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July 2024

PHOTONICS spectra®

IR Sensors
in the Fast Lane

PHOTONICS MEDIA

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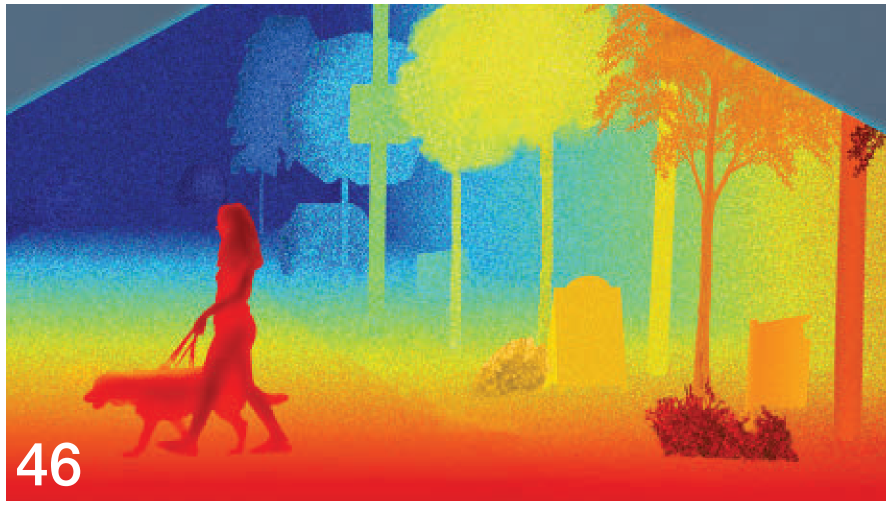
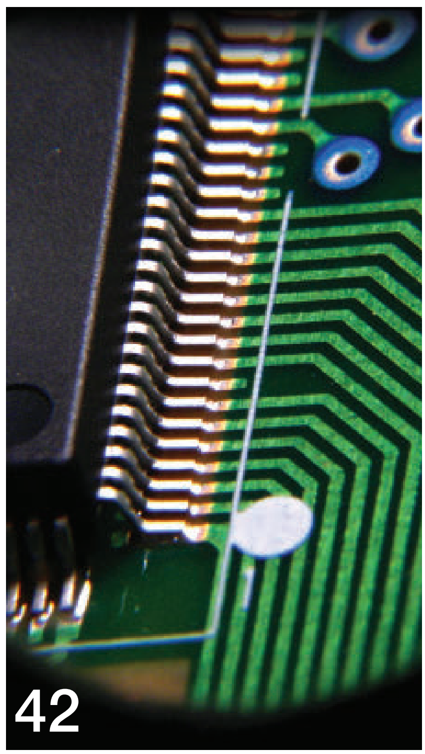
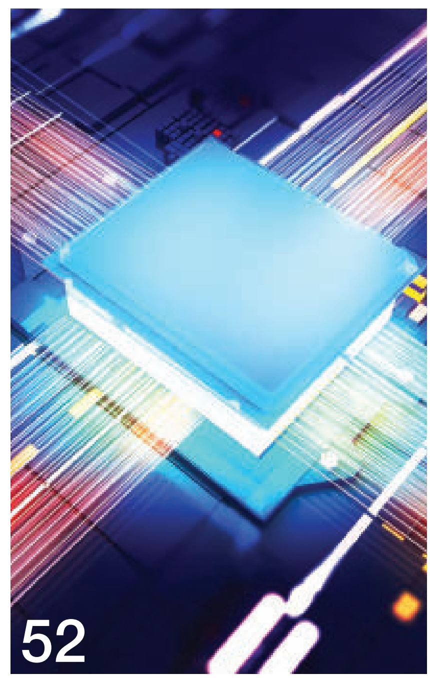
Features







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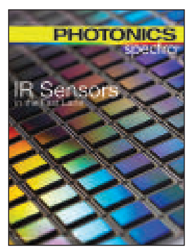
Departments

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

Infrared sensors, including those spanning the short- and longwave infrared, are an established technology for image acquisition in harsh and nighttime conditions. Amid the proliferation of advanced driver-assistance systems, these sensors are essential to ensure pedestrian safety on roadways. Cover image courtesy of Lynred. Cover design by Senior Art Director Lisa N. Comstock.

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Editor's Note

Enabling technologies never sleep

Several ways to chart the progress of a particular technology exist. Awards and accolades provide a measure of mainstream recognition, which is an important consideration for determining the economic impact that a certain technology will have on society. Financial success itself, as reported by focused market reports, provides a direct index of the monetary conditions facing a specific technology. A favorable report is a sound indicator of growth. Seminal breakthroughs in a particular branch of technology, meanwhile, offer a simple yet effective gauge.

All three have their time and place.

The technologies that exist under the umbrella of photonics have often been easy to locate when scientific innovation breaks. From early-iteration photonic devices, to today's most sophisticated light sources, photonic technologies flourish in their role as enablers to a vast number of research and industrial pursuits.

As this magazine has declared often, photonics never sleeps.

The reach of many of the solutions that are spotlighted in this magazine can be evaluated by turning to the periphery of photonics. Doing so, in fact, provides yet another measure of the influence of photonics. The machine vision sector, for example, is undergoing its own transformation. As automation applications using imaging, sensing, and lighting technologies advance, the photon — like the technologies that it enables — is never far removed from innovation.

Since 2021, *Photonics Spectra* has shared in the promotion of the *Vision Spectra* Conference, presented by our sibling publication and taking place July 16 to 18 this year. The conference delivers expert-led insights into the technology fundamentals and burgeoning trends permeating the machine vision landscape. In addition to sessions focused on systems in the imaging and sensing domains, this year's conference offers a glimpse into a future enhanced by AI, deep learning, and robotics. Each provides ample opportunities for photonics to serve as an enabler as well as a beneficiary of these technology areas.

A full program for this year's *Vision Spectra* conference can be found on page 11 of this issue.

As for *Photonics Spectra*, this month's cover story explores a range of components that will be familiar to the machine vision enthusiast: IR sensors. Contributing editor James Schlett's coverage on page 46 delves into pedestrian safety initiatives and the sensing and imaging technologies poised to help spur positive outcomes on roadways. Elsewhere, contributors Light Conversion, MKS/Spectra-Physics, and EPIC highlight pertinent topics in laser materials processing.

Whether the significance of the photon is judged on its applications, enabled technologies, or potential for growth, one need not look far for evidence that it pervades many fields, including those that run adjacent to optics and photonics.

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Contributors

Marco Arrigoni
Marco Arrigoni is vice president of marketing at Light Conversion. He has more than 30 years of experience in market development for ultrafast lasers. Page 36.

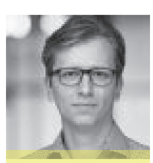
Jim Bovatsek
Jim Bovatsek is a manager of applications engineering at MKS/Spectra-Physics' industrial applications laboratory. He has focused on laser applications development using nanosecond, picosecond, and femtosecond pulsed lasers since 2000 and has authored numerous patents and publications. Page 57.

Domas Baliukonis
Domas Baliukonis is a product manager at Light Conversion, overseeing the development of the company's femtosecond lasers. Page 36.

Antonio Castelo
Antonio Castelo is technology manager for biomedical and lasers at the European Photonics Industry Consortium (EPIC). Page 62.

Yosef Ben-Ezra
Yosef Ben-Ezra is CTO at NewPhotonics and professor at Holon Institute of Technology in Tel Aviv, Israel. His team develops innovative photonics technology that aims to reduce the complexities of integrated photonic processing in data centers. Page 52.

Nicolas Le Thomas
Nicolas Le Thomas is a professor in the engineering faculty at Ghent University. His main interests include on-chip high-resolved microscopy, integrated photonic sensors, biological applications of subwavelength photonic structures, optical spectroscopy of nanostructures, and semiconductor lasers. Page 42.



Simas Butkus
Simas Butkus is head of the Applications Laboratory at Light Conversion. He specializes in femtosecond micromachining, laser light-matter interaction, and beam propagation effects. Page 36.

James Schlett
Contributing editor James Schlett is an award-winning author, poet, and journalist. He is the former editor of *BioPhotonics*. Page 46.

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COTS to Custom: Using Microscope Objectives in OEM Products

David Biss of Optikos navigates the trade-offs that must be considered when developing microscope architectures. In the expanse of life sciences, designing an OEM microscopy platform isn't a one-size-fits-all endeavor. This presentation delves into the common decision points and trade spaces encountered when designing a microscopy system. Biss investigates the pros and cons of implementing commercial off-the-shelf (COTS) and custom-designed objectives into OEM microscope systems, touching on considerations of performance, repeatability, price, scalability, and more. He explores the effect of system requirements, such as illumination, point scanning or wide-field imaging, fluorescence detection, and focus tracking, and also considers how they play into the demands of objective selection. He then addresses how sample handling affects system performance, whether cuvette, flow cell, disposable chip, or other. Presented by Optikos.
To view, visit **www.photonics.com/w1007**.

Advanced Thermoelectric Technology for Thermal Management of Optoelectronics Applications

Thermoelectric technology has been slow to meet the advancing needs of optoelectronic devices and systems. Though optoelectronics has seen significant improvements in transmission rates, operating temperatures, and miniaturization, thermoelectrics has since remained stagnant. Sheetak is revolutionizing this landscape, developing and commercializing advanced thermoelectric architectures that enhance efficiency, cooling density, and reliability, tailored to the scale and form factors required for modern temperature-controlled devices. Based in Austin, Texas, Sheetak boasts more than 100 years of combined experience in thermoelectric and thermal management technologies. Join this presentation for an introduction to Sheetak, a showcase of its current thermoelectric products, and a preview of its groundbreaking silicon-based QOOL CHIP thermoelectric architecture. Presented by Sheetak Inc.
To view, visit **www.photonics.com/w1020**.

sheetak
Advanced Thermoelectrics

Thermal Modeling of Lasers in Manufacturing Processes

For the modeling of lasers in manufacturing processes, it is common to treat the laser as a spatially, or volumetrically, distributed heat source that moves and reorients over time. COMSOL Multiphysics provides a computational modeling platform that can be used to easily model such heat sources. Beyond modeling heating profiles over time, it can also model phase change, ablation, and irreversible transformations. Applications of these techniques include precision fabrication processes, medical treatments, and 3D printing. This presentation overviews laser thermal modeling and demonstrates the software in action. Presented by COMSOL.
To view, visit **www.photonics.com/w1013**.

COMSOL

PHOTONICS spectra® SUMMIT

Optical Filters Summit


Iridian Spectral Technologies

Palidwar.


Edmund Optics

Callaghan.


Omega Optical

Washkevich.


Willey Optical Consultants

Willey.


Midwest Optical Systems

Das.

The editors of *Photonics Spectra* magazine invite you to the Optical Filters Summit, a one-day event exploring cutting-edge developments and practical applications for optical filters. The virtual event takes place on Aug. 14, and all presentations remain available on demand following the premiere.

Viewers will gain a comprehensive understanding of how filters can effectively optimize optical systems with guidance from professionals at Iridian Spectral Technologies, Edmund Optics, Omega Optical, Willey Optical Consultants, and Midwest Optical Systems. The latest methodologies for reducing cost and simplifying optical filter design will be explained.

Registration is free and opens the door to a comprehensive understanding of filter design. Attendees can exchange ideas in a summit chat box and explore potential collaborations with industry experts that foster innovation in optical filter technology.

Website

To learn more about the program go to **www.photonics.com/OF2024**.

Reducing Costs and Complexity with Multiband and Multizone Optical Filters
Jason Palidwar, Iridian Spectral Technologies

Optical Filters: Key Specifications and Metrology
Kathrin Callaghan, Edmund Optics

Simplified Optical Design Solutions with Innovative Fiber-Tip Coatings
Stephen Washkevich, Omega Optical

From Concept to Reality: How to Design Optical Filters
Ron Willey, Willey Optical Consultants

Clear Results: The Role of Optical Filters in Machine Vision Systems
Georgy Das, Midwest Optical Systems

Upcoming Summits

Scientific Lasers — *September 18*

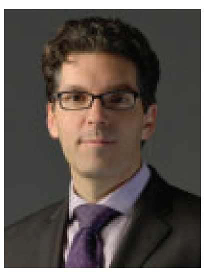
Sensors & Detectors — *November 13*

Polymer Optics — *December 4*

Register today at **www.photonics.com/OF2024**.

From AI to 3D Imaging, the 2024 *Vision Spectra* Conference Spotlights Innovation


Stephen Se.


Daniel Lau.


David Dechow.


Lars Johnsson.

Tracks cover optics, hyperspectral and SWIR imaging, vision-guided robotics, deep learning, AI and inspection, and cameras, systems, and sensors.

A variety of must-watch webcasts on topics ranging from optics to the ever-evolving landscape of deep learning in inspection is on the docket for the fourth annual *Vision Spectra* Conference. The online event takes place July 16 to 18 and features six technology tracks for end users and systems integrators, from industry stalwarts to up-and-coming startups.

Attendees can expect more than 40 presentations in the following tracks: Optics, Filters, and Illumination; Hyperspectral and SWIR Imaging; Cameras, Systems, and Sensors; Vision-Guided Robotics and Logistics; and Deep Learning, AI, and Inspection. For the first time in the event's four-year run, 3D Imaging will have a separate track.

Within the Deep Learning, AI, and Inspection track, discussions will include ways to enhance inspection systems and gigabit Ethernet (GigE) vision connectivity. Cognex, a first-time presenter, will cover the early advancements of AI to its current uses in the world of machine vision in its session, "AI: From Buzzword to Practical." Presentations from Soft Robotics and MVTec will discuss the implementation of AI and machine vision in robotics and tips for deep learning data handling.

The Vision-Guided Robotics and Logistics track will include presentations

Vision spectra CONFERENCE July 16-18, 2024

from several newcomers, including Orbbec, Cambrian Robotics, and Vayu Robotics. Basler's Sebastian Sauppe presents "Next-Level Vision: 3D Solutions for Logistic and Warehouse Automation," which addresses the usefulness of time-of-flight and stereo vision solutions in warehouse environments.

In the conference's largest section — Camera, Systems, and Sensors — Baumer's Mike Nagle joined by Event Capture Systems' Brian Mock and John Larkin will cover customer deployments in their joint session, "How to Get Started with Smart Cameras for AI applications." This jumpstarts additional topics in automotive sensing and line-scan cameras in mainstream applications.

Hyperspectral and SWIR

This year will also see the return of hyperspectral and SWIR imaging. This track features talks from newcomers such as Living Optics, along with ProPhotonix and Headwall Photonics, on topics such as maximizing hyperspectral SWIR imaging, hyperspectral snapshot video rate imaging in computer vision, and full-spectrum capture using multiple cameras.

Lastly, the Optics, Filters, and Illumination track will focus on topics such as UV lighting and filters, among others. Schneider Optics will deliver an educational presentation on lenses, focusing on the lack of standardization in lens specifications and tolerance metrics. Ansys will also present during this track and highlight a physics-based simulation framework that facilitates the integration of camera lens systems, 3D scene camera ray tracing analysis, sensor functionality, and post-processing that empowers the simulation of camera systems in real-world scenarios.

Register now

Registration for the 2024 *Vision Spectra* Conference is open now. For the most up-to-date information and to register, visit www.photonics.com/vsc2024.

3D Imaging

The Evolution of 3D Imaging in Industrial Applications
David Dechow, Machine Vision Source

Unlocking the Unseen: Enhancing Machine Vision Capabilities with Polarization Information
Lars Johnsson, Metalenz

Using Deep Learning to Convert Monocular Video to 3D
Daniel L. Lau, University of Kentucky

Stereo Vision Fundamentals and Use Cases for Industrial Robotic Applications
Stephen Se, Teledyne FLIR

Vision-Guided Robotics & Logistics

Enhancing Efficiency: Machine Vision in Scan Tunnels & Logistics
Ryan Marti, Omron Automation Americas

Next-Level Vision: 3D Solutions for Logistic and Warehouse Automation
Sebastian Sauppe, Basler

Plenoptic Cameras and AI for Advanced Mobile Robotics
Mahesh Krishnamurthi, Vayu Robotics

Quantitative Evaluation Method for Depth Accuracy and Precision Metrics in Depth and RGB Cameras
Xin Xie, Orbbec

Hyperspectral & SWIR Imaging

Broadband Imaging Using Quantum Dot Technology and Push Broom Sensor Development
Samiul Haque, Emberion

Capturing the Full Spectrum with Simultaneous Multicamera Acquisition
George Killian, Headwall Photonics

Maximizing Your Hyperspectral SWIR Imaging System with Optimized Illumination
Matthew Branch, ProPhotonix Ltd.

Snapshot Video Rate Hyperspectral Imaging for Computer Vision Applications
Daniel Pearce, Living Optics

The Importance of Signal-to-Noise in SWIR Hyperspectral Imaging
Martin H. Ettenberg, Princeton Infrared Technologies

Tiny Dots Solving Big Problems: The Evolution and Future of CQD SWIR Technology
Ethan Klem, SWIR Vision Systems

The Potential of Industrial Cameras: A Guide to Transitioning from Smart Cameras Without Fear
Frank Jakubec, Balluff

Cameras, Systems, & Sensors

PROMOTED: Performance Cameras, Software, and Systems for AI and Machine Learning Applications
John Ilett, Emergent Vision Technologies

Chromasens GmbH Presentation
Speaker TBA, Chromasens

3D Imaging of Transparency: The Next Frontier in Automated Item Picking
Bradley Vargo, Zivid

A Primer on Hybrid Event-Based Image Vision
Daisuke Saito, OMNIVISION

Event-Based Vision: Bringing More Performance and Efficiency to Improve Machine Vision Applications
Gareth Powell, Prophesee

HDR Imaging for Automotive Sensing: Technologies and Best Practices for High Dynamic Range Imaging and Tone Mapping
Alexis Teissie, LUCID Vision Labs

How to Get Started with Smart Cameras for AI Applications
Mike Nagle, Baumer, and Brian Mock and John Larkin, Event Capture Systems

The Evolution of Line-Scan Cameras and Their Increasing Impact on Mainstream Applications
Mihály Baki, JAI

Optics, Filters, & Illumination

Beyond the Numbers: Understanding Lens Specifications and Making an Educated Decision
Magnus Greger, Schneider-Kreuznach Group

Contrast, Repeatability, and Protection: The Integral Role of Optical Filters in Machine Vision Systems
Georgy Das, Midwest Optical Systems

Dynamic Machine Vision Camera Simulation in Operative Condition
Mina Nazari, Ansys

Eliminating Distortion in Machine Vision Applications
Mark Peterson, Theia Technologies

Importance of Numerical Aperture for Microscopy and Imaging
Nick Sischka, Edmund Optics

Novel Lighting for Today's High-Speed Machine Vision Challenges
Steve Kinney, Smart Vision Lights

Optimizing Lens Selection for Hyperspectral and Multispectral Imaging: Key Considerations
Ethan Ide, Kowa American Corporation

Uniform Top Hat Oblique Illumination for Machine Vision Applications
Ronian Siew, Venture Biotech Modules Business

Machine Vision and UV Use Cases
Paul Proios, Metaphase

Deep Learning, AI, & Inspection

AI-Enabled Machine Vision: A Game-Changer for Inspection and Robotic Guidance Applications
Harley Green, Soft Robotics Inc.

AI: From Buzzword to Practical
Eric Hershberger, Cognex

Enhancing Inspection Systems: Maximizing Efficiency Through Multisensor Integration
Albert Tu, Hamamatsu Corporation

Improve Inspection Processes Using Large Vision Models in Medical Devices and Pharmaceuticals
David Golembiewski and Ian Rysdale, Landing AI

The Advantages of GigE Vision Connectivity for Embedded Vision
James Falconer, Pleora Technologies Inc.

Tips and Traps in Deep Learning Data Handling
Jan Gärtner, MVTec Software GmbH

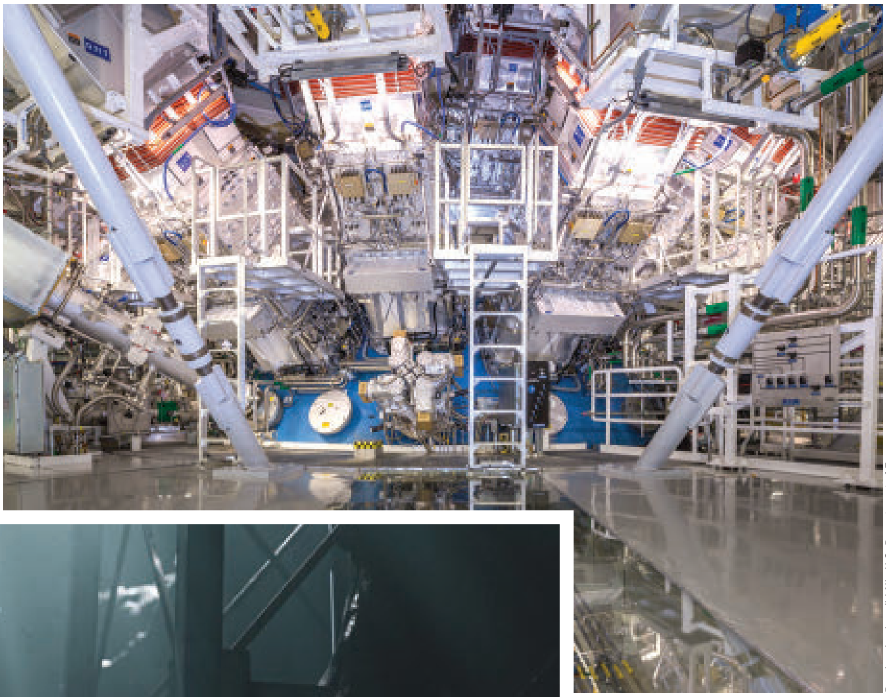
Exail signs LLNL contract, partners with Eelume

Exail, a high-tech industrial group specializing in photonics technologies, contracted with Lawrence Livermore National Laboratory (LLNL) to provide more than 60 dual-stage modulators to equip the high-fidelity pulse shaping (HiFiPS) system of the master oscillator room at the National Ignition Facility (NIF). This is the second optical component ordered from Exail to enhance NIF's capabilities.

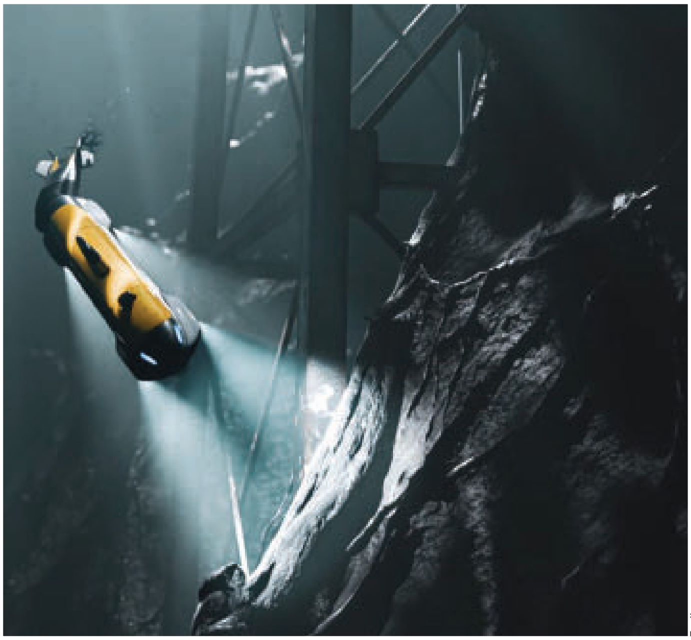
The HiFiPS system functions to enable better power balance and symmetry control in implosions by increasing accurate pulse shaping of NIF's 192 laser beams. Exail previously supplied the NIF radiation-resistant multimode graded-index fiber for diagnostic purposes that are important for understanding laser performance and refining laser delivery for fusion ignition experiments. The fiber is used to monitor the laser power signal entering the target chamber without radiation-induced losses limiting the monitoring capabilities. Since 2022, several kilometers of Exail fibers have replaced the NIF obsolescent fibers.

Prior to its contract with LLNL, Exail announced that it had been selected by Eelume, a provider of underwater technology, to supply its Phins Compact C3 inertial navigation system (INS) for Eelume's new S-Series all-terrain autonomous underwater vehicles (AUVs). The S-Series are all-terrain AUVs designed for mapping and operating in challenging underwater terrains, using 360° of maneuverability in roll and pitch.

The company said that the Phins Compact C3 INS will enhance Eelume AUVs' capabilities for efficient exploration, inspection, and monitoring in environments such as hillsides, under-ice areas, vessels, and harbors.



Damien Jemison/LLNL, U.S. Department of Energy



Exail

The National Ignition Facility (NIF) target bay **(above)**. Exail previously supplied optical fibers to the facility before it was contracted to supply NIF dual-stage modulators.

Eelume's S-Series autonomous underwater vehicles (AUVs), which will come equipped with Exail's Phins Compact C3 inertial navigation system (INS) **(left)**.

24% — estimated compound annual growth rate of the global metamaterials market by 2029, according to Mordor Intelligence

Hamamatsu's NKT Photonics acquisition gets green light

The Danish Business Authority approved the sale of NKT Photonics to Photonics Management Europe SRL, a 100% owned subsidiary of Hamamatsu Photonics K.K.

Hamamatsu said that it obtained regulatory approvals from the relevant authorities in Germany, the U.K., and the U.S. following its initial agreement to acquire NKT Photonics in a deal worth more than $215 million in June 2022. Per the offer, NKT Photonics was to become a Hamamatsu subsidiary. The acquisition was subsequently denied under the Danish Investment Screening Act, in May 2023.

In July 2023, Hamamatsu refiled its application to have the transaction approved in Denmark.

Per the recently obtained approvals, NKT said that it expects the transaction to be completed in the second quarter of 2024.

At the time of the initial acquisition announcement, Hamamatsu said its complementary relationship with NKT's business will support the company as it expands its laser application business. NKT, which specializes in fiber lasers, uses its photonic crystal fiber production to enable ultrashort-pulse amplification and fiber transmission. Its fiber laser portfolio supports applications in the fields of microscopy, semiconductor, quantum computing, and ophthalmic.

According to the initial announcement, Hamamatsu said that these lasers are also expected to be used in semiconductor wafer cutting and for nonthermal processing for industrial applications. Hamamatsu's laser diode business is based on compound semiconductor manufacturing technology.

$3.6B

— expected size of the global fiber optic gyroscope market by 2033, according to Future Market Insights

This month in history

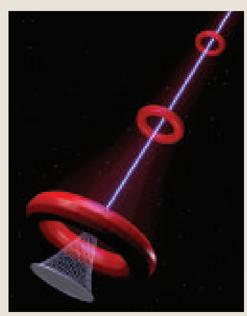
What were you working on five, 10, 20, or even 30 years ago? *Photonics Spectra* editors have perused past July issues and unearthed the following:

1994

John Paschke, an electrical engineering student at the university of Illinois, created a color-matching machine for paint blending based on paint chips. The machine matched paint colors by analyzing the red, green, and blue components of a given chip instead of every frequency in the visible spectrum, creating a cheaper alternative to similar machines.

2004

Mitsubishi Electric Corp.'s Advanced Technology R&D Center developed a high-power green Nd:YAG laser for the crystallization of amorphous silicon films into polycrystalline silicon films during the fabrication of thin-film transistor display screens. The laser's 200-W second-harmonic average output power set a world record at the time.

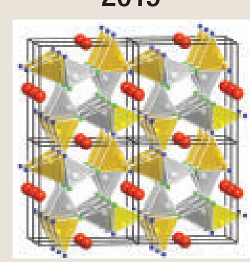


2014

A team from the University of Central Florida's College of Optics and Photonics and the University of Arizona developed a technique that uses a high-energy laser beam to trigger rain and lightning in clouds. Potential applications included microwave signal guidance, spectroscopy, and long-distance chemical sensing.

2019

A team at the University of Innsbruck, in cooperation with OSRAM Opto Semiconductors, synthesized a high-performing red phosphor for LEDs. Called SALON, the phosphor slightly shifted the light emission from red to blue, due to the emittance of more orange particles than red.



Fraunhofer ILT takes lead on PriFUSIO fusion energy project

The PriFUSIO project will bring together public research institutions, startups, medium-size businesses, and large corporations in a collaborative effort to tackle fundamental challenges in inertial fusion energy (IFE).

The PriFUSIO research project, led by the Fraunhofer Institute for Laser Technology ILT (Fraunhofer ILT), aims to develop key technologies for climate-neutral fusion power plants. The initiative, now underway, brings together fusion start-ups, medium-size companies, and large corporations, as well as Laser Zentrum Hannover and the Fraunhofer Institute for Applied Optics and Precision Engineering IOF (Fraunhofer IOF). The project will focus on principles for targeted component development and explore practical photonics approaches for the commercial use of laser-driven inertial fusion energy (IFE).

The Federal Ministry of Education and Research in Germany allocated €18 million ($19.2 million) for the project over the next three years as part of the "Fusion 2040 — Research toward the fusion power plant" funding program. The German government will invest up to €5 billion in this program.

"We want to build a fusion ecosystem of industry, startups, and R&D that pools existing strengths and creates synergies between the various players," said Bettina Stark-Watzinger, Germany's Federal Minister of Education and Research.

PriFUSIO project research will primarily seek to answer fundamental questions on how to develop the next generation of high-power lasers suitable for power plants: lasers that compress the millimeter-size fuel pellets and ignite fusion at temperatures of >100 million ºC. On one hand, this means that laser beams must be generated and manipulated at high energy levels and with unprecedented power. On the other, resulting plasma must be controlled completely to harness the fusion energy being released. The power required places extremely high demands on the materials, the engineering, and the highly complex optical system used to complete target processes.

According to Hans-Dieter Hoffmann, head of the lasers and optical systems department at Fraunhofer ILT, a technical challenge in IFE power plants is the use of large-area optical elements whose optical properties must remain stable despite operating with high energies and high average power. Although the absorption of the laser energy — and therefore the heating of the optics — can be minimized through the material properties and coatings, heat must be dissipated efficiently. It is also important to reduce costs by developing efficient machining and coating processes.

"If we succeed in meeting these stringent requirements, PriFUSIO will also result in synergies for industrial lasers that go beyond the application in IFE technology," Hoffmann said.

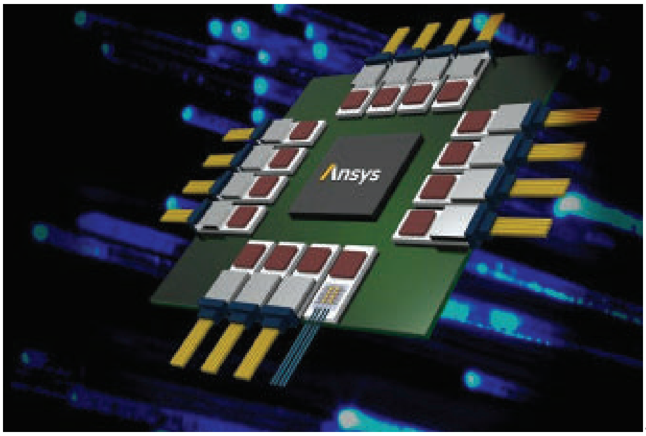
The consortium includes Focused Energy GmbH, based in Germany and Austin, Texas, and Marvel Fusion GmbH, based in Germany. The two startups are working on different technological paths toward the commercial use of IFE technology. Both are formulating requirements for the necessary high-power lasers from which Fraunhofer ILT and IOF are deriving the specific research and development required to implement these specifications.

