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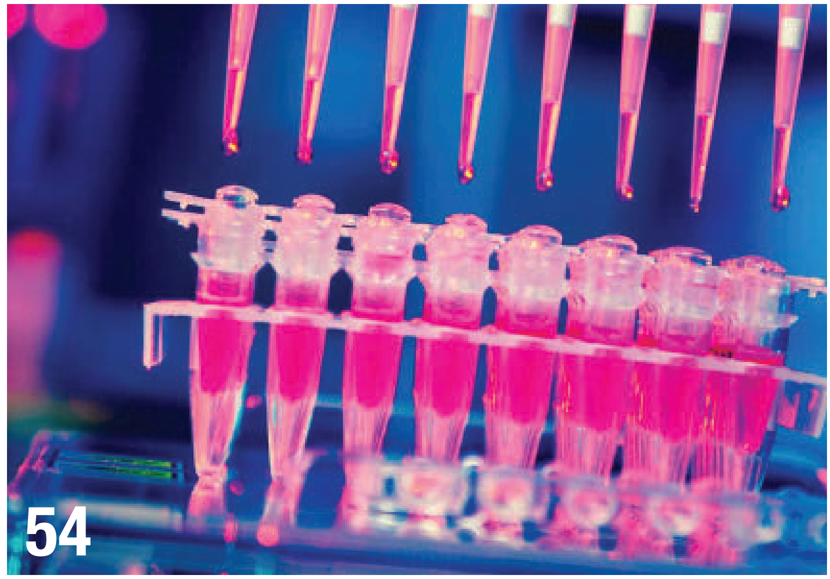

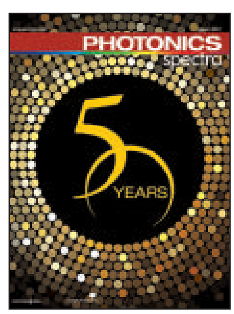

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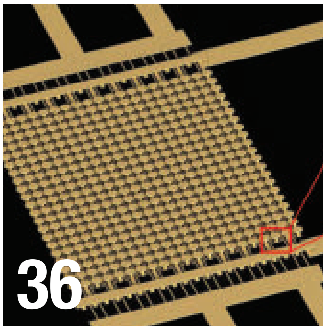

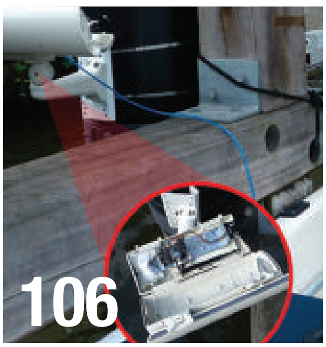

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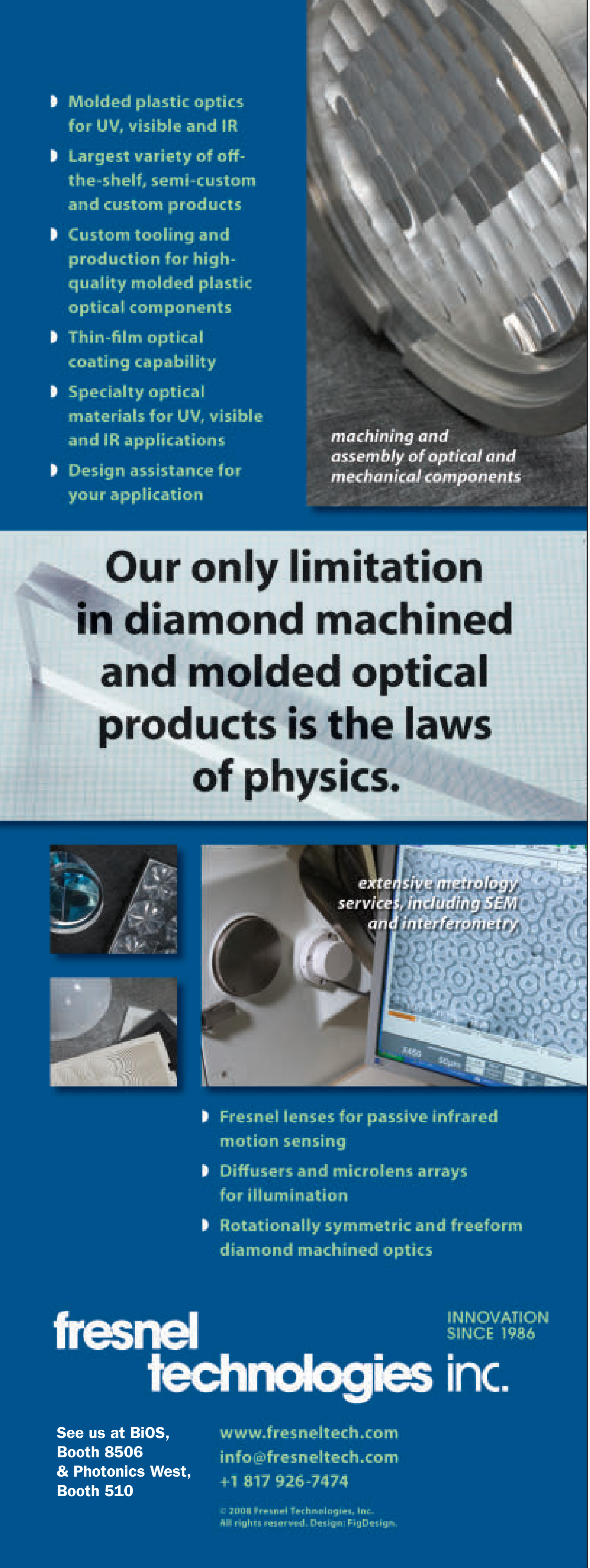

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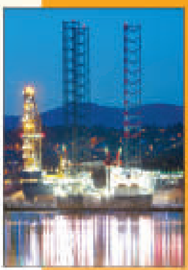

editorial COMMENT

An Eye to the Past and a View of the Future

If ever a single feature article embodied the spirit of an entire issue, I dare say it can be found in “From Viewfinders to Virtual Reality: The Evolution of Stereoscopic Lens Design,” on page 22. In it, longtime contributor and one-time *Photonics Spectra* advisory board member Bruce Walker examines optics in two eras.

In the early 20th century, wooden stereoscopic viewers were commonplace in living rooms on both sides of the Atlantic, bringing historic landmarks, jungle safaris and other curiosities to life in three dimensions. Curiously, a hundred years later, a similar occurrence is taking place as depicted in television commercials saturating the air waves: young and old exploring new worlds using virtual reality (VR) headsets. Those headsets, as Walker observes, employ similar optics as the first stereoscopes from a century ago; he presents a new lens design that promises greater image quality and clarity for the next generation VR headset.

Past and future.

Those are the twin themes that bind our 50th anniversary issue. In “Here’s to the First 50 Years,” Laurin Publishing President Tom Laurin reflects on the early years of *Optical Spectra*, when Smith Corona typewriters and metal letter presses were the tools of the trade. And no retrospective would be complete without revisiting the first issue itself, in which founder Teddi Laurin asserts the unique role of the publication in chronicling advances in the widening field of optics — and the importance in doing so.

The late ‘60s and early ‘70s also saw the rise of microelectronics, which would spur technological advances and drive the world’s economies for decades to come. Today, a similar revolution is beginning with integrated photonics — the intersection of microelectronics and photonics. On page 52, we hear from one of the pioneers of the field, John Bowers, who points to advances in autonomous vehicles, optical clocks, OCT, lab-on-a-chip and transceivers as transforming the areas of medicine, telecommunications, defense and other sectors in the years to come. See “The Revolution Has Just Begun.”

Along those themes our team of contributors each examines the future impact of photonic integrated circuits on various sectors, beginning with Marie Freebody’s “Medicine and Life Sciences,” page 54; Hank Hogan’s “Aerospace and Defense,” page 62; and science writer Valerie Coffey’s “Data Centers and Telecommunications” page 68. Also included is “Quantum Computing and Communications,” on page 76.

And finally, don’t miss senior editor Justine Murphy’s overview of this year’s Prism Awards finalists on page 84.

Enjoy the issue!

Michael D. Wheeler

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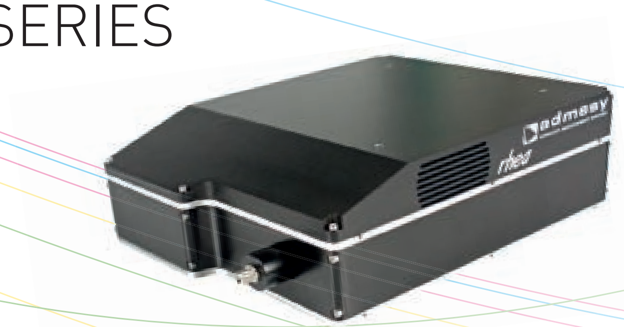

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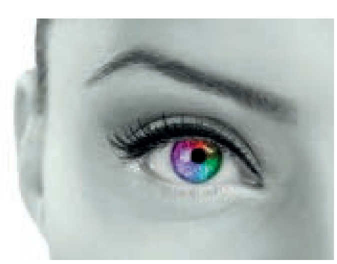

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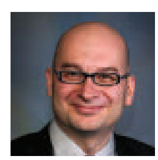

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Bruce H. Walker has worked in the fields of optical engineering and lens design since 1960, initially with GE and later with Kollmorgen Corp. Since 1991 he's been an independent consultant specializing in solving optical engineering problems and creating lens designs. Page 22.

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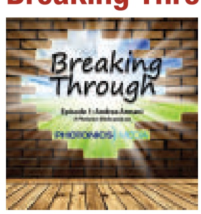
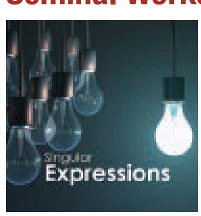
Breaking Through: Women in Photonics, episode 2



Senior Editor Justine Murphy talks with **Mackenzie Van Camp**, a Ph.D. candidate at Boston University who is studying ways to apply quantum mechanics of light for higher precision measurements. As a young woman embarking on a career in photonics, she shares her experiences and offers a unique perspective on the industry. Visit **www.photonics.com/V306**.

Seminal Works: An Interview with Federico Capasso



An interview with **Federico Capasso**, professor of applied physics and an electrical engineering research fellow at Harvard University. While Capasso is perhaps best known for his role in the invention of the quantum cascade laser at Bell Laboratories in 1994, pinning down just one seminal work is a challenge for a scientist whose career is a multidisciplinary continuum. Visit **www.photonics.com/V307**.

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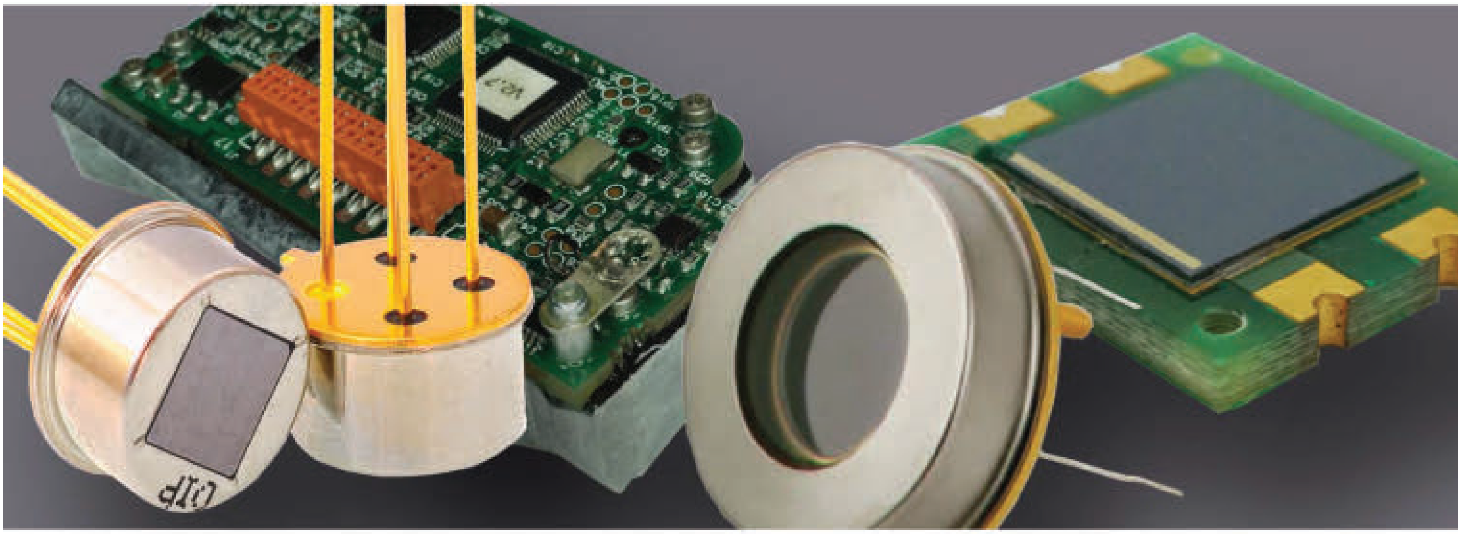

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Here's to the First 50 Years

Late last year while clearing out the contents of my parents' basement, I came across several heavy metal plates with raised lettering. No ordinary printing plates, these plates had history: They were used to print early editions of *Optical Spectra* in the 1960s.

Back then, printing was labor intensive. Movable type was locked into a chase and then eventually pressed against the paper, transferring the ink to the page.

Even preparing mailing labels was primitive in comparison to how it's done today. We'd load up the family station wagon with tray after tray of IBM 80-column punch cards and head out to Rensselaer Polytechnic Institute where we had an arrangement to use one of the university's mainframe printers — a process that required multiple trips and took five days.

The old punch cards and printing plates are tangible connections to the earliest days of the magazine when Teddi and her hardworking staff set out do something special: to create what would become a nascent industry's pre-eminent publication.

"Here, in this one spot, we are involved with one pursuit — spreading a glimpse of optics to an area that is engaged in its many facets," Teddi wrote in an editorial in January 1967.

It was a rousing vision for a heady time.

The field of optics was undergoing a profound transformation, driven by the emergence of the first commercial laser seven years earlier. The laser — and its related optics — would touch virtually every industry, from science and medicine to telecommunications, defense, manufacturing and space exploration.

Optical Spectra would experience growth and change, too, exemplified in the decision to rename the magazine. In the 1970s, a growing circle of researchers had adopted the term "photonics" to convey how photons behaved in ways analogous to electrons. Ultimately, Teddi and my sister Diane agreed and — in a dramatic move — *Optical Spectra* gave way to *Photonics Spectra* — the name it bears today.

There've been other notable changes — too numerous to mention — to the magazine along the way. What hasn't changed is our commitment to the mission Teddi set forth half a century ago.

Special to this issue are excerpts from the first issue of *Optical Spectra* and the inclusion of a feature by longtime industry friend Bruce Walker, who served for many years on our advisory board. His first piece was published with us in 1968. Fittingly, Bruce looks back on the field of stereoscopic viewers and ahead with a new lens design suited for today's virtual reality headsets.

More retrospective pieces are planned for the year ahead. Thank you for reading — and here's to the next 50 years!

Tom Laurin
President

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50 YEARS

"While Optical Spectra *is a new 'word recorder' in a field of publications that has long ago defied absorption, it intends to be a superior one. And it aims to bring, to the small segment of humanity that reads it, information of use."*
— excerpt from original editorial, *Optical Spectra*, January 1967.

In the words of Laurin Publishing founder Teddi C. Laurin, "Here, in this one spot, we are involved with one pursuit — spreading a glimpse of optics in an area that is engaged in its many facets." And although much has changed, that is still our pursuit.

Before the launch of *Optical Spectra*, Teddi had worked with Clifton M. Tuttle, an eminent retired Eastman Kodak physicist in producing the *Optical Industry Directory*.

The company's role as the chronicler of a rapidly expanding industry would grow significantly with the launch of *Optical Spectra* in 1967. As the publication followed the technology into an ever-widening range of applications, it became evident that the related fields of optics, lasers, fiber optics, electro-optics and imaging were interwoven and called for a unifying name. That led to a name change to *Photonics Spectra*, in 1982.

Throughout all these years, our mission has remained the same: In essence, not merely to hold a mirror to progress, but do what we can to help it along, realizing that all of us in the industry can best achieve that goal by sharing our knowledge, our insights and our visions for the future. It's been an exciting 50 years!

"Letters to the Editor" from 1967

"May I wish you the very best of luck with your new venture, Optical Spectra. *For many years we have considered the* Optical Directory *a bulwark in the optics business. Now we can look forward to the badly needed expansion of communication and optics through your new magazine."*
Letter to the Editor, *Optical Spectra*
January 1967

"My heartiest congratulations on your first issue of Optical Spectra. *You have accurately sensed the real void which existed in optical technology, i.e. the lack of a 'current-awareness'-oriented technical journal, and your first issue has given those of us who work in the field the promise of a truly significant contribution."*
Letter to the Editor, *Optical Spectra*
April-May-June 1967

"May I join in with your other readers to compliment you on the excellence of the general design of the magazine, and the high order of interest and usefulness of the technical content."
Letter to the Editor, *Optical Spectra*
Fourth Quarter 1967

Figure 1. Stereoscope viewer circa 1900.

Bruce H. Walker

Figure 2. Stereoscope viewer circa 2005.

Zeiss

Figure 3. Modern 3D virtual reality (VR) system.

From Viewfinders to Virtual Reality: The Evolution of **Stereoscopic Lens Design**

A new lens design promises improved image quality and an increased field of view for virtual reality headsets.

BY BRUCE H. WALKER
WALKER ASSOCIATES

In the late 1800s and early 1900s, the stereoscope was the subject of great interest and entertainment in the living rooms of families on both sides of the Atlantic. Invented by Sir Charles Wheatstone, it was made popular in Europe by Sir David Brewster and in the U.S. by Oliver Wendell Holmes Sr. The stereoscope typically included a pair of simple wedge lenses with a focal length of 180 mm, enabling the viewer to see a pair of images in 3D, each

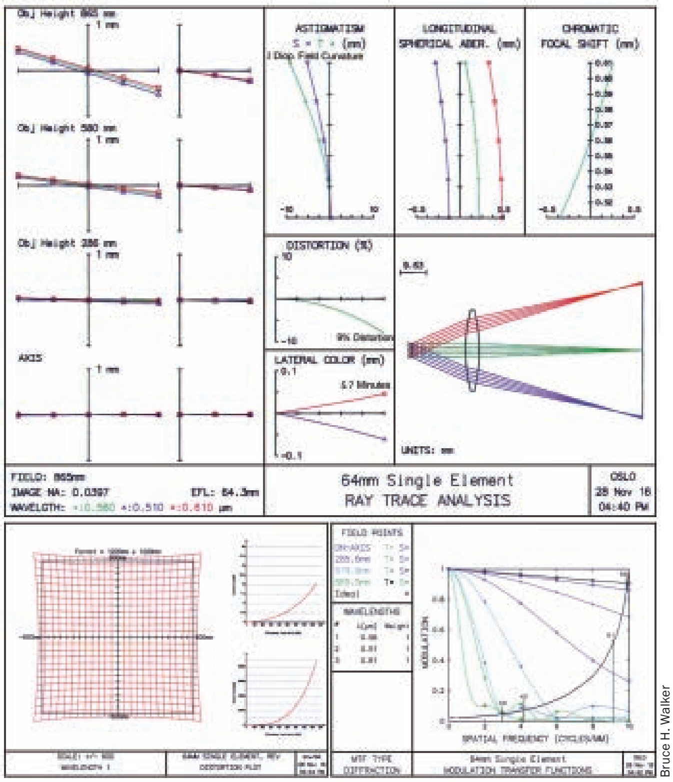


Figure 4. Aberration plots for the 64-mm single-element lens.

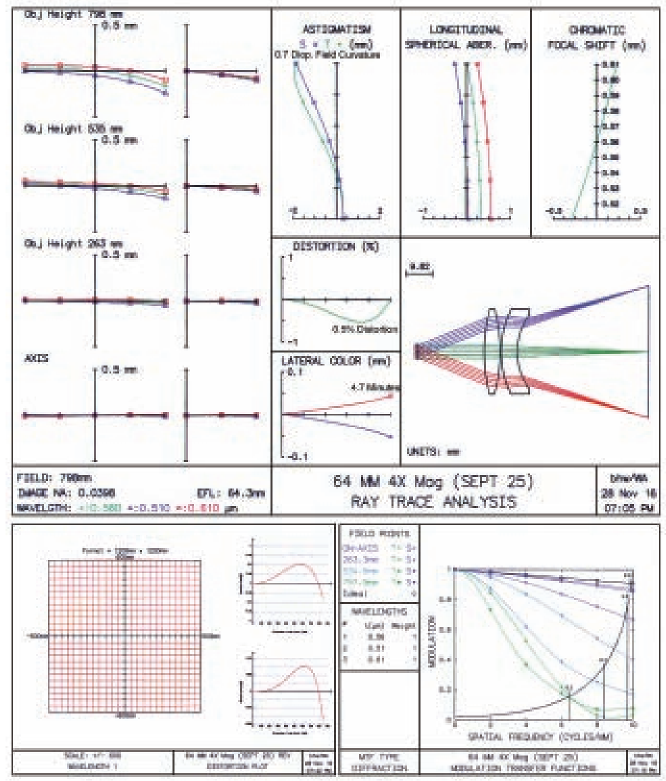


Figure 5. Aberration plots for the 64-mm 4× magnification glass lenses.

being 75 × 75-mm square. This resulted in a 3D field of view that is 24 × 24° (Figure 1).

During the second half of the 1900s, the stereoscope design was fine-tuned to allow the user to view bright, high-resolution color transparencies. In typical viewers of the day, the images were 50 × 50-mm square, viewed with 75-mm focal-length simple optics. This resulted in a viewed image with a field of view covering a full 36 × 36° square. Relative to the early stereoscopes, this yielded a 1.5× increase of the field of view (Figure 2).

Scanning 3D motion display

The first virtual reality (VR) systems emerged in 2010, and included an updated stereoscopic device. VR headsets view a pair of 3D images, often displayed on the screen of a modern iPhone or smartphone. A 3D bright-color, wide-angle display is not just a fixed image, but it can be a scanning 3D motion display with an audio mode (Figure 3).

Most of today's VR headsets include simple optics, usually a single molded aspheric acrylic lens for each eye. The primary advantages of these optics are their low cost and light weight, making them suitable for a large consumer market. The image quality of these systems is limited, however, though this reduced image quality is overcome by the dynamic nature of the 3D motion display presented by the cell phone.

In the sections that follow, a new lens design is proposed that meets the low cost and weight of the single lens element, while achieving a greatly improved image quality and an increased field of view presented to the eye.

Better lens design

For the single-molded aspheric acrylic lens element presently used in many new VR headsets, the image quality is considered acceptable by most, especially when dealing with a field of view of 36 × 36° square. When an increased field of view of 42 × 42° square is presented to the eye, however, the image quality of the optics must improve. The major image quality issues that must be dealt with when creating a new lens design covering the large field of view include: image modulation transfer function, distortion, field curvature-astigmatism and lateral color.

Before a better lens can be designed, however, it's necessary to analyze and understand the ray trace analysis, distortion and modulation transfer functions for a typical single-element lens (Figure 4). As the aberration plot shows, the residual astigmatism will be about 2 diopters of field curvature with 1.0 diopter of astigmatism. The remaining distortion will reach about 9 percent at 21 degrees off axis, and the lateral color plot indicates that a residual of 5.7 arc minutes is reached at 21 degrees off axis. In most visual systems, maximum lateral color of less than five minutes is generally acceptable. The distortion plot (Figure 4, lower left) displays how the 9 percent distortion will appear to the eye. Finally, the modulation transfer plot (Figure 4, lower right) indicates that the resolution of this system will be reduced from 9.8 cycles/mm on axis, to 3.0 cycles/mm at the field of view of 21 degrees. This modulation transfer function (MTF) plot assumes that the cellphone screen maximum resolution is 10 cycles/mm.

New optical design to improve image quality

It's the task of the optical lens designer to improve upon the image quality of the single-element design. The designer must deal with the weight, size and cost of the lens, while achieving the best possible overall optical image quality.

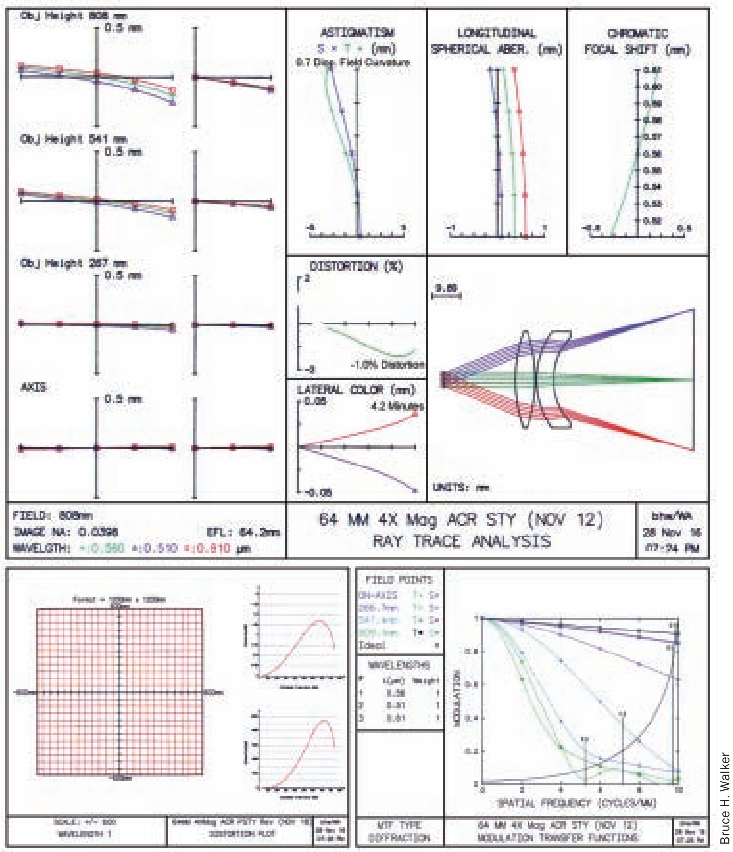


Figure 6. Aberration plots for the 64-mm 4× magnification plastic lenses.

A common five-element eye piece optical design has been simplified, step-by-step, to achieve a new design that has just two elements remaining. The resulting design performance depicts ray trace analysis, distortion and modulation transfer functions for the new "64 MM 4× Magnification Glass Lenses" design (Figure 5). The ray trace analysis shows that residual field curvature has been reduced to 0.7 diopters, with zero astigmatism. Also shown: Distortion is reduced to less than 1 percent at 21 degrees off axis. The resulting lateral color plot indicates that 4.7 arc minutes will be found at 21 degrees off axis. As stated earlier, in most visual systems, lateral color of less than five minutes is generally found to be acceptable.

The distortion plot (Figure 5, lower left) reveals that essentially zero percent distortion will appear to the eye. Finally, the modulation transfer plot (Figure 5, lower right) indicates that the resolution of the system will be 9.8 cycles/mm on axis, released to 6.3 cycles/mm as the field of view is increased to 21 degrees. Again, this modulation transfer plot assumes that the cell phone screen maximum resolution will be 10 cycles/mm.

The final plastic lens design

In generating the previous two-glass element len designs, the optical glass types selected have been Lak8 and

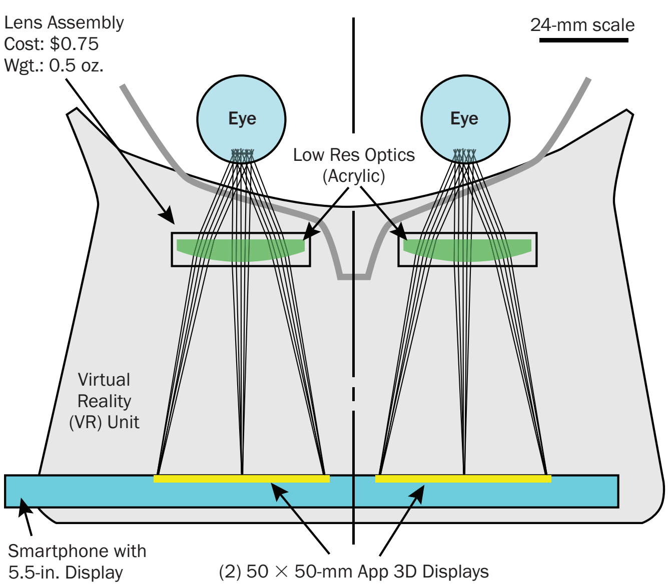


Figure 7. VR unit with low-resolution optics (single acrylic element).

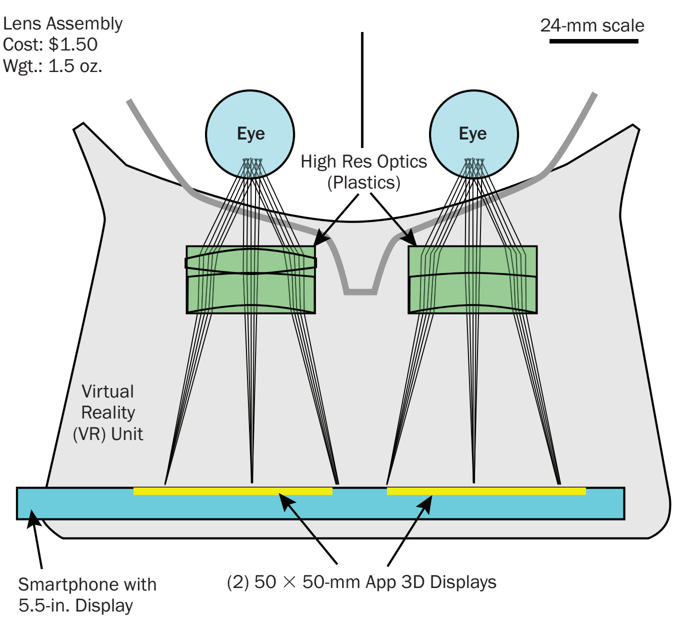


Figure 8. VR headset with high-resolution plastic optics.

