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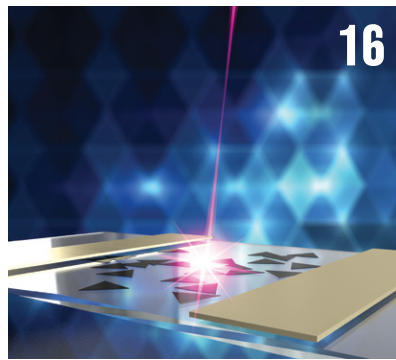
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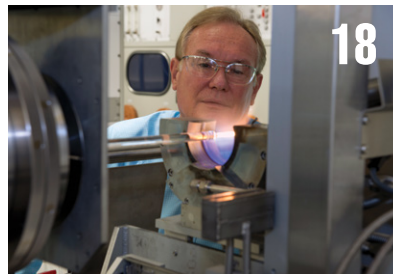
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Opening Lines

WE CAN ALL BE GRATEFUL THAT, upon debarking from the lunar lander, astronaut Neil Armstrong had prepared an ace opening line for the first audio transmission from the Moon to Earth: “That’s one small step for a man, one giant leap for mankind.” How much less impactful would that landmark technological achievement have been if Armstrong had said “You make it out of the hatch okay, Buzz? Watch your head, there.”

And yet, a quick survey of communication “firsts” suggests that Armstrong’s prescience and eloquence may have been the exception rather than the rule. During the first telephone call in 1876, Alexander Graham Bell somewhat (in)famously said to his assistant, “Mr. Watson, come here, I want to see you.”

The first email sent in 1971 by Ray Tomlinson was so unremarkable that not even he can remember what it said—his best guess is “Test123.”

The first Tweet, sent in 2006 by Twitter creator Jack Dorsey, said simply “inviting co-workers,” which doesn’t even have a clear intent, let alone opening and closing punctuation (though perhaps it was a foreshadow of the grammatical wasteland that Twitter would become). Was he inviting them to join Twitter (then Twttr)? Was he inviting them to a BBQ? Did he hit the Enter key too soon? We can only wonder.

What is clear is that these innovations in communication accomplished what they set out to do: they transmitted a message faster and/or farther than any previous communications platform could. And that goal has been the driver behind the communications industry for hundreds of years.

Today, 5G networks are only just becoming accessible to consumers, so most of us have yet to experience the expected peak data rates of 20 Gbps. Nonetheless, researchers and industry are already planning for 6G, which is expected to further increase data speeds. By how much, no one is yet sure.

An international program called Terabit Bidirectional Multi-user Optical Wireless System for 6G LiFi hopes to propel laser-based LiFi to an eye-watering terabit per second by 2024. The Innovative Optical and Wireless Network Global Forum is planning for a communications infrastructure that uses 1/100th the power to achieve 125 times the data transmission capabilities in 1/200th of the current latency achievable today. And while industry looks forward to new opportunities from ubiquitous LiFi connectivity, researchers are looking farther down the electromagnetic spectrum at the terahertz band as a key player in the next generation of optical communications.

As optical communications announce new “firsts” in the coming decade, we can only hope for more great soundbites like Armstrong’s, and fewer like Dorsey’s. Not that it really matters: so long as the message comes across faster, farther, and clearer than ever before.



GWEN WEERTS, PHOTONICS FOCUS MANAGING EDITOR



Dancing with Unicorns: Putting ambitions to work

Alaina G. Levine speaking
at the NIEHS Biomedical
Career Symposium in 2014

WHEN ALAINA G. LEVINE was an undergrad studying mathematics at University of Arizona, she imagined a bright future for herself as a theoretical mathematician. This dream included days spent scribbling topological formulae that would describe the properties of doughnuts and coffee cups—since that’s precisely what she and fellow students were doing in topology class. The future, says Levine, was a heavenly vision of wood-paneled offices among ivy-clad campuses where she, a self-described nerd, would think big thoughts with fellow nerds.

Of course, this wasn’t her only career option. Levine had majored in mathematics—the language of the universe—so surely a wide variety of more-than-decent opportunities lay ahead.

But, as Levine puts it, “something funny happened on the way to the quasar.”

When she asked her academic advisor what he thought her career options might be, instead of regaling her with tales of the myriad enchanting jobs she could choose from where she would be valued

for her unique perspectives, his reply was—aside from research, teaching, or actuarial studies, pretty much zilch.

Conversations like this, of course, can either crush your soul or send you in a more creative direction. Levine decided to be creative and go hunting for her own personal career unicorn.

Levine, who today earns a more-than-decent living guiding others through their own professional development—and is much more supportive of others than that long-ago academic adviser—has coined the phrase “unicorn career.” This, she says, “is a kind of career that you define, craft, and land for yourself, based on your own specifications and interests related to your career goals: what tasks you enjoy and what problems you derive intellectual pleasure from solving, balanced with your values and personal priorities.”

This could be a career in a traditional structure such as a corporation, university, or a nonprofit, or it could be something that you create for yourself, built with entrepreneurial spirit and

flair. This doesn’t necessarily mean that you have to become an entrepreneur and start your own business, but that you should look for opportunities to solve problems that are of interest to you.

“If you look for opportunities to add value or fill gaps in systems or alleviate pain points or knock down walls that are impeding innovation, you will be providing something of use and value to another party or an organization,” says Levine. “This allows you to create a career unique to yourself.”

In creating her own career, Levine looked at what she had enjoyed doing throughout her life and developed a checklist:

- ✓ She had degrees in math and anthropology – STEM (check!)
- ✓ She loved to write and tell stories – communications (check!)
- ✓ She had been on the stage in local theater since the age of five – performance (check!)
- ✓ She was a top magazine-subscription salesperson in her high-school choir – business (check!)



“ I TRULY BELIEVE THAT WE ALL HAVE
THE ABILITY, THE POSSIBILITY,
AND EVEN THE PROBABILITY
OF CREATING OUR OWN UNICORN CAREER.”



Drawing from these experiences and interests, Levine realized that what she really wanted to do was to communicate to the public why STEM is so wonderful and to help those who enter STEM careers understand their value in the employment marketplace. Over time, Levine has built a career as a professional speaker, STEM career consultant, corporate comedian, event planner, and science writer. She's also the author of *Networking for Nerds* (Wiley, 2015), and "Your Unicorn Career," a column in *Science* magazine.

This type of career creation isn't unique just to Levine. She points to examples such as Merritt Moore, "the quantum ballerina." A physicist and professional dancer, Moore combines her interests to research and explore the connections between choreography, dance, artificial intelligence, and machine learning. Like Levine, Moore rejects the idea that people with passions in a variety of fields have to choose just one.

Another example is the electrical engineer who wound up working with Cirque de Soleil, designing the computer programs that move the busy sets around. He always had a great interest in electrical and computer engineering and technical theater, and was able to combine these interests into his own personal unicorn career.

"I truly believe that we all have the ability, the possibility, and even the probability of creating our own unicorn

career," says Levine. "We just need to know what our value is, the value of what we can provide to an organization, a community, an ecosystem—and how to articulate that value to them."

This approach does require understanding the marketplace so that you can find the right people to engage and develop fruitful collaborations with: someone, that is, interested in investing in the value you can provide. This involves a lot of intrinsic data collection, where you seek to understand your own skills, abilities, priorities, and values, as well as extrinsic data collection through networking and researching the industries, communities, and ecosystems in which you want to operate and where you will thrive."

And ultimately, Levine adds, part of thinking about a unicorn career really entails thinking above the horizon and outside of the box. In other words, the career or job that you want may not absolutely exist yet. You may have to create it yourself.

ALAINA G. LEVINE presented "How To Be Persistent and Handle Rejection" (spie.org/Levine) as part of the *SPIE Online career development series*. She can also be reached on Twitter @AlainaGLEvine and LinkedIn.

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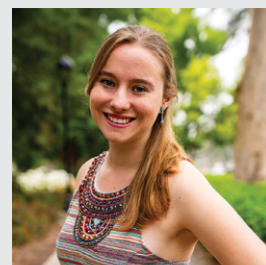
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—**EliseAnne Koskelo**,
Pomona College (USA)

2018 recipient of the SPIE
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Volunteering: Nothing to lose, much to gain

STUDENTS AND RECENT GRADUATES often find themselves caught up in the catch-22 cycle of “I can’t get a job because I don’t have experience; I can’t get experience because I don’t have a job.” Experience has long been the best teacher, and volunteering is a great way to broaden and diversify your experiences and develop important skills. Volunteer work also looks great on a resumé as it shows a prospective employer that you’re committed to your community and you have skills, connections—and, yes, hands-on experience—that will be valuable in the workplace.

Many people who are already busy with jobs and personal lives make time to volunteer. When they are energized by that experience, it drives them to keep up that good work.

While wearing many hats on two different continents, David Sampson, Pro-Vice-Chancellor of Research and Innovation at the University of Surrey and head of the Optical and Biomedical Engineering Laboratory at University of Western Australia, finds time to “do a bit of everything” as a volunteer, including organizing public science-related events and working with science fairs. “Volunteering is about building community and about giving back,” says Sampson. “It creates opportunities—for you and for others. It builds skills, networks, and experience. It is part of a well-rounded professional—and it is rewarding to make a difference.”

Volunteering also adds versatility: Through volunteer work, you can build and improve not only hard skills such as computing or writing, but also soft skills such as communicating with colleagues, working on a team, or organizing projects—all of which will prove useful as you advance in your career.

Jennifer Barton, professor of biomedical engineering, electrical and computer engineering, optical sciences, and agriculture and biosystems engineering at University of Arizona (UA), notes the eye-opening experience of volunteering with the Engineering, Science, and Technology Policy Committee

(ESTeP) at SPIE. “I’ve come to realize how much US and international government policy positions affect my day-to-day activities as a faculty member and leader of a research institute.”

Along with her many professor hats, Barton is also director of the BIO5 Institute at UA, which works with researchers from several scientific disciplines to develop solutions for issues such as treating disease, feeding humanity, and preserving livable environments. “BIO5 does a ton of outreach,” says Barton, “including a huge ‘Science City’ fair in the spring, and a high school internship program in the summer. I love the energy and enthusiasm of our future engineers and scientists.”

According to her, there’s great satisfaction in stepping out of your comfort zone and volunteering for a committee with a professional society “through which you can extend your skills and learn something new.”

Volunteering for various committees outside of or within your current organization allows you to try your hand at new skills and challenges. As you work through these situations, you will also be creating opportunities to learn more about yourself. Are you an introvert who wishes to be more of an extrovert? Are you an extrovert who needs to learn to listen more? Do you enjoy hands-on work or prefer coordinating and delegating work? What projects make you feel particularly inspired and fulfilled?

Through volunteering, Matt Posner, a process scientist at Excelitas Technologies, says he has met people who have given him the opportunity to work on exciting collaborative projects that have led to career growth and progress in his own work. “It’s been a long path from my first attendance at an SPIE Student Chapter meeting to chairing a governance committee that helps define programs for students and early career professionals,” says Posner. He describes these platforms as “great places to start and develop my online and in-person

Tom Scheffelin got started volunteering with Scouts through the FIRST LEGO League Challenge, which teaches kids ages 9-16 to program robots

involvement.” His advice to would-be volunteers is “be present, listen, be curious, and be prepared to help.”

As any job-hunting or career-building website will tell you, there are three important things to keep in mind: networking, networking, and networking. Volunteering gives you the chance to expand your network and make new contacts. These contacts may later serve as references or lead you to bigger and better opportunities—and, of course, you may be able to help them someday. Working within a network will also raise your awareness of current trends, issues, and resources in your community, which will give you insight as to how you might be able to help.

Tom Scheffelin, an engineer at California Air Resources Board, has long been involved in STEM activities with Scouts BSA. While attending a national meeting of the Society of Manufacturing Engineers (SME), Scheffelin, chair of the SME central western region, met the superintendent of a local school district in the hotel elevator. Since they were both wearing conference badges, they struck up a conversation.

“I mentioned I was looking for STEM ideas for elementary and middle-school students and he told me about First LEGO League, a recently created robotic contest for children aged 9-16,” says Scheffelin. “So, my SME region provided LEGO robot kits for four local elementary and middle schools.” This work inspired further volunteerism when local scouts working toward Eagle Scout volunteered to build First LEGO League playing fields for the four schools.

When it comes to volunteering, Scheffelin suggests “starting small, with something you are passionate and knowledgeable about. Younger students in classrooms will love it! The rest will follow.”

Volunteering not only expands your network but can also help you find a mentor who can guide and encourage you in your profession. As you gain more experience, you may find yourself eventually mentoring others.

Anne-Sophie Poulin-Girard, a research associate at Université Laval (UL), began her volunteering-in-STEM career as an undergraduate student when she worked with the SPIE Optics Outreach Games.

That activity inspired Poulin-Girard to help organize the annual engineering challenge at UL called Coupe de Science. In addition, she’s been a judge at Expo-Science (Québec’s official science fair), and has volunteered with Les Filles et les Sciences (Girls and Science), an annual event aimed at introducing girls from ages 14 to 16 to science and technology.

“What I am proudest of,” says the very busy Poulin-Girard, “is the young people in my community who took over from me and my colleagues after we graduated. They are enthusiastic, creative, and hard working. They provide continuity to projects and create their own. I see them becoming young professionals and supporting each other through their involvement and it is wonderful to witness.”

To those considering volunteering, Poulin-Girard says, “Just try it! As scientists and engineers, aren’t we trained to explore paths that can expand our horizons? And there is nothing to lose—except for maybe a little bit of your time—and so much to gain in the long term.”

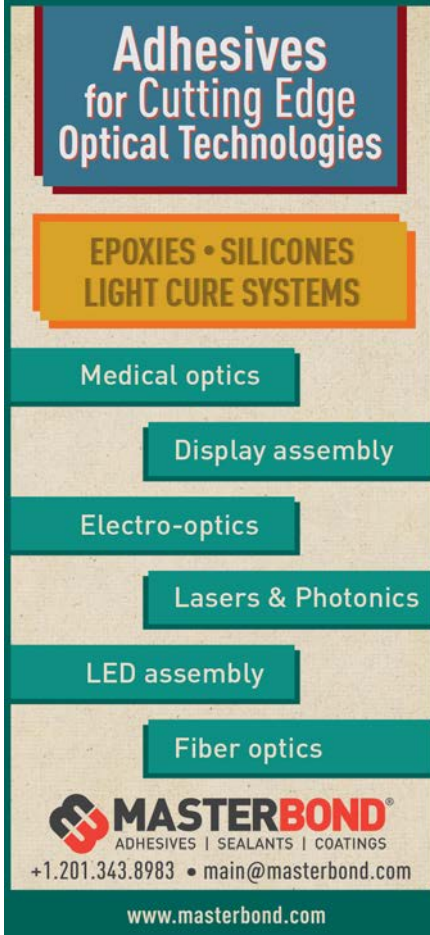
KAREN THOMAS is the *Bandwidth* editor for Photonics Focus.



VOLUNTEER

If you're interested in expanding your experiences through volunteering, check out these resources:

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(volunteermatch.org)
- Idealist.org**
(idealist.org)
- All For Good.org**
(allforgood.org)
- SPIE**
(spie.org/volunteer)



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Data Communications for Industry 4.0 and Beyond

A new global forum responds

SHOUTS AND MURMURS about the 4th Industrial Revolution (4IR) have been increasing in number and volume since the similarly titled 2016 Davos summit, “Mastering the Fourth Industrial Revolution.” For the unfamiliar, 4IR—according to Klaus Schwab, founder of the World Economic Forum—will lead to a fusion of physical, digital, and our biological selves.

Founded on a philosophical belief that the problems we face today are too big for any one country, government, or business to resolve, 4IR, or Industry 4.0, will—in theory—be smart, global, collaborative, inclusive, ambient, and actively seek ways to incentivize sustainability over consumption. It proposes, for example, that leadership collaborates on challenges such as CO₂ reduction, biodiversity, and plastics management, and work to resolve them with smarter technologies.

