound-Drever-Hall laser frequency locking, a common technique used to narrow down, stabilize, and reduce a laser’s noise.

“It’s a very important process that can be used for optical clocks that can measure time with extreme precision, but you need a lot of equipment to do that,” said Xue, noting that a typical setup might include instruments the size of a desktop computer, such as an intrinsic laser, an isolator, an acousto-optic modulator, and a phase modulator. “Our laser can integrate all of these things into a very small chip that can be tuned electrically.”

The research was supported in part by the Defense Advanced Research Projects Agency (DARPA) Lasers for Universal Microscale Optical Systems (LUMOS) program and the National Science Foundation.

The research was published in *Light: Science & Applications* (www.doi.org/10.1038/s41377-025-01872-4).

Petahertz phototransistor enables ultrafast computing in ambient conditions

TUCSON, Ariz. — Researchers from the University of Arizona, Caltech’s Jet Propulsion Laboratory, and the Ludwig Maximilian University of Munich demonstrated a way to manipulate electrons in graphene using pulses of light that last less than a trillionth of a second. Leveraging the quantum effect of tunneling, they recorded electrons bypassing a physical barrier almost instantaneously.

According to the researchers, the feat redefines the potential limits of computer processing power. The technique could lead to processing speeds in the petahertz range — >1000× faster than modern computer chips. Sending data at those speeds would revolutionize computing as we know it, said Mohammed Hassan, an associate professor of physics and optical sciences at the University of Arizona.

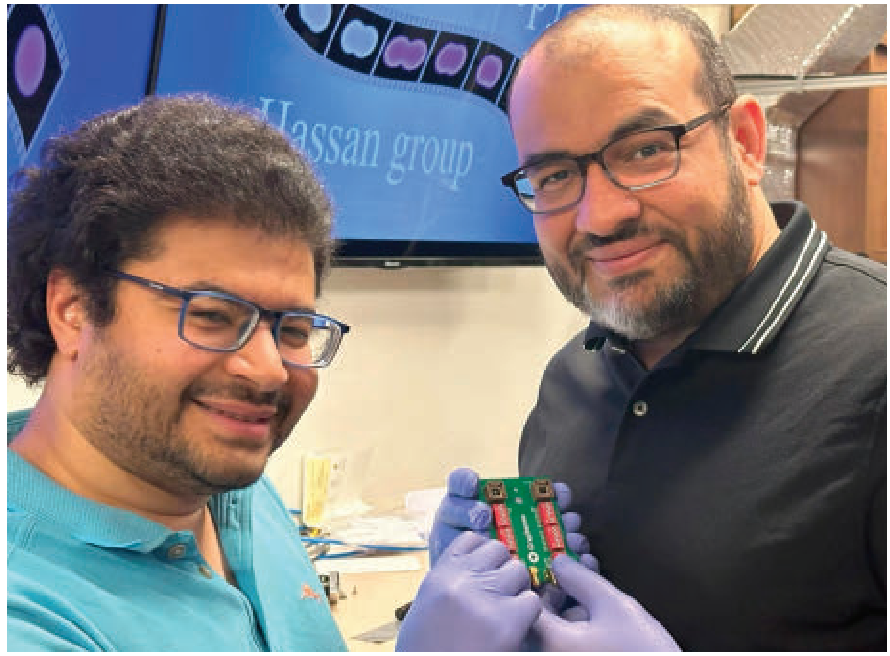
"We have experienced a huge leap forward in the development of technologies like artificial intelligence software, but the speed of hardware development does not move as quickly," Hassan said. "But, by leaning on the discovery of quantum computers, we can develop hardware that matches the current revolution in information technology software."

The work stemmed from the team's study of the electrical conductivity of modified samples of graphene, a material that is composed of a single layer of carbon atoms. When a laser shines on graphene, the energy of the laser excites electrons in the material, causing them to move and form into a current.

Sometimes, those electric currents cancel each other out. According to Hassan, this happens because the laser's energy wave moves up and down, generating equal and opposite currents on either side of the graphene. Because of graphene's symmetrical atomic structure, these currents mirror each other and cancel each other out without leaving a detectable current.

But what if a single electron could slip through the graphene, and its journey could be captured and tracked in real time? That near-instant tunneling was the unexpected result of the team's modifications to different graphene samples.

Using a commercially available graphene phototransistor that was modified to introduce a special silicon layer, the researchers used a laser that switches off and on at a rate of 638 attoseconds to create what Hassan called "the world's fastest petahertz quantum transistor."



University of Arizona

Mohammed Hassan **(right)**, associate professor of physics and optical sciences, and Mohamed Sennary, a graduate student studying optics and physics, hold the commercial transistor they used to develop a petahertz-speed transistor.

While certain scientific advancements can only occur under strict conditions, including temperature and pressure requirements, the quantum petahertz transistor performed in ambient conditions — opening the door to commercialization and use in everyday electronics. Currently, Hassan is working with Tech Launch Arizona to patent and market the recent innovations.

While the original invention used a specialized laser, the researchers are furthering development of a transistor that is compatible with commercially available equipment.

The research was published in *Nature Communications* (www.doi.org/10.1038/s41467-025-59675-5).

Quantum dots distinguish novel surface-emitting laser architecture

TOKYO — Collaborators from Sony Semiconductor Solutions Corp. and the National Institute of Information and Communications Technology (NICT) in Japan developed a surface-emitting laser architecture that uses quantum dots as the optical gain medium. According to its developers, the laser, which is designed for use in optical fiber communication systems, is the world's first practical and electrically driven VCSEL operating at 1550 nm (the standard wavelength for optical fiber communication) to use quantum dots as the optical gain material.

The NICT researchers developed a high-precision crystal growth method for compound semiconductors using molecular beam epitaxy. This approach can be used to precisely grow a distributed Bragg reflector (DBR) by strictly controlling the ratio of materials that are used in the growth of the crystal. Using this method, the team realized a semiconductor DBR with a high reflectivity >99% even at 1550 nm.

Next, the researchers applied strain-compensation techniques to VCSEL production. This served to cancel the internal crystal strain that occurs around the quantum dots, which increases the density of the quantum dots and improves the light-emitting performance.

Sony contributed to the second part of the project; the company conceptualized a device design and fabrication process that enables highly efficient current injections using a tunnel junction structure. Since VCSELs emit light perpendicular to the wafer surface, conventional electrode placement obstructs light extraction, even if quantum dots emit light. This tunnel junction permitted efficient current flow while facilitating light extraction using a precise device process.

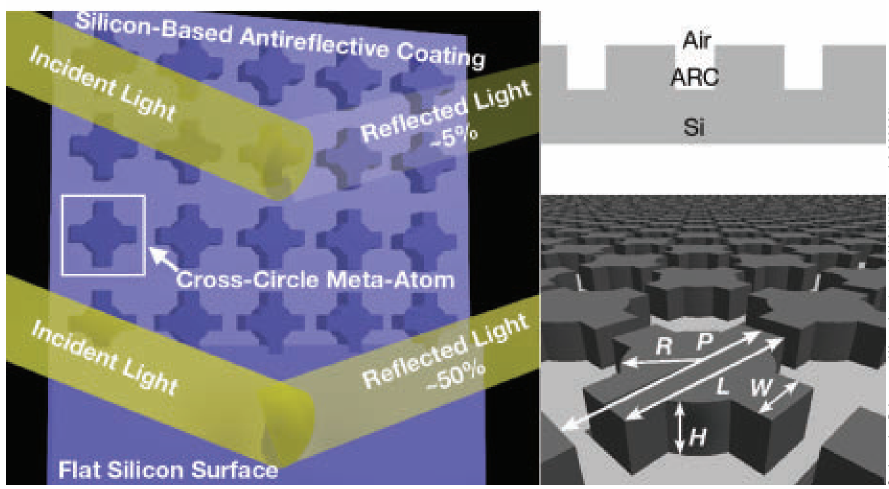
Through the integration of these two technologies, researchers lased VCSELs using quantum dots at 1550 nm as a light-emitting material with a small current of 13 mA. Furthermore, polarization fluctuations were eliminated, resulting in a stable output.

The VCSELs maintained temperature stability and exhibited scalable structures, which the researchers said enable mass production. The researchers aim to conduct advanced technical studies on quantum dot-based VCSEL technology to further enhance the capacity and reduce power consumption in optical fiber communication systems beyond the 5G era.

The research was published in *Optics Express* (www.doi.org/10.1364/OE.551300).

AI-aided approach yields metasurface-based antireflective solar coatings

KHARKIV, Ukraine — A newly developed single-layer antireflective (AR) coating for silicon solar cells minimizes sunlight reflection across a broad range of wavelengths and angles, surpassing the performance of existing single-layer coatings and approaching that of multilayered AR coatings. To develop the coating, researchers from Kharkiv National University, the National Academy of Sciences of Ukraine, and the Leibniz Institute of Photonic Technology used machine learning-enhanced photonic nanostructures, also known as metasurfaces, to create AR coatings with ultralow light reflection.



Ovcharenko, Polevoy, and Yermakov (www.doi/10.1117/1.apn.4.3.036009)

A metasurface-based silicon antireflective (AR) coating combines rectangular and cylindrical meta-atom geometries. The metasurface achieves just 5% reflection, compared to ~50% reflection from an unstructured silicon solar cell.

The metasurface-based coatings reduce reflection across the visible and near-infrared (NIR) spectrum between 500 and 1200 nm — where the irradiance of sunlight is at its maximum — and are effective even when the sunlight hits at steep angles. As a result, they have the potential to overcome the limitations of traditional coatings, which improve light transmission in only a narrow range of wavelengths (typically between 100 and 300 nm) and incidence angles.

The researchers used forward-design and inverse-design optimization algorithms to develop the metasurfaces. They based the forward-designed metasurfaces on cross-circular meta-atoms, and the inverse-designed structures on freeform meta-atom geometry.

Forward design can produce promising results when geometric parameters are appropriately selected, whereas inverse design does not require the geometric parameters to be predetermined. According to the team, both the cross-circular, forward-designed structures and freeform, inverse-designed structures demonstrated the highest-performing antireflection properties reported to date for single-layer designs.

Inverse design is beneficial for creating multifunctional broadband metasurfaces. The integration of AI, specifically machine learning algorithms, can further enhance the capabilities of inverse design.

The team found that the metasurface-based AR coatings reflected as little as 2% of incoming light at direct angles and ~4.4% of incoming light at oblique incidence in an angular range of up to 60°. The metasurface-based coatings enhanced reflection suppression by about one order of magnitude compared with unstructured flat silicon surfaces. The reflection of light from a flat silicon surface ranges from 35% to 50% in the visible and NIR spectra, reducing the efficiency of solar cells almost by half. Moreover, the use of AR coatings is especially challenging in silicon solar cells due to the high contrast between air and silicon, which results in high reflectance. The standard thin-film AR coatings with the highest performance are multilayered and narrowband, but real-world applications require ultrathin solutions that minimize light reflection over a wide range of wavelengths.

Because the metasurface-based coatings are both high-performing and relatively simple, they could potentially accelerate the transition to clean energy by increasing the power conversion efficiency of solar panels. The forward and inverse design of single-layer, metasurface-based broadband AR coatings for silicon solar cells may also pave the way for multifunctional photonic coatings that could benefit sensors and other optical devices, in addition to solar power devices.

The research was published in *Advanced Photonics Nexus* (www.doi.org/10.1117/1.apn.4.3.036009).

Single-chip system integrates optical and microwave processing

LEUVEN, Belgium — Researchers at imec and Ghent University demonstrated a fully integrated single-chip microwave photonics system that combines optical and microwave signal processing on a single silicon chip. The technology can replace bulky and power-hungry components, according to the researchers, enabling faster wireless networks, low-cost microwave sensing, and scalable deployment in applications such as 5G/6G communications, satellite communications, and radar systems.

Modern communication networks rely on both high-speed fiber-optic links and wireless radio-frequency microwave transmission. As the demand increases for higher data rates and operation at higher frequencies, new systems need much tighter integration between these two modes of communication to overcome challenges with signal processing complexity, high transmission losses, and power-hungry electronics.

Microwave photonics offers a promising solution by using optical technology to process high-frequency signals with lower loss, higher bandwidth, and improved energy efficiency. However, most microwave photonics systems rely on bulky, fiber-based architectures that limit scalability. Integrating microwave photonics onto a chip could enable more scalable and power-efficient systems, but early experimental demonstrations have either lacked key functionalities or required external components to achieve full performance.

Researchers at the Photonics Research Group and IDLab, two imec research groups at Ghent University and imec, created a chip that integrates high-speed modulators, optical filters, photodetectors, and transfer-printed lasers to process and convert both optical and microwave signals. The key innovation in this single-chip system lies in the combination of a reconfigurable modulator and a programmable optical filter enabling efficient modulation and filtering of microwave signals while significantly reducing signal loss. According to the researchers, the combination enhances overall performance, allowing the system to handle complex signal processing tasks with greater flexibility and efficiency for a wide range of applications.

The team built the chip on imec's standard iSiPP50G silicon photonics platform, which includes low-loss waveguides and passive components, high-speed modulators and detectors, and thermo-optic phase shifters for tuning the optical response. To provide an integrated light source, the researchers incorporated an indium phosphide optical amplifier (developed by III-V Lab) onto the chip using the micro-transfer-printing technology developed at the Photonics Research Group (imec/Ghent University). Combined with on-chip tunable filter circuits, this configuration enables the optical amplifier to function as a widely tunable laser, further enhancing the system's versatility, according to the team.

Single-pixel camera holds key to holographic video microscopy

KOBE, Japan — A camera setup developed by researchers at Kobe University records 3D movies with a single pixel. Moreover, the technique can obtain images outside the visible spectrum and even through tissue.

According to the researchers, the approach opens the door to holographic video microscopy.

Traditionally, recording holograms has required a laser. Recently, however, techniques have been developed that allow holograms to be recorded with ambient light or light emanating from a sample.

Two main techniques can achieve this. One, called FINCH, uses a 2D image sensor that is fast enough to record movies but is limited to visible light and requires an unobstructed view. The other, called OSH, uses a single-pixel sensor and can record through scattering media and with light outside the visible spectrum, but it can practically record only motionless objects.

A research effort led by assistant professor Yoneda Naru sought to create a holographic technique that combines the strengths of both techniques. To address the speed-limiting weakness of OSH, Naru and his team constructed a setup that uses a high-speed digital micromirror device to project the patterns required for recording the hologram onto the object.

“This device operates at 22 kHz, whereas previously used devices have a refresh rate of 60 Hz. This is a speed difference that’s equivalent to the difference between an old person taking a relaxed stroll and a Japanese bullet train,” Naru said.

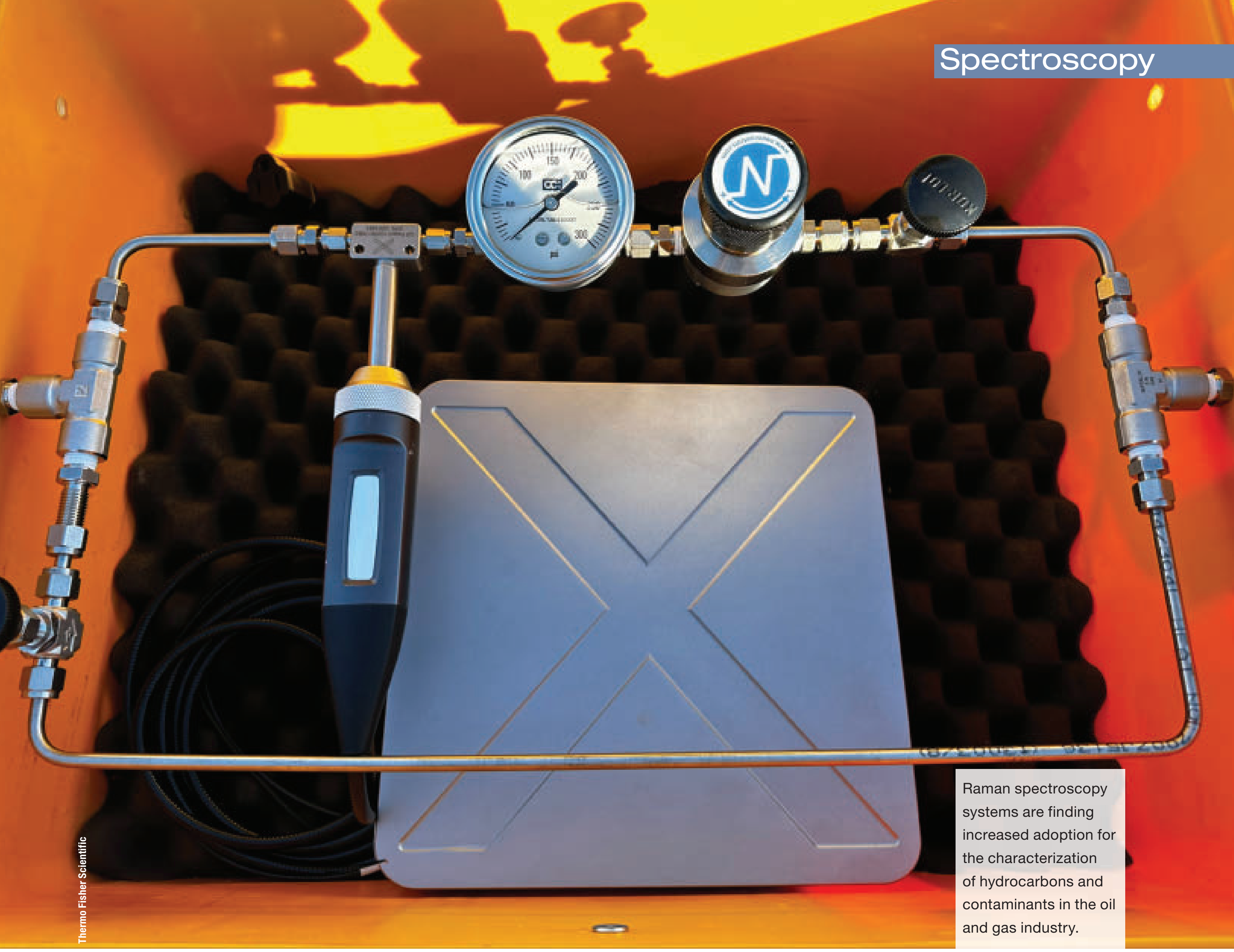
The work demonstrated that the setup could not only record 3D images of moving objects, but also showed the potential to construct a microscope capable of recording a holographic movie through a light-scattering object — specifically, a mouse skull.