SF10 — glass materials that can now be substituted by using the two most common optical quality plastics of acrylic and polystyrene. Also, a few minor changes have been made to the glass design to optimize the plastic lens design.

The glass prototype models would be used to confirm the acceptance of this general design approach. Then, the molded plastic elements could be used in the final system design, compatible with the manufacture of high volumes at low weight and low cost. In this plastic, two-element design, compared with the single lens, each eye lens assembly increases in weight from 0.5 to about 1.5 ounces, while cost will increase from 75 cents to an estimated $1.50 — moderate increases for this new two-element plastic design that most in the industry would likely deem acceptable.

The ray trace analysis shows that field curvature for the new 64-mm 4× magnification plastic lens has been corrected to 0.7 diopters, with zero astigmatism (Figure 6). Distortion is reduced to 1 percent at 21 degrees off axis. Finally, the lateral color plot indicates that 4.2 arc minutes are due at 21 degrees off axis. As stated earlier, in most visual systems lateral color of about five minutes is generally deemed acceptable. At 4.2 arc minutes, the image quality, due to lateral color, will be totally acceptable at the 21-degree field of view.

The distortion plot (Figure 6, lower left) shows how the 1 percent distortion will appear to the eye over a full field of view of 42 × 42° square. Finally, the modulation transfer plot (Figure 6, lower right) indicates that the resolution of this system will be reduced from 9.9 cycles/mm on axis, to 5.2 cycles/mm as the field of view is increased from zero to 21 degrees. Again, this plot assumes that the cell phone screen maximum resolution will be 10 cycles/mm.

Comparing the 64-mm single element with the 64-mm 4× magnifcation plastic lens

Figures 7 and 8 compare the currently used single plastic lens to the new "64 mm 4× Plastic" design with two lens elements, with each figure showing the VR unit viewing a 3D image that is displayed on a smartphone.

The single-element design will leave a residual of 2 diopters of field curvature with 1 diopter of astigmatism (Figure 4). The two-plastic element design will leave a residual of 0.7 diopters of field curvature with zero diopter of astigmatism (Figure 6).

The single element will leave residual of about 9 percent of distortion (Figure 4), whereas the two-element solution will leave residual of just one percent distortion (Figure 6).

Using the single-element lens plot compared to the plot for the 4× Magnification Plastic lenses, it's apparent that the single-element design will leave a residual lateral color of about 5.7 arc minutes. The two-element design will leave a residual lateral color that will be about 4.2 arc minutes.

Finally, the single-element design will leave a resolution from 9.8 cycles/mm on axis to about 3.0 cycles/mm at 21 degrees (Figure 4). The two plastic lens element design (Figure 6) achieves a resolution from 9.9 cycles/mm on axis, to about 5.2 cycles/mm at 21 degrees. These are the major, significant image quality improvements of the new lens design with two plastic lenses from the single plastic lens design.

For over one hundred years, 3D stereo viewing devices have been available for various applications. Now, virtual reality headsets use modern smartphone screens to view 3D stereo image displays.

With the possibility of developing a new eye lens design that will greatly improve image quality while maintaining the required reduced size, weight and cost of the optics, the stereo viewer is once again a captivating subject in families' living rooms.

Meet the author

Bruce H. Walker has worked in the fields of optical engineering and lens design since 1960, initially with GE and later with Kollmorgen Corp. Since 1991 he's been an independent consultant specializing in solving optical engineering problems and creating lens designs. From 1970 to 1999, Walker was a member of the Editorial Advisory Board of *Photonics Spectra*. He has authored two textbooks, *Optical Engineering Fundamentals* and *Optical Design for Visual Systems*. To learn more, visit www.waoptics.com.

Brookhaven National Laboratory receives 2016 R&D 100 Awards

Three technologies developed at the U.S. Department of Energy's Brookhaven National Laboratory have received 2016 R&D 100 Awards, recognizing innovations in microscopy, catalysis and nanomaterials.

The R&D 100 Awards recognize the 100 most innovative technologies and services of the past year. The Brookhaven Lab winners are the Hard X-ray Scanning Microscope with Multilayer Laue Lens Nanofocusing Optics, MoSoy Catalyst, and Nanostructured Anti-Reflecting and Water-Repellent Surface Coatings.

Brookhaven's custom-built x-ray microscope has advanced x-ray optics called multilayer Laue lenses for imaging a broad range of materials, with a spatial resolution of >15 nm.


Brookhaven National Laboratory

Brookhaven physicists Yong Chu **(left)** and Evgeny Nazaretski led the project to develop the first multilayer Laue lens-based microscope, which is installed at the Hard X-ray Nanoprobe beamline at Brookhaven's National Synchrotron Light Source II.

MoSoy Catalyst is a novel catalyst derived from low-cost, earth-abundant molybdenum metal and renewable soybeans to produce hydrogen in an environmentally friendly, cost-effective way. The catalyst eliminates the need for expensive metal catalysts to speed up the rate at which water is split into hydrogen and oxygen.

The nanotextured coatings are nanoscale features etched into the surfaces of silicon, glass and some plastics to absorb all wavelengths of light from any angle and repel water extremely efficiently, with the water droplets carrying away particles of dirt.

BAE Systems awarded US Navy contract

The U.S. Navy has awarded defense technology developer BAE Systems Inc. a $600 million contract for Advanced Precision Kill Weapon System (APKWS) laser-guided rockets.

With an initial award of more than $130 million, the three-year, indefinite delivery/indefinite quantity contract will help speed the delivery of these precision guidance rockets to meet the needs of the U.S. Navy, Marine Corps, Army and Air Force, as well as a growing number of allied nations.


BAE Systems

BAE Systems received a new contract that will help speed the delivery of APKWS laser-guided rockets to meet the needs of the U.S. Navy, Marine Corps, Army and Air Force, as well as a growing number of allied nations.

"The Navy has been a tremendous partner, and this latest contract includes valuable provisions that allow other services and allies to leverage this small guided munition program of record," said David Harrold, director of precision guidance solutions at BAE Systems. "The large demand for this cost-effective technology is a testament to its highly innovative design, and this contract will allow us to greatly increase production."

To meet demand, BAE Systems has invested in a new facility in New Hampshire that is optimized for precision guidance solutions and designed to meet a significant increase in production. The company expects it will be able to ramp up production to 20,000 APKWS guidance units per year with potential for additional growth.

BAE Systems provides defense, aerospace and security solutions.

Heliatek raises €80M to expand manufacturing

Organic photovoltaic and solar film developer Heliatek GmbH has raised €80 million ($88 million) to finance the expansion of its HeliaFilm manufacturing capacity.

This financing round comprises €42 million ($46.8 million) in equity, €20 million ($22.3 million) in debt and about €18 million ($20 million) in subsidies.

"This allows us to strengthen our world leadership in organic solar film and to accelerate our expansion," said Thibaud Le Séguillon, CEO of Heliatek. "We will continue to lead the way in enabling distributed energy generation on industrial and commercial buildings. We will follow our strategy by expanding the building integrated organic photovoltaic market through supplying large quantities of our HeliaFilms to our customers in the building and construction material field."

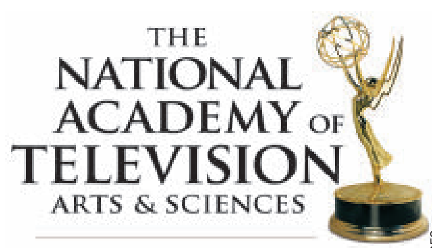
Heliatek plans to install its new manufacturing roll-to-roll facility on its site in Dresden over the next 18 months, offering a capacity of 1 million m² p.a. of solar films when fully ramped up. The company will continue in parallel its worldwide rollout of its HeliaFilm products to the building material and automotive industries.

The financing was led by European energy company Innogy SE. New investors include ENGIE, BNP Paribas and CEE Group, an investment company of Lampe Equity Management specializing in renewable energy. Existing investors Aqton, BASF, eCAPITAL, High-Tech Gründerfonds, Innogy Venture Capital, Tudag and Wellington Partners also participated.

The European Investment Bank, under the InnovFin European Union Finance for Innovator program, granted a €20 million ($22.3 million) loan to Heliatek. The program is a joint initiative launched by the European Investment Bank in cooperation with the European Commission under Horizon 2020.

$766B — value of the global photonics market by 2020, as projected by Transparency Market Research

OFS receives Emmy for fiber optic pioneering



OFS

Fiber optic network solutions developer OFS Fitel LLC has received an Emmy award from the National Academy of Television Arts and Sciences for contributions toward the pioneering and deployment of fiber optic cable.

The Emmy Awards for Technology and Engineering are presented to companies that engineer significant or innovative developments that affect the transmission, recording or reception of television. OFS's award recognizes the roles of the company's predecessors, Bell Labs and Western Electric, as well as OFS in the development of technologies that have refined and enhanced the use of fiber optic cable for broadcast television.

"The invention and widespread deployment of single-mode fiber optic cable has fundamentally changed broadcast delivery over the past 30 years. Today's fiber-rich broadcast networks help to enable flawless, on-demand delivery of increasingly higher resolution television programs while also containing the bandwidth needed to deliver whatever incredible offerings the broadcast television industry will create in the future," said Timothy F. Murray, CEO and chairman of OFS.

OFS is a designer, manufacturer and provider of optical fiber, fiber optic cable, connectivity, FTTx and specialty photonics solutions.

• B&W Tek receives R&D 100 Award in the Analytical and Test category •

This month in history

What were you working on five, 10, 20, 30 or even 50 years ago? *Photonics Spectra* editors perused past January issues and unearthed the following:

2012

Researchers at Fraunhofer Institute for Manufacturing Engineering and Automation IPA developed a laser-based 3D printed robotic spider that can explore environments considered unreachable by or too hazardous for humans.

2007

By "folding" a telephoto lens, engineers built a powerful yet ultrathin digital camera. This technology may yield lightweight, ultrathin, high-resolution miniature cameras for unmanned surveillance aircraft, cellphones and infrared night-vision applications.

1997

Scientists at Rutgers University and the Woods Hole Oceanographic Institute established the first permanent fiber optic link that allowed live, two-way communication with instruments on the bottom of the ocean.

1967

The Fraunhofer Institute of Freiburg and Carl Zeiss of Oberkochen, both in West Germany, embarked upon a series of balloon-borne solar observation experiments at the balloon-flight station of the National Center for Atmospheric Research in Palestine, Texas.

Light Speed

Monroe Community College eyed for top photonics training center

U.S. Sen. Chuck Schumer (D-NY) has called for federal funding to make Monroe Community College (MCC) a top photonics training center.

Schumer launched his push to secure over $500,000 for MCC through the National Science Foundation's Advanced Technology Foundation's Education program. The funding would allow MCC to expand its optics and photonics degree programs and purchase new equipment, as well as develop a new curriculum and expand student outreach.

Schumer said that MCC is currently the only community college in the U.S. with an optics and photonics associate's degree program, and it's looking to become a major training center. He hopes the school will ultimately become the Northeast Regional Center for Optics & Photonics, but said federal funding is needed to begin the expansion process.

"MCC is a proven leader in optics and photonics training, and we have an opportunity here to build on that success by creating a top-notch training center that will prepare Upstate New Yorkers for good-paying, middle-class jobs in this burgeoning field," Schumer said.

Monroe Community College

Quantel opens Chinese service center

Solid-state laser developer Quantel Laser has opened a new service center in China at the offices of its long-time partner, Titan Electro-Optics Co. Ltd (TEO).

The service center will provide local service to all Quantel customers in China. Local service will be available at the company's Beijing headquarters as well as in Shanghai and Shenzhen.

"The number of Quantel lasers in China has grown exponentially over the past several years," said Greg Smolka, vice president of sales and marketing at Quantel. "TEO has done a great job expanding our direct sales into China, especially in applications like lidar and flat panel display manufacturing. This new service center, however, will also support our many OEM customers who have also seen significant growth in China."

Quantel is a manufacturer of solid-state laser systems for scientific, military, industrial and medical applications.

$6B

— value of the packaged silicon photonics transceiver market by 2026, according to a new report from Yole Développement

Han's Laser expands with CorActive partnership

CorActive High-Tech, a private manufacturer of specialty optical fiber and fiber laser modules, has entered into a strategic partnership with Han's Laser Technology Group Co. Ltd., a China-based laser equipment manufacturer. This comes after receiving an investment from the company whose annual revenues reach the $1 billion mark.

CorActive is now a subsidiary of Han's Laser, which has acquired a majority of the company. CorActive will remain independent and will continue its current operation in Quebec City.

"This is beneficial for both sides and emphasizes the complementarity of both parties," said Jean Dubé, president and CEO of CorActive. "One of the main components needed for our laser modules can now be sourced internally, greatly reducing our production cost."

For Han's Laser, CorActive will help boost its capabilities in fiber laser manufacturing and expand into new applications and geographies.

"We have worked with Han's Laser for a number of years already. Han's Laser acquiring CorActive will be positive as it will propel and support us to become a more competitive player in the fiber laser module market," Dubé said. "Everything will continue as planned. We will keep our current operation and will continue developing our current markets."

CorActive's solutions are currently used for industrial, sensing, telecommunications and medical applications.

Han's Laser Technology Group Co. Ltd. is a laser machine manufacturer that offers laser processing solutions for the automotive, IT and solar industries, among others.

Sicoya wins European Photonics Startup Challenge

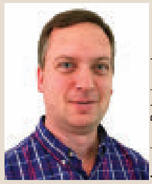
Silicon photonics transceiver developer Sicoya has won the European Photonics Startup Challenge at the Micro Photonics conference and expo.

The company received a cash prize of €4,000 ($4,300), a business coaching package worth €1,500 ($1,600) and various promotions in industry journals. The competition, part of the European outreach program Photonics4All, chose eight finalists from Germany, France and Austria to give a presentation on their technology and business model to a judging panel consisting of photonics company leaders and cluster managers.

"Due to our technological achievements, we can lower the power consumption and reduce the costs of silicon photonics transceivers tremendously," said Torsten Fiegler, business development manager of Sicoya. "This enables better interconnects and will enable a faster internet."

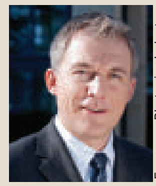
Sicoya, a Technical University of Berlin spin-off, develops fully integrated silicon photonics transceiver chips designed for server interconnects in data centers. Sicoya said it is on track to enter the market in 2017 with a 100-Gbps transceiver chip featuring integrated electronics and optics on a single chip.

PEOPLE IN THE NEWS


American Polarizers Inc.

Optical technology developer American Polarizers Inc. (API) has appointed **Jeffrey Snyder** as its new president. Snyder joined API in 2014, serving as the company's product engineering manager. He has spent more than 20 years in various specialized materials industries including fiberglass, graphite and wood products manufacturing. Snyder holds a bachelor's degree in electro-mechanical engineering and a master's degree in systems engineering from Penn State University.

Lidar sensor developer Quanergy Systems Inc. has appointed **Patrick Archambault** as its director of strategic financial planning, responsible for providing fiscal development and analysis to maximize Quanergy's innovative growth strategy. Archambault will be responsible for managing all forecasting and budgeting activities for the company and will serve as a liaison between Quanergy and the analyst and investment communities. Prior to joining Quanergy, Archambault served as the lead analyst at Goldman Sachs, covering the U.S. autos and auto parts sector for 12 years. He has been recognized multiple times on the Wall Street Journal's annual Best on the Street survey, and has received the Thomas Reuters StarMine and Financial Times awards for stock picking and estimate accuracy. Archambault has also been recognized for his extensive and cutting-edge research on the topic of automotive technology.


European Photonics Industry Consortium.

Jan Meise, CEO of optical and thermal management technology developer AMS Technologies AG, has joined the board of directors of the European Photonics Industry Consortium (EPIC). Prior to joining AMS Technologies in 2010, Meise was the director of strategic marketing for Finisar, a U.S.-based company offering optical transceivers for the data and telecommunication industry. He holds a master's degree in electrical engineering from the Technical University of Braunschweig, Germany. EPIC is an industry association that promotes the sustainable development of photonics organizations in Europe.

Steve Patterson has been named CEO of Quantel USA, a Quantel Laser subsidiary. Patterson comes to Quantel after leading DILAS Diode Laser's U.S. office through rapid growth and market expansion. A nine-year Army veteran, Patterson holds a Ph.D. from the Massachusetts Institute of Technology, has authored numerous technical papers and has two patents to his name. Quantel Laser is a designer and manufacturer of high-power, solid-state lasers for scientific, industrial, military and medical applications.


Jack Riccardi

Ocean Optics Inc.


David Schaefer

Ocean Optics Inc.

Optical technology provider Ocean Optics Inc. has named **Jack Riccardi** and **David Schaefer** executives and members of its board of directors. Riccardi has joined the company as its vice president of finance. He will be responsible for all aspects of finance, accounting, IT and office administration. Schaefer has joined the company as vice president of sales and strategic marketing. He will be responsible for global sales and marketing of the company's entire line of spectrometers, chemical sensors, analytical instrumentation and accessories.

• LEDs dominate global sapphire applications • Nanomechanics receives Tennessee Trade Excellence Award •

GSU, Alpao to upgrade CHARA array

Georgia State University's Center for High Angular Resolution Astronomy (CHARA) and optics developer Alpao SAS have signed a contract for the development of an adaptive optics upgrade for the CHARA array, the largest optical interferometer array in the world.

The organizations will develop new deformable mirrors and improve the sensitivity of the interferometric telescopes on Mount Wilson, Calif. Alpao will develop and manufacture six deformable mirrors, each composed of 69 actuators to deform a plane mirror membrane. These deformable mirrors represent state-of-the-art instrumentation to correct for the effect of atmospheric turbulence. The goal of this technique, known as adaptive optics, is to observe stars and their surroundings as clearly as they would appear in space.

"We are delighted to begin this new stage in CHARA's scientific mission with deformable mirrors from Alpao," said Theo ten Brummelaar, CHARA array director. "Investigators around the world are now planning new programs with the adaptive optics system that will reveal some of the smallest objects in the sky ever measured."

The modifications will allow the telescopes to measure stars three times fainter than now possible. The new system will increase the number of nights with high-quality data by about a factor of three in the summer and five in the winter, with much faster observation times. New important areas of study will include high-interest targets, such as dusty debris disks around young stars and accretion disks and gas flows around newborn stars.

"This contract will push us to develop six specific deformable mirrors with a precise elliptical surface," said Vincent Hardy, sales manager of Alpao. "All of our team is very excited to be a part of this project for the future of the interferometric telescope and the development of astronomical science."

Alpao designs and manufactures adaptive optics components and systems as well as deformable optical elements for the optimization and enhancement of optical systems.

$427.8M

— value of the global consumption of component-level fiber optic attenuators by 2021, according to a market forecast from ElectroniCast Consultants

For Commonwealth Games, Gold Coast lays its own fiber optics

The Gold Coast City Council in Australia is set to pay $3.6 million to lay down its own fiber optic cable in the quest for high-speed internet.

In preparation for the 2018 Commonwealth Games, the council network will run from Griffith University, the base of the Health and Knowledge Precinct and the Commonwealth Games Village, south to Broadbeach, connecting with the game's convention center. The Commonwealth Games is an international, multi-sport event involving athletes from the Commonwealth of Nations, including Australia, Canada, England, Ireland, New Zealand, Scotland and Wales.

The fiber optic cable will follow the light-rail route, branching out to Surfers Paradise, Southport and Broadbeach, and is expected to provide up to 100 Mb/s in both directions. The council took action after the National Broadband Network revealed that it would not arrive in the city until after the international event.

"We are committed to making fiber optics available for the Commonwealth Games," said Tom Tate, mayor of Gold Coast.

Mike Batterham

Fiber optic cables will be installed in conduits along the Gold Coast tramline.

PolyU to install fiber sensing technology in Singapore transit system

Hong Kong Polytechnic University's (PolyU) proprietary optical fiber sensing technology for railway monitoring has been adopted in Singapore metro lines.

Sensors were also installed in in-service trains to monitor the tracks on which the trains run. PolyU is the first in the world using fiber optic sensors in in-service trains for continuous monitoring of the tracks. Compared with the prevailing means of regular check-ups for tracks after close of traffic, the new system provides continuous, in-service monitoring to enhance service reliability through quick identification and rectification of defects.

"This PolyU technology will help enhance the performance of metro systems through an advanced predictive monitoring and maintenance regime, which is now the best practice in the railway industry and a global trend. This also shows how an academic institution in Hong Kong can develop leading technology in the world through collaboration with the industry," said professor Tam Hwa-Yaw, chair of the photonics department and head of the electrical engineering department at PolyU.

A total of six groups of sensors will be installed in tracks and trains of the East West Line and North South Line of Singapore's SMRT mass rapid transit system, the two busiest lines in the metro network. An agreement was signed with

SMRT in February 2016, and a trial run was completed successfully in June. The permanent monitoring system is now being installed in the two lines, to be completed in early 2017. PolyU will provide training to SMRT staff in operating the system, while the data collected during monitoring can also be sent to PolyU in real time for analysis when needed.

Coherent completes acquisition of Rofin-Sinar

Laser developer Coherent Inc. has completed the acquisition of Rofin-Sinar Technologies Inc., a developer of high-performance industrial laser sources, for $942 million.

The acquisition is valued at $32.50 per share. As a result of the acquisition, Rofin common stock will no longer trade on the Nasdaq Stock Market and Frankfurt Stock Exchange.

Rofin-Sinar is a developer, designer and manufacturer of lasers and laser-based system solutions for industrial materials processing applications.

Angstrom appoints All Scientific for representation

Magnetron sputtering technology developer Angstrom Sciences Inc. has appointed All Scientific LLC as its exclusive manufacturer's representation for the mid-Atlantic and southeast region of the U.S.

The region consists of the District of Columbia, Virginia, West Virginia, Kentucky, Tennessee, North Carolina, South Carolina, Alabama, Georgia and Florida.

Angstrom Sciences Inc. is the premier global supplier of magnetron technology used to produce thin films through the sputtering process. Sputtering is used to manufacture advanced products such as energy-efficient architectural glass, optical components, flat panel displays and micro-electronic devices.

Berk-Tek expands IP platform

Fiber and copper network infrastructure solutions manufacturer Berk-Tek Inc. has expanded its EVERYTHING IP platform to include fiber optic solutions.

The company cites the evolution in wireless technology as reasons for the adoption. As the speed and bandwidth of wireless access points continue to increase with 802.11ac, Category 6A will be needed for each point, with more points

• The global market for helium, an inert gas essential for medical resonance imaging (MRI), semiconductors, welding, and other manufacturing and industrial uses is growing at two percent per year, as reported by IHS Markit. •

needed to support the same square footage as previous generations. The EVERYTHING IP solution allows customers to extend their reach to 500 m at 40 Gbps without having to move to an expensive single-mode solution.

Berk-Tek is a manufacturer of more than 100 different network copper and fiber optic cabling products for the transport of high-speed data, voice and power transmissions.

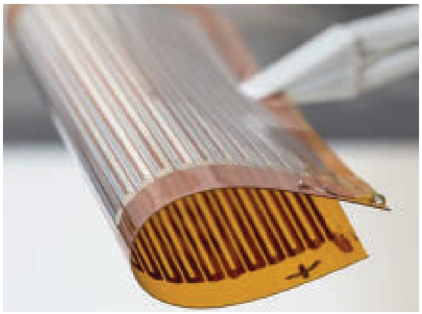
Industry and academia partner to advance thin-film coating technology

The University of Southampton and Plasma App Ltd. are collaborating on a one-year, £150K ($120K) feasibility study to explore novel thin-film coating technology and applications. The project collaborators intend to produce well-characterized samples of a range of novel Gallium, Lanthanum and Sulphur (GLS)-based optics for dissemination to members of the Chalcogenide Advanced Manufacturing Partnership. The wider community of chalcogenide glass users, especially those pursuing optical applications for aerospace, defense and IR imaging, will also use them.

GLS chalcogenide glasses are difficult to deposit as thick films using thermal techniques due to their complex chemistry, high melting points and electrical insulating properties. Plasma App's novel Virtual Cathode Deposition (VCD) technique uses pulsed beams of electrons to break up the GLS target material and deposit it as a thin film. Plasma App has demonstrated deposition rates of >0.2 µ per min of GLS glass onto a substrate at room temperature — a rate that is more than 10,000 times faster than conventional deposition by RF sputtering.

"This project provides a clear roadmap to increase the uptake of GLS glass into new technology areas that were previously considered difficult to access," said Dmitry Yarmolich, Plasma App CEO.

"We want to be able to give end users of IR optics a safe, robust and high-performance alternative to arsenic-based glasses and a faster, more accurate deposition method," said professor Dan Hewak of the Optoelectronics Research Center.



University of Southampton

A thermoelectric generator formed from doped chalcogenide materials on a flexible substrate.

The project is co-funded by Innovate UK and the Engineering and Physical Sciences Research Council (EPSRC).

Light-sheet microscope automatically adjusts to optimize image quality

ASHBURN, Va. and DRESDEN, Germany — A light-sheet microscope has been developed that can automatically adapt to the dynamic optical conditions of large living specimens. The smart microscope combines a novel hardware design with a software system that can analyze a specimen continuously and automatically adjust the settings to maximize image quality. Called the AutoPilot framework, this development could enable long-term adaptive imaging of entire developing embryos and improve the resolution of light-sheet microscopes up to fivefold.

Researchers from the Janelia Research Campus at Howard Hughes Medical Institute, the Max Planck Institute of Molecular Cell Biology and Genetics, and Coleman Technologies Inc. collaborated on the development of the microscope, which seeks to resolve one of the primary challenges of light-sheet microscopy: that the light sheet illuminating the specimen and the focal plane of the detection system must be perfectly co-planar.

"If they deviate in any way geometrically, it's like taking an image out of focus," said Philipp Keller, Janelia group leader for the research.

The AutoPilot framework enables the microscope to analyze and optimize the spatial relationships between light sheets and detection planes across the specimen volume in real time and automatically adapt to the dynamic optical conditions of living specimens.

"The microscope is smart in the sense that it controls the experiment itself," said Keller. "It's not the human who instructs the microscope exactly how to take images. The microscope figures out on its own what it needs to do to get a sharp image."

To enable the microscope, flexibility was added to the hardware, such as giving the microscope more freedom to rotate the light sheet in space. Software for the Autopilot framework was developed for analyzing images in real time, determining how to improve their quality, and adjusting the microscope parameters accordingly. Calculations, analysis and adjustments are performed during the microscope's brief downtime between collecting images.

"The system understands the relationship between all the different variables and when it observes that something is off, it can figure out which knob to turn to correct things," said Loïc Royer, developer of the software.

Researchers tested the microscope on various model systems, imaging the development of zebrafish and fly embryos over a 20-plus hour period. They also performed adaptive whole-brain functional imaging in larval zebrafish. These experiments demonstrated improvements in spatial resolution and signal strength by a factor of two to five and exhibited recovery of cellular and subcellular structures in many regions that could not be resolved by nonadaptive imaging.

With the AutoPilot's high level of instrument automation, even users without a technical background or training in light-sheet microscopy can produce optimal image data.

"We wanted to make the microscope as powerful as possible but also as easy to use as possible," said Keller. "The framework does this by helping the user ensure that the experiment is set up correctly, and also making sure the user can effortlessly and reproducibly produce optimal quality images in every single experiment."

Making microscopes adaptive and autonomous could contribute to the future use of light-sheet microscopy for automated high-throughput drug screens, mutant screens, and the construction of anatomical and developmental atlases in various biological model systems.

"So far, researchers had to sit at their microscope and tweak things manually — our system puts an end to this. It is like a self-driving car: it functions autonomously," said Royer.

The research was published in *Nature Biotechnology* (doi:10.1038/nbt.3708).

MPI of Molecular Cell Biology and Genetics

20-h imaging of a fruit fly embryo with the nervous system fluorescently labeled. AutoPilot automatically detects the onset of the expression of the marker and optimizes all parameters associated with this color channel in response to the emerging signal.

Photonics to play key role in spaceflight communications

GREENBELT, Md. — Making space communications more efficient for both near-Earth and deep-space missions is a priority for NASA, and photonics may provide the solution. Laser communications could significantly improve data rates in all space regions, from low-Earth orbit to interplanetary.

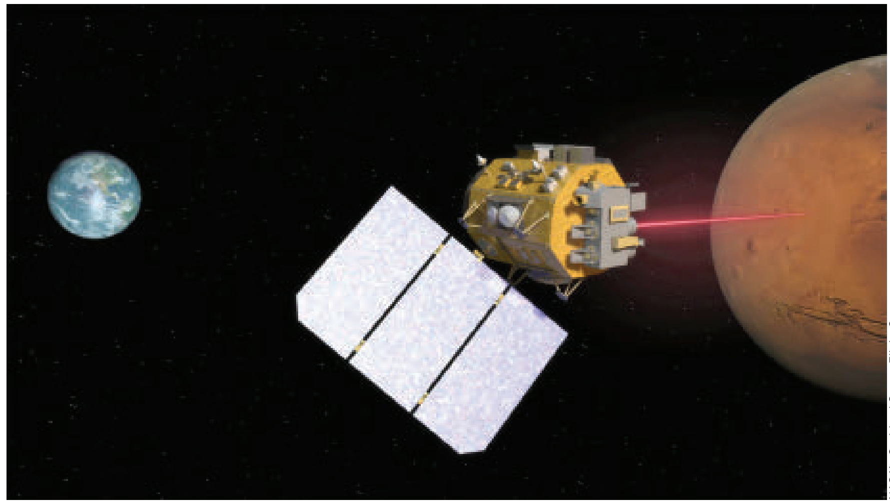
After more than 50 years of relying solely on radio frequency (RF) to send and receive data, several centers across NASA are experimenting with laser communications, which has the potential to provide data rates at least 10 to 100 times better than RF. These higher speeds would support increasingly sophisticated instruments and the transmission of live video from anywhere in the solar system. They would also increase the bandwidth for communications from human exploration missions in deep space, such as those associated with Journey to Mars.