Leading suppliers of optical glass and coating materials Schott AG and the Heraeus Group are also participating, as are processing and optical components coating companies LAYERTEC GmbH and LASEROPTIK GmbH. TRUMPF Laser AG will also contribute its expertise in the field of complex high-power lasers.

TSMC partnerships target integrated photonics capabilities

Taiwan Semiconductor Company (TSMC) has detailed three partnerships — with Ansys, Synopsys, and Cadence — to integrate added software platforms and capabilities. The integrations support TSMC's development of its silicon photonics integration system capabilities.

Ansys is collaborating with TSMC on multiphysics software for TSMC's Compact Universal Photonic Engine (COUPE). The COUPE silicon photonics integration system and co-packaged optics platform aims to mitigate coupling loss while accelerating chip-to-chip and machine-to-machine communication. TSMC COUPE,



Ansys

Taiwan Semiconductor Company's (TSMC's) Compact Universal Photonic Engine (COUPE) offers a standardized method for connecting electronic and photonic circuits to optical fibers that meets the needs of a broad range of data communication applications. The COUPE information flow and thermal behavior can be simulated with a set of Ansys multiphysics products.

along with Ansys' multiphysics solutions integrated with Synopsys' 3DIC Compiler unified exploration-to-signoff platform, enables next-generation silicon photonics and co-packaged optics designs for applications in AI, data center, cloud, and high-performance computing communications.

The work spans multiple areas, including fiber-to-chip coupling, integrated electronic-photonic chip design, power integrity verification, high-frequency electromagnetic analysis, and critical thermal management. TSMC COUPE integrates multiple electrical integrated circuits with PIC and fiber optic connections into a single package.

In a separate collaboration, Synopsys and TSMC will work together on electronic design automation and intellectual property for advanced node designs related to AI, high performance computing, and mobile designs. Among the newest solution area, Synopsys said, is a co-optimized PIC flow that addresses silicon photonics technology for increased power, performance, and transistor density.

Additionally, in extending a long-standing collaboration, TSMC and Cadence announced that the pair will continue to accelerate design, including developments in 3D integrated chip and advanced process nodes to design intellectual property and photonics. The ongoing collaboration, Cadence said, advances system and semiconductor design for AI, automotive, aerospace, hyperscale, and mobile applications.

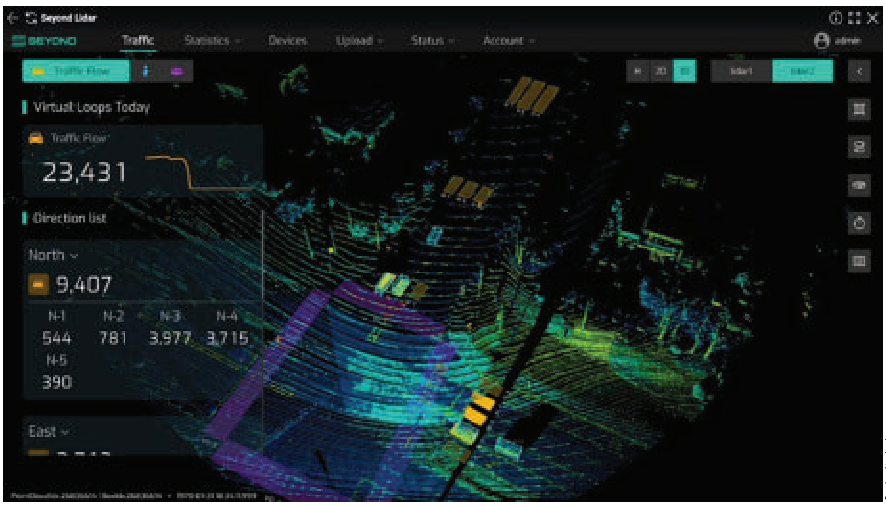
$8.1B

— estimated size of the global silicon photonics market by 2030, according to Grand View Research

Seyond's lidar solution finds further smart city implementation

Lidar technology company Seyond partnered with the city of Peachtree Corners, Ga., a 5G smart city powered by connected infrastructure, as well as the city's Curiosity Lab, to deploy and validate its lidar solutions in a real-world environment. The collaboration aims to create safer streets and smoother traffic flow for vehicles and vulnerable road users (VRUs).

With a range of up to 1640 ft, Seyond's lidar system can map large environments that would usually require multiple traffic cameras. The hardware, originally developed and tested for autonomous vehicles, is manufactured to be automotive-grade and has been designed to withstand extreme weather conditions.



Seyond's lidar solution will be further deployed within the city of Peachtree Corners, Ga., in an effort to increase road safety and efficiency for vulnerable road users (VRUs) and vehicles.

Curiosity Lab

The solution is currently deployed within Curiosity Lab's smart city ecosystem and at a select intersection in Peachtree Corners. These locations use a combination of Seyond's lidar, the OmniVidi perception service software platform, and Blue-Band's Integrator AI solution to provide real-time 3D mapping of the areas, with both vehicle and pedestrian object detection.

The combined technologies collect real-world data that can be used to implement traffic and VRU signal solutions to make intersections safer and more efficient, while also protecting citizen privacy, according to Seyond. The collected data from Seyond and Blue-Band's analysis can be used by the city to adjust traffic signals, pedestrian crossing signals, and intersection design, and will be used to address specific safety and efficiency needs based on real-world data.

Curiosity Lab is a 5G-enabled intelligent mobility and smart city living laboratory owned and operated by Peachtree Corners. The lab is designed as a proving ground for IoT, mobility, and emerging smart city technologies.

Mergers & Acquisitions

Bruker acquired **NanoString Technologies**, a developer of spatial single-cell imaging technology, for approximately $392.6 million. Per the deal, NanoString's business operations will no longer be the subject of a Chapter 11 proceeding and will be owned by Bruker. In a six-month period, Bruker entered into agreements to acquire Chemspeed Technologies, Tornado Spectral Systems, Nion, ELITechGroup, Spectral Instruments Imaging, and Nanophoton Corporation.

Belden Inc., a provider of network infrastructure and digitization solutions, entered into an agreement to acquire **Precision Optical Technologies** for approximately $290 million in cash. Belden intends to add the company to its Enterprise Solutions segment. Precision Optical Technologies is a supplier of value-added optical transceivers with proprietary software, firmware configurations, and related components. The acquisition strengthens Belden's portfolio through the addition of optical transceiver and fiber optic technology. The transaction is expected to be completed by the end of the second quarter of 2024.

Mobile Communications America Inc. (MCA), a provider of wireless communication solutions, acquired **LightSpeed Technologies Inc.**, a provider of broadband fixed networks, to be a part of its data division. The addition of LightSpeed strengthens MCA's footprint in the northeast region and nationally.

Provider of smart turnkey sensing systems **Opterro Inc.** completed its acquisition of **Redondo Optics Inc.**, a research and engineering company specializing in optical and acousto-optic sensors, fiber optics, nanotechnology, and advanced optical materials. The acquisition expands Opterro's end-to-end sensing solutions. Edgar Mendoza, president and CEO of Redondo, will lead the company as a subsidiary of Opterro and will serve as a member of Opterro's executive team.

Microchip Technology Inc., a fabless semiconductor company, completed its acquisition of Seoul-based **VSI Co. Ltd.**, a provider of high-speed, asymmetric, camera, sensor, and display connectivity technologies and products based on the Automotive SerDes Alliance open standard for in-vehicle networking. The acquisition enables Microchip Technology to better serve the advanced driver-assistance systems market. Terms of the transaction were not disclosed.

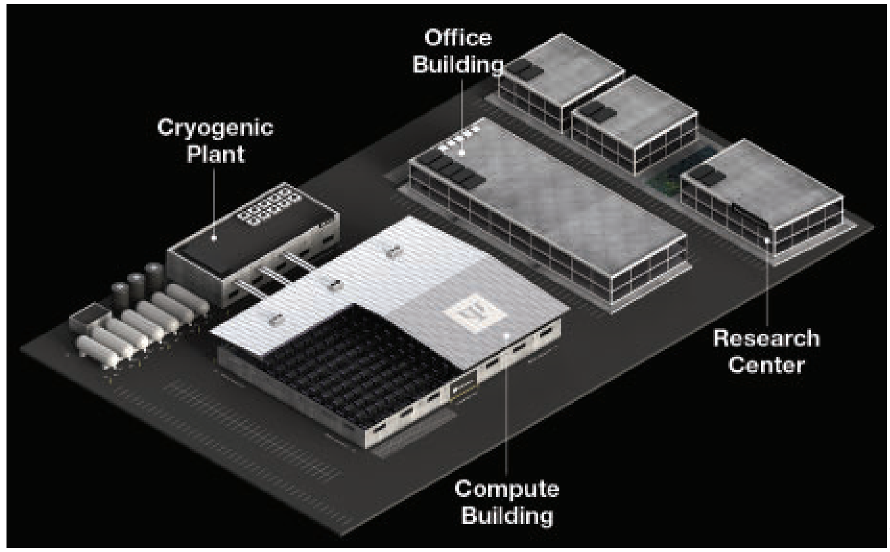
Averna, a test and quality solutions provider, acquired **ELCOM AS**, a test and measurement and industrial automation company, along with its subsidiaries **RH-Tech SRO** and **ELTIA SRO**. ELCOM's expertise and strategic positioning are in

PsiQuantum to build utility-scale quantum computer in Australia

The Australian Commonwealth and Queensland Governments will invest 940 million AUD ($620 million) in Silicon Valley-based quantum computing company PsiQuantum, enabling the firm to build the world's first utility-scale quantum computer at a site in Brisbane, Australia. The company intends for the first site to be operational by the end of 2027.

As part of the investment, PsiQuantum will establish its Asia-Pacific headquarters to build and operate successive generations of its utility-scale fault-tolerant quantum computer in Brisbane. PsiQuantum will also establish partnerships with Australian stakeholders and manufacturers in the quantum industry, invest in university and research collaborations, and create a dedicated climate research center, among other conditions.

PsiQuantum uses a fusion-based architecture for its quantum computing approach, leveraging infrastructure in the semiconductor manufacturing industry to fabricate and test its photonic devices. PsiQuantum's first utility-scale system will be hyperscale and consist of 1 million physical qubits, with a modular architecture that is able to leverage existing cryogenic cooling technologies.



A rendering of a PsiQuantum quantum computing site. The company intends to build a utility-scale fault-tolerant quantum computer at a site in Brisbane, Australia, which it expects to complete by the end of 2027.

PsiQuantum was valued at $3.2 billion in a 2022 article by Forbes and has research partnerships with the Air Force Research Laboratory, SLAC National Acceleratory Laboratory, and Defense Advanced Research Projects Agency (DARPA). The company also has partnerships with SkyWater Technology, Mitsubishi, and GlobalFoundries in technology and manufacturing. The company opened a U.K.-based R&D facility in March 2023, giving it access to one of Europe's largest liquid helium cryogenic plants.

Australia established a National Quantum Strategy in 2023 with the intention of making the country a leader in the global quantum industry by 2030 by encouraging research, applications, and commercialization. The country's Commonwealth Scientific and Industrial Research Organization established a Quantum Road Map in 2020.

the automotive/electric vehicles, energy, and machine vision sectors. Averna will add more than 150 ELCOM employees with the acquisition, for which terms were not disclosed.

Adhesive manufacturing company **Nitto Denko Corporation** will acquire a partial stake in **TruLife Optics**, a U.K.-based holographic optical element developer and manufacturer for wearable AR devices. This partial acquisition of TruLife's shares represents Nitto's entry into the AR glasses field.

HTA Enterprises, parent company of photomask developer HTA Photomask, acquired all assets of the **Roger K. Sherman Company**, including the rights to manufacture, sell, and certify as well as annual recertification services of the measurement standards.

Aquark unveils, details plans to develop cold atom clock

Quantum technology company Aquark Technologies won an approximiately £3.4 million (approximately $4.3 million) contract from Innovate UK to develop its high-performance cold atom clock. The system, AQlock, will be the U.K.'s first commercially available cold atom clock.

Cold atom clocks measure time using atoms that have been cooled to nearly absolute zero. Aquark's "super molasses" laser cooling method traps atoms without the use of an applied magnetic field, making the clock more portable, robust, and easier to commercially produce compared to other cold atom clocks, including those availabe on the market.

During a previous Innovate UK-funded project, Aquark successfully proved the feasibility of its cold atom clocking technology, including technical demonstration of an open-loop clock signal. The AQlock is designed to integrate into existing systems as an accompaniment or augmentation to global navigation satellite system-enabled technology.

Initial target sectors include telecommunications, defense, finance, and aviation, according to the company.

NIL Technology raises $31M to scale manufacturing

Flat optics developer NIL Technology (NILT) raised €29 million (~$31.2 million) to help scale its manufacturing organization and capabilities. With demand for its technology increasing, the company said, it has matured its meta-optics technology from design to prototyping. NILT is now placing focus on bolstering its nanoimprint lithography (NIL)-based production process to meet higher-volume requests, the company said, in announcing the financing.

NILT said that its NIL-based manufacturing strategy enables more precise and versatile nanostructures for higher performance meta-optics. High-volume production will be necessary to produce meta-optics for use in applications and devices, including consumer electronics products, such as smartphones and AR/VR headsets, as well as in automotive and robotics applications, the company said.

NILT recently brought to market its MetaEye eye-tracking camera. The camera's lens stack consists of meta-surfaces, apertures, antireflection coatings, and a bandpass filter integrated into a single cube, which can be bonded directly to the cover glass of the image sensor.

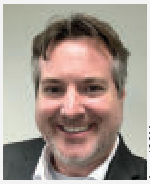
Functional materials developer to lay off 80% of workforce

The board of advanced materials and nanotechnology company Meta Materials approved a workforce reduction of ~80% of its employees, the company said in a statement. The Halifax, Nova Scotia-based company cited challenges with liquidity and securement of additional financing. Meta Materials said that it is continuing to evaluate alternatives including the divestiture of assets, as well as additional financing and/or the sale of the company.

Meta Materials' functional materials and nanocomposites offerings support applications in holography, banknote security, medical, sensing, lithography, augmented reality, and other technologies and applications that manipulate light and other forms of energy. The company's solutions include laser glare protection for the aerospace and defense sector, antireflection for automotive uses, and solar films.

Last year, Meta Materials announced a strategic restructuring to narrow the company's focus and reduce costs. It previously acquired Plasma App, for ~20 million CAD ($16 million) in 2022, and Nanotech Security Corp. for ~91 million CAD in 2021.

People in the News


AmeriCOM

Shelton.

AmeriCOM, the American Center for Optics Manufacturing, named **David Shelton** president and CEO. Shelton most recently served as an advanced systems manager at Ball Aerospace and previously served as senior principal scientist for BAE Systems Inc.


Gentec Electro-Optics

Dumas.

Gentec Electro-Optics (Gentec-EO) appointed **Charles Dumas** vice president of sales and marketing. Dumas previously served as international sales director at Gentec-EO for 10 years. Prior to Gentec-EO, Dumas served in a variety of roles at EXFO.

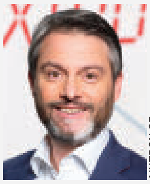
Optical sensing solutions company Neonode Inc. appointed CFO **Fredrik Nihlén** interim CEO following the resignation of **Urban Forssell**. Nihlén will serve as both CFO and CEO until a new CEO is found. Forssell will serve as a strategic advisor to the company and on the board of directors until the end of 2024.


Headwall

Gareau.

Headwall Group appointed **Jim Gareau** vice president and general manager of the Optical Components and Assemblies business unit. The unit governs Headwall's manufacturing capabilities in microlens arrays, holographic gratings, and vacuum coating technologies. Gareau most recently served as vice president and business line leader at IDEX Health and Science. Previously he held senior leadership roles with SCHOTT, Physik Instrumente (PI), and Aperture Optical Sciences.

Syntec Optics Holdings Inc., a provider of optics for defense and aerospace OEMs, made changes to its executive team to support strategic growth initiatives, including potential inorganic growth. The company appointed current chair **Al Kapoor** CEO and named previous CEO, **Joe Mohr**, chief manufacturing officer. The moves come less than six months after Syntec became a publicly traded company.


AIXTRON SE

Ludwig.

AIXTRON SE, a developer of deposition equipment for the semiconductor industry, appointed **Christian Ludwig** vice president of investor relations. Ludwig has previous experience in equipment purchasing for the semiconductor industry and equity analytics, most recently serving as vice president of investor relations, communications, and marketing at DEUTZ AG.

The European Photonics Industry Consortium (EPIC) added **Björn Dymke**, managing director of TRUMPF Laser, to its board of directors. Dymke served as CFO of TRUMPF in the U.S. from 2016 to 2023, after serving in a variety of executive positions in the company since 2008.

IPG names industry veteran Mark Gitin CEO

IPG Photonics named Mark Gitin CEO. Gitin, who formerly headed the photonics solutions division at MKS Instruments, succeeded IPG cofounder Eugene Scherbakov, effective June 5.

Gitin joined MKS in 2017 as vice president and general manager of the Photonics Business Unit, and in 2018 he assumed responsibility for the company's instruments and motion business. Between 1995 and 2017, he held several executive roles at Coherent, including vice president of strategic marketing, vice president of business development, and vice president and general manager of the Diodes, Fibers, and Systems Business Unit.

Scherbakov served as CEO since 2021, succeeding company founder Valentin Gapontsev. Prior to taking over as CEO, Scherbakov served as the company's COO; managing director of IPG Laser GmbH; senior vice president, Europe; and director. He has more than 30 years of experience with IPG.

Per the appointment, Gitin will also join the IPG board, which will expand to 11 members. Scherbakov will remain a member of the board and will serve as an advisor to the newly appointed CEO.

IPG announced the appointment concurrent with its first quarter earnings. The company posted revenue of $252 million, a 27% year-over-year decrease. IPG said that it expects to earn revenue between $240 million and $270 million for its second quarter.

5.6%

— predicted compound annual growth rate of the global functional films market by 2030, according to Coherent Market Insights

Luminar restructuring includes 20% workforce cut

Luminar Technologies intends to implement cost-cutting measures, including outsourcing of industrialization to existing partners and reduction of its workforce by ~20%. According to a statement from company CEO Austin Russell, the transition to a "more asset-light model" will enable the company to accelerate commercialization and scaling, boost profitability, and reduce overhead costs related to industrialization.

"Today, we stand at the crossroads of two realities: The core of our business has never been stronger across technology, product, industrialization, and commercialization," Russell said.

"Yet at the same time, the capital markets' perception of our company has never been more challenging."

In addition to outsourcing more of its industrialization process and reducing its workforce, Luminar is taking measures to streamline other costs by implementing changes to its organizational structure, realigning its employee base to R&D for product development, and renewing the company's strategic equity program for financial flexibility, the statement said.

According to Russell, the company is expecting savings of more than $400 million over the next five years. In the near term, the company expects to realize more than $80 million in savings on an annual run rate basis.

ams OSRAM sells passive optical components assets to Focuslight

China-based laser diode components and materials developer Focuslight Technologies agreed to acquire ams OSRAM's Passive Optical Components business in a deal worth €45 million ($48.4 million). The sale relates to ams OSRAM's Re-Establish the Base strategy, under which the company is exiting its noncore portfolio in its semiconductor business.

The transaction is subject to closing conditions, which include approvals by the shareholders of Focuslight Technologies and Chinese regulatory authorities. It is expected to close in the third quarter of 2024.

Focuslight, a developer and manufacturer of laser diode components and laser optics, previously acquired SUSS MicroOptics last November.

ams OSRAM's Re-Establish the Base strategy, which was announced last year, seeks to refocus the company's semiconductor portfolio on differentiated, intelligent sensor and emitter components, including micro-LEDs. Earlier this year, the company reported the cancellation of a cornerstone project for its micro-LED program and stated that it would consider additional cost improvements under the Re-Establish the Base program to lessen the effect to its balance sheet, estimated to be around €600 million to €900 million in the first quarter of 2024, with profitability for FY2024 affected by up to €50 million.

ams OSRAM's existing business in optical components for consumer applications is not part of the Focuslight transaction.

imec venture fund launches with $323M

imec's venture capital fund, imec.xpand, launched a €300 million ($323 million) fund designed to promote the growth of semiconductor and nanotechnology innovations. Established as a collaborative effort with imec, the fund will invest in startups with the intention of pushing semiconductor innovation beyond traditional applications.

Briefs

Menlo Systems' U.S. subsidiary, **Menlo Systems Inc.**, moved its headquarters from Newton, N.J., to Boulder, Colo. The facility doubles the square footage of the previous location and will be partly under construction to build out laboratory and warehouse space providing the required infrastructure to support development, production, and expanded service capabilities. The official opening of the premises is planned for the second half of 2024.

LightPath Technologies received a European Defense license, allowing the company to supply products to the European defense industry. In the last year, LightPath expanded the capacity and capabilities of its Latvia operation to vertically integrate and prepare for a significant increase in sales related to the European defense market.

PHIX Photonics Assembly moved into a new building in Enschede, Netherlands. The 1800-sq-m building contains ISO 5 cleanrooms to support the company's growth and house equipment for volume manufacturing of optoelectronic modules based on PICs and microelectromechanical systems (MEMS). Among the equipment housed at the facility will be an ASMPT Amicra Nano die bonder and flip chip tool, expected to arrive in September.

Coherent Corp. secured $15 million in funding from the CHIPS and Science Act to accelerate the commercialization of next-generation wide- and ultrawide-bandgap semiconductors, specifically silicon carbide and single-crystal diamond. The funding will be distributed through the Commercial Leap Ahead for Wide-Bandgap Semiconductors Hub led by North Carolina State University.

Medical device developer **Mauna Kea** executed an agreement to restructure €21.3 million ($22.8 million) in outstanding debt obligations related to the company's finance contract with the European Investment Bank (EIB). Initially signed in June 2019, the finance contract enabled Mauna Kea to access two loan tranches of €11.5 million and €6 million, respectively, set to mature in a single installment in July 2024 and July 2025. Under the newly agreed restructuring agreement, the EIB has consented to defer the final principal and interests for both tranches to July 2028 and July 2029, respectively.

Beam profiling and analysis company **DataRay Inc.** will move its offices to Monterey, Calif. The company said that it believes that the relocation will provide increased business development and growth due to its proximity to Silicon Valley. DataRay is headquartered in Redding, Calif.

Aeva, a sensing and perception systems developer, is expanding its presence in Europe with the opening of an Automotive Center of Excellence in Germany to support its growing momentum with

The fund is targeting imec venture technologies including AI, machine learning, AR/VR, and photonics. In the life sciences, imec.xpand seeks opportunities to advance cell therapy, sequencing, neuromodulation, and other applications to boost the efficacy of medical diagnostics and treatments.

imec.xpand's portfolio companies include Celestial AI, which recently raised $175 million to advance its optical compute and memory fabric solution for AI infrastructure; PsiQuantum, which revealed plans to build a fault-tolerant quantum computer in Australia; and Swave Photonics, developer of holographic extended reality chip technology designed for 3D holographic imaging and spatial computing.

The first imec.xpand fund launched in 2017. To date, imec.xpand has invested in 23 companies that, so far, have raised nearly €1.5 billion in financing.

PhotonVentures reaches $79M funding target

PhotonVentures raised more than €15 million ($15.9 million) in a funding round, bringing the fund to its target amount of €75 million. PhotonVentures is the investment arm of the Netherlands' photonics ecosystem PhotonDelta. It plans to raise more than €100 million ($106 million) for the closure of its initial fund by the end of 2024. This fund focuses on seed to series A investments, with participation ranging from €1 million to €2.5 million. The firm aims to facilitate the growth of 20 deep tech companies into international leaders within the European ecosystem. PhotonVentures also benefits from the Dutch National Growth Fund and the European Chips Act.

Since its inception, the firm has made investments in VitreaLab, a spinoff of the University of Vienna; integrated laser startup Brilliance; and MantiSpectra, a spinoff of Eindhoven University of Technology.

The funding was provided by private and strategic investors, with support from BOM (Brabant Development Agency), Oost NL, TNO, and the University of Twente. The round follows an initial €60 million round led by PhotonDelta and private investors.

automotive OEM customers. The center will also benefit Aeva's development of 4D lidar sensing and perception technologies for fully autonomous passenger and commercial vehicle programs. Axel Gern, who previously held senior engineering leadership positions at Mercedes Benz and Torc Robotics, was appointed head of engineering of the center.

Extended reality startup **OPTIX** closed its oversubscribed Pre-A funding round, bringing the company's total equity to $15 million. The investment is OPTIX's third funding round since its founding in August 2022. The company also recently established its own laboratory and manufacturing process, focusing on optics technologies for both AR and VR.

Researchers from **Tyndall National Institute**'s photonics packaging and systems integration group were awarded funding by the National Science Foundation to diversify and strengthen the supply chain for manufacturing and packaging of semiconductor devices. This is through the FUTUR-IC project led by MIT, which was created to bring together stakeholders from industry, academia, and government to co-optimize technology, ecology, and workforce.

GE Aerospace's additive manufacturing business, **GE Additive**, relaunched as **Colibrium Additive**. The company is a manufacturer of industrial metal 3D printers and metal powders, and it provides services for industrial-scale additive manufacturing. As part of the brand's transition, both the Concept Laser and Arcam EBM legacy brands will be retired. Originally, the names of the two companies were acquired by GE in November 2016 to form GE Additive. Concept Laser and Arcam EBM have been used most recently as product brands for Colibrium Additive's printer portfolio.

Dual-chirped methodology enables high-grade attosecond imaging

SENDAI, Japan — Extremely short laser pulses, in the order of attoseconds, provide a powerful way to probe and image ultrashort processes, such as the motion of electrons in atoms and molecules. However, this process is inhibited by the persistent difficulty in creating pulses that are both ultrashort and high energy. A stable, high-energy, single-cycle laser source with a long wavelength is necessary to scale up the photon energy, photon flux, and continuum bandwidth for isolated attosecond pulses.

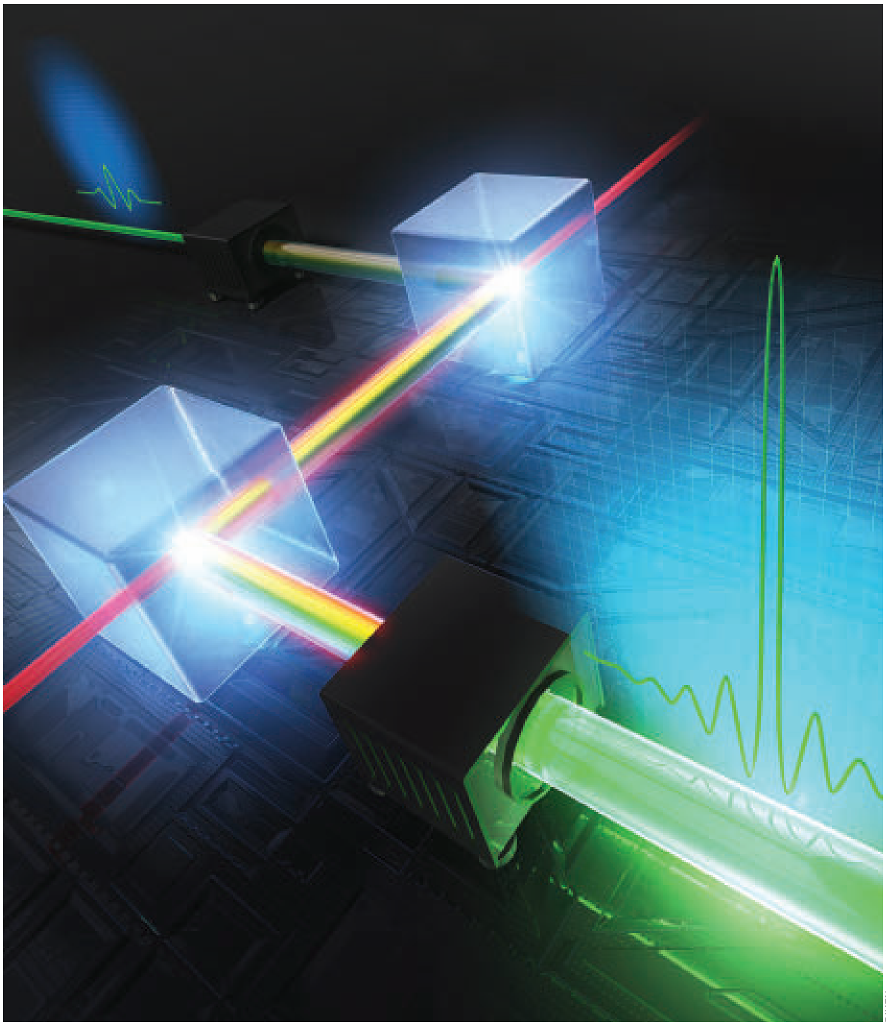
Researchers at the RIKEN Center for Advanced Photonics developed an approach to generate high-energy, single-cycle, MIR pulses. Their method, called advanced dual-chirped optical parametric amplification (DC-OPA), increases the energy of single-cycle laser pulses by a factor of 50, and can be used to generate extremely short pulses with a peak power of 6 TW.

"The current output energy of attosecond lasers is extremely low," researcher Eiji Takahashi said. "It's vital to increase their output energy if they are to be used as light sources in a wide range of fields."

The researchers used two types of nonlinear crystals to develop advanced DC-OPA — bismuth triborate oxide (BiB_3O_6) and lithium niobate doped with magnesium oxide ($MgO:LiNbO_3$). The crystals amplify complementary regions of the spectrum.

"Advanced DC-OPA for amplifying a single-cycle laser pulse is very simple, being based on just a combination of two kinds of nonlinear crystals," Takahashi said. "I was surprised that such a simple concept provided a new amplification technology and caused a breakthrough in the development of high-energy, ultrafast lasers."

The damage threshold of nonlinear crystals has limited the energy scalability of OPA at larger pulse energies. "The biggest bottleneck in the development of energetic, ultrafast infrared laser sources has been the lack of an effective method to directly amplify single-cycle laser pulses," Takahashi said. "This bottleneck has resulted in a 1-mJ barrier for the energy of single-cycle laser pulses."



RIKEN

Advanced dual-chirped optical parametric amplification (DC-OPA) increased the energy of single-cycle laser pulses by a factor of 50. The technique uses two crystals **(clear cubes)**, which amplify complementary regions of the spectrum.

The advanced DC-OPA method overcomes the bottleneck of pulse energy scalability using a single-cycle IR/MIR laser system.

The researchers used advanced DC-OPA with a 10-Hz, joule-class Ti:sapphire pump laser. The nonlinear crystals were combined in each stage of the parametric amplifiers. With this setup, the researchers amplified over-one-octave-bandwidth MIR pulses with a pulse energy of 53 mJ centered at 2.44 µm. After enforcing pulse compression using a sapphire bulk, the temporal pulse duration went to 8.58 fs, which corresponds to 1.05 cycles at 2.44 µm.

The researchers proceeded to demonstrate that the method could be used to amplify pulses whose wavelengths differed by more than a factor of two, and further, they expect that the advanced DC-OPA method will move attosecond laser technology forward more broadly. Due to the excellent energy scalability of the advanced DC-OPA method, it is possible that laser pulses with higher pulse energy and fewer cycle numbers of pulse duration, based on different crystal combinations and a higher pump energy, could be achieved. The expansion of pulse energy could facilitate high-flux detection conditions for research in strong-field physics.

Takahashi's overarching goal is to create even shorter pulses than the speed of attosecond lasers.