However, the frame rate is still fairly low, at just over 1 fps. Naru and his team demonstrated through calculations that the frame rate could theoretically be increased to 30 Hz, which is a standard screen frame rate. This improvement would be achieved through a compression technique called sparse sampling, which works by not recording every portion of the image continuously.

“We expect this to be applied to minimally invasive, three-dimensional biological observation, because it can visualize objects moving behind a scattering medium. But there are still obstacles to overcome.

We need to increase the number of sampling points, and also the image quality. For that, we are now trying to optimize the patterns we project onto the samples and to use deep-learning algorithms for transforming the raw data into an image,” Naru said.

The research was published in *Optics Express* (www.doi.org/10.1364/OE.560998).



Thermo Fisher Scientific

Raman spectroscopy systems are finding increased adoption for the characterization of hydrocarbons and contaminants in the oil and gas industry.

Out of the Lab and into the Line, Raman Rises for Process Analytics

Raman spectroscopy continues to gain favor as a powerful process analytical technology asset in industrial sectors.

BY MARIE FREEBODY
CONTRIBUTING EDITOR

Raman spectroscopy has a long-held association with biophotonics, and the same qualities that make the technique indispensable for biomedical imaging and sensing are now driving real-time process insights across industrial fields. Advancements in the sensitivity, speed, and ruggedization of Raman technology are enabling its deeper integration into materials science, failure analysis, chemistry, pharmacology, forensics, and more.

As a result, Raman systems are finding expanded use for many nonroutine applications. Raman's noninvasive chemical insights make it ideally suited for these applications and the evolving demands of modern process monitoring and control.

Material insights

The advent of Raman monitoring in manufacturing stems, at least in part, from the wave of automation spreading through industry. Increasingly automated and regulated processes require efficient and real-time process monitoring solutions. Technology providers in sectors ranging from biotechnology to oil and gas are focused on finding and implementing innovative analytical tools.

According to Mark Kemper, director of business development at Bruker Optics, obtaining a complete understanding of a set of processes is vital to achieve maximum control over them. "A technique like Raman can be extraordinarily valuable in this regard. Having a tool that can help diagnose what is happening, from a molecular standpoint, can be invaluable, [thereby] adding a piece to the overall puzzle of process understanding and control," he said.

Improving performance is not the only motivation for end users to adopt Raman systems; the portability and affordability are also compelling. Together, these qualities make Raman an inherently attractive technology.

During the past two decades, though, Raman's popularity has also surged because of component innovations, such as those underway in light sources, optics, and sensors. Advancements are especially evident in compact and rugged lasers, filters, lenses, and detectors. And, alongside these hardware improvements, expanded spectral libraries and more sophisticated matching algorithms have also extended Raman's capabilities. These areas of progress have converged into a trend that is enabling increasingly advanced analytical tasks.

In parallel, shifting industry needs are pulling Raman further onto the production floor. Faster, more accurate analytics are no longer merely desirable — they have become essential for an increasing number of critical applications, from detecting illicit fentanyl analogs and chemical warfare agents to real-time monitoring of downstream bioprocessing.

As it translates to system performance, adopters are turning to Raman solutions for what they can detect and for how quickly and clearly they tell a complete story.

"Process people need to pay attention to their processes," Kemper said. "Their process analytical technology [PAT] tools simply need to work. The minute [manufacturers] have to worry more about their analytical tools than their processes, the instrumentation will be mothballed."

Thermo Fisher Scientific

As manufacturing processes grow more automated and regulated, technology providers recognize the continued need for efficient, real-time process monitoring **(right)**. The focus is on developing innovative analytical tools that support industries ranging from biotechnology to oil.

A Raman fiber optic probe is inserted into a bioreactor to monitor cell growth under sterile conditions **(below)**.

Metrohm

Metrohm

A first responder uses a hand-held Raman analyzer to identify the compound xylene during a chemical spill response. A fiber optic immersion probe accessory provides high chemical resistance and can be used directly with the sample.

Automation in pharma manufacturing

Raman spectroscopy is widely used for reaction monitoring and crystallization of small molecules. As pharmaceutical manufacturing increasingly demands continuous process monitoring, Raman's role is expanding too, in both upstream and downstream processes.

Specifically, manufacturers are increasingly implementing Raman-based solutions for small-molecule manufacturing operations such as blending, mixing, tablet coating, granulation, and extrusion.

"The integration of the automation of biomanufacturing is a cutting-edge aspiration in the biopharmaceutical industry," said Nimesh Khadka, senior application PAT specialist at Thermo Fisher Scientific. "Reliable, accurate, real-time, and frequent data from in-line Raman process monitoring is key to achieving the automation goals."

Raman spectra have highly specific and attributable bands that can be traced to the molecular bonds in a material. This quality enables drugmakers, for example, to make qualitative and quantitative measurements — even from several hundred meters away, when necessary. This is critical for continuous process monitoring in the pharmaceuticals industry. Conventional analytical methods typically require offline analysis, which is often accomplished only via a time-consuming process that can lead to delayed feedback and potential product variability.

An example of this is raw material identification in manufacturing. "Traditionally, a package would be opened, a sample taken, delivered to a lab, and meanwhile, the material is quarantined," said Richard Crocombe, principal at Crocombe Spectroscopic Consulting. "With a portable spectrometer [Raman or NIR], the material can be scanned through a polyethylene liner or with an immersion probe and verified immediately and put into production."

Raman can also be used to make univariate measurements; these measurements focus on areas or intensities of single peaks and are easier to understand and use than multivariate methods. Further, nondestructive fiber optic-coupled probe measurements make in situ measurement much easier and simpler, contributing to better data than that which is typically obtained from offline measurements.

For extrusion in the high-volume pharmaceutical and polymer industries, process Raman spectrometers integrated with a fiber optic Raman probe are helping manufacturers to monitor the chemical composition of the extrudate and ensure uniformity and accurate concentration in real time.

"This is crucial for consistent drug release profiles and therapeutic efficacy," said Tom Dearing, senior scientist at Thermo Fisher Scientific.

"Process Raman spectrometers can also monitor polymorphic transformations, the formation of solid dispersions, and the distribution and chemical composition of combination products containing multiple active pharmaceutical ingredients," Dearing said.

The optical fiber probes used in these deployments are themselves the subject of ongoing design innovation. These components are now specifically designed to fit into the ports on the die or midbarrel.

Tracking chemical changes with speed

Raman plate readers that are currently on the market enable the live monitoring of reactions in up to 96 well plates. This capability is a boon to drug developers, and it marks a notable improvement compared to the first Raman systems to be used in and for PAT (see sidebar).

It also positions Raman to surpass the NIR technologies that, according to Michael Allen, vice president of products and marketing at Metrohm Spectro Inc., enabled manufacturers to pioneer PAT solutions.

“NIR has very broad peaks that must be integrated and deconvolved to construct meaningful analysis models,” Allen said. “In contrast, Raman spectra exhibit much sharper features, facilitating easier method development, more accurate analysis, and higher information density.”

Examples of monitoring chemical changes exist, though Fran Adar, HORIBA Scientific’s principal applications scientist, believes there is room to further develop this set of applications. She points to recent software developments that decipher chemical changes even in complex spectra, such as those that are typically associated with chemical reactions. Adar cites the 2D-correlation spectroscopy software developed by Isao Noda at Procter & Gamble as a solution for users to analyze the evolution of the spectra.

“Even when spectral features are heavily overlapped, this software enables one to follow the sequence of chemical changes as revealed in the spectra,” Adar said.

North Carolina-based Wasatch Photonics makes available open-access software, software development kits, and plug-ins, all of which aim to streamline and simplify the development of software for application-specific instrument developers. The company also offers spectral calibration and spectral response corrections to ensure that users obtain consistent results — whether from a single instrument or a thousand — with high reliability.

“We have one goal: to allow our OEM customers in PAT and other fields to focus on their application instead of the Raman hardware at its core, and to give them the raw data and software tools to have complete control over their analysis, to develop their own methodologies,” said Cicely Rathmell, the company’s vice president of marketing.

From vaccines to therapeutics

The monitoring and automation of feedback control of in vitro transcription reactions in messenger ribonucleic acid (mRNA) manufacturing real-time

Built for the Factory Floor

Decades ago, Raman instruments were massive systems — slow, delicate, and best suited for controlled laboratory conditions. “I started making measurements in the 1960s, when a Raman instrument was a very large double monochromator and had a single channel detector,” said Fran Adar, principal applications scientist at HORIBA Scientific. “It took something like an hour to produce a spectrum, and the output was a strip chart recorder.”

Digital cameras, single-monochromator systems, and edge filters triggered major turning points. “The first development that changed things was the introduction of a microscope as a sampling device and then the digital camera, which was used as a multichannel (multiwavelength) detector,” Adar said.

According to Adar, compact filters, benchtop computing, and multivariate analysis techniques accelerated the transition. “Finally, the development of chemometrics, also known as multivariate analysis, enabled extraction of information from complicated spectra with multiple components.”

Contemporary Raman systems benefit from high-throughput optical engines — such as virtual slit architectures — along with stable diode lasers and ultrasensitive detectors. These advancements support measurements on faster timescales and across more complex media, which is critical in the continuous and downstream operations necessary for process monitoring.

A hand-held Raman analyzer is used to measure through an opaque container to reliably identify gasoline **(left)**. A liquid sample is placed into a vial holder accessory of a Raman analyzer for identification **(middle)**. A Raman analyzer is used to determine the presence or absence of narcotics in a plastic bag **(right)**. A right-angle sampling accessory allows the operator to contact the sample without exposure.

monitoring is an application that gained prominence during the COVID-19 pandemic. mRNA manufacturing hit the headlines for enabling the rapid development of Moderna's COVID-19 vaccine. mRNAs also find use in the pursuit of personalized cancer vaccines. By packing mRNAs within lipid nanoparticles, the immune system receives "instructions" to target specific cancer cells.

"Raman spectroscopy provides valuable information on individual lipid quality, their distribution within [lipid nanoparticles], and encapsulation efficiency by measuring the lipid-to-mRNA ratio. This ensures high-quality and effective drug delivery," Thermo Fisher Scientific's Khadka said.

Similar biopharmaceutical applications include monitoring antibody-drug conjugate reactions for cancer therapy, as well as the manufacturing of chimeric antigen receptor (CAR) T-cells or viral vectors. For antibody-drug conjugates, clinicians use Raman spectroscopy to monitor the conjugation process and ensure the precise attachment of cytotoxic drugs to antibodies.

Energy: Production, storage, and recycling

Raman spectroscopy is proving to be invaluable in the pursuit of high-performance energy storage at industrial scales, and, specifically, in the development and production of battery materials. The technique delivers insight into the composition and uniformity of anode materials, such as graphite and silicon; cathode materials, such as lithium cobalt oxide and nickel manganese cobalt oxide; and certain electrolytes.

According to HORIBA scientist Peng Miao, the Raman spectrum of hard carbons used in lithium and sodium batteries can be effectively analyzed spectroscopically because the approach can monitor and predict whether organic materials can be graphitized. In particular, the grain size, which predicts electronic conductivity and ion mobility, can be derived from the Raman spectra.

For this application, according to Thermo Fisher Scientific's Dearing, a Raman-based approach can help detect impurities, analyze the formation of the solid-electrolyte interphase layer, and provide information on molecular interactions and phase changes that occur during battery cycling. "This aids in optimizing the manufacturing process, ultimately leading to more reliable and efficient batteries for various applications, from consumer electronics to electric vehicles," he said.

Raman spectroscopy also plays a critical role in end-of-life battery recycling. It helps to identify and characterize recovered anode and cathode materials, as well as electrolytes, to ensure their purity and readiness for reuse.

But Raman's utility extends further across the broader clean energy landscape; solutions are emerging in support of the modern demands of energy production. Among other end uses, Raman offers the necessary versatility to analyze materials and processes in solar cells and characterize hydrocarbons and contaminants in the oil and gas industry. For example, in carbon capture, use, and storage, Raman spectroscopy is crucial for analyzing the chemical composition of captured carbon dioxide, monitoring the efficiency of capture processes, and ensuring the integrity of stored carbon dioxide.

Configuration trade-offs

End users determine the degree to which a system-level advancement represents an improvement in comparison with prior iterations of a given solution. While an upgraded system must offer tangible benefits compared to the earlier version, it must also retain the most useful attributes for a given process monitoring task.

As it relates to Raman instrumentation, the development of the high-throughput virtual slit has led to improved outcomes across application areas. This technology builds on traditional fiber-coupled dispersive Raman spectrometers. These devices exhibit a trade-off between sensitivity (signal strength) and spectral resolution (the instrument's ability to distinguish closely spaced peaks). Narrowing the spectrometer slit improves resolution. At the same time, however, the system design restricts the amount of light entering the system, which reduces sensitivity.

Conversely, widening the slit boosts throughput. But this serves to degrade resolution.

Bruker's Tornado High Throughput Virtual Slit (HTVS) technology is one of the commercial offerings that decouples this trade-off. "Instead of relying solely on a physical slit to define resolution, HTVS maximizes the amount of Raman light collected while maintaining high spectral resolution," Bruker's Kemper said.

Specifications play a role in gauging the extent to which systems designers must weigh such a trade-off. According to Metrohm Spectro's Allen, it is common for trade-offs to be made when configuring a system.

At the same time, chasing top parameters is often unnecessary, he said. "[For example,] achieving fast, high-resolution measurements is more challenging and often unnecessary for monitoring a process. Overall, the miniaturization and low power requirements of all components allow a 'more than good enough' Raman spectrum to be collected."

Some Raman peaks are broad, Allen said — so increasing the system's resolving power will not improve performance.

"Designing a portable Raman system involves balancing competing demands, guided by the principle of achieving performance that is 'good enough' for the specific application," Wasatch Photonics' Rathmell said.

Lingering limitations

Despite its impressive growth, constraints remain for Raman technologies — particularly Raman spectroscopy. Fluorescence remains the most stubborn bottleneck. It is a noticeable obstacle in complex biologicals, crude mixtures, and/or heavily pigmented materials.

Citing examples, Kemper said, "Applications such as crude oil analysis and analyses of certain foodstuffs and coffee are generally unsuitable for Raman. Fluorescence is simply too much of a barrier in some cases."

Advancements such as 1064-nm excitation, gated detection, and shifted-excitation Raman help to reduce this effect, though a silver bullet still eludes the industry.

Cost is another consideration. While Raman instrumentation often appears more expensive than alternatives, its ability to measure multiple analytes simultaneously can help offset cost concerns. But this is not a simple one-to-one trade-off. Device costs remain prohibitive in some cases.

Continued research, collaboration, and regulatory support across pharmaceutical and industrial markets are likely to promote the wider adoption of Raman spectroscopy as an integral PAT. In addition, the introduction and eventual integration of next-generation technologies, such as AI, will further automate monitoring and control processes.

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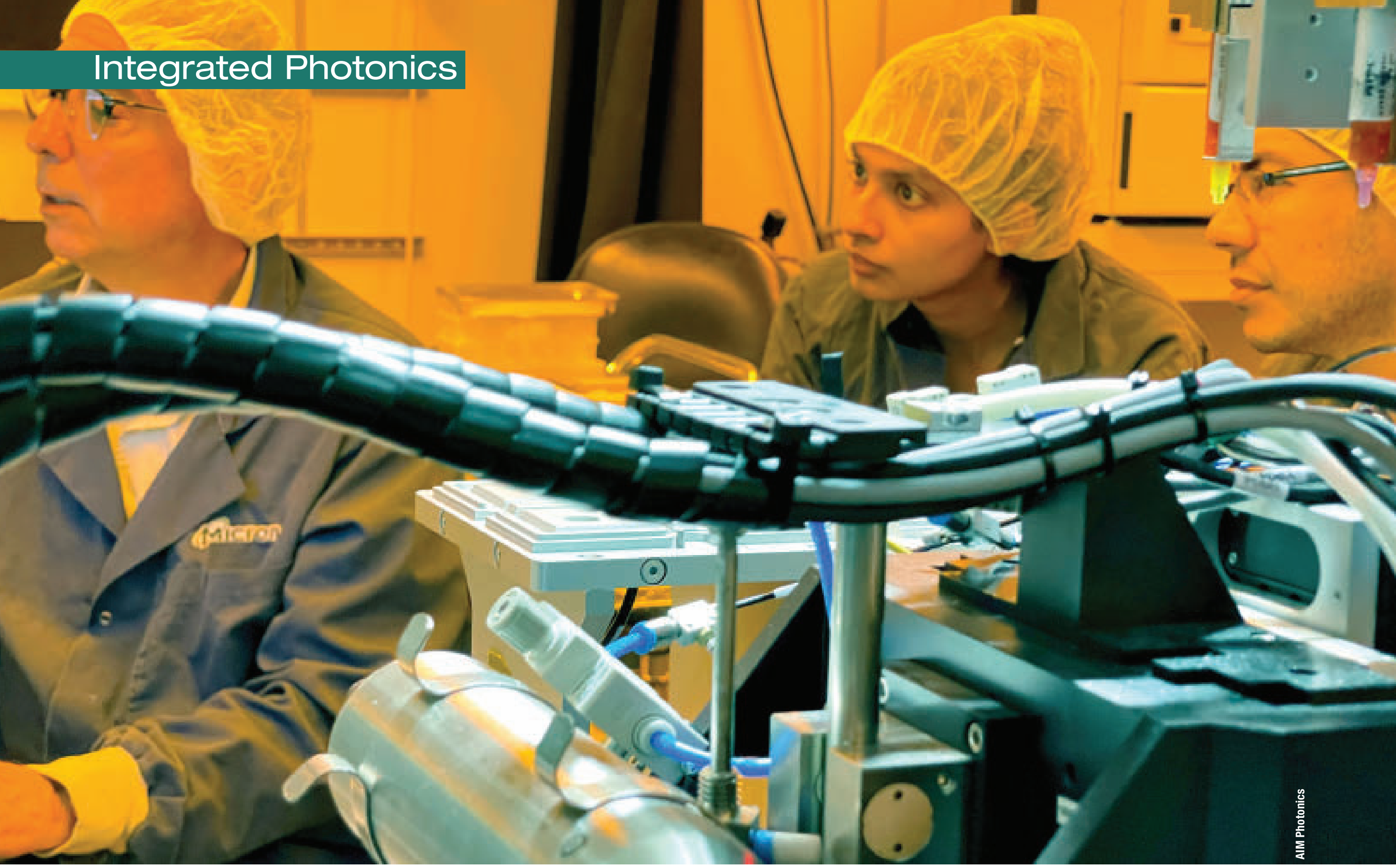


AIM Photonics

A Photonics Production Ramp-Up Prompts Reprioritization in Workforce Development

Institutions are expanding hands-on experiences to help develop a skilled workforce of integrated photonics technicians and engineers.