NASA began using lasers for satellite laser ranging, a technique to measure distances, in 1964. The laser ranging system at Goddard Space Flight Center uses laser stations worldwide to bounce short pulses of light off reflectors installed on satellites and on the moon during the Apollo and Soviet rover programs. By timing the bounce of the pulses, engineers can measure distances and orbits with an accuracy of within a few millimeters.

The first laser communications pathfinder mission, the Lunar Laser Communications Demonstration (LLCD), was launched by Goddard in 2013. LLCD demonstrated that a space-based laser communications system was viable and could survive both launch and the space environment. The Goddard team is now planning a follow-on mission called the Laser Communications Relay Demonstration (LCRD) to prove the proposed system's longevity and provide engineers with the opportunity to learn how to best operate the system for near-Earth missions.

Scheduled to launch in 2019, LCRD will simulate real communications support, practicing for two years with a test payload on the International Space Station and two dedicated ground stations in California and Hawaii. This mission could be the last hurdle to implementing a constellation of laser communications relay satellites similar to the Space Network's Tracking and Data Relay Satellites.

"We have been using RF since the beginning, 50 to 60 years, so we've learned a lot about how it works in different weather conditions and all the little things to allow us to make the most out of the technology, but we don't have that experience with laser comm," said Dave Israel, exploration and space communications architect at Goddard and principal investigator on LCRD. "LCRD will allow us to test the performance over all different weather conditions and times of day and learn how to make the most of laser comm."


NASA's Goddard Space Flight Center

Artist concept of satellite relaying data from Mars to Earth via laser.

NASA's Jet Propulsion Laboratory and Glenn Research Center are also building on LLCD's success to discover how laser communications could be implemented in deep-space missions.

The team at Glenn is developing Integrated Radio and Optical Communications (iROC), an idea for putting a laser communications relay satellite in orbit around Mars that could receive data from distant spacecraft and relay the signal back to Earth. The iROC system would use both RF and laser communications and promote interoperability among all of NASA's assets in space. By integrating both RF and laser communications systems, iROC could provide services both for new spacecraft using laser communications systems and older spacecraft like Voyager 1 that use RF.

The data-rate benefits of laser communications for deep-space missions are clear; less recognized is that laser communications can also save mass, space and/or power requirements on missions. That could be monumental on missions like the James Webb Space Telescope, which is so large that, even folded, it will barely fit in the largest rocket currently available. Although Webb is an extreme example, many missions today face size constraints as they become more complex. The Lunar Reconnaissance Orbiter mission carried both types of communications systems, and the laser system was half the mass, required 25 percent less power and transferred data at six times the rate of the RF system. Laser communications could also benefit a class of missions called CubeSats, miniature satellites about the size of a shoebox. These missions are becoming more popular and require miniaturized communications and power systems.

Power requirements can become a major challenge on missions to the outer solar system. As spacecraft move away from the sun, solar power becomes less viable, so the less power a payload requires, the better. A small spacecraft battery saves space and is easier to recharge.

From communications to altimetry and navigation, photonics' importance to NASA missions cannot be understated. As the technology continues to evolve, NASA will continue to invest in novel ways to use photonics to provide solutions to some of its most pressing challenges in future spaceflight.

The original article appeared on the nasa.gov website.

The web version of this story features a video showing how NASA is using photonics to solve some of the most pressing upcoming challenges in spaceflight, such as better data communications from space to Earth: **www.photonics.com/61263**.

Nanophotonic cloaking could eliminate crosstalk between photonic devices

SALT LAKE CITY — A nanophotonic cladding cloak that prevents crosstalk between two closely spaced single-mode waveguides could allow photonic devices to be integrated at a much higher density, without causing light to leak from one waveguide to another. This would allow billions of photonic devices to be packed into a single photonic computer chip and reduce the footprint of the chip, overcoming a major obstacle to the use of photonic chips in computers, data centers and mobile devices.

Researchers at the University of Utah placed a nanopatterned silicon-based barrier between two photonics devices to render neighboring devices invisible to one another. An inverse-design algorithm was employed to design an integrated cloak with a footprint of just a few micrometers.

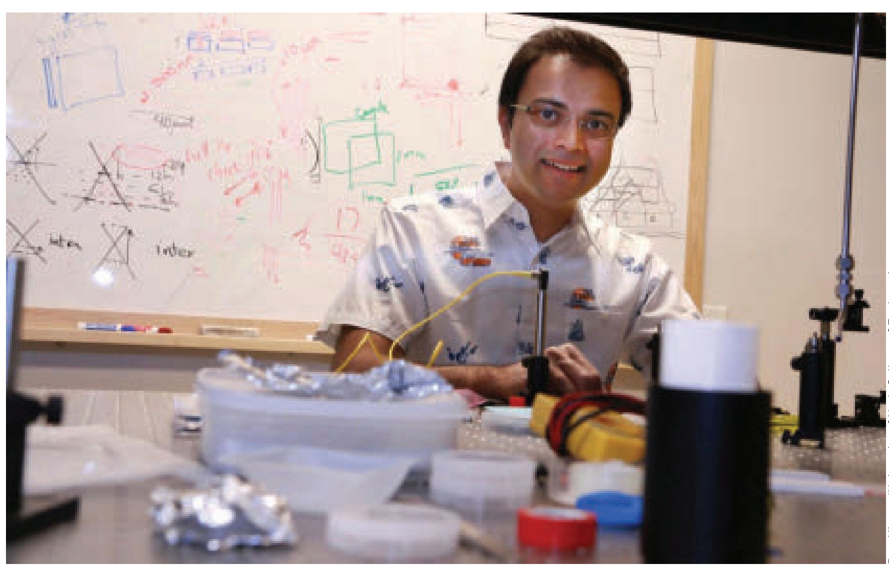
Experimental results demonstrated that waveguides with a center-to-center spacing as small as 0.8 µm (λ0/1.94) were feasible. This could potentially double the integration density of planar lightwave circuits (PLCs), as the conventional minimum center-to-center spacing between parallel waveguides is about 1.5 µm.

The nanophotonic cloak also prevents crosstalk between a single-mode waveguide and a closely spaced microring resonator. This device configuration is commonly used for filters, and such cloaks could be useful for integrating multiple filters into a small area.

"The principle we are using is similar to that of the Harry Potter invisibility cloak," said professor Rajesh Menon. "Any light that comes to one device is redirected back as if to mimic the situation of not having a neighboring device. It's like a barrier — it pushes the light back into the original device. It is being fooled into thinking there is nothing on the other side."

The devices used in the research are metal-oxide-semiconductor compatible, with a minimum pitch of 200 nm, and can be fabricated with a single lithography step. The nanophotonic cloaks can potentially be used with all passive integrated photonics.

Menon believes the most immediate application for this technology and for photonic chips in general will be for data centers similar to the ones used by services like Google and Facebook. According to a study from the U.S. Department of Energy's Lawrence Berkeley National Laboratory, data centers just in the U.S.



Dan Hixson/University of Utah College of Engineering

University of Utah electrical and computer engineering associate professor Rajesh Menon and his team have developed a cloaking device for microscopic photonic integrated devices — the building blocks of photonic computer chips that run on light instead of electrical current — in an effort to make future chips smaller, faster and consume much less power.

consumed 70 billion kW hours in 2014, or about 1.8 percent of total U.S. electricity consumption. Power usage is expected to rise another four percent by 2020. Photonic chips consume 10 to 100 times less power and give off significantly less heat than silicon-based chips, and are also faster than silicon-based chips.

"By going from electronics to photonics we can make computers much more efficient and ultimately make a big impact on carbon emissions and energy usage for all kinds of things," Menon said. "It's a big impact and a lot of people are trying to solve it."

Currently, photonic devices are used mostly in high-end military equipment. Menon expects full photonic-based chips will be employed in data centers within a few years.

The research was published in *Nature Communications* (doi: 10.1038/ncomms13126).

Photon source lighting the way for quantum computing

CORK CITY, Ireland — As today's computers show fundamental limitations in calculation capacity for future use, a scalable, electrically driven photon source could make quantum computing a reality sooner than expected.

Quantum computing — a technology for designing computers based on quantum mechanics, the science of atomic structure and function — uses the qubit, or quantum bit, which can hold an infinite number of values. With this capability, quantum computers would harness the capacity to superimpose information in the qubits state by encoding and operating on a few thousand properly entangled qubits.

Researcher Emanuele Pelucchi, head of epitaxy and physics of nanostructures, and a member of the Science Foundation Ireland-funded Irish Photonic Integration Center (IPIC) at Tyndall National Institute, told Photonics Media that quantum computing is the future.

"This capacity of encoding enormous amounts of information and then operating on it would simply supersede any classical computer capability we can possibly predict," he said. "This is why we need a quantum computer: to solve large-scale problems which we cannot solve today. They need to be encoded differently from what a classical computer can or will ever be able to do."

Pelucchi and his research team at Tyndall National Institute in Cork City, Ireland, have successfully developed a technique that enables quantum dot LEDs to produce entangled photons, which can then, in turn, be positioned where needed. The new development uses easily sourced materials and conventional semiconductor fabrication technologies.

According to Pelucchi, entangled photons are the simplest way of encoding a superposition of two qubits. The two qubits become linked in a way that when one operates, the other reacts — this is a quantum correlation.

"What we showed is that it is possible to build ordered arrays of entangled photon light-emitting diodes, providing good quality entangled photons. These would be the source of qubits in an optical quantum computer, for example, where thousands of sources operating in unison are needed," he said. "This is the first time that such potentiality was demonstrated, while in the past only isolated devices could be obtained, that is, devices with little potential for photonic integration."

The researcher said this is major progress in the quest for quantum computing as scientists and researchers plan for the new technology.

"There are visionary scientists who predict quantum computers will be a reality in a relatively short time scale, such as 10 or 15 years from now. However, there are extraordinary challenges to overcome first. We have provided a partial solution to one of them with this latest development at Tyndall," said Pelucchi.

The researchers are making strides, and their photonics innovations are being commercialized across a number of sectors as a result.

Autum C. Pylant
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User-friendly crime scene forensics for snow and soil

WEST LAFAYETTE, Ind. — Encoding data in LED light could lead to improvements in portable crime scene forensics technology, allowing investigators to take more precise high-resolution 3D images of shoeprints and tire-tread marks in snow and soil.

Researchers have invented this "binary defocusing technique" that is projected onto the snow or soil surface. The light bouncing back to the camera contains the pre-encoded information, allowing the system to determine the depth of surface features while using a single camera. A laptop computer performs necessary computations needed to operate the projector and camera. Unlike some other systems, the new approach does not require the use of lasers.

"This is the biggest contribution we are making to the forensics community," said Song Zhang, an associate professor at Purdue University School of Mechanical Engineering and director of Purdue's XYZT Lab. "Current 3D imaging products on the market are very difficult to use. You need expertise to be able to capture good images. What we want to do is bring in some intelligence to the algorithms so the forensic examiner just has to click a button to capture good images."

With help from a two-year, $788,167 grant from the National Institute of Justice, Zhang's team is working on the 3D imaging system that will have "auto-exposure control." The system will also have an intuitive user interface, allowing investigators with little to no technical expertise to take high-quality images.

The research team comprises Zhang; forensic research scientist David Baldwin of the Special Technologies Laboratory, a U.S. Department of Energy National Nuclear Security Administration facility in Santa Barbara, Calif.; retired forensic scientist and footwear and tire track examiner James R. Wolfe; and two doctoral students.

The team hopes to develop a system that produces immediate images with a resolution of 600 dpi, providing more precise results than casting.

"Our project has promise to deliver a device that will improve the quality and accuracy of tire and footwear impression evidence," Baldwin said. "We plan to develop an affordable and easy-to-use system that will provide the forensic science community with more and better evidence from crime scenes."

According to the researchers, snow and light sand are difficult to photograph and make castings in. The team is now working on that issue.

"This project has the potential to develop a system that can quickly obtain the 3D detail in such impressions, maximizing the value of this type of evidence in a criminal investigation," Wolfe said.

The system will cost about one-tenth the cost of commercial systems, with a price tag of around $5,000, and will serve as an alternative to traditional plaster casting methods. The project officially begins in January 2017.

Out-of-this-world fiber optics

MOUNTAINVIEW, Calif. — Made in Space (MIS) produced a zero-gravity 3D printer, which has been aboard the International Space Station (ISS) for the past two years. Now, the company is attempting to make fiber optics in zero-gravity conditions via its MIS fiber making machine.

"Historically, the commercial space industry has profited off of satellite telecommunications — sending ones and zeros back and forth. Made in Space's in-space manufacturing activities expand the commercial envelope to making valuable goods there, too," said MIS CEO Andrew Rush. "We believe in-space manufacturing of goods valuable to people on Earth will soon drive significant commercial activity in space, perhaps one day creating a space-based economic boom."

For the project, MIS teamed up with Thorlabs, which has been working on the quality of heavy-metal glass fiber ZBLAN for more than a decade. Manufacturing ZBLAN fiber optics on Earth has been difficult due to gravity-causing imperfections to its structure.

Both companies believe ZBLAN has great potential for lower transmission losses than other materials normally used for telecommunication cables. They plan to launch the MIS fiber making machine into space in early 2017.

Made in Space Inc. was founded in 2010 as a way to enable humanity's future in space. It has developed additive manufacturing technology for use in zero gravity.

Photomotility of polymers could enable soft robots to "travel light"

WRIGHT-PATTERSON AFB, Ohio — Novel materials that convert UV light into energy without the need for electronics could provide the basis for a lightweight internal power source that would mobilize miniaturized robots efficiently, without adding bulk.

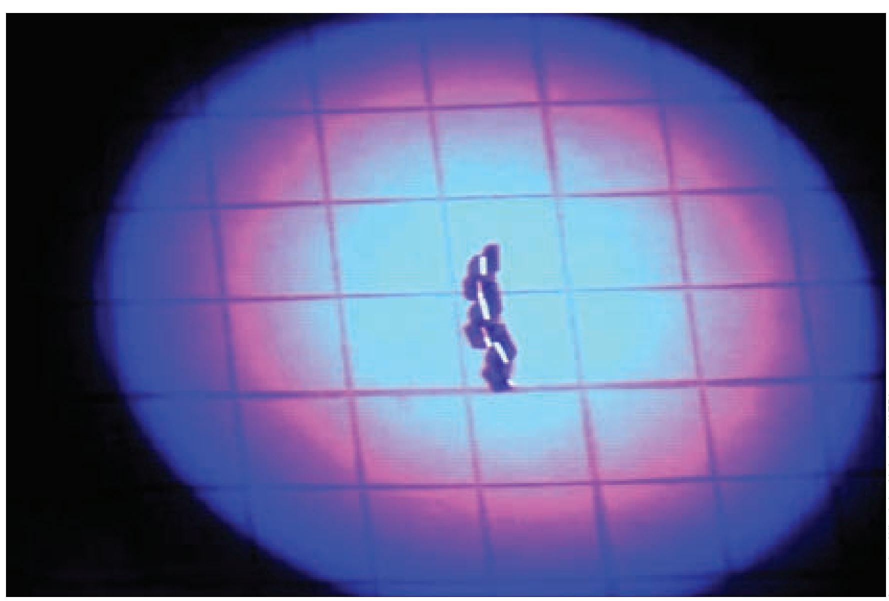
A joint team from Inha University, University of Pittsburgh and the Air Force Research Laboratory (AFRL) demonstrated photoinduced motion in monolithic polymer films prepared from azobenzene-functionalized liquid crystalline polymer networks (azo-LCNs). The material was irradiated with a broad spectrum UV-visible light (320 to 500 nm), which transformed the films from flat sheets to spiral structures that could translate large distances when irradiated continuously.

"Our initial research indicated that these flexible polymers could be triggered to move by different forms of light," said professor M. Ravi Shankar. "However, a robot or similar device isn't effective unless you can tightly control its motions. Thanks to the work of Dr. White and his team at AFRL, we were able to demonstrate directional control, as well as climbing motions."

The directionality of the photomotility was programmed by the orientation of the anisotropy to the principal axes of the specimens. Motion was found to occur without modulating or multiplexing the actinic light source, and could occur on an arbitrary surface. Previous engineered constructs required a temporally modulated stressor and anisotropic surface interaction to manifest directional motion.

According to the researchers, the photomotility is a spontaneous mechanical response of the anisotropic materials. The material by itself is the motile device and there is no requirement for a composite, multimaterial design or other special conditions. By directly transducing photons into motion, the weight penalty of articulated mechanisms, actuators or on-board power sources is eliminated.

"Complex robotic designs result in additional weight in the form of batteries, limb-like structures or wheels, which are incompatible with the notion of a soft or squishy robot," said professor Jeong Jae



Jeong Jae Wie, Inha University/AFRL

An azobenzene-functionalized liquid crystalline polymer moving when exposed to broadband ultraviolet-visible light.

Wie. “In our design, the material itself is the machine, without the need for any additional moving parts or mechanisms that would increase the weight and thereby limit motility and effectiveness.”

In addition to simple forward movement, the team was able to make the polymers climb a glass slide at a 15° angle. While the flat polymer strips are small (approximately 15-mm long and 1.25-mm wide), they can move at several millimeters per second propelled by light. As long as the material remains illuminated, movement can be perpetual.

“The ability for these flexible polymers to move when exposed to light opens up a new ground game in the quest for soft robots,” Shankar said. “By eliminating the additional mass of batteries, moving parts and other cumbersome devices, we can potentially create a robot that would be beneficial where excess weight and size is a negative, such as in space exploration or other extreme environments.”

The research was published in *Nature Communications* (doi:10.1038/ncomms13260).

FS pulses in mid-IR range could reveal inner workings of atoms

CAMBRIDGE, Mass. — A laser pulse synthesizer that can attain ultra-short pulses in the mid-IR range while maintaining favorable energy scalability could provide a more complete view of the inner workings of atoms, molecules and solids.

For the past several decades, the only technology available for studying high-speed atomic processes has relied on NIR wavelengths, which work well for studying gases but can cause damage to solids before any observations are made.

Much like a musical synthesizer combines notes to generate a new sound, the laser pulse synthesizer combines pulses from the range of mid-IR wavelengths to generate shorter pulses. When the pulses are combined, constructive interference in the middle of the pulses is additive while deconstructive interference cancels out the outer edges of the pulses. The pulses become shorter and shorter, until a sub-cycle pulse is created.

To develop the device, researchers at the Massachusetts Institute of Technology used phase-stable 2.1-µ laser light to pump a mid-IR optical parametric amplifier (OPA) and create coherent pulses spanning either 2.5 to 4.4 µ with a pulse width of about 20 femtoseconds (fs) or 4.4 to 9 µ with a 30-fs pulse width. By maintaining pulse stability and making sure that the pulses precisely overlapped both temporally and spatially, researchers were able to combine them into synthesized pulses that were only 13 fs wide and spanned 2.5 to 9 µ with 33 microjoules (µJ) of energy.

Although the 13 fs pulse duration is longer than what is possible with NIR and visible wavelengths, it corresponds to less than one optical oscillation cycle of 5 µ wavelength, enabling the sub-cycle control of electron motion.

Mid-IR pulses could be used in a variety of applications and scientific research areas. For example, in noninvasive surgery these wavelengths could be used to remove diseased tissue without damaging the surrounding healthy tissue. These pulses are also useful for spectroscopy and for observing fast chemical reactions, since many biological molecules and atmospheric chemicals absorb in this wavelength range.

"These mid-IR pulses will allow new types of experiments that explore dynamics taking place in atoms, molecules and solids," said researcher Kyung-Han Hong. "For example, we can use them to take a movie of how electrons behave inside of atoms and solids."

The research team has explored using the high-energy, mid-IR pulses for high-harmonic generation to produce coherent pulses in the extreme UV and soft x-ray regions.

"Compared to near-IR and visible light, mid-IR pulses accelerate electrons to much higher energies and, thereby, generate higher energy photons," said Hong. "Also, isolation of soft x-ray pulses becomes easier at these wavelengths." Soft x-ray and extreme UV pulses could be used to study various phenomena inside atoms and molecules at an attosecond time scale.

"Scientists want to watch how electrons move around inside solids on timescales of 1,000 attoseconds or less," said Hong. "At the mid-IR wavelengths it is much easier to drive high-harmonic generation in solids because the optical damage due to multiphoton processes is much less pronounced."

Adding more OPAs to the optical setup would allow higher energy scales, which could make the mid-IR pulses useful for additional experimental studies and applications.

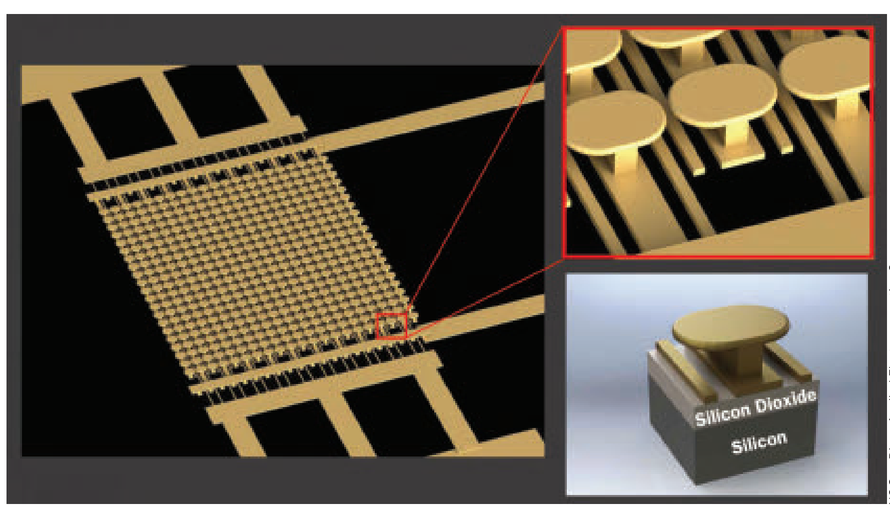
"This type of pulse synthesis has been routinely done in the microwave region, but it is much more difficult to do this in the optical region because the pulses are traveling much faster," added Hong.

The research was presented at the 2016 Advanced Solid State Lasers Conference, a meeting of OSA, the Optical Society.

Photoemission-based microelectronics are semiconductor-free

LA JOLLA, Calif. — A semiconductor-free, optically controlled microelectronic device fabricated using metamaterials has shown a significant increase in conductivity when activated by low voltage and a low power laser. The discovery may facilitate the development of microscale electronic devices that are faster and capable of handling more power, and could also lead to more efficient solar panels.

The device consists of an engineered metasurface on top of a silicon wafer, with a layer of silicon dioxide in between. The metasurface is made from an array of



UC San Diego Applied Electromagnetics Group

The designed semiconductor-free microelectronic device.

gold mushroom-like nanostructures on an array of parallel gold strips.

Researchers at University of California, San Diego, who developed the device, showed that the interaction between the device's metasurface and a low-power IR laser could generate enough photoemission via electron tunnelling to activate microelectronic devices such as transistors, switches and modulators. When a DC voltage of under 10 V and a low power IR laser were applied to the metasurface, "hot spots" with high-intensity electric fields were generated. These hot spots provided enough energy to pull electrons from the metal and liberate them into space.

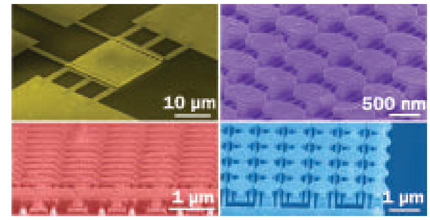
Tests on the device showed a 1000 percent increase in conductivity.

Replacing semiconductors with substitute materials may open up new opportunities for scaling characteristics such as speed and power for some applications. As further optimization of semiconductor devices becomes more challenging, photoemission-based devices, which benefit from the advantages of gas-plasma/vacuum electronic devices while preserving the integrability of semiconductor-based devices, may be a feasible option.

"This certainly won't replace all semiconductor devices, but it may be the best approach for certain specialty applications, such as very high frequencies or high power devices," said professor Dan Sievenpiper. "Next we need to understand how far these devices can be scaled and the limits of their performance."

According to researchers, this particular metasurface was designed as a proof-of-concept. Different metasurfaces will need to be designed and optimized for different types of microelectronic devices. The team is also exploring other applications for this technology besides electronics, such as photochemistry, photocatalysis, and enabling new kinds of photovoltaic devices.

The research was published in *Nature Communications* (doi:10.1038/ncomms13399).



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These are scanning electron micrograph images of the semiconductor-free microelectronic device **(top left)** and the gold metasurface **(top right, bottom)**.

Is there life on Mars? Lidar device may be able to tell us.

GREENBELT, Md. — A biosensor currently used by the U.S. military to remotely monitor the atmosphere for potential toxins has inspired a novel device that could be used for detecting biosignatures in space.

The Bio-Indicator Lidar Instrument, or BILI, is a prototype of a fluorescence-based lidar that may ultimately be used in space exploration to analyze particles for organic material. Positioned on the mast of a planetary rover, BILI would scan the terrain looking for dust plumes. Once a plume was detected, pulsed light from two UV lasers would be directed at it, causing the particles inside the plume to resonate or fluoresce. By analyzing the fluorescence, scientists could determine if the dust contained organic particles created relatively recently or in the past. The analysis also could reveal particle size.

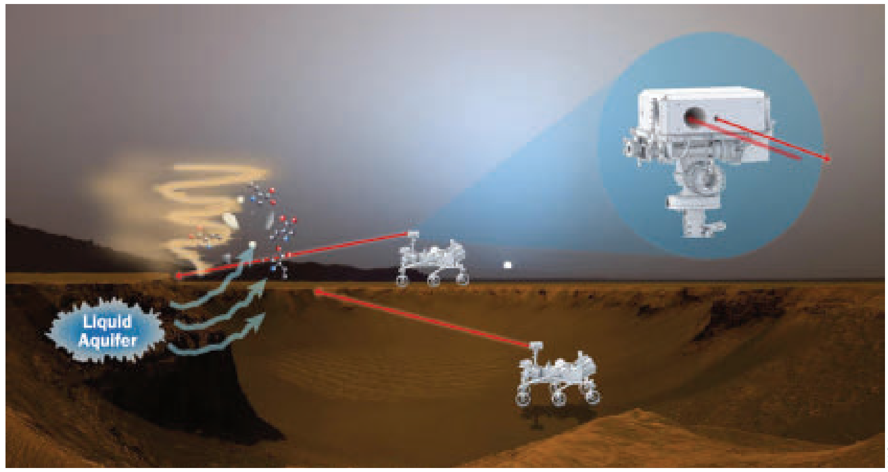
"If the biosignatures are there, it could be detected in the dust," said NASA Goddard technologist Branimir Blagojevic.

BILI, which has the ability to detect in real time small levels of complex organic materials from a distance of several hundred meters, could autonomously search for biosignatures in plumes above recurring slopes and other areas not easily traversed by a rover. Further, BILI could perform a ground-level aerosol analysis from a distance, reducing the risk of sample contamination.

"This makes our instrument an excellent complementary organic-detection instrument, which we could use in tandem with more sensitive, point sensor-type mass spectrometers that can only measure a small amount of material at once," Blagojevic said. "BILI's measurements do not require consumables other than electrical power and can be conducted quickly over a broad area. This is a survey instrument, with a nose for certain molecules."

With such a tool, which also could be installed on an orbiting spacecraft, NASA could dramatically increase the probability of finding biosignatures in the solar system, he added.

"We are ready to integrate and test this novel instrument, which would be



NASA

An artist's rendition showing how a proposed laser-fluorescence instrument could operate on Mars.

capable of detecting a number of organic biosignatures," Blagojevic said. "Our goal is increasing the likelihood of their discovery."

Blagojevic hopes to further advance BILI by ruggedizing the design, reducing its size, and confirming that it can detect tiny concentrations of a broad range of organic molecules, particularly in aerosols that would be found at the ground level on Mars.

Blagojevic formerly worked for a company that developed the sensor used by the military. By developing BILI, he has shown that the same remote-sensing technology used to identify biohazards in public places could be effective at detecting organic biosignatures on Mars and other targets in the solar system.

"This sensing technique is a product of two decades of research," he said.

Fast antenna-assisted switches could expand potential for optical memory

SOUTHAMPTON, England — Fast optical switches developed using nanoantenna-assisted phase transition could open novel routes to the next generation of optoelectronics.

The properties of nanoantennas were tuned to achieve low-energy optical switching of a phase-change material, vanadium dioxide (VO_2). Gold nanoantennas were fabricated on top of this thin film and were used to locally drive the phase transition of the VO_2.


University of Southampton

Professor Otto Muskens.

The picosecond all-optical switching of the local phase transition in plasmonic antenna VO_2 hybrids was shown by exploiting strong resonant field enhancement and selective optical pumping in plasmonic hotspots. Polarization- and wavelength-dependent pump-probe spectroscopy of multifrequency crossed antenna arrays revealed that nanoscale optical switching in plasmonic hot spots did not affect neighboring antennas placed within 100 nm of the excited antennas. The antenna-assisted pumping mechanism was confirmed by numerical model calculations of the resonant, antenna-mediated local heating on a picosecond timescale.

The hybrid, nanoscale excitation mechanism resulted in 20 times reduced switching energies and five times faster recovery times than a VO_2 film without antennas, enabling fully reversible switching at over two million cycles per second and at local switching energies in the picojoule range. Results of the work show that the hybrid solution of antennas and VO_2 provides a conceptual framework to merge the field localization and phase-transition response to enable precise, nanoscale optical memory functionality.

The research was conducted by a team of scientists led by the University of Southampton.

Professor Otto Muskens said, “The nanoantenna assists the phase transition of the vanadium dioxide by locally concentrating energy near the tips of the antenna. It is like a lightning-rod effect. These positions are also where the antenna resonances are the most sensitive to local perturbations. Antenna-assisted switching thus results (in) a large effect while requiring only a small amount of energy.”