"By combining single-cycle lasers with higher-order nonlinear optical effects, it could well be possible to generate pulses of light with a time width of zeptoseconds (one zeptosecond = 10^{-21} s)," he said. "My long-term goal is to knock on the door of zeptosecond-laser research and open up the next generation of ultrashort lasers after attosecond lasers."

The research was published in *Nature Photonics* (www.doi.org/10.1038/s41566-023-01331-9).

3D holography-integrated glasses could unlock mixed reality

PRINCETON, N.J. — The 3D shape of holographic images grants them real depth, compared to monitors, which can only simulate depth on a 2D screen. Because humans perceive the world in 3D, holographic images could, in theory, be integrated seamlessly into the normal view of the everyday world.

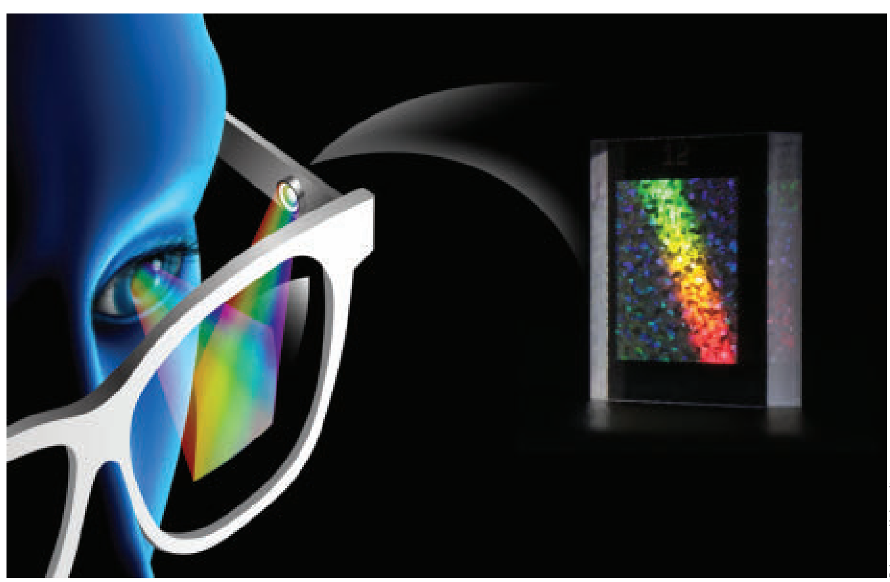
With this possibility in mind, researchers from Princeton University and Meta are working toward mixing the real and virtual worlds using high-definition 3D holographic images. The collaborators developed a spatial light modulator (SLM) that can project these images and fits on a standard pair of glasses. The compact optical device could be the foundation for an AR and VR display that is fully immersive to the human eye, the researchers said.

This would differ from conventional AR and VR technologies that rely on a 2D screen in headsets or phones to project a 3D world. Though it is immersive, the user is aware of a break between simulated and actual reality when using these devices because the image can be lost when in motion.

According to Felix Heide, assistant professor of computer science at Princeton, to have a similar experience using 3D holographic images versus a 2D plane, a monitor would need to be the size of the average cinema screen with the user sitting right in front of it. Because the proposed technology would be using holographic image projections and can fit on a pair of glasses, the researchers believe that they can bypass the use of VR headset hardware entirely. This could make VR more accessible for many applications.

"Holography could make virtual and augmented reality displays easily usable, wearable, and ultrathin," Heide said. As a result, the researchers believe that the technology could transform how humans interact with their environments, from getting directions while driving, to monitoring a patient during surgery, to

Princeton University and Meta researchers created a small optical device that makes holographic images larger and clearer. The device is small enough to be fitted on a pair of glasses.



Princeton University


Princeton University

Holographic images made by spatial light modulators (SLMs) are high definition but too small to be used in an immersive setting **(left)**. Using an SLM with a newly developed optical element similar to a piece of frosted glass **(right)** allows the same image to be enlarged without a loss of clarity.

accessing instructions while doing a home repair.

One of the challenges faced by the researchers was image quality; SLMs, which create holographic images, create high-definition images on a small scale. This trade-off between image size and clarity results in a narrow field of view.

The scientists built a second optical element to work in tandem with the SLM, filtering the light from the SLM to expand the field of view while preserving the stability and fidelity of the image. The result was the creation of a larger image with only a minimal drop in quality.

The second newly developed optical element is similar to a small custom-built piece of frosted glass, Heide said. Designed using AI and optical techniques, the etched surface scatters light created by the SLM in a very precise way, pushing some elements of an image into frequency bands that are not easily perceived by the human eye. This improves the quality of the holographic image and expands the field of view.

The research was published in *Nature Communications* (www.doi.org/10.1038/s41467-024-46915-3).

Programmable processing provides multifaceted networking boost

VALENCIA, Spain — Scientists from the Photonics Research Laboratory (PRL)-iTEAM of the Universitat Politècnica de València (UPV) and programmable PICs company iPronics developed a multifunctional, programmable photonic processor for applications in the telecommunications sector, data centers, and infrastructure for AI computing systems. The device uses properties found in photonic systems, such as high bandwidth and speed, while working synergistically with electronic processors.

Ultrahigh speed 5G and 6G mobile networks, AI computing, and other state-of-the-art applications strain the existing infrastructures that connect the wireless and fiber segments in communication networks. The multifunctional, programmable silicon photonic processor can connect wireless and photonic segments of communication networks. In this way, the device increases bandwidth and reduces power consumption.


UPV

Universitat Politècnica de València (UPV) professor José Capmany led a collaboration with iPronics that yielded a multifunctional, programmable photonic processor with application potential in the telecommunications sector and data center applications.

According to UPV professor José Capmany, the chip can be programmed on demand to increase the efficiency of the circuit in each system.

Microwave photonic (MWP) systems use optical devices and techniques to generate, manipulate, transport, and measure high-speed radio frequency signals. Until now, however, most MWP applications have been implemented by application-specific PICs (ASPICs). Further, prior demonstrations of MWP systems using ASPICs have been limited to the implementation of one functionality, with minimal reconfigurability and flexibility.

The programmable photonic processor overcomes these limitations by providing full flexibility in terms of functionality selection and parameter reconfiguration for the selected application. The programmable photonic processor, to the best of the team's knowledge, is the first photonic processor to integrate the challenging technology stack needed to implement all the main functionalities found in individual MWP systems.

For example, because applications, such as 5G and autonomous cars, require a higher frequency, it is necessary to shrink the size of the antennas and associated circuits in these applications. Using the programmable photonic processor technology, the UPV team designed the converter behind the antenna to be as compact as possible to support current and future frequency bands. Also, the researchers demonstrated that simultaneous implementation of several functionalities in the photonic core is possible with the programmable photonic processor, and therefore, parallel processing operations are feasible. The researchers' findings indicate that the photonic processor can work in frequency ranges of up to 100 GHz, featuring power consumption values in the order of a few watts.

Implementing all achievable functionalities with a single processor will enable scaling down the processor size to dimensions compatible with next-generation, millimeter wave base stations and satellites, and the processors to be used for custom applications. The gains that can be achieved by replacing electronic subsystems with programmable photonic processors include ultrahigh bandwidth, high-speed operation, and low power consumption. Programmable photonic processors provide flexibility, reduce engineering fabrication costs, and provide the ability to reuse resources, which can increase sustainability. These capabilities are critical for applications, such as next generation 5G and 6G wireless systems, in which reconfigurable filtering, frequency conversion, arbitrary waveform generation, and beamforming are currently provided by MWP subsystems that cannot be scaled down.

In addition, the programmable photonic processor can realize these benefits while operating in a complementary, synergistic way with electronic processors.

The processor has been integrated into an iPronics product, called the Smartlight, and iPronics' collaborator Vodafone has used it in testing.

In addition to AI and 5G/6G networks, the multifunctional, programmable photonic chip could benefit many other applications, including data centers, quantum computing, satellite, lidar, drone technologies, and autonomous driving.

The research was published in *Nature Communications* (www.doi.org/10.1038/s41467-024-45888-7).

DUV laser design enhances lithography performance

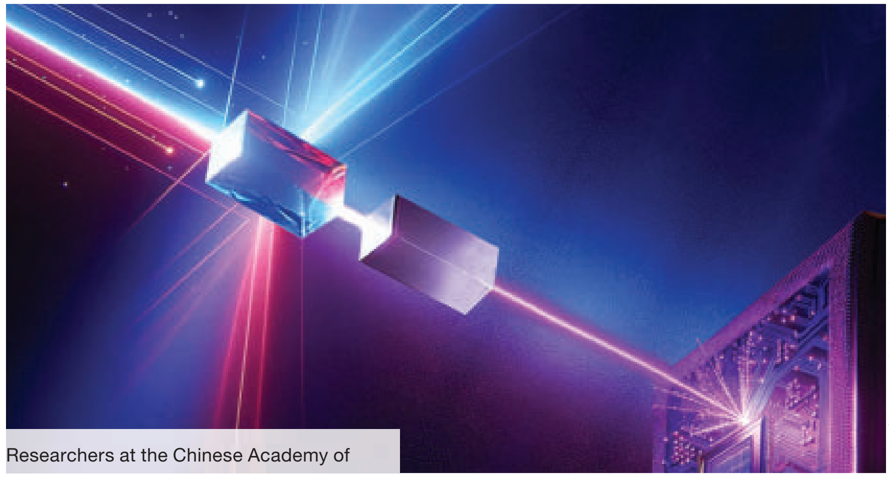
BEIJING — Argon fluoride (ArF) excimer lasers — deep-ultraviolet (DUV) lasers emitting at 193 nm — are used in lithography to create precise patterns. However, the limited coherence of conventional ArF excimer lasers hinders their effectiveness in applications that require the creation of high-resolution patterns, such as interference lithography.

To generate highly coherent DUV light for such lithography applications, researchers at the Chinese Academy of Sciences (CAS) developed a hybrid ArF excimer laser that delivers both narrow linewidth and high coherence at 193 nm. In the hybrid ArF excimer laser, the researchers replaced a conventional ArF oscillator with a narrow-linewidth, solid-state, 193-nm laser seed. The laser seed, which exhibits good beam quality, improved coherence and maintained high output power in the hybrid ArF excimer laser system.

The hybrid ArF excimer laser's intensified photon energy and coherence facilitated the direct processing of various materials, including carbon compounds and solids, with minimal thermal impact. This versatility could extend the usefulness of the hybrid ArF excimer laser to a range of applications, from lithography to laser machining, the researchers said.

Conventional DUV source architectures based on solid-state lasers use multistage frequency conversion from the near-infrared, with solid or fiber lasers as pump sources. In addition to a pump laser, a nonlinear optical crystal is used to achieve a DUV source that is reliable and economical.

In contrast, the newly developed laser is based on two stages of cascaded sum frequency generation in lithium triborate (LBO) nonlinear crystals between an erbium (Er)-doped fiber laser and a ytterbium (Yb)-hybrid laser. The low-cost, low-complexity LBO crystal is generally considered a favorable candidate for 193-nm lasers for industrial applications.



H. Xuan, GBA branch of Aerospace Information Research Institute, CAS

Researchers at the Chinese Academy of Sciences (CAS) developed a 193-nm deep-ultraviolet (DUV) laser generated by cascaded lithium triborate (LBO) crystals. The system architectures differ from conventional DUV source designs in their use of LBO nonlinear crystals.

The pump light of the 193-nm, narrow linewidth, nanosecond-pulsed laser is generated from two actively synchronized pulsed lasers. The pump lasers, at 258 nm and 1553 nm, are derived from a custom-built Yb-hybrid laser that uses fourth-harmonic generation and an Er-doped fiber laser, respectively. A 2 × 2 × 30 mm Yb:YAG bulk crystal for power scaling completes the setup.

The maximum output power of the laser at 193 nm and 221 nm is 60 mW and 220 mW, respectively. The 193-nm laser has a pulse duration of 4.6 ns and a repetition rate of 6 kHz, corresponding to a pulse energy of 10 µJ. The linewidth of the 193-nm laser is estimated to be ~640 MHz, which is the narrowest linewidth from a solid-state, pulsed laser using LBO crystals reported so far, according to the team.

To the best of the researchers' knowledge, the 193-nm DUV laser demonstrates the highest average power ever reported for both 193 nm and 221 nm lasers by frequency mixing in LBO crystals. The conversion efficiency is 27% for 221 nm to 193 nm and 3% for 258 nm to 193 nm, which is the highest DUV conversion efficiency ever reported using LBO, according to the researchers.

Although the LBO crystal has a small nonlinear coefficient in the DUV region, it could be grown and cut to a large dimension while still maintaining a low cost, which allows for compensation through a longer interaction length, according to the researchers. They said that the research shows the potential of LBO crystals to generate DUV lasers at power levels ranging from hundreds of milliwatts to watts and could facilitate the development of LBO to generate lasers at other DUV wavelengths. Coherent light sources in the DUV region are used in defect inspection, metrology, and spectroscopy, in addition to lithography.

The research was published in *Advanced Photonics Nexus* (www.doi.org/10.1117/1.APN.3.2.026012).

Metamaterial progress advances with programmable metafluid

CAMBRIDGE, Mass. — Metamaterials, artificially engineered materials whose properties are determined by their structure, rather than composition, have been widely used in a range of applications for many years. Most of the materials in this class are solid, which inherently dictates physical properties and parameters. Viscosity, for example, is rarely a consideration for metamaterials.

Researchers from the Harvard John A. Paulson School of Engineering and

Applied Sciences (SEAS) developed a programmable metafluid with tunable springiness, optical properties, viscosity, and the ability to transition between a Newtonian and non-Newtonian fluid. The first-of-its-kind metafluid, according to the researchers, uses a suspension of small, elastomer spheres — between 50 and 500 µm — that buckle under pressure, radically changing the characteristics of the fluid. The metafluid could be used in hydraulic actuators to program robots; intelligent shock absorbers that can dissipate energy, depending on the intensity of the impact; and/or optical devices that can transition from clear to opaque.

"Unlike solid metamaterials, metafluids have the unique ability to flow and adapt to the shape of their container," said Katia Bertoldi, William and Ami Kuan Danoff Professor of Applied Mechanics at SEAS and senior author of the paper describing the work. "Our goal was to create a metafluid that not only possesses these remarkable attributes but also provides a platform for programmable viscosity, compressibility, and optical properties."

Using a highly scalable fabrication technique developed in the lab of David Weitz, Mallinckrodt Professor of Physics and of Applied Physics at SEAS, the researchers produced hundreds of thousands of these highly deformable spherical capsules filled with air and suspended them in silicon oil. When the pressure inside the liquid increases, the capsules collapse, forming a lens-like half sphere. When that pressure is removed, the capsules pop back into their spherical shape.

This transition changes many of the liquid's properties, including its viscosity and opacity. These properties can be tuned by changing the number, thickness, and size of the capsules in the liquid.

The researchers demonstrated the programmability of the liquid by loading the metafluid into a hydraulic robotic gripper and having the gripper pick up a glass bottle, egg, and blueberry. In a traditional hydraulic system powered by simple air or water, the robot would need some kind of sensing or external control to be able to adjust its grip and pick up all three objects without crushing them.

But with the metafluid, no sensing is needed; the liquid itself responds to different pressures, changing its compliance to adjust the force of the gripper to be able to pick up a heavy bottle, a delicate egg, and a small blueberry, with no additional programming.

"We show that we can use this fluid to endow intelligence into a simple robot," first author of the paper Adel Djellouli said.

The team also demonstrated a fluidic logic gate that can be reprogrammed by changing the metafluid. Additionally, tests showed that the metafluid also changes its optical properties when exposed to changing pressures.

The optical properties of the metafluid could also be used for a range of applications, such as e-inks that change color based on pressure, for example.

The research was published in *Nature* (www.doi.org/10.1038/s41586-024-07163-z).

Optofluidics platform keys label-, amplification-free diagnostics

SANTA CRUZ, Calif. — Since 2019, many have become accustomed to test for COVID-19 via a nose swab, using either at-home rapid antigen tests or the more accurate, though longer-to-process, polymerase chain reaction (PCR) tests commonly provided by clinics. Bridging speed and accuracy, a diagnostic tool developed by researchers at the University of California, Santa Cruz (UCSC) and Brigham Young University (BYU) tests for SARS-CoV-2 and Zika virus in a matter of hours with the same or better accuracy as high-precision PCR tests.

The researchers' lab-on-a-chip diagnostics system combines optofluidics and nanopore technology. Stemming from their success in tests on animal models, the researchers believe that the technology could be an innovation for the future of rapid diagnostics beyond the two diseases initially trialed.

While PCR testing is currently considered the gold standard of accuracy for virology testing, these tests are highly complex and require chemical reactions that must be performed by skilled operators, typically at a central laboratory. These complex reactions are needed for the amplification of viral DNA or RNA, a process of making multiple copies of the genetic material that can introduce and amplify errors. Ultimately, it may take days for the results to be returned.

Also, PCR tests can only detect nucleic acids, the material that makes up DNA and RNA. But in the case of some diseases, it can be incredibly useful to detect other biomarkers, such as proteins.

The UCSC/BYU diagnostic tool requires little sample preparation and is completely amplification-free. It is also label-free, dramatically cutting the time and complexity of the diagnosis process.

For this study, the researchers used biofluids, including saliva and blood, from baboons and marmosets at Texas Biomedical Research Institute. To run the test, a sample of biofluid is mixed in a container with magnetic microbeads. The microbeads were designed with a matching RNA sequence to the disease for which the test is designed to detect.

If a virus is present in the sample, the virus's RNA binds to the beads. After a brief waiting period, the tester pulls the magnetic beads down to the bottom of the container and washes everything else out. The beads are put into a silicon microfluidics chip, designed and fabricated by the BYU researchers, where the beads flow through a channel covered by an ultrathin membrane. The beads get caught in a light beam that pushes them against a wall in the channel, which contains a nanopore, an opening just 20-nm across. For comparison, a human hair is ~80,000- to 100,000-nm wide.

Then, the testers apply heat to the chip, which makes the RNA particles come off the beads and get sucked into the nanopore, which detects that the virus RNA is present.

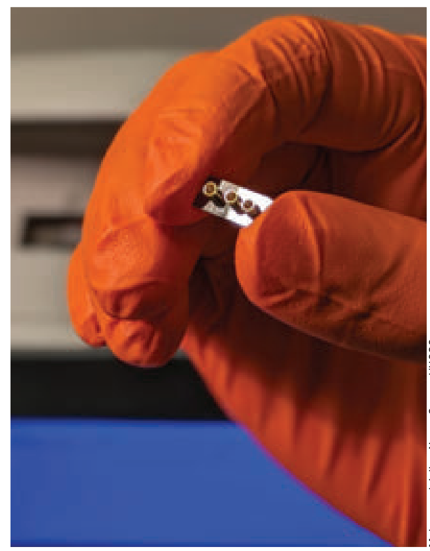
If their concept combining low-complexity label- and amplification-free sensing with a low limit of detection and wide dynamic range is brought to market, the researchers believe the product's compact size could extend its use beyond the confines of a research laboratory. The lab-on-a-chip product, they said, would enable much faster results for virology testing, increasing testing accessibility, and speeding up the time to results from days to hours.

In addition, the researchers believe that they could adjust their platform to find any virus for which they have a genetic sample. They plan to further simplify and miniaturize the system, and they aim to enable it to test for multiple types of disease at once — a feature called disease multiplexing.

The research was published in *Proceedings of the National Academy of Sciences* (*PNAS*) (www.doi.org/10.1073/pnas.2400203121).

BYU/Mark Philbrick

The microfluidics chip in the Brigham Young University (BYU) cleanroom **(above)**. Biofluid is mixed with magnetic microbeads with the RNA sequence of the virus to be detected and placed onto the chip in the operation of the University of California, Santa Cruz (UCSC)/BYU platform.



Mohammad Julker Neyen Sampad/UCSC

The nanopore optofluidic chip used in the diagnostic system **(right)**. The tool was designed to test for Zika and COVID-19 viruses in a smaller package than traditional polymerase chain reaction (PCR) testing systems while also being more accurate.

Laser photoacoustic analyzer gauges air quality in harsh settings

DÜSSELDORF, Germany — The World Health Organization estimates that 4.2 million people die prematurely from the high levels of toxic gas molecules and particulate matter that they breathe outside, or ambient air pollution. Currently, methods for assessing air quality in urban environments rely on units the size of refrigerators, which can cost up to €100,000 (approximately $107,000). Low-cost sensors relying on chemical reactions can be inaccurate due to false readings.

Collaborators on a European Union-funded research project developed a miniature hyperspectral optics-based air quality monitoring system. Called PASSEPARTOUT, the €6.9 million project uses laser technology to detect the smallest amount of toxic gases in large, densely populated regions.

Specifically, PASSEPARTOUT uses photothermal and photoacoustic effects from laser pulses. When the laser light hits a toxic gas, the molecule absorbs light energy, giving off a heat signature that is reported back to the system. The system then identifies the harmful gas as well as how much of it is present.

To complete this function, the PASSEPARTOUT system uses quartz-enhanced photoacoustic spectroscopy (QEPAS). “QEPAS is particularly useful for the detection and quantification of trace gases in challenging environments,” said William Whelan-Curtin, coordinator of the PASSEPARTOUT project.

According to Whelan-Curtin, the scientists use a quartz tuning fork with a sharp mechanical resonance for detections, while also suppressing background noise. The tuning fork detects acoustic waves formed by the gas as it oscillates between hot and cold, Whelan-Curtin said. The laser wavelengths can then be made to match the absorption spectrum of the gas, categorically detecting any targeted gas. These may include nitrogen oxides, sulfur dioxide, ammonia, methane, carbon monoxide, carbon dioxide, and black carbon.

The project aims to make its real-time metropolitan networks commonplace in towns and cities. “We would like to make the technology as common as video surveillance by installing a detector on every lamppost,” Whelan-Curtin said.

The project further calls to develop a smartphone app to check air quality in real time.

“In the future, we hope this can be integrated into Google Maps so that your journey to and from work or school can show you not just traffic hotspots but also the route with the cleanest air,” Whelan-Curtin said.

The PASSEPARTOUT team is trialing the technology in landfill sites, seaports, and other sites. The project is coordinated by Munster Technological University and includes 19 other partners from academia and industry. The project is planned to conclude later this year.

Generative AI achieves superresolution with minimal tuning

GÖRLITZ, Germany — Diffusion models for AI produce high-quality samples and offer stable training, but their sensitivity to the choice of variance can be a drawback. The variance schedule controls the dynamics of the diffusion process, and, typically, it must be fine-tuned with a hyperparameter search for each application. This time-consuming task can cause suboptimal performance.

An open-source algorithm from the Center for Advanced Systems Understanding (CASUS) at the Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Imperial College London, and University College London, improves the quality and resolution of images, including microscopic images, with minimal fine-tuning. Called the Conditional Variational Diffusion Model (CVDM), the model learns the variance schedule as part of the training process.

In experiments, the CVDM's approach to learning the schedule yielded results that were comparable or better than those from models that set the schedule as a hyperparameter. Specifically, the CVDM can be used to achieve superresolution using an inverse problem approach. The availability of big data analytics, along with new ways to analyze mathematical and scientific data, allow researchers to use an inverse problem approach to uncover the causes behind specific observations.

"You have an observation — your microscopic image," researcher Gabriel della Maggiora said. "Applying some calculations, you then can learn more about your sample than first meets the eye."

By calculating the parameters that produced the observation, for example, the image, a researcher can achieve higher-resolution images. However, the path from observation to superresolution is usually not obvious, and the observational data is often noisy, incomplete, or uncertain.

Diffusion models help researchers solve complex inverse problems. To generate images, the diffusion model learns which pixel arrangements are common and which are uncommon in the training data set images. It generates the desired image, bit by bit, until it arrives at the pixel arrangement that correlates most closely with the underlying structure of the training data.

The model is sensitive to the choice of the predefined schedule that controls the diffusion process. When too little or too much noise is added, for example, a failed training can result. "Diffusion models have long been known as computationally expensive to train … But new developments like our Conditional Variational Diffusion Model allow minimizing 'unproductive runs,' which do not lead to the final model," said researcher Artur Yakimovich.

The researchers tested the CVDM in three imaging modalities. For superresolution microscopy, the CVDM demonstrated comparable reconstruction quality and enhanced image resolution compared to previous methods. For quantitative phase imaging, it significantly outperformed previous methods. For image superresolution, reconstruction quality was comparable to previous methods.

The researchers concluded that fine-tuning the schedule by experimentation should be avoided; the schedule can be learned during training in a stable way that yields the same or better results. And, the CVDM supports probabilistic conditioning on data, is computationally less expensive than established diffusion models, and can be easily adapted for a variety of applications.

Researchers presented the work, published in *Proceedings of the Twelfth International Conference on Learning Representations, 2024* (www.arxiv.org/abs/2312.02246), at International Conference on Learning Representations 2024.

Low-power lasers prepare novel polymer for use in biotech, nanotech

ADELAIDE, Australia — Researchers at Flinders University discovered a photosensitive polymer, made from elemental sulfur and low-cost dienes. The polymer can be modified quickly with low-power lasers emitting infrared and visible light, and could therefore provide a safe, inexpensive method to produce polymer surfaces for biomedical devices, electronics, information storage, microfluidics, and other applications.

The researchers made the discovery during a routine chemical analysis. "The novel polymer was immediately modified by a low-power laser — an unusual response I had never observed before on any other common polymers," researcher Christopher Gibson said. The polymer identified by Gibson was invented in the lab of Flinders University professor Justin Chalker in 2022. The researchers further investigated the polymer's atypical reaction, conducting a detailed analysis of how low-power laser beams modified the polymer and how the type and size of the modifications could be controlled.

Using low-power, continuous-wave lasers with wavelengths of 532 nm, 638 nm, 690 nm, and 786 nm, the researchers made a variety of surface modifications to copolymers made from sulfur and either cyclopentadiene or dicyclopentadiene. By controlling the power, wavelength, and beam diameter, the researchers installed spikes, raised dots, pits, channels, and holes on surfaces of the polymer. The rapid exposure times were on the timescale(s) of milliseconds to seconds.

The inclusion of maghemite (γ-Fe_2O_3) nanoparticles in the polymer matrix facilitated modification at lower laser powers. The researchers erased the polymer's swelling modifications by heating the sample at 160 °C, but they could not erase ablated areas because of an irreversible loss of sulfur species from the polymer in these regions.

The team demonstrated the synthesis and laser-induced modification of the photosensitive polymer systems in examples of direct-write laser lithography and erasable information storage, featuring a laser-etched version of da Vinci's "Mona Lisa" and micro-braille printing smaller than a pinhead.

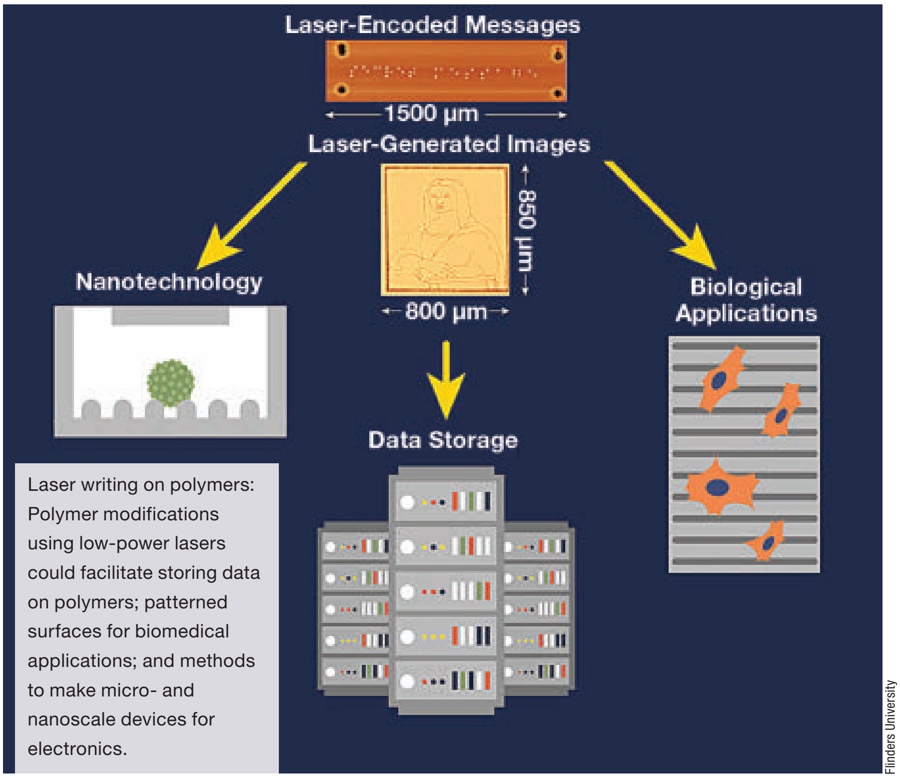
Many applications, from biomedical devices to opto- and microfluidics, rely on the ability to modify polymer surfaces using laser light. Typically, these modifications are made with high-power lasers that require specialized equipment and facilities. Additionally, polymer systems that can be easily modified by lasers are often complex and costly to prepare.

The researchers' simple approach using low-cost materials and low-power laser systems compares favorably to other methods of lithography that require complex polymer structures, high-power lasers, and multistep masking, developing, and washing protocols.

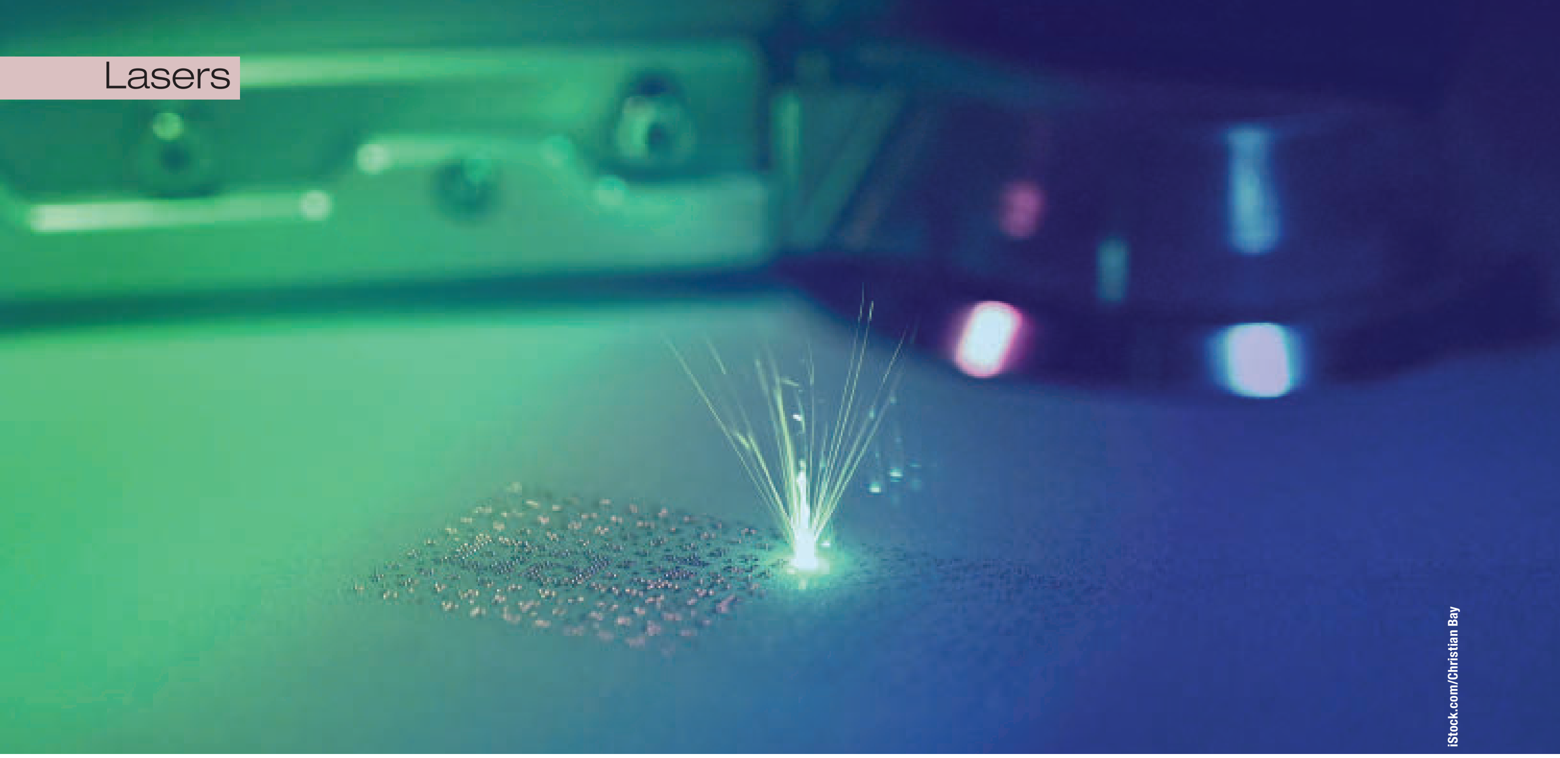
"This could be a way to reduce the need for expensive, specialized equipment, including high-power lasers with hazardous radiation risk, while also using more sustainable materials," Chalker said.