In a 2019 talk in Chicago, Schwab made a salient point: governments are often too distracted by crisis management to properly understand and direct the full force of the accelerating digital transformation. Therefore, corporations, medical organizations, manufacturing industries, agriculture, private businesses, and others have moved ahead with innovations that are smart, networked, and that increasingly utilize artificial intelligence. Japan has gone one step further and announced its plan to realize “Society 5.0,” which blends Internet of Things (IoT) into the fabric of daily human life.

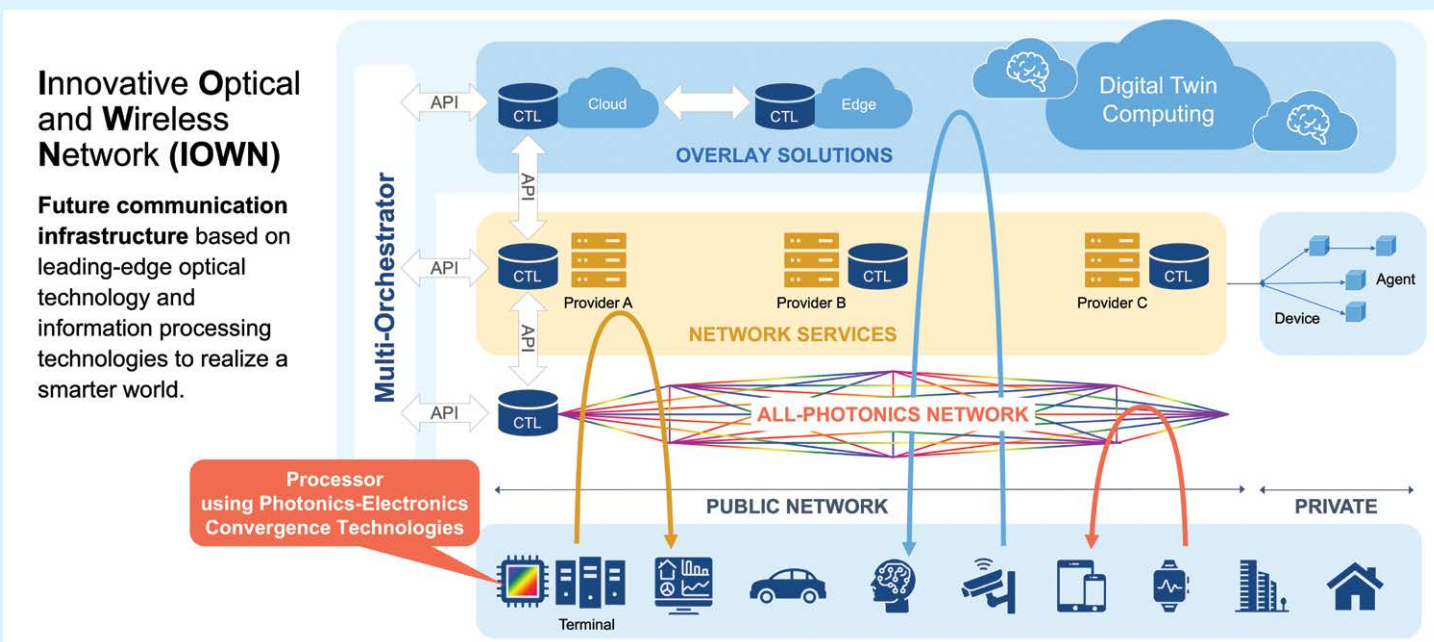
Data is the lifeblood of smart environments. Therefore, there is a common and pressing need for communications infrastructures that can process the unprecedented amount of data that will be generated. These infrastructures must be ultra-reliable, affordable, fast, and clean. This is where a new global collaborative, the Innovative Optical and Wireless Network Global Forum (IOWN GF), offers a value proposition.

...

“Advanced and emerging economies alike stand to gain if they can leverage new technologies to optimize processes and production, reduce transaction costs, and upgrade their supply chains. But progress will be hampered if they cannot overcome structural issues related to the generation, storage, processing, and transfer of data.”

- World Economic Forum

...



Founded in January 2020 by Intel, NTT, and SONY, the IOWN GF was visualized and established as a global collaborative standards body seeking to align with United Nations' sustainability goals. Its mission is clear: to define the parameters of an all-photonics network of technologies that uses silicon photonics, edge computing, dynamic computing scaling, and wireless distributed computing in a new type of networked infrastructure.

The organization began with a conversation between NTT Holdings CEO Jun Sawada and key leaders of Sony and Intel, around their interest in leveraging cutting-edge technologies in photonics and wireless. According to Katsuhiko Kawazoe, president and chairperson of the IOWN GF, their objective was "to look at ways in which the three companies could collaborate and harness the creativity inherent in the industry and develop next-generation communication and computing technologies, solutions, and IT infrastructure."

The companies agreed that a substantial industry investment would be necessary to improve access, connectivity, latency, service provisioning, point-to-point heterogeneous computing, and power efficiency. These discussions seeded the formation of the organization.



BECAUSE SMART ENVIRONMENTS are data-centric environments, they must support the gathering, sending, receiving, and analysis of data. Increased power consumption, which is a natural result of the hardware and processing required for IoT/AI, represents a significant challenge.

Imagine, for example, the hardware needed for a smart factory or city: hundreds of cameras will continuously capture images and send them to central servers and AI systems for analysis. It is estimated that capturing, transferring, and analyzing data from a camera requires about 10 to 15 W, equal to the power required by a traditional light bulb. Just as traditional power-hungry light bulbs are being replaced by efficient LEDs, surveillance cameras must realize similar efficiencies to be viable.

As defined by IOWN GF, its goals for an ultra-efficient infrastructure include using 1/100th the power to achieve 125 times the data transmission capabilities in 1/200th of the current latency achievable today.

Increasing power efficiency by orders of magnitude is just one challenge to solve; another is designing sensors "beyond humans." Today's digital technologies are optimized for human cognitive systems: video motion is optimized for human viewing at 30 frames per second (fps); sensors are designed to respond to human motions and sounds; cars are designed around human skills and response times.

But as AI capabilities and photonic technologies advance, key performance requirements of next-gen networking will not be constrained by the limits of human cognition—particularly audio-visual perception and response time—and it will move beyond them.

Machine sensing and control in factory processes will require visual recognition at 120 fps. Autonomous vehicle response times will be <10 milliseconds, much faster than a human's, which is about 0.1 second. Image sensors will detect wavelengths beyond visible light.

Additionally, next-gen technologies will enable vast amounts of environmental data to be collected. Advanced sensors and feedback devices will be touchpoints with the real world, and the information retrieved from them will be analyzed via distributed computing networks and used to forecast possible futures. Using feedback from future prediction, it is theoretically possible to improve outcomes. For example, action plans on wildlife, land, and water resources can be altered based on feedback from estimated futures. Digital twins will simulate multiple options before one is chosen.

In the near future, the IOWN GF will study use cases such as smart finance, mobility, cities, and entertainment. It will also be devising architectures, protocols, and interfaces based on optical and wireless networking, distributed computing, photonics, and optoelectronics.

At its first all-member meeting in September, IOWN GF announced membership had tripled since January, now up to 30 international companies. The roster includes, among others, Ciena, Fujitsu, Red Hat, Microsoft, Deloitte, and Toyota.

SUSAN PETRIE *is a science writer with an MFA in poetry from Bennington College.*

Like every new technology, Industry 4.0 comes with its own lexicon.

Ambient computing

A system of computing that deepens technology's involvement in our daily lives with motion tracking, speech recognition, gestures, wearables, and artificial intelligence in order to seamlessly and invisibly blend computing into our personal environments.

Digital twins

Leverages AI to build a model of a person, place, or thing that exists physically.

Digital twin computing

A new computing paradigm that will enable large-scale, high-precision, real-world reproductions of objects, including human characteristics and biologies. This model allows analysis of data and monitoring of systems to head off problems before they occur, prevent downtime, and plan for the future by using simulations.

Distributed computing

A system for data transfer, storage, and processing that consists of multiple software components on multiple computers but run as a single system.

Edge computing

A distributed computing framework that brings enterprise applications closer to data sources such as IoT devices or local edge servers.

Heterogenous computing

A computer network that combines one or more different computers or protocols.

Communications Industry in the Time of COVID

IN 2020 WE EXPERIENCED A WORLDWIDE PANDEMIC that will have many lasting effects long after it is controlled. Through all of this, communications equipment sales have had ups and downs, along with the laser components that power a lot of communications equipment.

My company, Laser Markets Research, tracks laser shipments and revenue for all applications worldwide, with lasers for communications being the largest of the 12 segments I track. Revenue in this segment is generally consistent, with a compound average growth rate (CAGR) of 6.9% since 2010, and for the next five years, I forecast communications laser revenue will grow at just under 10%.

To better understand what is driving this growth, and how COVID-19 might change things, we have to look back a bit to see how we got to this point. Just 30 years ago, the World Wide Web went live to the world. With the internet in place, a need arose for giant data centers, followed by a cellular network that kept people connected while on-the-move.

Back in 2002, when the 3rd Generation (3G) cellular network was introduced, cell towers could be spaced 22 miles apart, and copper-based backhaul using T1/E1 protocols was the norm to connect these cell towers to the core mobile network. 21 Mbps of backhaul per cell tower was typical. Remember those 3G download speeds of 1.5–3.0 Mbps?

Today, 5th generation (5G) cellular systems are being rolled out worldwide, and these networks are expected to supply 250–500 Mbps data speeds to a growing userbase. But how do these superfast speeds happen? By densely packing many smaller cell sites in high-usage areas. For this to work, you need many more cell towers, and each one needs much faster backhaul. To put this in perspective, compared to 3G infrastructure, 5G infrastructure can require ten times the number of cellular base stations to cover the same area, with the backhaul to each needing to be ten times as fast. While some backhaul is wireless, in the US over 70% of cellular backhaul is fiber.

The development of these wireless networks is driving the communications transceiver revenue worldwide, and thus associated laser revenue. Over the last 10 years, wired telecommunications revenue growth has been roughly 3.5% per year, whereas wireless telecommunications revenue growth has been about 12% per year. That makes it pretty clear where service providers will focus their efforts.

Lasers for communications (mostly for transceivers) saw growth up through 2018, with cellular and new data centers driving much of it. In 2019, the Chinese economy slowed, and demand for data centers softened. Innolight, the largest transceiver manufacturer in China, was especially hard hit. US-based suppliers of high-speed ethernet transceivers were also impacted by weaker demand. In Q4 of 2019, the US government imposed a 15% import tariff on optical transceivers made in China just as China's economy was starting to recover. (In January 2020, the tariff on transceivers was reduced to 7.5%.) In general, the tariffs didn't have much of an impact on revenues, but slow economies, especially in China, kept overall laser transceiver revenue flat for 2019. Although, laser pump revenue for optical amplifiers did increase.

In late 2019, the world witnessed the beginnings of a global pandemic. In China, the pandemic caused temporary business closures generally in Q1 2020, and this negatively impacted Q1 revenues. In the US and Europe, the first set of temporary closures hit hardest in Q2 2020, greatly impacting revenue for that quarter, and many of these workers switched to working from home. According to a study done by Stanford University, 42% of the US labor force is now working from home full-time, more than double what it was before COVID-19. Interestingly, most businesses report that their workers are more productive working at home as well.

The shift from workers being in an office to workers spending their working day at home will ultimately pro-

COMPARED TO

3G INFRASTRUCTURE, 5G INFRASTRUCTURE

CAN REQUIRE TEN TIMES
THE NUMBER OF CELLULAR BASE STATIONS
TO COVER THE SAME AREA,
WITH THE BACKHAUL TO EACH NEEDING TO BE
TEN TIMES AS FAST.

vide some boost to communications laser revenue. These home users will require faster internet speeds in their homes (especially if their businesses will reimburse them for it), and the transition to cloud computing is expected to accelerate as well. It also seems likely that this shift to remote work will stick around long after COVID-19. Many transceiver manufacturers have acknowledged this trend, and are optimistic that they will see a bump in revenues in the months and years ahead.

Things were looking up for the market until September 2020, when the second wave of lockdowns started around the world. Equipment manufacturers were still optimistic, but service providers couldn't get out to install new equipment with a virus still raging. If equipment can't be installed, equipment purchases will be delayed.

Still, with six weeks left in 2020 at the time of writing, we are optimistic for laser communications revenue for 2020 as a whole. In the first three quarters of 2020 compared with the same three quarters in 2019, laser revenue for communications equipment was up almost 13%, despite the fact that manufacturers have been selling much less equipment to Huawei lately due US sanctions. If pandemic closures ease in 2021, as everyone hopes, it could be an even stronger year than 2020. If there is any bright side to the COVID-19 pandemic, it's that many of the changes to work and communications spurred by the pandemic will ultimately bring better and more varied communications infrastructure, and thus increase demand for communications equipment as well as lasers for communications.

ALLEN NOGEE is president and founder of Laser Markets Research. He will provide a full update on global laser markets at the Lasers & Photonics Marketplace Seminar. bit.ly/LaserMarket

Industry Updates

M&A

- » **Quality Thin Films, Inc.** was acquired by **Edmund Optics Inc.** for an undisclosed amount effective November 12, 2020.
- » **Coherent, Inc.** to acquire **Electro-Optics Technology, Inc.** for an undisclosed amount. Closing date TBA.
- » **Raytheon Technologies Corp.** to acquire **Blue Canyon Technologies Inc.** for an undisclosed amount. The transaction is expected to close in early 2021. **Blue Canyon** will be merged into **Raytheon Intelligence & Space**, headquartered in Arlington, VA.
- » **Rocky Research** acquired by **Honeywell International Inc.** for an undisclosed amount effective October 7, 2020.
- » **Ascatron AB** and **INNOVION Corp.** acquired by **II-VI Inc.** for an undisclosed amount effective October 6, 2020.
- » **Applied Thin-Film Products** acquired by **Vishay Intertechnology, Inc.** for \$26.5M effective October 1, 2020.
- » **Chinook Therapeutics, Inc.** has merged with **Aduro Biotech, Inc.** effective October 6, 2020. The combined company is called **Chinook Therapeutics, Inc.**
- » **Geodetics, Inc.** acquired by **AEVEX Aerospace** for an undisclosed amount effective October 5, 2020.
- » **Alluxa, Inc.** acquired by **EnPro Industries, Inc.** for \$255M effective October 27, 2020.
- » **Advanced Micro Devices, Inc.** to acquire **Xilinx, Inc.** for \$35B. The transaction is expected to close by the end of 2021.

Executive Updates

- » **Robert Strain** will retire as president of **Ball Aerospace Corp.** on January 1, 2021. He will be succeeded by current **COO David Kaufman**.
- » **Geoffrey Martha** appointed CEO of **Medtronic, Inc.** effective April 2020 upon the retirement of **Omar Ishrak**, who remained with the company as Chairman. Ishrak will retire from his Chairman role effective December 11, 2020.
- » **Charles Treadway** appointed CEO of **CommScope, Inc.** effective October 1, 2020.
- » **Blair LaCorte** appointed CEO of **AEye, Inc.** effective October 20, 2020. AEye's founder, **Luis Dussan** will assume the role of President and CTO.
- » **Kun-Hee Lee**, Chairman of **SAMSUNG Group**, passed away October 25, 2020 at the age of 78.
- » **Jim Winkel** to retire as President of **Aviation Specialties Unlimited, Inc.** effective December 31, 2020.
- » **Eric Ashleman** appointed CEO of **IDEX Corp.** effective December 15, 2020. He succeeds **Andrew Silvernail** who is stepping down as CEO and a member of the Board of Directors.
- » **Amar Maletira** resigned as CFO of **Viavi Solutions Inc.** to become President and CFO of **Rackspace Technology** effective November 20, 2020. **Pam Avent**, Viavi's current Global Controller, will serve as interim CFO.