BY JAMES SCHLETT
CONTRIBUTING EDITOR

Both in the U.S. and overseas, semiconductor manufacturers are ramping up the production of devices that integrate photonics technologies. Workforce development and training initiatives aim to ensure that these device manufacturers have a sizeable pool of talent from which to identify the most qualified workers. But the technology is advancing faster than the current talent pipeline can supply workers with the requisite skill sets.

This trend is familiar in the integrated photonics space. Still in the nascent days of these sophisticated technologies, workforce training programs are struggling to bridge the skills gap that exists between effective photonics design and manufacturing, and the competencies that workers obtain from peripheral disciplines, such as electrical engineering.

Recently though, spearheaded by tech giants, the semiconductor industry has reached a new inflection point. NVIDIA's unveiling of its co-packaged optics networking switches this spring was a pivotal moment in the semiconductor industry's shift from optical-to-electronic transceivers to silicon photonics. For a company of NVIDIA's reach and market share to categorically embrace silicon photonics technology to this extent signaled that the industry's appetite for photonic devices had become a catalyst for unprecedented challenges to the design houses and companies tasked with manufacturing them.

When NVIDIA subsequently announced that it would produce its AI supercomputers entirely in the U.S., this shift had also become a turning point for the industry's integrated photonics workforce.

And NVIDIA is just one example of photonics coming into favor with chipmakers. Tower Semiconductor has begun the heterogeneous integration of quantum dot lasers on a silicon photonics platform at its foundry in Newport Beach, Calif. GlobalFoundries, meanwhile,

Xanadu

Xanadu

Quantum photonic computing company Xanadu expects its integrated photonics prospective worker talent pool to grow by up to 50% during the next few years. The Toronto-based company introduced its universal photonic quantum computer, Aurora, earlier this year.

plans to build a first-of-its-kind advanced packaging and photonics center in upstate New York. The facility would support the company's differentiated silicon photonics platform.

According to Elizabeth Moore, a postdoctoral associate at MIT's Materials Systems Laboratory, developments such as these are an appropriate measure of the acceleration in photonic integrated circuit (PIC) production in the U.S. This surge in production, Moore said, exacerbates a challenge that is ongoing.

"With workforce shortages already present, particularly at the middle-skilled worker (technician) level, the existing photonics workforce is unlikely to scale quickly enough to meet the industry's demand at the scale needed," Moore said.

These developments also represent the tip of the iceberg. In a 2023 *Applied Optics* paper, Moore and her co-authors estimated that by 2030, the U.S. photonics industry will need 42,000 new middle-skilled technician workers to meet manufacturing demand[1]. Moore was also among several MIT researchers who, along with consulting firm Conducere, published a photonic integrated devices manufacturing workforce preparation assessment report on middle-skilled technicians.

The MIT-Conducere team published its report this year, and identified two manufacturing technician roles that will be critical amid the ramp-up of integrated photonics production: PIC technician and functionalization technician.

"There is generally a robust demand for professionals trained in integrated photonics, advanced packaging, and high speed," said Radha Nagarajan, senior vice president and CTO for optical engineering at semiconductor firm Marvell Technology.

"Integrated photonics is being actively integrated into multiple scale-up and scale-out applications, across multiple business units," he said.

Employer-specific training

Earlier this year, Toronto-based quantum computing company Xanadu debuted its universal photonic quantum computer. The machine, called Aurora, operates at room temperature and consists of 35 photonics chips, 12 qubits, and 13 km of fiber optics. Since debuting the solution, Xanadu has announced agreements with Corning, for advanced fiber interconnects; Applied Materials, for superconducting transition-edge sensors; and the U.S. Air Force Research Laboratory, for the accelerated development of silicon integrated photonics for quantum computing applications.

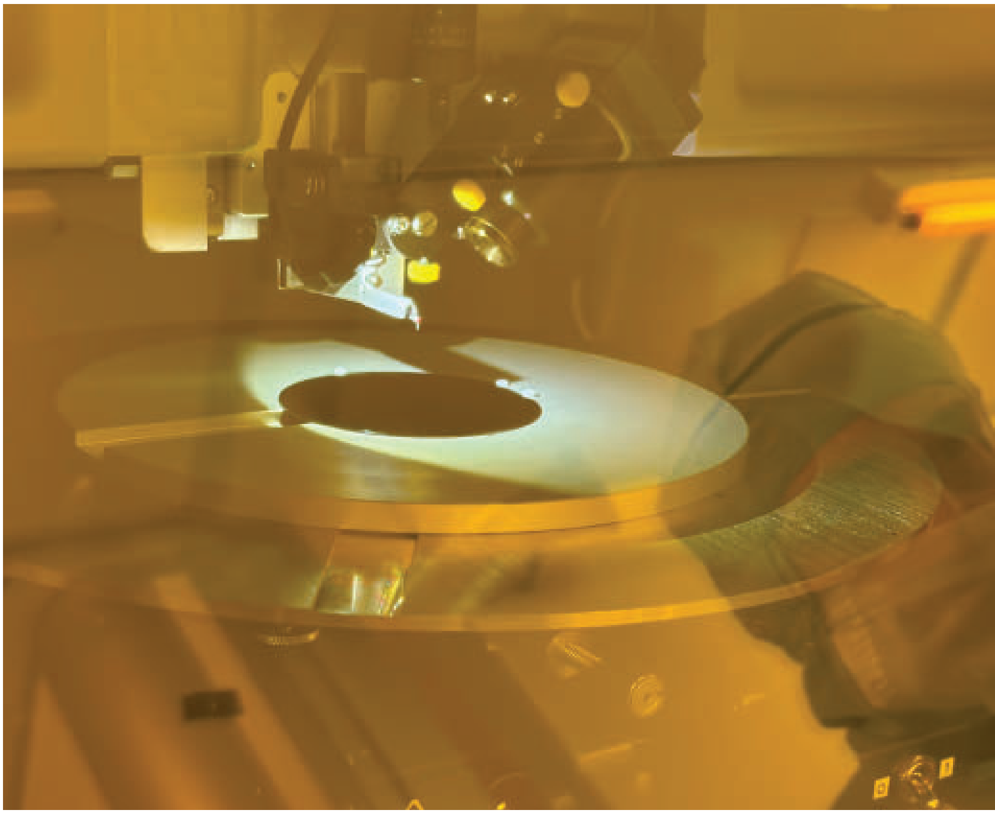
Xanadu's 200-plus-member workforce includes roughly 50 engineers and technicians with backgrounds in integrated photonics technology. According to company founder and CEO Christian Weedbrook, Xanadu expects its integrated photonics engineering talent pool to grow by 30% to 50% during the next few years.

Positions on Xanadu's engineering team often require specialized skill sets and a distinct combination of capabilities, making talent sourcing a challenging undertaking. "There are certain positions that are incredibly specialized, so finding candidates that have been focusing in those areas can be difficult at times," Weedbrook said.

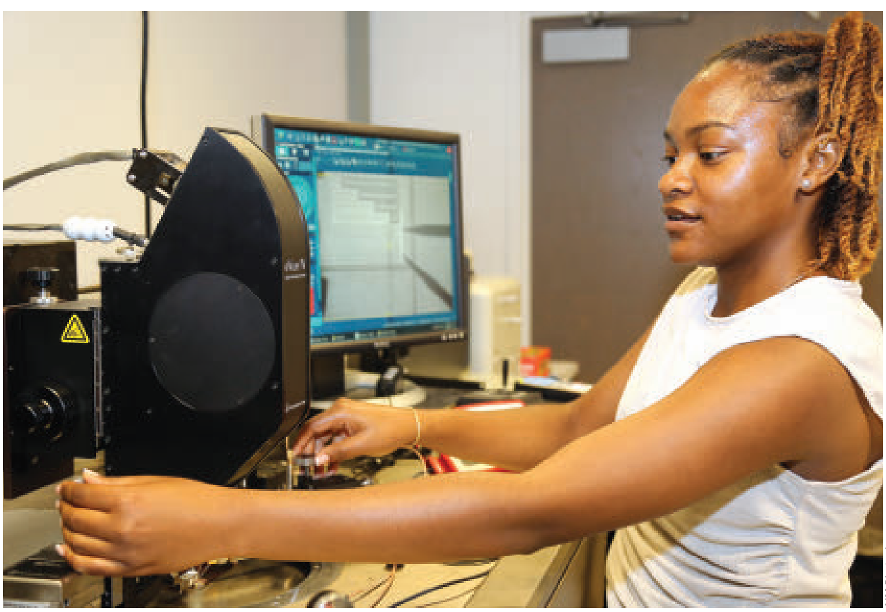
To help recruit talent and meet its hiring goals, Xanadu has forged partnerships with academic institutions such as the National Quantum Laboratory at the University of Maryland. While the company does not currently have a formal, structured training program, it pairs new hires with senior and lead engineers. It also sponsors team members' attendance at skill-building industry events.

These events can be critically important for introducing and developing many of the industry-specific skills that engineers must master to succeed in photonics design and manufacturing roles. Though they qualify as "industry" events, the nature of these meetings, sessions, and trainings can be hard to characterize using a broad-based definition. In many cases, the knowledge necessary to learn these skills overlaps between electronics and photonics. While an electrical engineering degree has traditionally served as a ticket to careers in the semiconductor industry, this is not necessarily the case in integrated photonics.

"Not all electrical and electronic engineering programs offer extensive courses, or maybe they don't offer [any] courses in photonics, optical waveguides, photonics circuits engineering, light-matter interac-



SMART Photonics



In 2024, PhotonDelta launched a "MasterPlus" optics and photonics program at three Dutch technical universities **(top)**.

AIM Photonics has introduced the Hands-On Photonics Education Kit, or HOPE Kit. Each kit contains six integrated photonic chips, which recipients can explore individually or as a system **(above)**.

Approximately 65% of SMART Photonics' 200-plus-member workforce has some background experience in photonics engineering **(left)**. The Dutch photonic integrated circuit (PIC) foundry offers generic photonic integration as well as multiproject wafer services.

tion, or optical fibers," Weedbrook said. "And most importantly, there is a vast lack of [practical experience in] building optical setups, using photonics-grade lasers and equipment, handling optical components, and manipulating and managing optical fiber, for example."

At the same time, photonics and electronics disciplines *do* share many similarities. In Marvell's case, according to Nagarajan, the California-based company has benefited from this overlap — specifically between advanced packaging and integrated photonics — in addition to maintaining partnerships with universities nationwide. This has created an internal pool of skilled engineers, he said.

According to the findings of the MIT-Conducere study, some employers placed greater emphasis on on-the-job training and viewed the completion of photonics courses more as an indicator of interest in the field than of competency in it. Juliet Aiken, a Conducere managing partner, said that each company interviewed for the study had a unique approach to developing photonic integrated devices, making employer-specific training — which supplements broader, more generalizable academic exposure — vital to each company's workforce development efforts.

Since its first cohort in 2021, the photonics and optical engineering certificate program at Massachusetts-based Stonehill College has enrolled about 60 students.

"I think both approaches are needed, but employer-specific training models that incorporate apprenticeships and certificates are more likely to have immediate and scalable impact," said MIT's Moore. "These models offer more flexibility — which is needed in this fast-moving industry — and can allow workers to enter the workforce more quickly while building expertise over time."

Internal training

Like Xanadu, the PIC foundry SMART Photonics, headquartered in Eindhoven, Netherlands, fosters strategic partnerships with academic institutions, particularly Eindhoven University of Technology. At SMART Photonics, senior employees also mentor junior colleagues.

SMART Photonics' internal training regimen also includes courses on aspects of photonic integration from the JePPIX technology center in Eindhoven, credential-bearing certifications in Design for Six Sigma (DFSS), project management training, and access to more than 250 online courses for continuous professional development.

Nearly two-thirds of SMART Photonics' 200-plus-member workforce has some background in photonics engineering. According to the company, growing applications of PICs across various sectors — including AI, telecommunications and data communications, automotive lidar, and quantum — are driving the increased demand for its technology offerings. "This growing demand leads to a need for a larger skilled workforce to support this expansion," said Ilse de Graaf, talent acquisition lead at the company.

The photonic integration courses that SMART Photonics made available through JePPIX are similar to initiatives that AIM Photonics spearheads in the U.S. AIM Photonics' education and workforce development program helps employees to build comprehensive skill sets, with courses covering topics such as PIC testing, PIC packaging, and more. Companies including GlobalFoundries, Northrop Grumman, Lockheed Martin, L3Harris, Tokyo Electron, NVIDIA, and Toshiba are among those that have subscribed to AIM Photonics' education and workforce development courses and programs, said Robert Geer, director of education and workforce development at AIM Photonics.

"Typically, companies do not share details of their internal training and apprenticeship programs. It is safe to say that if there are needs for PIC skills that are not met by educational institutions, then companies find ways to fill the gap," Geer said.

Intel, Infinera, and Analog Photonics are among the manufacturers that have demonstrated leadership in technician training by adopting structured, in-house development models aligned with production needs, according to Peter Rice, manager of quality at IQE, a manufacturer of advanced compound semiconductor wafers and material solutions. "This systematic investment in technician development is especially critical as the demand for PIC manufacturing talent grows and the field continues to evolve with AI, datacom, and quantum applications," he said.

HOPE in higher education

One of the greatest challenges that colleges and universities face in preparing students for careers in integrated photonics is providing hands-on experiences in addition to structured trainings. Chip and PIC testing requires expensive, complex laboratory setups, which many schools lack. According to Rice, in addition to cleanrooms, essential equipment and resources that many colleges and universities are unable to provide for students include wafer-scale test and inspection equipment, packaging and fiber alignment stations, real-time process monitoring tools, and equipment for III-V materials processing. Rice also serves as interim director of an integrated photonics certificate program at Stonehill College in Easton, Mass.

In response to this challenge, AIM Photonics has introduced the Hands-On Photonics Education Kit, or HOPE Kit. Developed in collaboration with MIT, Rochester Institute of Technology (RIT), the University of Rochester, Bridgewater State University in Massachusetts, and Spark Photonics, each HOPE Kit features packaged PICs that can be tested and characterized without the need for expensive, specialized laboratory setups. AIM Photonics sent its first shipment of HOPE Kits last year to Western New England University in Massachusetts, MIT, and Bridgewater State University.

According to Geer, the design and packaging of the six chips in each HOPE Kit enables recipients to explore them individually or as a system. "Students can dive into testing real, functioning devices and learn how to collect and interpret data, troubleshoot designs, and build a stronger understanding of how these components work," he said.

Another initiative that debuted last year is a joint MIT-Massachusetts Bay Community College-led "boot camp." The hands-on program was part of a National Science Foundation Advanced Technical Education program called the Northeast Consortia for Advanced Integrated Silicon Technologies. Participating students received instruction on electronic-photonic packaging technologies and evanescent chip-to-chip passive assembly. They also received training at the MIT.nano laboratory facility.

Certification programs

In 2020, with the goal of providing intensive, hands-on experience, two Massachusetts colleges — Stonehill College and Bridgewater State University — launched certificate programs in photonics and optical engineering. The schools launched the certificate programs with grant funding from MIT's Initiative for Knowledge and Innovation in Manufacturing in partnership with the U.S. Office of Naval Research.

Since its first cohort in 2021, the Stonehill certificate program has received 100 inquiries and 74 applications, and nearly 60 enrolled students to date. Students learn and experience waveguide design, photonic device fabrication, optical materials science, optical circuit simulation, and techniques for systems packaging. The nine-month, or two-semester, program aims to extend education beyond standard electrical engineering courses, and includes a three-month paid internship. Industry partners include Thorlabs, IQE, VEIR, Insulet, WiseTech Global, SiPhox, 3DEO, and Woods Hole Oceanographic Institution.

"Meeting industry needs long-term will require a systematic shift toward tighter education-industry partnerships and faster credentialing," said Cheryl Schnitzer, director of Stonehill's photonics and optical engineering certificate programs. "To accommodate this, we have focused on tightening our academic model, ensuring specific competencies and techniques are mastered by students, and frequently infusing new industry feedback into our courses and program."

Post-graduate shift

In the Netherlands, photonics consortium PhotonDelta has started ramping up its vocational college programs for technicians after initially placing greater emphasis on applied sciences program development, according to Evi Somers, PhotonDelta's program director of human capital. For example, at certain regional training centers, programs are being developed for teaching cleanroom and cleantech skills to students at the associate's (MBO) and bachelor's (HBO) levels. Additionally, LiS (Leidse Instrumentmakers School) is developing an extended program on optical engineering, through which MBO students will learn about laser and optical fiber technology.

While growing its technician training regimens, the Netherlands is continuing to expand its higher professional education programming. Last September, PhotonDelta and Optics Netherlands launched a "MasterPlus" optics and photonics program at three Dutch technical universities: Delft University of Technology, Eindhoven University of Technology, and University of Twente. With a first cohort of 35 students, the program focuses on optics and photonics courses and features challenge-based projects. For many students, it also culminates in an internship with a major company in the integrated photonics realm, such as ASML, Signify, SMART Photonics, and LioniX International.

This September, the Netherlands will see the launch of a new master's program in applied quantum technology at universities of applied sciences in Amsterdam, Eindhoven, Delft, and Enschede, with Fontys and Saxion focusing on quantum light in PICs and quantum processors.

"In the Netherlands, we focus our efforts on both skilling up the existing workforce and educating [new] talent in master programs," Somers said.

"Within the PIC industry, a lot of different topics are needed."

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Optimizing the Alignment: CO_2 Laser and Scan Head Integration

The integration of CO_2 lasers and galvanometer-based scan heads presents technical challenges. Optimizing alignment parameters holds the key to maximizing efficiency.

 All images courtesy of Novanta.

BY JULIA JANIK
NOVANTA

Figure 1. Laser marking with a CO_2 laser and an optimized scan head is performed on standard glassware **(opening image)** and architectural glass **(above)**.