Potential applications for the new approach to modifying polymer surfaces with low-power lasing could include methods to store data, develop patterned surfaces for biomedical applications, and make microscale and nanoscale devices.

The research was published in *Angewandte Chemie International Edition* (www.doi.org/10.1002/anie.202404802).



Laser writing on polymers: Polymer modifications using low-power lasers could facilitate storing data on polymers; patterned surfaces for biomedical applications; and methods to make micro- and nanoscale devices for electronics.



Femtosecond Lasers Spur a Precision Revolution in Materials Processing

BY SIMAS BUTKUS,
DOMAS BALIUKONIS, AND
MARCO ARRIGONI
LIGHT CONVERSION

Industrial femtosecond lasers deliver the performance and versatility for the precise processing of materials supporting various industrial fields.

The physical parameters and versatility of femtosecond sources help to facilitate operations that are beyond the reach of more conventional laser technologies. As emitters of high-intensity, ultrashort-pulse (USP) radiation, the current class of femtosecond lasers is essential to materials micromachining — and these lasers enable precision fabrication that supports applications across industries ranging from aerospace and defense to finance.

While these lasers can be built in fiber or free space (solid-state media), free-space femtosecond lasers outperform their counterparts due to their superior pulse quality, characterized by the absence of background radiation that is present in fiber-based systems. Also, the burst mode capability of contemporary femtosecond lasers allows a single USP to be divided into a series of pulses separated by hundreds of picoseconds to tens of nanoseconds. This mode significantly enhances ablation efficiency, improves overall materials processing quality, and delivers a distinctive surface finish.

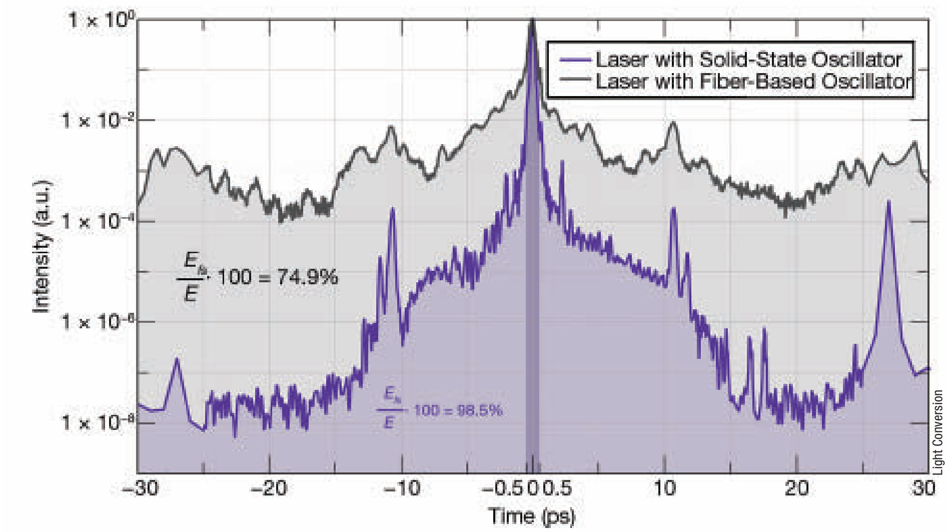


Figure 1. Pulse contrast ratio measurements comparing Light Conversion's CARBIDE femtosecond laser with a solid-state oscillator to a laser with a fiber-based oscillator. Approximately 25% of the power stored in the femtosecond time frame is lost in the case of fiber-based technology.

From research to commerce

Almost everyone owns an electronic device containing components processed with a femtosecond laser, from a smartphone to a flat-panel display. Many of us have even been "processed" by a femtosecond laser ourselves: Ophthalmic procedures commonly use these lasers, and femtosecond lasers also find use with stents and other medical devices that must be cut or scribed in some way.

Although the use of femtosecond lasers for these purposes is currently commonplace, femtosecond processing was an upcoming technology at the start of the century. The first reports of material ablation using femtosecond pulses date to 1987. In an initial demonstration of polymethylmethacrylate (PMMA) ablation, scientists used an excimer laser at 248 nm — significantly different from the tools that currently drive the realization of femtosecond materials processing. In the 1987 report, the study authors found two key advantages of femtosecond pulse processing: "cold" ablation, which resulted in a minimal heat-affected zone, and the multiphoton absorption process, which circumvents the wavelength requirements that are typical of linear absorption.

This seminal demonstration occurred two years after Gérard Mourou and Donna Strickland invented chirped pulse amplification (CPA). Before the development of this energy-scaling technology, femtosecond pulse energies were limited to sub-microjoule levels due to peak power-dependent nonlinear processes that could damage the laser medium during the optical amplification process. CPA, with its stretch-amplify-recompress approach, scaled the energy of femtosecond pulses to hundreds of millijoules or more, making femtosecond materials processing practically feasible.

By 2000, femtosecond processing applications were developing, though at a slow rate. These applications were based on titanium sapphire (Ti:Sapphire) amplifiers, which were expensive and complex platforms, and which required a continuous-wave laser and a nanosecond laser to pump the femtosecond laser and amplifier, respectively. Most Ti:Sapphire amplifiers excel at producing 5- to 10-mJ pulses at a 1-kHz repetition rate — a clear mismatch with materials processing applications that require much higher average power and rely on high pulse repetition rates to achieve high industrial throughput.

The mid-2000s marked the advent of lasers based on a new active media, specifically ytterbium (Yb)-based laser amplifiers, which quickly became available in a variety of formats, including fiber, bulk crystal (solid-state free-space), and thin disk. In each format, the superior flexibility and scalability of the Yb platforms enabled systems to deliver average powers reaching tens of watts at up to megahertz repetition rates. The longer pulses of Yb-based systems (200 to 400 fs) compared with Ti:Sapphire amplifiers (50 to 100 fs) were not a limitation. Rather, they simplified dispersion management during propagation because optical materials dispersion affects longer pulses less profoundly than shorter ones. Today, nearly every industrial USP laser is based on a Yb-active medium.

Pulse cleanliness

It is generally accepted that a pulse is considered "clean" if most of the energy is stored within a few hundred femtoseconds and no residual background photons are present outside this time frame. Yet, this property of femtosecond pulses often lacks proper, comprehensive consideration, and few measurements quantify this effect.

This is not a trivial factor to overlook; a typical autocorrelator, for example, may not detect the background. And, the power level, as measured with a conventional power meter, will show as adequate regardless of pulse cleanliness. In fact, it is only possible to detect the background when using alternative pulse measurement techniques, such as a third-order nonlinear autocorrelator.

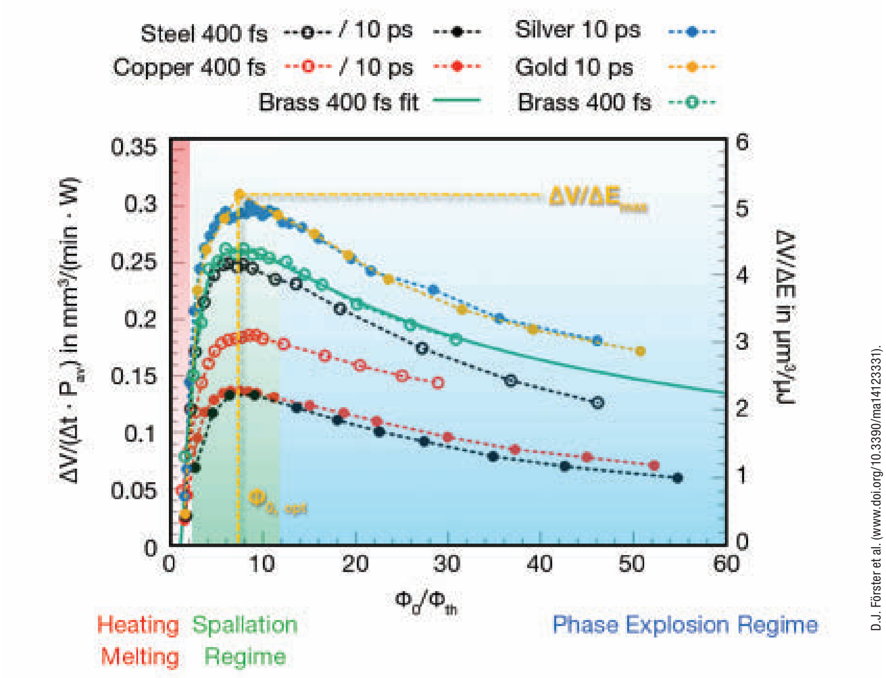
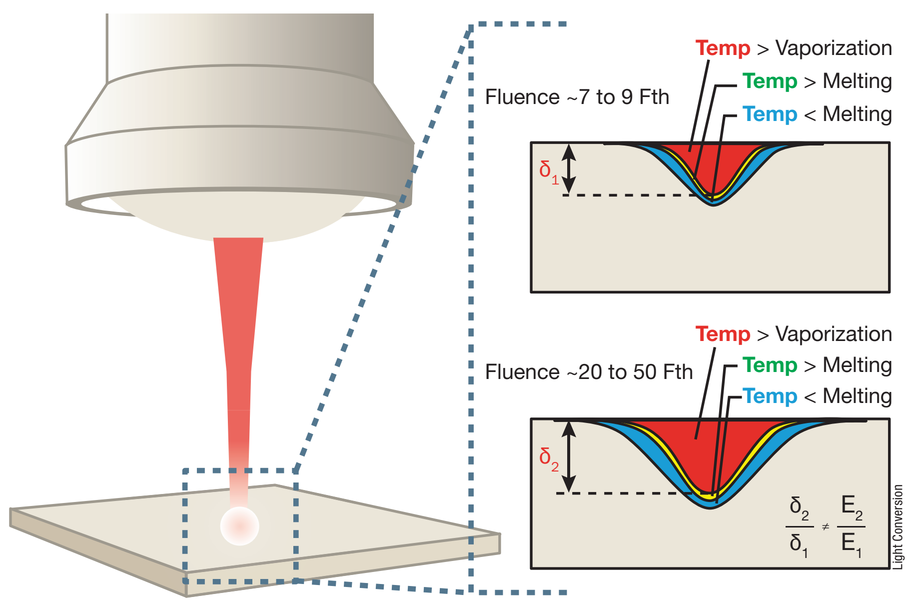


Figure 2. A typical ablation efficiency diagram of metals using ultrashort-pulse (USP) laser technology, depicting energy-specific volume for single-pulse laser ablation **(left)**[6]. With the pulse fluences just above the ablation threshold, the ablation efficiency is low, as shown by the curve. The ablation efficiency is also low even at high fluences, since a significant portion of the pulse energy is converted into thermal energy in the ablated mass.

Figure 3. A demonstration of energy penetration into a material at different fluence levels **(below)**. The higher fluence results in a mild increase in the total ablated mass. Temp: temperature.



This is not the only common oversight influencing perceptions of pulse cleanliness as it relates to materials processing. Typically, a femtosecond laser system consists of an oscillator and an amplifier, and the importance of the oscillator is often unmentioned in the realm of materials processing. Indeed, the implementation of this technology can have a considerable influence on the results. Although almost all femtosecond laser oscillators are Yb-based, there are differences in the technology and, specifically, in how it is implemented for a system.

Two approaches are used most often: fiber-based oscillators and solid-state free-space oscillators. Although fiber-based technology is considered the simpler and cheaper approach, there are nuances to consider prior to their use.

Figure 1 shows these discrepancies as well as typical contrast measurements. The first measurement reflects a femtosecond laser after amplification and compression within a 60-ps timescale around the main 300-fs pulse. This measurement was conducted by integrating the intensity in this time frame:

$$E_{fs} = \int_{-0,5}^{0,5} I \, dt.$$

The measurement was conducted using a Light Conversion CARBIDE series femtosecond laser and a commercially available third-order nonlinear autocorrelator.

In this sequence, >98% of the photons are concentrated within a 1-ps range around the main femtosecond pulse. This indicates that the system generates femtosecond pulses with minimal trailing or leading photons. The background radiation does not significantly contribute to the overall power measurement in this case, as it decreases from a level of 10^{-4} below to 10^{-7}, relative to the main pulse within the measured range. From this figure, it is evident that such a system can produce clean pulses, achieving high peak intensity.

Figure 1 also shows a measurement performed with the same setup on a fiber-based laser. The number of photons within the same (1-ps range around the 300-fs pulse) accounts for only ~75% of the total photons within the 60-ps range.

The presence of spontaneous emission in fiber-based technology is the main contributor to the difference between the two systems. Though at first glance this variation may not seem significant in terms of influencing system performance, it can have a strong effect in processing materials. The background radiation may result in a higher damage threshold for many materials and can lead to additional unwanted sample heating. The measured damage threshold for a specific material can be >1.3× lower when comparing a laser with a good temporal contrast to a poor temporal contrast laser source, because the low-intensity background does not contribute to the damage. Ultimately, in this case, ~25% of the average power of the fiber-based laser source does not contribute to the processing of the material.

Even in cases of bulk material(s) processing, temporal pulse cleanliness plays a role in transparent materials, such as glass. A less optimal pulse shape results in energy in its plateau being transmitted through the material, which inhibits its usability for the nonlinear absorption process. Consequently, more power is required to produce modifications inside the bulk of transparent materials using fiber-based USP lasers[1]. A recent use case investigating laser writing in silica glass demonstrated the favorable pulse temporal contrast of a free-space Yb-based laser, which in turn offers multiple benefits compared to fiber laser systems for the same purpose[1].

In response to this limitation, a typical commercial laser source from Light Conversion combines a Yb-based solid-state free-space oscillator with a regenerative amplifier. The solid-state oscillator generates femtosecond pulse trains with high temporal contrast, resulting in clean pulses after amplification, ensuring sustained performance for the most intricate industrial applications.

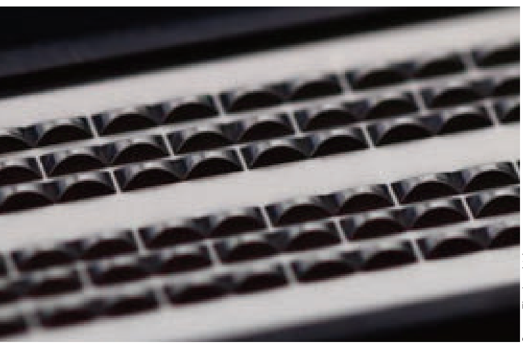
Ablation efficiency

Ablation efficiency has been extensively studied across various materials and laser sources. These sources include fiber- and free-space-based systems. These investigations prove that comparing degrees of ablation efficiency highlights the importance of the pulse cleanliness effect on materials processing.

There are distinct differences in ablation efficiency values between fiber-based technology and free-space-based systems. When considering the ablation efficiency of copper, for example, for a single pulse (non-burst mode), the material removal rate for a fiber-based system[2-4] is 0.2 mm^3/minW, whereas the removal rate for a free-space system[5] is 0.3 mm^3/minW. While pulse cleanliness is not single-handedly responsible for such large differences (approaching 50%) the effect nevertheless plays a significant role in the ablation process. Background radiation, which does not cause ablation, mainly results in the heating of the peripheral regions, or is reflected from the surface of the sample.

Figure 2 shows a typical ablation efficiency graph for various widely used metals, in a sequence using a USP source. With the pulse fluences just above the ablation threshold, the ablation efficiency is low, shown by the curve. This occurs because only the top part of the Gaussian

Light Conversion



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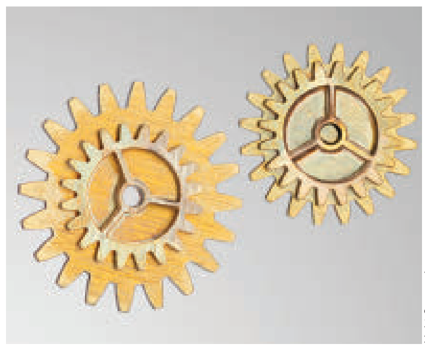

Light Conversion

Figure 4. A demonstration of ultrashort-pulse (USP) laser processing shows cutting and welding of microscopic watch parts from brass **(top, right)** and an ablation of 3D shapes and surface texturing.

beam contributes to ablation, while the wings mainly contribute to the heating of the material(s). In this case, the amount of removed material mass, or volume per unit of average power, is low.

After reaching a peak, the ablation efficiency decreases at very high fluences. This is because a significant portion of the pulse energy is wasted in the form of kinetic or thermal energy in the ablated mass, which itself results because the penetration depth of light does not increase linearly with the fluence (Figure 3). However, if the fluence is set to ~7 to 9× the damage threshold, the ablation efficiency is at its highest. There are various explanations for this behavior, which are attributed to different ablation mechanisms[6]. These include spallation or fragmentation of the exposed area without overheating as well as material ejection at moderate velocities and lower temperatures. In these cases, most of the average power is used for ablation and not wasted as heat and kinetic energy.

Burst pulses

The ablation efficiency values in Figures 2-3 demonstrate how it is typically necessary to set the fluence value to <10 J/cm^2 for most materials. However, this poses a problem: In recent years, as USP laser average powers have reached 100 W and above, it has become complicated to harness the full power of the laser for use and maintain optimal ablation settings. For a 100-W laser source, for example, it may be practically difficult to maintain a fluence setting of <10 J/cm^2. Additionally, operating at this regime would require the laser to function in the megahertz repetition rate range, which could introduce additional unwanted heating effects, such as pitting of the ablated surface, melt formation, burr formation, metallic phase change, and/or chemical degradation.

The so-called burst mode addresses these issues by splitting the pulse energy of a single conventional pulse into a train of femtosecond pulses, temporally separated by tens of nanoseconds (megahertz burst) or hundreds of picoseconds (gigahertz burst).

In a burst mode, the pulse separation is such that transient material properties become relevant insofar as they may now affect the entire process. For example, the pulse spacing may be so short that locally generated heat does not have sufficient time to diffuse in the material, and the hot mass would be more efficiently ablated out of the surface by the trailing pulses. Moreover, it is easier to maintain the fluence of each intra-burst pulse closer to the ideal fluence for maximum efficiency. Heat input into the material can be controlled by tailoring the burst configuration — the number and energy of each pulse — to create unique surface features, such as viewing-angle-independent white markings, polishing an ultrafine layer of the ablated surface, or unique surface texturing. Figure 4 shows typical burst mode applications in multiple contexts.

Final thoughts

Tracing the evolution of femtosecond processing to current-generation laser platforms, based almost exclusively on Yb media, requires the consideration of process parameters as well as the exploitation of increased powers and pulse energies. This article highlights the relevance of clean pulse shape, providing examples in both opaque and transparent materials. Finally, configurable burst-mode operation fully exploits the increased average power and pulse energy available from current-generation lasers.

Often, "the devil is in the details" when it comes to picking the right laser and optimizing the parameters for a specific material and process. There is no substitute for in-house expertise both in laser design and application development.

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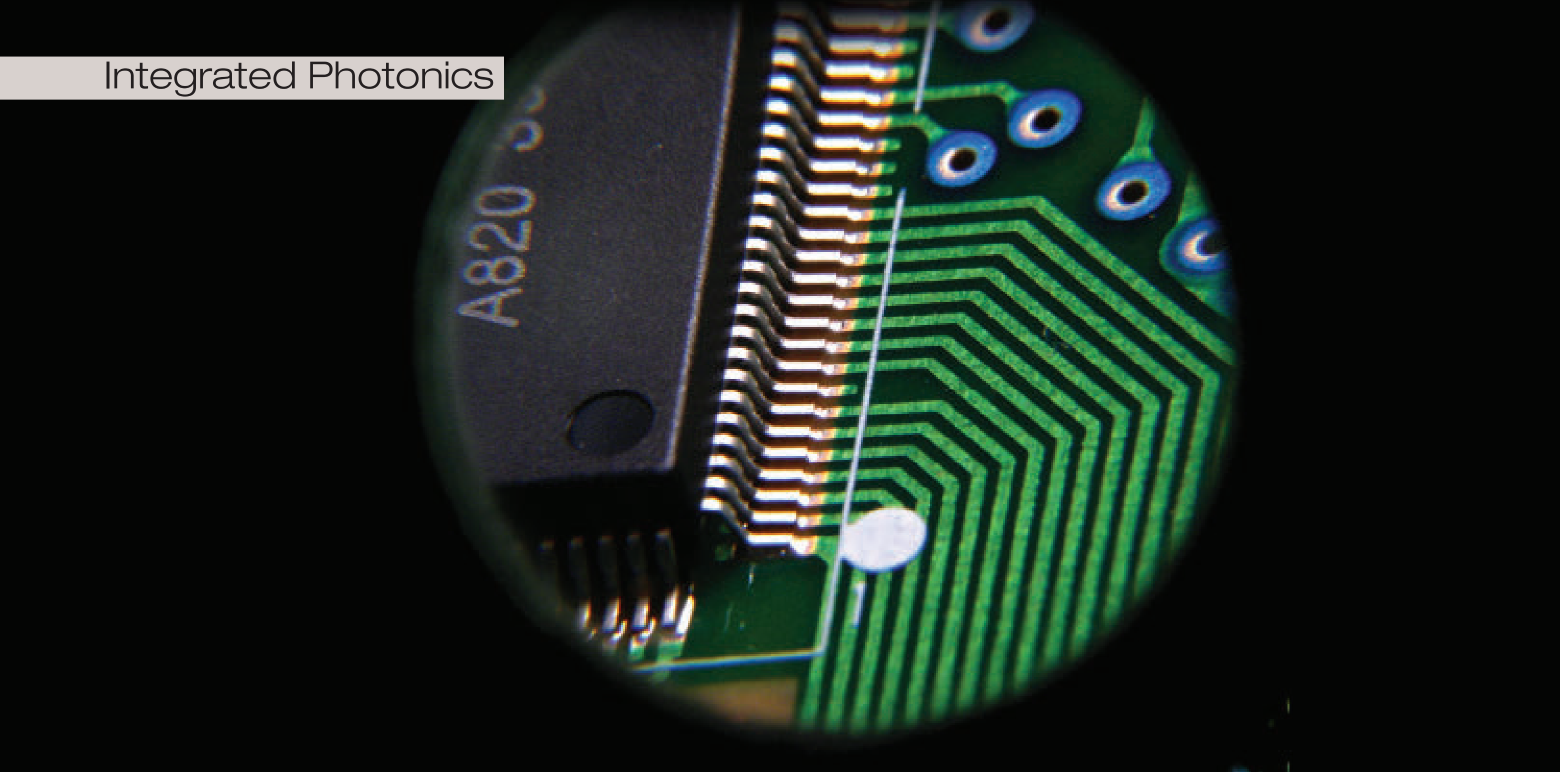


Ultraviolet PICs
Push the Potential of Nonvisible Microscopy

A convergence of nanotechnologies and ultraviolet imaging is charting its course through the domain of optical microscopy.

BY NICOLAS LE THOMAS
GHENT UNIVERSITY-IMEC

Manipulating ultraviolet (UV) light beams is historically difficult and costly. As it relates to imaging, bulk optics in the UV range are expensive because they require unique materials, such as quartz, magnesium fluoride, or fused silica, to ensure aberration-free imaging with necessary degrees of focus and resolution. And, from a technical perspective, UV imaging microscope objectives with a high numerical aperture, which are required

Image on this page, courtesy of iStock.com/Digiphoto.
All other images are courtesy of
imec/Ghent University Photonics Research Group.

for high-resolution microscopy (operating below 360 nm), are rare. The high price tag that is typically associated with these objectives limits their use.

Increasingly, nanotechnologies are revolutionizing the usability of UV light across imaging applications. By integrating multiple optical components, including waveguides, modulators, and detectors — as well as their distinct functions — into a single chip, photonic integrated circuits (PICs) deliver precise control and manipulation of light from a compact design. For example, PICs may reduce the path length that light needs to travel for a particular application, reducing the chance of misalignment. PICs may also integrate customized waveguide designs that are tailored to a target wavelength.

Because standard semiconductor manufacturing processes make PICs increasingly cost-effective and scalable to high volumes, PICs are already well established across a range of wavelengths in the visible and near-infrared. Now, PICs are drawing increased attention for applications that harness the UV spectrum. The precise control that PICs offer for beam shaping is critical for optical UV microscopy, for example, in which the shorter UV wavelength compared to visible light enables interaction with comparably smaller structures and particles. Precise manipulation of the light beam ensures that it accurately focuses on the sample, thereby improving resolution.

In addition, PICs enable developers to build compact and cost-effective imaging systems. Such systems can be fabricated with more readily available materials compared to the legacy exotic materials on which traditional bulk optics rely, without compromising the optical properties in the UV range.

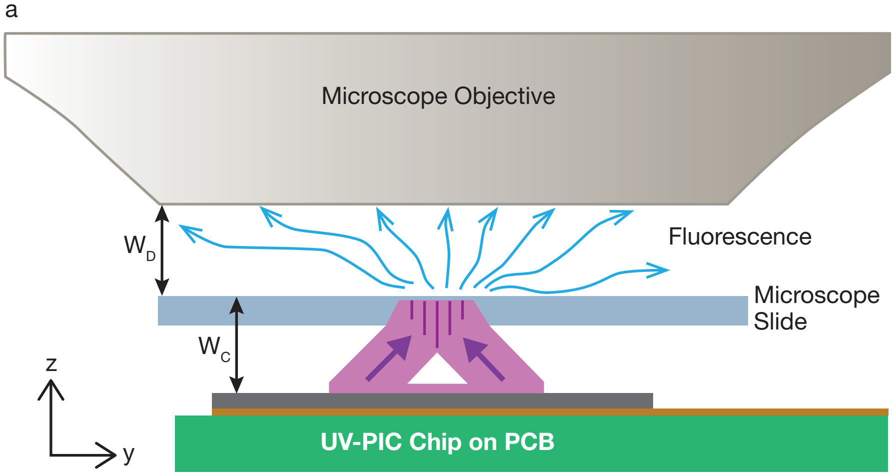
Ultraviolet capabilities

The arrival of nano- and integrated photonics technology into the UV band complements many important advantages that the properties of UV light offer for imaging applications. Indeed, the fundamental need for improved resolution and specificity has already driven the adoption of the UV wavelengths from ~200 to 400 nm for optical applications. The band is essential for probing subcellular structures and nanoscale material properties.

The UV spectrum is also critical for the observation of molecular interactions, because biomolecules exhibit a strong interaction with UV light. This quality increases the prospects of achieving favorable outcomes in many applications. First, some amino acids, such as tryptophan and certain proteins, emit an autofluorescent signal upon illumination, which enables label-free imaging. This is particularly useful for superresolution microscopy techniques, such as structured illumination microscopy (SIM), which has historically required the use of fluorescently labeled samples. At the same time, achieving label-free SIM does not discount the importance of UV light-sensitive fluorophores, which remain an important tool in microscopy and for life sciences imaging.

Further, a strong absorption in the UV wavelengths can significantly improve the Raman scattering process. This occurs when incoming light interacts with a sample and generates scattered light at lower and higher energy and as a result enhances the signal-to-noise ratio. Investigations are ongoing into the use of UV light to overcome background noise in on-chip Raman sensing applications.

UV waves also drive nonimaging applications; in addition to biological and



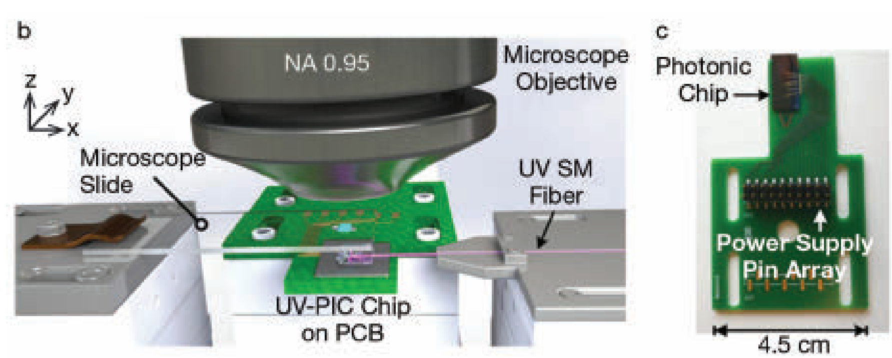


Figure 1. The compact ultraviolet photonic integrated circuit (UV-PIC) enables seamless integration into existing microscopy setups. A zoom-in on a sample area under the microscope with UV excitation light in violet and the fluorescent signal in blue **(a)**. A schematic of the Ghent University-imec chip-based far-field structured illumination microscopy (SIM) setup, including a conventional microscope **(b)**. The PIC mounted on an electric printed circuit board with wire connections **(c)**.