Competing for Space

Companies race to manufacture optical fiber in the microgravity environment of low-Earth orbit

IN 2016, MADE IN SPACE ANNOUNCED A PARTNERSHIP with ThorLabs to manufacture optical fiber in low-Earth orbit (LEO) aboard the International Space Station (ISS). While many people could have seen it as a gimmick, if successful, it could represent a possible goldmine, and one with multiple prospectors. At this moment, there are three companies—Made in Space, Physical Optics Corporation (POC) and Fiber Optics Manufacturing in Space (FOMS)—with fiber draw towers on ISS, and in 2020, two more—DSTAR and Apsidal—saw their proposals for in-space optical fiber production selected by NASA. They all have plans to make a commercially viable product. In space.

Whereas the bulk of optical fiber that currently powers our connected world is made from silica, these companies are all investigating the production of ZBLAN fiber. ZBLAN is a fluorinated optical fiber composed of zirconium, barium, lanthanum, aluminum, and sodium. With a broader spectrum that can offer 10 to 100× signal loss reduction as compared to silica fiber, mass-produced ZBLAN would be a boon for communications. However, production of ZBLAN on Earth, under the influence of pesky gravity, results in imperfections in the crystal lattice of the fiber that cause significant transmission losses. Work by NASA in the 1990s indicated that manufacturing ZBLAN in microgravity could eliminate those imperfections and unlock its commercial potential for use in medical devices, high-power lasers, and ultrafast data transmission.

Which brings us back to the ISS. Over any six-month period, the ISS has up to 250 science experiments taking place on board, ranging from 3D-printed human tissue to growing lettuce. Those experiments are confined within gloveboxes (closer in visual to a NICU incubator than a vehicle's glovebox) or microwave-sized modules known as lockers that are mainly autonomous in nature. Several of those lockers and gloveboxes

currently aboard the ISS contain fiber draw towers specially designed by POC, FOMS, and Made in Space.

These companies have spent the past few years iterating on and perfecting their draw towers. Howard Warner III, VP and general manager of integrated systems at POC, says that they're currently on the design and development phase of their third fiber optic production machine, which, having already proven the ability to manufacture high-quality fiber in microgravity, is now focused on increased automation. They ultimately need a production line in LEO that requires minimal human interaction. Their goal is to be able to produce tens or even hundreds of kilometers per month.

"As we look ahead, I think from a fiber optic perspective, we're looking at a five-year timeline before full-rate production. We're looking at 2025, and we'll use that time to work on defining the marketplace and supply chains," says Warner.

The marketplace seems to be interested. Both POC and FOMS have bootstrapped with Small Business Innovation Research R&D awards from the US Air Force (POC) and NASA (FOMS). Made in Space, on the other hand, raised all of their funding privately, and their early partnership with ThorLabs gives them a leg up on distribution, if they're able to make the numbers crunch.

And that's, perhaps, one of the most remarkable things about this idea to manufacture optical fiber in LEO. It could be commercially viable.

Dmitry Starodubov, the principal investigator for FOMS, shared his math during the 2020 ISSR&D Meeting: "The specialty optical fibers have been priced at \$100-200 USD per meter. One kilogram of optical fiber has the length of 10-30 km and has the commercial value of \$1-6M USD. With the delivery price of around \$60K USD per kilogram to the station and back, we have healthy margins to grow our space fibers business."

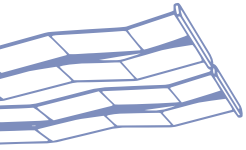
Now that these companies have all achieved proof of concept, they will continue to chip away at problems of scaling and economics. If they succeed, their business models will depend on a space platform willing to host

OVER ANY SIX-MONTH PERIOD

THE ISS HAS UP TO

250 SCIENCE EXPERIMENTS

TAKING PLACE ON BOARD.



their production facility. But does the ISS want to become a fab? In short, yes.

Ryan Reeves is the ISS National Lab Program Director for Advanced Materials. He says that early experiments on the ISS were focused on R&D, with a desire to learn things that could translate to Earth. “Now, both NASA and ISS National Lab, we’re seeing an opportunity for exploring in-space production. The opportunity for microgravity science opens up new possibilities,” he says. “If the investigators are successful in making high-quality ZBLAN fiber in microgravity, then we’re going to have to find commercial platforms that can do that at industrial scale.”

And that platform could be the ISS, at least for a while, until a commercial space platform is ready. And that’s in the works, too. Privately owned company Axiom is planning to build a fully commercial space facility for research, manufacturing, and tourism, in cooperation with ISS. Initial concepts show modular segments that will be built onto the ISS, like LEGOs, before ultimately separating into an independent and autonomous space platform.

Reeves is confident that space manufacturing is part of our future, on both ISS and Axiom platforms. But he’s waiting to see whether companies can make the financials work out. “A lot of times [with ISS experiments] we can get there with the science and be sure that the quality is there,” he says. “But the big question is the economics of translating the science into scalable and sustainable production.”

Staradubov is optimistic that FOMS can succeed commercially. “With the existing pricing of the space industry, we should be able to reach commercial sustainability and pay for the space services in the medium future from our growing production capabilities,” he says. “The critical part for sustainable space economy is building the healthy cash flow while leveraging the competitive advantages. If you run the numbers, the commercial efficiency is the key factor.”

And part of a healthy commercial ecosystem—in space or otherwise—is competition.

GWEN WEERTS is the Managing Editor for Photonics Focus.



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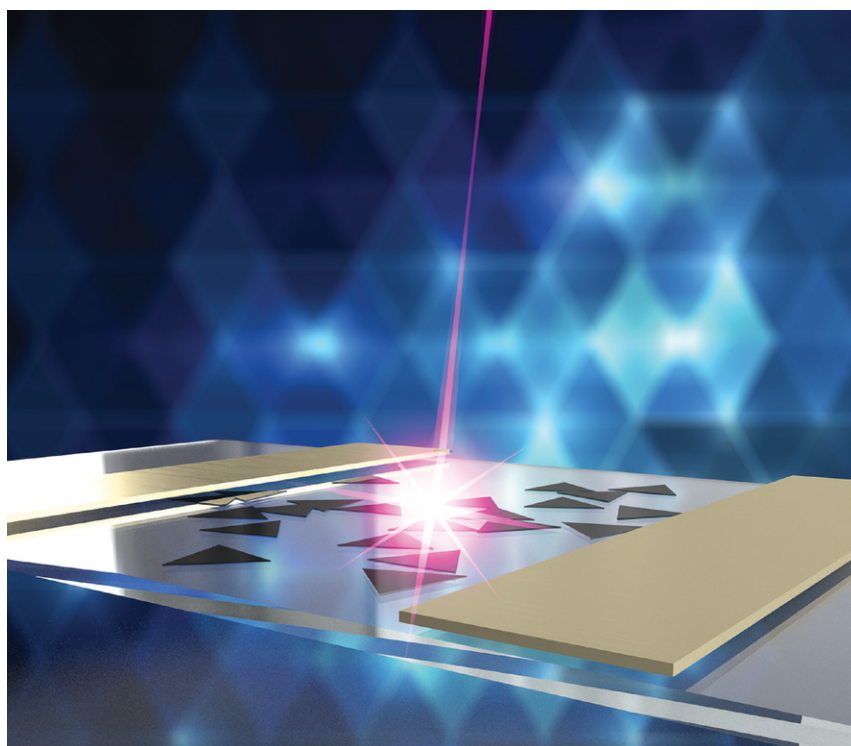
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Gorilla Glass Gets Smart

PHOTODETECTORS ARE OFTEN AT WORK BEHIND THE SCENES of everyday tasks like opening automatic sliding doors at the grocery store, or automatically adjusting a cell phone's screen brightness in different lighting conditions. Integration of photodetectors with Corning's Gorilla glass, like that found on modern smart phone screens, could lead to the commercial development of smart glass with automatic sensing properties.

A team at Penn State University identified two main problems to overcome: first, glass degrades at high temperatures, so the manufacturing has to be done at relatively low temps. Second, the photodetector has to operate on glass using minimal energy. "The photodetectors need to work in resource-constrained or inaccessible locations that by nature do not have access to sources of unrestricted electricity," said Saptarshi Das, principal investigator on the study.

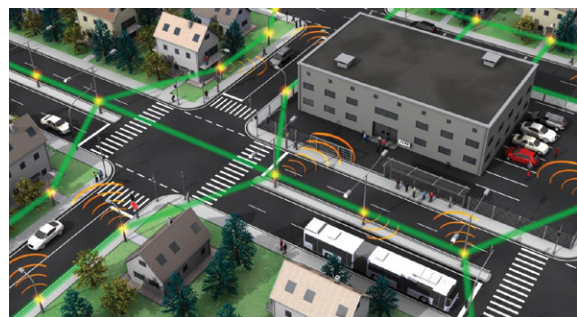
The team used molybdenum disulfide to coat the glass, and then fused it to the glass using a low-temp chemical reactor. They then patterned the photodetector using a conventional electron beam lithography tool. Their photodetector demonstrated successful detection of low-intensity visible light at high speed and with low energy expenditure.

Joshua Robinson, coauthor on the study, envisions numerous commercial applications for their technology, including energy, healthcare, transportation, and aerospace engineering. "Smart glass on car windshields could adapt to oncoming high-beam headlights when driving at night by automatically shifting its opacity using the technology," Robinson said. "And new Boeing 757 planes could utilize the glass on their windows for pilots and passengers to automatically dim sunlight."

That's so smart.

(*J. Nasr et al., ACS Nano 2020, doi: 10.1021/acsnano.0c06064*)

Thank You, Next: Moving on to 6G



WHILE MOST OF US are still figuring out how to access elusive 5G signals, researchers are already working on 6G. The sixth generation of mobile communications promises even higher data rates, shorter latency, and strongly increased densities of terminal devices, while exploiting AI to control devices or autonomous vehicles in the Internet-of-Things era.

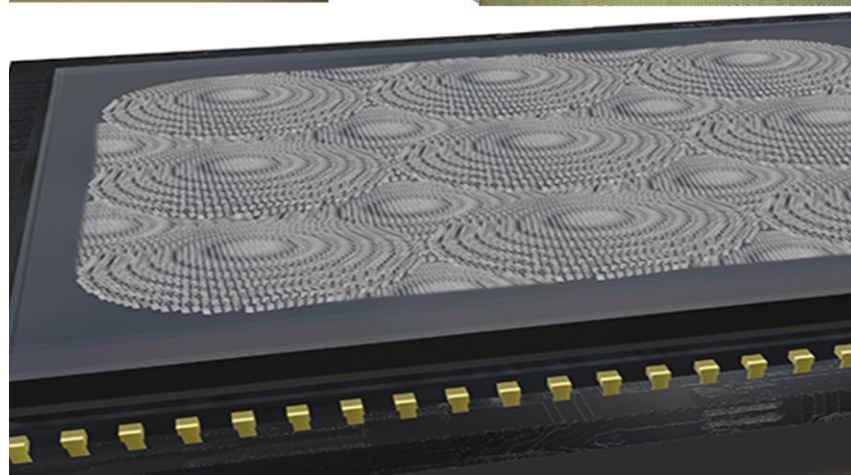
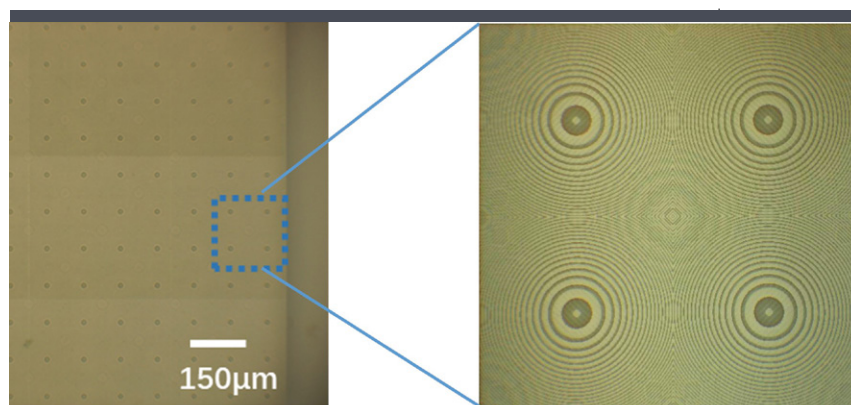
These future networks are expected to consist of lots of small radio cells placed fairly close together on building facades and streetlights. The short distances between the cells will allow high-data-rate transmission with minimum energy consumption, and terahertz (THz) frequencies are an attractive solution.

Unfortunately, THz receivers are still complex, expensive, and often create a bandwidth bottleneck in the link. But researchers at Karlsruhe Institute of Technology in Germany have developed a receiver for THz signals that solves all of those problems.

The receiver consists of a single Schottky barrier diode, which rectifies the THz signal. In combination with a dedicated signal processing technique, their method demonstrated transmission at a data rate of 115 Gbit/s, and a carrier frequency of 0.3 THz over a distance of 110 meters.

"This is the highest data rate so far demonstrated for wireless terahertz transmission over more than 100 m," says Christoph Füllner, a researcher on the study. Because it's so technically simple, this new THz receiver design could lend itself to cost-efficient mass production.

(*T. Harter et al., Nat. Photon. 2020, doi: 10.1038/s41566-020-0675-0*)



Mini Metasurface Microscopes

THE PURSUIT OF EVER-HIGHER IMAGING RESOLUTION in microscopy is coupled with growing demands for compact portability and high throughput. While imaging performance has improved, conventional microscopes still suffer from the bulky, heavy elements and architectures associated with refractive optics. Metalenses offer a solution: they're ultrathin, ultralight, and flat, and benefit from lots of recent research that has improved their efficiency, FOV, and polarization functionalities.

In spite of all the ongoing work to improve metalenses, most research groups are using them as a substitute for conventional refractive lenses in conventional optical settings. For metalenses to move toward real-world application, it's important to learn how to integrate them into ultracompact optical devices.

In pursuit of a compact integrated microscope system, a research team at Nanjing University mounted a metalens on a CMOS image sensor to create a prototype of a coin-sized imaging device. Their metalens-integrated device exhibits an ultracompact architecture with a working imaging distance in the hundreds of micrometers. Using a simple image-stitching process, they are able to obtain wide-field microscope imaging with large FOV and high resolution.

According to author Tao Li, professor of engineering and applied sciences at Nanjing University, "An ultra-compact metalens for imaging will miniaturize and even revolutionize conventional optical devices."

(Xu et al., *Adv. Photon.* 2020, doi: 10.1117/1.AP.2.6.066004)

Optical Fibers are under so Much Pressure to Deliver

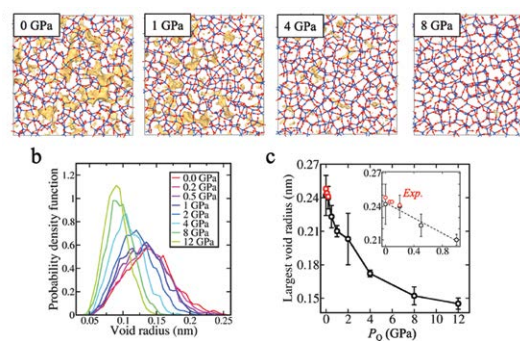
IN SPITE OF EVERYTHING WE KNOW about silica glass and its suitability for optical communications, we don't know much at the atomistic level about optical attenuation in the glass. But we do know that light scattering due to imperfections in the fiber can cause the data signal to peter out before it reaches its final destination.

A research group from Japan has tackled this problem by using computer simulations to study how the density fluctuations of SiO₂ glass can be suppressed under various amounts of pressure. First, they discovered that large voids between silica atoms form when the glass is heated up and cooled down under low pressure. Those voids cause scattering, and therefore signal loss.