Due to their high efficiency and versatility, CO_2 lasers are widely used for various applications in the industrial, medical, and scientific sectors. These lasers typically operate at a wavelength of 10.6 µm in the infrared spectrum. This wavelength is particularly effective for cutting, engraving, and marking materials, such as glass, ceramics, plastics, and wood.

Aside from selecting the optimal laser for a target application, it is crucial for users to ensure that the laser beam is precisely delivered to the material. A scan head, which uses two galvanometer mirrors to steer the laser beam across the material surface in the x and y directions, is one of the most common methods for directing and steering the beam.

Scan heads are effective for applications beyond material marking, in areas such as cutting, drilling, and 3D printing applications. Certain applications heighten the importance of precisely matching the laser and the corresponding scan head. The exact alignment of this combination is paramount to achieve the best possible performance: a stable focus and effective marking quality over the whole scanning field.

CO_2 laser marking of glass is one such application. This process involves creating stress-relieved marks using a small focus spot size between 100 and 300 µm. The laser beam rapidly heats and cools the glass surface, causing microfractures that form visible marks (Figure 1). Sharp temperature differentials can lead to larger, inconsistent fractures, and gradient differentials can create smaller, consistent fractures. For high-speed marks, using a dashed line can improve mark consistency by encouraging the system to make secondary parallel fractures. Pulsed lasers are particularly effective for this method. Large or out-of-focus spots >300 µm create a controlled continuous fractured look, requiring slower scan speeds due to the low energy density.

Of course, depending on the application, an end user may desire different results or geometries for these marks. Therefore, the focus size must be carefully selected and stabilized to ensure consistent microfractures, leading to accurate and homogeneous marks.

Selecting the right CO_2 laser and scan head is crucial to achieve a consistent focus over the whole marking field. Further, the subsequent integration of both components must be precise. Users must select the optimal mechanical, electrical, and optical components, and ensure that the design of the optical beam path is robust and cost-effective.

Though textbook solutions exist for many integration problems, these fixes are often expensive, time-consuming, and complex. Fortunately, many preemptive approaches are available to end users to ensure reliable and consistent operation.

$$P_{max} = \frac{P_{max,\ absorbed}}{1 - R\%} = \frac{\frac{D}{20}}{1 - R\%} = \frac{D}{20(1 - R\%)}$$

Equation 1. A representation of the relationship between the maximum power (P_{max}) output of the laser and the scan head performance. P_{max} must be compatible with the scan head's mirror aperture size (D) and mirror reflectivity (R).

$$Power\ Loss = e^{-2\frac{\left(\frac{Clear\ Aperture}{2}\right)^2}{\left(\frac{Beam\ Size}{2}\right)^2}} < 1\%$$

$$\left(\frac{Clear\ Aperture}{Beam\ Size}\right) = \sqrt{-\frac{1}{2}\ln(Power\ Loss)} > \sqrt{-\frac{1}{2}\ln(1\%)} = {\sim}1.52$$

$$Beam\ Size < \frac{Clear\ Aperture}{1.52}$$

Equation 2. A calculation of the power loss and ratio for Gaussian beams. To ensure that 99% of the laser beam's energy passes through the scan head, this calculation indicates that a safety factor of ~1.5× should be applied between the beam size — given as the $1/e^2$ value — and the clear aperture.

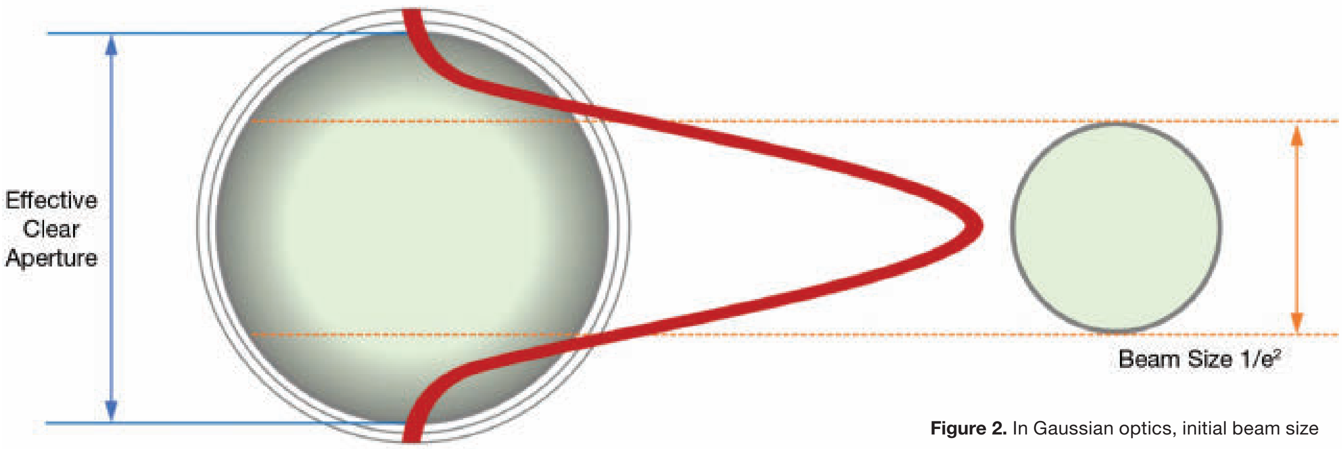

Figure 2. In Gaussian optics, initial beam size partially determines the focused spot size produced by a scan head. Laser beam width is reported as the $1/e^2$ diameter, representing where beam intensity falls to ~13.5% of its peak value. Here, the comparison of an effective clear aperture is made to $1/e^2$ beam size.

Matching beam and scan head

A user must consider several parameters, including wavelength, collimation, ellipticity, mode, size, and input angle, to accurately match the incoming laser beam to the scan head and ensure optimal scan head performance. The user must first confirm that the laser input beam is within the wavelength range of the coating on the optics in the scan head. Then, the user must select and match the laser beam diameter to the scan head's clear aperture.

Generally, larger scan head apertures enable smaller focal spot sizes and accommodate higher laser powers. Accordingly, smaller apertures facilitate faster and more dynamic beam manipulation. Because smaller scan heads are often more affordable than larger versions of these components, it is necessary to ensure that the laser's maximum power output (P_{max}) is compatible with the scan head's mirror aperture size (*D*) and mirror reflectivity (*R*) performance (Equation 1).

In Gaussian optics, for example, the initial beam size significantly influences the focus spot size produced by a scan head. Ideally, the clear aperture of the scan head would be used with the largest diameter beam to attain the smallest focused spot size (Figure 2). Laser beam width is typically reported as the $1/e^2$ diameter; this value represents the point at which the beam intensity falls to ~13.5% of its peak value. This should be compared with the scan head's effective clear aperture, which is available in the product or system datasheet.

To ensure that 99% of the laser beam's energy passes through the scan head, a safety factor of ~1.5× should be applied between the beam size — given as the $1/e^2$ value — and the clear aperture (Equation 2).

A clear aperture-to-beam diameter ratio of <1.5× may cause meaningful diffraction rings and laser power loss within the system, which could result in reduced marking or cutting performance and shorter component lifetimes. Conversely, a higher ratio will increase power density on the optical components and produce a larger spot size in the focal area.

To obtain the desired beam size, a user must select an adjustable beam expander with the correct expansion ratio. Beam expanders are critical to achieve desired performance, ensuring both effective beam shaping and size control. The ideal solution, in terms of performance, is a zoom beam expander that covers a wide range of expansion ratios, which a user can adjust to achieve necessary beam size.

However, this type of beam expander is highly complex and expensive. And, largely due to their complex design, these expanders are generally more sensitive to external influences such as shock, vibration, and temperature changes. Using a commonly available beam expander that produces a beam size as close as possible to the ideal input beam is a solution that balances cost-effectiveness and robust performance.

Implementing these considerations and tailoring the system and components to the target application should deliver predictable performance and optimal results (see sidebar and table on page 43).

Aligning the laser

The optical axis, an imaginary line through the center of the scan head's input aperture, is essential for aligning all components to ensure high-quality results. Misalignment can cause off-center beam outputs, power loss, and/or degraded scan field performance.

CO_2 lasers often vary in beam exit location and angle. This requires the precise alignment with scan heads. This alignment, involving both angular and translational adjustments, is complex. Any misalignment in the beam input will be amplified in the optical far field, leading to degraded process performance and nonoptimal results.

The standard approach for laser alignment in free-space optics is the use of two individual mirrors on kinematic mounts and two targets as reference points. This configuration enables both lateral and angular alignment of the beam into the scan head aperture (Figure 3). This approach may also support different mirror configurations, depending on the available space and the position of the laser and scan head.

Since CO_2 lasers emit invisible infrared radiation, the beam must be visualized at the target. A common solution is to use a wire-mesh mode screen that glows at the beam contact point when sufficient power is applied. The hole in the center of the mesh is designed to allow the beam to be precisely centered in the target. Using a crosshair target, with a piece of thermal paper to mark the position of the beam at low power, is one simple alternative to the wire-mesh method.

In theory, laser alignment methods, including the example in Figure 3, offer highly accurate solutions. However, these architectures assume perfect conditions and a stable environment, and they often carry significant investments of costs and time. Most industrial environments will not be suitable for such textbook solutions. Companies must balance precision with cost-efficiency in most cases, and a slightly less precise but more practical solution is often preferable and more financially viable.

Additionally, for these setups to support optimal performance, each laser can have only a slightly different beam path. This makes it impossible to rely on a fixed, one-size-fits-all design. Instead, alignment systems must be flexible enough to account for these small variations to ensure consistent performance.

Laser and scan head control

In addition to the optomechanical design, users seeking to maximize the performance of the laser and scan head subsystem must also consider the conditions needed for seamless laser and scan head control. For the best possible system performance, a user must streamline communication between laser, scan head, and controller. The usability of the software is another core parameter that must be controlled.

When pairing a scan head with a controller, the scan head's specifications — such as field size, speed, and accuracy — should be matched with the capabilities of the controller. For example, high-speed applications may require a controller to support rapid signal processing and feedback. Larger mirrors, on the other hand, may demand more powerful control signals to maintain accuracy at high speeds.

Fundamentally, the scan head and controller should be compatible and use the same communication protocol — for example, XY2-100 or SL2-100. Certain scan heads require specific calibration software or offer bidirectional communication protocols. In these cases, the controller must support these features. To simplify this challenge, users should select a scan head and controller that support several common communication protocols, and select one communication protocol that supports bidirectional communication to serve as their standard.

The controller must also synchronize the scan head with the laser and properly time the signals to avoid distortions. A controller with precisely timed laser controls that optimize synchronization between scan heads and lasers should enable users to bypass delays. The implementation of real-time scanning feedback controls can further improve system performance.

Finally, although complex software interfaces can be difficult to use, and may therefore increase the risk of errors, many user-friendly software options exist on the market. These solutions integrate seamlessly into the hardware and simplify operations. Software that supports integration with various hardware components, such as vision systems, positioning systems, and conveyor belts, further enhances automation and improves overall system productivity.

Keeping all these factors in mind can be challenging, especially if the components are sourced from different suppliers and have different specifications. In application, though, these measures help to ensure the development of a well-matched and high-performance system.

Thermal management considerations

For CO_2 lasers, the laser gas mixture gain decreases as the gas heats up, resulting in a loss of output power. Maintaining a

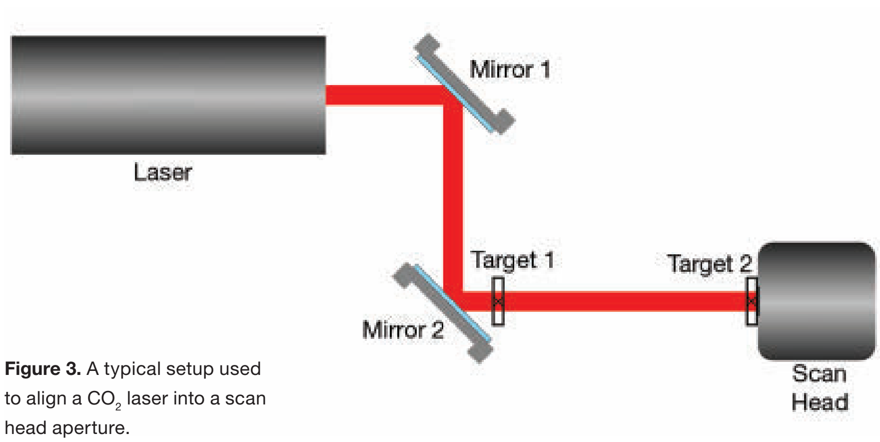

Figure 3. A typical setup used to align a CO_2 laser into a scan head aperture.

Spotlight on Laser Beam Expanders

For a scan head with a 14-mm clear aperture and a CO_2 laser with a 2.5-mm beam diameter ($1/e^2$), the ideal beam size, as calculated using Equation 2 (see page 41), is 9.2 mm. The table shows commonly available beam expanders and their corresponding beam sizes. Using the table values, a 3.5× beam expander is the optimal choice, because it most closely matches the ideal diameter without being excessively large.

Commercial Beam Expanders: Effects of Ratios on Beam Sizes

Laser Beam Size (mm)	2.5		
Expander Ratio	3×	3.5×	4×
Final Beam Size (mm)	7.5	8.8	10

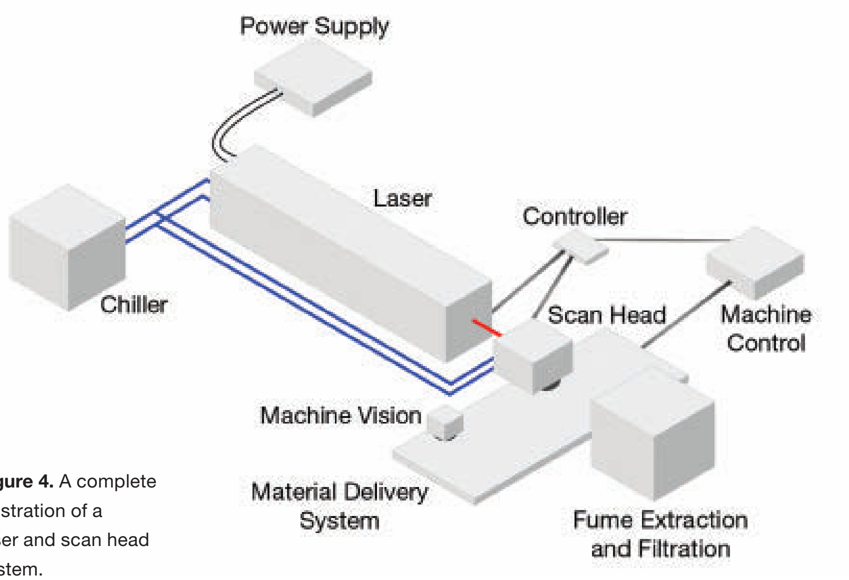

Figure 4. A complete illustration of a laser and scan head system.

stable laser temperature provides the best output power stability. The gas mixture is driven with either direct current or radio frequency energy to cause the mixture to emit photons and develop the laser beam. These electronics generate a significant amount of heat that must be carefully removed to prevent damage to the components.

This logic applies to all industrial laser types: Overheating can reduce the lifetime of components and increase the risk of equipment failure. Even before overheating occurs, simple fluctuations in temperature are apt to negatively affect a lasers' output power, beam quality, and stability.

Although not all scan heads are actively cooled, cooling their components — mirrors and/or galvanometers, for example — can improve system performance. Galvanometer cooling increases the stability of scan head performance and minimizes temperature drift. This is important for high-duty-cycle, full-speed, and full-range applications that require exceptional accuracy.

The challenge with the mirrors is that despite their highly reflective coating, the components are still affected by a hot spot where the laser beam gets reflected. Cooling the galvanometer mirror reduces the heat, and, therefore, the degradation of the coating, which over time can lead to overheating and sudden failure.

Passive cooling via heat dissipation is sufficient for many low-power laser systems, whereas systems that achieve an output power of >100 W require water cooling. This option is the most efficient to remove heat and provide a stable operating environment. Most water-cooled systems use a closed-loop circuit with a chiller.

Users should base the selection of a suitable chiller on a combination of factors, including the required cooling capacity, flow rate, pressure limits, and tubing design. Chillers must meet flow rate requirements to offer enough cooling capacity to absorb the heat load, and the minimum flow rate of the system must be covered, while not exceeding the maximum pressure.

Additional subsystem factors

CO_2 lasers are Class 4 lasers; they are therefore governed by a well-established set of laser safety protocols. To limit the risk of injury or system damage, enclosing the laser system as well as possible and covering all beam paths is paramount. Additionally, the laser system should be integrated into the machine safety with an interlock and emergency stop mechanism to shut down the system immediately in case a door is opened or in the event of an emergency situation. And, since the laser process can create harmful fumes that may cause injury to the machine operator and pose a fire or explosion risk, proper fume extraction, with the right filter material, is needed to maintain machine safety.

Especially for free space systems, with multiple alignment mirrors, these requirements can become complex and carry high costs. Nevertheless, users must maintain compliance with local regulations for industrial laser safety such as OSHA, ANSI Z136, and IEC 60825.

The seamless integration of the laser system with other machines for automation and procession is another consideration. For certain industrial applications, the controller and software must communicate with existing vision systems, positioning systems, and/or conveyor belts, for example. Industrial communication interfaces such as Ethernet/IP, RS-232, Modbus, and input/output connectivity are important to support integration.

Also, since the power supply must be compatible with the laser model and its operational requirements, users must be sure to correctly select the appropriate power supply element. The user and/or system integrator must match voltage and current needs while considering that the power requirements for scan heads and controllers are lower compared to those of the laser. Scan heads and controllers can have similar power requirements, and so both components in an optimized system could share one power supply to reduce complexity and cost.

Ensuring lasting performance

Accurate optical matching of the laser beam and scan head aperture is essential to achieve optimal system performance (Figure 4). Still, additional variables must be considered to ensure user safety and limit system damage. Though achieving the ideal integration scenario may be challenging, systematically approaching the selection of the right components and the implementation of all necessary practices can significantly enhance performance and ensure high-quality results.