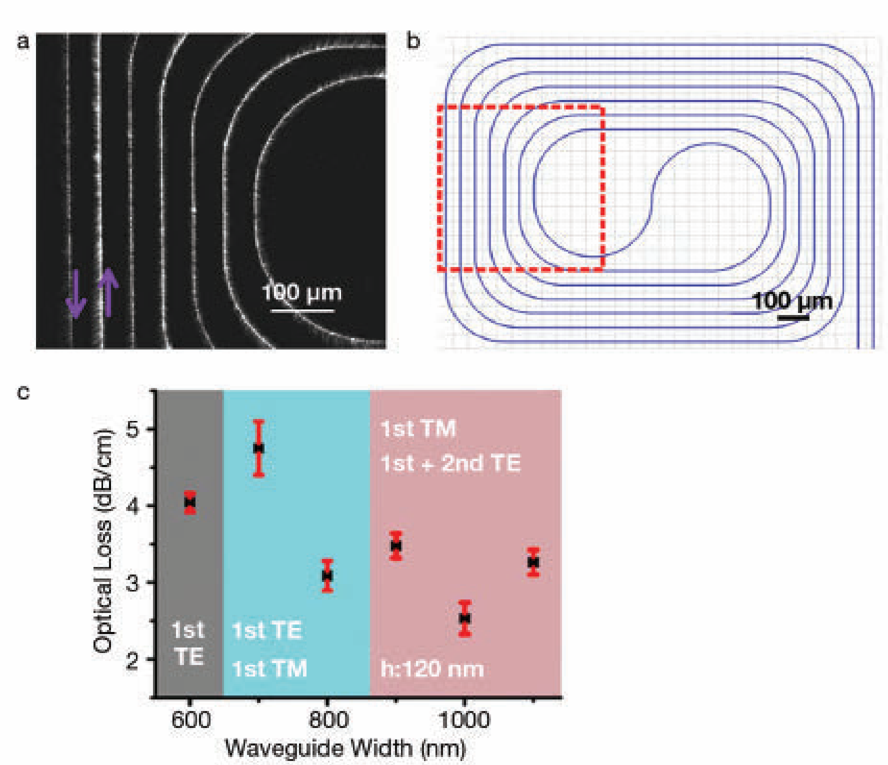


Figure 2. With 800-nm-wide waveguides fully etched in 120-nm-thick layers of aluminum oxide (AlOx), the researchers achieved scattering losses of only 3 dB/cm at 360 nm. A microscopy image of the light scattering from a waveguide (λ = 360 nm) **(a)**. The layout design of the waveguide corresponding to *(a)* **(b)**. The relationship between the propagation losses and the width of the AlOx waveguide; the different shaded areas correspond to an increasing number of possible guided modes **(c)**.

materials sensing and detection, which are used in pharmacology and materials research, UV waves are instrumental in quantum computing through ion trapping. In ion-trapped quantum computing, individual ions function as qubits to store and control quantum information. UV sources can generate the necessary electromagnetic fields to trap, cool, and manipulate ions with high precision.

Toward plug-and-play UV optics with PICs

For all their promise, the current class of commercially available PICs does not target the UV range. Laboratory demonstrations from the joint Ghent University-imec research team, however, have shown the efficacy of ultraviolet photonic integrated circuits (UV-PICs) — namely, UV-PICs that operate with low-loss single-mode waveguides at 360 nm[1]. In these laboratory demonstrations, single-mode waveguides allow only light with nearly identical properties, including wavelength and phase, to pass through. These components and the systems that they support, are essential for applications such as UV-SIM where precise light control is absolutely necessary.

SIM has previously been demonstrated in the far field as a traditional microscopy technique, allowing a user to look at a sample from a distance using bulk optics. PICs have previously been investigated in the near field, whereby the user looks very closely at the sample in the evanescent field. However, these near-field instances required the sample to be placed on top of the chip.

Recent research showed that the far-field SIM technique can also leverage the advantages of PICs, including in the UV wavelength range for label-free samples[2]. This advancement avoided inflicting any disturbance on the chip, which yielded a plug-and-play PIC element. In Figure 1, the sample is placed under the microscope. Here, the PIC is integrated into a conventional microscope setup, and it is used to shape the light beam in the far field.

Reducing UV propagation losses

The Ghent University-imec team addressed the challenges of realizing low propagation losses in the UV, which presents a considerable challenge in UV chip-level operation. Many conventional optical materials used in PIC fabrication have higher absorption in the UV range. This means that a significant portion of the light is absorbed as it propagates through these materials, resulting in higher losses. In addition, waveguide surface structure is highly consequential at the nanoscale, with roughness causing scattering and the absorption of light. Because scattering losses scale as the reciprocal of the wavelength to the power of four, sidewall roughness also becomes a critical parameter in the UV. Further, the UV-transparent material must be compatible with standard semiconductor manufacturing processes to support the prospect of large-scale production.

Alumina, or aluminum oxide (AlOx), is one promising option as a core waveguide material. It is compatible with large-scale manufacturing, and it theoretically has good optical transparency down to at least λ = 250 nm.

In its investigation of this material, the Ghent University-imec team showed that the high-temperature deposition of the AlOx layer via atomic layer deposition (ALD) coupled with an optimization of the etching process achieved propagation losses as low as 3 dB/cm at 360 nm in 800-nm-wide waveguides fully etched in 120-nm-thick AlOx layers, as shown in Figure 2.

Breaking the field-of-view barrier

In tests, the developed UV-PIC enabled imaging of a field of view as large as 150 × 200 µm — a 22-fold improvement over the group's previous work — and achieved an optical resolution enhancement factor of 1.84 compared to conventional visible light microscopy.

In combination with the UV-SIM technique, the researchers believe that the solution can be used to overcome the impasse that exists between optical resolution and field of view: Increasing field of view means resolution losses, and vice versa. In tests, the researchers used the design incorporated into the SIM setup, in a label-free, far-field, and wide-field (WF) configuration, to observe features in yeast cells that are otherwise invisible with standard WF microscopy.

Pushing boundaries

The study of large ensembles of bacteria or cells is a viable “killer application” for UV-SIM; incorporating PIC technology could further enable UV-SIM to provide similar benefits to flow cytometry for such study, for example. Traditional flow cytometry enables users to probe cells or particles, though only once. This inhibits users from charting the evolution of the same particle over time.

In contrast, with a vast field of view, a user could image up to hundreds of thousands of particles simultaneously and measure the evolution of seed cells or bacteria over time, and under various experimental conditions, such as upon the addition of nutrients or pharmacological substances. In addition, as UV light induces a strong autofluorescent signal, UV-SIM avoids the requirement of cell labeling.

Still, R&D advancements have not resolved all challenges. Photobleaching, which causes autofluorescence intensity to decrease gradually over time when exposed to light, thereby increases the amount of noise present in the final image and can reduce image quality.

Another microscopy approach, quantitative phase imaging (QPI), could be used to resolve this effect. QPI provides detailed information about cellular morphology and dynamics without relying on fluorescence, and as a result provides high value for the study of live cells and tissues. Ultralow noise UV-QPI would bypass photobleaching and enable the imaging of bacteria or single-atom-thick monolayer materials, such as graphene.

Decreasing wavelength and chip sizes

The current iteration of laboratory-demonstrated UV-PICs operates at 360 nm, exploiting the ultraviolet-C (UV-C) range between 200 and 280 nm, and introduces a considerable range of potential applications. This is due to the stronger interaction of lower-wavelength

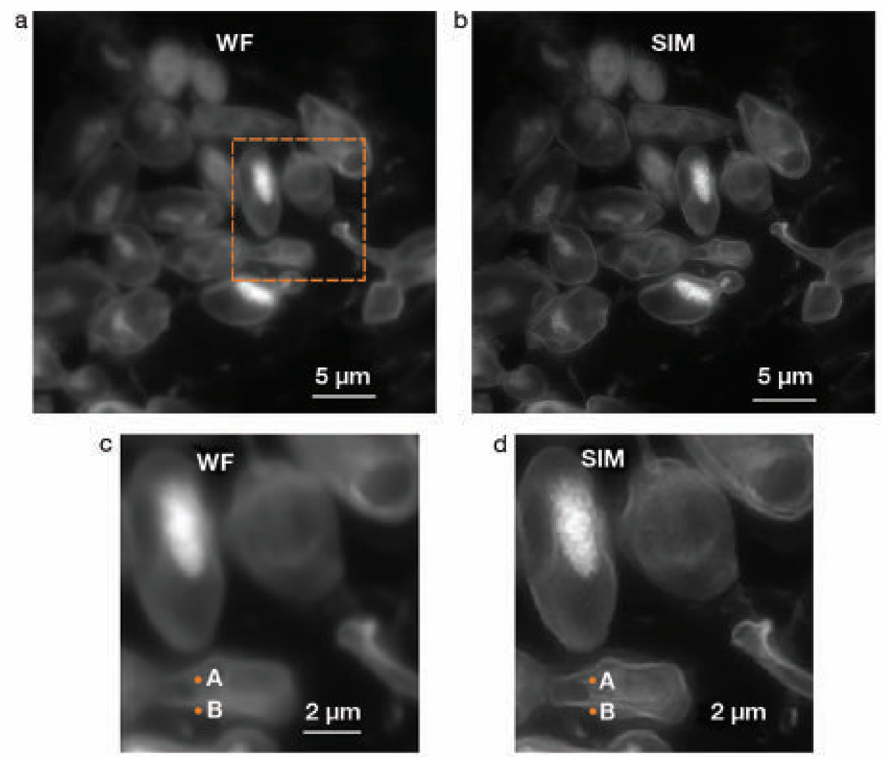


Figure 3. The ultraviolet photonic integrated circuit (UV-PIC) chip enables the observation of features in yeast cells that are otherwise invisible with standard wide-field (WF) microscopy. The images were obtained via structured illumination microscopy (SIM) in a label-free, far-field, and WF configuration. Autofluorescence images of a coenzyme in yeast cells under UV-SIM and standard WF microscopy **(a,b)**. Zoomed-in images of the area delimited by the orange rectangle **(c,d)**.

UV light and biological molecules. imec is investigating new waveguide designs and the integration of low-loss materials, such as silicon oxide.

At the same time, the joint researchers aim to make increasingly compact PICs by integrating the UV light source on-chip. For 360-nm light, this includes the development of an ALD-AlOx platform on-chip for sensing and quantum applications. Additionally, in a collaborative European Union-funded initiative, the researchers will investigate transfer-printing aluminum gallium nitride sources on-chip.

At deep-UV wavelengths <280 nm, on the other hand, light beams possess even higher energy levels and will require specialized materials and manufacturing processes. Semiconductor UV-C lasers are at a very early stage, and further research is needed to increase the compactness of PICs for UV-C applications.

Meet the author

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TriEye's detection and ranging platform delivers 2D and 3D SWIR images. The company combines the advantages of SWIR imaging with an approach that aims to overcome challenges that traditional windshields face for assisted and fully autonomous driving.

TriEye

Thermal Imaging Solutions Mitigate Risks to Pedestrian Safety

Infrared sensing and camera technology offer support as regulators push proposals for nighttime pedestrian automatic braking systems and improved outcomes on roadways.

BY JAMES SCHLETT
CONTRIBUTING EDITOR

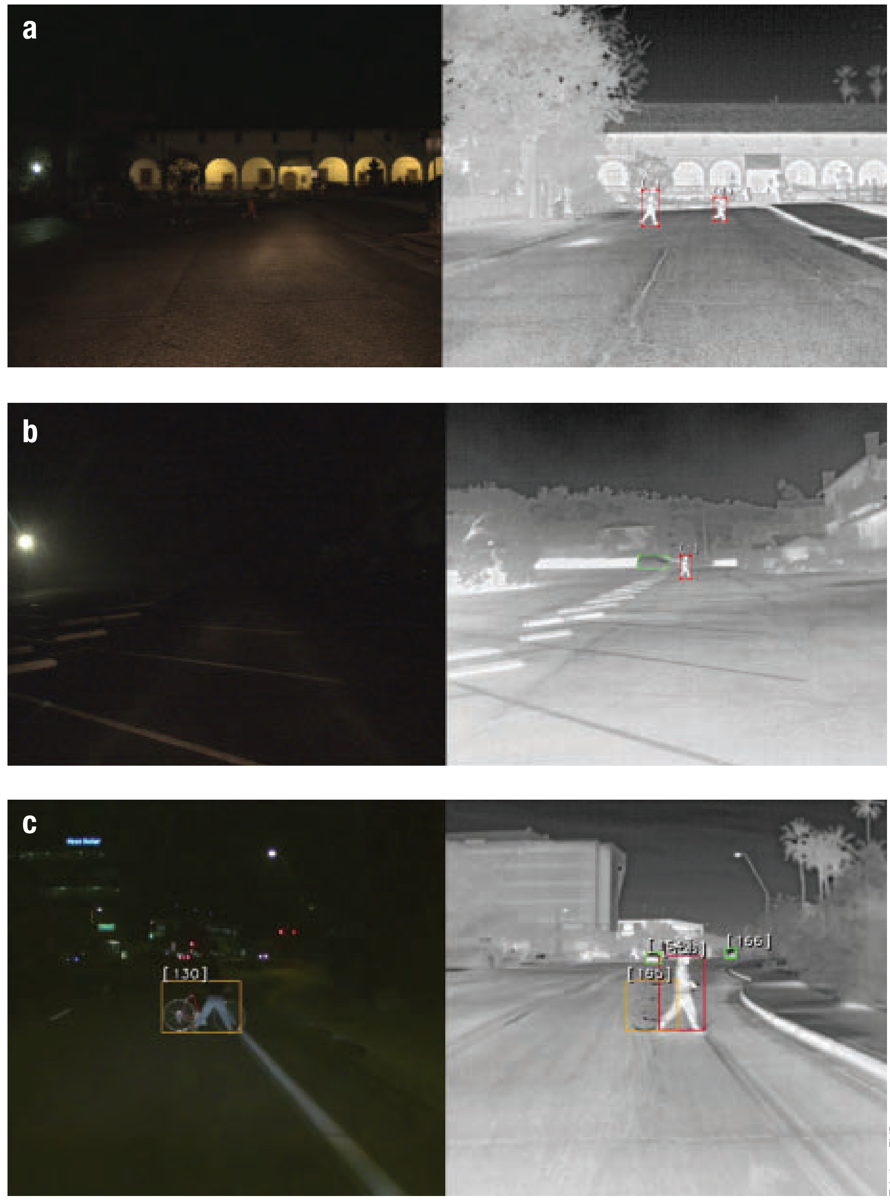
According to data from the National Highway Traffic Safety Administration (NHTSA), more than 75% of automotive-related pedestrian fatalities in the U.S. in 2021 occurred at night. This value is hardly an outlier. Nighttime pedestrian fatalities in the U.S. increased at a rate of more than 3× that of comparative daytime incidents since 2010, per the Governors Highway Safety Association.

As investigations into the causes of this disparity are ongoing, prospective solutions built on IR sensor-enabled advanced driver-assistance systems (ADAS) are ramping up, with the aim to help reduce nighttime pedestrian fatalities. For developers of IR sensors and cameras, the race is on to position SWIR and LWIR technologies for mass adoption by the automotive industry.

Regulations and technologies

This spring, the NHTSA finalized a federal motor vehicle safety standard that would make automatic emergency braking (AEB), including pedestrian AEB (PAEB), standard on all passenger cars by September 2029. Around one year earlier, the agency proposed a set of standards that would govern PAEB nighttime detection. Under these proposed rules, new lightweight vehicles must be equipped with PAEB systems that can enable nighttime drivers to avoid hitting other vehicles when traveling at 62 mph (~100 km/h) and to avoid hitting pedestrians when traveling at 37 mph (~60 km/h).

A car equipped with PAEB traveling at 37 mph would need ~148 ft (45 m) to come to a complete stop. The detection of a pedestrian at this distance, at a high level of confidence, can be achieved with a low-resolution thermal camera (<0.1 MP). According to Sebastien Tinnes, global market leader for IR detectors designer and manufacturer Lynred, a 12-µm pixel pitch quarter video graphics array resolution thermal camera (320 × 240 pixels) can fulfill all the NHTSA's proposed PAEB requirements.



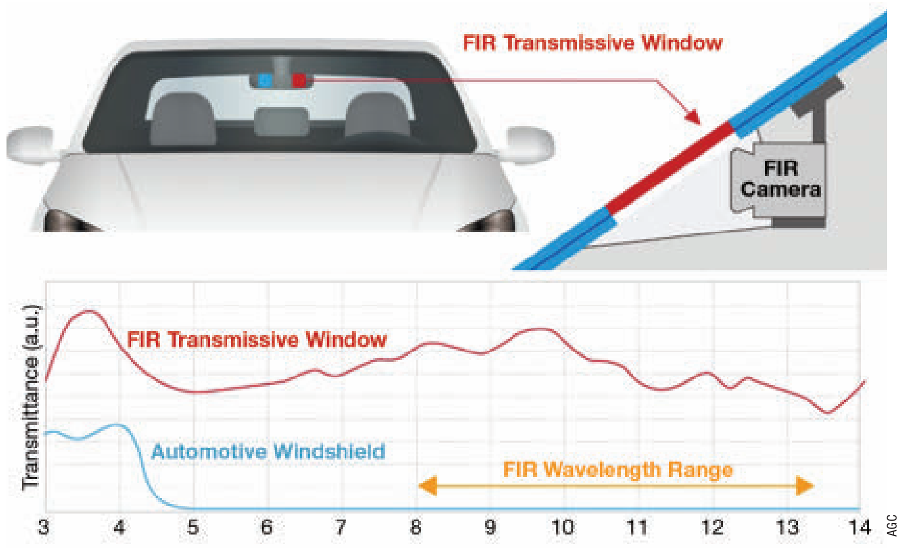
Teledyne FLIR

A comparison of nighttime driving imaging with visible **(left, a-c)** and thermal cameras.

Sensors and cameras are the principle photonic technologies at the heart of the undertakings of the NHTSA as well as of comparable agencies worldwide. And, currently, thermal imaging and lidar are the two modalities at the fore of meeting the proposed PAEB standards. But other technologies in this conversation must be considered. The ADAS in most vehicles primarily use radar. Some also include visible cameras.

Strengthening synergies among detection technologies will be the key to meeting the NHTSA's targets. While ADAS, for example, are effective during daytime hours with clear weather conditions, their efficacy in preventing accidents involving pedestrians diminishes in poor weather and dark driving conditions.

Lidar, on the other hand, is an expensive solution compared to similar technologies. Also, many current iterations struggle to make identifications and classifications of living objects, espe-



AGC has developed a windshield that fuses traditional glass with a material capable of transmitting far-IR (FIR) wavelengths.

cially in crowded urban environments, said Ezra Merrill, senior director of marketing at Teledyne FLIR for OEMs and emerging markets.

"An additional sensor is needed to address nighttime and poor weather conditions," Merrill said.

"As a result, Teledyne FLIR is seeing a significant increase in demand from automotive OEMs that understand the need to expand sensing capabilities to pass upcoming testing standards in review with the NHTSA. In many cases, this means adding a thermal camera to the existing visible-and-radar fused solution."

Sensor fusion is an established concept for automotive, bringing the strengths of multiple modalities together in a common system or application. Fusion in the context of ADAS, however, is still evolving. Last fall, Teledyne FLIR announced that its thermal cameras were operating in Ansys' sensor simulation software. Teledyne FLIR also partnered with Valeo to deliver thermal imaging technology for night-vision ADAS. The system at the heart of this collaboration will use Valeo's ADAS software stack to support functions, such as nighttime AEB, for passenger and commercial vehicles as well as autonomous cars.

Teledyne FLIR's upcoming automotive-grade thermal camera will be less than half of the size and weight of its previous generation. At a pixel resolution of 640 × 512, the automotive thermal cameras' resolution standard is equal to video graphics array resolution and is 4× greater than the pixel count of previous thermal-enhanced driver-aided systems, Merrill said.

Comparisons between the technical and performance capabilities of thermal sensors and their visible counterparts feed into additional considerations.

"Combined with the reduced pixel count needed, thermal sensors can be smaller than visible sensors and come closer to visible sensor prices," Tinnes said. For its part, Lynred plans to introduce a product that brings the pixel pitch down to 8.5 µm within the next two years.

SWIR and LWIR

Many of the technologies that factor into autonomous mobility and automotive safety systems are well established. Sensing and imaging in the SWIR band, for example, is often favored in harsh environments and nighttime settings. This method delivers high-resolution images in these challenging environments. Solutions for industrial manufacturing, surveillance, counterfeiting detection, and food inspection rely on SWIR sensing and imaging.

Israeli startup TriEye is developing a CMOS-based SWIR sensing solution for ADAS. TriEye's detection and ranging platform leverages a CMOS-based high-definition SWIR sensor and merges the functionalities of a camera and lidar into a single modality that delivers 2D and 3D mapping capabilities.

Unlike LWIR sensors, TriEye's SWIR technology can be positioned behind the standard glass of windshields and headlamps. Windshield glass is opaque to LWIR light, which means that system integrators are unable to place many thermal cameras behind standard windshields since the incoming and perceived light inhibits their use in nearly all conditions.

"The compatibility of SWIR camera outputs with existing computer vision algorithms streamlines the integration process, avoiding the need for extensive training of new deep learning algorithms — a requirement for thermal camera systems due to their unique heat-based imagery," said Nitzan Yosef Presburger, head of marketing at TriEye. Presburger said that SWIR illumination, compared to MIR and LWIR illumination, makes it less susceptible to external environmental conditions. SWIR cameras also rely on a photodiode effect that produces detailed views of scenes that are unlike those based on the thermal differences measured by the bolometric sensors that are commonly integrated into LWIR cameras. Further, thermal imaging's extended wavelength, ~10 µm, can compromise resolution by enlarging pixel sizes and physically constraining pixel density. The bigger pixels also contribute to thermal cameras' need for larger lenses, compared to their visible light counterparts.

In this way, TriEye's technology aims to circumvent the challenges posed by traditional windshields while also leveraging the advantages of SWIR imaging.

Despite these advantages, SWIR solutions may be expensive, and, according to Merrill, these cost concerns are largely driving automotive industry customers away from SWIR and toward LWIR. SWIR sensing and imaging's reliance on active illumination also makes it vulnerable to the potential for a living light source, whether a person or animal. The additional light sources required to support SWIR sensors add cost to existing solutions as well as power concerns, in some cases.

"If all cars are equipped with SWIR illuminators, it leads to the same effect

TriEye

Windshield glass is opaque to LWIR light, which means that system integrators are unable to place many thermal cameras behind standard windshields. TriEye's SWIR technology can be placed behind windshields as well as headlights.

Nighttime detection with combined visible and thermal imaging. ADASKY's shutterless LWIR camera is designed to withstand harsh requirements: −40 to 85 °C.

as headlamps for a visible camera: The camera is bloomed by other illuminators from other vehicles," Tinnes said.

According to Presburger, frequently occurring conditions that may affect the performance of a SWIR sensing solution include the presence of sand or chemicals. In response, TriEye is developing advanced filtering and predictive analytics to minimize effects of severe conditions.

LWIR properties and windshield worries

Since they cannot achieve their desired function in or behind a standard windshield, system integrators have historically placed LWIR thermal cameras on the grills of cars. There, the cameras cannot benefit from windshield wipers that clean water and debris from the lens, although hydrophobic coatings, air blasts, and/or spray nozzles are often used to clear the window for such exterior-situated thermal cameras, according to Merrill.

In response, several suppliers to the automotive industry have developed LWIR-conducive windshields. Last September, for example, Lynred, in collaboration with Saint-Gobain Sekurit, unveiled a design that integrates a visible and thermal camera. This windshield features a small area that is transparent to longwave radiation. The windshield enables a sensor fusion that improves daytime detection rates, via redundancy, and extends the PAEB's nighttime operational design domain. The collaborators showcased a third-generation windshield with improved integration at AutoSens USA 2024 in Detroit, Tinnes said.

The solution found by Lynred and Saint-Gobain Sekurit followed Tokyo-based glass technology company AGC's development of a far-IR (FIR) sensor-enabled windshield. Windshields are typically comprised of a single material and subjected to strict standards, including those that govern reliability and safety. The introduction of a FIR-conducive material posed several challenges, such as ensuring that it could resist scratching from water drops mixed with sand and withstand ultraviolet light damage. To overcome these challenges while also minimizing shine, AGC developed an optical coating film. The company expects to begin integration of the FIR windshields into new vehicles in 2027.

Athermalization effects

Especially in terms of robustness, many LWIR cameras benefit from designs that optimize these imagers for military use. However, these cameras may not offer levels of adaptability that make them suitable for the wide temperature ranges demanded by automotive standards, said Raz Peleg, vice president of business development at smart thermal sensing technologies developer ADASKY.

This quality makes athermalization, or the consistent performance in varying environmental conditions, critical, he said.

ADASKY has developed a shutterless LWIR camera that is designed to withstand the harsh automotive requirements of −40 to 85 °C (−40 to 185 °F). ADASKY's camera weighs <50 g and is sized at 26 × 44 mm. Similarly, Teledyne FLIR's forthcoming automotive thermal camera is specified to operate athermally from −40 to 85 °C ambient temperature, Merrill said.

However, ADASKY has designed its solution to be located outside the vehicle. It is envisioned to be paired with a heated lens to prevent frost.

“LWIR is a camera-based modality. The camera needs to stay clean, and the OEM is responsible for cleaning it,” Peleg said. He said that the small size of the camera supports high mounting, such as on the roof of the vehicle. This positioning would help to minimize the effects of debris and reduce damage, according to Peleg.

Though the ADASKY and Teledyne solutions differ in the specifics of how they are to be deployed, both reflect the advantages of harnessing the LWIR band for automotive. According to Merrill, tests conducted at Sandia National Laboratories’ fog facility in 2021 showed that LWIR sensors provided the best overall visibility through various fog types and densities. The Teledyne FLIR-Sandia tests compared LWIR results to those obtained via visible, MIR, SWIR, and lidar sensors.

> Since they cannot achieve their desired function in or behind a standard windshield, system integrators have historically placed LWIR thermal cameras on the grills of cars.

AI-enabled

Whether the automotive thermal cameras are integrated inside or outside the windshield, they still face cost challenges. As designers pursue cost-effectiveness, autonomous intelligence, a subset of AI, is already making inroads in that direction.

Chuck Gershman, CEO and cofounder of Owl Autonomous Imaging (Owl AI) in Fairport, N.Y., said that the three biggest roadblocks facing cost reductions to thermal cameras are converters that turn sensor analog outputs into digital data; the processor that subjects the sensor data to nonuniformity corrections; and the need to provide flat image data via a mechanical shutter for defining the correction factors.

Owl AI has developed a thermal HD camera system that performs the necessary digitization and corrections in a readout circuit in a semiconductor layer below the microbolometer array. As a result, the mechanism bypasses the costs that are typically associated with a mechanical shutter. This design also supports improvements in resolution that are most straightforward, reducing the need for high amounts of circuitry around the sensing area. While most LWIR cameras perform digitizing, correction, and interfacing in circuitry on several PC boards, Owl AI’s design leverages the sensor device to perform many of those functions. This supports a single-board camera with designs similar to its visible light counterparts.

“Properly executed internal corrections for nonuniformity and temperature remove the need for additional preparation of the image for the classification and range-finding tasks,” Gershman said. “AI, therefore, is needed only for tasks directly related to extracting the data used by the ADAS, not for fixing bad images.”

Owl AI’s software identifies hundreds of objects at frame rates of 30/s. Currently, the AI can identify several types of objects, including pedestrians, cyclists, some animals, and various types of vehicles. It can accurately process thermal signatures to ~40 m, and Owl AI aims to extend that range to 180 m with its next-generation system.

At the same time, ADASKY’s shutterless LWIR offering has also incorporated generative AI in its synthetic thermal data set. This incorporation has enabled the company to advance detection (≥100 m) as well as classification.

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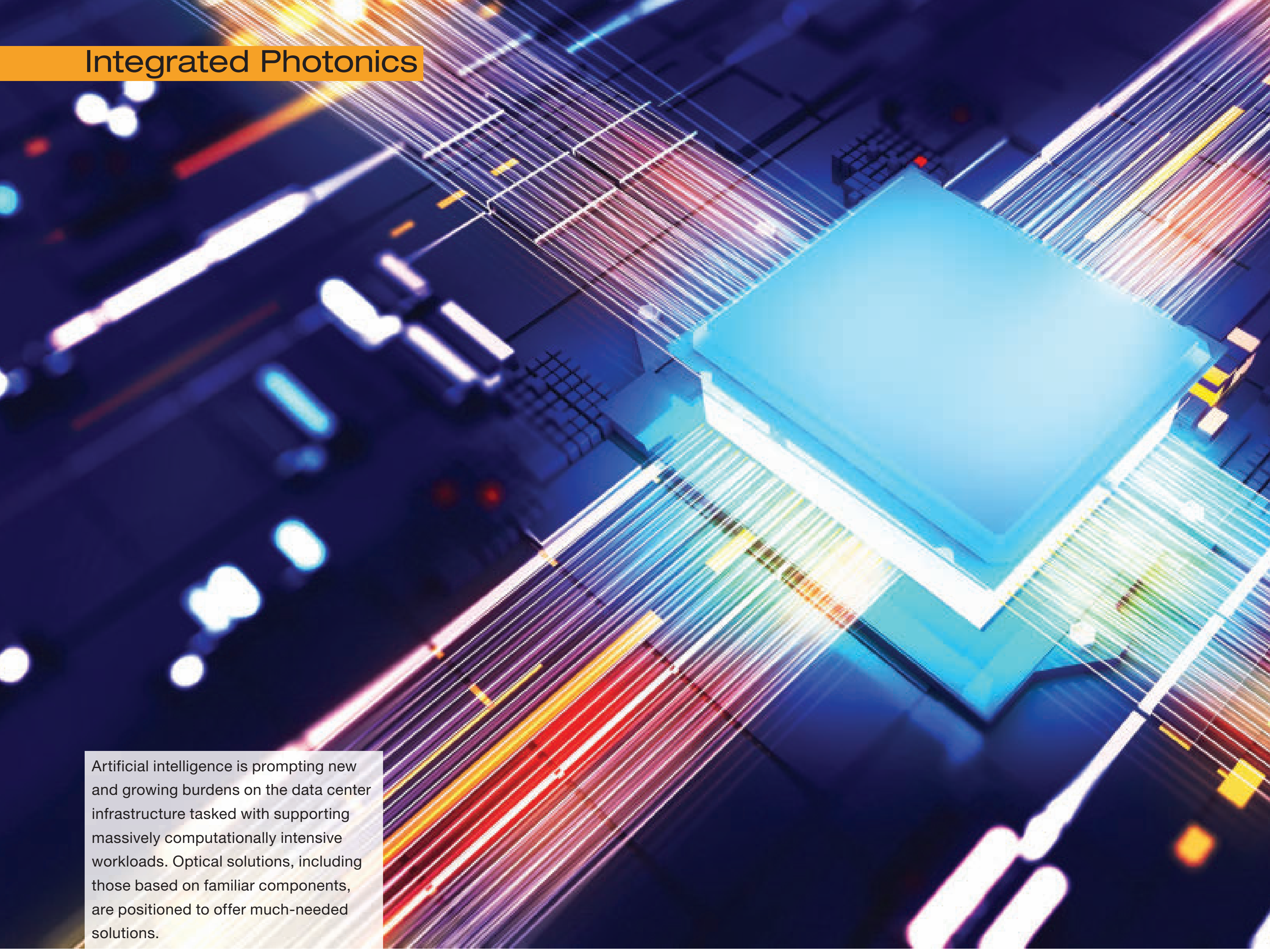


Artificial intelligence is prompting new and growing burdens on the data center infrastructure tasked with supporting massively computationally intensive workloads. Optical solutions, including those based on familiar components, are positioned to offer much-needed solutions.

In the All-Data Revolution, Optical Solutions Advance Beyond PICs

With the modern AI workload intensifying, integrated photonics offers a promising solution with an eye toward the future of work.

Images courtesy of NewPhotonics.

BY YOSEF BEN-EZRA
NEWPHOTONICS

As the field of integrated photonics has transformed from one of theory into one of practice, rapid progress in materials science, device design, and manufacturing processes in the past two decades has helped drive the commercialization of PICs for various applications. Today, photonic integration is characterized by multiple photonic components integrated onto a single chip. These highly efficient, compact, and versatile devices represent a new frontier for advanced optical signal processing (OSP) and communications.

Accordingly, the possibilities for these miniaturized photonic devices to transmit, manipulate, and process information have advanced beyond delivering data at unprecedented speeds. Emerging PIC innovations include heterogeneous integration of varying materials and technologies, ultrasecure compute quantum photonics, neuromorphic photonics, and packaging. Each of these innovation subfields exists outside the bounds of ultrafast data and telecom, combining high levels of performance, reliability, and scale to deliver next-generation technology.