But when the fiber is formed under 4 gigapascals (GPa) of pressure, most of those voids disappear, and the glass takes on a more uniform lattice structure that can decrease signal loss by more than 50 percent.

Researcher Madoka Ono, an author on the study, believes their theoretical simulations will help guide future production processes to produce this ultra-transparent silica glass. However, 4 GPa is easier to simulate than practically recreate: the pressure is comparable to 580,150 lb/in², or 326× the pressure exerted on a stiletto heel worn by a 100 lb woman. Ono admits, "It will be technically challenging."

(Y. Yang et al., *npj Comput. Mater.* 2020, doi: 10.1038/s41524-020-00408-1)



AMP IT UP

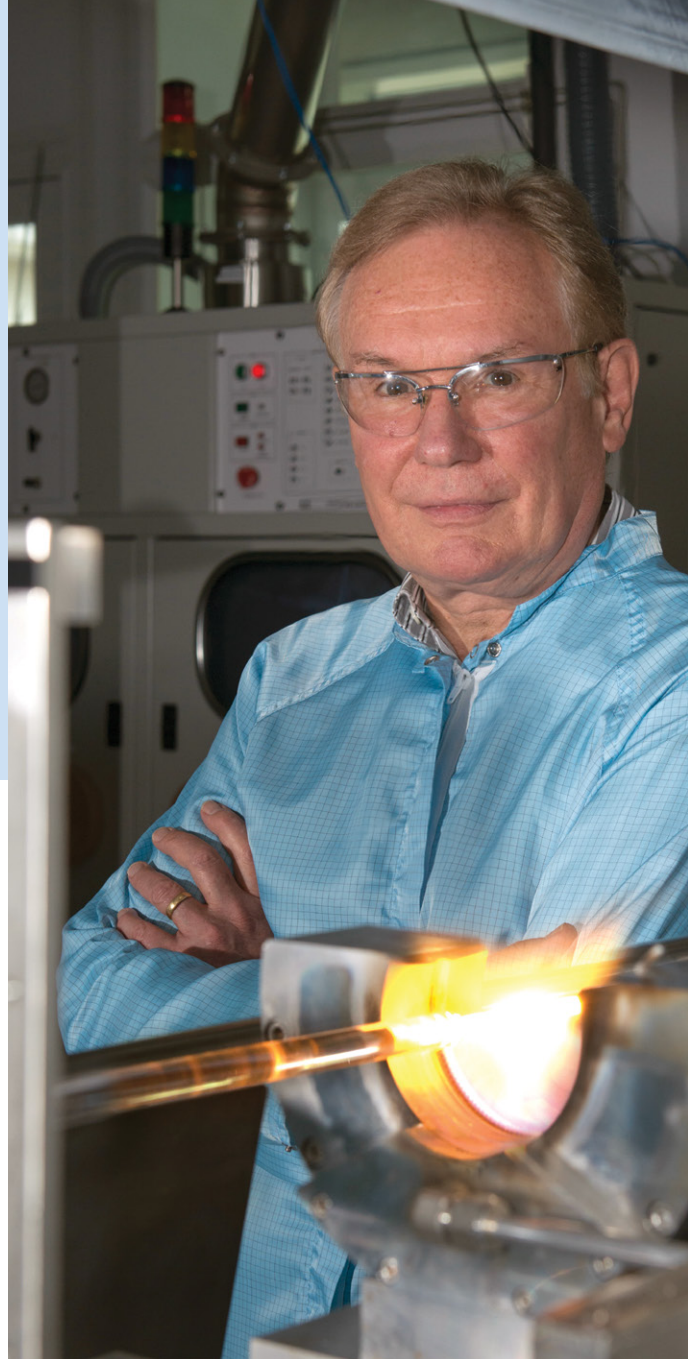
How David Payne made fiber optic communications into a bandwidth superhighway

Signals inevitably fade with distance, so communication systems need amplifiers or regenerators to maintain signal strength. In early communication systems, electromagnetic relays regenerated the dots and dashes of telegraphs. Vacuum tubes and later transistors amplified voices on telephones. When fiber-optic systems needed optical amplifiers, David Payne developed a remarkably good one.

INVENTION OF THE LASER triggered a burst of interest in optical communications in the 1960s. Early demonstrations modulated a laser beam or other light source, and transmitted the signal through a hollow tube to a detector that converted the light signal to electrical format. Fiber optic transmission didn't take over until the early 1970s. When tests reached a point where they ran out of light, the experimenters directed the weakened signal to a detector, and directed its electrical output to an electronic amplifier, which in turn powered a second optical transmitter that sent signals through a new length of fiber. The result was an electro-optical regenerator, good enough for some purposes, but far from ideal.

The quest for all-optical amplifiers got serious in the early 1980s. By then, semiconductor diode lasers had matured as light sources and seemed the best candidates for optical amplifiers because they were small, electrically powered, and potentially inexpensive. Research boomed, but the results fell short of hopes. Semiconductor optical amplifiers turned out to have high noise, low gain, became nonlinear at high speeds, and were sensitive to polarization. Fiber-optic system developers began considering alternatives.

David Payne started working in fiber optics in 1967, building the first fiber draw tower in academia at the University of Southampton. "After that, it was like surfing a giant wave, as result after result showed fiber telecommunications was not just a possibility but a high probability," he recalls. He stayed because "photonics is a lot of fun and as an enabling technology there are so many opportunities to move into different applications."



At a time when many labs focused on purifying glass in an effort to reduce losses and extend transmission distances, Southampton developed a reputation for producing special purpose fibers, including polarization-maintaining fibers and metal-containing fibers. In 1973, Payne discovered the wavelength where silica fibers have zero dispersion, and thus the broadest bandwidth, which became the 1.3-micrometer transmission window. In 1974, Payne earned Southampton's first PhD in fiber optics, and turned to developing fibers for sensing.

That led to making fibers with small amounts of rare-earth elements in their cores, as Payne searched for effects that might be useful in making sensors or solid-state lasers. The rare earths were well known for their useful optical properties, with several among the best solid-state laser materials. He started by doping a fiber core with neodymium and putting mirrors on the

ends to make a neodymium fiber laser, and was surprised to discover that adding a rare earth to the silica increased light absorption only in the neodymium pump bands, but not at other wavelengths. He also noted that pumping along the length of a fiber could produce a high pump intensity, reducing the laser threshold to a very low level. Both were important insights.

Neodymium fiber lasers were not a new idea. Eli Snitzer had made one in 1961 at the now-defunct American Optical Co. in Southbridge, Massachusetts. However, it had proved impractical because it had to be pumped from the side with a flash lamp, which was painfully inefficient because so little light went into the fiber, and neodymium absorbed even less of that light. Payne found that pointing the narrow beam from a laser down the length of the fiber coupled much more light into the fiber and excited much more light-emitting neodymium.

Payne knew that erbium emitted at the 1550-nm minimum loss of fibers, which would be attractive for amplification, but when he started with lasers, the conventional wisdom was that rare-earth elements could only amplify light weakly outside of a laser resonator. Thulium and ytterbium lasers followed neodymium. Erbium came last because its laser transition includes only three levels, rather than the four levels usually needed for efficient lasing.

Nonetheless, erbium proved a much better laser than expected. Payne performed a long series of experiments and wrote 26 papers on erbium-doped fiber lasers before he removed the mirrors to measure single-pass gain in an erbium-doped fiber.

Erbium's 1550-nm wavelength was a logical choice for amplifier experiments because it is where telecommunication fibers are most transparent, but he expected low amplification. He was surprised to see gain peak at an impressive 30 decibels—a factor of 1,000. That made erbium fiber amplifiers a promising challenger to two more widely pursued options: semiconductor optical amplifiers and a then-exotic Raman amplification process in pure silica fibers.

The erbium amplifier still had serious limitations when Payne introduced it at the Optical Fiber Communications Conference in January 1987. “We knew it would be very important, but we did not know it would beat the intense competition at the time from semiconductor diode and Raman amplifiers,” he recalls. The biggest concern was its need for pumping by a dye laser, which itself had to be pumped by a massive and

inefficient argon-ion laser. With colleagues Simon Poole and Robert Mears, Payne searched the erbium spectrum for better pump bands and soon found that 980 nm offered stronger absorption and lower noise levels.

Others soon developed efficient indium-gallium-arsenide diode lasers emitting at 980 nm. Snitzer, then at Polaroid in Cambridge, Massachusetts, found another pump band at 1480 nm where InGaAsP diode lasers were available. Emmanuel Desurvire at Bell Labs made detailed measurements and developed rules for designing erbium fiber lasers. Wavelength-division multiplexing eventually allowed the 1535–1565 nm erbium band to carry up to a hundred separate signals.

Erbium-doped fibers have proved almost ideal for communications. Their properties are the best of any optical amplifiers, and their wavelength matches the minimum absorption band of silica fibers. Erbium amplifiers can be cascaded in series to span distances beyond 10,000 km. While early experiments could amplify directly modulated signals at 2.5 gigabits per second, today they amplify coherent signals at data rates of more than 100 gigabits on dozens of separate wavelengths. After thirty years, fiber-amplified fiber-optic systems are bumping up against the fundamental limits on data transmission rates imposed by noise. “I still find it remarkable that despite intense competition, no one has ever managed to supersede the EDFA at 1550 nm,” says Payne. Settling for semiconductor or Raman amplifiers “would have seriously limited the capacity of fiber links.”

Knighted by Queen Elizabeth in 2013, Sir David Neil Payne has received a long list of awards for his work on fiber amplifiers, including the UK Rank Prize for Optics, the Benjamin Franklin Medal for Engineering in 1998, the Kelvin Medal for applying science to engineering in 2004, and the Marconi Prize in 2008. He has founded companies including Southampton Photonics, and continues to push optical frontiers. His latest enthusiasm is hollow-core fibers, in which a Southampton team in 2020 reported a record low attenuation of 0.28 dB/km, just a factor of two above the lowest loss in pure silica fiber.

JEFF HECHT *is an SPIE Member and freelancer who writes about science and technology.*

**“PHOTONICS
IS A LOT OF FUN
and as an
enabling technology
THERE ARE SO MANY
OPPORTUNITIES
to move into
DIFFERENT
APPLICATIONS”**

A Timeline of COMMUNICATION TECHNOLOGY

Since early history, humans have relied on technology to increase the speed and ease of communication.

60 BC

Smoke and torch signals were the first known “optical” telegraphic media. They transferred messages over large distances with the help of relay stations. Just like in *Lord of the Rings*

27 BC

Romans draw glass into fiber



1826

Joseph Nicéphore Niépce makes the first photograph using the process of heliography: Bitumen of Judea was coated onto a piece of glass, and the Bitumen hardened in proportion to the amount of light that hit it

Credit J. Paul Getty Museum



1837

The electric telegraph is invented by Charles Wheatstone

1926

John Logie Baird patents the idea of using arrays of transparent rods to transmit images for television

1897

Marconi sent the first wireless communication over 6 km of open sea: “Are you ready?”



1888

George Eastman sells his Kodak Camera Number 1 for \$25



16 August 1858

First transatlantic telegraph cable completed. It functioned for just three weeks

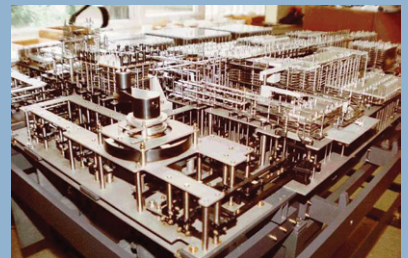
Credit: Division of Work & Industry/ National Museum of American History/Smithsonian Institution

1840s

Jacques Babinet guides light in water and bent glass rods

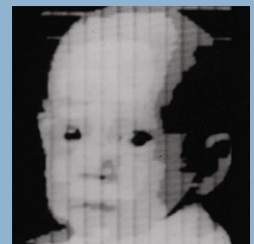
1930

Heinrich Lamm transmits an image through a bundle of transparent optical fibers



16 May 1936

Konrad Zuse builds the Z1 computer, complete with keyboard input



1957

The first digital photograph is created, 20 years before the first Kodak digital camera. The photo is a digital scan of a film photograph, in an Instagram-worthy 176 × 176 pixels

16 May 1960

Theodore Maiman demonstrates the first laser

1966

Charles Kao indicates that fiber losses could be reduced to below 20 dB per kilometer for office-to-office communications

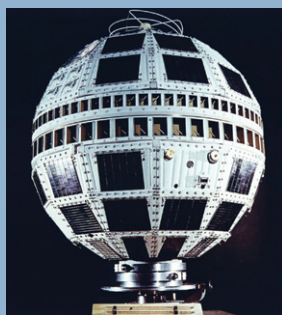
1966

AT&T's Bell labs debuts the "Picturephone" at the World's Fair in New York City and makes the first transcontinental videocall between two venues



1962

Robert Hall demonstrates the first semiconductor laser



10 July 1962

Telstar 1 communication satellite is launched by NASA. It allowed live broadcasts of television images between the US and Europe

1970

The US Air Force created the Space Laser Communications Program to develop system concepts and component designs for high-data-rate laser communications systems

1973

The first mobile phone, DynaTAC, invented by Martin Cooper, weighed 2 pounds and measured 9 x 5 x 1.75 in.



1975

Steven Sasson invented the first digital camera at Eastman Kodak, weighing 8 lbs. The image was recorded onto a cassette tape

Credit: George Eastman House



1983

Transfer Control Protocol/Internet Protocol was established and the Internet was born

January 1987

David Payne introduced the first erbium-doped fiber amplifier for optical fiber communications

1988

TAT-8 becomes operational as first transatlantic fiber optic cable

2020

Zoom surpasses 300 million daily online meeting participants

2019

The total global bandwidth stands at 466 Tbps, a near tripling of bandwidth since 2015

2017

First quantum encrypted international video call

2011

Zoom Video Communications founded



29 June 2007

First iPhone is released

2002

Internet population surpasses 500 million

1997

Fiber optic link around the globe (FLAG) went into service spanning over 28,000 kms and offering 10 Gbps services

9 August 1991

First email sent from space via RF. Atlantis astronauts Shannon Lucid and James C. Adamson said, "Having a GREAT time, wish you were here"


LiFi

COMING TO A FACTORY, A SCHOOL, AND A CAR NEAR YOU

By **Rebecca Pool**

A decade after demonstrating its potential, LiFi is poised to become a data communication standard. Our connected world can barely wait.

A lighthouse on Graemsay Island, United Kingdom, was equipped with a LiFi system to provide high-speed internet to the island's 28 residents

An aerial photograph of a small island, likely Graemsay in the Orkney Islands. A prominent white lighthouse with a black top and a gold band stands on the left. The island is surrounded by deep blue water, and the surrounding landscape consists of rolling green hills under a clear sky. The text of the article is overlaid on a dark blue semi-transparent background on the right side of the image.

NOT SO LONG AGO, THE REMOTE ARCHIPELAGO OF ORKNEY ISLANDS off the north coast of Scotland had the slowest broadband internet speeds in the UK. In a study, consumer watchdog *Which?* highlighted that this cluster of islands had data rates of around 6 Mbps, often dipping to 2 Mbps, way below the government's promised download speed of 10 Mbps.

Local Members of the Scottish Parliament called for action amid fears that the Orkney Islands could slide into the “digital divide.” And then LiFi pioneer Harald Haas stepped in.

With government funds, the chief scientific officer of pureLiFi and director of the LiFi Research and Development Centre at Strathclyde University devised a scheme that transmitted data via light and more than quadrupled the broadband speed on the diminutive Orkney Island, Graemsay, population 28.

As part of the setup, a nearby lighthouse was equipped with a low-power laser to transmit data-enriched light to homes up to 50 meters away. These homes used domestic solar panels as outdoor broadband detectors to receive the data.