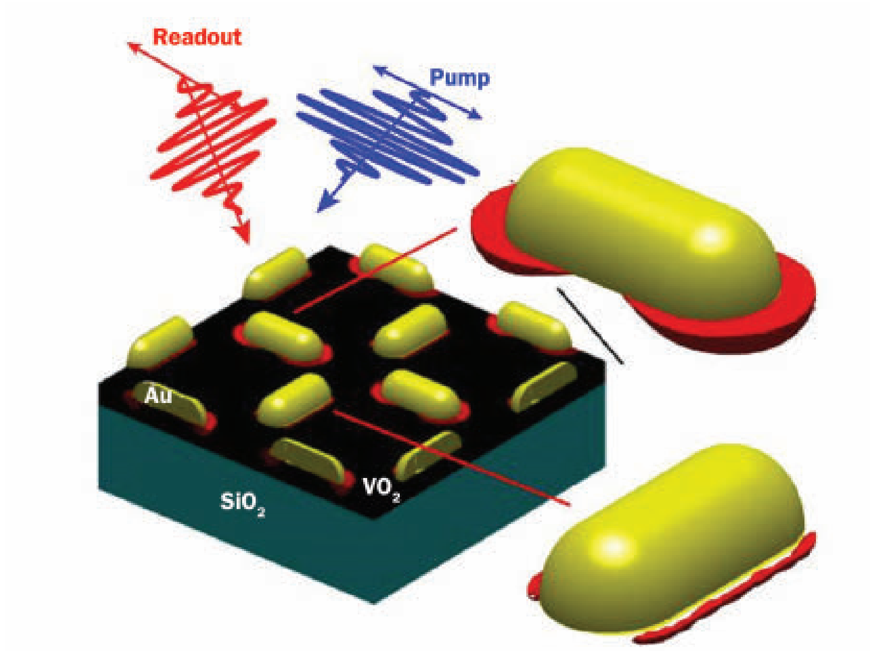
With the miniaturization of optical components and the convergence of electronic and photonic technologies, ultracompact devices are needed to control and switch light on length scales comparable to the optical wavelength. Resonant plasmonic antennas at visible and NIR wavelengths offer the capability to concentrate energy in space and time and enhance light-matter interaction and nonlinear response. Hybrid devices combining plasmonic antennas with materials showing a structural or electronic phase transition provide unique opportunities because they can provide very large changes in optical response. Excitation of this phase-change response using the optical near-field opens up routes for achieving ultrasmall switching volumes and low-energy devices.

“If we are able to actively tune a nanoantenna using an electrical or optical signal, we could achieve transistor-type switches for light with nanometer-scale footprint for data communication. Such active devices could also be used to tune the antenna’s light-concentration effects leading to new applications in switchable and tunable antenna-assisted processes,” said Muskens.

Fabrication of the VO_2 was done by a team at the University of Salford who specialize in thin-film deposition. The theoretical modeling was done by a team from the University of the Basque Country. Their calculations revealed that the nanoantennas provided a novel pathway by local absorption around the antenna.

The antenna-assisted mechanism resulted in a much lower switching energy compared to just the VO_2 film, corresponding to picojoule energies and a calculated efficiency of over 40 percent.

The research was published in *Light: Science & Applications* (doi:10.1038/lsa.2016.173).



University of Southampton

An artist’s impression of gold antennas on vanadium dioxide thin film, with antenna-assisted phase transition **(red)**.

Trends in Integrated Photonics

As integrated photonics marks its coming of age in telecommunications and use in data centers, the public is finally getting a glimpse of what viable photonic integrated circuits (PICs) might look like across other commercial sectors.

In the pages that follow, our contributing editors delve into how PICs are set to transform medicine and life sciences, enabling lab-on-a-chip functionality for the rapid screening of hundreds of disease markers — or smaller, more compact OCT systems. Learn how optical clocks and integrated optical gyroscopes will transform precision navigation or how the optical lidars of tomorrow will accelerate the deployment of autonomous vehicles.

We invite you to read on for a look into how PICs are set to transform many facets of everyday life.

Inside this special section:

The Revolution Has Just Begun
Q&A with **John Bowers**

One of the foremost names in the world of integrated photonics is John Bowers, Ph.D., who is credited with leading a team that successfully demonstrated an electrically pumped hybrid silicon laser a decade ago. That advance has paved the way for the commercial production of high-bandwidth silicon photonic devices. Today, Bowers is leading UC Santa Barbara's Institute for Energy Efficiency's involvement in the AIM initiative and is a central figure in this exciting field. *Photonics Spectra* spoke with Bowers about AIM, his breakthrough work and the impact of integrated photonics on medicine, communications and defense.

UCSB

John E. Bowers holds the Fred Kavli Chair in Nanotechnology, and is the Director of the Institute for Energy Efficiency. He is a member of the National Academy of Engineering, National Academy of Inventors, a fellow of the IEEE, OSA and the American Physical Society, and a recipient of the IEEE Photonics Award, OSA Tyndall Award, OSA Holonyak Prize, and the IEEE LEOS William Streifer Award.

Q: Could you provide us with a snapshot of where you see the state of integrated photonics at the moment?

A: Integrated photonics is transforming telecommunications and data communications. Infinera, Acacia and others are introducing new telecommunication products with much higher capacity and performance that have been enabled by integration. Intel, Luxtera, Lumentum, Finisar and others are increasing capacity and lowering cost by integration. Virtually all 100-Gbps transceivers are highly integrated, and the next generation at 400 Gbps are only possible with integration. This started with integration on InP but high volumes are now being shipped by many silicon photonics suppliers, including Intel, Luxtera, Acacia and others.

The line between electronics and photonics will blur to the point that we don't recognize the integrated circuits of the future and that will enable many new applications.

Q: Please elaborate on how you feel integrated photonic circuits are likely to impact such fields as transportation, medicine and defense in the years ahead?

A: Optical lidars are being deployed on autonomous vehicles today, but they are too bulky and expensive to be practical. Integration is critical to reduce the size, improve the performance and achieve a price point for widespread application. Optical clocks and integrated optical gyroscopes will transform precision navigation and timing. Similarly, in medicine, OCT has demonstrated tremendous potential, but the best performance uses coherent receivers, and integration is important. The same is true for defense; fiber optical links have advantages over microwave links, particularly at millimeter wave frequencies, but the cost has been prohibitive. Now, low-cost integrated millimeter wave generators on silicon are smaller and cheaper than the alternative.

Q: Your work in '06/'07 successfully bonding III-V material to a silicon waveguide has been cited as one of the seminal breakthroughs in integrated photonics. A decade later, can you share your reflections on this work and some of the primary challenges you overcame?

A: Fiber optics enabled the internet revolution, but telecom transceivers were still expensive and produced in relatively low volumes. We enabled a transformation to high-volume manufacturing using low-cost, large-area silicon substrates and high-quality silicon processing combined with high gain III-V materials. We married the best of both worlds through Alex Fang's Ph.D. research at UCSB and very productive collaborations with Intel, HPE and Aurrion, now Juniper Networks. The most important aspects are just beginning to happen: automated packaging and automated wafer-scale testing using tools that are only available at 200- and 300-mm wafer sizes, and that will be the real revolution.

Q: Has the hybrid silicon III-V laser reached commercial viability?

A: Yes, Intel has successfully introduced a 100G PSM4 QSFP transceiver and a 100G CWDM4 transceiver, and is shipping them in volume. Other companies are also planning integrated PIC products with integrated lasers.

Q: In 2015, the AIM initiative was formed and you were tasked with heading up UC Santa Barbara's Institute for Energy Efficiency's involvement in the program. Can you discuss recent advances?

A: The AIM photonic process line at SUNY is running wafers, and is just starting the second multiprocess wafer run. Cadence, Synopsys, Mentor and Analog Photonics are rapidly evolving a variety of photonic design tools and coming out with new versions of the PDK every six months. An advanced photonic packaging line in Rochester is being designed and should come online next year. UCSB's focus is III-V integration to bring lasers and amplifiers into the AIM platform and that is moving very rapidly.

Q: How is integrated photonics likely to transform the world in which we live in the years and decades ahead?

A: The big revolution is taking photonics from the edge of the circuit board and embedding close to electronics, increasing capacity and reducing power and cost by eliminating the SerDes [serializer/deserializer] required today. We will move to 3D integration of electronics and photonics, enabling processors, memory, switching chips, and sensors with far more capability than is available today. This photonic revolution has only just begun. The line between electronics and photonics will blur to the point that we don't recognize the integrated circuits of the future and that will enable many new applications.

Medicine and Life Sciences

While it's early days for integrated photonics in medicine and the life sciences, its impact promises a health care revolution by bringing early diagnosis and point-of-care monitoring to the masses.

BY MARIE FREEBODY
CONTRIBUTING EDITOR

Imagine testing for a host of diseases and conditions in a single sample of blood, saliva, urine or even a few tear drops. Cancers, heart conditions, viruses, food allergies and sepsis are just some of the tests that could be carried out using next-generation lab-on-a-chip concepts that are being explored and patented by today's top researchers.

Such disposable chips could be loaded with the sample and then quickly analyzed using a computer, tablet or even a smartphone for fast diagnostic testing and simple disease monitoring and management.

It's not just health care worldwide that could be transformed; a host of other applications stand to benefit from such scalable photonics — from environmental monitoring and food sorting to fingerprint detection and lighting to enhance health.

Compared with today's often bulky lab equipment, which requires either the patient to visit a clinic or sending samples away for testing, integrated photonics could transform the health care system, reduce waiting times and costs as well as provide better care for patients worldwide. For those in rural or underdeveloped areas, it may bring direct access to doctors for the first time.

"What is really important is that such lab-on-chip sensors have been applied for real diagnostic applications of pathologies and conditions employing only few drops of bodily fluids such as blood, saliva, urine or tears," said Laura Lechuga, leader of the Nanobiosensors and Bioanalytical Applications Group at the Catalan Institute of Nanoscience and Nanotechnology (ICN2), Barcelona, Spain. "This is opening the route to an instantaneous diagnostic for the identification of many diseases — such as cancer or infection — at a very early stage in a fast, simple and cost-effective way."

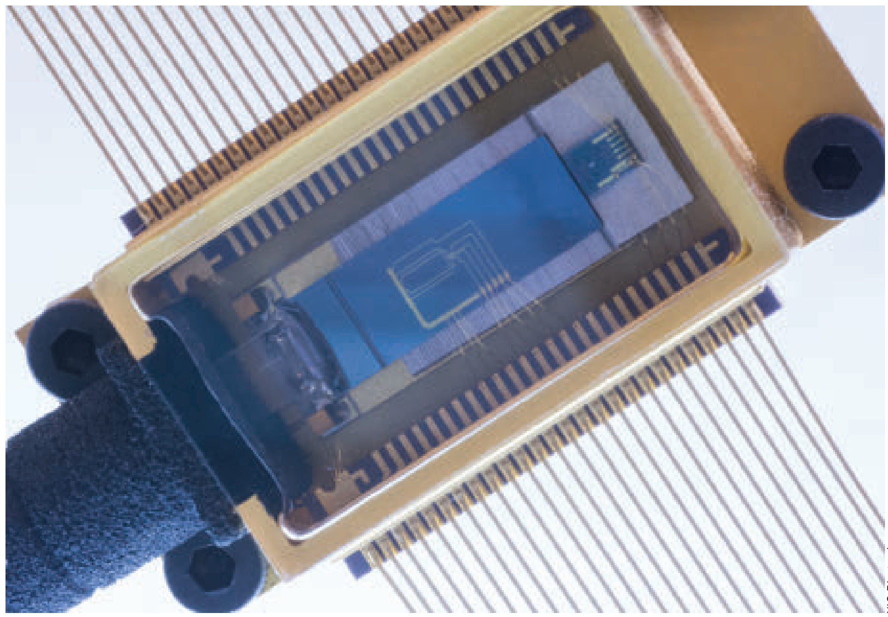
Hurdles: integration and demonstration

Translating any new technology from basic science into products always poses challenges. This is particularly true for devices intended for life sciences or clinical applications where living things — and people in particular — are involved.

Crucial obstacles must first be overcome: One significant effort is gathering the relevant statistics for evaluation of success. Since there are so many variables in medical procedures, it is often not easy to gather success rates. Therefore, translating new technologies into existing clinical settings would require a convincing argument to improve success rates that are challenging to statistically determine.

"In the aspect of the real bioapplication, the key challenges are to attain enough selectivity and sensitivity in the detection when using only few drops of body fluids without any pre-cleaning or conditioning of the sample," Lechuga said. "This aspect is common for other transduction schemes, not only to optical sensors, [therefore] the improvements are coming by the hand of other disciplines, such as chemistry or biotechnology."

Another crucial challenge is full integration in compact platforms: Efficient in- and out-coupling of light in tiny waveguides is needed, as is a reliable solution for multiplexed actuation — detecting

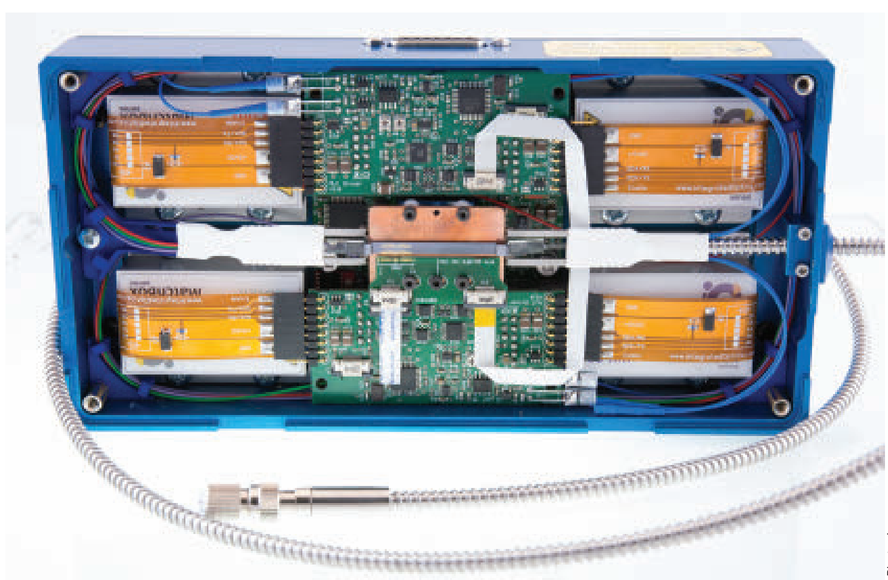


XiO Photonics

Example of a tunable external cavity laser containing a tunable reflective mirror with hybrid attachment of two chips of different material — in this case an InP gain chip and TriPleX chip.

PICS 101

- Photonic integrated circuits (PICs) are devices on which several optical components are integrated, often together with electronic components.
- PICs are usually fabricated with a wafer-scale technology on substrates (chips) of silicon, silica or a nonlinear crystal material.
- Most PICs use waveguides to allow the realization of couplers, filters, power splitters, combiners and active elements with optical gain or attenuation.
- The technology has matured enough to offer devices and systems with performances not seen before and which are indicators of the real capabilities of the technology.



XiO Photonics

Multicolor laser system (marketed by Integrated Optics as ARA) based of four Matchbox lasers and a visible PIC. The PIC combines the four wavelengths to one output as well as stabilizes the output power using a feedback measurement.

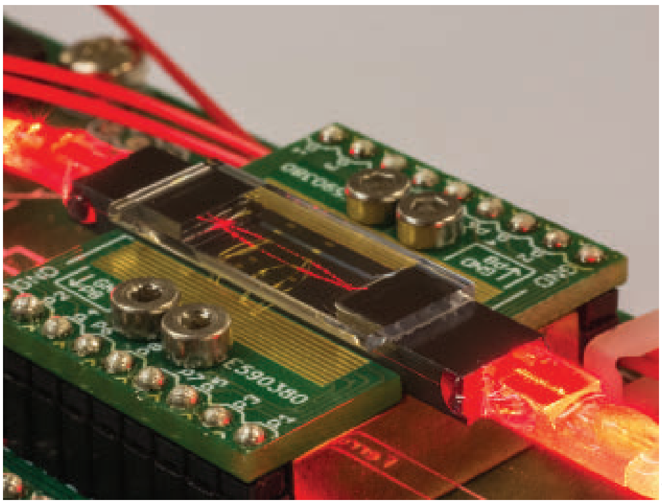
more than 25 biomarkers in the same patient's sample, for example.

The combination of electronics with photonics also is an important aspect for the future, which will make further miniaturization feasible, with potential new innovative solutions for all kind of applications.

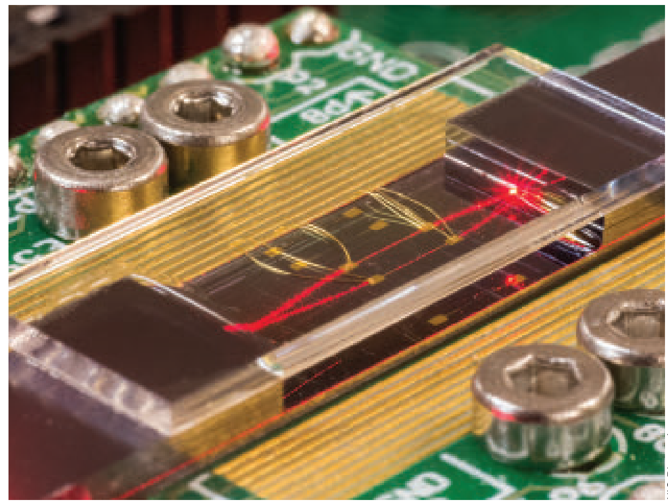
"With the continuous improvements and research in the field of integrated photonics and microfluidics, we are confident that such challenges will be soon surpassed," said assistant professor Amy Foster at Johns Hopkins University, Baltimore, Maryland. "Hopefully in the next few years, integrated photonic systems and devices will continue to mature and find little windows of opportunities in life sciences and medical markets to enable more widespread adoption."

From shrinking OCT to early cancer detection

Putting some solutions to the test is



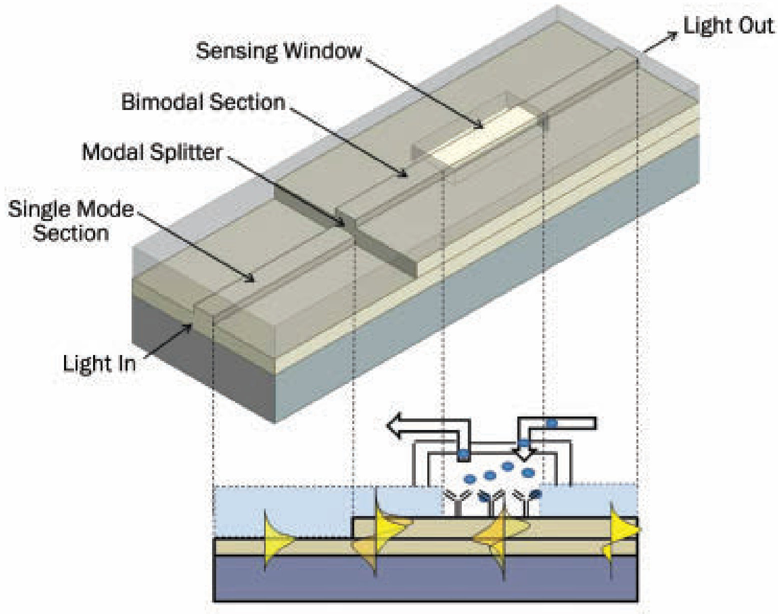
XiO Photonics



XiO Photonics

An example of a visible light PIC. Photos show the PIC with the waveguides visible, as well as the fiber connection and driving electronics.

LioniX International, a leading global provider of customized microsystem solutions, which has developed a specific set of assembly and packaging capabilities for visible light photonic integrated circuits (PICs). This year LioniX, XiO Photonics, Satrax and others merged to form LioniX International, based in Enschede, the Netherlands.



ICN2

Scheme of a BiMW sensor.

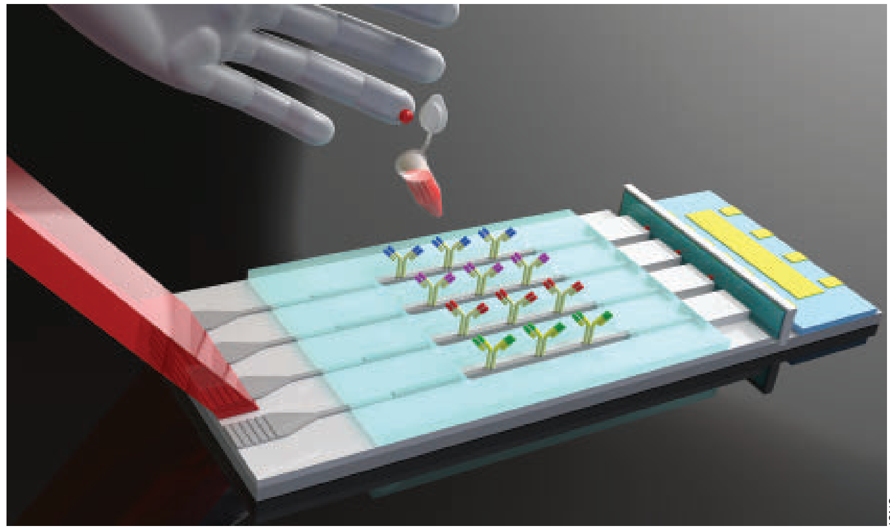
"The main challenge for integrated photonics is that no customer wants to deal with the PIC alone. Turning the PIC into a photonic module requires a complete additional set of capabilities besides the microsystem technology capabilities for creating the PIC," said Douwe Geuzebroek, sales and marketing manager at XiO Photonics. "Making a photonic module that can be used by photonic OEM companies like Carl Zeiss and Pacific Bioscience requires assembly and packaging as well as electronics integration expertise."

LioniX International has been addressing the life sciences and medical markets for over 10 years and is currently engaged with many companies with its TriPleX chips in which fibers are attached to a visible light PIC for wavelengths in the range of 400 to 700 nm.

"Since last year we feel that the market is really beginning to understand the potential of integrated photonics. We see

Breakthroughs

- Passive devices such as waveguides, multiplexers, add-drop multiplexers, diffractive optical elements, isolators, polarizers, etc.
- Active and functional devices, such as switches, modulators, deflectors or integration with laser sources and photodetectors.
- Packaging and interconnections in photonics integrated circuits have experienced radical improvements in recent years.



ICN2

Scheme of the ideal point-of-care BiMW biosensor using full integration of PICs.

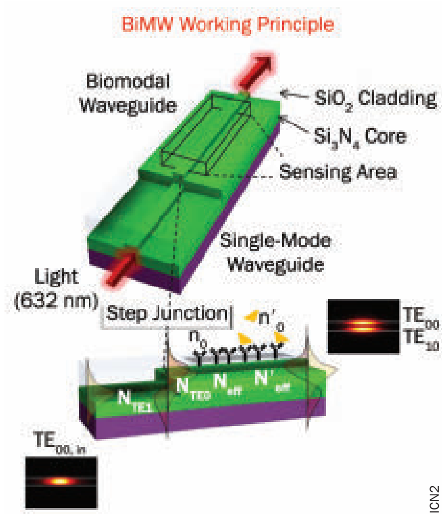
this both in an increased number of new contacts in this field as well as in the number of existing customers that reach production volumes with PIC modules," said Geuzebroek. "Furthermore we see more companies and institutes starting to work with PIC in life science applications in general and more specifically in PIC technology for visible light."

One example is the company's collaboration with the Academic Medical Center, one of Netherland's largest hospitals and research institutions, in which PIC technology is being incorporated into optical coherence tomography (OCT) devices.

"Together with LioniX, we have designed and characterized an OCT chip in which eight parallel sample arms with different arm lengths were fabricated, making parallel OCT with one swept source feasible," explained Ton van Leeuwen, chairman of the Biomedical Engineering & Physics department. "We showed that it was possible to make cross-sectional images of layered tissue phantoms with these interferometers on a chip."

Ongoing demonstrations show that even the lens could be integrated on the chip. By combining the interferometer with a swept source based on integrated photonics, built by 2 M sensors, van Leeuwen and colleagues are making the whole system much cheaper.

"The next steps are to combine the swept source, the interferometer and the detectors on a chip, thereby reducing the footprint and costs even more," van Leeuwen said. "I envision that the combination of various imaging or sensing techniques, like for instance Raman/



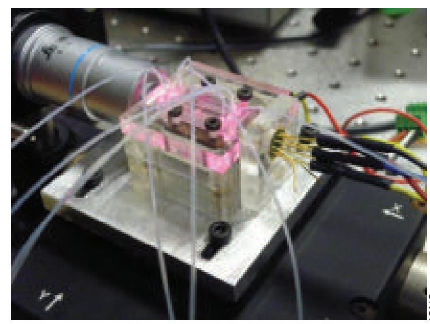
ICN2

BiMW working principle, showing the two modes of the light propagating in the single and bimodal section and interacting in the sensor area.

fluorescence spectroscopy, are combined with OCT, in order to reveal chemical or functional information next to images of the tissue structure."

Other avenues of research apply OCT to monitor industrial processes such as the flow and diffusion of bead solutions as well for contactless determination of fingerprints based on the epidermal-dermal junction.

At optics sensor solutions specialist AMS, based in Premstaetten, Austria, circadian lighting is gaining greater acceptance whereby lighting is controlled to enhance the health and productivity of workers. The company recently acquired Mazet, integrated circuit and filter design



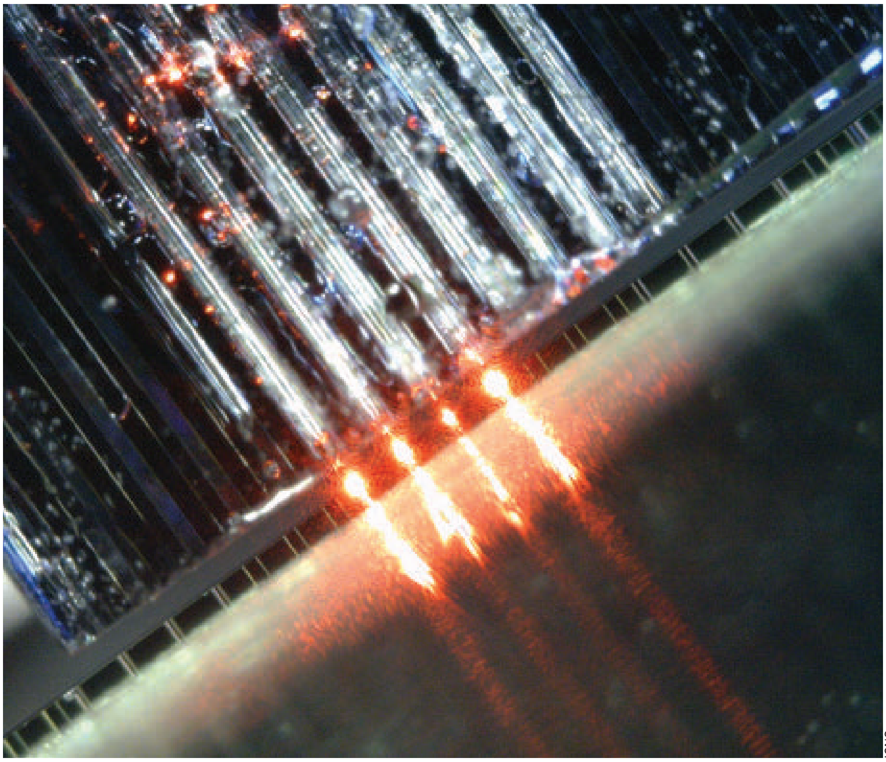
ICN2

BiMW biosensor embedded in a microfluidics cartridge and connected by optical fibers. The sensor is intended to be allocated inside a buoy for real operation to monitor the ocean pollution. (Work done under the EU BRAAVOO project.)

experts, and now offers CMOS image sensors such as its NanEye 2D, a fully digital system-on-a-chip camera head.

"A small lens is assembled to the chip, making it the world's most compact digital camera for applications such as medical endoscopy," said Otilia Ayats-Mas, senior marketing communications manager.

Biophotonic probes are of particular interest in minimally invasive real-time imaging and sensing applications where tools such as micro-endoscopes can be used to observe behavior, perform pathology, or even provide guidance for surgical tools. Beyond imaging and sensing, biophotonic probes can deliver optical power at high spatial resolution for stimulation of nerves or neurons, or be used in targeted drug delivery.


ICN2

BiMW biosensor operating in visible light connected by optical fibers for multiplexed diagnosis.

An example is the innovative nanophotonic biosensor based on silicon photonics technology, developed by Lechuga's ICN2 group, known as the Bimodal Waveguide interferometer (BiMW). The BiMW has shown promise in the early detection of colorectal cancer, which could avoid the need for a colonoscopy; dietary control of celiac patients through a simple test of the presence of gluten consumption by analyzing a few drops of urine; early detection of infectious diseases such as tuberculosis or sepsis using body fluids such as urine or serum, among others.

"There are clinical evidences that when a person is initiating a colorectal cancer, the cancer cells segregate antigens which trigger our immunosystem. As a consequence, our immunosystem produces proteins (autoantibodies) which circulate in our blood," explained Lechuga.

By detecting the presence of these autoantibodies, this type of cancer could be detected up to four years earlier than using current diagnostic methods.

"As the concentrations are very low, we need a very sensitive sensor device, such as the one provided by integrated optics, to perform the analysis," she said. "We believe that we will be able to deliver in the future, a hand-held device able to do the testing — employing a few drops of a person's blood — contributing to the comfort of the population and decreasing the cost on the health system."

As part of the European project BRAAVOO (www.braavoo.org), Lechuga and LioniX are employing biosensors for early warning of dangerous ocean pollution. On the coast of Ireland, an integrated optics-based lab-on-a-chip biosensor, which has been fitted inside a buoy, is monitoring sea pollutants including antibiotics, algae toxins, hydrocarbons and biocides. The aim is to explore the potential of large-scale marine quality surveillance and allow sustainable multi-usage of the marine environment.

Borrowing from telecoms

Integrated photonics is making great strides in areas such as telecoms and computing with the development of high-speed interconnections and devices such as transceivers, modulators and detectors. But the application of integrated photonics for the life sciences and medical markets is only just being explored.