Advancements in these areas also carry the potential to extend beyond a core focus area of high technology today: the AI workload.

Yet, much of the current focus on applying this transformative technology is tied to addressing existing bottlenecks and processes — as opposed to the dynamic data management, processing, and networking challenges that are forthcoming. Currently, the predominant goal is to use PICs to break down legacy processes and infrastructure barriers that are limiting on-pace growth of data-driven AI workloads and use cases. This high-level focus comes as AI revolutionizes industries at a global scale, placing an ever-growing burden on data center infrastructure to support computationally intensive workloads.

Meanwhile, the broader optical realm is charting a more immediate and sustainable path. In its aim to replace electrical dependence, its most obvious targets are the latency and power imperatives facing data connectivity for compute and transmission.

Photonic integration in the era of AI

Amid the present AI workflow, achieving low-latency inference with effective sub-millisecond response times is a primary concern. Real-time decision-making for AI-powered applications, as well as for autonomous vehicles and applications involving interactive user experiences, necessitates stringent infrastructure requirements. The complex computations and large data sets involved in AI inference can introduce significant latency, especially as models become more sophisticated. Strategies to address this latency challenge include using specialized hardware accelerators, implementing edge computing architectures that bring the processing closer to the data sources, and optimizing software and algorithms.

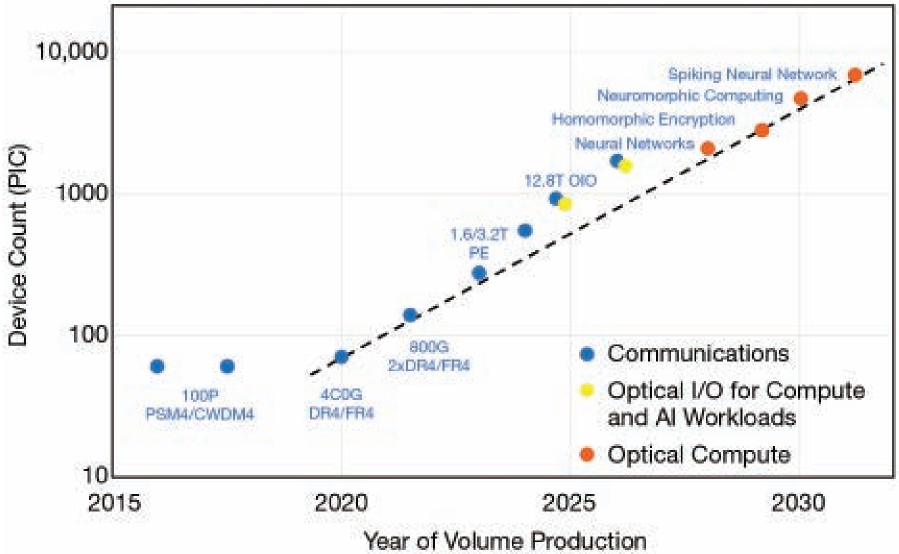
A parallel concern is energy consumption of AI workloads: The computational intensity of these applications leads to significant power draw and cooling requirements. Data centers must simultaneously reduce energy usage and carbon footprint without compromising the delivery of the processing power and performance that AI workloads demand.

Data centers themselves also face increased challenges in physical space and resource use. Traditional server racks and computing infrastructure may not — and, in fact, are unlikely to — accommodate the high-density computing requirements of modern AI applications. As data centers seek ways to pack more AI processing power into limited physical spaces without sacrificing efficiency, cooling, or power distribution, they rely on density and efficiency of not only packaging but also technology innovation in the design and deployment of optical components.

PICs are a cornerstone of the ongoing data revolution. At the same time, emerging optical solutions and systems are poised to push boundaries even further to deliver advantages over both traditional electronics- and PICs-based systems. These performance gains will yield higher bandwidth, lower latency, and improved energy efficiency.

The PIC and beyond

The exponential growth of data-intensive applications spurred by the rise of cloud computing and cloud-based services, as well as big data, generative AI, and Internet of Things sensors, among other contributors, has stressed the limits of traditional electrical interconnects. These mechanisms rely on copper wiring and electronic switching and have struggled to keep pace with the insatiable demand for faster, more efficient data transmission. Combined with the physical limitations of miniaturization, these challenges have driven the search for alternative solutions that can overcome the inherent



A forward-looking perspective and projection on scaling optics on silicon, with increased on-chip functionality via increased component integration for datacom pluggable modules.

constraints that electrical systems commonly present.

Within this context of increasing demand for higher performance, energy efficiency, and functionality, PICs and silicon photonics have more broadly become viable alternatives. PICs have delivered major improvements in size, cost, and performance compared to discrete optical components.

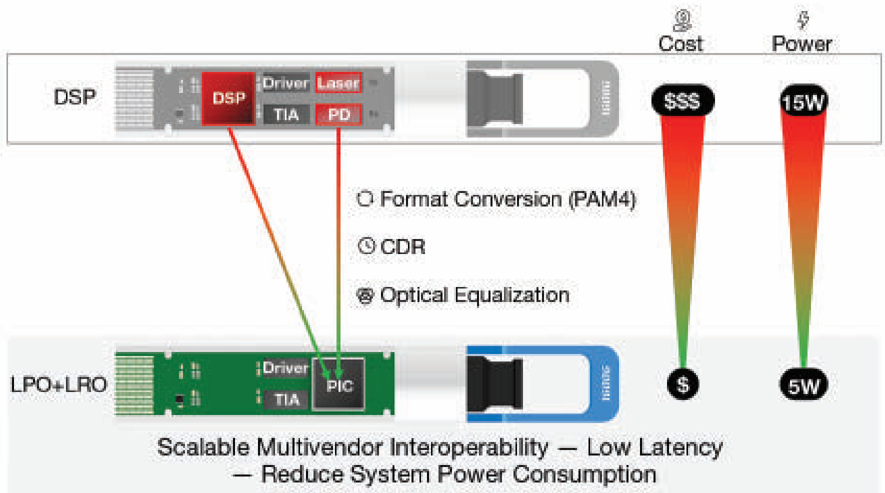
In focusing on more than just the PIC element, the functionality of optical interconnects offers a promising solution to the limitations of electrical interconnects. Optical signals are immune to electromagnetic interference, allowing for higher-bandwidth and lower-latency data transmission. Moreover, optical components are inherently more energy-efficient, because they do not suffer from the same heat generation and power consumption issues as their electronic counterparts. This makes them particularly well suited for high-speed data transmission, real-time signal processing, and low-power applications.

Optical systems can also operate in harsh environments, making them ideal for industrial, defense, and space-based applications. Plus, integrating optical and electronic components on a single chip already enables the development of compact, multifunctional devices that can perform a wide range of sensing, imaging, computing, and communications tasks. From reconfigurable optical devices to heterogeneous integration and quantum optics, these advancements will enable high-speed, energy-efficient, and versatile optical systems that will be transformational across industry sectors.

The advantages to optical interconnects emerge as limitations to traditional PICs are increasingly apparent, particularly for use in telecom, data center, and sensing systems. Existing PICs face challenges in packaging and thermal management. Further, the rigid, planar nature of traditional PIC architectures often limits the ability of a PIC to fully exploit the potential of nonlinear optical effects, such as for advanced functionalities in signal processing, sensing, and frequency conversion. And, integrating electronic and photonic components on a single chip has proved to be a significant technical hurdle. In many cases, it has lead to suboptimal performance and increased complexity.

Linear-drive pluggable optics

Linear-drive pluggable optics (LPO) represent an early and effective use of PICs to reduce power consumption and cost while meeting the demands of high-speed, high-density optical communication connections. Using a linear drive approach to replace power-hungry and expensive digital signal processors (DSPs) with PICs demonstrates many



The implementation of optical pluggable transceivers in the all-optics paradigm promises to deliver improved performance as well as reduced power and latency. Such a solution also supports multivendor interoperability. CDR: clock and data recovery (circuit); LPO: linear-drive pluggable optics; LRO: linear receive optics; PD: photodiode; TIA: transimpedance amplifier.

of the efficiencies in PIC design to date; users are now using integrated photonics capabilities to perform functions previously implemented via CMOS-based DSPs. In these deployments, the PIC(s) function(s) to drive the optical modulators with enhancements, such as optical equalization.

The advantages of using LPO technology, especially in datacom and telecom, are considerable. LPO technology allows users to achieve low latency when replacing DSPs with PIC-based optical signal processors using linear modulators with channel equalization functionality. As a result, systems can achieve reduced power consumption by at least 50% compared to pluggable optical modules. An LPO approach can also significantly reduce overall materials costs. LPO-based designs support streamlined pluggable packaging, thereby simplifying any subsequent updates and/or scaling.

Critically, replacing DSPs with OSP mitigates link performance challenges and facilitates multivendor interoperability.

Yet, interoperability remains a limiting factor to the adoption of LPO. Due to the variation in channel characteristics, interoperability requires comparable signal processing capabilities. Still, this bottleneck has sparked some of the most significant contributions to OSP.

Meeting challenges

Remaining challenges must be addressed on several fronts to continue scaling true all-optical solutions. For one, integrating optical components, such as lasers, modulators, and detectors, onto a single chip continues to present significant technical challenges. Scaling all-optical systems to support the growing demand for bandwidth and processing power also requires overcoming obstacles related to the efficient distribution and routing of optical signals as well as managing the interconnectivity between the optical components that a system may use. Although optical components can be more energy-efficient than their electrical counterparts, the overall consumption of all optical systems, including the required supporting infrastructure, must be carefully managed to maintain the advantages of these technologies.

Reliability and stability pose additional challenges. Despite their operability in extreme environments, temperature fluctuations and vibrations can limit optical system performance. This is noticeable especially for mission-critical applications.

For these reasons, the widespread adoption of all-optical interconnects and systems will require a collaborative effort from stakeholders in the research and engineering communities as well as industry. Continued progress to optical component technology, integration techniques, and system-level design will be crucial to bringing these transformative technologies further into the mainstream. It must also be coupled with the development of scalable, cost-effective manufacturing processes.

In the face of these challenges, researchers and engineers pursuing integrated photonics and other optical solutions are exploring a range of approaches. These range from the use of advanced materials — wide-bandgap semiconductors and 2D materials — to the development of 3D-integrated photonic architectures, which use the third dimension to enhance device density, improve optical routing, and better exploit nonlinear optical phenomena. Additionally, integrating microelectromechanical systems (MEMS) and reconfigurable optical elements has introduced new levels of tunability and adaptability to optical systems.

Combining advancements in these emerging technologies with advancements in photonic-electronic codesign and the latest packaging solutions indicates that the optical industry is poised to unlock an era of high-performance, energy-efficient, and versatile integrated photonic systems. As the industry moves forward, and as innovations in signal processing and networking become increasingly vital, a clear road map of technological progress, standardization efforts, and collaborative research will benefit all constituents.

The heart of PIC innovation

Integrated and silicon photonics have made significant contributions to the wider field of photonics and can be critically applied to the challenges ahead. Companies in the ecosystem are developing groundbreaking technologies such as high-speed optical transceivers, compact and energy-efficient photonic chips, and sophisticated sensing solutions. By leveraging their agility and creativity, early commercial entities are often able to bring these cutting-edge technologies to market faster than larger players who may also be more established in the marketplace.

At the same time, big industry is increasingly collaborative and eager to build on the agility and creativity of early innovators. This serves to push progress in a mutually beneficial ecosystem that is necessary to reach the full potential of all-optical integration. Meanwhile, others in the integrated photonics and silicon photonics space are applying rapid prototype, iterate, and novel technology approaches to this market, which is still in a phase of explosive development. Furthermore, companies are identifying still-unmet needs while simultaneously applying solution concepts that push the boundaries of what is possible.

Meet the author

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Picosecond Sources Optimize Silicon Carbide Scribing for Device Fabrication

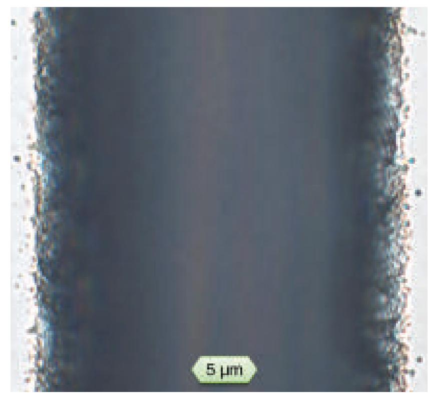
BY JIM BOVATSEK
MKS/SPECTRA-PHYSICS

With legislative and environmental considerations converging into powerful tailwinds, the e-mobility sector is a blossoming innovation area in all reaches of its value chain. Today, electric vehicle (EV) battery packs are scaling to higher voltages, achieving levels as high as 800 V in some cases.

This increase provides benefits including greater horsepower, improved efficiency, increased range, and faster charging times. Within the vehicle, power electronics devices convert high direct current voltage into the forms that various systems require. Traction motors, for example, require a three-phase alternating current. On-board chargers, meanwhile, dynamically adjust the current and voltage.

Despite its broad utility in many reaches of consumer and power electronics, silicon inflicts a bottleneck on this upscaling. Power electronics based on traditional silicon integrated circuits (ICs) do not work well with high voltages, temperatures, and switching frequencies.

As a result, manufacturers must turn to other semiconductor materials to realize



A close-up microscopic view shows that UV picosecond pulses in burst mode generate excellent edge quality, devoid of large chipping. Such a result is elusive for traditional mechanical saw processing.

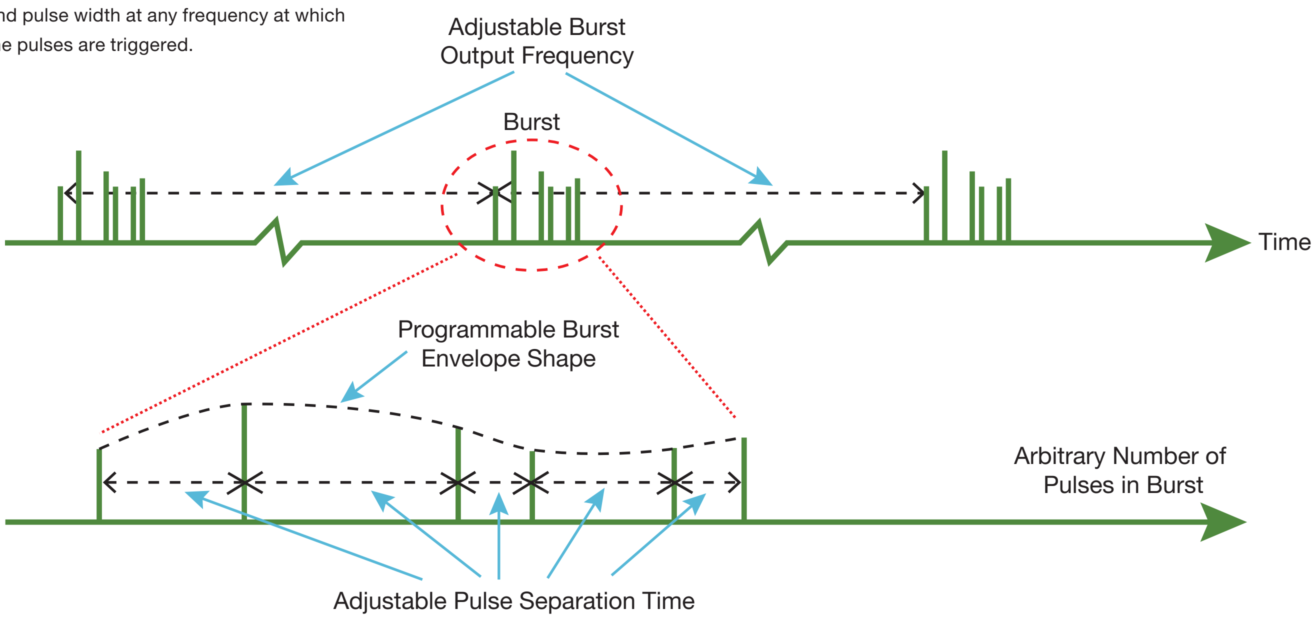


Figure 1. Both the temporal spacing and overall amplitude envelope of a pulse burst are controlled with precision. The system shown is an MKS/Spectra-Physics IceFyre UV 50 laser applying the TimeShift technology feature to achieve constant pulse energy and pulse width at any frequency at which the pulses are triggered.

All images courtesy of **MKS/Spectra-Physics**.

the full advantage of high voltage battery packs in EVs.

The single most promising alternative semiconductor is silicon carbide (SiC). This material offers characteristics that are almost ideal for EV power electronics, and, as a result, SiC holds the key to improving the performance and range of EVs as their popularity grows.

However, fabricating SiC devices is not without its own challenges. In a field in which established processes and protocols dominate, the mechanical, chemical, electronic, and optical characteristics of SiC differ significantly from silicon. The hardness of SiC, for example — the material is one of the hardest known materials, on par with diamond — makes wafer dicing using conventional mechanical methods, such as sawing, problematic. SiC is also a brittle material and chips easily when it is saw-cut. Additionally, SiC rapidly wears saw blades, including those fabricated with hard diamond, necessitating the frequent replacement of this costly consumable. Saw cutting itself is a relatively slow process and generates heat that is apt to negatively affect the material properties.

The combination of these obstacles creates a roadblock for EV manufacturers, since many proven IC fabrication processes do not work the same way, or work at all, with SiC.

Singulation, or wafer dicing, is a prime example; mechanical sawing, which is the dominant method for singulating silicon wafers, does not effectively translate to SiC. Though laser singulation is promising, substituting the materials translates to — at minimum — a changed set of parameters for the process. End users must also identify the optimal sources for SiC singulation compared to the conventional approach using silicon.

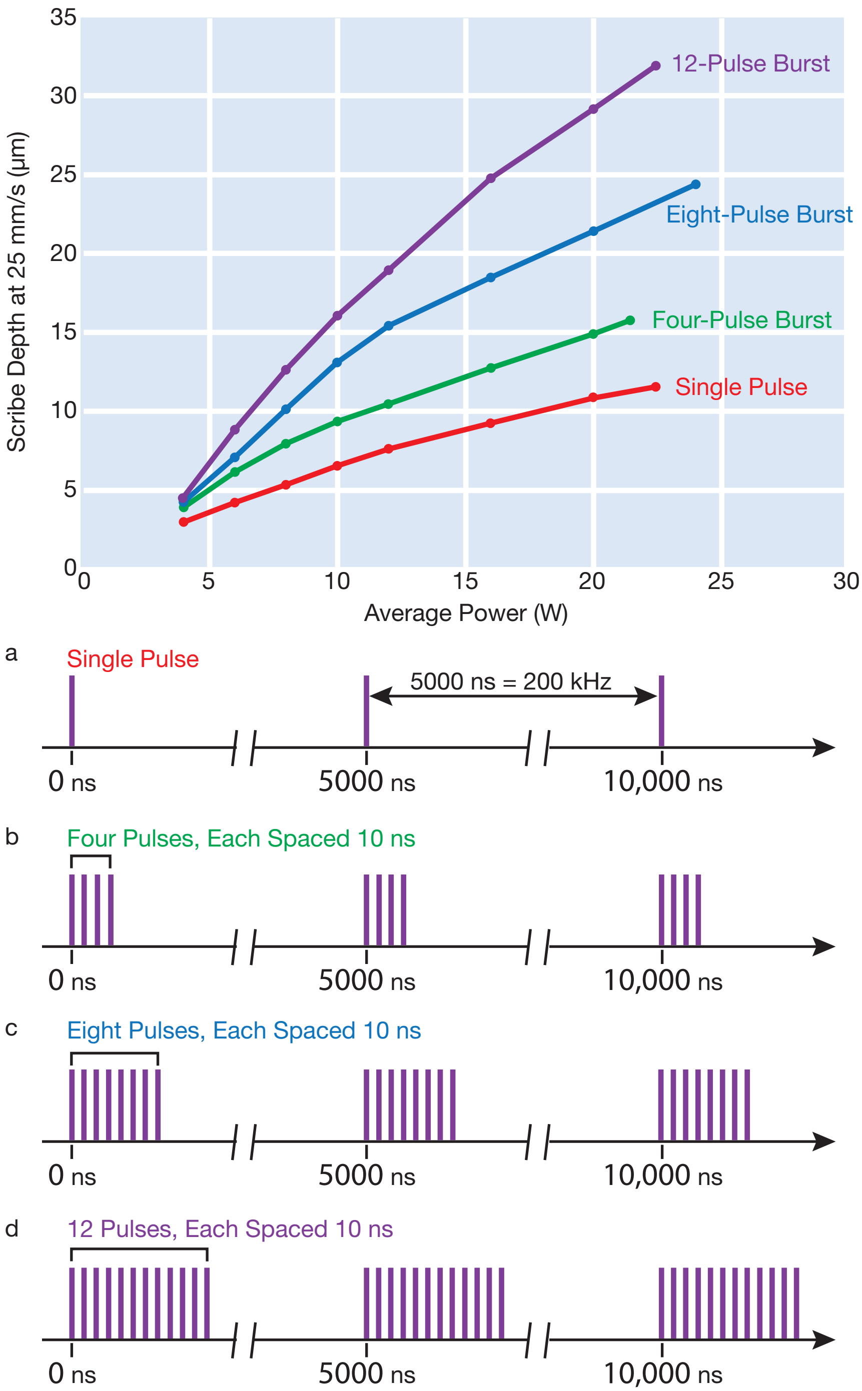


Figure 2. The depictions show scribe depth(s) for four passes at 25 mm/s as a function of power for single pulses **(a, top)** and various burst configurations **(b-d, middle and bottom)**. The data shows how pulse bursts improve ablation rates.

Picosecond laser ablation

SiC device fabrication is performed the same way as in traditional silicon microelectronics: Large numbers of individual ICs are created on a single wafer and then singulated into individual chips. These chips are then prepared for packaging.

The reduction or full elimination of edge chipping, versus mechanical sawing, is imperative when dicing brittle SiC wafers. Singulation should also cause minimal mechanical changes in the material. The minimization of kerf width should be prioritized, too, to limit the "street" size — the empty area between adjacent circuits — and thereby maximize the number of dies per wafer.

An engineer must balance these factors against cutting speed, yield, and other determinants that affect cost. The use of consumables such as coolants and clean-

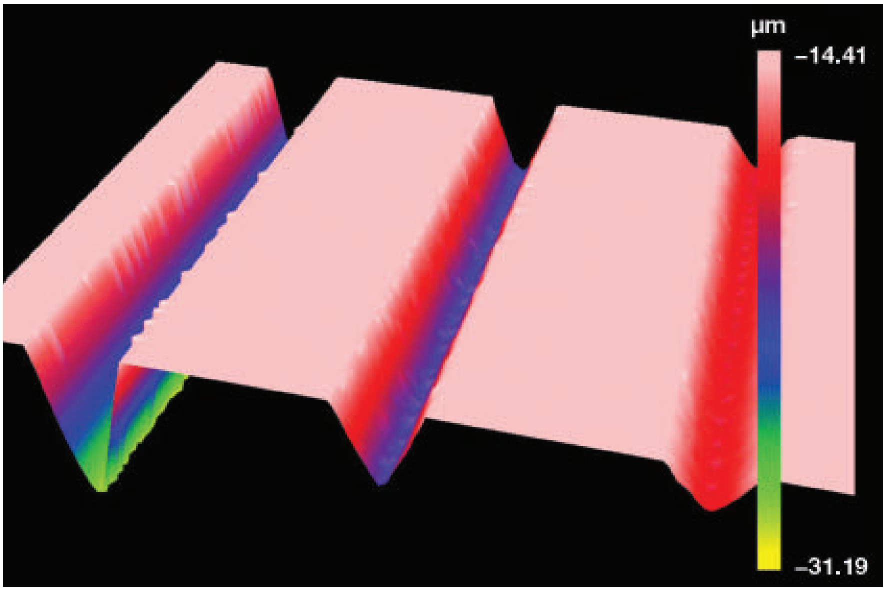
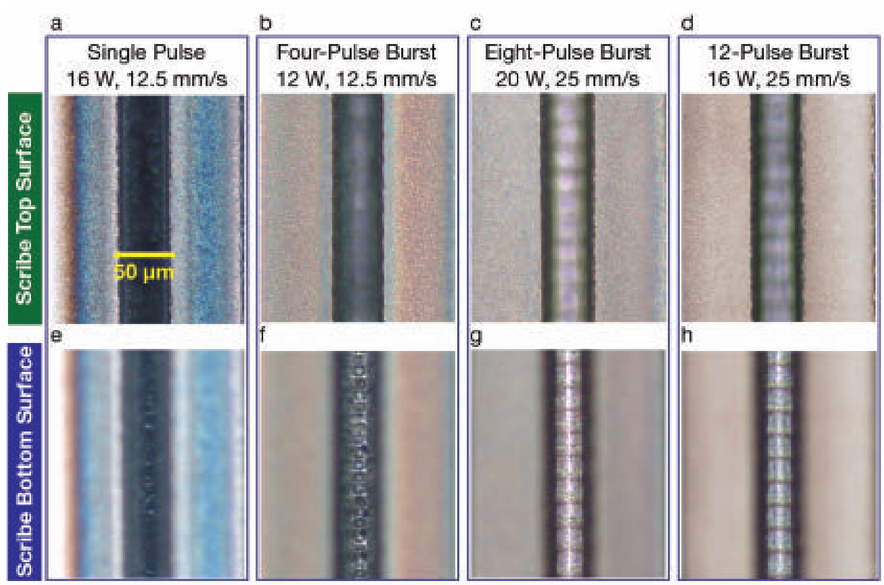


Figure 3. Scribes obtained with a scanning white light interferometer verify that the picosecond UV laser delivers clean, debris-free cuts **(left)**.

Figure 4. Close-up images of the tops **(below, a-d)** and floors **(e-h)** of 25-µm deep grooves. The grooves, at various values, show steady improvement in cut quality as the number of pulses in the burst increases.



ing fluids in the cutting process poses additional considerations.

Ultrashort-pulse lasers in the picosecond and femtosecond pulse width regime are established for high-precision cutting and ablation of many different materials, including hard, transparent, and/or brittle materials. Minimal bulk heating of the material and a negligible heat-affected zone (HAZ) are among the benefits of using ultrashort-pulse widths for processing. These sources also yield improved edge quality and less debris production compared with other classes of lasers.

The infrared output of most picosecond lasers can be frequency multiplied to deliver visible green or UV light, and the UV wavelength is often chosen for demanding applications. Sources operating in this band can typically achieve smaller focus spot sizes and an increased depth-of-focus, or Rayleigh range, at a given spot size.

These qualities make UV picosecond lasers a top choice for producing high aspect ratio features and thinner kerf width cuts with more precise depth control. Also, the larger depth-of-focus makes these sources easier to implement in wide-field galvanometer scanning systems. And the limited penetration of UV light further minimizes the HAZ.

Experimental setup

Still, achieving higher throughputs with short pulse widths and short wavelengths can be challenging in any setting. To ensure the repeatability of results in the context of SiC singulation, different system designs and parameters must be trialed. MKS/Spectra-Physics performed a series of cutting tests to evaluate the prospects for a UV picosecond pulse laser to deliver performance benefits, such as smaller focus spot sizes and increased depth of focus. These trials also sought to achieve physical advantages pertaining to ease of implementation and a decreased HAZ. Finally, beyond gauging the technical and economic viability of this process, these tests aimed to investigate how various pulse burst configurations might influence results.

In a first round of tests, samples of 340-µm-thick 4H-SiC wafers were processed with a 50-W, 355-nm picosecond laser. The laser offers >60-µJ maximum pulse energy and delivers 50 W of average power at repetition rates of 750 kHz to 1.25 MHz. It can be operated at a maximum of 10 MHz. Tests were performed at repetition rates between 200 and 400 kHz to ensure that all pulse output formats remained at similar levels of pulse energy and average power to enable a direct comparison of results.

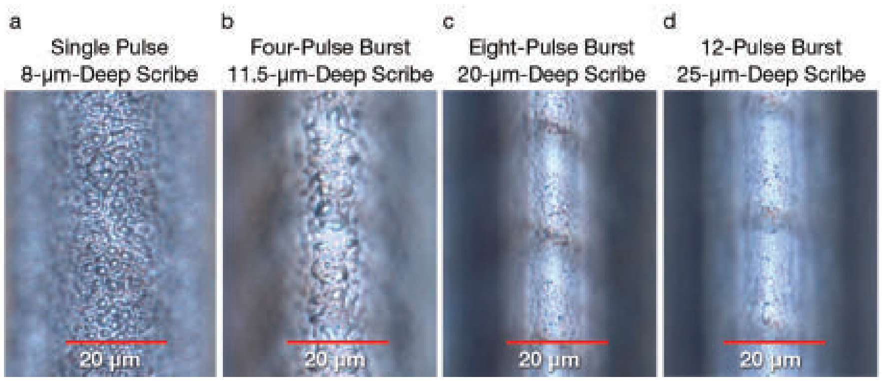


Figure 5. The extremely good edge/surface quality that can be achieved with picosecond UV laser processing serves to make the advantage of higher pulse count bursts visually evident **(a-d)**.

Discoloration around the scribe, which indicates a change in the surface or bulk material, shrinks and then disappears for higher pulse counts. The higher pulse counts also provided the best results at higher feed rates.

The picosecond laser was paired with a two-axis galvanometer scanner and a 330-mm focal length f-theta objective. The focus spot size at the work surface was ~30 µm ($1/e^2$ diameter). The scanner was operated at speed ranges between 2 and 4 m/s, and multi-pass scanning was used for each scribe, delivering net cutting speeds between 12.5 and 25 mm/s.

The laser used in these tests supported pulse bursts: The laser emitted a series of closely spaced burst subpulses, followed by a time gap before the next burst sequence. Although the laser-material interaction that occurs with pulse bursts remains an active field of investigative study, it has been well established in practice that pulse bursts can increase ablation rates and reduce surface roughness in many materials processing scenarios.

Moreover, the laser used in testing supported programmable pulse bursts. This means that the number of pulses in the burst, as well as the amplitude and the temporal spacing of each pulse in the burst, were controllable. Further, the timing jitter on the bursts was low enough to enable placement directly on the work-surface at levels of high precision, even at rapid scan speeds. These flexible pulsing capabilities enabled the exploration of a wide "process space" during testing.

Interpreting results

Figure 2 plots scribe depth values as a function of average laser power for various pulse burst configurations spanning a single pulse to a 12-pulse burst. For each test, the scribe was produced with a total of 80 passes over the same location on the material. Close control over the placement of each individual pulse burst on the work surface — the total pulse overlap — was maintained. In this case, the effective spatial overlap of the pulses was ~84%. These results demonstrate that the use of pulse bursts significantly improves the ablation rate. This outcome was expected and is consistent with the use of picosecond laser burst processing in other materials. Similarly, the ablation threshold decreased (essentially logarithmically) with the number of pulses contained in each burst. This demonstrates the "incubation" phenomenon that generally occurs in many materials with multipulse irradiation.

Both 3D and 2D surface topography tools were used to precisely measure scribe depth and edge quality. An image obtained with a scanning white light interferometer shows a scribe in further detail (Figure 3). With a surface that is smooth and free of chips, the picosecond UV laser delivered another expected result: high-quality cuts.

Further qualitative assessment of the scribes can be derived from Figure 4. The individual images show a series of 25-µm depth grooves produced with 1-, 4-, 8-, and 12-pulse bursts, successively. The average power was adjusted as needed to obtain the best results for each case. The four images in the top row are focused on the top surface of the wafer. The four images in the bottom row are focused on the floor of the scribe. Figure 4e-h shows a clear comparison and progression of cut quality as a function of the number of pulses in each burst.