LiFi systems from pureLiFi were installed into the Graemsay homes, using LED bulbs equipped with a LiFi transmitter and receiver as wireless access points, to stream that data to computers and laptops. These devices then used USB LiFi dongles containing photodetectors to detect and decode the incoming LED light. Integrating infrared laser diodes into the dongles also provided a data link back to the LEDs, enabling a communication link.

“Graemsay only had a copper network to connect its residents and businesses, and this only delivered a data rate of around 2 to 3 Mbps on average,” says Haas. “But with LiFi, we brought this up to 10 Mbps and provided affordable last-mile connectivity and high-speed indoor wireless networking to the island.”

“Rain is often expected [in the Orkneys] and we were worried that this would affect performance, but because the solar panels are very large detectors, this isn't really impacting the system at all,” he adds.

Haas is thrilled with the results and is already experimenting with more sophisticated solar panels, including gallium arsenide photovoltaics, to bolster transmission ranges and data rates.

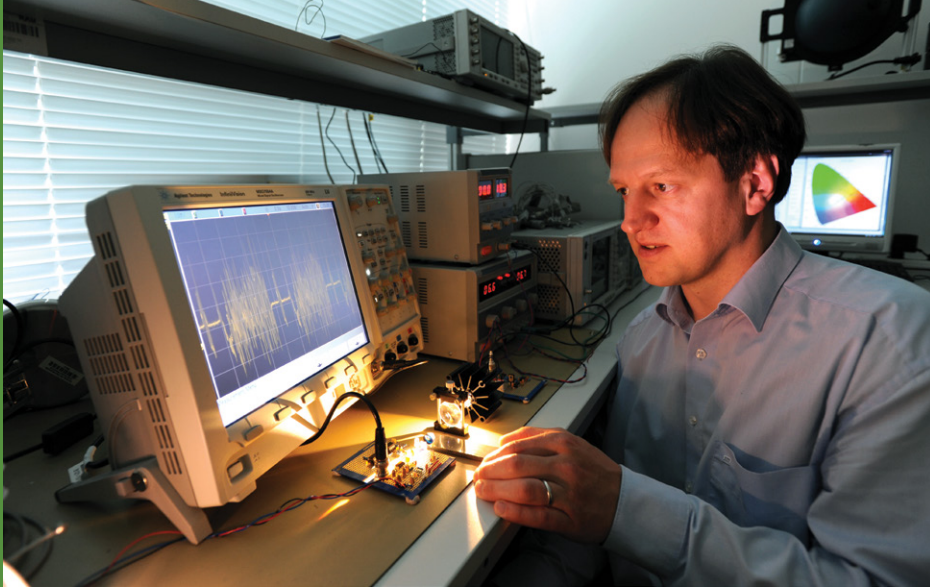
“We've not reached gigabit data rates here as we've only used off-the-shelf solar panels, but we've published results that show other solar cells can provide at least 1 Gbps speeds,” he says. “Following COVID-19, if we see more people moving into rural areas, they will need high data rates and LiFi can provide this.”

Graemsay was just the beginning of today's LiFi activities. Demonstrations and applications have mushroomed since 2011, when Haas showed how his LiFi-retrofitted LED bulb could stream high-definition video to a computer by modulating its light intensity.

Since that time, Haas has been diligently raising data rates and bandwidth by upgrading light sources. First came your humble LED, and then the more powerful micro-LED arrays, shifting data rates from megabits to gigabits per second.

But most recently Haas has been working with dazzlingly bright laser-based light sources, manufactured by US-based SLD Laser, a company co-founded by Nobel Laureate and LED legend, Shuji Nakamura. Lasers can be modulated much faster than LEDs, which when twinned with higher optical powers, really fires up performance: Both Haas and SLD Laser have demonstrated 20 Gbps data rates across 3 m.

Along the way, Haas has also used ultra-sensitive photodetectors and detector arrays to collect more of the incoming data-encoded light streams, as well as new algorithms alongside combined light sources and photodetectors to create higher capacity LiFi networks. And by using increasingly sophisticated modulation schemes, he has also beamed thousands of streams of light in parallel to vastly multiply data bandwidths.



◀ Harald Haas, LiFi pioneer and pureLiFi chief scientific advisor

“We’re now looking to slice up the optical spectrum into different wavelengths so each color—red, green, blue, yellow and so on—carries data in parallel,” he adds. “We’ve reached 15 Gbps speeds already with this approach, and that’s just with off-the-shelf LEDs.”

Haas reckons laser-based LiFi data rates will reach 100 Gbps by early 2022. And as part of an international program called Terabit Bidirectional Multi-user Optical Wireless System (TOWS) for 6G LiFi, he hopes to propel LiFi to an eye-watering terabit per second by 2024.

However, the pureLiFi chief scientific officer has hardly been working in a vacuum. A growing army of high-tech startups and industry heavyweights have also been exploiting LiFi, demonstrating the technology in offices, schools, factories, museums, and hospitals.

In 2019, France-based Oledcomm and Signify—formerly Philips Lighting—from The Netherlands each joined forces with AirFrance to deploy LiFi on planes. In October that year, and working with aircraft equipment supplier, Latécoère, the French airline hosted a LiFi-enabled gaming competition aboard an Airbus A321.

Meanwhile, both Velmenni of India and US-based VLNComm have been looking at factory and warehouse applications. At the same time, VLNComm and French company Lucibel have also worked with the military to provide LiFi internet access at command posts. Several armies around the world have been looking at using LiFi instead of WiFi in tactical centers and camps to increase data security and ease operations setup.

For Sylvain Leroux, IoT and LiFi marketing director at French telecoms multinational, Orange, the rising number of companies on the LiFi scene spells good news for the up-and-coming industry. “LiFi is now a very robust technology with capabilities that have been growing so quickly in the last two to three years,” he says. “We noticed huge competition in the market and felt this wasn’t growing the market.” Given this, Orange works with myriad businesses, helping to develop LiFi and expose the technology to as many users as possible.

Indeed, in recent years, Orange has used pureLiFi’s LiFi network at the technical area of the Tour de France, providing internet access to the race’s many hundreds of broadcasters and journalists. Leroux also highlights a recent project in which Oledcomm worked with the France-based digital services group, SPIE ICS (no relation to the Society), to equip a classroom within a school in the French town of Tours with LiFi internet access. A second school-based project is already underway.

“For me, the main usage of LiFi right now is indoor applications,” he says. “The technology can provide reliable and secure connections in schools, industrial buildings, as well as hospitals that don’t want [interference] from WiFi radio waves.”

According to the Orange marketing director, he’s currently seeing typical data rates close to 300 Mbps in such applications, but believes that by 2021 commercial products will be offering 1 Gbps as standard. “We’ve got Signify, Oledcomm, pureLiFi, and many more companies

working here—so I’m pretty sure we’ll see this kind of data rate,” he says.

Although LiFi data rates exceed those of today’s WiFi, speed isn’t everything. With ever-rising data volumes, latency, which drives the responsiveness of any network, is more important than ever before. As Leroux points out, “Data rates are not a challenge anymore—low latency is now the key differentiator with WiFi.”

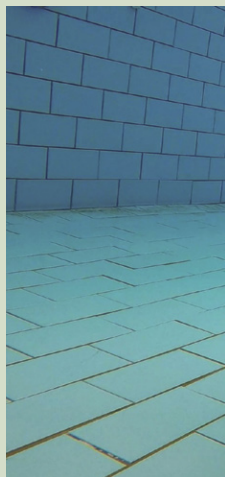
Latest figures from pureLiFi indicate that LiFi already offers a latency some three times lower than WiFi. And with a low- or high-latency internet connection making the difference between winning or losing your next game of Grand Theft Auto or Minecraft, many in the industry couldn’t agree more.



CHAO SHEN, a researcher in gallium nitride optoelectronics at Saudi Arabia-based King Abdullah University of Science and Technology (KAUST) and co-founder of LiFi systems developer SaNoor Technologies, believes the low latency of LiFi, together with the super-high speeds and bandwidths that laser-based light sources can bring, will make laser-based LiFi indispensable for future augmented reality and virtual reality applications. He is also looking forward to seeing the technology used in vehicle-to-vehicle communication between autonomous cars.

Unlike others in the industry, Shen has been interested in laser-based LiFi from word go, thanks to his strong background in compound semiconductors such as gallium nitride. About a decade ago, he started to develop high-performance optoelectronic devices, and was soon working with Shuji Nakamura and many other colleagues on high-speed GaN laser diodes for LiFi systems as part of a collaboration between KAUST, University of California, Santa Barbara, and King Abdulaziz City for Science and Technology, Saudi Arabia.

A SaNoor LiFi laser being hoisted underwater by a subsea vehicle ▶



DATA RATES

are not a challenge anymore—

LOW LATENCY

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WITH WiFi.

Then he was approached by an industrial partner that wanted to stream data underwater. “That is the moment that we realised we had a solution for them, as light can transmit in water,” he says.

Immediately, Shen started to investigate how best to implement laser-based LiFi in subsea environments, tackling issues such as low visibility, turbulence, and inhomogeneous salinity and temperature, that plague the murky depths. In addition to honing light sources, he devised a large-area, high-bandwidth photoreceiver to optimize links in choppy conditions, experimented with modulation schemes to ensure robust communications, and, alongside his KAUST supervisor Boon Ooi, spun out SaNoor to commercialize these technologies.

“Oil and gas, and offshore windfarm industries, all need low-latency, high-speed, wireless communications links to connect devices in the subsea environment—laser LiFi can provide this,” says Shen. “Today’s acoustic underwater data transmission technologies typically provide speeds of a few kilobits per second, but in recent underwater trials, our LiFi platform reached data rates of 4 Gbps.”

Subsea environment developments continue apace. With its laser-based LiFi systems, SaNoor intends to be at the forefront of “The internet of Underwater Things,” which beyond pipeline monitoring could eventually be used to detect

approaching storms, sea-level changes, and even coral bleaching.

Shen also has his eye on the more terrestrial applications. “With our systems we’ve already achieved more than 30 Gbps data rates in free space,” he says. “We are not a large company, and can’t do everything, but we’re watching the car industry in particular, and if we see a good opportunity, we will jump in.”

Beyond indoor, underwater, and more futuristic applications, many industry players believe LiFi is set to play a key role in providing last-mile broadband connectivity in developing nations and the world’s remote regions, as demonstrated in Orkney’s Graemsay. Indeed, this application is particularly close to Deepak Solanki’s heart.

As the Velmenni founder and chief executive points out, “Only 20 to 25 percent of India’s telecom towers and small cells are connected via fiber-optic backhaul, with the rest still relying on microwave and other RF-based wireless technologies.” He adds, “These can be very limited in terms of throughput, coverage, and range, and can’t necessarily be deployed at street level.”

Given this, Velmenni has developed a fiber-to-the-X LiFi system for homes, businesses, and telecoms infrastructure. The system uses LEDs with custom lenses to boost optical power, and crucially, provides a 1 Gbps data rate across a distance of 200 m. Following trials with Cisco and one of India’s largest telecoms operators, the product is launching at the end of 2020. Solanki is excited.

“Cisco and customers have faced many challenges when laying cables for public WiFi access points in densely populated cities, and I believe nothing will prevent the adoption of this technology here, as we are solving a huge problem,” he says. “We’ve also reached out to potential customers in the US and Europe, and Orange is very interested in exploring the possibilities with us ... there are so many places where LiFi can provide this kind of broadband connection that will also complement existing last-mile systems.”

At the same time, Solanki reckons LiFi will also support existing wireless telecoms infrastructure, as nations make the transition from 4G to 5G. And so,

it would seem that initial conceptions of LiFi competing with WiFi are long gone. With Haas, Solanki, and other key players busy developing the necessary techniques to ensure a seamless hand-over between LiFi and WiFi, the two technologies are set to complement each other from here on in.

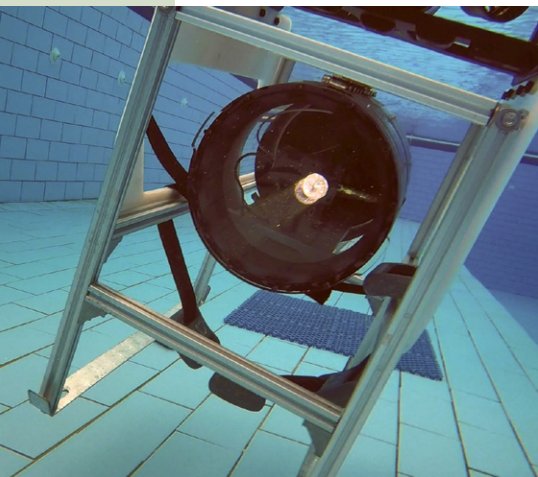
So as LiFi demonstrations and applications proliferate, why isn’t LiFi commercially ubiquitous? What is the world waiting for? Simply put: a standard.

Despite progress from the International Telecommunication Union, IEEE, and LiFi industry consortium, Light Communication Alliance, the Global standard for LiFi—802.11bb—is not set for release until the end of 2021. Following this, manufacturers of smartphones, laptops, and other devices will be more inclined to embed LiFi receivers in products, bringing an end to the not-so-convenient dongle. Indeed, at the time of writing and claiming a world first, Taiwan-based rugged laptop and tablet manufacturer, Getac, had just integrated a pureLiFi receiver to a tablet, while mobile communications company Oppo of China had patented a smartphone with LiFi technology.

For his part, Haas hopes to see LiFi well and truly integrated into mobile devices within the next three years. And as Solanki puts it, “Right now, the most important thing is to have this common standard. With this, device integration will still take at least another year, but then the use cases will be unlimited.”

When that time comes, SaNoor’s Shen is confident the start-ups and spin-offs will fan the flames of LiFi progress. “Look at Facebook, Twitter, and TikTok—these companies didn’t come from IBM or Google, they all began as start-ups,” he says. “I do think that something similar will happen in the LiFi industry—it won’t be pushed by established industry leaders. The revolution is going to come from the small company.”

REBECCA POOL is a science and technology writer based in Lincoln, United Kingdom.



LASERS HARKEN A DATA REVOLUTION FOR SPACE

Optical communications are poised to pull space out of the dial-up dark ages

By **Mara Johnson-Groh**

IF YOU GAZE UPWARD ON A CLEAR NIGHT, it won't be long before you see the blinking lights of a passing satellite. Such a sight would have been rare a couple decades ago, but today nearly 3,000 active satellites orbit Earth, and many more spacecraft explore the solar system and beyond. In five years, there could be as many as 1,000 satellite launches annually.

Outer space is no longer a lonely frontier. This bustling, futuristic skyscape provides us with a global communications platform, observational data about our planet, and even mysteries deep in space. However, the way we communicate with this ever-growing fleet is far from futuristic. In fact, the increasing amount of data streaming through space is leading to an information traffic jam.

Since the first satellites were launched into space, scientists have used radio frequencies to communicate with their space voyagers. Radio frequencies have the advantage of being impervious to most weather conditions, and their long wavelengths make for a wide beam that's easy to receive. But radio frequencies are limited and increasingly overused, which makes for slow data rates—on the order of early internet dial-up speeds.

Even 40 years ago, scientists realized that there was a better option: lasers. With wavelengths 10,000 times shorter, lasers have the potential to improve data transfer rates by four orders of magnitude while simultaneously using less power. But back then, laser technology didn't have the durability and power capabilities to operate from space, so the technology largely was shelved.

Now, decades on, the technology is coming to fruition—and not a moment too soon. A booming population of spacecraft equipped with increasingly high-resolution instruments is pushing space communications to its bandwidth limit. Interplanetary communications have



increased by eight orders of magnitude since the 1960s and deep space communications are expected to increase tenfold each of the next three decades.