Meet the author

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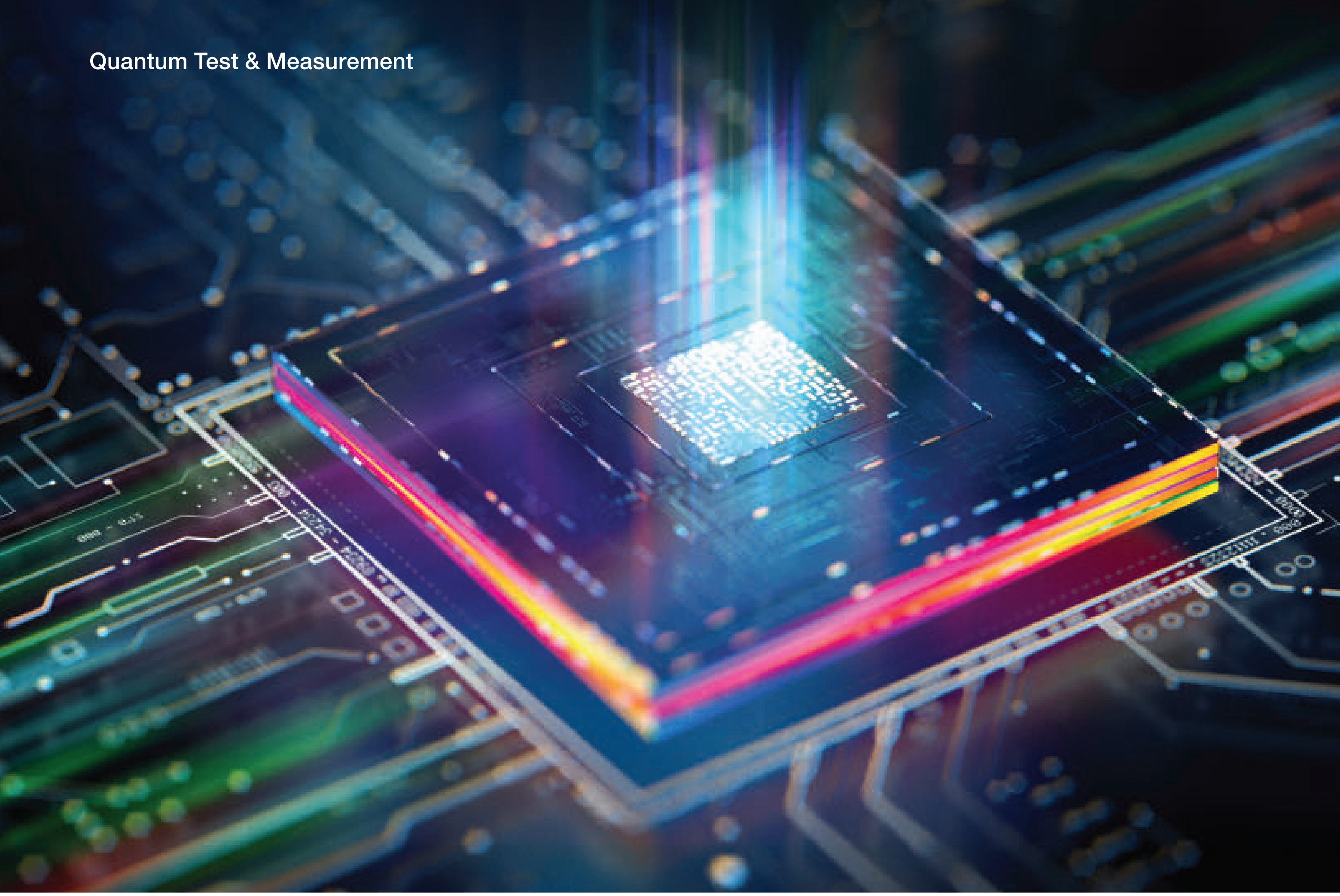
Test and Measurement Breakthroughs Bring Optical Quantum Experiments Under Control

Innovations in the photonics test and measurement sector are needed to ensure that increasingly sophisticated quantum technologies reach their target applications.

Opening image courtesy of **Liquid Instruments**.



BY JASON BALL
LIQUID INSTRUMENTS

For all of its promise — including ultrasecure communications, exponential computing speedup, and unprecedented precision in sensing and measurement — quantum technology presents numerous dynamic challenges. Though the complex nature of quantum's algorithmic and scientific requirements is well understood, implementing even the most mature quantum technologies demands significant time, labor, and resources. Even now, more than 100 years since Einstein posited the particle-like nature of light, the scientific community continues to grapple with fundamental barriers to implementation, such as noise, scalability, and entropy.

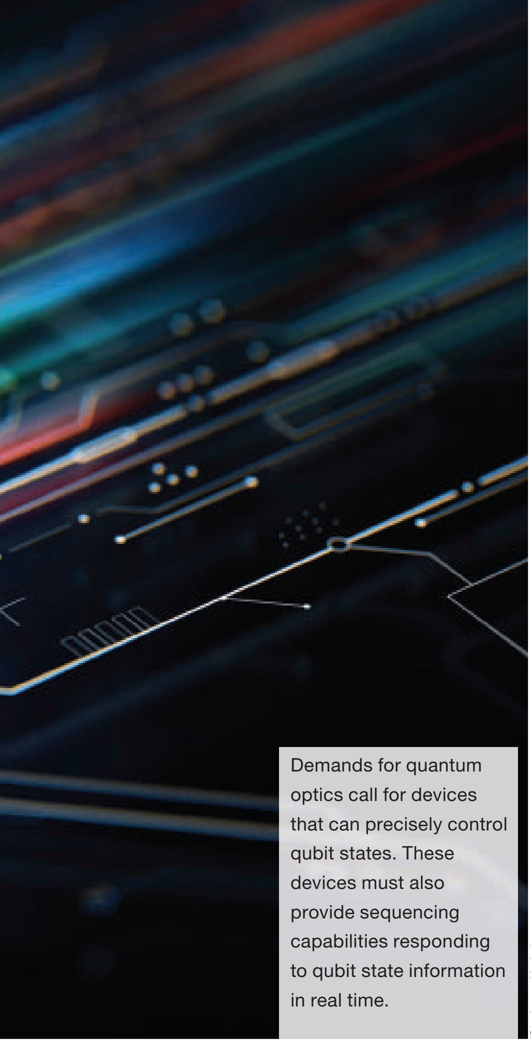
Against this backdrop, overall progress in quantum technology maintains a slow but steady course. Quantum researchers are leading the charge to push the limits of current laboratory technology.

At the same time, the role of quantum information science for industry and society is already vast. Quantum computers built on atomic arrays, for example, are poised to exponentially speed up the calculation times for certain types of problems that are difficult for classical computers. Concepts such as entanglement and superposition can help achieve more precise electromagnetic and gravitational field sensing for users in the field, as well as improved results from superresolution imaging in laboratory settings. Quantum key distribution (QKD) techniques using optical carrier frequencies can also transmit information that is extremely difficult to intercept, supporting ultrasecure data and telecommunications. Many additional applications are already in practice. Others are on the way.

Continued progress in these applications and the emergence of those on the horizon is not a guarantee. To ensure future gains, the photonics test and measurement sector must itself evolve to address the technical challenges posed by distinct quantum applications such as sensing, computing, and cryptography. Advancements in measurement precision — resulting in reduced noise floors and increased sampling speeds — as well as the introduction of flexible hardware platforms such as field-programmable gate arrays (FPGAs), are critical to meeting these challenges. It is also essential for manufacturers of these test and measurement instruments to develop streamlined and scalable processes, ultimately making it easier for end users to adapt to changes in scope or requirements.

Optical quantum systems

Optical quantum systems offer a range of desirable characteristics, making these systems attractive options for quantum sensing, computing, and cryptography. These systems often use atomic energy levels to represent classical 0 and 1 states, and the indistinguishability of atoms means that any two of a certain species will be identical in structure. For this reason, atoms have earned a reputation as "nature's perfect qubit." Opportunities abound to harness quantum mechanics



Demands for quantum optics call for devices that can precisely control qubit states. These devices must also provide sequencing capabilities responding to qubit state information in real time.

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in the domain of atomic, molecular, and optical physics.

Given their higher transition energies, optical systems are also stable at room temperature and do not require large-scale cryogenics or dilution refrigerators for operation. This stability means that optical frequencies are well suited for the transmission of quantum state information over long distances. Atoms can also be packed in dense formations, which is an advantageous quality for scalable quantum computing. Importantly, atoms benefit from a well-established photonics infrastructure that comprises many manufacturers of lasers, optical components, and test and measurement equipment.

Technical challenges in quantum optics

The cutting-edge technologies that are driving progress in quantum sensing, compute, and cryptography face several challenges. An ion trap, for example, has widespread potential for use in quantum chemistry, metrology, and sensing[1]. But experiments involving these devices have many moving parts.

An ion trap consists of 1D or 2D arrays of ionized atomic nuclei. Researchers must tightly control and synchronize an array of lasers, maintain direct current and radio frequency fields, and continuously check for the presence of ions in the trap via fluorescence measurements. These requirements place stringent demands on the control electronics, necessitating devices that can quickly and precisely control qubit states, both for single-qubit and two-qubit gates, and provide agile sequencing capabilities that respond to qubit state information in real time.

An active reset, where a user checks if a qubit is initialized into the quantum ground state, creates another technical bottleneck. There is no action for the user to take if the qubit is measured to be in the 0 state. But, if the qubit is in the 1 state, the user will need to return it to the ground state through a laser pulse. Also, to ensure that the user obtains any benefit from the reset, the sequence must take place on a scale faster than the qubit's coherence time.

Stabilizing multiple concurrent laser beams is also a technical challenge since these optical setups are extremely sensitive to external noise. Again, this approach requires electronics that can provide active, real-time feedback.

Quantum communication protocols, such as BB84, present challenges, too. Signal integrity becomes a concern when transmitting over long distances, limiting the scale to which current networks can operate. The detection of signals must also be rapid and precise, so that QKD protocols can be verified in real time.

The hub of the measurement

To address these demands, industry is pioneering solutions at both component and system level. Detectors such as lock-in amplifiers offer low input noise for extracting weak signals from noisy backgrounds, and frequency- and event-counting modules provide highly efficient time-tagging and coincidence counting for fluorescence detection and QKD validation. Meanwhile, signal generators are rapidly increasing in sampling rate, meaning that they can synthesize frequencies in both the radio frequency and microwave domains. This eliminates the need for separate electronics.

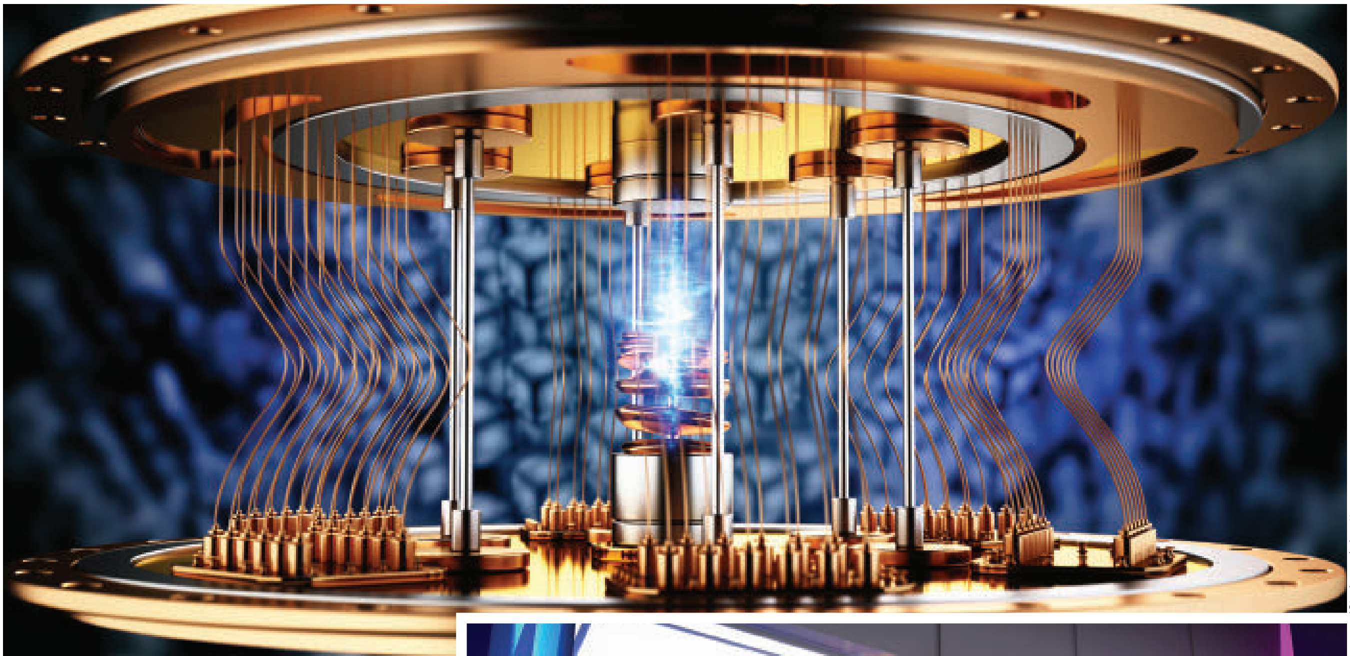
The resulting increase in time resolution also enables more precise timing of laser pulses and improved qubit manipulation. Automated control loops and hardware for the stabilization of lasers and frequency combs are also evolving, benefitting from recent advancements in machine learning. These algorithms can help eliminate much of the guesswork and time loss involved in tuning proportional-integral-derivative loops. Additionally, many of these improved hardware solutions also feature efficient software integration. This allows users to deploy new technologies in their experiments without excessive delays or a reduction in productivity.

Other breakthroughs in test and measurement technology are helping to meet the multifaceted technical challenges posed by quantum systems. The proliferation of FPGAs is one such trend. These integrated circuits are rapidly gaining traction as the first choice for a variety of quantum technology applications.

Parallel processing capabilities, which enable FPGAs to perform the same functions as a CPU with lower power consumption and deterministic temporal behavior, are among their most enticing features. This, in turn, enables rapid response times, eliminates the need to communicate with a host PC, and provides large data handling capabilities — all essential for data-heavy tasks such as QKD postprocessing.

The reconfigurable nature of FPGAs also means that they can be customized to perform different functions across a wide range of quantum systems and experiments. For example, an FPGA can operate as a signal source, detector, or signal processor. While the relatively low sampling rate of FPGAs has historically been a barrier to direct signal generation, FPGAs on the market today achieve speeds that are sufficient for many applications.

For other quantum applications, such as those requiring microwave frequencies of up to 10 GHz, the FPGA can accomplish this through image frequency generation in higher Nyquist zones or through heterodyne mixing. Because they can both generate and process signals in real time, FPGAs excel as the "hub" of the measurement, improving speed and reliability. Moreover, they make excellent choices for active feedback due to their low latency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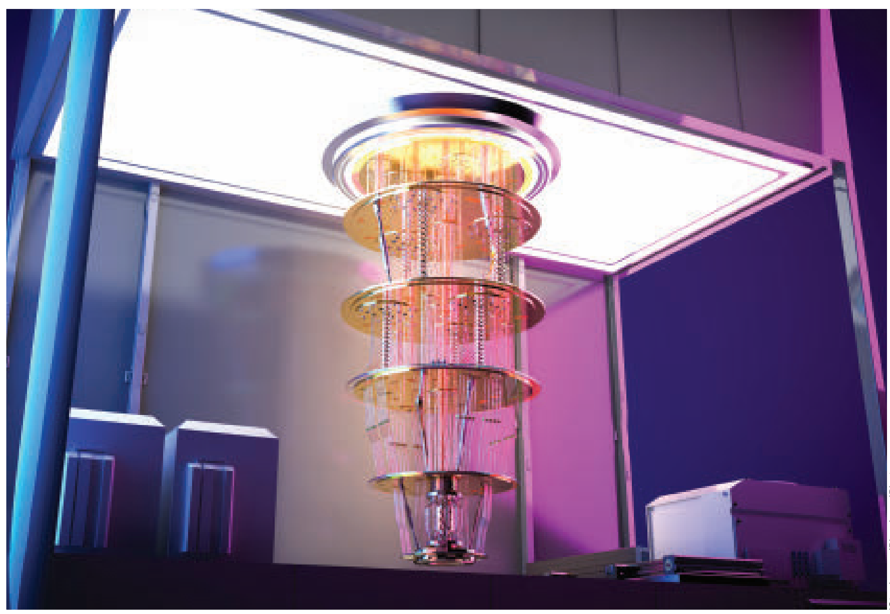
Quantum computing is emerging as a promising field for advancing atomic energy research. These systems use qubits, which can exist in a superposition of 0 and 1 simultaneously.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Evolving test and measurement equipment, systems, and protocols are helping to resolve the complex technical challenges that quantum systems present. Field-programmable gate arrays (FPGAs) are among the most promising technology solutions for addressing these and future challenges.

and responsiveness, enabling their operation within a qubit's decoherence time.

These benefits offer strong motivations for incorporating FPGAs into commercial solutions — such as those from companies such as Liquid Instruments and others — as well as open source projects. These devices typically implement custom firmware to streamline functions such as generating pulse sequences, setting the frequency and phase of the local oscillator, and demodulating readout data for the end user. Certain devices even allow users to directly implement FPGA code for their own unique functionality.

Of course, challenges to the use of FPGAs persist even as adoption increases. For example, many users struggle with programming FPGAs, particularly the large number of physicists with a lack of direct experience. For this reason, numerous projects seek to make the technology more accessible to a wider audience.

Quantum and machine learning

The intersection of quantum technology and machine learning, particularly artificial neural networks (ANNs), is another catalyst for growth in quantum technologies. ANNs consist of interconnected layers of artificial neurons, with a nonlinear function operating on a weighted linear combination of the previous layer to determine the values of the next layer. The weights applied to these individual neurons are at first randomly generated and become more refined as training data passes through. The result is checked against a cost function. This function is then minimized by adjusting the weights and biases of the network through a process called backpropagation.

ANNs have tremendous utility in predictive modeling and identifying correlations in large data sets. It is easy to see why ANNs hold conisderable appeal for quantum researchers. Yet amid growing interest in whether quantum algorithms can reduce the training time and energy consumption of deep learning models, this claim remains the subject of intense debate.

What is clear, though, is that machine learning is already bolstering quantum technology. Machine learning algorithms are very efficient at data processing, which is a trend that readily extends to the quantum space. Demonstrations have also revealed that these algorithms can infer quantum states without full information, leading to more rapid readout and, potentially, improved fidelity. Machine learning algorithms can also improve experimental protocols and feedback strategies, and may even suggest new techniques.