Discoloration around the scribe, which indicates a change in the surface or bulk material, shrinks and then disappears for higher pulse counts. The higher pulse counts also provided the best results at higher feed rates. This indicates that the process can simultaneously deliver adequate throughput and favorable quality.

Figure 5 isolates higher magnification views of the floors of a series of scribes, all made under the same laser operating conditions of 16 W of average power and a net processing speed of 25 mm/s. The scribe depth for each condition is shown as a range from 8 to 25 µm at differing pulse burst values. This higher resolution view highlights the improvement in smoothness with increasing pulse count. For a constant average power and overall processing speed, tailoring the pulse output delivered a threefold increase in scribe depth.

Technology implementation

In advancing from theory to practice, the potential to apply UV picosecond lasers for scribing SiC wafers feeds into the ability to use burst output to both improve the machining quality and increase processing speed. Further exploration is needed to gauge and evaluate the parameters and results for the complete cutting of a 340-µm wafer.

Meanwhile, research is underway to adapt the mechanical saws that are traditionally used for silicon wafer scribing for SiC. Published results indicate that this approach continues to suffer from limited feed rates and that it produces significant debris, for example, in chips >10 µm.

Still, mechanical sawing is a familiar method in the semiconductor industry, and any alternative technology will need to demonstrate substantial advantages in terms of throughput, yield, and operating costs to gain industry acceptance and become a candidate to undergo further sustained improvements. The obtained UV picosecond results, though requiring further exploration in terms of demonstrating complete cutting, target the exact range of benefits needed to drive such an adoption.

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Laser Microprocessing Conquers the Challenge of Ultrafine Components

BY ANTONIO CASTELO
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CONSORTIUM (EPIC)

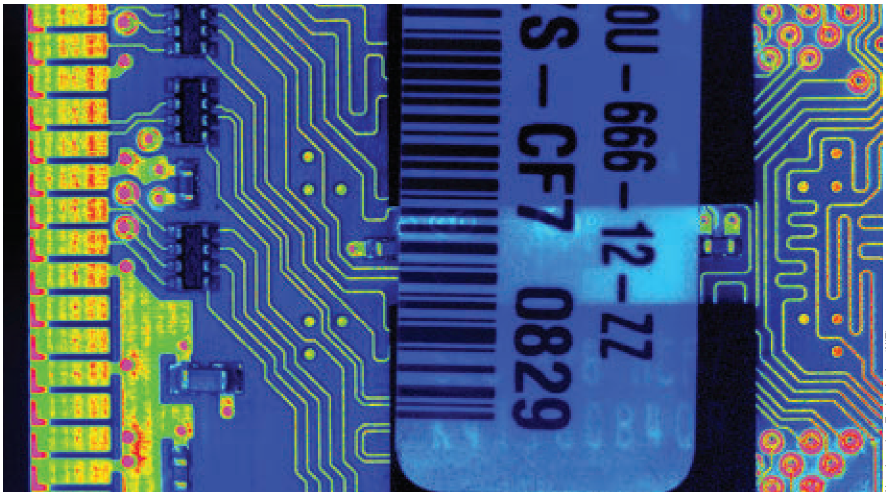
Laser microprocessing covers a broad scope of laser processes used in the machining of ultrafine structures. In this area of technology, micrometer-scale levels of precision and accuracy are required to obtain the desired structures and, more critically, ensure the functionality of produced parts. The rise in the number of markets and applications for these processes in recent years corresponds to the increasingly demanding requirements from end users, in terms of throughput as well as precision.

To meet necessary thresholds, industry players are spearheading developments to laser sources and the additional components that complete the modern workstation. Ultrashort-pulse lasers, high-performance operability at MIR wavelengths, scanners, robots and movement stages, software, and integration capabilities are among the active areas of innovation.

At the same time, process monitoring is reaching new levels of functionality, providing a means to control the laser process in-line and ensure the quality of the produced parts.

The semiconductor and consumer electronics industries are two prominent adopters of these advancing technologies. For example, both sectors benefit from the advantages that industrial lasers provide for the various processes needed for the manufacture and refinement of wafers, displays, and circuit boards.

As virtually every feature of the components found and used in these industries has become smaller, current versions require higher precision from processing steps as well as finished parts. The architectures of electronic components pose a particular challenge; these parts consist of multiple layers that could each comprise very different materials. Further, cleanness must be ensured in the manufacturing process. The combination of these factors compounds the challenges of the laser systems tasked with enabling such precision processing.



New Imaging Technologies (NIT)

As advancements in laser microprocessing flourish in the semiconductor sector, process monitoring, including via SWIR imaging, is further increasing the chances to achieve favorable outcomes in processing compact components.

Source optimizations

Femtosecond lasers are already an advanced optical processing technology, and generally address extremely demanding requirements. Still, improvements to durability and performance are further driving these lasers into challenging processing environments.

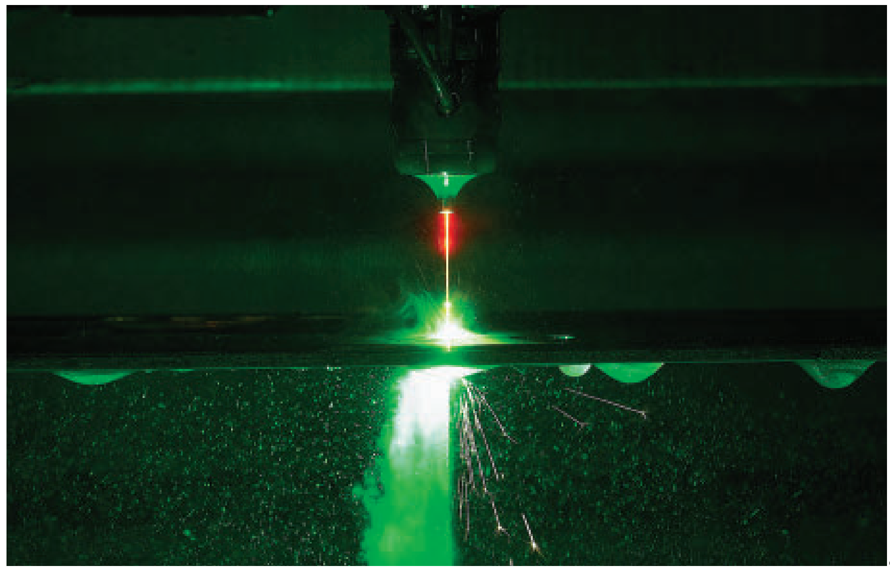
Lithuania-based Litilit has developed a range of industrial femtosecond lasers for these processing functions, including a class of industrial lasers that achieves a burst mode with a virtually unlimited pulse number in the package, and up to 400-µJ pulse energy per burst. These lasers offer emission wavelengths of 1030 nm and 515 nm, pulse widths between 400 fs and 4 ps, and repetition rates between 100 kHz and 1 MHz.

Given the wide range of applications — which corresponds to a range of performance requirements — that command these high-performance industrial femtosecond lasers, Litilit is engaged in application trials, and in one case the company explored the laser etching of copper electrodes on glass substrates. In these trials, Litilit removed the copper layer from different glass substrates and created a structure with minimal damage to the substrate. Further observations revealed no delamination or defects of the copper layer after the laser process.

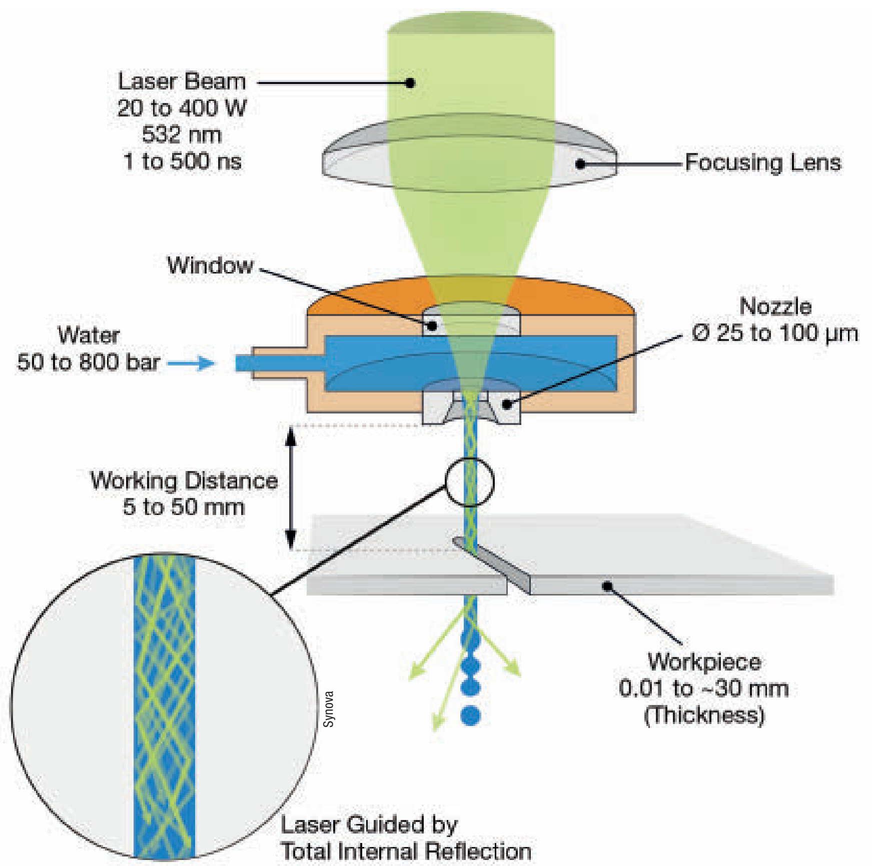
Certain hybrid machining methods enable the use of nanosecond lasers for high-throughput processing tasks for the semiconductor and consumer electronics industries, while mitigating the drawbacks that are inherent to these sources. One example is Synova's laser MicroJet (LMJ) technology, which combines a laser with a thin water jet. This jet uses total internal reflection to precisely guide the beam in a manner similar to that which can be achieved via conventional optical fibers. The LMJ mechanism guides the laser beam over distances of up to 10 cm without requiring focusing or distance control, enabling narrow and highly parallel cuts in materials from 1 to 40 mm in thickness, as shown in the figure on this page (page 63).

Synova's LMJ technology resolves significant problems that are commonly associated with nanosecond lasers: thermal damage, contamination, deformation, debris deposition, oxidation, microcracks, and taper. The technology can also be used with UV, visible, and NIR sources.

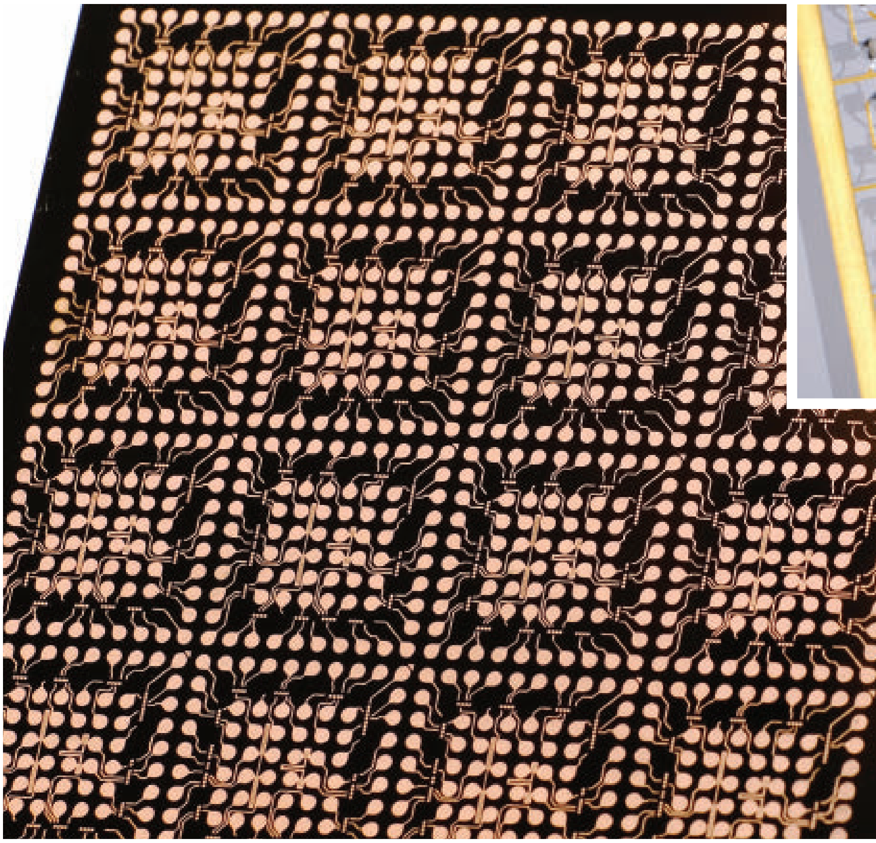
Applied to the semiconductor and consumer electronics industries, the LMJ method enables the cutting, grooving, and dicing of sensitive materials, resulting in smooth edges, high wafer fracture strength, and an overall reduction in the risk of breakage. Further, this technol-



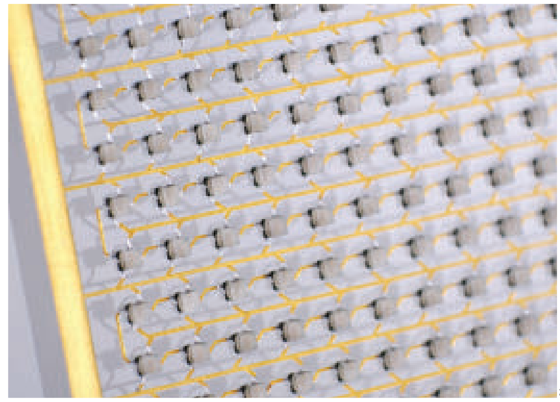
Synova



An image **(top)** and the scheme **(bottom)** of Synova's laser MicroJet (LMJ) technology. The solution combines a laser with a water jet that precisely guides the beam via total internal reflection. The technology can thereby resolve problems, such as thermal damage and debris deposition, that commonly plague nanosecond lasers in industrial use cases.

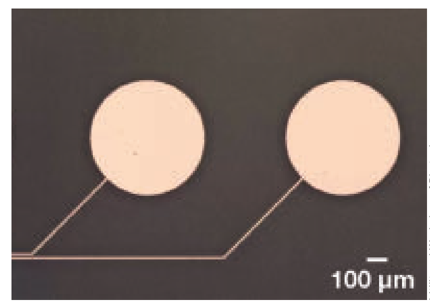


Akoneer



Akoneer

Conductive traces formed on a dielectric material via Selective Surface Activation Induced by a Laser (SSAIL) method technology **(left and above)**.



Litilit and Workshop of Photonics

In trials demonstrating the laser etching of copper electrodes on glass substrates, femtosecond laser developer Litilit removed the copper layer from different glass substrates, including Corning Eagle XG and fused silica glass.

ogy enables precise cutting of various semiconductor materials, such as silicon, gallium arsenide, silicon carbide, low-K dielectrics, and even coated materials such as epoxy-molded compound wafers of various thicknesses between 50 µm and 2 mm.

For semiconductor fabrication specifically, Synova's technology also enables multidirectional 2D cutting, high throughput processing of thick semiconductor equipment. Applications include silicon showerheads and silicon carbide susceptor plates, as well as the downsizing and detouring of wafer ring holders.

Meeting material demands

Transparent conducting films (TCFs) present another compelling use case for advanced laser processes. These thin films can carry electricity when deposited on substrates of glass, silicon, and/or polymers, which makes them important components in devices such as OLEDs, touch screens, and LCDs. Both indium tin oxide and doped zinc oxides are largely used, due to their excellent transparency and electrical properties. Newer materials, such as graphene oxide and PEDOT, also show promise for flexible electronics due to their excellent bending behaviors.

Industry has used several laser processes since the 1990s to perform various tasks on TCFs. These include pulsed laser deposition to grow transparent conducting oxides on different substrates; laser annealing to enhance the crystallinity of the films; and etching to obtain grooves on transparent electrodes. Lasers have also been used for patterning, which can be used to remove some parts of the material layer to functionalize the surface's electrical properties and generate a circuit.

In patterning TCFs, two primary challenges place heightened demand on the laser system. First, it is required to selectively remove the thin film without affecting the substrate. The laser must also be used to perform back processing — removing the layer through the substrate — since this procedure may be preferable for certain applications.

To address these challenges, Québec City-based Femtum, a portfolio company of Germany's ELAS Technologies Investment, has developed a MIR-pulsed fiber laser at 2.8 µm for selective removal of TCFs on different substrates. MIR-pulsed lasers are advantageous for thin-film patterning because they are based on oxide materials that strongly absorb at wavelengths ~3 µm. Compared to UV or NIR-laser patterning, it is easier to selectively remove these thin layers without affecting the substrate, since the substrate possesses a much higher ablation threshold at these MIR wavelengths. Femtum's solution enables users to precisely process TCFs on various substrates, including flexible polymers or other MIR transparent substrates, such as silicon and germanium, to thereby achieve very small feature sizes.

Fabricators are also applying novel laser methods to processing tasks in the consumer electronics and semiconductor industries. The Selective Surface Activation Induced by a Laser (SSAIL) method, developed by the Center for Physical Sciences and Technology (FTMC) in Lithuania, is one such method. This technique derives from the objective to solve emerging production issues for electrical conductors on polymers, such as the formation of electrical circuit traces on 3D-shaped dielectrics. SSAIL comprises three steps: laser modification of the dielectric surface, which is achieved by scanning the surface with the beam; chemical activation of the modified areas; and electroless plating of the activated parts.

Lithuanian company Akoneer has implemented this technology in its laser micromachining workstations, which are used for applications such as high-resolution conductive traces on polymers, glasses, ceramics, silicon, and other dielectric materials. It enables tighter electronics packaging on flat or 3D surfaces, with traces down to a width of 1 µm in some materials, making antennas directly on/in parts and creating functional surfaces.

Monitoring process

Visual inspections have traditionally been used for quality control in the production processes of consumer electronics. However, as components have become increasingly sophisticated, some inspection tasks today — for example, the evaluation of weld seams — can only be assessed with an automated monitoring system. These in-line and on-line inspections are critical, especially when applied to an industry that demands high production rates.

Automated laser and 3D measurement technology company Precitec is precisely addressing this dynamic. Its Laser Welding Monitor (LWM) 4.0 real-time quality monitoring system records the emission signals of the welding process as it happens. Recorded data is compared with reference curves to report any deviations to the higher-level control system, also in real time. As a result, error detection takes place at an early stage to ensure the stability of the monitored process in the long term. Such a system is particularly valuable for monitoring processes involving mixed joints of aluminum, stainless steel, and copper.

In the imaging domain, SWIR cameras are favored for semiconductor inspection due to the capability of SWIR light to "see" inside silicon to detect cracks and other potential wafer defects, or defects to solar cell panels. SWIR imagers are further used to perform failure analyses of integrated circuits. New Imaging Technologies' (NIT's) line-scan array camera solution, for example, which is based on an indium gallium arsenide detector, provides extremely sharp images of defects in materials at a high throughput. This system achieves 2K resolution (2048 × 1 pixels at 7.5-µm pixel pitch). NIT has also recently launched a high-resolution SWIR sensor for the most demanding inspections in this field, with an 8-µm pixel pitch and 2-MP resolution at 1920 × 1080 pixels. This solution achieves ultralow noise of 25 e^- to ensure image clarity even in challenging environments.

Ensuring a prolific combination

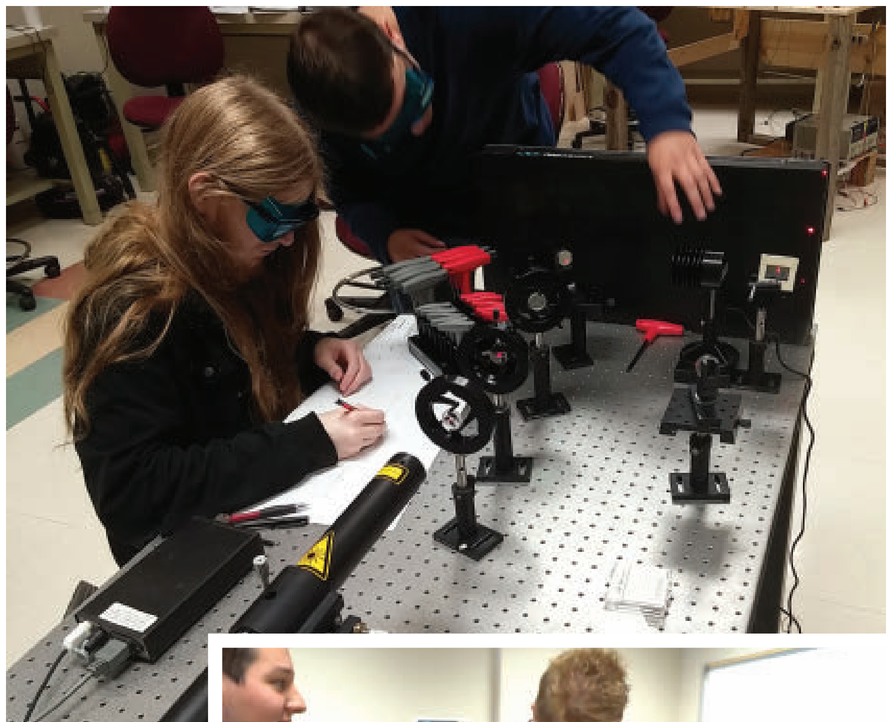
Together, advancing laser technologies and process monitoring solutions are shifting the landscape of the consumer electronics and semiconductor industries. To drive the adoption of these laser-based advanced manufacturing technologies, consortia and networks — already established and new to form — are committing to support the photonics companies driving these product innovations as well as the semiconductor and electronics industries.

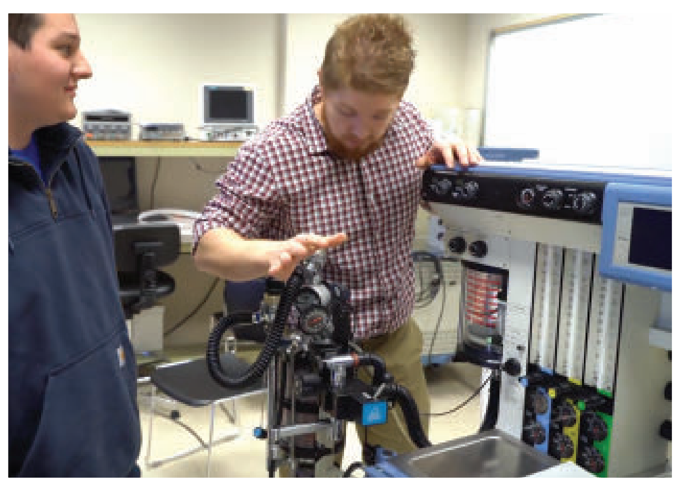
The Pan-European network PULSATE aims to connect digital innovation hubs in Europe with expertise in laser-based manufacturing technologies. PULSATE helps companies that are interested in integrating these capabilities into their production processes, as well as those interested in exploring their capabilities to make optimal implementations. Since physical, logistical, and financial entry barriers can hinder the adoption of these dynamic technologies, PULSATE serves as a single-entry point to support users and companies. This includes connecting all constituent companies with the proper partners based on need and capability, and helping the industry develop and promote trainings, technical webinars, and networking events.

antonio.castelo@epic-photonics.com

State Technical College of Missouri
Linn, Missouri

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





State Technical College of Missouri students assemble their final project for the lasers/optics course.

State Technical College of Missouri has offered associate degrees and certificate programs in electronics engineering and biomedical engineering technology for more than 30 years. Its Associate of Applied Science tracks include a degree program in electronics engineering technology with a specialization in laser photonics as well as a program in biomedical engineering technology. The college also offers a one-semester certificate course in biomedical equipment technology.

More than 350 technicians have graduated from the programs and are working in the electronics, biomedical, laser, and photonics industries across the U.S. and internationally. Companies that have hired graduates include Garmin, Honeywell Nuclear Security Division, JT3, GE Biomedical, and the Mercy Hospital system.

Program description

Students pursuing State Technical College's associate degree programs for electronics engineering technology and/or biomedical engineering take part in a two-year program that provides a strong technical core, with hands-on training in state-of-the-art labs stocked with the latest industrial-grade equipment.

During the first year, technicians in both programs receive a solid foundation in electronics and computers. In their second year, the technicians' paths diverge. Electronics engineering technology students study photonics, fiber optics,

 Images courtesy of State Technical College of Missouri.

geometrical optics, laser technologies, and high-end radio-frequency electronic systems. Graduates of this program qualify to work as technicians for industrial production companies — in R&D, national labs, field service, and system repair, among other areas.

Biomedical engineering students learn about diagnostic imaging machines, electrical safety testing, preventative maintenance procedures, and medical devices. Graduates of this program qualify as technicians in hospitals, R&D, field service, and third-party system repair shops.

Graduates of both degree programs have the skills to:

- Troubleshoot integrated electronic systems using oscilloscopes, digital multimeters, spectrum analyzers, and beam analyzers during laser applications.
- Tune helium neon and diode lasers for maximum power and beam quality.
- Align optical systems.
- Perform high-quality fusion splicing for single- and multimode fibers.
- Use an optical time domain reflectometer to identify problems in fiber optic links.
- Properly clean and maintain precision optics.
- Apply laser safety rules according to ANSI and OSHA standards.

How to recruit from this college

If you are interested in recruiting students from State Technical College, please arrange a visit to our college to present your company and employment opportunities to our students. We will provide, free of charge, a private room in which to interview interested students. Graduates are available every May.

Contact Information

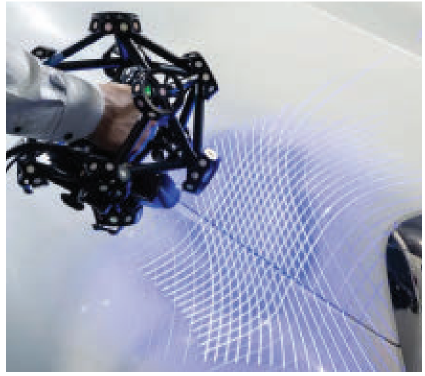
Drew Collins
+1 573-897-5227
drew.collins@statetechmo.edu
1 Technology Drive
Linn, MO 65051

Website

www.statetechmo.edu/program/electronics-engineering-technology

Co-Packaged InGaAs Photodiodes

Marktech Optoelectronics' multichip packages with indium gallium arsenide (InGaAs) photodiodes and LED emitters can be used for analytical, medical, aerospace, and industrial sensing applications. The packages come with either a visible, NIR, or SWIR emitter with an option to add an additional silicon detector when UV and visible LED light must be monitored or detected. The LED emitters can produce multiple wavelengths with high emission stability and enable a quick variation of light power output and wavelength.
info@marktechopto.com

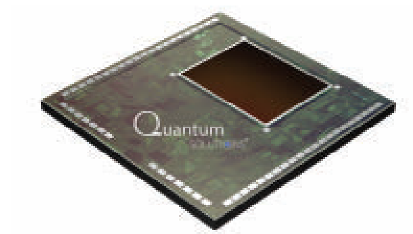


Optical Scanners

The MetraSCAN BLACK+ and MetraSCAN BLACK+|Elite from **Creaform** are optical coordinate measuring machine (CMM) 3D scanners for the measurement of large parts in industrial settings. The scanners' sensor acceptance test procedure is based on ISO 10360 standards and offers an accuracy specification of up to 0.025 mm + 0.015 mm/m in the extended measuring volume. Both the MetraSCAN BLACK+ and MetraSCAN BLACK+|Elite feature 360° magnetic targets, guidance tools that provide visual guidance feedback on positioning targets when creating a setup, troubleshooting tools, and control tools.
creaform.info@ametek.com

3D Lidar Solutions

The Q-Track HD and Q-Track Dome from **Quanergy** are 3D lidar solutions for tracking and defense applications. The Q-Track HD features a 360° horizontal field of view that allows the solution to track and classify more than 1000 people simultaneously in challenging environments, such as crowded airports, large malls and stores, industrial and manufacturing facilities, and education and corporate campuses. Optimized for dense areas, the Q-Track Dome uses a 90° vertical field of view and is designed to track and classify people within office buildings, corridors, mantraps, and transportation terminals.
sales@quanergy.com



Quantum Dot SWIR Sensor

The Q.Eye SWIR from **Quantum Solutions** is a quantum dot-based SWIR image sensor for applications such as industrial machine vision, drones, robotics, advanced driver-assistance systems, and surveillance. With a broad spectral range of 400 to 1700 nm, the sensor offers video graphics array resolution at a pixel pitch of 5 µm and a compact sensor design of 4.1 mm diagonal due to its solution processing and monolithic integration on CMOS wafers. The Q.Eye SWIR also features a test electronics kit that includes a USB-driven, 30-g quantum dot camera that is designed to facilitate first-hand testing of the sensor.
sales@quantum-solutions.com

COB Module

The M3X3L9 from **Violumas Inc.** is a chip-on-board (COB) module comprised of the Violumas VC3X3 UV LED COB and a fan-cooled heatsink. Using a 3-PAD LED flip chip and super pillar metal core printed circuit board, the COB array is structured with a high density nine-chip LED array under a single 90° fused silica lens, allowing for focused illumination. The M3X3L9 is available in UVB and UVC wavelengths, including 265 nm, 275 nm, 295 nm, and 310 nm, and is meant for high-intensity applications, such as disinfection, spectroscopy, and phototherapy.
info@violumas.com

Nano-Focus Scanners

The P-725.1CDE1S and P-725.4CDE1S from **Physik Instrumente (PI)** are nano-focus scanner packages for applications including surface metrology, superresolution microscopy, light-sheet microscopy, and digital slide scanning,

among others. The scanners are based on a closed-loop piezo flexure design with capacitive position feedback for high linearity, stability, and repeatability, and include a compact digital controller with software. The P-725.1CDE1S and P-725.4CDE1S have a travel range of 100 μm or 400 μm, settling times of ≤19 ms or ≤35 ms, a large clear aperture with Ø 29 mm, and nanometer resolution due to capacitive sensors.
info@pi-usa.us

Supercontinuum Laser

The SLP-1050 from **SuperLight Photonics** is a compact and high-powered supercontinuum laser developed for industrial, research, and medical applications. Using an amplified seed laser, this supercontinuum laser is designed to deliver >40 mW and a wide spectral range in the NIR to SWIR regions with stability and a low noise output. The SLP-1050 is a small form factor class 3 laser and features a short startup time, no need for calibration, high uptime, and a maintenance-free designation.
info@superlightphotonics.com

Science-Grade Thermal Cameras

The X6980 HS high-speed family and the X8580 high-resolution family from **Teledyne FLIR** are science-grade thermal cameras for R&D, leveraging both the MIR and LWIR spectra. The cameras come with 10 GigE and CoaXPress 2.1 high-speed interfaces that provide more than an hour of fast image streaming and data transfer, ensuring data fidelity while improving efficiency. The X6980 and X8580 families also include an on-camera recording option with a removable nonvolatile memory express solid-state drive (SSD) to ensure lossless recording of critical thermal events as well as a 4-TB high-speed SSD.
flir@flir.com

Measurement Vision System

The Baty Venture FV Series from **Bowers Group** are vision systems for measurement and inspection applications. The systems use software to

streamline the measurement process, allowing for unobstructed operation and data analysis. The Baty Venture FV Series features auto part recognition capabilities and a camera that are coupled with LED lighting for clear field-of-view measurements.
sales@bowersgroup.co.uk

Cobot Laser Welding System

The LightWELD Cobot System from **IPG Photonics** is an automated cobot laser welding and cleaning system that can be configured with IPG's existing and future LightWELD welding laser sources for the fabrication and manufacturing industries. The system is capable of quickly switching between laser welding and laser cleaning by changing its nozzle without tools and is compatible with the LightWELD wire feeder. The LightWELD Cobot System also features an industrial base, a 1- × 1.5-m work surface, a drag-and-drop operator user interface, and a long-reaching cobot arm.
info@ipgphotonics.com

Imaging Colorimeter

The I16-G from **Radiant Vision Systems** is an imaging colorimeter and metrology solution that can be used to measure properties of light that influence the visual quality of devices such as LEDs, displays, augmented and virtual reality projections, and head-up displays. Able to provide accurate, repeatable measurements, the colorimeter uses a scientific-grade, 16.1-MP (5312 × 3032) image sensor. The I16-G's sensor enables pixel-level measurement of displays, inter- and intra-character luminance measurement of backlit keyboards and panels, and measurement of LED luminance and color from single diodes to large arrays.
marketing@radiantvs.com

Micro-LED Sputtering System

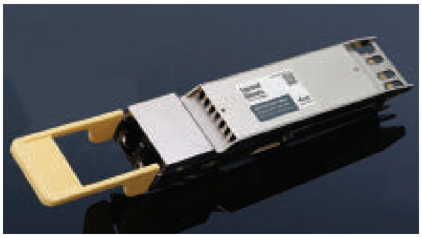
The TIMARIS STM from **Singulus Technologies** is a modular high-vacuum sputtering system for the manufacturing of micro-LEDs. The system can use up to six process modules, along with a single target module, pre-clean module, and heater module. The TIMARIS STM enables efficient placement and alignment of micro-LEDs on a substrate while controlling the crystal structure of the semiconductor material.
sales@singulus.de

Infrared Glass

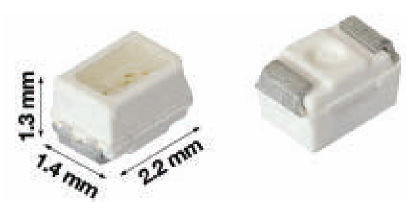
BDNL-4 from **LightPath Technologies Inc.** is the first in a series of BlackDiamond-NRL infrared glass, a material in the chalcogenide glass series licensed from the U.S. Naval Research Laboratories (NRL) as a substitute for germanium. The glass exhibits a negative thermo-optic coefficient that enables the design of devices that are unaffected by temperature changes and is a true multispectral material that can be used across SWIR, MIR, and LWIR imaging bands. The BDNL-4 is offered with antireflective and protective DLC coatings and is meant for applications such as thermal cameras in drones, advanced driver-assistance systems, and other optical systems.
sales@lightpath.com

OSFP Transceiver

The OSFP 800G SR8 from **Approved Networks** is an 800G OSFP transceiver supporting data-intensive applications and enabling real-time AI processing across networks for data centers and broadband providers. Facilitating fast data transmission of up to 800 Gbps, the transceiver has a higher bandwidth capacity that results in faster data transfer and more efficient handling of processes across network infrastructures.