Although disparate industries, the fabrication techniques to integrate multiple platforms as well as access to increasing foundry processes geared toward integrated photonic fabrication means that medical and life sciences researchers are able to create larger arrays of photonic devices with higher yield.

With extensive clinical trials requiring thousands of disposable chips, high yield will enable more cost-effective research.

Apart from fabrication techniques, technological advances in free-space optical communication also lend themselves well to biophotonics applications. Integrated photonic devices and arrays for beam steering and beam shaping have recently been demonstrated. Many applications depend on the ability to quickly and accurately steer a laser beam, ranging from the fiber endoscope in biological imaging to lidar scanning in large-scale landscape surveying.

Traditional approaches are often mechanical, requiring bulky motors and gimbals to physically move the entire laser system, or alternatively use tilted mirrors through micromechanical or galvanometer-based devices. The problem is, these solutions can be relatively slow and achieve limited angular range.

"We are working on integrated silicon OPAs [optical phased arrays] in end-fire configuration. We have demonstrated a one-dimensional OPA device on an integrated silicon platform capable of edge-emitting light in the plane of the chip with apertures spaced at half the operational wavelength," said Johns Hopkins' Foster. "Our aperture spacing is the smallest to-date, thereby enabling the largest total steering range. We have thus far demonstrated up to an angular steering range of 52°."

As PICs continue to advance, powerful point-of-care diagnosis and treatment will be driven from acute care settings through to community care and eventually to home care, using simple-to-use lab-on-a-chip technology.

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Measuring strain with fiber optics allows computation of wing deflection and slope, which can be used for structural health monitoring, active drag reduction and active flexible motion control. NASA researchers have come up with a way to do this using only one wire per fiber optic strain sensor. Courtesy of NASA.

Defense and Aerospace

With integrated photonics, gone is the tedious, expensive and error-prone manual connecting of components, thanks to integration that brings these onto a single chip.

BY HANK HOGAN
CONTRIBUTING EDITOR

When it comes to spacecraft, planes and military gear, weight is all important. That's understandable, as it costs about $10,000 to put a pound in orbit, in the case of spacecraft. For planes and military gear, there are limits on what can be flown or carried. Hence, the importance of keeping weight down — and the growing interest in and use of photonic integrated circuits (PICs).

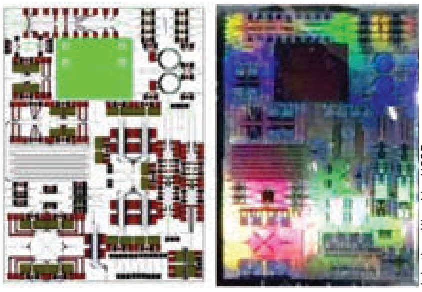
"We're buying size, weight and power," said Michael Krainak of the technology.

Krainak is head of the laser and electro-optics branch at NASA Goddard Space Flight Center in Greenbelt, Md. He is also NASA's liaison to the American Institute for Manufacturing Integrated Photonics, a Rochester, N.Y., joint public-private initiative that has funding from the U.S. Department of Defense and elsewhere.

What integrated photonics enables is the mass production of devices. Gone is the tedious, expensive and error-prone manual connecting of components, thanks to integration that brings these onto a single chip. Another plus is that putting everything on a chip fabricated in a cleanroom eliminates dust, which scatters light and consequently degrades photonic signals.

Sensing machine health and more

In an October 2016 presentation, Krainak said that the areas where photonics could help aerospace include sensing



Jonathan Klamkin, UCSB

Photonics integrated circuit for deep space laser communications.

and communications. Defense application areas are the same, although military uses will also likely include remote detection of chemical and biological agents as well as explosives, Krainak added in a later conversation.

In discussing sensing, Jose Pozo, director of technology and innovation at the European Photonics Industry Consortium, pointed to lidar, which measures distances by sending out laser pulses. It is useful in missile guidance and tracking, autonomous flight, and aircraft damage detection. Implementing this technology using photonic integrated circuits would cut size and cost.

"Using PICs for the optical beam steering of laser light without the use of moving parts has become a key development for such a purpose," Pozo said.

Other promising applications include optical gyroscopes, with researchers at City University of New York coming up with a scheme in 2015 for one that only measures a fraction of a millimeter and thus could potentially be incorporated entirely onto a chip[1]. Other sensing applications could involve optical accelerometers and multiwavelength imagers.

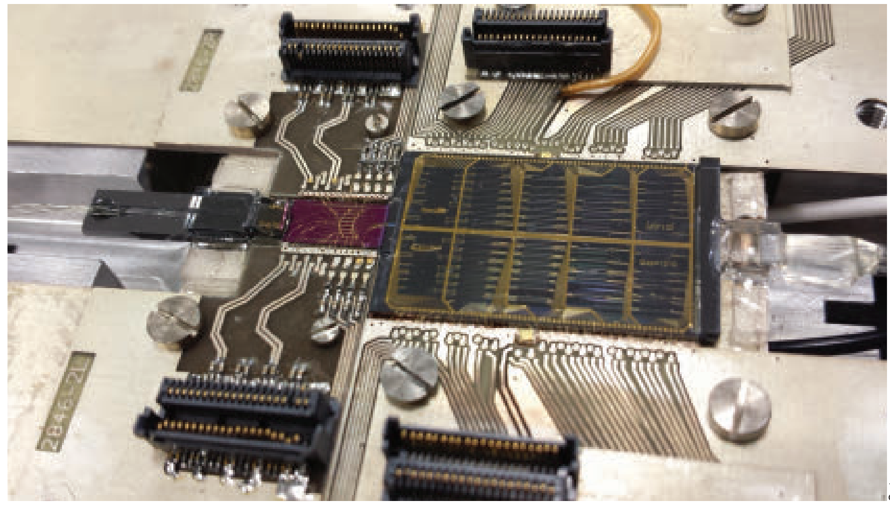
Vehicle health monitoring applications are also important because airplanes, spacecraft and military vehicles are subject to repeated and sometimes violent movement, which causes strain. This can be measured by writing a Bragg grating into an optical fiber and then attaching the fiber to the component of interest.

"A fiber Bragg grating reflects one part of the light. If you stretch this grating, you will get a slight change of the reflected light. That is what we are looking at and basically you do that with a narrow band spectrometer," said Pim Kat, president and CEO of the Technobis Group. Located in Alkmaar, the Netherlands, the company concentrates on aerospace and medical applications.

In the past, this measurement has been done using free space optics, which leads to large, heavy, expensive and power-hungry systems, as compared to what's possible with photonic integrated circuits. Richard Visser is CEO of Smart Photonics BV, an Eindhoven, Netherlands-based foundry that works exclusively in indium phosphide. He said that the integrated strain-measuring chips are only a few square millimeters in size, making them much smaller and lighter than the free space optics equivalent.

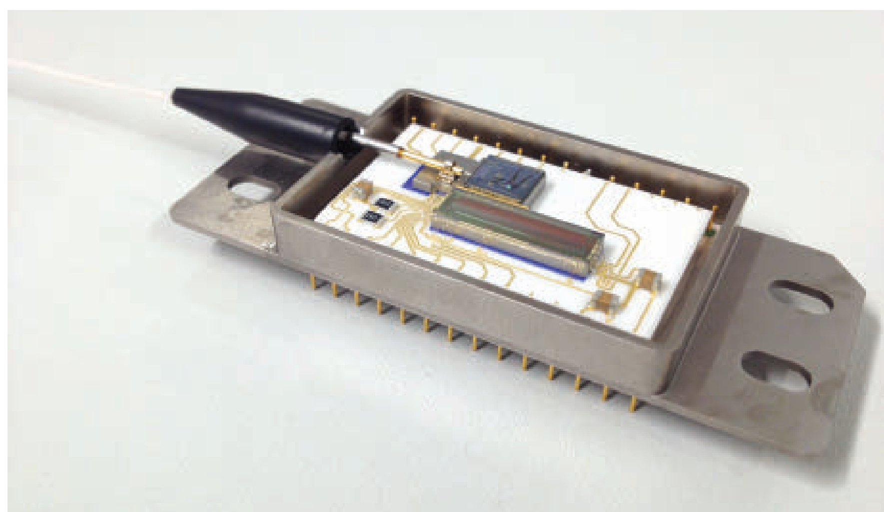
"They are also thousands of times more accurate due to a lack of vibration effects," Visser said.

Because of these characteristics, systems built using integrated components can be deployed in more places aboard a vehicle. This means its health can be more closely monitored, which is of interest to both civilian and military aircraft makers and users.



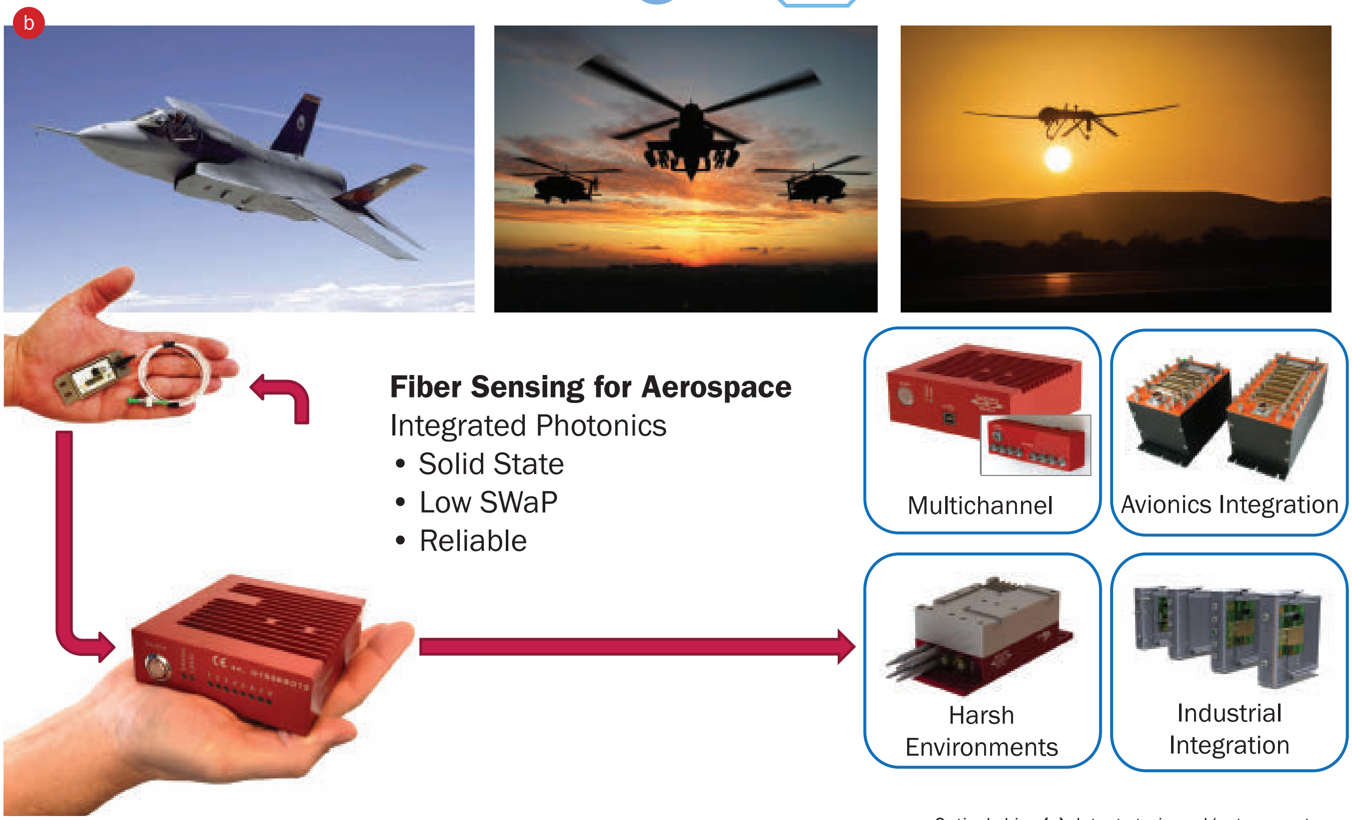
Satrax

Integrated photonic beamformer with steering through time delays. On-chip modulators (the purple color) are built using InP with a beamforming network in silicon nitride-silicon dioxide (Si_3N_4-SiO_2).

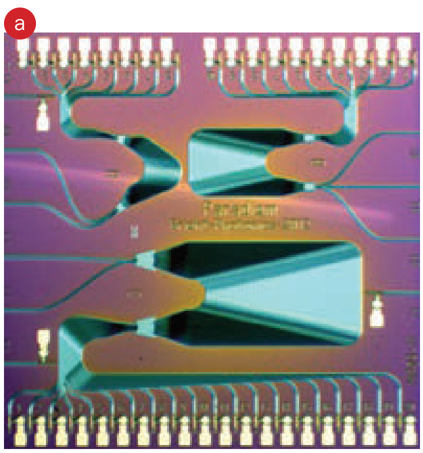


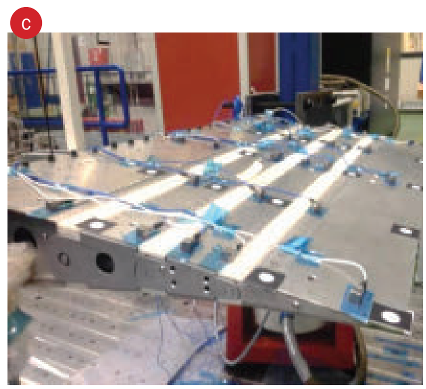
Tyndall Institute

Because they are lightweight, robust and offer better performance, integrated photonic devices like the one pictured above are used in space and harsh environment sensing applications.



Technobis





Optical chips **(a)** detect strain and/or temperature changes via fiber Bragg gratings, enabling health monitoring of wings **(b)** and other structures. They also can be used to help monitor and control structures that change shape, as shown in this demonstrator **(c)** of an adaptive trailing edge that morphs into different shapes to improve aerodynamic performace.

Communication benefits

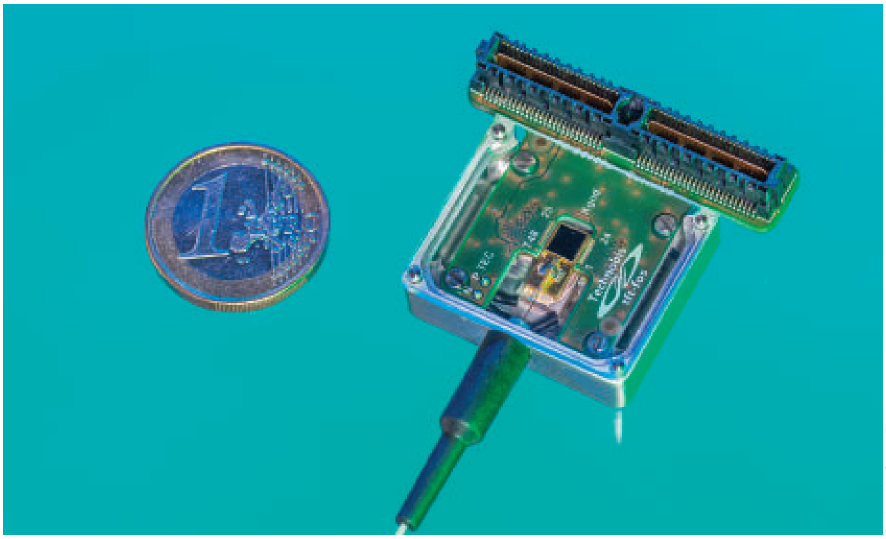
As for communications, an important point about optical beam steering is that it offers an advantage beyond simply getting rid of mechanical parts that can fail, according to Paul van Dijk, vice president for strategy and innovation at LioniX International, a pure-play integrated photonics foundry based in Enschede, Netherlands (see also Marie Freebody's "Medicine and the Life Sciences" on p. 54). The company recently absorbed van Dijk's previous enterprise, satellite-to-airplane communications systems maker Satrax BV.

Photonic-based beam steering allows Satrax to connect planes in flight to satellites while replacing a domed enclosure that protrudes from the plane with one that is flush with its skin. This lessens drag on a plane and improves its aerodynamics. This would save airlines around €100,000 ($109,000) in fuel costs a year, based on van Dijk's calculations.

Photonic integrated circuits enabled Satrax to take discrete components and modules that are shoebox-size and put them all on a chip as big as a coin. "We came from the sizable unit with lots of fibers and discrete modulators and detectors to a design with on-chip functionalities, reducing size, weight and making it robust and compact," van Dijk said.

This beam steering for external communication is done using microwave photonics. Communication within an aircraft or military vehicle could be over fiber optics, with signals that are insensitive to electromagnetic interference and cross talk.

Integration offers a 10- or 100-fold reduction in size, as well as a significant savings in weight, said Iñigo Artundo, CEO of independent design house and manufacturing services broker VLC Photonics of Valencia, Spain. He noted that there also can be a substantial performance boost with a cost and power consumption decrease, as compared to what's possible with discrete components. However, those cost savings somewhat


Technobis Group BV

PIC is considered to be the most promising technology for the next generation of interrogation devices for fiber optic sensing. In the picture is a packaged PIC-based fiber sensor interrogator developed by Technobis.

depend upon volume production, something that rarely happens in aerospace and defense applications.

This means that it may make more sense to piggyback on developments originally intended for other areas, like telecom or data centers. If this can be exploited, then aerospace and defense applications can benefit from the economies of scale created by such large markets.

Challenges in validation, materials and more

However, that could prove difficult because aerospace and defense have exacting requirements when it comes to packaging and testing. “The biggest challenges to overcome are surely on the validation and certification of photonic integrated circuits for these markets, as procedures and standards are very important here, operation under harsh environments is critical, and significant investments are required,” Artundo said.

Another challenge for photonic integrated circuits in general is there is no single material system suitable for all applications, with silicon, silicon-on-insulator, silicon nitride and indium phosphide all popular substrates. Silicon, which is dominant in electronics, is used for passive components, detectors and modulators. In contrast, indium phosphide enables electrically pumped amplifiers and lasers. However, it is expensive and users cannot exploit silicon’s vast manufacturing base.

Solutions under evaluation include growing indium phosphide on a silicon substrate or putting a chip of it directly atop a silicon one. The future is likely to be a combination of both approaches, with CMOS silicon used for the electronics and other materials for photonics, said Katarzyna Ławniczuk, photonic integration group project coordinator at the Eindhoven University of Technology in the Netherlands.

“There will be more of the hybrid solution with electronics and optics than single optical photonic functionality,” she predicted.

On the other hand, NASA’s Krainak noted that optical gain materials can be built using CMOS-compatible processes. For instance, Laura Agazzi and colleagues in a 2010 *Optics Express* paper[2] reported using erbium-doped aluminum oxide as a gain medium that can be optically pumped. They fabricated demonstration devices in a CMOS pilot line. There is the possibility that a CMOS-compatible gain material could be electrically pumped. More materials and device architecture work is needed to further explore the limits and possibilities of this approach, Krainak said. Having a single material platform could help cut costs, as has happened in electronics.

A final issue that confronts photonic integrated circuits is packaging. Peter

O'Brien, head of the photonics packaging group at the Tyndall National Institute of Cork, Ireland, said that future manufacturing needs to be done passively, as opposed to active packaging. The latter looks at the output of the device and then tunes the alignment and other packaging parameters to get the best signal. It's a method that costs more and has a lower throughput than a passive approach, but it is currently necessary.

The situation may change, thanks to research and development at Tyndall and elsewhere. That may lead to a different manufacturing flow than is used today. "That will be wafer scale, with passive processes as opposed to active, using an electronic assembly manufacturing process that is machine vision based, for example," O'Brien said.

He added, though, that a premium is placed on performance and reliability in aerospace and defense applications. Therefore, manufacturers of these products may opt to go with a more expensive approach because of what it buys, particularly in terms of improved reliability.

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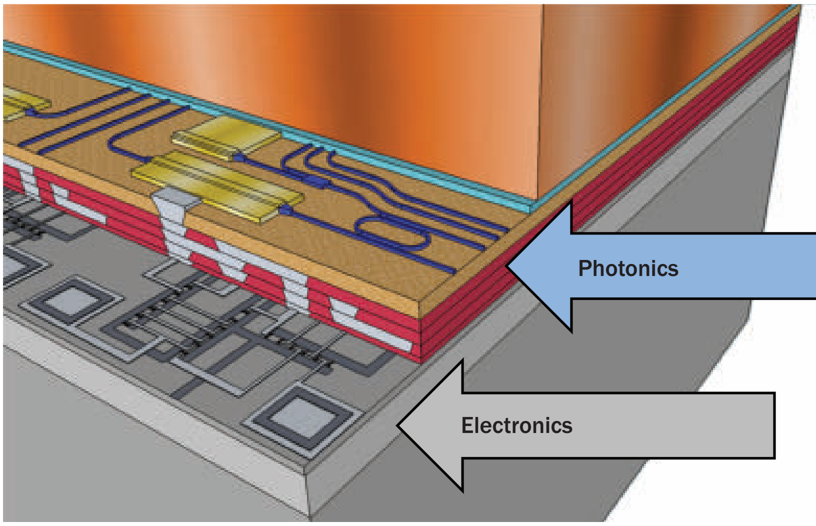

Katarzyna Ławniczuk, Eindhoven University of Technology

Future photonic integrated circuits may take a hybrid approach, using silicon as a substrate for electronics and another material for the photonics.

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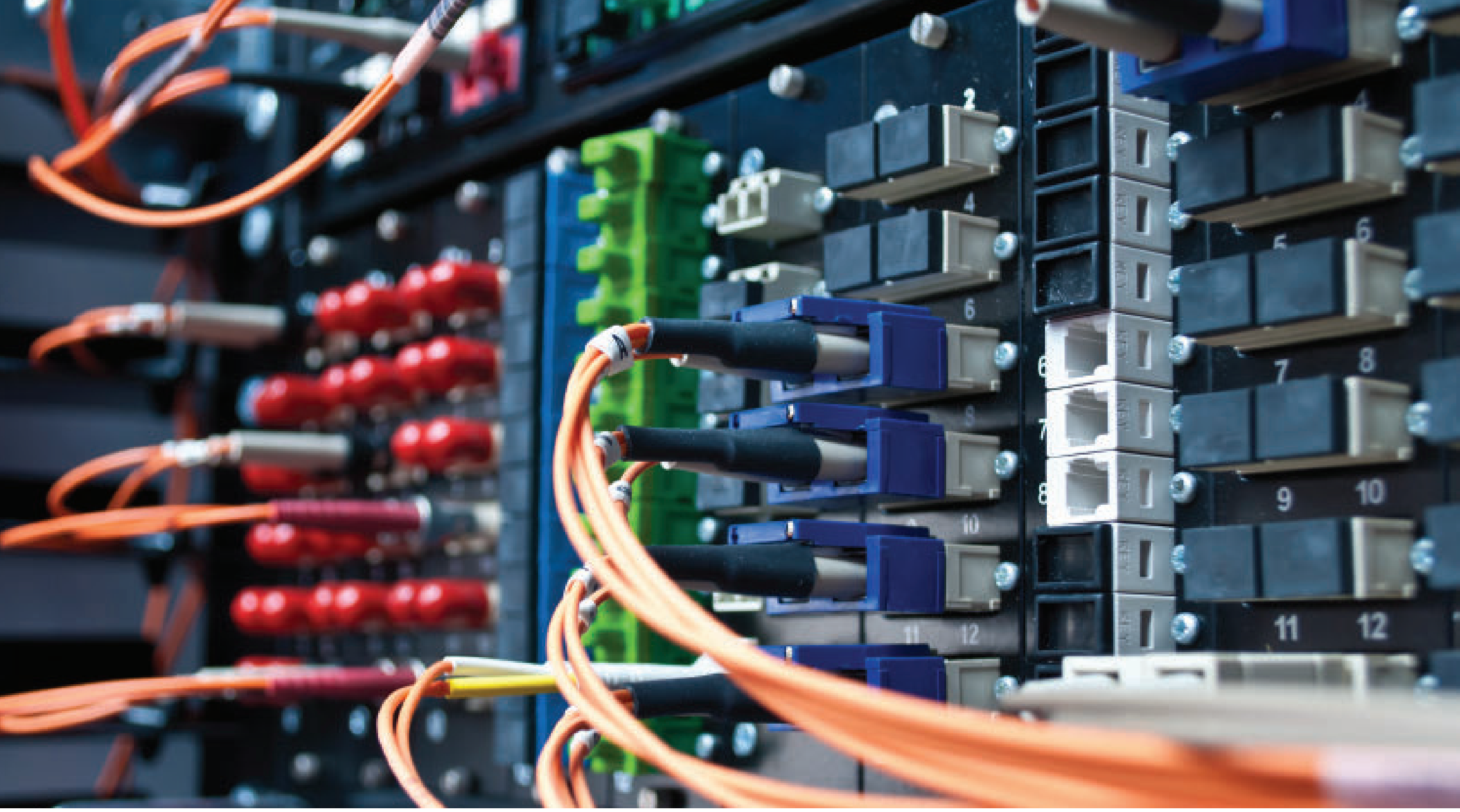


Data Centers and Telecommunications

Integration and packaging of optical components such as laser sources, multiplexers, detectors and modulators into a single chip are ushering in a new era of communications to 100 Gbps and beyond.

BY VALERIE C. COFFEY
CONTRIBUTING EDITOR

Today's data centers deliver millions of services, processing terabytes of data per second around the world for billions of devices. Considering the volume, it's amazing that we ever have a signal. As the need for connectivity increases, data centers are under constant pressure to add more and more massive racks of servers and fiber optic interconnects, which takes money and time, energy and real estate.

The demand for large-scale cloud computing and ever-faster processing is growing so fast that network traffic in data centers is doubling every twelve months, according to Diane Bryant, vice president and general manager of data centers at Intel.[1] And copper wires struggle to transmit at data rates of 25 Gbps over a few meters, says Microsoft's general manager of hardware engineering, Kushagra Vaid. "As data rates start getting to 100 Gbps — and this will happen in the future — we are going to hit a brick wall," Vaid said.

Many experts in government, industry and academia predict that photonics integrated circuits (PICs) — chips that integrate photonics components alongside the electronics — will be an important part of the solution. These monolithic PICs will improve upon today's vertical-cavity surface-emitting laser (VCSEL) technology, in which VCSELs are coupled to the chip via multimode optical fiber links, but are bandwidth-distance limited. After decades of research and development, the public is finally getting a glimpse of what viable PIC solutions might look like (Figure 1).

In August, Intel officially introduced a commercially available silicon (Si)

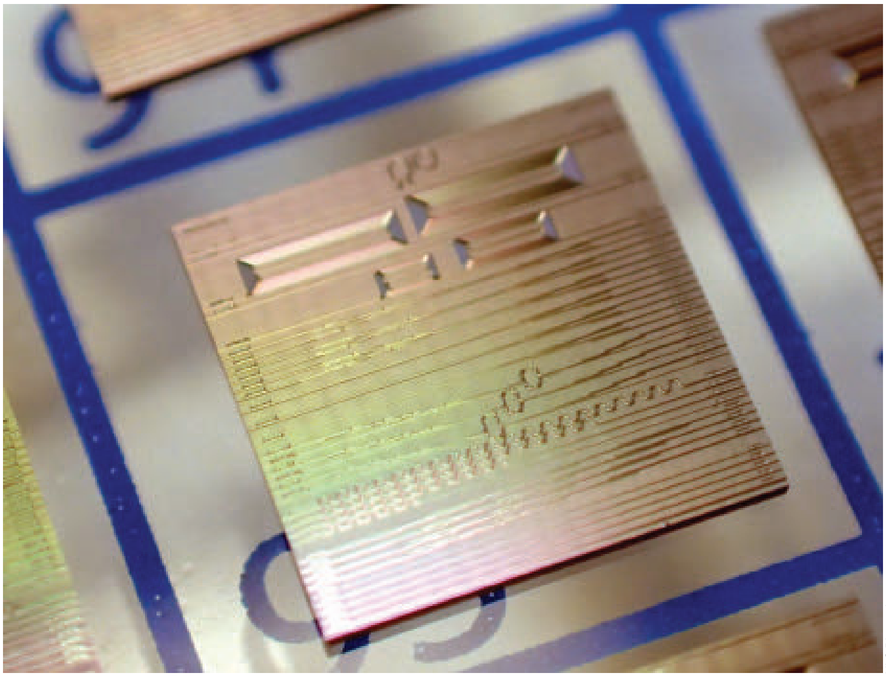
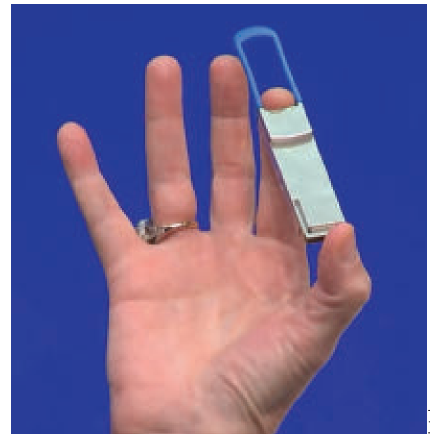


Figure 1. A prototype SiN photonics integrated circuit fabricated at Ligentec (Lausanne, Switzerland) is one example of a better, smaller, faster chip that will introduce economies of scale in future telecom and datacom build-outs.



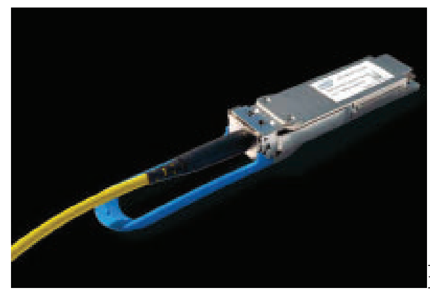


Figure 2. Sixteen years in the making: Intel's Bryant announces the first commercially available Si photonics platform at the Intel Developer Forum in San Francisco in August. **Inset:** Intel claims the 100G PSM4 (parallel single mode fiber 4-lane) QSFP28 optical transceiver is the world's first commercial Si photonics chip to feature a fully integrated InP hybrid laser.

photonics transceiver for data center network switches at the Intel Developer's Forum in San Francisco (Figure 2). In development for 16 years, Intel claims its QSFP28 switch-to-switch interconnect is the first product to integrate a hybrid indium phosphide (InP) laser directly into the silicon. The PIC-based platform can handle data rates of 100 Gbps over 2 km of singlemode fiber, leveraging wavelength division multiplexing and lower power requirements to allow data centers to scale to 400G modules in the future. Microsoft is already a customer; other targets include Facebook, Google, Amazon and Alibaba.