Another benefit is that these types of neural networks avoid consuming large amounts of CPU or GPU processing power, in contrast to the massive computational and training requirements of generative AI and/or large language models. In fact, small-scale neural networks can comfortably operate within the confines of FPGA architecture, using parallel processing. In this way, researchers can use the flexibility and low latency that FPGAs offer to implement custom signal analysis, predictive modeling, and active feedback loops via a neural network. By operating in real time within experimental procedures, researchers have used FPGA-based neural networks to diagnose the states of multiple qubits simultaneously, while retaining measurement fidelity.

Future perspectives for quantum optics

Despite the many advanced tools that are currently available, optical quantum information science has traveled a long road to maturity, owing to the intrinsically difficult and sensitive nature of the technology. The road to commercialization for many applications — especially full, error-correct quantum computing — remains years, if not decades, away.

Fortunately, test and measurement equipment continues to grow in sophistication, spurred on by progress in the field at large and its capability to meet increasingly stringent requirements. As is true of quantum research itself, these hardware requirements are constantly evolving and shifting. Dead ends and impractical solutions abound, but only rigorous testing serves to reveal these flaws.

For this reason, researchers and scientists must future-proof their equipment against such changes. By combining powerful hardware, customizable FPGAs, and machine learning, quantum research scientists can ensure that their experiments will meet upcoming challenges with flexibility and speed.

Meet the author

Jason Ball is an engineer at Liquid Instruments, where he focuses on applications in quantum physics — particularly quantum optics, sensing, and computing. He holds a Ph.D. in physics from the Okinawa Institute of Science and Technology; email: jason@liquidinstruments.com.

Reference

1. K. Gilmore et al. (2021). Quantum-enhanced sensing of displacements and electric fields with two-dimensional trapped-ion crystals. *Science*, Vol. 373, No. 6555, pp. 673-678.

Quantum Magnetometers Are Crossing the Magnetic Frontier

BY DAVID ROY-GUAY
SBQUANTUM (SBQ)

The number and variety of device prototypes that have advanced from the lab into the real world in recent years offers irrefutable evidence that quantum sensing technologies are making major forward strides. As end users and systems integrators increasingly deploy these prototypes to perform useful, industrial applications, some have begun to emerge as bona fide disruptors to existing commercial systems.

The innovative prototypes that have achieved this status have met two critical benchmarks. First, they effectively harness the advantages of quantum technology to improve upon the capabilities of baseline, nonquantum systems. Second, they target essential applications, often as these applications evolve or pose new challenges that push the limits of the current solutions.

Quantum magnetometers, particularly those based on nitrogen-vacancy (NV) centers in diamonds, are among these innovations, offering a powerful alternative to conventional magnetic-based systems. For decades, magnetometers have been used in applications ranging from anti-submarine warfare to compassing technology. More recently, magnetic-based navigation has gained favor in global navigation satellite system-denied environments. In the present age of minerals, geophysical surveying is moving quickly toward autonomous platforms that use cost-effective and compact magnetometers to perform high-resolution surveys. And, with conflict zone complexities intensifying, so-called advanced concealment techniques — sensing technologies that “see” through smoke, underground, and underwater — are paramount.

Because NV centers are atomic, their applicability is also extending into nano- and micrometer applications in the medical space. Critically, quantum magnetometry is also a room-temperature technique, which further broadens its application potential.

Both as an improvement to conventional vector magnetometry, as well as in its widened range of supported use cases, NV centers are redefining how magnetometry can be used in the field by offering superior performance and situational awareness.

The quantum edge

At their core, quantum magnetometers harness the quantum mechanical properties of specific materials to detect magnetic fields with exceptional precision and sensitivity. These types of magnetometers — atomic vapor magnetometers, for example — have driven the adoption of large-scale regional magnetic surveys for geophysical modeling.

Parameters such as size, drift, and environmental interference often constrain classical sensors. Quantum sensors by contrast can measure fields with precision down to one millionth of Earth’s magnetic signal, enabling the detection of magnetic signals over longer ranges and in environments where signals are weak or noisy. Additionally, the stability of quantum reference states enables drift-free measurements, circumventing the need for constant recalibration and ensuring that users can compare data sets with high reliability. And quantum sensors optimize size, weight, and power parameters. Miniaturized designs make them ideal for deployment on small autonomous platforms such as drones, or in restricted spaces such as inside medical equipment or in underground sensors.

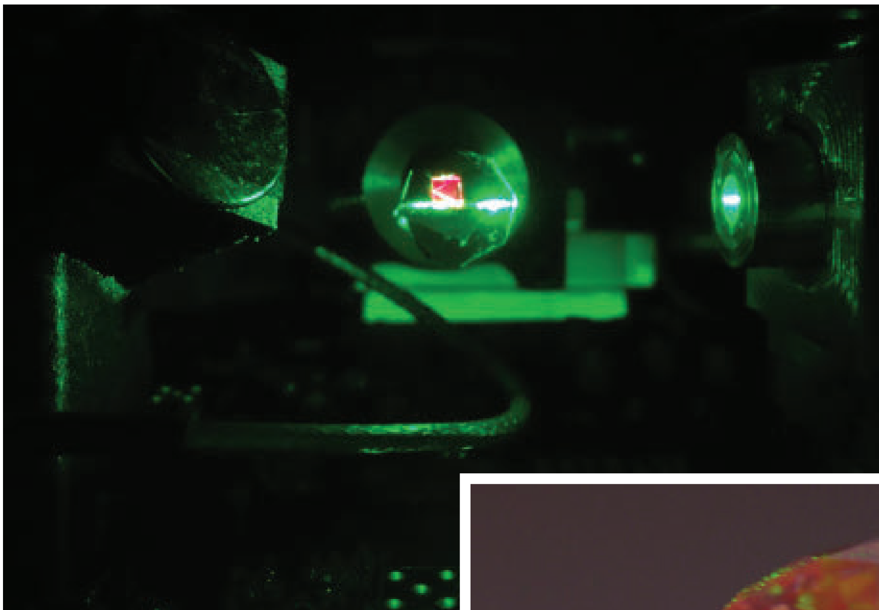
A flawed photonic system

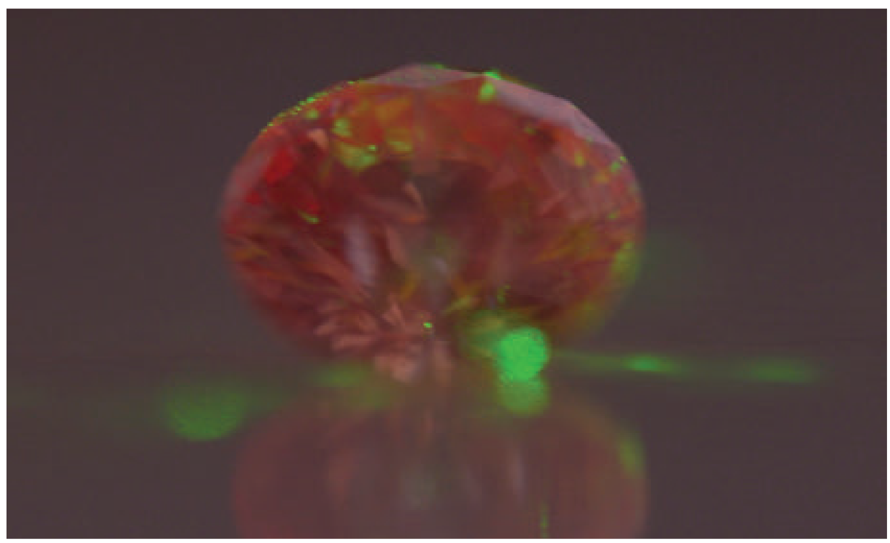
NV centers are point defects in a diamond lattice in which a nitrogen atom replaces a carbon atom adjacent to a vacancy, which is an empty lattice site. This structure results in a two-electron spin system with unique quantum properties that can be optically initialized and read out.

NV centers are particularly suited for magnetometry because of their quantum mechanical spin-1 property, which includes three energy levels: $m_s = 0, \pm 1$. These energy levels are sensitive to the local magnetic field via the Zeeman effect, especially along the NV axis. Visible (green) laser excitation polarizes the spin system and results in red light emission, or photoluminescence, the intensity of which depends on the spin state. Upon the application of microwaves at resonant frequencies corresponding to the spin transitions, the fluorescence intensity dips. This action provides a means to detect magnetic fields via optically detected magnetic resonance.

Due to the tetrahedral symmetry of the lattice, a diamond crystal typically contains NV centers in four orientations. With appropriate signal processing and a carefully applied bias magnetic field, each orientation can be resolved, enabling full vector magnetometry. This potential to reconstruct the vector components of magnetic fields in three dimensions is

 All images courtesy of SBQuantum.





A green laser shines on a nitrogen-vacancy (NV)-center diamond **(left)**. This excitation polarizes the spin system and results in the red light emission. The spin state determines the intensity of this photoluminescence.

An artificial diamond with NV-center defects glows red upon laser excitation **(below)**.

imperative for applications ranging from navigation to the advanced calibration of systems in complex environments.

Field-ready advantages

Traditional high-sensitivity vector magnetometers include superconducting quantum interference devices and vectorized atomic vapor magnetometers. These systems often require the use of cryogenics, or large, power-hungry electronics. NV magnetometers operate at room temperature with compact form factors and deliver similar or even superior performance in the field. Notably, since these magnetometers are based on a solid-state material — diamond — they avoid the need to vaporize a vacuum cell; this process requires heating elements that are apt to consume large quantities of energy.

The performance benefits of NV magnetometers are particularly evident in challenging or dynamic environments. Because of their tolerance to high magnetic field gradients, due to the small sensing volume, NV centers maintain high resolution even in areas with steep field variations. The robustness of these quantum sensors to mechanical and thermal disturbances is another area in which the benefits are clear, especially for field deployment. The diamond host is both a mechanical and thermal insulator. Its inertness and stability enable sensing in conditions that would degrade or destroy conventional sensors.

A third example relates to high dynamic range. NV magnetometers are operational in the presence of strong ambient fields and noise sources, such as metallic structures or electromagnetic interference from nearby equipment, without saturating or losing accuracy. This may not seem critically important. But, for field-deployed accurate sensors, the platform noise, such as from a drone or satellite, can alter readings to a point of frustration that forces many users to simply turn off their magnetometers.

Streamlined quantum navigation

One of the most compelling and high-growth applications of NV magnetometry is in navigation, especially in environments where global navigation satellite system signals are unavailable or degraded. Submarines, drones, spacecraft, certain indoor facilities, and even underground mining operations require alternative navigation systems that are accurate and autonomous.

NV magnetometers offer a viable solution for magnetic navigation. By enabling precise readings of Earth's magnetic field at high spatial resolution with vector readings, and operating reliably within a platform magnetic noise, these sensors represent a highly accurate alternative to traditional systems. For example, NV-based magnetometers used on small satellites allow for the creation and refinement of global magnetic field maps, such as the World Magnetic Model. This model underpins digital compasses used in smartphones and navigation systems, providing orientation cues in situations such as exiting a subway station — or orienting the blue arrow on your cellphone's map.

Additionally, NV magnetometers can be placed close to magnetic noise sources such as batteries or metallic components. This means that they can be used to accurately map and compensate for platform-induced fields, and that these sensors can be integrated into the very platforms that they help navigate, from autonomous drones to robotic explorers. This quality makes it possible to design potentially costly deployment platforms with compact and off-the-shelf components.

Quantum geophysics and remote sensing

In geophysics, precise magnetic field data helps locate mineral deposits, detect voids or anomalies underground, and map geological structures. Quantum sensors enable measurements with higher resolution and repeatability than traditional instruments, making them ideal for long-term monitoring or exploration in remote regions.

In remote sensing scenarios such as detecting buried structures or monitoring magnetic signatures of underwater vehicles, the high sensitivity and dynamic range that NV magnetometers offer enable them to detect subtle changes in the environment, even when deployed at a distance or in noisy surroundings.

Moreover, the potential for miniaturization and low-power operation means that arrays of NV sensors can be distributed over autonomous platforms to create an accurate digital magnetic twin. The result in this case is a compact solution that bypasses reliance on a magnetometer on a bulky boom.

Overcoming technical barriers

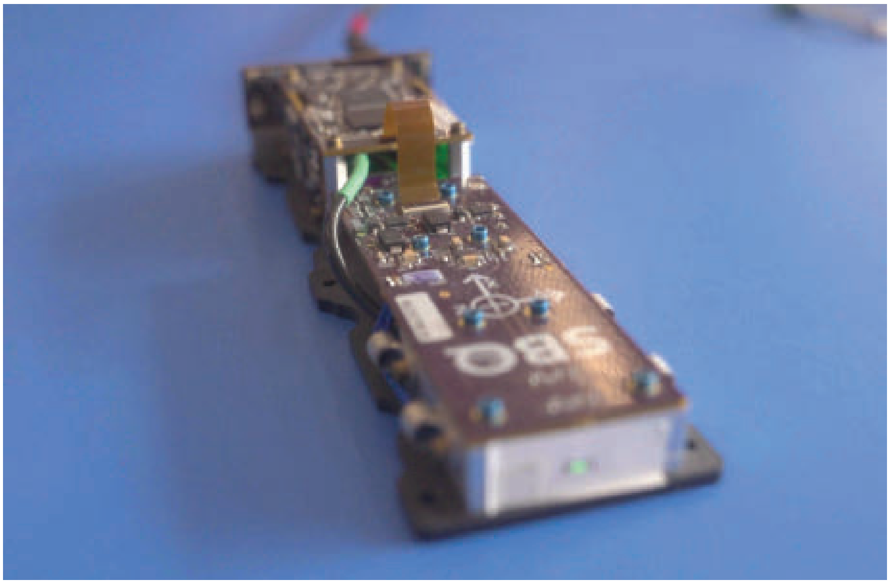
To realize the full potential of NV-based quantum magnetometers, designers and engineers must address several technical challenges. These range from optimizing the selection of the light source, to the further suppression of excess noise, to continued advancements in materials science.

First, the efficient excitation of NV centers requires a powerful and compact light source, in the green band, typically at 532 nm. Although recent innovations to solid-state lasers and semiconductor diodes are making these devices more practical, these sources have historically been bulky, inefficient, or both.

The collection of photoluminescence is another issue of efficiency. NV centers emit red light (~637 to 800 nm) upon relaxation. Collecting >50% of this light, particularly in compact devices, requires careful optical design due to the high refractive index and internal reflections of diamond.

NV magnetometers may also struggle with noise suppression and referencing. Instabilities in the green excitation laser directly translate into noise in the photoluminescence signal. This creates a need for advanced referencing systems and modulation techniques to suppress the effect. Additionally, more sensitive photodetectors, as well as low-noise electronics, are needed to read out potentially weak fluorescence signals from NV centers. Applications that take place in uncontrolled or high-noise environments highlight this need.

Finally, there is an ongoing challenge to source and procure high-quality diamond materials. The attributes of a diamond crystal dictate the sensor's performance. NV centers must exhibit long coherence times and minimal background noise, which depend on the concentration of defects. Achieving this balance between quantum coherence time and defects is a delicate trade-off;



A portable quantum diamond magnetometer. The product achieves room-temperature operation and robust performance in a compact design form factor, optimizing its performance even in magnetically noisy environments.

quantum diamond growth is itself an art mastered by few.

From the lab to the field

SBQuantum's NV-based quantum magnetometer addresses two of the fundamental challenges to quantum magnetometer performance. The compact, portable product delivers sub-nT/√Hz vectorial sensitivity at room temperature. Such sensitivity is suitable for most real-world applications, especially where platform or environmental noise dominates.

The solution additionally addresses potential bottlenecks caused by low-performing sources and material(s). Custom-designed optics ensure the sensor system's efficient collection of fluorescence. Both compact visible green light sources and noise referencing circuits are incorporated. The noise referencing circuits suppress detection noise, even when the full system architecture uses lower-performing laser systems. Also, the solution benefits from high-quality diamonds, which are now on the market, to offer long coherence times and sensitivity. And these magnetometers are small and rugged enough to be integrated on drones, rovers, and/or satellites, making them suitable for mineral exploration in remote terrain, autonomous underwater navigation, and other demanding applications.

Sensing tech: Making the quantum leap

As quantum technologies continue to mature, the practical use of quantum sensors will reshape the landscape of sensing and navigation. Indeed, NV-based quantum magnetometers represent a key bridge between the quantum lab and the real world. Their room-temperature operation, compact design, and robust performance give them an edge compared to other systems, especially in more magnetically noisy environments.

But the complete story extends beyond quantum sensing. Additional ancillary building blocks are required to fully harness quantum's potential. These include platform noise reduction, high-accuracy map generation, and the fusion of data with other sources — for example, quantum gravimetry. Interpretation algorithms will also help to move magnetometry from a niche industry into the mass market.

The industry is entering an era in which quantum sensing technologies will no longer be confined to research labs. With the commercialization of robust NV magnetometers, a fundamental change is underway in how we perceive, map, and navigate our environment, whether on Earth or beyond.

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Jasper Stackawitz

Awarded 2025 Teddi C. Laurin Scholarship

SPIE, the international society for optics and photonics, awarded Jasper Stackawitz the 2025 Teddi C. Laurin Scholarship. Stackawitz earned the distinction, and a $5000 scholarship, in recognition of potential contributions to optics, photonics, or a related field.

Stackawitz began his research in photonics with Casey Schwarz, a professor at Ursinus College in Collegeville, Pa., with a focus on the fabrication and properties of antimony triselenide and $Ge_2Sb_2Te_5$ thin films and their potential applications in imaging technologies[1]. Stackawitz developed novel methods for processing glass compositions that significantly enhanced their viability for advanced optical applications. The work led to a publication in SPIE's *Journal of Optical Microsystems*, and the authors presented their findings at the 2024 Materials Science and Technology Conference.

Stackawitz's current research is focused on the properties of optical phase-change materials. He is leading a nanophotonics project at Stony Brook University's Garcia Center for Polymers at Engineered Interfaces as he continues his studies.

A rising senior at Pennsbury High School in Fairless Hills, Pa., Stackawitz is also completing coursework at Stanford University via dual enrollment as a physics/math double major, and he plans to put the scholarship funding toward this opportunity. As a high school student, Stackawitz established a tutoring program and served as president of the school's competitive robotics team, which has earned six gold medals during his tenure.