The OSFP 800G SR8 has an operating wavelength of 850 nm and features a dual multifiber push-on (MPO)-12 angled physical contact connector, a maximum power consumption of 14 W, and a maximum operating distance of 50-m OM3 and 100-m OM4 with forward error correction.
sales@approvednetworks.com



Surface-Mount Mini-LEDs

The VLMB2332T1U2-08 and VLMTG2332 ABCA-08 from **Vishay Intertechnology** are blue and true green, respectively, surface-mount LEDs in a mini-LED package for medical light treatment, heart rate monitoring, telecommunications equipment, smoke detection, and LCD switches. Using an indium gallium nitride chip, the LEDs produce a typical wavelength of 525 nm at 20 mA and 465 nm at 20 mA and offer a ±60° angle of half-intensity, a wide viewing angle of 120° for homogenous illumination and backlighting, and a forward voltage of 2.9 V typical. The VLMB2332T1U2-08 and VLMTG2332ABCA-08 come in a compact form factor of 2.2 × 1.3 × 1.4 mm, are available in 8-mm tape, are RoHS-compliant, and halogen free.
business-americas@vishay.com

Wavefront Phase Camera

The SEBI RT1000 from **Wooptix** in collaboration with poLight ASA is a wavefront phase camera developed for laboratory applications, including quantitative phase imaging, optical metrology, material inspection, laser measurement, and oncological research. Using a piezo MEMS-based tunable poLight TLens and Wooptix's wavefront phase imaging technology, the camera can be used for autofocused imaging without optical instability, changing field of view, magnetic interference, or effects of gravity. The SEBI RT1000 features a development kit that includes the SEBI Analyzer Suite of software to assist users in the phase camera system development process.
info@wooptix.com

40-W LED Pattern Projectors

The LT2PRXP series from **Opto Engineering** are 40-W continuous and strobe LED pattern projectors meant for applications including inspection, pick-and-place robot guidance, 3D industrial reconstruction, and alignment. The pattern projectors are available in two different

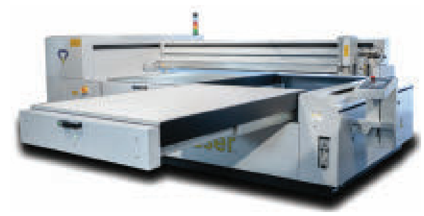
versions, including a standard version that integrates a built-in driver for continuous and strobe mode operations and a compact version designed for strobe mode only operations in tight spaces. The LT2PRXP projectors feature a standard five-pin M12 connector with PNP/NPN/analog dimming input and an aluminum heat sink designed to dissipate heat, ensuring a long lifetime for the LED module and driving electronics.
press@opto-e.com

Small Fluorescence Module

The Fluo Sens Micro Fluorescence Module from **Electro Optical Components Inc.** is a micro fluorescence measurement system that can be used for mobile measurement systems or integrated into systems for online process monitoring. The detector enables synchronous confocal fluorescence measurement and is placed inside a solid casing that protects the device from dust and humidity as well as shields the sensor from electromagnetic radiation. Available in single- or dual-channel formats, the Fluo Sens Micro Fluorescence Module has a lack of moving parts and a low operating voltage of 5 V direct current, making it suitable for use in hazardous environments without the need for extensive housing modifications.
info@eoc-inc.com

AI FPGAs

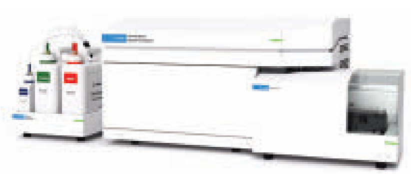
The Agilex 5 FPGAs from **Altera** and **Intel** are AI-enabled FPGAs designed for mid-range applications including video, industrial, robotics, medical, and others. With AI infused into the fabric, the FPGAs offer a high level of integration, low latency, and improved computing capabilities. The Agilex 5 FPGAs feature package sizes between 15 × 15 mm and 23 × 23 mm, logic elements of 50K to 656K and 103K to 644K, multicore arm processors of dual-core A55 at 1.5 GHz and dual-core A76 at 1.8 GHz, and MIPI D-PHY v2.5 at up to 3.5 Gbps per lane.
contactpr@intel.com



Twin Table Laser System

The Twin Table System from **eurolaser GmbH** is a laser processing solution developed to fulfill requirements in the processing of adhesive films and other applications. The system uses a permanent vacuum under the added material to make sure it stays in place while being cut and during downstream process steps. The twin moveable material carriers enable continuous loading and unloading during the machining process and increase the accessibility of the already machined workpieces during removal. The Twin Table System is open, making robot loading possible, and features permanent

extraction of cutting emissions, automatic table changing, and version availability from manual to fully automatic.
sales@eurolaser.com



Flow Cytometer

The NovoCyte Opteon from **Agilent** is a spectral flow cytometer for acquiring, analyzing, and reporting flow data in research, drug discovery, and therapy development. Its configuration uses three to five lasers and supports up to 73 high-quality detectors, so the cytometer can be used in large-panel flow cytometry assays. The NovoCyte Opteon can analyze more than 40 markers simultaneously.
cag_sales-na@agilent.com

Fizeau Interferometer

The AccuFiz Duo from **4D Technology** is a dual source dynamic laser Fizeau interferometer for measuring flats and lenses without the need for coating surfaces to attenuate extraneous interference fringes. This is due to a short coherence

mode that enables surface error, transmitted wavefront error, remote cavity, wedge, optical thickness, and homogeneity measurements of plane parallel transparent surfaces down to 0.2-mm thick. The AccuFiz Duo also includes a long coherence source that uses a stabilized 632.8-nm helium-neon laser for digital holograms as well as 4D Technology's 4Sight Focus analysis software.
4dinfo@ontoinnovation.com

SWIR InGaAs Sensor

The NSC2101 from **New Imaging Technologies (NIT)** is a SWIR indium gallium arsenide sensor for applications such as defense, wafer inspection, and surveillance. The sensor has an 8-μm pixel pitch and a 2-MP resolution at 1920 × 1080 pixels. The NSC2101 also features a low noise of 25e- for favorable image clarity in challenging environments and a dynamic range of 64 dB.
info@new-imaging-technologies.com

Image Processor

The EVK ALPHA G100 CS from **EVK DI Kerschhaggl GmbH** is a real-time image processing device capable of supporting multisensory data streams for sorting applications. In addition to material classification of hyperspectral camera image data, the processor supports the fusion of this data with data from color cameras or inductive metal sensors, with the output data directly steering the ejection systems of optical sorter systems. The EVK ALPHA G100 CS also supports fusion with cameras that classify metals based on chemical composition and SWIR cameras and can be used with chemometric software for application development.
office@evk.biz

Industry Events

JULY

SEMICON West & FLEX
(July 9-11) San Francisco.
Contact Semi Global Headquarters, +1 408-943-6900, **semiconwest@semi.org**; www.semiconwest.org/about/welcome.

Laser Additive Manufacturing (LAM) Workshop
(July 15-17) Dayton, Ohio.
Contact the Laser Institute, +1 407-380-1553, **info@lam.ngo**; www.lam.ngo/.

Optica Sensing Congress
(July 15-19) Toulouse, France.
Contact Optica, +1 202-223-8130, **info@optica.org**; www.optica.org/events/congress/optical_sensors_and_sensing_congress/.

***Vision Spectra* Conference 2024**
(July 16-18) Virtual.
Contact Photonics Media, +1 413-499-0514, **conference@photonics.com**; www.photonics.com/vsc2024.

Microscopy & Microanalysis
(July 28-Aug. 1) Cleveland.
Contact the Microscopy Society of America, +1 703-234-4115, **associationmanagement@microscopy.org**; https://mmconference.microscopy.org/.

Optica Advanced Photonics Congress
(July 28-Aug. 1) Québec City.
Contact Optica, +1 202-223-8130, **info@optica.org**; www.optica.org/events/congress/advanced_photonics_congress/.

AUGUST

SPIE Optics + Photonics
(Aug. 18-22) San Diego.
Contact SPIE, +1 360-676-3290, **customerservice@spie.org**; www.spie.org/conferences-and-exhibitions/optics-and-photonics?SSO=1.

The 10th International Conference on Machine Vision and Machine Learning 2024 (MVML)
(Aug. 19-21) Barcelona, Spain.
Contact International ASET Inc., +1 613-834-9999, **info@mvml.org**; www.mvml.org.

SEPTEMBER

SEMICON Taiwan 2024
(Sept. 4-6) Taipei, Taiwan.
Contact SEMI Taiwan, +886 3-560-1777, **semicontaiwan@semi.org**; www.semicontaiwan.org/en.

European Optical Society Annual Meeting (EOSAM) 2024
(Sept. 9-13) Naples, Italy.
Contact Boglárka Selényi, **eosam@europeanoptics.org**; www.europeanoptics.org/events/eos/eosam2024.html.

World Molecular Imaging Conference
(Sept. 9-13) Montréal.
Contact World Molecular Imaging Society, +1 310-215-9730, wmis@wmis.org; www.wmis.org/wmic-2024-about.

CIOE
(Sept. 11-13) Shenzhen, China.
Contact China International Optoelectronic Exposition, +86 755-8629-0901, **cioe@cioe.cn**; www.cioe.cn/en.

SEMICON India 2024
(Sept. 11-13) Greater Noida, Delhi, India.
Contact SEMI India, **semiconindia@semi.org**; www.semi.org/en/connect/events/semicon-india-2024.

ECOC 2024
(Sept. 22-26) Frankfurt, Germany.
Contact VDE, +49 69-63080, **ecoc2024@vde.com**; www.ecoc2024.org.

Frontiers in Optics + Laser Science
(Sept. 23-26) Denver.
Contact Optica, +1 202-223-8130, **custserv@optica.org**; www.frontiersinoptics.com/home/.

BIOMEDevice
(Sept. 25-26) Boston.
Contact Informa, +1 310-445-4273, **registration.ime@informa.com**; www.biomedboston.com/en/home.html.

OCTOBER

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

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

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

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

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

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

PAPERS

Single-Molecule Sensors and Nanosystems International Conference — S3IC 2024
(Oct. 28-30) Paris.
Deadline: Abstracts, July 5
Contact S3IC 2024 Organizing Committee, +33 1-46-60-89-40, **s3ic2024@premc.org**; www.premc.org/conferences/s3ic-single-molecule-sensors-nanosystems/registration.

SPIE Photonics West 2025
(Jan. 25-30) San Francisco.
Deadline: Abstracts, July 17
Contact SPIE, +1 360-676-3290, **customerservice@spie.org**; www.spie.org/conferences-and-exhibitions/photonics-west/presenters/abstract-submission-guidelines.

Cell Bio
(Dec. 14-18) San Diego.
Deadline: Abstracts, Aug. 6
Contact ASCB, +1 301-347-9300, **info@ascb.org**; www.ascb.org/cellbio2024/.

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

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

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

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

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

NOVEMBER

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

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

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

DECEMBER

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

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

JANUARY

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

FEBRUARY

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

PHOTONICS SHOWCASE

Measure Divergent Light

Designed for flux measurement or optical attenuation of divergent and collimated light sources – such as laser diodes, LEDs, and VCSELs – the Newport Series of Integrating Spheres features precisely calibrated sensors that measure powers from 20nW to as high as 30W, with up to ±40 degrees divergence. Models available for collimated input beams, diverging input beams, and fiber optic sources.

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www.trumpf.com

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The FCI-InGaAs-XX-XX-XX with active area of 75um and 120um are part of OSI Optoelectronics's family of high speed IR sensitive detectors with fiber pigtail package. The single/multi-mode fiber is optically aligned to either the hermetically sealed InGaAs diode in TO-46 lens cap package enhancing the coupling efficiency and stability or directly to the InGaAs diode mounted on a ceramic substrate. Custom packages are also available!

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872 Series Laser Wavelength Meter

The 872 Series High-Resolution Laser Wavelength Meter is ideal for the frequency stabilization of lasers. Offering a frequency resolution as high as 200 kHz, the 872 Series provides exceptional sensitivity to wavelength deviations. With a built-in PID controller and 1 kHz sustained measurement rate, the 872 Series is well suited to precisely stabilize lasers used in applications such as atomic cooling and trapping.

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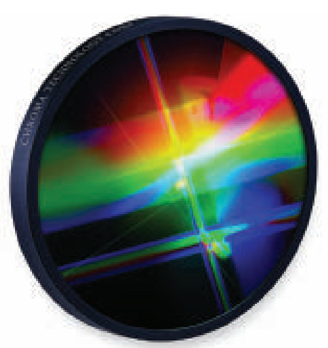
info@bristol-inst.com **www.bristol-inst.com**

Improving Performance in the SWIR



Discover Chroma Technology's SWIR filters, engineered for unparalleled precision in environmental monitoring and industrial inspection. Detect gases, monitor pollutants, and ensure flawless quality control with filters built for exceptional results. Rely on Chroma's SWIR filters for superior performance and reliability.

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www.chroma.com/swir

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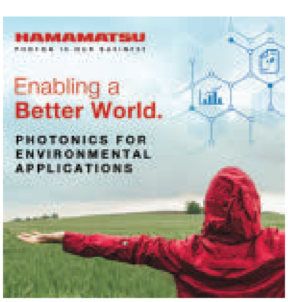
info@microlaser.com **www.microlaser.com**

Photonics for a Better Environment



Photonic technologies are at the core of the innovative solutions that reduce pollution and promote a more sustainable, cleaner environment. At Hamamatsu, we're committed to advancing the technologies that help protect our environment, such as sensors for pollution detection, water purification with targeted contaminant removal, and waste management with better detection, sorting, and recycling. Enable a better world with us.

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6-Axis Precision Hexapods

The versatility of the hexapod parallel kinematics design allows motion in all degrees of freedom, not unlike the human hand, yet at much higher precision and stability.

PI hexapods are supported by powerful, easy-to-use controllers, along with extensive programming examples and software tools for simulation and workspace verification. PI hexapods come in different sizes and load ratings from 2 lbs to 1000 lbs.

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The Cricket™² is a plug & play image intensifier camera attachment enabling low-light or single photon imaging functionality and extremely high shutter speeds for every CCD or CMOS camera. Equipped with industrial-leading Photonis Image Intensifier technology, and recognized for best value, Cricket™² sets an unmatched standard for connectivity with scientific microscopes and cameras.

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rfq-us@hypoptics.com
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Non-Contact VIS, NIR Beam Profiler

Conventional beam measurement places a probe in the beam, causing potential damage and slowing measurement. Ophir® BeamWatch® Plus is a non-contact beam profiler that takes continuous measurements using Rayleigh scatter. This provides instant readings of focus spot size, beam position, full beam caustic, and dynamic measures of focal plane location during start-up. Operates in VIS wavelengths (420 - 635nm), as well as NIR (950 – 1100nm).

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sales.ophir.usa@mksinst.com **tinyurl.com/35cddf7h**

Optical-to-Electrical Converter

The J744 is a compact 2.5” × 3.3” analog O/E converter that includes a fast fiber-coupled photodiode, a transimpedance amplifier, an output amplifier, mounting flange, and power supplies. Available in 850 nm, 1310 nm and 1550 nm versions with optional ST or FC input. Features include DC coupled, 1 GHz analog bandwidth, nominal 1V/mW gain, <350 ps risetime, and <12 ps RMS jitter.

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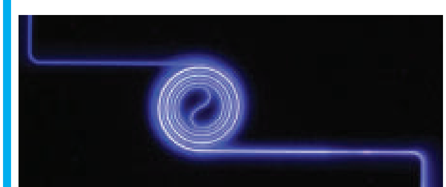
Photonic Integrated Circuits in UV



Aluvia Photonics offers cutting-edge PICs on our custom Al2O3 platform. Offering record low-loss, an ultra-broad spectral window from UV to mid-IR and capabilities for optical amplification. Perfect for sensing, quantum computing, datacom and more. Access affordable multi-project wafer runs with a user-friendly PDK and rapid turnaround or partner with us for dedicated development. Unlock new capabilities for your PICs with Aluvia Photonics.

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Dione series — LWIR cores of compact form factor, low weight (SWaP) with QVGA to SXGA resolutions, 12 µm pixel pitch microbolometer detectors and low NETD options. Available with or without shuttered version, low-latency image transfer, quick startup to image, multiple interfaces, and GenICam compliance adds flexibility to various operational environments like defense, transportation, and industrial markets on vehicle or aerial platforms.

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Solidifying our role as your all-inclusive optics supplier, we’ve broadened our capabilities to include optical assemblies. Whether it’s producing custom optical components, depositing thin-film coatings, precision assemblies, or offering design support, LaCroix has the manufacturing capability and expertise to meet your needs. Discover the LaCroix advantage and experience how we deliver your project at the speed of light.

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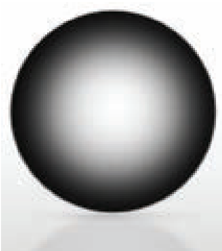
PHOTONICS SHOWCASE

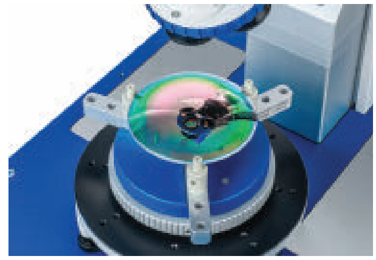
Bullseye® Apodizing Filters



Bullseye® Apodizing Filters radially modify beam distribution in optical systems. Standard Gaussian or customized filters inserted in line with a light source reduce undesirable intensity variations. Configurations include both dark-in-the-center, typically used to reduce low-frequency variations or create top-hat wave fronts, and clear-in-the-center functions, typically used to reduce high-frequency variations outside of the main beam profile. ISO9001:2015, ITAR, Cybersecurity compliant.

Reynard Corp. **(949) 366-8866**
sales@reynardcorp.com **www.reynardcorp.com**

Highly Precise IR Lens Centration



TRIOPTICS OptiCentric® 101 IR for testing and assembly of infrared lenses in VIS, MWIR, and LWIR reaches an unrivaled centration measurement accuracy of <0.25 µm in the IR and <0.1 µm for VIS. The unique IR-compatible air gap and center thickness measurement completes the optomechanical characterization of the lenses. Intuitive and simple operation of all integrated measurement heads is ensured by the software OptiCentric® 9.

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Liquid Light Guides

Liquid Light Guides are flexible, unbreakable, and very durable, and they have significantly better transmission, more homogeneous illumination, and a larger aperture than fiber bundles at lower costs! They are the perfect solutions for applications that demand uniform, high-intensity light. We offer four different series designed for diverse spectra ranging from ultraviolet to infrared and a broad selection of end fittings.

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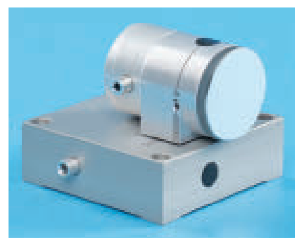
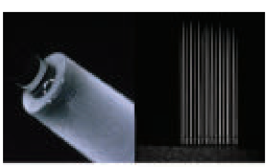
Nanoradian Beam Steering



The Nano-MTA Series are closed loop piezo nanopositioning mirror tip/tilt actuators. With nanoradian resolution, the Nano-MTA Series is ideal for beam steering, tracking, and scanning. Proprietary PicoQ® technology provides absolute, repeatable position measurement under closed loop control. The Nano-MTA series has high speed, high stability motion and has been used for applications such as optical tweezers and gravitational wave detection.

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

The NYFORS SMARTSPLICER



NYFORS

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

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Compact 594 nm 100 mW for Bioimaging

HÜBNER Photonics announces the addition of a new orange wavelength on the Cobolt 06-01 Series of modulated lasers. The 06-DPL 594 nm has 100 mW output power and can be directly modulated in either digital or analogue modulation up to 50 kHz, making it ideal for exciting red fluorophores, such as AF594, mCherry, mKate2, that are often used in optogenetics and other bioimaging applications.

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Neo High-End Spectrometer

Admesy's new Neo Series offers a versatile solution for different spectral measurement needs, fit for a wide array of applications. Its well-thought-out optical and mechanical construction assures the highest optical performance, even under tough conditions. Creating an OEM solution? Integrating spectral measurements into your production testing? Needing spectrometer answering to the highest expectations for development applications? Neo is your choice.

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Metal optics viz spherical and off-axis parabolic mirrors can be made up to diameter of 380 mm. Additional thin-film metallization with silver and gold can be applied to the reflective surfaces.

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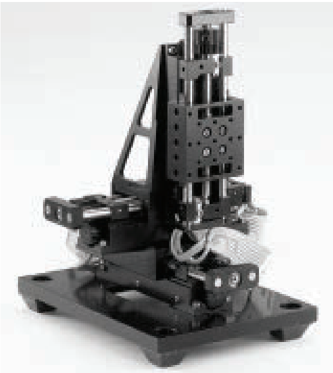
www.hhvadvancedtech.com

PHOTONICS SHOWCASE

MM-3M-F Translation Stage



The MM-3M-F-XX is our most popular stage, available with an anti-backlash, in speeds from 0.1033 mm/s to 25 mm/s, with resolutions from 1 µm to 100 nm per encoder count. Available in 1-, 2-, or 3-axis configurations and travel from 0.5 to 2.5 in.

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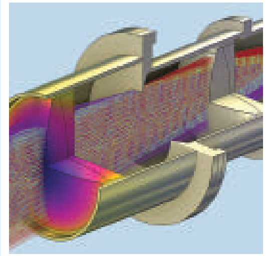
sales@nationalaperture.com
www.nationalaperture.com

Multiphysics Modeling and Simulation



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

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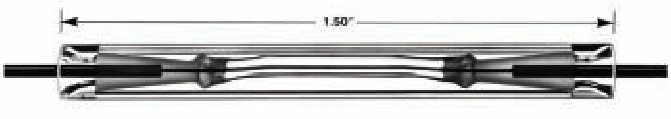
info@comsol.com **www.comsol.com/products**

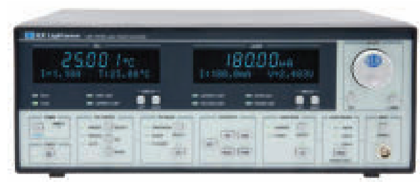
Norland Optical Splice



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

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

High Accuracy Laser Diode Controller



The LDC-37X6 Series Laser Diode Controllers are an industry-leading family of high performance, microprocessor-based instruments that offer a high stability, low noise current source with an integrated temperature controller specifically designed for controlling the current and temperature of laser diodes. These controllers are known throughout the industry for their reliability, precision, and ease-of-use.

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Pixelink PL-D7924 24-MP Camera

Pixelink's PL-D7924 24MP camera, with the Sony IMX540 Pregius S sensor, offers reliable, high-performance imaging. Features include global shutter to capture fast-moving objects without distortion and legible text within images, excellent readout speed, and HD-image capture of wider areas. With 2.74 µm and 17 fps, this 1.2-in. color or mono camera is ideal for inspection, testing, and analysis.

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TECHSPEC® Sapphire Windows

TECHSPEC® Sapphire Windows are manufactured from single-crystal sapphire, making them ideal for demanding applications (such as laser systems) because of their extreme surface hardness, high thermal conductivity, high dielectric constant, and resistance to common chemical acids and alkalis. Sapphire windows can be made much thinner than other common windows with improved transmittance due to their structural strength.

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High Power Fiber Optic Components

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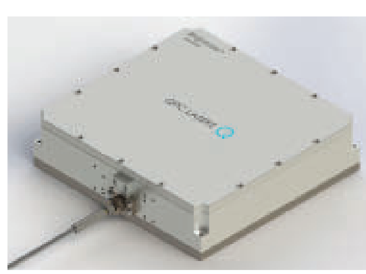
1726-nm Acne Therapy Lasers



QPC Lasers offers fiber-coupled, highly reliable laser OEM modules with optimal performance for acne treatment. Features include powers to 100 W, Brightlock® spectral locking ensuring narrow, stable output at the 1726 nm line, internal power and wavelength monitoring sensors, as well as visible pilot beams and protective blast shields.

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Precision Micro-Marking Laser

Precision micro-marking with the power of the 193nm DUV Excimer laser in a compact turnkey design. Ultra-precision beam control and a high-accuracy integrated motion/vision system. Ideal for: Diamonds, glass, polymers, ceramics, metals Applications across Quantum devices, Micro-optics, MEMS, Microfluidics Industries such as medical devices, electronics, aerospace, R&D Intuitive software for desktop rapid prototyping with unmatched reliability.

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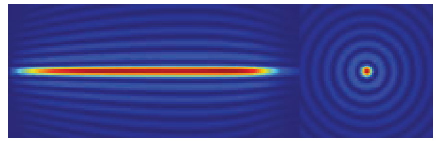
info@photoscribetech.com **www.photoscribetech.com**

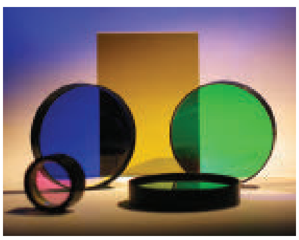
PowerPhotonic Bessel Beam Generator



The Bessel Beam Generator can simultaneously lead to improved edge/cleave quality and increased processing speed when using ultra-short pulse (USP) lasers. It has a flattened intensity profile, providing a uniform intensity throughout the depth of the cut/cleave. This product is intrinsically capable of high peak & average power – facilitating the use of the highest power USP lasers for the fastest possible glass processing.

PowerPhotonic Ltd **+441383825910**
sales@powerphotonic.com **www.powerphotonic.com**

More Signal, Less Background



Iridian's custom optical filters provide wavelength selectivity from the UV to LWIR to applications including communications (telecom/datacom/satcom), spectroscopy (Raman/fluorescence/molecular diagnostics), sensing and imaging (gas detection/Earth observation/lidar). With high transmission and deep and broad blocking, our custom filter solutions and multizone filter arrays are designed and manufactured to optimize technical and commercial needs in our customers' systems.

Iridian Spectral Technologies Ltd. **(613) 741-4513**
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And now for the intergalactic weather

Alanis Morissette famously interpreted a rained-out wedding as "ironic." It isn't clear if Morissette consulted a weather forecast in the hours leading up to the ceremony, but one thing is certain: Doing so would have greatly reduced the chances of a ruined wedding.

That said, who are we to discount the unpredictability of weather?

Meteorology is a difficult job. Even for the most accommodating global citizen, it can be hard to forgive and forget a poor-performing forecaster — a fact that has created a stigma that dates to the days when people watched television to receive their forecasts.

Simply, public trust can be hard to maintain for meteorologists.

Compounding this issue is a recent NASA undertaking: The agency will create its own forecasts for planets in different galaxies. By gathering precise brightness measurements over a broad spectrum of mid-infrared light, combined with 3D climate models and previous telescope observations, investigators from the NASA Webb Mission team have used the James Webb Space Telescope to map the weather on a Jupiter-size, gas-giant exoplanet 280 light-years from Earth, called WASP-43b.

The exoplanet is only 1.3 million miles away from the sun. For context, Mercury, the closest planet to our sun, is 40.5 million miles away from the great lightbulb in the sky and ~3% the size of WASP-43b. With an orbital period of 19.5 h, even a middling meteorologist could predict the presence of extreme weather patterns within its atmosphere. But NASA was curious to see just how extreme things might be.

Studying the exoplanet is almost impossible using normal telescopy. It just so happens, however, that conditions are perfect for phase curve spectroscopy — a technique that can be used to measure tiny changes in the brightness of a star-planet system as a planet orbits its star. Using the telescope's mid-infrared instrument to measure light from the planet's system every 10 s for more than 24 h, the scientists calculated temperatures for both sides of the planet, while creating a temperature map across the planet's surface. Like the moon to Earth, WASP-43b is tidally locked, meaning that the sun only ever sees one side of the planet's swirling mass of hot gas.

The team found the hottest mass of gas to be 1250 °C (2300 °F), while the coolest soared only to a brisk 600 °C (1100 °F).

NASA and its Webb Mission team may be more apt to look beyond the stars for weather forecasts than they are to report the weather at home. Still, could NASA drive meteorologists on Earth into high gear when it comes to accurate forecasts?

Another possibility is that NASA's work will catalyze a change to Morissette's ironic lyrics. After all, what's more ironic than having a better grasp of what's happening on other worlds rather than your own?

The research was published in *Nature Astronomy* (www.doi.org/10.1038/s41550-024-02230-x).

Image courtesy of NASA, ESA, CSA, Ralf Crawford (STScI) and iStock.com/mokee81.


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