Scaling via packaging

Multinational giant IBM, based in Armonk, N.Y., isn't far behind with another PIC-based solution for data centers and cellphone towers, using a different approach. In 2015, researchers at IBM announced the successful testing of a fully integrated wavelength division multiplexing (WDM) Si photonics chip for Big Data and cloud services, enabling the download of an entire HD digital movie in two seconds (Figure 3).

According to Tymon Barwicz, Ph.D., researcher in Silicon Nanophotonic Packaging at IBM Thomas J. Watson Research Center in Yorktown Heights, N.Y., the PIC program at IBM has two parts: the first is the finessing of the wafer fabrication using existing CMOS fabrication processes (a business licensed to GlobalFoundries in 2015 when the company acquired IBM's semiconductor business), and the second is the packaging of the photonics using existing high-throughput microelectronics assembly facilities.

"The IBM wafer technology integrates the photonic devices and transistors side by side on the same chip," said Barwicz. "We can now make a photonics integrated chip in a standard CMOS foundry, notably reducing its cost."

In addition, IBM is leveraging the existing pick-and-place tools from high-volume microelectronics packaging to do the photonics assembly instead of using expensive custom automated tooling or manual assembly lines.

"Our approach was to say, hey, the same way we applied microelectronics fabrication for PICs can be used in pho-

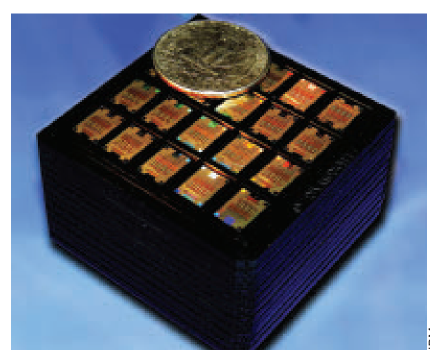


Figure 3. Several hundred monolithic chips incorporating optical and electrical circuits are combined in a cassette to demonstrate 100-Gbps transmission suitable for deployment in cloud servers, datacenters and supercomputers.

NASA

Figure 4. Michael Krainak, head of integrated photonics at NASA's Space Technology Research Grants Program, and head of the Laser and Electro-Optics Branch at NASA/Goddard Space Flight Center, holds the PIC that will be demonstrated as a key communications capability for future spacecraft.

tonics circuit packaging, with a big cost and yield advantage," said Barwicz.

The challenge was to overcome the inaccuracy of high-throughput pick-and-place machinery (with +/− 10-µm accuracy) to align fibers with 1- to 2-µm accuracy[2]. Mode engineering and self-alignment schemes were able to overcome the placement problem. Then the machines were fit with customized vacuum pick tips and chip holders to enable photonic assembly. The result will be a scalable, cost-effective photonic packaging technology that doesn't rely heavily on manual labor. Today, the project is close to commercialization; no timetable has been announced, but the technology is in the reliability and yield stage.

PIC partners

Big multinational innovators like Intel, IBM and Cisco are working hand in hand with partners in business, academia and government to develop PIC-based solutions to communications challenges. For smaller enterprises, public-private partnerships have forged national research consortiums like the American Institute for Manufacturing Integrated Photonics (AIM Photonics, Rochester, N.Y.) in the U.S., and the European Photonics Industry Consortium (EPIC, Paris) in Europe. These innovative initiatives have sprung up to provide a manufacturing infrastructure, support, partnerships and financial assistance — with PIC development in mind.

With members encompassing the entire value chain of photonics, EPIC works with companies like VLC Photonics, a fabless PIC design house in Valencia, Spain, to help customers in industry and academia with early PIC concepts, and then assist them in development all the way to pilot production and beyond.

The nonprofit AIM Photonics, sponsored by the U.S. Department of Defense and managed by the State University of New York (SUNY), announced in October a new Tier 1 industry member, Infinera, a pioneer in InP lasers on PICs. Infinera is offering its resources and expertise in large-scale PICs and packet optical convergence to other members — all for the purpose of leveraging past success in electronics into the acceleration of integrated photonics for lower power, smaller-area networks.

PICs in space

Another AIM Photonics partner, NASA, is heavily involved in Si photonics R&D for its communications needs (see also "In Defense and Aerospace" on page 62). Earlier this year, the U.S. space agency announced plans to build the first integrated photonics modem for use on the International Space Station as part of NASA's multiyear Laser Communications Relay Demonstration (LCRD)[3]. The modem, named the Integrated LCRD Low-Earth Orbit User Modem and Amplifier (ILLUMA), will incorporate lasers, encoders, optical switches and transmitters on a single chip, designed for eventual high-speed laser communications from Earth to spacecraft all over the solar system (Figure 4). The technology, scheduled for testing in 2020, will be made available to industry and other government agencies in the future.

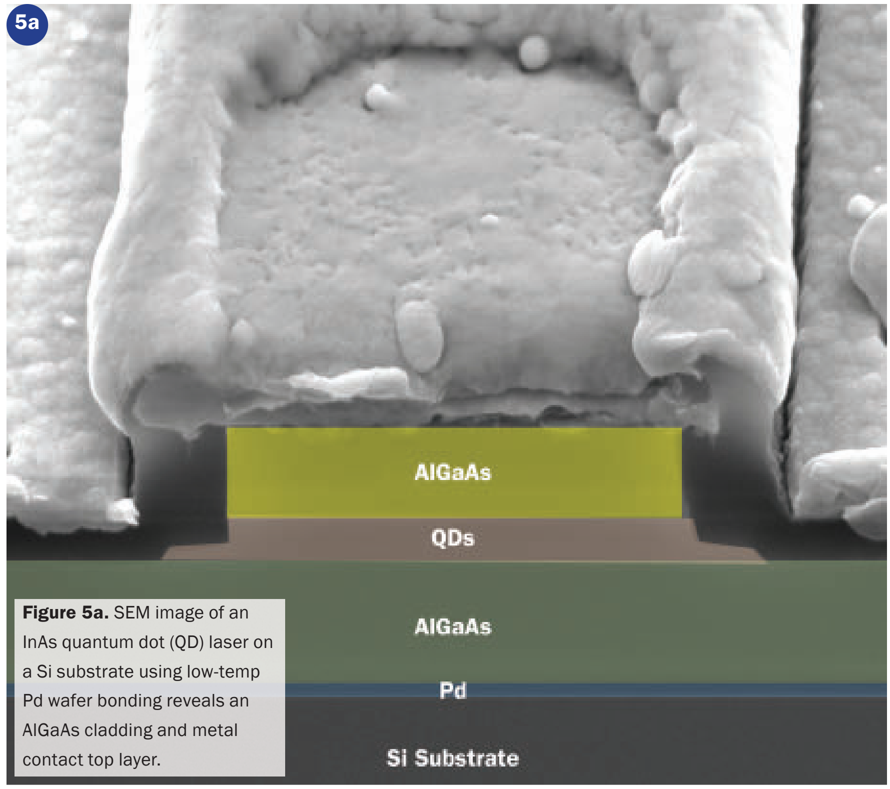
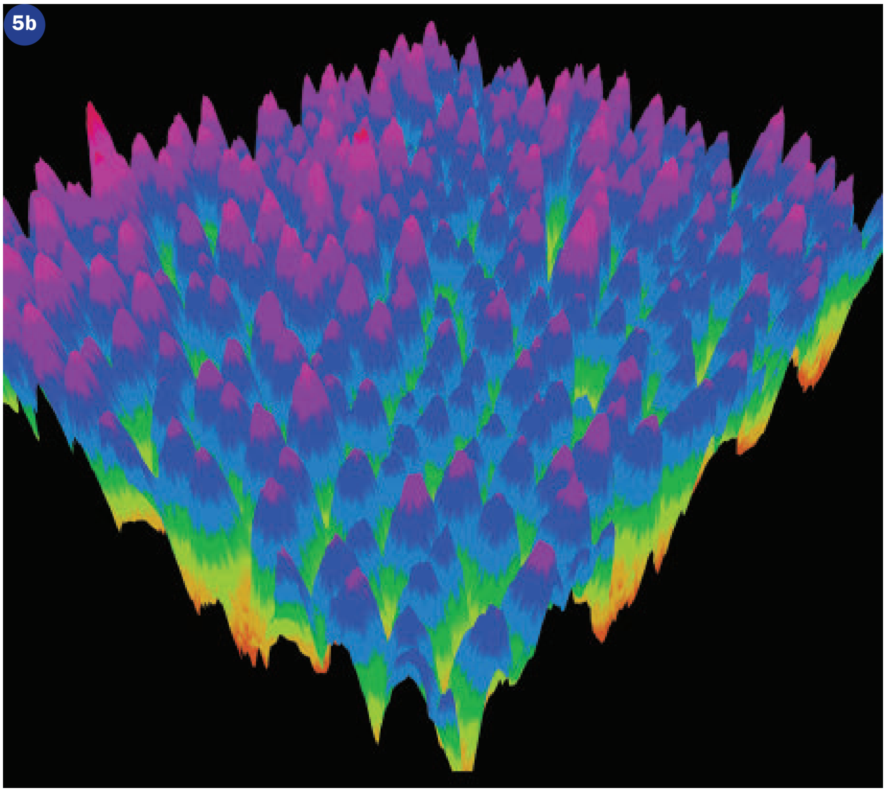


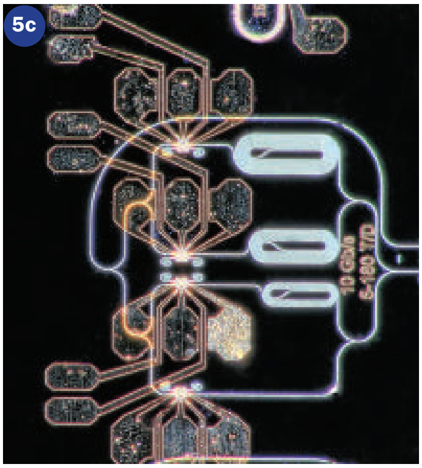
Figure 5a. SEM image of an InAs quantum dot (QD) laser on a Si substrate using low-temp Pd wafer bonding reveals an AlGaAs cladding and metal contact top layer.

5b



K. Tian and Z. Wang, RIT

5c



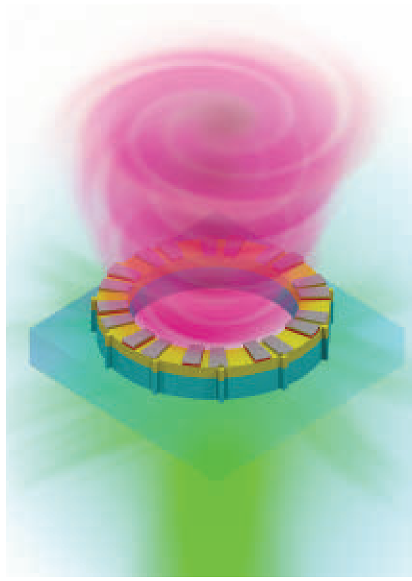
M. Fanto, RIT

Figure 5b. This false color 3D atomic force microscope image shows the height profile of the InAs QDs on Si **(at left)**. **Figure 5c.** The Si PIC generates optical time-division multiplexing signals at 40 Gbps from 10 Gbps QD mode-locked lasers **(above)**. The circuit splits the short pulses from the laser into four separate paths, each modulated by Si ring resonator electro-optic modulators, delayed and recombined at the higher data rate of 40 Gbps.

PICture this

One of the steepest challenges to widespread adoption of PICs is incorporating lasers into the chip. More than one material may emerge as a winner for use in hybrid lasers on PICs. Silicon itself doesn't lase, although adding a layer of a III-V material helps overcome that limitation; Intel added InP, for example. But III-V materials are inherently not compatible with conventional CMOS fabrication, leading to expensive work-arounds. Research is hot on the trail of graphene, a two-dimensional layered material that can emit, transmit and detect photons, but issues of CMOS scalability and performance are handicaps that will take time to overcome[4].

One lasing material showing great promise is quantum dots (QDs) (Figure 5). Recently, researchers at Rochester Institute of Technology (RIT, Rochester, N.Y.) demonstrated that indium arsenide (InAs) QD laser heterostructures can successfully be grown and transferred to Si substrates via a low-temperature palladium (Pd)-mediated wafer bonding process (Figure 5a, 5b). Associate professor of microsystems engineering Stefan Preble and colleagues at RIT, in collaboration with professor Wei Guo at the University of Massachusetts, Lowell, further dem-



L. Feng/Univ. at Buffalo

Figure 6. Structured helical wavefronts from a vortex laser could someday carry an unlimited number of orbital angular momentum modes for next-gen terabyte optical communications.

onstrated mode-locking of these lasers, which would enable stable optical pulse trains of short pulses (<10 pc) at high repetition rates for optical time-division multiplexing (OTDM), among other uses (Figure 5c)[5]. The group is looking at schemes to combine wavelength division multiplexing (WDM) with OTDM to get to data rates beyond 400 Gbps. The biggest hurdle with QDs is efficiency, but their temperature stability is making them hot prospects for next-generation PICs.

"Quantum dots have recently been pulling ahead of quantum wells as a promising next-gen PIC solution," said Preble. "The QD is less susceptible to defects that destroy performance over time. And several promising approaches for direct growth of QDs on Si chips are emerging. But the yield and long-term reliability of QDs on silicon remains to be proven."

Other schemes beyond WDM and OTDM may someday be able to carry terabyte data rates on a single chip. Assistant professor of electrical engineering Liang Feng at the University at Buffalo, State University of New York, and colleagues recently demonstrated a tiny microring laser that emits photons in a radially polarized stream. The orbital angular momentum (OAM) of the photons creates a vortex shape that offers novel degrees of freedom and flexible control through on-demand topological charge and polarization states. The scheme may enable mode multiplexing over many orders (potentially an infinite number of orders) for tens of OAM channels[6,7,8] (Figure 6). The OAM laser might offer entirely new ways of implementing high-speed, secure optical signals in both classical and quantum regimes.

"Fifty years ago you couldn't have imagined what our everyday life would be like today," said Feng. "The power in our laptops is as great as the supercomputers that helped put astronauts on the moon. We certainly have a very long way to go, but all over the world people are trying to increase the laser energy emission in photonic circuits. In the next 50 years, it's exciting to imagine what we'll accomplish."

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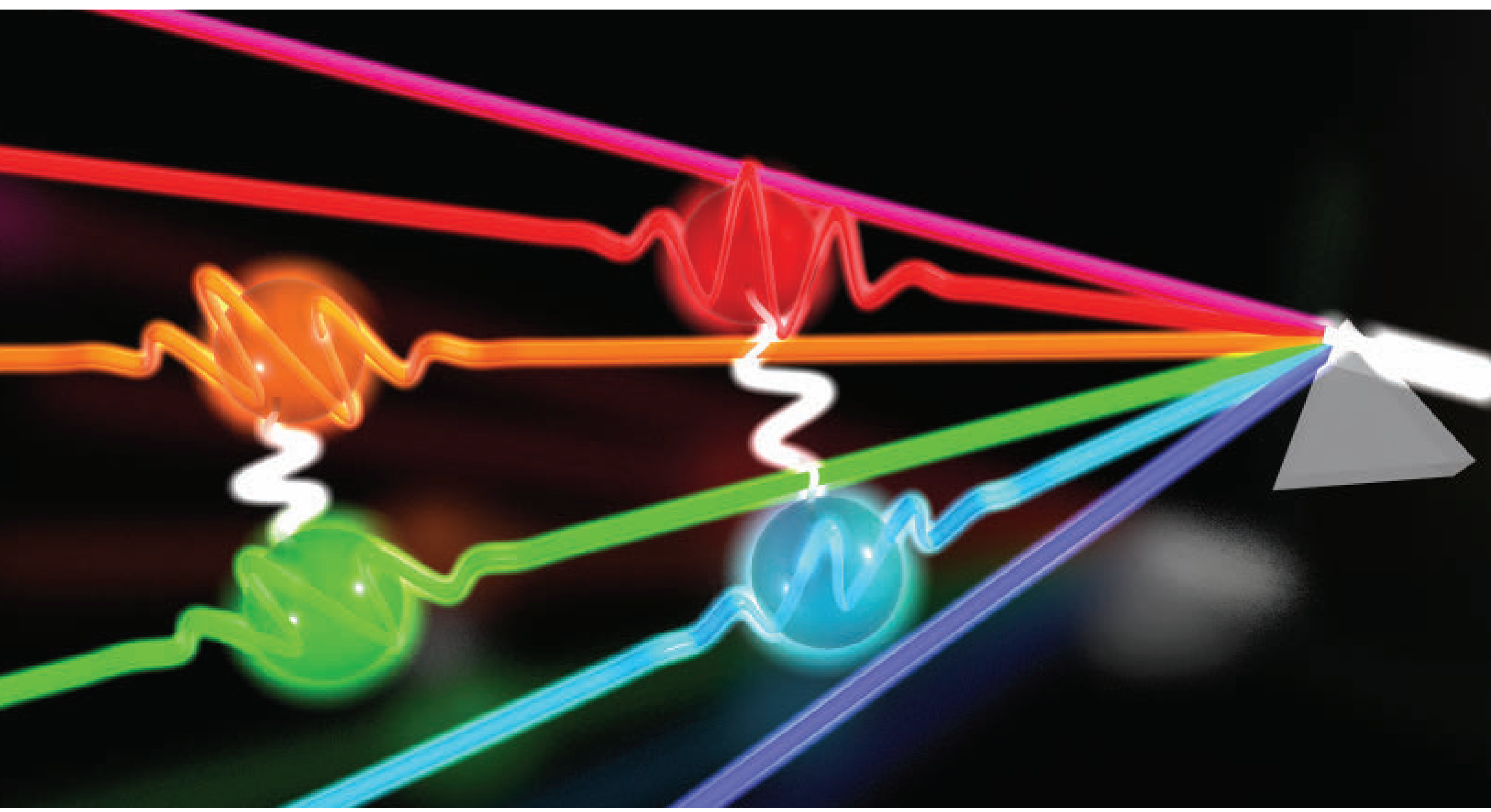
Quantum Communications and Computing

Broadband quantum light sources with many frequency modes in a single waveguide show potential for scalable quantum state generation.

BY MICHAEL KUES, CHRISTIAN REIMER, PIOTR ROZTOCKI, DAVID MOSS AND ROBERTO MORANDOTTI, INSTITUT NATIONAL DE LA RECHERCHE SCIENTIFIQUE (INRS)

Quantum mechanics offers a range of properties that have a great potential for complex information processing capable of outperforming classical processes. As commercial quantum cryptography and even quantum computing have been realized in recent years, research into on-chip quantum light sources has emerged as a broad and promising field, driven toward the development of a practical and powerful platform that will bring quantum information systems out of the lab.

Photons, in particular, are well-suited to carry quantum information. In comparison to solid-state quantum systems based on the agglomeration of atoms, ions or electrons that need extensive and complex shielding from both thermal and electromagnetic environmental noise and necessitate operation at cryogenic temperatures, photons interact very little with their surrounding environment. Therefore, they have longer de-coherence times — the average time until a quantum state is destroyed. Furthermore, photons can be prepared to form entangled states, which are photons with linked particle states that show unique, nonclassical correlations. These entangled states constitute the basis for quantum information processing, where entanglement can be achieved in



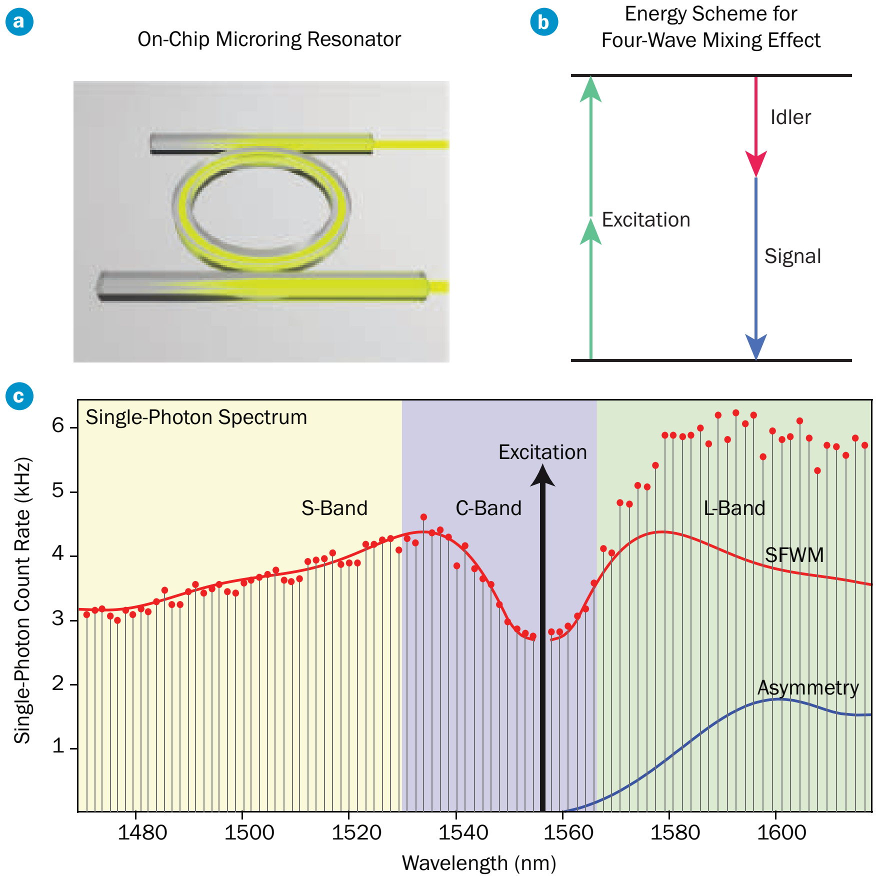


Figure 1. Schematic of four-port nonlinear microring resonator **(a)**. Four-wave mixing effect **(b)**. Single-photon spectrum emitted by the microring resonator when exciting a single resonance **(c)**.

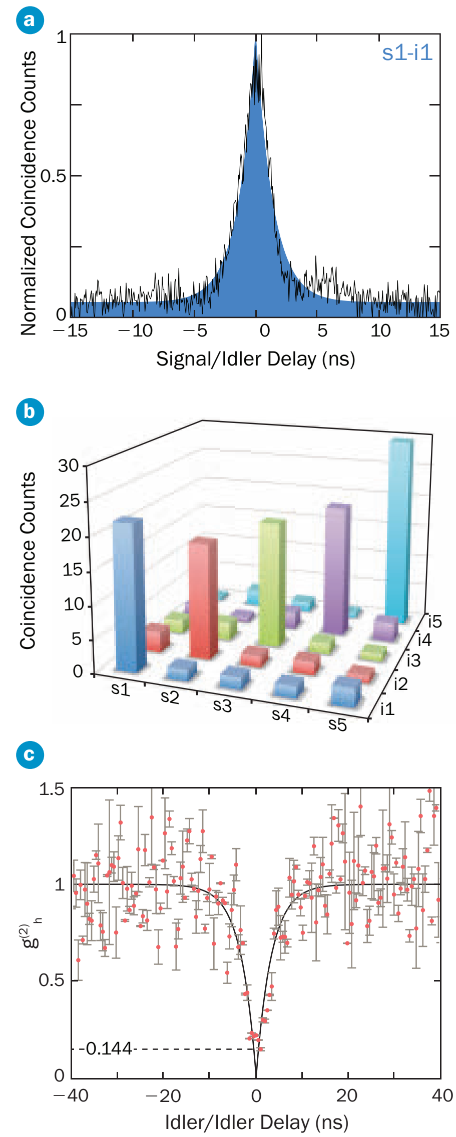


Figure 2. Correlation measurement of the first signal/idler pair **(a)**. Correlation matrix showing all signal/idler channel combinations of the first five resonances **(b)**. Heralded idler autocorrelation demonstrating the heralded single photon nature of the source **(c)**.

various degrees of freedom, such as spatial modes, polarization, position, orbital momentum, frequency or time.

Complex photon states with entanglement shared among several modes are especially necessary for solving high-level problems in quantum information processing, quantum imaging and microscopy, as well as quantum communications. However, realizations of on-chip quantum states and manipulation gates have mainly focused on the use of polarization, or path-entangled photons, wherein each state dimension corresponds to a single waveguide mode. Such architectures run into scalability issues as both the quantum circuit footprint and intricacy scale with problem complexity, posing significant challenges for today's fabrication technologies.

Recent research from a team from the Institut National de la Recherche Scientifique (INRS) illustrates how the concept of integrated frequency combs — broadband light sources comprised of equidistantly spaced spectral lines, with many frequency modes in a single waveguide — can bring about scalable, single-spatial-mode quantum state generation. By exploiting the resonance characteristics and nonlinear frequency-conversion effects of on-chip optical microring resonators, the team succeeded in the realization of a so-called "quantum frequency comb" — a multifrequency-mode quantum light source emitting correlated photon pairs, as well as bi- and multiphoton-entangled quantum bits (qubits, the quantum analogue of a classical bit) on many frequency modes, with direct applications for quantum communications and computation. The approach is compatible with contemporary fiber network infrastructure and with chip-scale semiconductor technology, enabling compact, low-cost and scalable implementations.

Nonlinear microring resonator

At the basis of realizing large, complex photon states is the generation of correlated photon pairs: two photons that are created at the same instance and thus show correlations in their generation time.

The INRS approach toward an integrated multimode photon pair source is based on a nonlinear microring resonator (Figure 1) coupled to two access waveguides (four-port configuration). Similar to a free-space Fabry-Pérot cavity, consisting of two facing mirrors, the microring allows electromagnetic fields with only certain frequencies to resonate, propagate and to

Images courtesy of the Ultrafast Optical Processing Group at INRS-EMT.

experience field enhancement inside the device. This characteristic is reflected in its transmission spectrum consisting of sharp spectral lines or resonances, which, for this device, are nearly perfectly aligned to the standardized 200-GHz-spaced telecommunications frequency grid. The microring resonator is based on a CMOS-compatible, high refractive index glass platform, featured by negligible nonlinear optical losses and a high effective nonlinearity. Thus, the resonant frequency components experience light-matter interaction while oscillating within the device, giving rise to nonlinear frequency conversion effects boosted by the field enhancement. A dominant effect is spontaneous four-wave mixing (SFWM), a third-order nonlinear process where two photons from an excitation field (or multiple fields) are annihilated, giving rise to the generation of two twin photons, referred to as signal and idler (Figure 1b). The effective dispersion is designed to be small and anomalous, guaranteeing a large four-wave mixing gain bandwidth at telecom wavelengths.

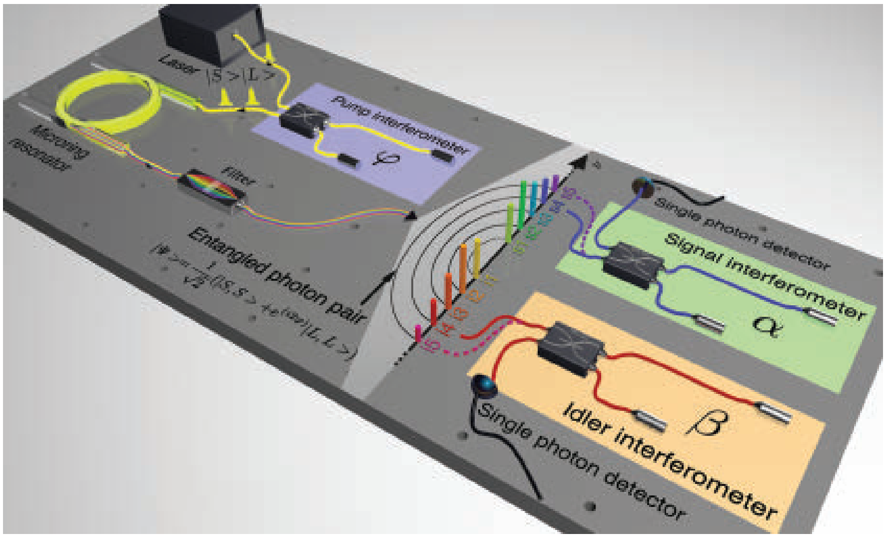


Figure 3. Experimental setup for the generation of a quantum frequency comb of time-bin-entangled photons.