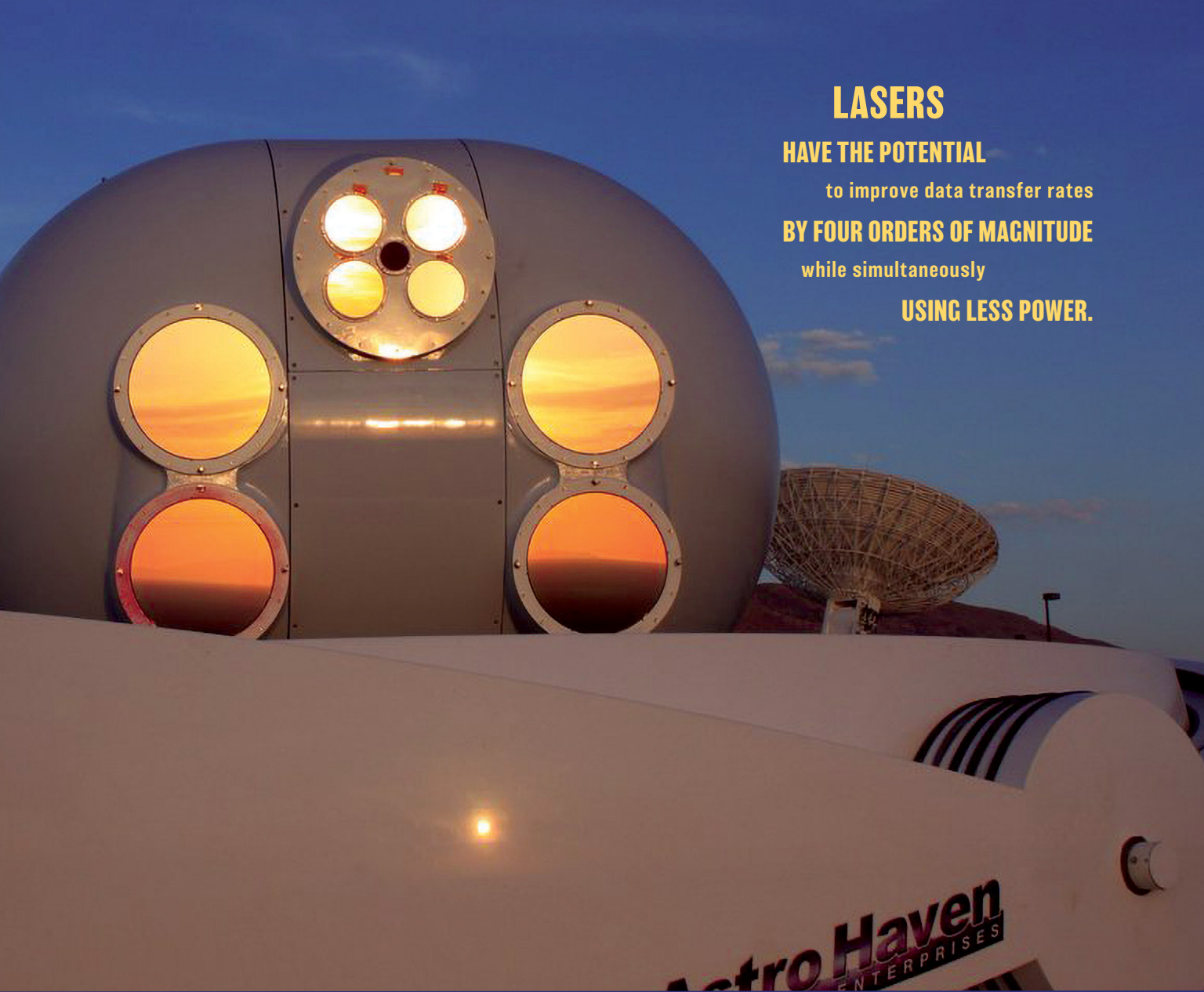
“Optical communication is going to be revolutionary,” says Scott Hamilton, researcher and leader of the Optical Communications Technology group at MIT Lincoln Lab. “It’s going to allow for things to be done that really haven’t been done before.”

Optical communications may revolutionize the space age, but first it must overcome the final remaining hurdles.



ANY MESSAGE TRANSMITTED FROM THE MOON OR BEYOND by laser will reach its biggest hurdle once it reaches Earth’s atmosphere. Turbulence in atmospheric layers can distort signals, but researchers have developed techniques to combat this issue. However, they haven’t yet been able to overcome the opacity of clouds.

Unlike radio frequencies, which travel freely through clouds, optical communications are entirely cut off as soon as a cloud rolls in. To avoid losing a signal during stormy weather, more ground



LASERS

HAVE THE POTENTIAL

to improve data transfer rates

BY FOUR ORDERS OF MAGNITUDE

while simultaneously

USING LESS POWER.

stations could be built in the hopes that one will have a clear line of sight clear if the others are blanketed. But with limited investment and high costs, it's not yet feasible to create such a widespread network. So instead, researchers are working on developing alternative solutions.

Jean-Pierre Wolf is one of those researchers. Wolf is a physicist at the University of Geneva who is developing a laser system that could clear tiny pathways through clouds. Someday, this could allow for laser communications signals to be sent even during cloudy weather.

At first, Wolf and his team tried creating a shockwave by ionizing the water droplets, but more recently they used a trick that allows the laser beam to rotate the droplets out of the way. This specially designed laser system flashes thousands of times per second and uses ten times less energy than is required for ionizing

a pathway. And theoretically, it's feasible over long distances.

"This method, it's really a drilling machine," Wolf said of the work. "It clears the pathway in the clouds, creating a channel so that you can transmit telecom data."

The laser operates at a frequency of one micrometer, which allows for no disruption to the data transmission that is standardized at 1.5 micrometers. Tests have also shown the heated channel doesn't disrupt the transmission signal. A small no-fly zone will have to be erected over ground stations using this method, but such areas are not unprecedented.

So far, demonstrations of this technique have only been achieved in laboratory settings over a distance of half a meter. While the initial results are promising, the technology is a long way off from being implemented at ground stations,

▲
Ground station used by the Lunar Laser Communication Demonstration at NASA White Sands Complex in 2014

which would require channels hundreds of meters long. While interested parties are tracking the advancements, it's not yet considered a viable option in the near future. For now, laser communications will have to rely on a growing network of ground stations.



LASER COMMUNICATIONS SUFFERS from one of the same issues electric cars have faced—lack of infrastructure. For radio communications, ground stations have been developed through international collaborations around the world. NASA's Deep Space Network uses multiple facilities that provide continuous worldwide coverage. But since optical beams are narrower, they require many more ground stations to provide ongoing coverage, even in good weather. Since optical is much more weather dependent than radio, new ground stations have been placed in clear sky locations, such as a mountaintop in Hawaii and the deserts of New Mexico. NASA has developed a few of these ground stations across North America, and European Space Agency (ESA) is working to construct more in Europe with industry collaboration, but costs to build and maintain such stations are high.

“There was always a problem, what we call the chicken and egg problem. Nobody wants to fly optical terminals because there's no ground infrastructure,” said Klaus-Jürgen Schulz, head of the ground station engineering division at ESA's European Space Operations Center. “So we are trying to break this [cycle], and in a year from now we will have our first network of optical terminals.”

Even without a dedicated network, ESA is using lasers in space. In 2014, ESA demonstrated the first gigabit-speed laser communications with the European Data Relay System, or EDRS.

EDRS came on the heels of two NASA missions in 2013. Early in the year, a signature smile, albeit a little fuzzy, made an appearance in an unusual place. NASA sent the Mona Lisa on a 240,000-mile journey to the Moon using a laser. The digital image was the Lisa's first appearance in space, but it was also marked by a more notable first—the first use of laser communications at interplanetary distances. Only months later, another lunar mission used the Lunar Laser Communications Demonstration to showcase much more powerful two-way laser communications, at record-breaking speeds of 622 megabits per second with centimeter-precision ranging to the spacecraft.

Today, EDRS remains the only real operational use of optical communications in space, although its connection to Earth is purely conducted via radio frequencies. EDRS uses two geostationary satellites to provide near real-time communications for ESA's Earth science fleet of low-Earth orbit satellites using optical frequencies. Previously, the low-Earth orbit satellites could only send

information down every ninety minutes as they passed over a ground station in Svalbard. Now, the observational satellites can transmit their data to EDRS with optical wavelengths, who then in turn can downlink them to Earth at near-real-time speeds using radio wavelengths. This allows for ongoing monitoring of activity and emergency situations on Earth, like checking transoceanic ships for oil leaks.



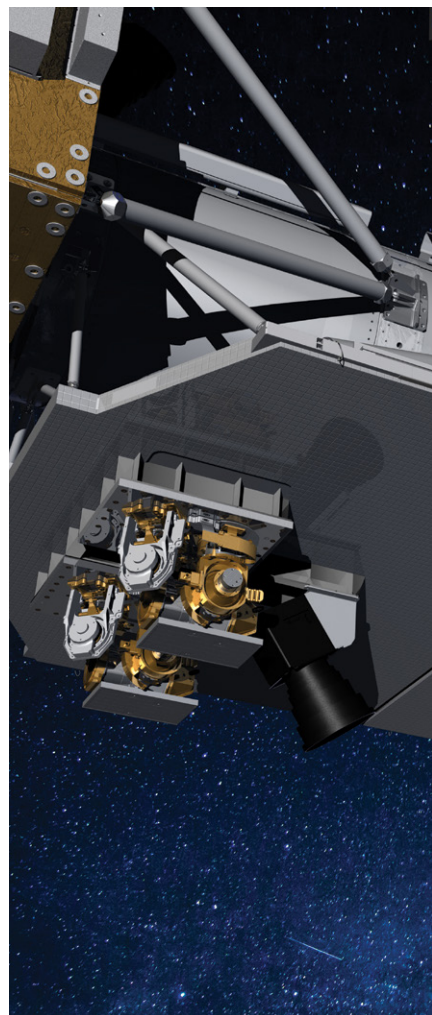
WHILE CONSISTENT transmission is the largest remaining barrier to optical communications in space, more technology development is necessary for its usage to become widespread. Costs are still high and the scientific community as a whole is not yet won over. But things are changing rapidly.

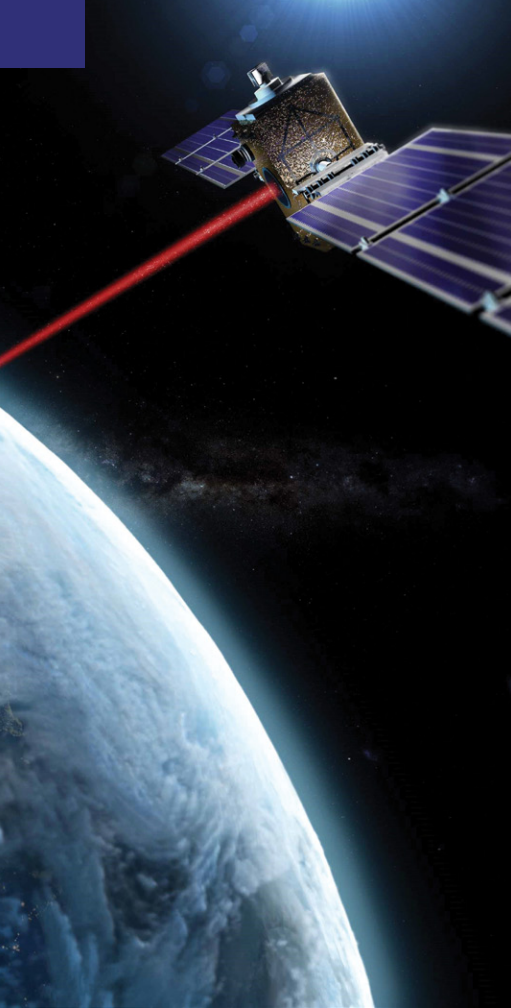
“As [optical communications] was starting up, it was very expensive,” said Betsy Park, a project manager at NASA's Goddard Space Flight Center who is working to develop optical communications for the agency. “When I started with it, there weren't that many vendors that were interested in working on it. And now, more and more of them actually have finished products that they're getting ready to put on the market.”

Indeed, an increasing number of businesses from small startups to multinational corporations are getting into the game. Both ESA and NASA work with industry partners, and such collaboration is expected to make laser technologies more reliable

Artist's rendering of the laser “drilling machine” that clears a pathway in the clouds to open a channel for laser communications (above)

Artist's rendering of the Laser Communications Relay Demonstration, planned to launch in 2021 (below)





INVOLVEMENT OF **INDUSTRY** WILL ULTIMATELY FEED BACK INTO
IMPROVING **LASER COMMUNICATIONS** FOR DEEP SPACE USE,
AS WELL AS HELPING TO GET THE **SCIENTIFIC COMMUNITY**
FULLY ONBOARD WITH **LASER COMMUNICATIONS**.

and reproducible, ultimately driving down prices. Already many companies are seeing the potential in upgrading to optical communications in space.

Perhaps the most notable of upcoming optical communications endeavours is the private company SpaceX's Starlink. This program has been met with concern from astronomers who warn of its threat of light pollution, but it has also garnered significant interest over its goal of providing universal access to low-latency internet with bandwidths surpassing a gigabit. Currently, some 700 satellites in low-Earth orbit have demonstrated 100 megabits per second of bandwidth. Ultimately, they may be succeeded by thousands more, all interconnected by laser links, which would provide unrivalled low latency.

Involvement of industry will ultimately feed back into improving laser communications for deep space use, as well as helping to get the scientific community fully onboard with laser communications. Currently, the technology is seen by some as too new for standard use.

"Right now [scientists] have to compress their data, and they have to manipulate their data, because they can't ever bring it all back," Park said. "When they see how much they can bring back [with laser communications] they're going to want this. And then they're not going to take no for an answer."

Those tests won't be long in coming. In 2021 NASA plans to launch Laser Communications

Relay Demonstration, a geostationary orbiter that will use optical communications to send and receive data from the ground as well as an optical communications module that will be put aboard the International Space Station. The demonstration will showcase the benefits of optical communications, including a bandwidth increase of 10 to 100 times more than radio systems, run by a smaller, lighter system that uses less power.

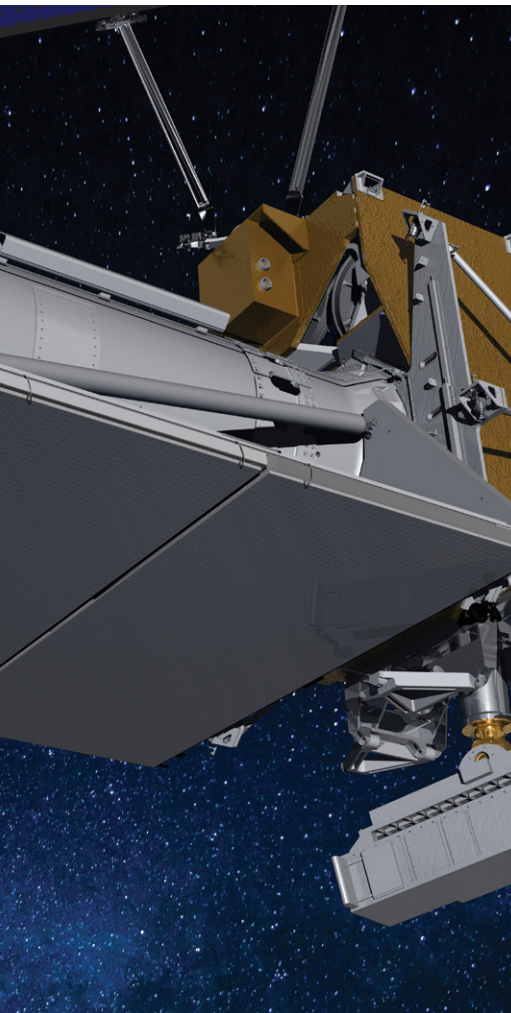
Further down the line, the Orion Artemis II Optical Communications System, which is currently in production, will allow for high-definition video calls on NASA's next crewed mission to the Moon planned for launch in 2023. For deep space communications, NASA's Psyche mission aims to launch in 2022 to test distance communications as the spacecraft travels hundreds of millions of miles to the giant metal asteroid 16 Psyche. While optical communications at these interplanetary distances are possible, truly distant missions will still require further engineering.