Photonics Media partners with SPIE to fund the Teddi C. Laurin Scholarship to raise awareness of optics and photonics and foster growth and success in the photonics industry by supporting students involved in photonics. The scholarship is awarded yearly in memory of Teddi C. Laurin, the founder of Laurin Publishing and Photonics Media.

SPIE

Jasper Stackawitz.

Photonics Spectra spoke with Stackawitz about his pursuits in optics and photonics.

What sparked your career path in optics and photonics?

A strong general interest in physics led me to take AP Physics 1 and 2 as a high school freshman, and Physics 2 has a chapter that covers optics specifically. I was also a part of our school's robotics team, so those two things, in combination, intensified my interest in physics.

In robotics, I distinctly recall a project where we were trying to characterize underwater objects — anything from fish to coral reefs. We used a light intensity circuit and a camera, among other devices. That project exposed me to real-world engineering applications of optics. When I began to gain an understanding of the theory I was learning, I found the whole field to be very interesting.

My mother has a chemistry Ph.D., and through her, I've also been exposed to the research process. And I've seen the opportunities that research can open up, and where it can bring you on your career path.

I've also always had an interest in pursuing interests independent of my coursework. I met a professor at Ursinus College, named Casey Schwarz, whose research focuses on photonics exclusively. I reached out via email, and we ended up scheduling a lab tour. Her work, and her lab's equipment, and the projects that her lab undertakes really clicked. That exposure ultimately led to the launch of the research project that you mentioned earlier.

Tell us about your work with phase-change materials? How did it start? How has it developed?

The current project builds on previous work that was performed in collaboration with researchers at the University of Central Florida on optical phase-change materials. It is considered a material that can switch between a cluttered state and a crystalline state through an energy transfer. These materials exhibit major contrasts in their optical properties, like refractive index, for example. And so, you have these materials where a small amount of energy is able to completely change how it interacts with light.

These materials have been used for data storage because they can be treated as a binary system, using zeros and ones for the two different states. But their effectiveness for other technologies, like integrated circuitry and medical diagnostics, is rather limited because the materials that we were working with tend to have high absorption loss. We were looking for a material that didn't have that problem.

We landed on a material called antimony triselenide. This is a low-loss, reversible alternative to other phase-

1. $Ge_2Sb_2Te_5$ is a phase-change material.

change materials. A study on the material from nearly 60 years ago demonstrated how the material could be used for semiconductors. But recently, because of its low absorption loss in the visible region, it has been used in things like solar panels.

We studied the material using a technique called drop casting. This technique is an alternative to physical vapor deposition. It proved to be a lot more efficient, easier to replicate, and easier to perform on a larger scale. So, if this method were to be used to make something like a photonic integrated circuit, that would, in theory, be a lot more efficient. Our work essentially moved in that direction.

What we found is that we can consistently flip back and forth between two states that have very different refractive indexes. We also found that our material has very low toxicity, which means that it is safe for consumer applications. By using these techniques, we found a lot of properties that suggest it could be used for more widespread applications.

What do you plan to pursue in your college career?

I just want to keep an open mind, explore, and see what I can find as I move into college. I am planning on majoring in physics. I'm potentially interested in a double major, maybe in something like data science or computer science, to broaden that scope. But I'm definitely interested in material physics.

What can the optics and photonics community do to garner more interest from students?

Early exposure is the key. I think that things like demos and outreach events for high school students, and even undergraduates, is something that should be a more common practice. At least in my experience, it felt like there was a high barrier of entry to a field like this. My research mentor, Casey Schwarz, was very helpful, certainly. But before I was able to understand what I was going to be working on, I had to read so many papers and look at so much material that is largely inaccessible to someone who is coming in from the outside, or without a lot of help and guidance.

I also think that while theory is something that may be of interest to those already in the field, and those who may be able to understand it, theory doesn't really do much for someone who has yet to step into a more rigorous scientific world. This is where things like active demos take on importance. Lasers and optics are genuinely interesting. There is major opportunity to show what these instruments and devices can do, and how they can solve real problems.

Finally, raising awareness about the availability of interdisciplinary careers is something that could be very helpful to a younger population. There are vast applications in medicine as well as in chemistry and engineering. Photonics is central to all of those fields.

Class 1 Laser Systems: Is a Laser Safety Officer Needed?

BY KEN BARAT
LASER SAFETY SOLUTIONS

At times, the nature of laser hazard classifications can seem perplexing. But, in terms of individual laser classes, Class 1 lasers have proved to cause the most confusion — by far.

In many cases, the use of obscure vocabulary regarding these lasers is the cause of the uncertainty. For example, "Class 1" and "Class 1 product" are used interchangeably, and "embedded laser" is synonymous with both of these terms. In reality, with only a few exceptions, members of the public rarely encounter Class 1 lasers. On the other hand, Class 1 laser products such as laser markers, printers, and scanners are frequently used.

Per ANSI Z136.1 Safe Use of Lasers-2022, a Class 1 laser is described as:

> **3.3.1.1 Class 1.** Any laser or laser system that cannot emit accessible laser radiation levels during operation in excess of the applicable Class 1 (accessible emission limit) for any emission duration within the maximum duration inherent in the design or intended use of the laser or laser system is a Class 1 laser or laser system during operation. A Class 1 laser or laser system is exempt from user control measures with the exception of requirements applicable for embedded higher-class lasers.

Accessible emission limit is the maximum accessible emission level permitted within a particular laser hazard class. In simple terms, Class 1 lasers do not emit more than a few hundred microwatts.

On the other hand, "Class 1 products" — although the Z136 series does not use that title — are characterized by an enclosed laser that has a higher classification than the laser system in which it is incorporated. In these systems, the lower classification is appropriate, since the engineering features limit the accessible emission. The public may know Class 1 products as embedded lasers.

All of this to say, Class 1 lasers and Class 1 products are the subjects of many questions, most of which are familiar to laser safety professionals. "Do I need labeling?" is among the most common questions, and one of the easiest to answer. Since Class 1 products do not present a hazard to users during normal operation, they do not require manufacturers to use a hazard label — placing them in contrast to Class II, IIIa, IIIb, and IV laser products. Still, some laser product manufacturers prefer to place a Class 1 label on their products.

In other cases, manufacturers will place a Class 4 Danger label on their Class 1 industrial products, even though these systems are completely safe for use. Although this may send a mixed message, the Class 4 Danger label pertains to the internal laser system alone. Therefore, if a manufacturer places a label on the outside of the unit, it must either be clear that it governs the internal laser, or it must be placed in an appropriate location on the product. Often, this labeling mechanism creates an avoidable challenge for the end user, who may question the safety of a mainstay product as a result of a confusing or poorly located label.

The laser safety officer: Assessing need

Z136.1-2022 Appendix A, section A1.1 introduces the notion of designating a laser safety officer (LSO) for Class 1 lasers and products. Under certain circumstances, according to the standard, an operator may opt to designate an LSO in certain situations, or upon the need for certain protocols. These include instances when a service is performed on a laser system that has an embedded Class 3B or 4 laser. In these cases, "Management may

Image courtesy of iStock.com/onuma Inthapong.

designate the service person requiring access to the embedded laser as the LSO. In any case, there shall be a designated LSO for all circumstances of operation, maintenance, and service of a Class 3B or 4 laser or laser system."

The ambiguity of this portion of the standard is evident: It begins with an offer, yet it ends with an instruction. It also fails to address who — the operator, an LSO, a third-party vendor, or another professional — is performing the service.

Though the use of a third-party vendor could hypothetically enable a company to bypass the process of finding and then training an LSO, the services of these trained and certified officers are still needed. Section 4.4.2.7.3 Enclosed Beam Path (All Classes) of Z136.1-2022 makes this clear. Simply, once protective barriers are removed from a Class 1 product or system, the responsibility shifts solely to the LSO. This scenario could emerge during servicing or in other instances in which protective housing requirements are more relaxed.

While the servicing of a laser is a common occurrence, the dangers are serious and must be managed. Once barriers and/or protective housings are removed, and all members of the service staff are wearing laser protective eyewear, the perception of risk can exist to those working around the area. The use of temporary barriers and control areas becomes important in these instances. If the perception of risk-needs is unaddressed, a simple accommodation to the laser system, such as that which occurs for standard servicing, may generate undue worry and even trigger regulatory inspections.

Class 1 in context

Though many safety requirements apply more obviously to lasers beyond Class 1, for example, Class 3B and 4 lasers, there is little doubt regarding the standard protocols and best practices. According to 4.4.3.9 Service Personnel (All Classes), "Personnel who require access to Class 3B or 4 lasers or laser systems enclosed within a protective housing or protected area enclosure shall comply with the appropriate control measures of the enclosed or embedded laser or laser system. The LSO shall confirm that service personnel have the education and safety training commensurate with the class of the laser or laser system contained within the protective housing."

It is also clear that any in-house members of staff who perform service work on or with Class 3B or Class 4 lasers are considered laser operators and, as a result, require appropriate training. For outside vendors, though requirements are harder to establish, this task often falls to the LSO, who can resolve it intuitively. While not all LSOs will naturally question the laser safety training of these third-party service personnel and whether they have received appropriate laser safety training, this should be considered a best practice.

Third-party vendor training is the responsibility of the employing firm, not the company or institution for which they are working. At Lawrence Berkeley National Laboratory, for example, I would meet with outside service staff to ensure that each member of the staff understood our facility-specific safety expectations and requirements. Having these third-party staff members sign a temporary work document, or even a service standard operating procedure to verify compliance, often yielded some insight into their firm's laser safety program. Though these individuals often traveled without warning signs to display or even laser-protective eyewear, understanding their background helped facilitate their transition into working at our facility.

Chain of command

Per the standards referenced earlier, the LSO can work as an in-house staff member to perform services. In my experience, this is an unusual occurrence. If an LSO can be an equipment supervisor, for example, a large facility is apt to have several eligible LSOs. For this reason, it may be more viable to delegate the role of the LSO to the person who drafted the facility's service standard operating procedure. The LSO could also be an outside or independent professional.

Necessary knowledge

For all laser users and prospective users, it is important to know that limited open beam paths can achieve Class 1 status. Once again, per the Z136.1 Standard, "Lasers or laser systems intended for a specific use may be designated Class 1 by the LSO on the basis that use for a limiting exposure duration of T_{max} is less than 100 s. In that instance, the accessible laser radiation shall not exceed the corresponding Class 1 [accessible emission limit] for any emission duration within the maximum duration inherent in that specific use."

One simplified interpretation of this standard is that the LSO can classify limited beam paths — such as some robots on assembly lines, or industrial laser systems whose footprint prevents anyone from getting close enough to be exposed during normal operation — as a Class 1 system.

An additional wrinkle to Class 1 laser and laser product safety is that Class 1 laser products can be difficult to narrow down. Especially in a university setting, for example, common devices such as 3D printers, laser cutters, laser scanning confocal microscopes, and cell sorters — each of which falls into the category of a Class 1 laser product — are perceived as tools by their users, and not necessarily a laser device. Only during servicing, or other instances in which a beam may be exposed, is the perception of these devices likely to differ.

With all this in mind, let us close with the question: Does the use of a Class 1 product require an LSO?

I believe that contrary to what most users think, if the product contains embedded Class 3B and Class 4 lasers that must be accessed while energized, the Z136 series says YES!

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Product News

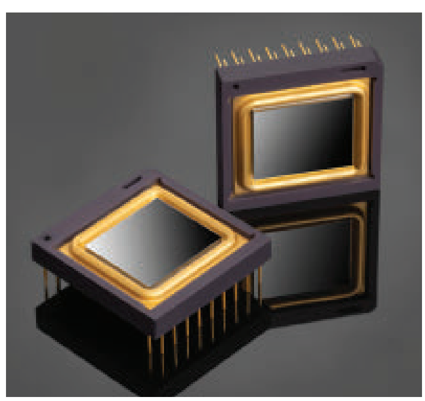
sCMOS Camera
The ORCA-Halo, C17440-20U from **Hamamatsu Photonics** is a scientific CMOS (sCMOS) camera designed for applications such as advanced microscopy and light-sheet microscopy. The camera features a back-illuminated sensor with a peak quantum efficiency of 86%. The ORCA-Halo, C17440-20U offers 9 MP of resolution, a pixel size of 3.76 µm, low readout noise, and uses both forced air and water for cooling.
photonics@hamamatsu.com

Fiber Optic Assemblies
The V-Groove Assemblies from **OZ Optics** are designed for optical connectivity applications. The assemblies are capable of handling up to 96 fibers in a single array and are available in hermetic feedthrough versions with either glass or metal solder options for durability. Designed to meet Telcordia specifications, the V-Groove Assemblies are also available with standard 900-µm jacketed breakouts and lengths of up to 2 m.
sales@ozoptics.com

Beam-Shaping Module
READYFlow from **FISBA** is a beam-shaping module for advanced flow cytometry. The compact module supports standard cytometry wavelengths and single- or multiple-wavelength configurations for multiplexed assays. READYFlow features a top-hat beam profile, which provides uniform excitation, consistent signal strength, and uniform intensity throughout the beam cross section. The alignment reduces sensitivity to positioning, enabling easy x/y/z adjustment in front of the flow cell.
info@fisba.com

Upright Microscopes
The Visoria series from **Leica Microsystems** features upright microscopes designed for use in pathology, industrial quality control, and research. The digital microscopes allow users to view and analyze images of samples directly on a tablet without the need for a computer and eyepieces. The Visoria series also features automatic storage of microscope settings and imaging parameters — including filters used and magnification — within the image metadata, and is powered by the company's Enersight software platform.
corporate.communications@leica-microsystems.com

Spatial Light Modulator
The SLM-310 from **Santec AOC** is a liquid-crystal-on-silicon-based spatial light modulator engineered to withstand 1-kW-class laser power in the 1-µm-band near-infrared spectrum. The spatial light modulator can be used in advanced industrial applications such as metal 3D printing and precision laser processing. It features a water-cooling system, a resolution of 2.3 million pixels, and 10-bit high phase resolution.
tkamikura@santec-net.co.jp



Uncooled Infrared Detector
The PICO640S Broad Band 7-14 from **LYNRED** is an uncooled infrared detector designed for optical gas imaging in the oil and gas industry. It features a noise equivalent temperature difference of 30 mK for early-stage leak detection, a video graphics array resolution of 640 × 480, and low power consumption of <130 mW, making it suitable for embedded systems.
info@lynred.com

Micro-LED Reference Design Kits
VueReal's reference design kit (RDK) bundles are purpose-built for automotive and consumer electronics. The RDKs feature micro-LED displays that can be installed in products such as intelligent taillights, in-glass applications, AR head-up displays, interior lighting, infotainment systems, electronics, wearables, embedded smart displays, and AR interfaces. Designed for direct integration, the RDKs aim to help customers validate products faster, reduce development risk, expand design possibilities, and scale efficiently using a platform that grows with demand without requiring high capital investment.
chaji@vuereal.com

Laser Beamsplitting System
The Modular Beam Splitting System (MBSS) from **Jenoptik** is an optical system for laser beam guidance and shaping, with applications in solar cell and laser machine manufacturing. It features a powerful beamsplitter with uniform beam homogeneity across the entire field. The MBSS has intensity fluctuations of <3% and distance variations of <5 µm between individual spots. It weighs <10 kg and can be mounted in various installation positions.
systems@jenoptik.com

Cyan Laser Diode
The PLT5 488HB_EP from **ams OSRAM** is a cyan laser diode designed for life sciences applications, including DNA sequencing and flow cytometry. It emits at 488 nm with wavelength control of ±2 nm and delivers high light intensity of 300 mW. The PLT5 488HB_EP also features

an integrated photodiode for output control and an electrostatic discharge protection diode.
sensors@ams.com

Solar Simulators

The Newport Solaris series from **MKS** features solar simulators for photovoltaic applications, including solar panel manufacturing and photovoltaic research. Based on a full spectrum, single-emitter design that incorporates a xenon arc lamp, the simulators natively match the full solar spectrum — including UV, visible, and IR — and are certified to the latest IEC 60904-9:2020 standards. The Newport Solaris series features filters that cover an extended reporting range of 300 to 1200 nm, an illumination area of 12 in. × 12 in., and a partial sun attenuator that allows light intensity adjustments to fit the sample while maintaining stable relative irradiance across the entire wavelength spectrum.
sales@newport.com

Measurement Sensor Series

The OPT Thrubeam Measurement Sensor SmartAxis Series from **OPT Machine Vision** is designed for real-time dimensional inspection in industrial environments. The sensors feature dual telecentric optical lenses for distortion-free imaging, along with a high-brightness LED light source synchronized with the optical system to capture images simultaneously. Powered by image processing algorithms and subpixel edge extraction technology, the OPT Thrubeam Measurement Sensor SmartAxis Series supports ultrafast 15-μs exposure times.
optmv@optmv.com

Optical Gas Imaging Camera

AerialOGI-N from **Teledyne FLIR OEM** and **AerialOGI** is an optical gas imaging (OGI) camera module that features a two-click connection to both hand-held and drone gimbals, enabling detection of fugitive gas emissions from the ground or air. It incorporates a 640- × 512-resolution MWIR camera core and can detect and quantify >25 distinct greenhouse gases in real time, including methane and other volatile organic compounds. The AerialOGI-N uses a one-button leak event capture to pass actionable data directly to leak detection and repair software. It also uses an advanced gas-detection algorithm that leverages high-resolution data from Teledyne FLIR's Neutrino LC OGI camera. Additionally, the AerialOGI-N provides real-time in-flight data processing and edge-based reporting.
emea.service@flir.com

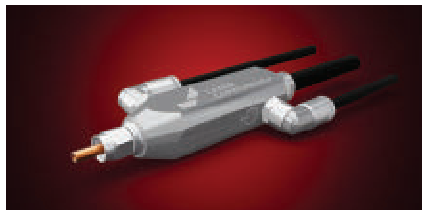
Lidar Sensor

The Eve 1D from **Aeva** is a frequency-modulated continuous-wave (FMCW)-based laser displacement sensor designed for high-volume and in-

line industrial automation applications, including factory and process automation. Powered by Aeva's CoreVision lidar-on-chip modules, the sensor operates across target standoff distances ranging from 100 mm to 20 m and offers an accuracy of 100 parts per million (0.01% linearity).
press@aeva.ai