In order to exploit the four-wave mixing effect for the generation of photon pairs, the ring resonator needs to be excited by a classical laser field with a frequency matched to a resonance of the cavity. To avoid the use of an external pump laser (which leads to meta-stable pump configurations due to thermal and environmental changes and thus requires active stabilization), the team utilized a novel excitation scheme termed self-locked pumping. This scheme consists of embedding the micror-

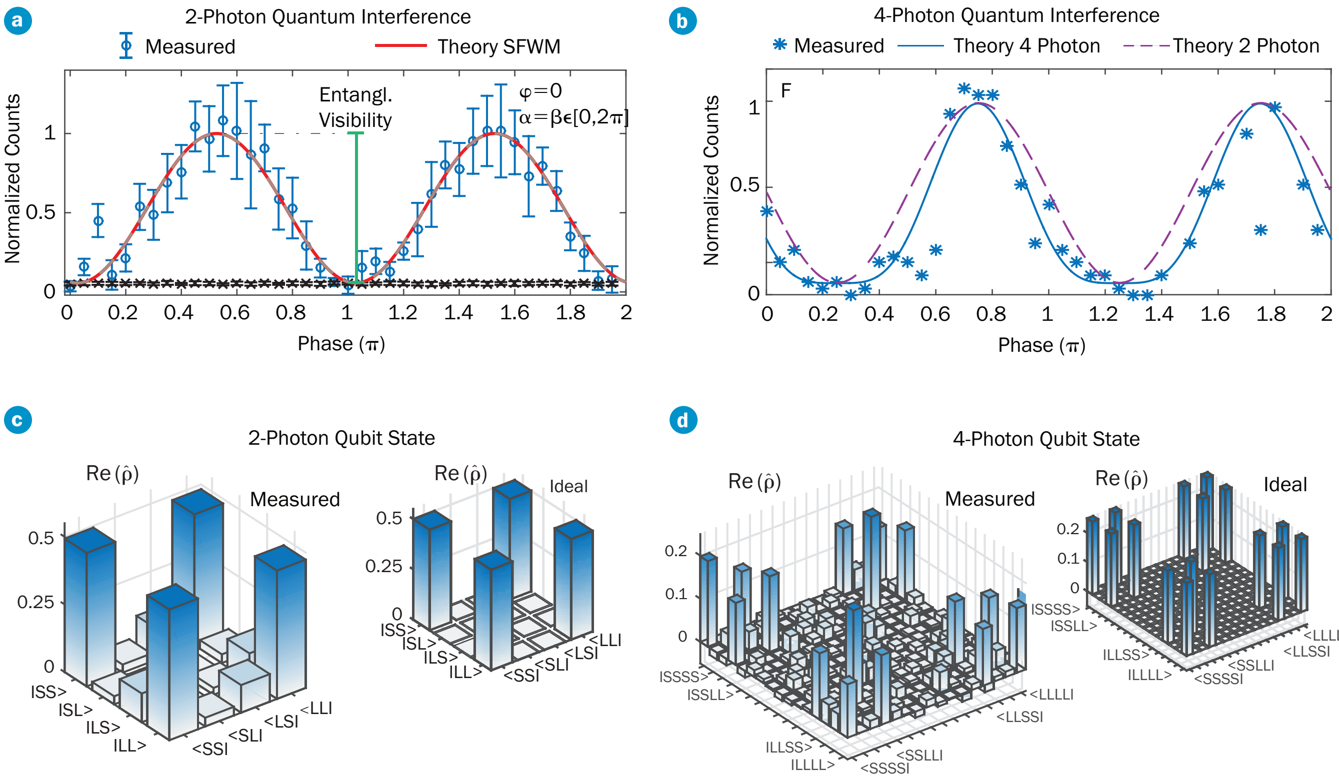


Figure 4. Quantum interference measurements for the 2-photon- **(a)** and 4-photon- **(b)** entangled state. Tomographic reconstruction of the density matrix for the 2-photon- **(c)** and 4-photon- **(d)** qubit state.

ing in an external active cavity, including an erbium-doped fiber amplifier. Such a setup allows a continuous wave excitation of the ring resonator that is intrinsically locked to the resonance, rendering external stabilization unnecessary.

Correlated photons with narrow photon bandwidth

Excited by such a continuous wave field, the SFWM effect generates signal/idler photon pairs on each resonance symmetric to the excitation frequency. To measure their generation, the signal/idler pairs were separated from the classical pump field and then individually rerouted by a filter to single-photon detectors. The single-photon spectrum emitted by the microring resonator (Figure 1c) covers the S, C and L telecommunications band with more than 50 frequency pairs.

Since the signal/idler photons are generated in a single quantum process, the photons are correlated in their generation time, which is reflected in a coincidence peak in the correlation function of their arrival times. The measurement of the signal-idler correlation function for the first resonance pair around the excitation frequency is shown in Figure 2a. The full width half maximum of the coincidence peak of ~2.9 ns corresponds to 110 MHz, which is consistent with the linewidth of the microring resonator (140 MHz). This very narrow photon bandwidth is suitable for use with state-of-the-art quantum memories and quantum repeaters. Similar and clear photon coincidences were measured for all channel pair combinations of the first five resonances symmetric to the pump field, while no coincidences were measured between nondiagonal elements of the frequency matrix (Figure 2b), due to energy conservation.

Photon-pair sources based on nonlinear processes can be used as single-photon sources. Specifically, for the realization of so-called heralded single-photon sources, we can exploit the fact that the twin photons are created at the same time: One photon's detection heralds the presence of the other. In order to demonstrate a heralded single-photon source such that detection of a signal photon implies that precisely one idler photon is present, it is necessary to perform an idler autocorrelation that is heralded by the signal photon. For a true twin photon source, only a single photon is present in the idler arm, and thus no coincidences are expected at zero time delay. The researchers performed this measurement for a particular signal/idler resonance pair and found a dip as low as 0.144 in the heralded idler-idler correlation function (Figure 2c), below the required 0.5. Remarkably, this characteristic is exhibited over the whole bandwidth of the quantum frequency comb.

Generating bi- and multiphoton-entangled quantum states

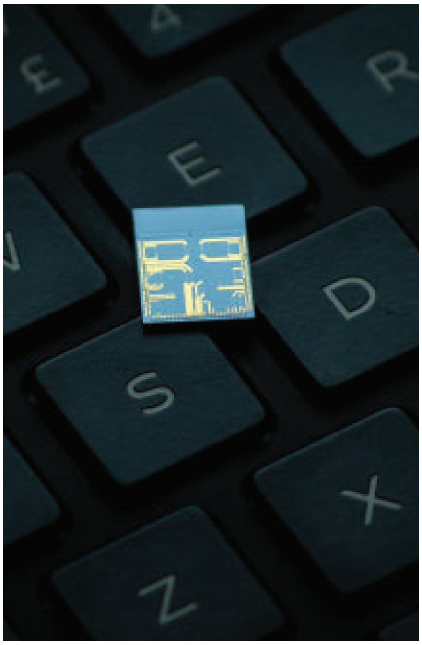
Complex photon states hold answers to fundamental questions in quantum physics and are the cornerstone of quantum communication and computation. In order to extend our configuration to enable the generation of entangled photons on multiple frequency modes, we employed time-bin entanglement, where the photons are entangled in two time modes. This has several intrinsic advantages, including being particularly suitable for information processing and transmission, since it is directly compatible with integrated devices, is robust with respect to polarization fluctuations and can be preserved even over long propagation distances in standard fiber networks.

The INRS team's quantum frequency comb of entangled photons is generated using the previously described microring resonator. In this case, however, the device is pumped with a passively mode-locked fiber laser, which is spectrally filtered to excite a single ring resonance. This generated pure single-mode photons in each resonance, as confirmed by single-photon autocorrelation measurements. Starting from the single-mode photon pairs, the researchers generated time-bin-entangled qubits by passing the pulsed pump laser through a stabilized unbalanced fiber interferometer with a delay longer than the pulse duration of the laser, thereby producing double pulses of equal power with a definite relative phase difference. The double pulses were then coupled into the microring resonator. This pump configuration transforms the originally single-mode photon pairs into entangled states, where the two photons (signal, s, and idler, i) are in a superposition of two temporal modes, namely short $|S\rangle$ and long $|L\rangle$. Most importantly, these entangled qubits are created over all the microring resonances, thus leading to a quantum frequency comb of time-bin-entangled photon pairs. In order to characterize the degree of entanglement, the generated signal and idler photons were each passed through a different fiber interferometer with an imbalance identical to the one used for the pump laser (Figure 3).

This setup allowed the measurement of quantum interference between the signal and idler photons. For five different frequency channel pairs within the C band, a quantum interference with raw visibility above 82.4 percent was recorded. Being greater than $1/\sqrt{2}\approx 71$ percent, this confirmed entanglement through the violation of the Clauser-Horne-Shimony-Holt (Bell-like) inequality (Figure 4a).

Four-photon state

The distinct multimode characteristics of the frequency comb architecture presented here can be further exploited to create multiphoton-entangled states. By selecting two different signal-idler pairs (Figure 4a,b), it's possible to generate two-photon qubit states. By post-selecting four-photon events with one photon on each frequency channel, the two states are multiplied, resulting in a four-photon time-bin-entangled product state.



An illustration depicting the size of a next-generation optical chip.

For the generation of a four-photon state, the coherence length of both photon pairs has to be the same and must be matched to the excitation field's coherence time. This requirement is intrinsically fulfilled through the resonant characteristics (equal resonance bandwidths) of the ring cavity, in combination with the excitation scheme described above. The researchers performed four-photon quantum interference measurements (Figure 4c). Four-photon interference generally is not present for two completely independent two-photon qubit states. The data follow the expected relation, having a visibility of 89 percent without compensation for background noise or losses.

To fully characterize the entangled states, the researchers performed quantum state tomography. This analysis reconstructs the state's density matrix, from which it is possible to extract important characteristics such as fidelity, which describes how close the measured state is to the targeted entangled state. The team first measured the two-photon qubits generated on comb lines that were symmetric with respect to the pump wavelength (Figure 4b) and found a fidelity of 96 percent, confirming that the generated quantum states are of high quality and very close to the ideal entangled state. For the four-photon entangled state (Figure 4d), the researchers obtained a fidelity of 64 percent without compensation for background noise or interferometer imperfections, a value comparable to the fidelity measured for non-integrated four-photon states used for practical applications. The generated four-photon state is the product of two Bell states and constitutes a good starting point to create more complex states by manipulation through quantum gates or the involvement of more resonance frequencies to achieve six, eight, or more photon states.

The researchers' results indicate that integrated quantum frequency comb sources based on third-order nonlinearities allow the generation of many frequency-mode quantum states in one spatial-waveguide mode and can open up new venues for the generation of complex quantum states, thus providing a scalable and practical platform for optical quantum information processing.

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Prism Awards: The Oscars of the Industry

BY JUSTINE MURPHY
SENIOR EDITOR

Doug Cody/SPIE

The 2016 Prism Award winners and event sponsors: Photonics Media and SPIE.

The industry is primed and ready for Photonics West 2017. It's a time for networking, sharing products and research, and learning. It's a time to recognize the world's top innovators, as well.

This largest conference and expo in the photonics industry gives companies and researchers from around the world the chance to bring their advances to center stage, by way of the Prism Awards for Photonics Innovation. To be held Feb. 1, and sponsored by SPIE and Photonics Media, this annual event recognizes the industry's top companies and products. This year's finalists, chosen from hundreds of entries, were determined by a panel of judges who represent all fields of photonics. And the competition is fierce.

Notable new innovations include a breathalyzer device that allows rapid screening of infectious diseases, as well as a unique optical component technology that can sense nanovibrations of the body with very high precision. The market's first femtosecond fiber laser-pumped mid-IR supercontinuum source is also among the finalists, as is a drone-mounted natural gas surveillance system for indoor natural gas leakage inspection.

Additive manufacturing/3D printing

The AMBIT Industrial 3D Printing System, by **Hybrid Manufacturing Technologies**, offers users "the freedom of [additive manufacturing] with the precision of CNC machining."

Patented laser processing heads enable fully automated changeover between disparate types of laser processing without a beam switch for the first time. The new system achieves cladding and laser drilling seamlessly in the same machine. And unlike using beam switch or multiple cells, AMBIT achieves flexibility in a single machine through a new innovation in beam delivery.

According to the company, the system enables easy adoption of additive manufacturing and laser processing by conventional machine tool users. Deposited metal can be machined in situ — proliferation of design and manufacturing freedoms without compromise to accuracy and surface finish limitations inherent in layer-based additive manufacturing techniques.

Multiphoton Optics' LithoProf3D printing platform allows optics implementation closer to the chip, supporting "a significant reduction in energy consumption," and, in turn, more efficient computing.

The LithoProf3D processes commercially available and semicon-approved materials for both additive and subtractive manufacturing of arbitrary structures ranging from 100 nm to the centimeter scale, making integration of 2D and 3D processes into the semicon workflow possible. The packaging concept for on-chip, chip-to-chip or die-to-fiber coupling uses in situ-created waveguides for photonic integration, saving as much as 80 percent of the process steps. Micro-optics such as lenses or lens arrays with different sizes and shapes can be flexibly created with best optical quality; replication master fabrication is also supported by this technology.

The Tungsten-LAM, developed by **PolarOnyx Inc.**, employs a femtosecond fiber laser as an energy deposition source for 3D printing. It combines additive and subtractive manufacturing in a single platform via one tunable pulsed fiber laser. The company has found this significantly reduces the cost and time required for 3D metal and ceramic printing, by eliminating separate post-processing. This system also enables layer-by-layer modification to create complex structures that have previously not been possible.

The company notes that this is the first femtosecond fiber laser-based 3D printing machine. It can be used with high-temperature materials, a function that differs from existing additive manufacturing technologies, which are limited to lower temperatures and always need post-processing.

Biomedical instrumentation

A Personal Vision Tracker now enables measurement of refractive errors and order corrective eyewear. Developed by **EyeQue Corp.**, this new device "helps cut cost significantly and will help those in need achieve clear vision, reducing productivity loss due to impaired vision."

The tracker is a self-administered refraction system that uses a miniscope optical device to estimate the user's refractive error, based on an inverse Shack-Hartmann principle. It is the first such human refraction correction measuring device accessible to consumers, according to the company, essentially providing access to services that have previously only been available through optometrists.

The TB Breathalyser, from **Rapid Biosensor Systems,** is the first biophotonics system available for noninvasive testing for active infectious diseases (namely tuberculosis). The novel system integrates laser, optical and engineering design with medical requirements for fast, breath-based testing. It will be effective for screening people in rural communities, the company notes, and in Europe and North America it has the potential to support screening programs at ports of entry, prisons, military establishments and schools, ultimately prompting lower health care costs.

The system has already been accepted by tuberculosis medics in India and Ethiopia as the fastest test for active infectious tuberculosis with high sensitivity and specificity >95 percent.

Wasatch Photonics' MicroAngio platform is a next-generation Fourier-domain OCT technology that provides a new imaging modality for a wide variety of applications, impacting diagnosis, drug discovery and fundamental understanding of disease mechanism. According to the company, this system is designed to help patients suffering from cancer, visual disorders and skin burns.

The MicroAngio employs broadband light source and spectral interferometry to extract phase and intensity variation of incident light. Changes are analyzed using statistical algorithms, which extract the information of red blood cell motion in the arteries and veins, while ignoring the bulk motion of the surrounding tissue. This provides "a depth-resolved map of the vascular structure without any external contrast agents."

The 2017 Finalists

Additive Manufacturing/ 3D Printing

Hybrid Manufacturing Technologies (Moira, England)
AMBIT

Multiphoton Optics (Würzburg, Germany)
LithoProf3D

PolarOnyx (San Jose, Calif.)
Tungsten-LAM

Biomedical Instrumentation

EyeQue Corp. (Newark, Calif.)
Personal Vision Tracker

Rapid Biosensor Systems (Cambridge, England)
TB Breathalyser

Wasatch Photonics (Logan, Utah)
MicroAngio

Detectors & Sensors

Aeris Technologies (Redwood City, Calif.)
Laser-Based Gas Analyzer

Alphanov (Talence, France)
GoSpectro

Hesai Photonics Technologies (Shanghai)
Drone-Mounted Natural Gas Surveillance System

Luxmux Technology Corp. (Calgary, Alberta, Canada)
BeST-SLED

Imaging & Cameras

e2v Technologies (Chelmsford, England)
3D Time-of-Flight Solution

TAG Optics (Princeton, N.J.)
TAG Inspector

TruTag Technologies (Kapolei, Hawaii)
Handheld Hyperspectral Imager Model 4100

Industrial Lasers

Amplitude Systèmes (Pessac, France)
Tangor amplifiers

Photonics Industries International (Ronkonkoma, N.Y.)
RGH Series/Pulse Picker Technology

QD Laser (Kanagawa, Japan)
Ultra-short Pulsed Seeder for Fiber Laser

Materials & Coatings

Crystalline Mirror Solutions (Vienna)
XTAL MIR

Element Six (Luxembourg)
Single Crystal Synthetic Diamond

InVisage (Menlo Park, Calif.)
QuantumFilm

Metrology

4D Technology Corp. (Tucson, Ariz.)
4D InSpec Surface Gauge

8tree (Konstanz, Germany)
dentCHECK

Leica Geosystems (St. Gallen, Switzerland)
Leica BLK360 Imaging Laser Scanner

Optics & Optical Components

ContinUse Biometrics (Tel Aviv, Israel)
Opto-phone

Nufern (East Granby, Conn.)
NuBEAM Flat-Top

SoraaLaser (Goleta, Calif.)
LaserLight SMD

Scientific Lasers

Integrated Optics (Vilnius, Lithuania)
MatchBox2 Series

Thorlabs (Newton, N.J.)
Mid-Infrared Supercontinuum Laser

Trumpf Scientific Lasers (Munich)
Dira 200-1

Detectors and sensors

The new MIRA analyzer, developed by **Aeris Technologies Inc.**, represents a disruptive advance in the laser-based gas analysis space, achieving “gold standard” ppb-level performance comparable to systems that are 10 to 15× larger and heavier.

The gas sensing device is based on simple and robust direct absorption spectroscopy that uses solid-state lasers in the mid-IR region, where molecular absorption is typically thousands of times stronger than the commonly used near-IR. Combined with compact custom electronics, “this miniature sensor core enables the world’s smallest autonomous, ppb-level analyzer on the market.” For natural gas leak detection, the device is able to measure both methane and ethane simultaneously at the 2 ppb level, discriminating methane from fossil fuels versus biogenic sources.

GoSpectro, from **Alphanov**, is a universal device that connects to any smartphone or tablet, turning it into a compact, easy-to-use, cost-effective light spectrometer. It makes possible the characterization of light sources (LEDs, etc.), displays, tunable lasers, optical filters or fluorescent dyes in a matter of seconds. It is a handheld tool that also measures emission and absorption peak wavelengths, cut-off wavelengths or spectral bandwidth, and enables material analysis (e.g., gemstones, crystals), or chemical analysis in liquids associated with color-based reagents for assessing water or food quality.

GoSpectro users can measure spectra, adjust acquisition parameters, display and save spectral data. Spectra are measured from 400 to 750 nm, with a resolution of <10 nm and an accuracy of <1 nm.

Hesai Photonics Technologies Co.’s Drone-mounted Natural Gas Surveillance System is the first drone-mounted methane remote sensor for indoor natural gas leakage inspection. It has the ability to cover thousands of households a day, making it 50 times more efficient than conventional sensing methods. The company says its new system “makes enormous contributions to preventing accidents and saving lives.”

The system features a very light methane remote sensor with high sensitivity detection, range and response — “0.5 kg, compared to 4.5 kg from major competitor.” It takes advantage of wavelength-scanned, wavelength-modulation-absorption spectroscopy with multiple harmonic detections.

By using its own algorithm, the sensor can identify false alarms due to the etalon interference from windows or other occasions where parallel optical surfaces are present. These false alarms have occurred frequently during operations in other products.

Developed by **Luxmux Technology**, the BeST-SLED light source will ultimately reduce greenhouse gas emissions and water usage through detection efficiencies. It is already being used in the medical and manufacturing industries through increased visiblilty in OCT.

BeST-SLED’s main component is the butterfly package, which is a multiple superluminescent diode light source. It allows integrators to put the power of laboratory-grade photonics into their solutions, while providing “unparalleled spectral coverage.” This butterfly package

provides 500 nm (1230 to 1730 nm) with up to 50 mW of optical power from a single-mode fiber. The system's miniaturization is achieved without sacrifice of quality or performance.

Imaging and cameras

Developed by **e2v**, the 3D Time-of-Flight Solution and 3D vision systems are designed to increase the autonomy and effectiveness of robots and machines for the factory automation market, while also protecting workers in factory settings from intensive human/machine interactions.

This new system features the first commercially available 1.3-MP 3D depth resolution in 1-in. optical format in the full range to enable real-time 3D vision from fast-moving robots. It keeps the accuracy and frame rate performances at the same level as current ToF products, and ultimately allows users to obtain more information and increase the effectiveness and autonomy of industrial systems.

The TAG Inspector, from **TAG Optics**, is a high-resolution single camera, telecentric inspection system with the unique ability to visualize complex geometries without the need for multiple detectors or sub-system assemblies. According to the company, it is the only system that can give users independent, electronic control over the height range to be imaged without changing the system's f-number of sacrificing resolution. It is also the first device capable of imaging multiple user-selectable focal planes simultaneously, which can be used for go/no-go inspection of complex parts.

Efficient algorithms that make use of the physical and optical characteristic of the system allow the user to obtain precise 3D quantitative and qualitative information about the part being imaged, such as surface finish, defects and relative height measurements.

The first device to capture and process a full multi-megapixel hyperspectral data cube without the need for external processing, the new Handheld Hyperspectral Imager Model 4100, by **TruTag Technologies Inc.**, essentially displaces existing multispectral imagers, which trade off spectral resolution for spatial resolution.

This new handheld imager allows users to dynamically select acquisition wavelengths that are not necessarily contiguous. It offers real-time processing, as well, the company notes, enabling processing for object identification and characterization. The camera can also identify and decode TruTag's optical memory microparticles, decode their spectra, and authenticate the origin of things like foods and pills.

Industrial lasers

The Tangor 100W, from **Amplitude Systèmes**, is an extremely compact, industry-ready, affordable ultrafast tool for high-precision processing. Its unique combination of high power, short pulse duration and high repetition rate could prompt new industrial applications, according to the company. This is currently not possible with other existing laser technology such as surface texturing or functionalization.

The new Tangor system is the first true (<500 fs), affordable 100-W femtosecond laser, designed for 24/7 high-precision, high-yield industrial manufacturing.

The Tangor shows potential for micromachining applications where process quality and speed are key to an efficient and economically advantageous solution.

Photonics Industries International's RGH Series/Pulse Picker laser has been proven a more efficient ps laser with an enormous impact enabling this massive market. Specifically, it is able to more efficiently manufacture novel high-end devices.

The RGH series industrial ps lasers offer the highest pulse energy (up to 700 µJ), the smallest footprint, and are the lightest weight commercially available.

The RGH series also touts a unique all-in-one single box design to simplify installation and system integration by removing the need to manage a separate controller or power supply box and umbilical cable.

The Ultra-short Pulsed Seeder for Fiber Laser, from **QD Laser**, features a less than 10 ps optical pulse, which, according to the company, "has been strongly needed." And its ultra-short pulsed seed laser is one of the key components for MOPA (Master Oscillator Power Amplification)-type fiber lasers.

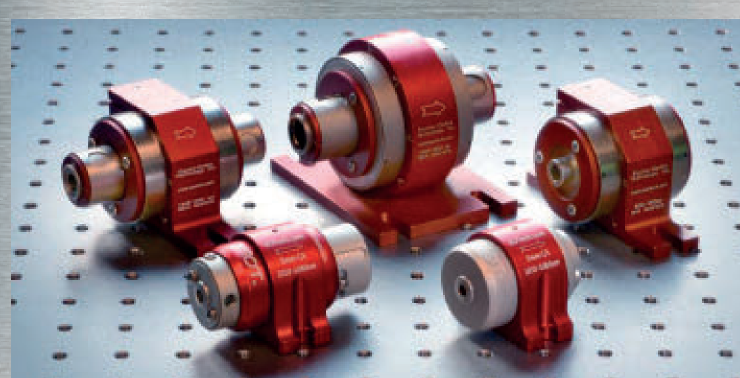
By designing this laser chip and high-speed module, the company notes that next generations of such short optical pulse become possible. These lasers can be used for nonthermal precise microprocessing and have become a strong competitive light source to mode-locked lasers. Other advantages such as flexible tuning of repetition rate and high reliability are also possible, enabling "an enormous impact for the progress of the precise microprocessing technology."

Materials and coatings

Crystalline Mirror Solutions has developed the XTAL MIR, a "crystalline supermirror" coating that is based on substrate-transferred, single-crystal semiconductor multilayers. This novel technology exhibits a number of advantageous properties, according to the company, including a 10× reduction in Brownian noise, the highest thermal conductivity (~30 $Wm^{-1}K^{-1}$ compared to <1 $Wm^{-1}K^{-1}$ for SiO_2/Ta_2O_5). This new technology targets ultralow-loss mid-IR optical coatings for the 3- to 5-µm wavelength range. The coatings are designed for high finesse optical cavities for power enhancement and signal recycling, enabling previously unachievable signal-to-noise ratios in the measurement of trace gases.

Element Six's Single Crystal Synthetic Diamond creates an engineered SC chemical vapor deposition (CVD) diamond. It is useful in attenuated total reflectance (ATR) accessories as compared to other IR materials because it has the widest transmission spectrum of any optical material, the company notes, from 220 nm to greater than 50 µm. Combine this with its extreme hardness and scratch-resistance properties, and the CVD optical-grade SC diamond is the most versatile ATR accessory.

The NIR QuantumFilm sensor, developed by **InVisage Technologies Inc.**, is a proprietary solution of quantum dots that senses light with near-IR, and allows cameras to achieve 35 percent quantum efficiency at the 940-nm wavelength with built-in global shutter. The new QuantumFilm eliminates the need for NIR sensors to operate at 850 nm, which produces an



obtrusive red glow and competes with ambient infrared in sunlight. IoT devices rely on active illumination for authentication, autonomy and augmented reality, and NIR QuantumFilm enables them to perform more accurately and safely.

Metrology

4D Technology Corp.'s 4D InSpec Surface Gauge reduces measurement time from over an hour to just a few seconds, enabling more accurate and thorough assessment of surface defects, as well as faster reporting and better traceability. The result is fewer missed critical defects and greatly reduced scrapping of expensive components, and safer products.

The 4D InSpec, designed for aerospace applications, has shown it can fundamentally change precision surface measurement by enabling direct inspection of components on the shop floor. According to the company, it is the only system that provides the speed, portability, resolution and affordability now required by manufacturing and field service inspectors.

Made for use by airline line technicians and mechanics in airline maintenance applications, **8tree**'s dentCHECK technology produces first-of-its-kind objective and consistent dent-inspection results. It has demonstrated reduced aircraft turnaround time, which, in turn, reduces lost revenues and improves operational efficiency for airlines. This enhances safety, as well, through an improved understanding of airframe reliability.

Existing methods for inspecting dents and corrosion are subjective, inconsistent and manual. The new dentCHECK overcomes these problems by consistently delivering a go/no-go answer, as opposed to just data, which satisfies the specified accuracy (+/−50 µm).

Leica Geosystems has developed the Leica BLK360 Imaging Laser Scanner, "a technological leapfrog and a picture of creative expression." It provides users a unique ability to capture the reality around them in a way that was previously impossible.

The new device touts faster tablets, virtual reality goggles, ubiquitous bandwidth, and awareness of laser scanning. It generates massive amounts of content, for use in applications such as reality capture for virtual retailing, space mapping, and stage calibration for films and the visual arts. The laser scanner provides a degree of miniaturization that has never been seen before, allowing users to spend more time analyzing data and less time performing scans. The technology ranges up to 60 m, which can be measured with a precision of a few millimeters.

Optics and optical components

The Opto-phone, from **ContinUse Biometrics**, is a unique photonic technology with the ability to sense nanovibrations of the body with very high precision. It is designed for biomedical remote sensing and can provide authentication based on the acoustic signature the heart is making.

The technology features a laser, fast camera and special lenses that are positioned to prompt the secondary speckle patterns generated after back-reflecting the laser beam from the inspected subject; this changes in time and space in a very predicted way that is associated with the movements and vibrations of the back-reflecting tissue. In addition to biomedical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applications, the Opto-phone could be used for smart homes as part of other such smart modules, including a smart mirror, television or smart cars.

NuBEAM Flat-Top fiber technology, developed by **Nufern**, offers simplified system integration, improved efficiency, reproducibility and reliability of performances, as well as a smaller footprint and less expensive execution. According to the company, the new flat-top fiber technology offers an all-fiber solution designed as a simple drop-in replacement, compared to existing beam shaping techniques that are based mainly on free-space systems or complex optical assemblies.

The new technology employs well-established advantages of optical fiber technology — easy integration, efficient light transmission, robustness over time, small footprint, low maintenance and cost-effectiveness.

SoraaLaser's LaserLight SMD is the world's first laser lighting package that utilizes a high-power blue laser diode to excite a very small spot (300 µm) on a remote phosphor target in reflection mode. Specifically, in addition to the blue laser diode, the system pumps phosphor to safely produce 500 lumens of high luminance output; this output can be collimated to <2 degree beam angle for 5 to 10× range compared to LEDs.

LaserLight SMD is based on the company's semi-polar GaN laser diodes, combined with advanced phosphor technology. These laser light sources combine the benefits of solid-state illumination, such as minimal power consumption and long lifetime, with the highly directional output that has been possible only with legacy technology.

Scientific lasers

The MatchBox2 Series of lasers will allow analytical instruments to become smaller and more affordable. Developed by **Integrated Optics**, the laser enhances point-of-care diagnostics, food safety and homeland security.

Lasers in the MatchBox2 series utilize diodes, VBG diodes, DPSS (CW and Q-switched), and dichroic combiner techniques. New to this series of lasers are single-frequency nanosecond lasers that are based on passive Q-switch to offer unmatched pulse-to-pulse stability. The company anticipates market expansion, and more accessible Raman and fluorescence spectroscopy.

The Mid-Infrared Supercontinuum Laser, developed by **Thorlabs Inc.**, is a compact MIR-SC laser designed to accelerate instrument development in the mid-IR market. It is the first such femtosecond fiber-laser pumped source on the market.

Trumpf Scientific Lasers has developed the Dira (disk regenerative amplifier) 200-1, the world's first laser system that combines high average power with high pulse energy at kHz repetition rates. The company notes that it solely eliminates the damage risk caused by lightning strikes, thereby increasing the safety of airplanes at departure and landing.