"With radio frequencies we've figured out how to build mesh, very lightweight, big antennas that fold out in space," Hamilton said. "Optically we're nowhere near anything like that, so we needed to do some work in that area."

In the long run, laser systems will undoubtedly change space communications for the better. But those nostalgic for the olden days of dial-up speeds, there's no need to worry about radio communications disappearing.

"I think we're going to see more and more optical in the future," Hamilton said. "But I suspect because of the pros and cons of each, that radio frequencies will always have a place in communications architecture."

MARA JOHNSON-GROH is a freelance science writer and photographer who writes about everything under the Sun, and even things beyond it.



The Light Way to 6G

Photonics might be the defining technology for the sixth generation of wireless communications

By **Vineeth Venugopal**

IN THIS FUTURE, we live inside an invisible spider web of high-frequency radiations that tie together billions of cellular devices, millions of autonomous vehicles, and trillions of sensors.

Our reality seamlessly merges with the virtual. Our decisions are informed by data, computed by artificial intelligence with zero latency. We converse with holograms, conduct surgeries remotely, and no longer hear the phrase “outside network coverage.”

Hopefully, this would also be a future where hunger and poverty are close to being eliminated—one where the wealth of data in the clouds have come to mean an equality of opportunity for those living below it.

The sixth generation of wireless technology—shortened to 6G—sounds a lot like science fiction. However, the systems required to implement this vision are not too far away. Samsung Research estimates that 6G could reach full-scale commercialization around 2030—which is just a decade away.

World over, research into the technology needed to actualize 6G has gathered momentum over the last few years.

In 2018, The Academy of Finland announced “6Genesis,” an eight-year research program to conceptualize 6G through a joint effort with Nokia. Universities in the UK, US, Japan, South Korea, and Singapore have launched research to meet the insatiable needs of the Internet of Things (IoT), medical devices, sensing, and communications. Industries—large and small—are gearing up to carve out a space for themselves in 6G, even though 5G is only starting to be deployed.

As Daniel Mittleman, professor of engineering at Brown University, puts it, “With the exact parameters and performance of 5G still unknown, it is too early to say what 6G will require.” He is a world leader in terahertz technologies—one of the leading candidates for communication beyond 5G—and also the former chair of the The International Society of Infrared, Millimeter, and Terahertz Waves.

It’s quite possible that there will be no clear demarcation between 5G and 6G. However, we do know of one requirement that all future wireless communications need to provide: hyperfast data transfer rates.

The world of 6G will be one of abundance.



By the time 6G matures in 2030, the way we communicate with each other could change drastically, incorporating everything from holograms to virtual reality. Most of these systems are very data hungry.

Consider that a realistic 3D hologram of a human face requires 19.1 gigapixels. Updating these points in real time to match gestures and expressions will need a download rate of 1 terabits per second (Tbps)! Creating a virtual replica or “digital twin” of a 1 m x 1 m space needs 0.8 Tbps assuming synchronization every 100 milliseconds (ms). Similarly, truly immersive augmented reality (AR) and virtual reality (VR) require high data rates.

The peak data rate for 5G is expected to be 20 Gbps. As a frame of reference, that is four orders of magnitude higher than the 4G LTE in our current generation of phones.

At the same time, Samsung Research estimates that the global market for AR and VR is expected to reach a total \$131.7B USD by 2030, which is an indicator of the data rates that will be required. Clearly, 5G’s 20 Gbps will not be enough to satisfy these requirements.

It’s not just these futuristic technologies—cell phones and cloud-connected devices are estimated to proliferate until there are over 10 million devices per square kilometer. The global tide of the Internet of Things will create up to a trillion sensors that are all bound by a network. Many of these devices will have built-in “native AI” systems that compute decisions rapidly from available information.

Those that require more powerful AI systems—such as autonomous vehicles—will offload computations rapidly to the web where the results will be processed and returned in real time.

Combined, the global mobile traffic is predicted to reach 5,016 exabytes per month in 2030 (compared to just 7.462 exabytes per month in 2010). Further, the needs of industrial automation, emergency response, and personalized medicine require that these communication channels have high reliability and extremely low latency to enable real-time data processing.

This means that 6G requires high bandwidths—much higher than 5G.

“The relation between the amount of information that can be carried by a channel and its bandwidth is given by Shannon's Capacity theorem,” explains Ranjan Singh of the Nanyang Technology University, Singapore, where he explores novel methods for fast data transfer using photonics.

A high-frequency channel has a larger bandwidth and can carry more information than one at a lower frequency. 4G runs in the megahertz or a million cycles per second. 5G will cover a higher frequency range up to a maximum of 75 GHz.

That leaves us two frequency bands where 6G could operate competitively.

The first is the band of radiation spanning from red to blue of the electromagnetic spectrum, the intimately familiar photons that we identify as visible light. The technology to generate and manipulate them is widely available—a white light LED, for example, costs less than a US dollar. As Marcos Katz, professor at the University of Oulu, Finland, points out, “Light-based wireless communications technology has been researched and developed for a couple of decades.”

The challenge however, is that light is easily blocked or absorbed by walls, trees, moving objects, fog, or rain. This severely restricts the range of these systems. “When we talk about optical wireless communications, we refer to two approaches: namely free-space optics (FSO) and visible light communications (VLC). The former refers to a connectivity up to a few kilometers using laser beams, whereas the latter refers to short-range wireless communications typically in indoor environments, with ranges below 10 meters,” Katz explains. His work, as part of the 6Gensis consortium, is in this second approach.

The second option is the terahertz band—a band of radiation extending from 0.1 THz to 30 THz—where electric and magnetic fields oscillate at the rate of trillions of cycles per second. Because their wavelength is less than a millimeter, they are also called submillimeter waves.

The terahertz band is the dark horse of the electromagnetic family. They are not just less well known than radio or microwaves, there are also fewer devices that can generate and or modulate these waves. With the exception of submillimeter telescopes in astronomy, the terahertz regime is a technological backwater, so much so that this band is often referred to as the “terahertz gap.”

“Terahertz systems are much less well developed and, as a result, more expensive,” concurs Mittleman. “On the other hand, there are some real reasons that THz is a superior alternative. Issues such as pointing stability, sensitivity to atmospheric turbulence, and eye safety all argue for THz wireless over FSO. Their performance in

adverse weather conditions are complementary: THz is better in rain or fog, but FSO is probably better in snow.”

It is these reasons that have made terahertz an active area of research in the last few years. In particular, a number of photonic technologies built on silicon such as waveguides, filters, multiplexers and demultiplexers, modulators, antennas, and photodetectors have been developed to meet the technological requirements for this medium.

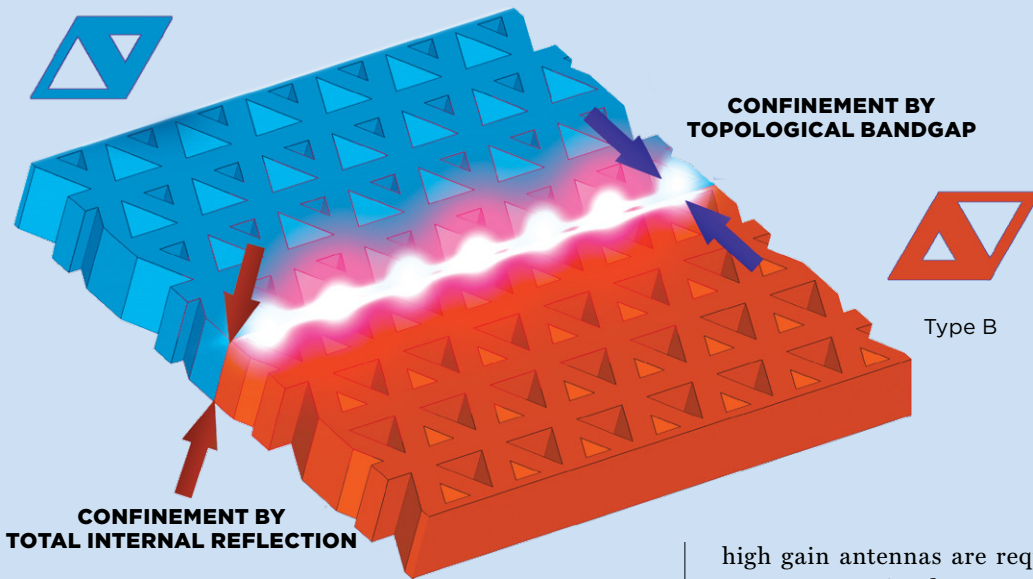
The photomixer, for example, is a simple photonic device that converts optical radiation to terahertz waves in a single step. Here, two laser beams with different frequencies are made to coincide with each other. The result is a wave with frequency equal to the difference of the base frequencies, which falls into the terahertz regime. Coupled with an antenna, photomixers become an excellent terahertz generator that can produce custom terahertz frequencies.

Another photonic technology that is used to generate terahertz signals is the quantum cascade laser. Unlike a typical laser where the electron falls from a higher energy level to a lower energy level, the electrons in this laser “cascade” through a sequence of energy levels before reaching the ground state. A common quantum cascade laser is made of slices of gallium indium arsenide (GaInAs) and aluminum indium arsenide (AlInAs) that are stacked periodically on an indium phosphide (InP) substrate. The cascading energy states of the electron is a product of this periodicity.

Photonics offer a distinct improvement over electronics in the terahertz band. As Guillaume Ducournau, professor at the University of Lille and a leader of THz wireless communications activity explains, “Photonics is one of the driving technologies for THz/6G. It initiates the highest data rates so far and enables characterizations of advanced devices like active circuits in 6G systems.” In 2018, his team demonstrated the first wireless terahertz link using a silicon photonics transmitter. An embedded Ge photodiode generated a 300 GHz signal at a data rate of 10 Gbps that was received by a commercial GaAs Schottky diode.

Another win for silicon photonics is that it's also compatible with current CMOS fabrication facilities. “This allows semiconductor foundries to mass produce 6G devices without a major overhaul of their facilities,” adds Singh. “The key goal is to generate and modulate terahertz signals at the chip level.”

This year, Singh's team at NTU, in collaboration with Masayuki Fujita's team at Osaka University in Japan, attained the highest on-chip terahertz wireless data transfer rate ever recorded: 16 Gbps.



A topological photonic insulator made by etching alternatively large and small triangular holes on a silicon chip

They achieved this using a novel concept called a photonic topological insulator (PTI). This is a material that behaves as an insulator on the inside but conducts electrons or photons at the surface. These conduction states are remarkably robust. They survive twists, turns, bends, and deformation.

Achieving a photonic topological insulator is remarkably simple. A silicon chip is etched with alternating triangular holes of two different sizes so that they arrange themselves into a hexagonal lattice—much like carbon atoms in graphite. The interface of these triangles with air traps light through total internal reflection, ensuring that all the photons are conducted from one end to the other without any scattering. Using this chip, the teams from NTU and Osaka University transmitted an uncompressed 4K video in real time at the rate of 11 Gbps, while navigating 9 bends. The channel frequency was 335 GHz, safely in the 6G terahertz band.

Using a more complex encryption technique known as quadrature amplitude modulation (QAM), the collaborating teams from NTU, Osaka, and Lille have recently pushed this up to 75 Gbps at a bandwidth of 25 GHz. By changing the geometry of the crystal, they are confident of pushing the rates even higher. “The ultimate dream is to get past 100 Gbps using a photonic topological insulator,” said Singh.

While terahertz communications is pushing towards new frontiers, some of the old challenges remain. These waves are absorbed by water and oxygen molecules in the air, and lose energy to free space which severely restricts the range of application. To overcome these,

high gain antennas are required to send focused directional waves. Innovative data transfer methods are also needed, such as multiple-input-multiple-output (MIMO), which multiplies the number of channels at which we receive and send information, increasing the total amount between devices.

However, as Katz reminds us, terahertz communications also has a cost barrier. “THz components could be highly expensive as their design is complex and time-consuming, while optical components are well known, studied, and relatively low cost,” he says.

Katz’s team is pioneering a light-based sensor network designed to collect and exchange information from every part of the human body. “Complementing the IoT, the Internet of the Body (IoB) will keep track of crucial body functions such as heart rate, enzyme levels, and other vital signs. It will safely and securely link implant devices such as pacemakers, gastrointestinal pills, and in-brain devices. Near-infrared signals can easily penetrate up to 5 cm inside the body—enough to reach chest implants—and transmit at 100 Kbps. The hyperfast data rates of 6G are not as much a requirement for the IoB as are safety, reliability, and security.

A light-based Internet of Things (LIoT) is also being explored by Katz and others. The idea is that light signals could connect devices within a room with each other and to the WiFi. To be effective, these signals will need to be directly aimed from the source to the receiver. The advantage is that these devices might be cheap and easily attainable. In aircrafts, visible light communication, also known as LiFi, has been shown to be effective and safe even during takeoff and landing.

In the end, when 6G does come about, it is quite likely that it will use both terahertz and visible light. Katz says, “In the end, optical wireless communications and THz communications could well co-exist in 6G.”

Daniel Mittleman agrees. “Right now, if you want to forecast where we’ll be in 10 years, there is certainly no clear winner between these two approaches. Ultimately, I think there is a place for both of these technologies—and, in situations where maintaining a link is absolutely crucial, you’d probably want both.”

VINEETH VENUGOPAL is a scientist and science writer who loves all things and their stories.

2021 | Light Brings Us Together



IT IS AN UNDREAMED-OF HONOR, AND DEEPLY HUMBLING, to be elected as President of SPIE and accept the many responsibilities that come with the position. When I look back, I never fail to be grateful for the many ways in which my career, indeed my life story, have been enriched through involvement with SPIE. Quite apart from the cutting-edge science and technology I have learned about, I have met so many delightful, clever, and helpful people, and made friends for life. I cannot hope to repay the huge debt I owe this Society, but I do hope, this year especially, to be of useful service to all Members and staff. Please never hesitate to contact me on anything that matters to you, wherever and whoever you are.

Having intended to avoid mention of the coronavirus pandemic, even when the societal influence of the contagion is so relentlessly pervasive, I find myself nonetheless musing on its impact on weathering the past year. Let me share two aspects with you: community and communications. One facet is human; the other, technological.

SPIE's heart is its community—individuals from across the globe, drawn together by technical interests, sharing news and visions, and establishing priceless human contact at the personal level. Close contact is what we most miss, with the ongoing upheaval of all of our familiar ways, plans, and expectations. But as we wait to reset our society when the worst of the pandemic is done, we have meanwhile learned to value more than ever the various means of communication that keep us connected—whether amongst family and friends, or digital forum interactions in virtual symposia.

SPIE Members are well aware of how extensively optics and photonics provide enabling technologies for modern channels of communication. We are accustomed to making high-definition videocalls across the globe, using the fantastic optics built into a modern smartphone. But the means of such direct communication is perhaps less obvious. Well over 99 percent of global data traffic is conveyed by cable, under the water covering two thirds of our globe. And with today's fiber optics, signals travel between North America and Europe in as little as 60 ms.

To put this in perspective, I have on my desk (pictured) a small section of the first permanent transatlantic telegraph cable. On this cable, messages were sent by Morse code at a rate of one alphanumeric character every two minutes—a bit rate of perhaps 0.05 bps. Now, using fiber optics, such intercontinental communications reach speeds of more than 10 Tbps. At each end of the connection, and along most of its length, optical technology is at the heart of our communications. Light brings us together.

Sincere best wishes to all the SPIE community for a safe, healthy, well-connected, and enlightened year.

A handwritten signature in black ink, consisting of a stylized 'D' followed by a long horizontal line extending to the right.