Spinning Disk Confocal Microscopes

The IXplore IX85 SpinXL and the IXplore IX85 SpinSR from **Evident** are spinning disk confocal microscopes designed for imaging rapid cellular dynamics. The IX85 SpinXL features a 26.5-mm field number and imaging speeds of up to 498 fps at full frame. It uses NIR wavelengths to enable deeper tissue penetration with reduced autofluorescence and crosstalk. The IX85 SpinSR offers xy resolution down to 120 nm to accelerate 3D superresolution imaging. It also incorporates an image processing filter based on signal-to-noise ratio, enabling optimal processing for live-cell imaging under dim fluorescence conditions.
kristopher.lee@evidentscientific.com

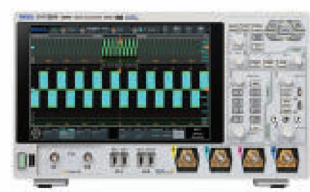


High-Power Laser Fiber Cables

LASER COMPONENTS' fiber cables with active or passive cooling are designed to meet the requirements of high-power lasers. Depending on the fiber diameter, the cables support laser powers between 200 and 450 W while maintaining optimal beam quality across a wide wavelength range of 300 to 1900 nm. This makes them well suited for laser cutting, welding, cleaning, and soldering. The cables are available in both passive and actively water-cooled versions, with configurations featuring either SMA or D80 connectors.
info@laser-components.com

Tube Light Illumination System

The Combined Tube Light LED line-scan illumination system from **Chromasens** acquires images of the same object under three different lighting conditions using three separate segments. These include a light tube segment with up to 1,000,000 lx for general imaging, a dark-field segment with up to 800,000 lx for edge and surface defect detection, and a bright-field segment with up to 12,000 cd/sq m for direct feature visualization. The compact LED modules measure 170 mm each, with the option to connect up to four modules for a total length of 680 mm. Available LED colors include white, red, green, blue, and IR at 850 nm and 940 nm.
sales@chromasens.de



Digital Oscilloscopes

The RIGOL MHO2000 series from **Saelig Company** features four-channel mixed-signal digital oscilloscopes designed for debugging, test and measurement, and design applications. Based on the Centaurus platform, the oscilloscopes provide 12- to 16-bit resolution with bandwidths ranging from 200 to 350 MHz, a waveform capture rate of up to 1,000,000 waveforms/s, and up to 500 megapoints of internal memory. The RIGOL MHO2000 series also includes automatic measurements for up to 41 parameters, statistical analysis, xy cursors, pass/fail testing with hardware masks, six-digit frequency counters, and an integrated digital voltmeter.
info@saelig.com

Surface-Mount Photoresistors

The NSL-RHS99 and NSL-SMD65 series photoresistors from **Advanced Photonix** are cadmium sulfide light-dependent resistors designed for applications such as solar lighting, flame detection, camera light meters, and exposure or shutter controls. The NSL-RHS99 series is available in three resistance values and comes in a compact 5.2- × 4.4-mm package. The NSL-SMD65 series features surface-mount photoresistors that can be integrated into automated assembly lines, helping to reduce production time and costs. Both series feature light sensitivity with resistance decreasing as light intensity increases, mimicking the response of the human eye.
info@advancedphotonix.com

AUGUST

◉ SPIE Optics + Photonics
(Aug. 3-7) San Diego.
Contact SPIE, +1 360-676-3290, **customerservice@spie.org**; www.spie.org/conferences-and-exhibitions/optics-and-photonics/attend/invitation.

Optica Nonlinear Optics
(Aug. 4-7) Honolulu.
Contact Optica, +1 202-223-8130, **info@optica.org**; www.optica.org/events/topical_meetings/nonlinear_optics.

Optica Imaging Congress
(Aug. 18-21) Seattle.
Contact Optica, +1 202-223-8130, **info@optica.org**; www.optica.org/events/congress/imaging_and_applied_optics_congress.

European Optical Society Annual Meeting (EOSAM) 2025
(Aug. 24-28) Delft, Netherlands.
Contact Boglárka Selényi, **eosam@europeanoptics.org**; www.europeanoptics.org/events/eos/eosam2025.html.

SEPTEMBER

FABTECH
(Sept. 8-11) Chicago.
Contact FABTECH, +1 888-394-4362, **information@fabtechexpo.com**; www.fabtechexpo.com.

◉ CIOE
(Sept. 10-12) Shenzhen, China.
Contact China International Optoelectronic Exposition, 0755-8629-0901, **cioe@cioe.cn**; www.cioe.cn/en.

MEMS & Sensors NextGen 2025
(Sept. 16-18) Milpitas, Calif.
Contact Michelle Fabiano, **mfabiano@semi.org**; www.semi.org/en/event/mems-sensors-nextgen.

◉ ECOC
(Sept. 28-Oct. 2) Copenhagen, Denmark.
Contact +45 70-20-03-05, **info@cap-partner.eu**; www.ecoc2025.org.

World Molecular Imaging Congress
(Sept. 29-Oct. 3) Anchorage, Alaska.
Contact the World Molecular Imaging Society, +1 310-215-9730, **wmis@wmis.org**; www.wmis.org/wmic-2025.

MEDevice
(Sept. 30-Oct. 1) Boston.
Contact Informa Markets, +1 310-445-4273, **registration.ime@informa.com**; www.medeviceboston.com/en/home.html.

PAPERS

SPIE Medical Imaging 2026
(Feb. 15-19) Vancouver, British Columbia.
Deadline: Abstracts, Aug. 6
Contact SPIE, +1 360-676-3290, **customerservice@spie.org**; www.spie.org/conferences-and-exhibitions/medical-imaging.

Pittcon 2026 Conference + Expo
(March 7-11) San Antonio, Texas.
Deadline: Posters, Aug. 31
Contact The Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy, +1 800-825-3221, **info@pittcon.org**; www.pittcon.org.

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

SPIE Smart Structures + NDE 2026
(March 16-19) Vancouver, British Columbia.
Deadline: Abstracts, Sept. 10
Contact SPIE, +1 360-676-3290, **customerservice@spie.org**; www.spie.org/conferences-and-exhibitions/smart-structures-nde.

OCTOBER

◉ SCIX
(Oct. 5-10) Covington, Ky.
Contact FACSS, +1 856-224-4266, **scix@scixconference.org**; www.scixconference.org.

◉ AutoSens Europe
(Oct. 7-9) Barcelona, Spain.
Contact Sens Media, +44 (0)208-133-5116, **info@sens-media.com**; www.auto-sens.com/europe.

◉ Manufacturing Technology Series WEST
(Oct. 7-9) Anaheim, Calif.
Contact SME, +1 800-733-4763, **westec@sme.org**; https://west.mtseries.com.

◉ SEMICON West & FLEX
(Oct. 7-9) Phoenix.
Contact SEMI, +1 408-943-6900, **semiconwest@semi.org**; www.semiconwest.org/special-features/FLEX-Conference-and-Exhibition.

◉ ICALEO
(Oct. 13-16) Orlando, Fla.
Contact the Laser Institute, +1 407-380-1553; www.icaleo.org.

◉ European Machine Vision Forum 2025
(Oct. 16-17) Fürth, Germany.
Contact European Machine Vision Association, +34 931-80-70-60, **info@emva.org**; www.emva.org/events/more/european-machine-vision-forum-2025.

Optica Laser Applications Conference
(Oct. 19-23) Prague.
Contact Optica, +1 202-223-8130, **info@optica.org**; www.optica.org/events/congress/laser_congress/program/laser_applications_conference.

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

◉ Manufacturing Technology Series SOUTHEAST
(Oct. 21-23) Greenville, S.C.
Contact SME, +1 800-733-4763, **southtec@sme.org**; https://southeast.mtseries.com.

◉ Frontiers in Optics + Laser Science Conference and Exhibition
(Oct. 26-30) Denver.
Contact Optica, +1 202-416-1907, **info@optica.org**; www.frontiersinoptics.com/home.

NOVEMBER

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

AutoSens and InCabin China 2025
(Nov. 18-20) Hefei, China.
Contact Sense Media Group, +44 208-133-5116, **info@sense-media.com**; www.auto-sens.com/china.

SEMICON Europa 2025
(Nov. 18-21) Munich.
Contact SEMI Europe, +49 30-3030-8077-0, **semiconeuopa@semi.org**; www.semiconeuropa.org.

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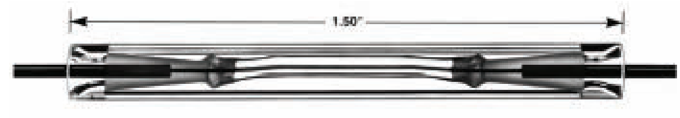

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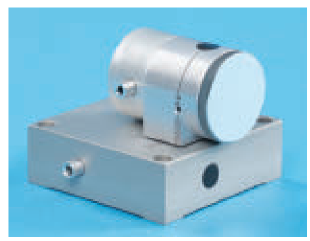

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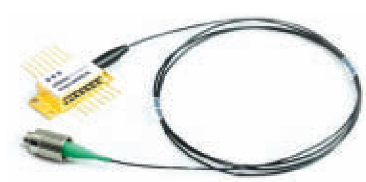

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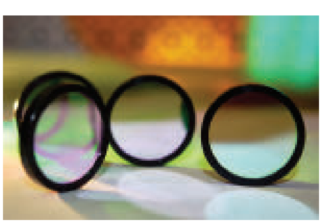

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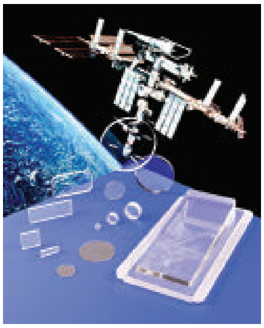
Photonics Showcase

Sapphire Windows for Aerospace



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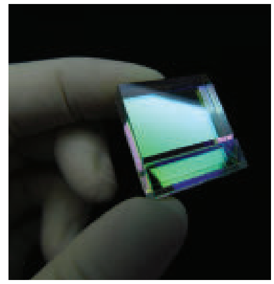

To resolve spectral features at 0.5 picometers, traditional echelle spectrometers need to be massive — four to five times larger than the Hyper-Fine Spectrometer from LightMachinery. VIPAs pack high angular dispersion into an ultra-compact form, enabling LightMachinery's HyperFine Spectrometers to deliver echelle-level resolution in a fraction of the footprint (and cost) — with higher throughput and faster acquisition.

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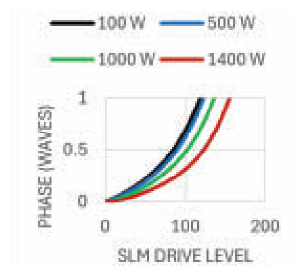

The newest SLM from Meadowlark Optics boasts CW power handling of ≥1 kW at 1070 nm. In tests at SPICA, the SLM retained its full >1 wave range of phase modulation at powers up to 1.4 kW. With sapphire cover-glass, built-in water cooling, and a suite of calibration tools, the high-power SLM can maintain calibrated performance under extreme laser power loads.

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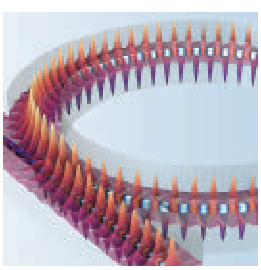

COMSOL Multiphysics® is a software environment for creating physics-based models and standalone simulation apps. Add-on products provide specialized functionality for electromagnetics, structural, acoustics, fluid flow, heat transfer, and chemical simulations. Interfacing products offer a unified workflow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

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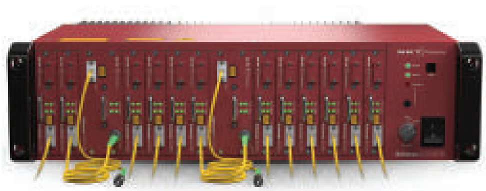

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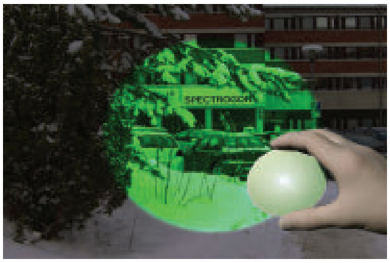

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Teaching a blind dog new tricks

For those of us who have furry companions, it's a difficult pill to swallow when their health isn't up to sniff, or snuff, rather. When we humans are in a bad way, we have a range of options to help us feel better, from medicines to procedures that vary from minor to highly invasive. Dogs and other pets, however, don't always have those same options — especially when it comes to eyesight.

While laser-based eye surgery for dogs does exist, finding a clinic that performs canine LASIK can be challenging. Even if you do find one, it often comes with a hefty price tag. For owners of vision-impaired pups, traditional solutions such as halo frames and Elizabethan cones — similar to those used to prevent dogs from biting themselves post-surgery — offer practical alternatives to help dogs avoid painful collisions with furniture and other hazards. However, these devices often lack the full coverage and comfort needed to provide a fulfilling life for our canine companions.

Kunde, a fluffy four-legged native of Houston was having a similar problem when he lost his vision due to advanced glaucoma. Fortunately, a team of engineering students at Rice University took on the challenge of creating a system that would allow Kunde to safely navigate his surroundings. The team members, who have dubbed themselves "Kunde's Friends," created a vest that uses haptic feedback powered by a stereoscopic camera system to provide real-time spatial awareness without restricting his movement or play.

The lightweight vest was fitted with linear resonant actuator motors, commonly used in smart devices, that vibrate to alert the dog when obstacles are nearby. Then, a set of stereoscopic cameras mounted near the dog's head captured real-time depth information, processed by a custom-designed printed circuit board and a stereoscopic vision-processing computer module. Similar to a car's backup sensor, the vest offers haptic feedback at various degrees of intensity, depending on how close Kunde is to a potential obstacle, thus enabling him to move freely about the world without the need for human intervention.

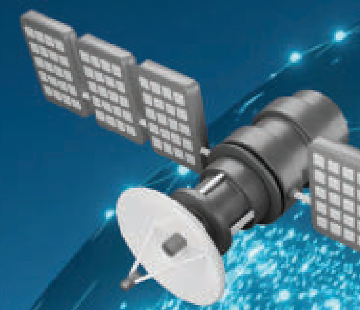
Every part of the system — the vest, cameras, custom-fabricated electronic housing, and waterproofing components — is relatively affordable, with a total cost of under $150, according to Kunde's Friends. This work could have a significantly greater impact than just helping Kunde — the dog days of restricted movement due to blindness may soon be over for pets, and possibly even for humans, thanks to the potential for cross-species applications in rehabilitation technology and therapeutic devices.

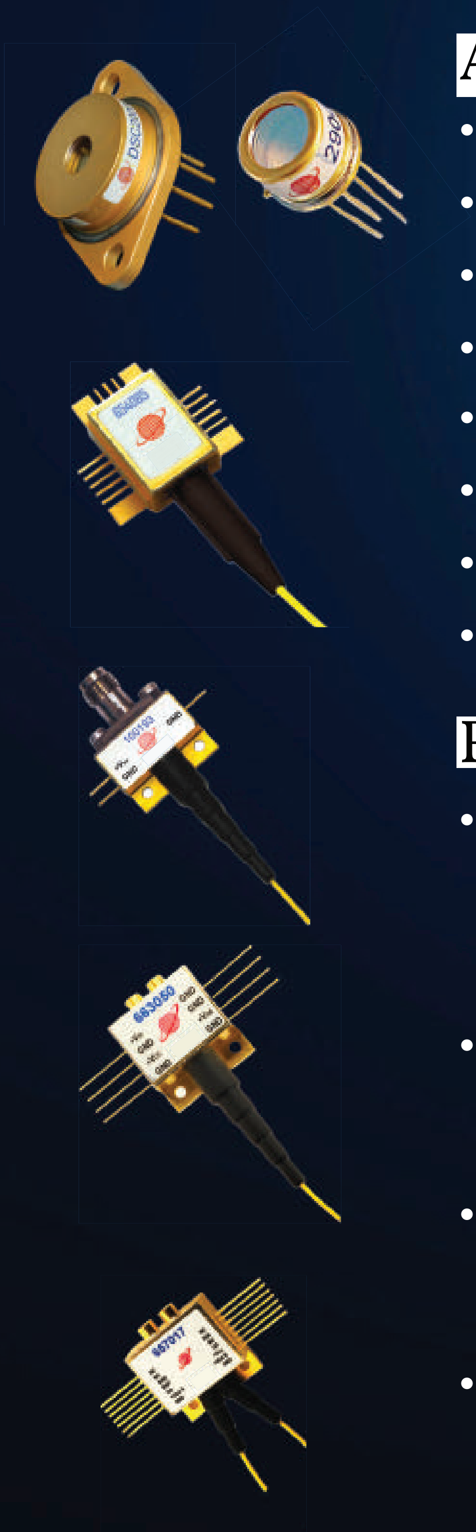
The vest hasn't quite made it to this stage, though, because it's still undergoing testing with Kunde. Nevertheless, the team is optimistic that the vest will eventually lead to a significant reduction in canine collisions, with the final prototype offering a range of up to 8 m and a battery life of ~2 h.

If this technology is successful, it is safe to say that many pet owners, and their dogs, could be howling at the moon with excitement for a chance to live a better life.

Image courtesy of iStock.com/VladimirGerasimov.

WIDE BANDWIDTH OPTICAL RECEIVERS FOR MAXIMUM NETWORK FLEXIBILITY





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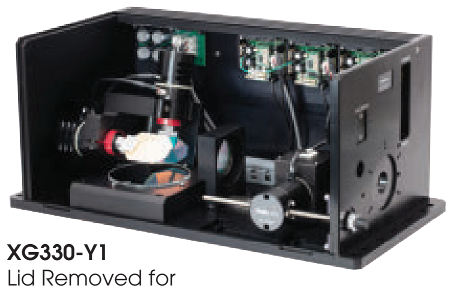
Three-Axis VantagePro® Galvo System Scan Heads



XG330-Y1
Lid Removed for View of Inside

XY Scanning Mirrors with Dynamic Z-Axis Focusing for Field Sizes Up to 1000 x 1000 mm² or Spot Sizes Down to Ø22 µm

Narrow-Linewidth Ultra-Low-Noise Laser System

ULN13TK

Turnkey Laser System with Emission at 1310 nm and >90 mW Output Power (Also Available at 1550 nm)

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