The new system uses, for the first time, the scaling capabilities of thin-disk technology to reach unrivaled ultrafast output parameters.

justine.murphy@photonics.com

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1 Inverted Microscope Platform

Carl Zeiss AG has announced the Axio Observer inverted microscope platform for life science research. The line consists of three stable and modular microscope stands for flexible and efficient imaging. Scientists benefit from reproducible results from their experiments and high-quality image data from a range of samples in a variety of conditions. The Axio Observer series has automation features that allow researchers to perform demanding multimodal imaging of living and fixed specimens. **info.microscopy.us@zeiss.com**

2 Fiber Laser System

The new-generation ultra-stable Koheras BOOSTIK lasers from **NKT Photonics A/S** combine low noise and high power to create a maintenance-free, single-frequency fiber laser system. The BOOSTIK lasers provide high free-running wavelength stability and large tuning range. They feature internal, fast wavelength modulation capabilities and a built-in wave-function generator, which are both controlled through a user-friendly graphical user interface, eliminating the need for a costly external piezo driver and ensuring the lowest possible noise. The system is available at any wavelength in the ranges of 1050 to 1090 nm and 1540 to 1570 nm, with up to 15 W of output power.
sales-us@nktphotonics.com

3 High-Speed Laser Sensors

The PowerMax-Pro USB/RD high-speed laser sensors from **Coherent Inc.** use a novel, thin-film technology for broad wavelength sensitivity, dynamic range and laser damage resistance of a thermopile. With the response speed of a semiconductor photodiode, PowerMax-Pro sensors are more than one million times faster than conventional thermopile sensors. This increase makes them an ideal solution for fast CW laser power and rise time measurements, full modulated laser characterization and pulsed laser energy measurements over the 300 nm to 11 µm spectral range.
tech.sales@coherent.com

4 Sub-nanosecond Laser

Onefive GmbH has announced the Katana HP laser, significantly reducing cost and complexity of a stimulated emission depletion (STED) microscope with respect to the use of stretched pulses from a mode-locked femtosecond laser. The laser has the capability to be extremely triggered, allowing the synchronization and temporal alignment of STED pulses to the excitation pulses with the use of an electronic picosecond delayer. It offers several wavelengths covering most commonly used fluorophores. It is available at high-power and sub-nanosecond pulse durations in green, yellow, orange, red and IR.
contactus@onefive.com

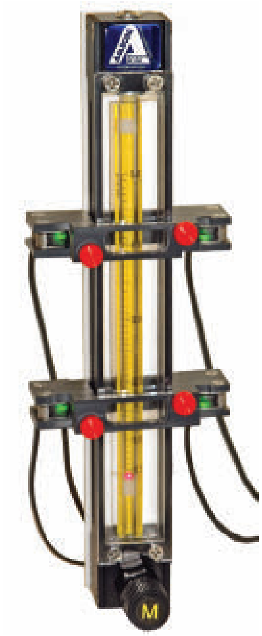
5 Polishing Powder

The Microlux Alumina Powders from **Meller Optics Inc.** are a line of high-purity calcined alumina polishing powders that can be mixed into slurries and applied to a spot block as parts are oscillated. The powders are ready to mix with deionized water and offered in two grades and seven particle sizes from 0.05 to 3.0 µms. Ideally suited for application directly to optics on spot blocks, they are capable of producing surface finishes to 10-5 scratch-dig on a wide range of hard and soft materials including zinc selenide, germanium and silicon.
sales@melleroptics.com

6 Measurement Sensors

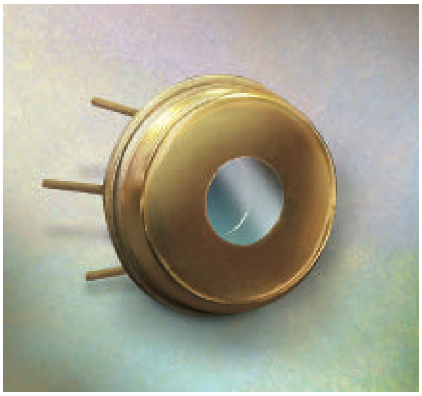
The F50A-BB-18 thermal power and energy laser measurement sensors from **Ophir-Spiricon LLC** are designed for continuous use at high laser powers. A compact, fan-cooled sensor with a wide dynamic range, the F50A-BB-18 has measuring powers from 10 mW to 50 W and energies from 6 mJ to 50 J. The sensor includes a spectrally flat broadband coating, usable from far UV to far IR. The F50A-BB-18 laser power/energy sensor is highly linear, providing precision readings of power stability over time with no drift. It has a fast response time of 0.8 s and low noise of 0.5 mW. The sensor features a 17.5-mm aperture and broad wavelength range of 0.19 to 20 µm.
sales@us.ophiropt.com

Request info about these products at **Photonics.com/rsps**



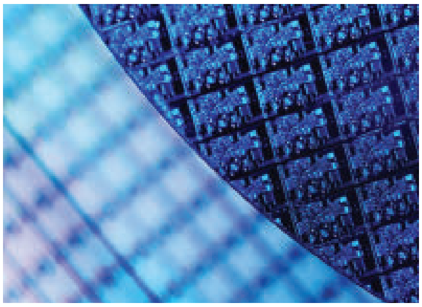
Optical Sensor Switches
Optical Sensor Switches from **Aalborg Instruments & Controls Inc.** noninvasively detect high- or low-flow rates that can damage equipment and processes. The devices are ideal for OEM applications and consist of a transmitter and receiver. They signal a cut-off valve, alarm or other device when the float passes above or below the desired setting. These versatile optical sensor switches can be used with the company's P, S and T rotameters. The Hi-Lo Switch contains two sets of enhanced, self-contained mini-slim photoelectric sensors located on two solid carriers. The Hi-Lo can also be used in conjunction with a control relay to power alternate equipment or monitoring devices.
info@aalborg.com

Dimming Receptacle
The ANSI C136.41-compliant dimming receptacle from **TE Connectivity Ltd.** allows the photo node to be pointed due north in order to optimize light capture in street, parking area or roadway lighting applications. The receptacle provides an electrical and mechanical interconnection between the photo control cell and the luminaire. It is available with two or four dimming contacts to support one or two channel-dimming protocols and provides a reliable power interconnect with three robust twist-lock contacts. Preterminated power leads simplify system integration, and design versatility is provided with the 105 and 150 °C-rated wire insulation. The new 76-mm diameter photo control base assembly and dome cover — also ANSI 136.41-compliant — incorporates an IP66-rated photo control enclosure, which helps to ensure protection from harsh conditions including rain, snow and salt spray.
www.TE.com



Extreme Ultraviolet Photodetectors
The SXUV20C from **Opto Diode Corp.** is a low-noise, extreme ultraviolet photodetector that features a large 20-sq-mm circular active area. The device has superior responsivity in the 1- to 200-nm wavelength region. It is specially designed to be stable over long periods of time when exposed to high-intensity extreme ultraviolet energy. The 20-sq-mm circular active area provides a

substantial surface for easy alignment to the laser. The SXUV20C offers superior hardness in extreme ultraviolet environments while providing lower noise than previous devices.
sales@optodiode.com



Motorized Stepper Stage

The H116 motorized stepper stage from **Prior Scientific Instruments Ltd.** can scan a wide range of semiconductor wafers, photo masks, flat panel displays and printed circuit boards. The device is suited for use with larger microscopes and can accommodate 8-in. wafers and a variety of large specimens. Offering a travel range of more than 255 × 216 mm, the large area scanning capability of the H116 stage has a minimum step size of 0.04 µm and a repeatability of +/−0.7 µm. The stage is manufactured using precision bearings, zero backlash recirculating ball screws, X and Y limit switches, two high-precision stepper motors and a scratch-resistant coating.
info@prior.com

First Surface Mirrors

Esco Optics Inc. has announced the addition of precision-quality, first-surface mirrors to its online catalog of stock optics. Manufactured from fused silica, the substrates benefit from the material's low coefficient of thermal expansion, providing a stable 0.10 wave surface figure and 40-20 scratch/dig over an 85 percent clear aperture. The second surface is ground and all edges are beveled. The front surface mirrors are available in both 1- and 2-in. diameters.
sales@escooptics.com

Test Solution

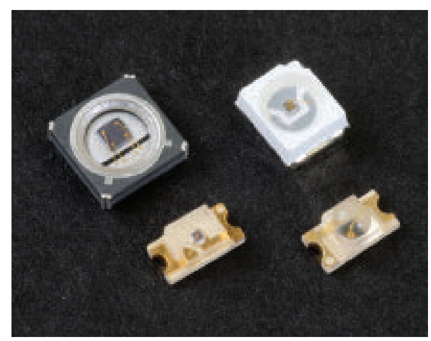
Anritsu Co. has announced the 56-Gbaud NRZ/PAM4 BER Test Solution that integrates the 64-Gbaud PAM4 DAC G0374A with the Signal Quality Analyzer MP1800A and 56G/64G DEMUX MP1862A. The G0374A is used with the 32-Gbps built-in Pulse Pattern Generator of the MP1800A to convert half-rate 32G NRZ signals and generate 64-Gbaud NRZ/PAM4 signals. Additionally, the 28/32-G Error Detector with high sensitivity of

25 mV built in to the MP1800A can be used with the 56/64-Gbps DEMUX MP1862A to generate wideband PAM4 signals up to 64 Gbaud to support highly accurate 400-GbE, 53.125-Gbaud BER measurements. The solution supports 53.125-Gbaud PAM4 transmission defined by the next-generation 400-GbE standard and was developed to address the need for scalable and flexible test solutions to verify next-generation communications devices, optical devices and optical transceiver modules during the R&D stage.
www.anritsu.com

Laser Stent and Tube Cutter

Amada Miyachi America Inc. has upgraded its Sigma Laser Stent and Tube Cutter, which can be configured with either microsecond fiber or femtosecond lasers. Featuring three or four axes of motion, wet and dry cutting, an automated tube

loader option and easy access to sub-assemblies, the updated system can cut stents and tubes with diameters from 0.2 to 25 mm. The operator-friendly control software features a 22-in. graphic user interface on a swing arm. The Sigma system has been designed for efficient production and practical operation. New features include an open architecture, work space access and a sliding door that provides quick access for part unloading and setup changes. In addition, all service components are now on drawers that can be easily accessed.
melissa.brackell@amadamiyachi.com



SWIR Emitter Packages

Through-hole and surface mount short-wavelength-infrared (SWIR) emitter packages from **Marktech Optoelectronics** feature wavelengths from 1050 to 1720 nm and operating currents ranging from 20 to 350 mA for high-power applications. The package offerings include TO-46 flat, TO-46 lens, TOPLED PLCC4, SMD 1206, SMD 1206 lens and SMD high-power black. The SWIR emitters complement Marktech's other emitter products, ranging from deep UV 280 to SWIR 1720 nm. SWIR can be used in biofluorescence and blood chemistry analysis in a medical setting, as well as night vision technology, security equipment, anti-counterfeiting currency validation, fiber optics and produce inspection systems, among other applications.
info@marktechopto.com

VCSEL Array

Princeton Optronics Inc. has announced a 250-W VCSEL array at 808 nm for hair removal. The array can be operated for a pulse duration of 25 to 100 mS. For hair removal applications, 12 to 24 arrays will be mounted on a submount and the output light will be focused down to a smaller area,

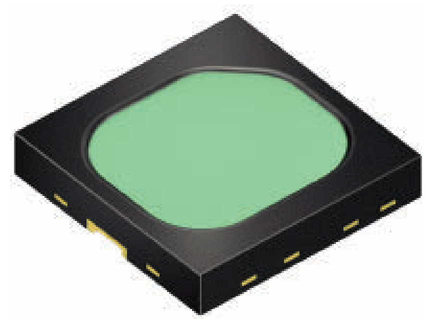
delivering a pulse energy between 20 to 100 J. Applications include hair removal and other aesthetic uses such as wrinkle and fat mitigation.
sales@princetonoptronics.com

Post Top LED Lamps

A line of Conical LED Post Top Lamps from **LEDtronics Inc.** are DLC-listed and come in base-up and base-down variations. The LED40B post top series has a conical-shaped LED layout, which targets light toward the desired location, eliminating light loss due to reflection and redirection. It greatly improves lighting efficiency and provides maximum luminance to the targeted area. The lamp was specifically designed for energy efficiency, consuming 55 W base up and 57 W base down, replacing older HID lamps up to 250 W. These conical LED post top lamps are fully functional and customizable. They are available in multiple color temperatures, such as warm white with 3000 K, natural white with 4000 K and pure white with 5000 K. Potential applications include post top lamps, driveways, parks and playgrounds, outdoor and covered parking areas, security lighting, pendant lighting, globe lighting and railroad station platforms.
info@ledtronics.com

Opto-Mechanical Positioners

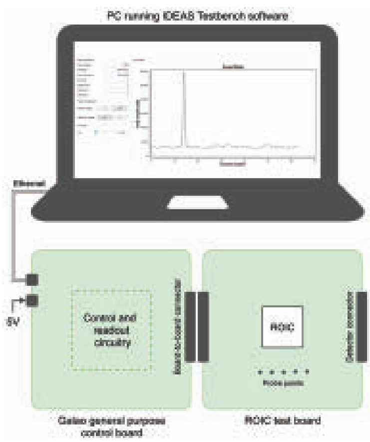
SMFCx, a new series of opto-mechanical positioners for coupling light into and out of fiber optics from **Siskiyou Corp.** offers ease of use, high precision and full six-axis adjustment in a compact package. SMFCx products accept fiber optics, physical contact, angled physical contact or subminiature A connectorized fibers. They utilize a precision aspheric lens to focus in a collimated laser beam or collimate fiber output. Near diffraction-limited focusing make SMFCx positioners useful with both single-mode and multimode fibers. The miniaturized translation stages and gimbal style mounts used in the SMFCx series deliver true, independent, orthogonal adjustment in all three linear dimensions, as well as tip/tilt angular adjustments. The fiber itself can be rotated to control orientation when utilizing polarization-preserving fibers. SMFCx products are compact and can be mounted directly to an optical table, mounting plate or laser cavity platform surface. Standard optics are available for laser wavelengths throughout the visible and NIR. The products are ideal for a wide range of laboratory and OEM uses in research, biotechnology, sensors and telecommunications applications.
sales@siskiyou.com



Food Analytics IR LED

The SFH 4735 broadband IR LED from **Osram Licht AG** is designed for everyday food analytics. The LED emits broadband IR light in a wavelength range from 650 to 1050 nm, opening up IR spectrometry for the consumer market. The device uses converter technology. The component is ideally suited as a light source for NIR spectroscopy that can be used for determining the quality

of food through smartphone add-ons, and other means.
www.osram-os.com



Readout IC

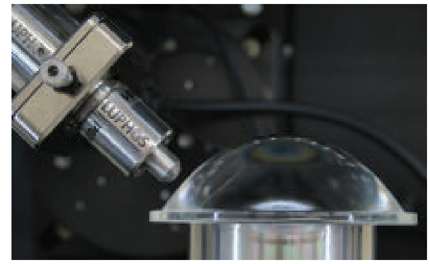
The IDE3380 general purpose integrated circuit from **Integrated Detector Electronics AS** is designed for the readout of silicon photomultipliers. The circuit covers a wide range of detector technologies and applications for space and terrestrial use, including high-resolution gamma-ray spectroscopy, detector front-end readout for diagnostic imaging in nuclear medicine, fast photon counting and timing. The circuit can also read out state-of-the-art photomultiplier tubes. Like photomultipliers, silicon photomultipliers and their arrays can be used for many applications such as medical imaging, life sciences, industrial scanning and rangefinding.
www.ideas.no

Micro-Tactical Cable

AFL's Micro-Tactical Fiber Optic Cable can withstand high tensile loads, severe crushing forces, repeated impact and extreme temperature. Designed for rapid deployment in networks that require high mechanical performance specifications, the military-grade cable features a fiber count of 96. The high fiber density allows for longer deployment lengths without sacrificing bandwidth. With longer assembly lengths, optical connections are reduced, thereby enhancing network performance.
sales@AFLglobal.com

3D Form Measurement Platform

Taylor Hobson Ltd. has announced the ultra-low-noise LuphoScan platform for 3D form measurement of high-quality optical surfaces. The new-generation instruments provide an industry first with instrument accuracy better than ±50 nm on sample slopes up to 90°. The LuphoScan HD takes



advantage of real-time temperature compensation, guaranteeing highly accurate, reproducible results. This ensures the stability and accuracy even under the most adverse environmental conditions such as manufacturing. The LuphoScan 260 HD is ideal for applications where the highest accuracy is required and essential for the manufacturing process. This is most beneficial for surfaces with steep slopes, varying pitch directions and small surfaces such as molds for smartphone lenses. The absolute measurement capability of MWLI sensor technology enables LuphoScan 260 HD instruments to inspect segmented lenses, annular lenses, asphero-diffractive lenses and axicons.
taylor-hobson.sales@ametek.com

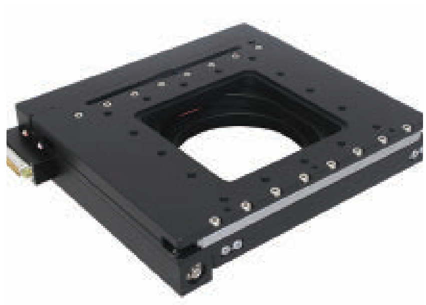
Fiber Chucks and Adapters

Fiber chucks and adapters from **Owis GmbH** are now part of the company's standard product range.

With a standard diameter of 6.35 mm, the chucks allow an easy and safe exchange of the fibers and support flexible working. The fiber adapters are available as SMA and FC, with or without mounting. All devices are compatible with various Owis beam handling systems.
www.owis.eu

Laser-Driven Light Source

Energetiq Technology Inc. has announced the fifth generation of its EQ-77 Laser-Driven Light Source. The EQ-77 offers higher radiance and irradiance than previous models from a truly broadband white light source. It features a compact lamp house with clean construction that ensures long life and ultimate stability. With a wavelength range from 170 nm in the deep ultraviolet to >2 µm in the NIR and a choice of dual-beam output or a single-beam output with retro-reflector, the EQ-77 is flexible for a broad variety of applications.
info@energetiq.com



Stage

The OE-1250 GEN II Stage from **Applied Scientific Instrumentation Inc.** is designed to be configurable and easily integrated into manufacturers' systems. The OE-1250 stage has custom mounting options, flat top design with multiple configurations, higher load capacity, precise motion and high repeatability. It provides controlled linear motion alignment, orthogonal movement and lower driving friction. All axes derive their precise control through the use of closed-loop direct current servomotors employing high-resolution rotary encoders for positioning feedback. By using closed-loop control of the stage position, there is no chance that the stage will become lost, as can occur with open-loop micro-stepped stages after a number of moves and direction changes. The OE-1250 XY stage utilizes crossed-roller slides, high-precision lead screws and zero-backlash miniature geared direct current servomotors for smooth and accurate motion. The microprocessor-controlled OE-1250 control unit provides for RS-232 and USB communication with a host computer.
www.asiimaging.com

JANUARY

● **A3 Business Forum (Jan. 18-20)** Lake Buena Vista, Fla. Contact AIA - Advancing Vision & Imaging, +1 734-994-6088; www.a3automate.org/events/a3-business-forum/.

● **BiOS (Jan. 28-29)** San Francisco. Colocated with SPIE Photonics West. Contact SPIE, +1 360-676-3290, customerservice@spie.org; www.spie.org/conferences-and-exhibitions/photonics-west/bios-expo.

● **SPIE Photonics West 2017 (Jan. 28-Feb. 2)** San Francisco. Contact Cathy DeVries, +1 360-676-3290, customerservice@spie.org; www.spie.org/SPIE-PHOTONICS-WEST-Exhibition.

Photons Plus Ultrasound: Imaging and Sensing - 2017 (Jan. 28-Feb. 2) San Francisco. Contact SPIE, +1 360- 676-3290; www.spie.org/pwb/conferencedetails/photons-plus-ultrasound.

FEBRUARY

MD&M West (Feb. 7-9) Anaheim, Calif. Medtech. Contact UBM, +1 310-445-4200, TSOperations@ubm.com; http://events.ubm.com/event/3242/mdm-west.

● **Advanced Manufacturing Expo & Conference (Feb. 7-9)** Anaheim, Calif. Contact UBM, +1 310-445-4200, tshowreg@ubm.com; www. anaheim.ubmcanon.com.

● **SPIE Medical Imaging (Feb. 11-16)** Orlando, Fla. Contact SPIE, +1 360-676-3290; www.spie.org/conferences-and-exhibitions/medical-imaging.

● **Biophysical Society 61st Annual Meeting (Feb. 11-15)** New Orleans. Contact Biophysical Society, +1 240- 290-5600, society@biophysics.org; www.biophysics.org/2017meeting.

● **IPC Apex Expo 2017 (Feb. 11-16)** San Diego. Contact IPC, +1 877-472-4724, registration@ipc.org; www.ipcapexexpo.org.

● **Laser Additive Manufacturing workshop (LAM) (Feb. 21-22)** Houston. Contact Laser Institute of America, +1 407-380-1553; www.lia.org/conferences/lam.

SPIE Advanced Lithography (Feb. 26-March 2) San Jose, Calif. Contact SPIE, +1 360-676-3290, customerservice@spie.org; www.spie.org/x10942.xml.

PHOTOPTICS 2017 (Feb. 27-March 1) Porto, Portugal. 5th International Conference on Photonics, Optics and Laser Technology. Contact-PHOTOPTICS Secretariat, +351 265-520-185, photoptics.secretariat@insticc.org; www.photoptics.org.

● **Photonics. World of Lasers and Optics 2017 (Feb. 28-March 3)** Moscow. Contact Ms. Margarita Semyakina, +7 499-795-29-06, ms@expocentr.ru; www.photonics-expo.ru.

PAPERS

European Conference on Biomedical Optics (ECBO) (June 25-29) Munich
Deadline: Abstracts due by Jan. 19
Submissions will be accepted on the following topics: clinical and preclinical optical diagnostics, diffuse optical spectroscopy and imaging, novel biophotonics techniques and applications, advances in microscopic imaging, opto-acoustic methods and applications, optical coherence imaging techniques and imaging in scattering media and medical laser applications and laser-tissue interactions. Contact Ellen Richter-Maierhofer, +49 899-49-2037, info@photonics-congress.com; www.osa.org/en-us/meetings/topical_meetings/european_conferences_on_biomedical_optics.

CLEO/Europe-EQEC 2017 (June 25-29) Munich
Deadline: Abstracts due by Jan. 19
A number of contributed papers covering original, unpublished work on the conference topics will be accepted for presentation. The online paper submission system is now open. Contact European Physical Society, cee2017@sciconf.org; www.cleoeurope.org.

CYTO 2017 (June 10-14) Boston
Deadline: Oral presentations, Jan. 19; poster and multimedia presentations, Feb. 16
Submission of abstracts is encouraged in all aspects of cytometry. To aid placement in the program, each submission should identify a topic category that is most relevant to the abstract. The review committee reserves the right to reclassify abstracts during the review process. Contact International Society for the Advancement of Cytometry (ISAC), +1 301-634-7017, info@cytoconference.org; cytoconference.org.

MARCH

● **Pittcon 2017 (March 5-9)** Chicago. The Pittsburgh Conference on Analytical and Applied Spectroscopy. Contact The Pittsburgh Conference, +1 412-825-3220, info@pittcon.org; www.pittcon.org.

● **AeroDef Manufacturing Conference and Exhibition (March 6-8)** Fort Worth, Texas. Contact SME, +1 866- 635-4692, service@sme.org; www.aerodefevent.com.

PIC International Conference (March 7-8) Brussels. The Photonics Integrated Circuits Conference is colocated with the Seventh CS International Conference focusing on the compound semiconductor industry. Contact Angel Business Communications, +44 0-2476-718-970, info@picinternational.net; www.picinternational.net.

● **LASER World of PHOTONICS CHINA (March 14-16)** Shanghai. Contact Katrin Hirl, +49 89-949-20324, katrin.hirl@messe-muenchen.de; www.world-of-photonics-china.com.

● **Image Sensors Europe 2017 (March 14-16)** London. Contact Smithers Apex, +44 1372-802000, info@smithersapex.com; www.image-sensors.com.

● **OFC 2017 (March 19-23)** Los Angeles. The Optical Fiber Communication Conference and Exhibition. Contact OSA, +1 202-416-1907, custserv@osa.org; www.ofcconference.org.

● **International Laser Safety Conference (ILSC) (March 20-23)** Atlanta. Contact Laser Institute of America, +1 407-380-1553; www.lia.org/conferences/ilsc.

● **SPIE Smart Structures NDE 2017 (March 25-29)** Portland, Ore. Contact SPIE, +1 360-676-3290, customerservice@spie.org; www.spie.org/x88673.xml.

APRIL

● **OSA Biophotonics Congress: Optics in the Life Sciences (April 2-5)** San Diego. Contact The Optical Society, +1 202-223-8130, info@osa.org; www.osa.org/en-us/meetings/osa_meetings/optics_in_the_life_sciences/.

● **AUTOMATE 2017 (April 3-6)** Chicago. A3 Association for Advancing Automation. Contact +1 734-994-6088, info@automateshow.com; www.automateshow.com.

● **WCX17: SAE World Congress Experience (Apr. 4-6)** Detroit. SAE World Congress and Exhibition is now WCX17: Sae World Congress Experience. Contact SAE International, +1 877-606-7323 (U.S. and Canada), +1 724-776-4970 (Outside U.S. and Canada), customerservice@sae.org; www.wcx17.org.

● **ASLMS 2017 (April 5-9)** San Diego. 37th Annual Conference of the American Society for Laser Medicine and Surgery. Contact ASLMS, +1 715-845-9283, information@aslms.org; www.aslms.org/annual-conference.

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

SPIE Defense + Commercial Sensing (April 9-13) Anaheim, Calif. Contact SPIE, +1 360-676-3290, customerservice@spie.org; www.spie.org/conferences-and-exhibitions/defense--commercial-sensing.

SPIE Technologies and Applications of Structured Light (April 18-21) Yokohama, Japan. Part of Optics & Photonics International Congress 2017. Contact SPIE, +1 360-676-3290, customerservice@spie.org; www.spie.org/conferences-and-exhibitions/structured-light.

SPIE Optics & Optoelectronics (Apr. 24-27) Prague. Contact SPIE, +1 360-676-3290 or +1 888-504-8171, customerservice@spie.org; spie.org/conferences-and-exhibitions/optics-and-optoelectronics.

MAY

Design & Manufacturing New England 2017 (May 3-4) Boston. Contact UBM Canon, +1 310-445-4200, UBMCanonConferences@ubm.com; design-manufacturing-new-england.designnews.com.

LIGHTFAIR International 2017 (May 7-11) Philadelphia. Contact LIGHTFAIR International, +1 877-437-4352, info@lightfair.com; www.lightfair.com/lightfair/V40/index.cvn?id=10000.

RAPID + TCT 2017 (May 8-11) Pittsburgh. Contact SME, +1 800-733-4763 (U.S. and Canada), +1 313-425-3000 (outside U.S. and Canada), service@sme.org; www.rapid3devent.com/.

Control Stuttgart (May 9-12) Stuttgart, Germany. Contact Messe Sinsheim GmbH, +49 726-16-890, info@messe-sinsheim.de; www.tradefairdates.com/Control-M129/Stuttgart.html.

CLEO 2017 (May 14-19) San Jose, Calif. Conference on Lasers and Electro-Optics. Contact The Optical Society, +1 202-416-1907, info@cleoconference.org; www.cleoconference.org/home.

EASTEC (May 16-18) West Springfield, Mass. Contact SME, +1 800-733-4763 (U.S. and Canada), +1 313-425-3000 (outside U.S. and Canada), service@sme.org; www.easteconline.com.

Display Week 2017 (May. 21-26) Los Angeles. Contact Society for Information Display, mhardcastle@mcapr.com; www.displayweek.org.

Bio-IT World Conference & Expo '17 (May 23-25) Boston. Co-located with Medical Informatics World Conference. Contact Cambridge Healthtech Institute, +1 781-972-5400, chi@healthtech.com; www.bio-itworldexpo.com/.

SENSOR + TEST 2017 (May 30-Jun. 1) Nuremberg, Germany. Contact AMA Service GmbH, +49 503-39-6390, info@sensorfairs.com; www.sensor-test.de/welcome-to-the-measurement-fair-sensor-test-2017.

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Lidar ensures smooth sailing on Dutch waterways

When you think of the canal systems in the Netherlands, chances are solar panels and lidar aren't the first things to come to mind. Instead, one might imagine picturesque scenes of waterways and beautifully distinctive architecture.

Canals have been — and remain today — an essential part of many Dutch city layouts. Originating in the 17th century, these manmade waterways led to significant economic growth. Today these channels continue to play a vital role in the country's economy, attracting tourists and enabling commerce. But their continued heavy use has posed a challenge for canal authorities: how to monitor shipping traffic in real time and automate the opening and closings of bridges.

The Dutch company Vicrea, known for creating integrated information systems, has teamed up with Libelium World to create a solution. The companies developed a customized wireless sensor network powered by solar panels that employs lasers to monitor the direction, distance and speed of any ship within the canals.

To monitor the shipping traffic, they used LIDAR-Lite v3 sensors. The 40-m, laser-based optical ranging sensor has an edge-emitting 905-nm, single stripe laser transmitter. The sensor can be placed anywhere depending on the needs of each canal, and detects any sea vessel that passes by.

Vicrea business consultant and architect, Erkan Efek, told Photonics Media this particular sensor was chosen for its portability.

"The lidar helped us to detect sailing boats and motorboats that do not use the Automatic Identification System," said Efek, explaining the tracking system that allows vessels to electronically exchange data with other ships. "The canals are relatively small with many bridges, so the lidar was ideal to use."

The shipping traffic data monitored by the sensors is then added to Libelium's Waspmote Sensor Internet of Things (IoT) platform and further distributed wirelessly for analysis and prediction.

Efek said, "The data is then sold to the provinces; they use it in the Blue Wave project which involves more organizations. The [Blue Wave project's] goal is to prevent traffic jams on the canals or roads when bridges open."

Thus far the Vicrea and Libelium World solution is deployed in Delft, The Hague, Leiden, Alphen aan den Rijn and Gouda. The companies are discussing the solution with other provinces and with the Ministry of Infrastructure, which controls all the waterways in the Netherlands, according to Efek.

High-density shipping traffic in some of the Netherland's most well-known and visited cities is monitored 24 hours a day, 7 days a week, ensuring smooth sailing from here on out.

Autum C. Pylant
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Vicrea

Zegerbrug Bridge, Alphen aan den Rijn, Netherlands.

Vicrea

A technician programming the installation on a bridge.