DAVID ANDREWS
2021 SPIE PRESIDENT



SPIE

Deadlines and Events

January 2021

- 6: Abstracts due for SPIE Digital Optical Technologies
- 6: Abstracts due for SPIE Optical Metrology
- 12-14: *Advanced Photonics* Colloquium (online)
- 13: SPIE Startup Challenge semi-finalists announced
- 14: Abstracts due for SPIE Structured Light
- 25-28: SPIE Photonics West Preview (online)
- 26: Henri Poincaré Optical Polarization and Related Phenomena Webinar: Poincaré and his Sphere(s)

February

- 3: Abstracts due for SPIE Optics + Photonics
- 8-12: Mirror Technology SBIR/STTR Workshop
- 15-19: SPIE Medical Imaging Digital Forum
- 16: Abstracts due for OSA/SPIE European Conferences on Biomedical Optics
- 22-26: SPIE Advanced Lithography Digital Forum
- 15: Applications due for SPIE Optics and Photonics Education Scholarships
- 28: Applications due for SPIE Education Outreach Grants

March

- 6-11: SPIE Photonics West Digital Forum
- 7-9: SPIE AR,VR,MR Digital Forum
- 7-10: SPIE Smart Structures + Nondestructive Evaluation Digital Forum
- 12: SPIE Startup Challenge Finals (Healthcare Track)
- 15: Applications due for the Joe and Agnete Yaver Memorial Scholarship
- 15: Nominations due for SPIE Senior Members
- 19: SPIE Startup Challenge Finals (Deep Tech Track)
- 31: Applications due for the Michael Kidger Memorial Scholarship
- 31: Abstracts due for SPIE Remote Sensing and Security + Defence

April

- 11-15: SPIE Defense + Commercial Sensing
- 19-22: SPIE Optics + Optoelectronics
- 20-22: SPIE Structured Light

May

- 12: Abstracts due for SPIE Photomask Technology + EUV Lithography
- 16: International Day of Light
- 16: SPIE International Day of Light Photo Contest opens
- 18-19: SPIE Translational Biophotonics



SPIE. DEFENSE+ COMMERCIAL SENSING

11 – 15 April 2021
Orlando, Florida, USA

See and hear the latest in April

The exchange of information is more important than ever, and as soon as we are able, gathering with colleagues will be essential to reigniting collaborative projects.

We are planning for an in-person experience for SPIE Defense + Commercial Sensing in April 2021. If we cannot safely gather together in person, we will host this event online as a Digital Forum.

SPIE is committed to providing visibility to research results and new solutions in sensors, infrared technology, laser systems, spectral imaging, radar, lidar, AI/machine learning, and more. Learn from experts working on materials, components, systems, and analytics for defense, security, and commercial applications.

spie.org/dcs
[#SPIEDCS](https://twitter.com/SPIEDCS)

2021

SPIE Awards Announced

SPIE Maiman Laser Award

ANNE TROPPER, professor of physics at University of Southampton, in recognition of her pioneering contributions to rare-earth doped fiber and optically pumped semiconductor lasers.

Named in honor of Theodore H. Maiman, the physicist and engineer widely credited with the invention of the laser, the SPIE Maiman Laser Award recognizes individuals who have made sustained contributions to laser source science and technology at the highest level.



Anne Tropper

SPIE Britton Chance Biomedical Optics Award

ENRICO GRATTON, professor in the Department of Biomedical Engineering at the University of Irvine, California, in recognition of his lifetime contributions to the field of biomedical optics, including pioneering theoretical and instrumentation developments in fluorescence spectroscopy, fluorescence microscopy, and diffuse optical imaging, as well as a tireless dissemination of his creative approaches through dedicated conference sessions, short courses, and the establishment of a research resource continuously available to students and scientists since the 1980s.

The SPIE Britton Chance Biomedical Optics Award recognizes outstanding lifetime contributions to the field of biomedical optics through the development of innovative high-impact technologies.



Enrico Gratton

SPIE Biophotonics Technology Innovator Award

SPIE FELLOW KEISUKE GODA, professor in the Chemistry Department at the University of Tokyo, adjunct professor in the Department of Bioengineering at University of California, Los Angeles, and adjunct professor in the Institute of Technological Sciences at Wuhan University, in recognition of significant contributions to the field of biophotonics through the development of innovative ultrafast optical imaging and spectroscopy methods and their integration into microfluidic platforms.

The SPIE Biophotonics Technology Innovator Award recognizes extraordinary achievements in biophotonics technology development that show strong promise or potential impact in biology, medicine, and biomedical optics.



Keisuke Goda

SPIE Frits Zernike Award for Microlithography

SPIE FELLOW BRUCE SMITH, professor and director of the Microsystems Engineering Doctoral Program at Rochester Institute of Technology, in recognition of his many contributions as a researcher and leader in the microlithography community, and for his achievements in educating an entire generation of engineers who continue to advance academic research and industry understanding.

The SPIE Frits Zernike Award for Microlithography recognizes outstanding accomplishments in microlithographic technology, especially those furthering the development of semiconductor lithographic imaging solutions.



Bruce Smith

Tune in to the 2021 SPIE Startup Challenge

THE SPIE STARTUP CHALLENGE is a competitive platform for new businesses that utilize optics and photonics for innovative products or applications. Winning teams share more than \$85,000 in cash and other prizes. Today, light-based technologies enable developments in a proliferating number of areas, from healthcare and high-speed communications, to quantum computing, AR/VR, and self-driving vehicles. The Startup Challenge events aim to create an investor-focused view of the latest trends in optics and photonics, from hot technology markets to the mergers and acquisitions that are reshaping industries.

In this challenging year, the Startup Challenge's 11th year, the industry-judged competition will be moving to an all-online, live-pitching format. Additionally, SPIE will offer a free online entrepreneurial training program that includes pitch clinics, customer-discovery training, and investor-relations training. Anyone considering a startup in optics and photonics is welcome to take part. Teams applying specifically for the Startup Challenge will get feedback on their business and pitch from business development experts and investors.

The semifinals of the competition will feature more than 40 teams pitching new products in photonics-enabled healthcare and deep tech. During the weeks of the SPIE Photonics West, the finals will showcase the best startup participants' pitches and an engaging lineup of photonics-industry speakers and investor roundtables.

Join the kick-off event on 13 January on "Finding Startup Resources in Uncertain Times" for the live announcement of this year's cohort of semifinalists. Learn more at spie.org/startup

Application System is Open for 2021 SPIE Family Care Grants

SPIE BELIEVES THAT PARENTS AND CARE GIVERS should have an equal opportunity in sharing their research and participating in conferences and symposia. SPIE 2021 Family Care Grants are designed to supplement caregiving costs incurred by SPIE Members who are registered to attend any SPIE meeting—including SPIE Digital Forums.

Grants cover caregiving expenses (at home or on site) for children under the age of 13 or dependent care if you are a care giver. The maximum grant amount for in-person meetings is \$500 and the maximum grant amount for attending an SPIE Digital Forum is \$250.

We are working hard to ensure safe and productive opportunities to connect. If you are planning to participate in an SPIE event and need family-care support, consider applying for an SPIE Family Care Grant.

Learn more: spie.org/familycare-grants



SPIE Partners with Global Open-Knowledge Platform The Lens

IN A PUBLISHING-PARTNERSHIP FIRST, SPIE has partnered with The Lens, a robust and comprehensive resource of linked datasets of scholarly and patent works run by Cambia, a long-established global social enterprise.

Under the agreement, all scholarly citation and patent citation data for SPIE publications curated by The Lens will be integrated into the SPIE Digital Library and available to readers.

The SPIE Digital Library, the world's largest collection of optics and photonics applied research, comprises more than 500,000 publications which cover topical areas ranging from biomedical optics and neuroscience, to physics and astronomy-related technology.

Throughout its 20-year history as a public good project, The Lens has been committed to enabling innovation and making problem solving more inclusive, affordable, and transparent. The Lens makes critical knowledge openly available to policy makers, researchers, librarians, tech transfer offices, investors and funders, publishers, law firms, inventive companies, and many others. The Lens hosts and serves discovery, analytics, metrics, and management tools across a massive corpus of scholarly literature and patents linked through citations on an open, verifiable, and privacy-assured platform.

Integrating this data into the SPIE Digital Library will allow SPIE to better communicate the impact of its publications. Importantly and uniquely, this partnership will help researchers and practitioners in industry find each other, build productive partnerships, and see research delivered to the public as real-world outcomes.

Learn more at spie.org/TheLens

First Baur-SPIE Endowed Chair in Optics and Photonics Announced

CINDY REGAL has been named the first recipient of the Baur-SPIE Endowed Chair in Optics and Photonics, JILA's first-ever endowed chair position.

Regal is a renowned and recognized physicist. Her pioneering research has been highly cited and earned a CO-Labs Governor's Award for high-impact research in 2016. Among her other achievements, she won a Packard Fellowship in 2011, was named an American Physical Society Fellow in 2017, and received a 2020 FRED Award from the Research Corporation for Science Advancement.

Her group at JILA pursues a wide range of research in optics and photonics, particularly employing lasers to control and probe quantum objects. For example, she uses lasers to cool mechanical vibrations to their quantum ground state and measure forces at quantum limits. Her group is also exploring quantum processing using optical tweezers that hold and control individual neutral rubidium-87 atoms. The Regal Lab collaborates with the Lehnert Lab to study transduction between microwave and optical signals—work that is important for future quantum-based communications.

"I have been fortunate to be part of the vibrant JILA and Colorado scientific community, and I am grateful to the Bours and SPIE for this incredibly opportunity to advance my group's latest ideas and research at JILA," said Regal.

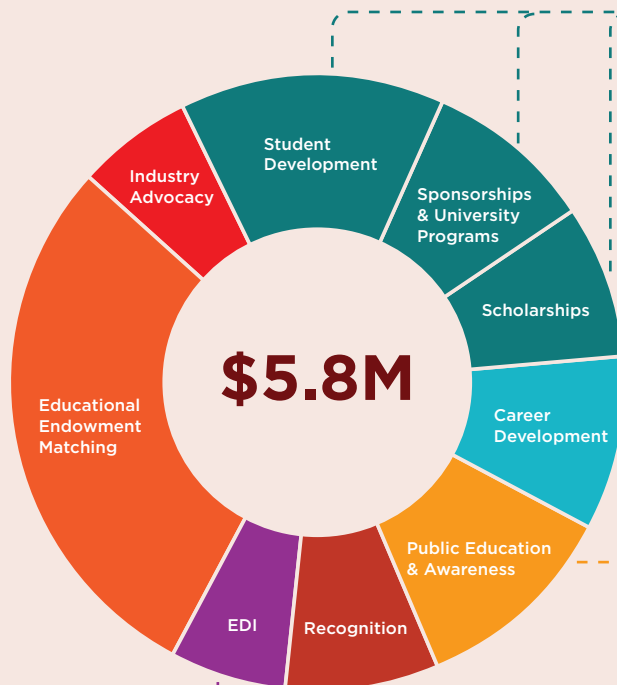
The Baur-SPIE Endowed Chair in Optics and Photonics was founded in 2020. It is funded by a gift of \$1.5 million from private donors Tom and Jeanne Baur of Meadowlark Optics, and a \$500,000 matching gift from SPIE, the international society for optics and photonics. In addition, CU Boulder is contributing \$500,000. The chair is designed for early-to-mid career researchers affiliated with groups historically under-represented at CU Boulder, as well as academics who have an established interest in teaching and mentoring.

INFOGRAPHIC

Your Support at Work in the Community

In a year that tested our resilience, our community made a difference. Together with our Members and customers, SPIE provided over \$5.8 million in community support in 2020.

With your support, SPIE gives back to the next generation of scientists and engineers. Thank you for creating a brighter future; here are just some of the ways your Membership had impact.



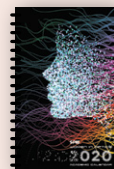
\$5.8M

Equity, Diversity & Inclusion



4,700

Buttons and **1,135** ribbons distributed



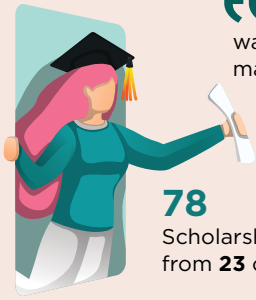
4,000

Women in Optics planners given away

730

Attendees at SPIE EDI events





“ The scholarship...is a real and effective way of supporting my education and I feel that many more opportunities await me now. ”

78
Scholarship winners
from **23** countries

342
Student Chapters in
54 countries, totalling
4,327 students



Student Support

SPIE Quantum West Debuts at Photonics West

ON WEDNESDAY, 10 MARCH, SPIE will offer a one-day, industry-focused conference on quantum technology as a part of SPIE Photonics West. Attendees will learn about the role that photonics plays as quantum technology moves from R&D to engineering products for the commercial marketplace—including the building of a commercial infrastructure and supply chain.

This event, organized in partnership with the Quantum Economic Development Consortium (QED-C) will feature invited talks, a panel, an exhibition, and networking opportunities.

Confirmed speakers at this time include:

- Sir Peter Knight of Imperial College London and the UK National Quantum Technology Strategic Advisory Board for UKRI will give a keynote address
- Jean-François Bobier, partner and associate director of Digital R&D Boston Consulting Group will give a market overview
- Noel Goddard, CEO of Qunnect, Inc. will discuss communications
- Murray Reed, CEO of QLM Technology Ltd will cover sensing and imaging
- Eric Ostby, product manager at Google, will discuss building the quantum industry and its path to the future

Learn more at spie.org/qw

56%
Increase in Career Lab
members from 2019

Career Development



1,200
Attendees at career
advancement programs



Outreach



14
IDL grants totaling more
than **\$30,000** given to
recipients in **10** countries

300K
IDL social media
impressions



2,000
Entries to the IDL photo contest,
including **80** youth entries

Recognition



74
New Senior Members



72
New SPIE Fellows



1,200
Community Champions
recognized for supporting the
optics and photonics
community

9
Companies recognized
with Prism Awards




24
SPIE Award winners,
including two new awards



Reflections

Spectral light was generated from a prism in sunlight and refracted onto a piece of paper. This spectral light was further refracted and reflected by placing five prisms into the path of the light. The prisms were arranged to form a composition of dynamic dispersion patterns on the paper and interesting reflections in the prism faces.

Camera: Nikon D850 Lens: Tamron 28-300mm at 90mm ISO: 50 Aperture: f/16 Shutter speed: 4 sec

Photo by Elizabeth Kazda  beth.kazda

Your Resource. Your Society. Your Community.

Now more than ever, the importance of community is critical. While things may look different, as a Membership Society, our job is still the same: To support our Members.

We will continue to provide recognition, networking opportunities that build connections, access to research, and resources that expand your impact—we are simply increasing the value of your Membership.

Some new benefits include:

- SPIE Online webinar recordings
- Career development webinar recordings and courses
- Free access to LinkedIn Learning courses
- The SPIE Fellow Spotlight podcast series
- Discounted access to in-person and virtual conferences

spie.org/members-only

RECOGNIZE OUTSTANDING MEMBERS

Nominate an SPIE Member—or yourself—for SPIE Senior Member by 15 March 2021.

spie.org/senior-membership



SPIE Photonics West leads the way

The SPIE Photonics West Digital Forum is a convenient, high-quality, and timely way for the photonics community to connect researchers, engineers, and technology providers 6-11 March.

Presentations and discussions will be accessible at any time during the Forum. In addition to high impact technical presentations, the Forum will include networking and business connection opportunities to further your career and research, plus product launches and demonstrations from the world's top technology suppliers and innovators.

Technical Program—Presentations to keep you informed and inspired

- BiOS
- LASE
- OPTO
- Plenaries and Hot Topic sessions
- Training courses and workshops
- Networking opportunities

Digital Marketplace—Connect with the best solutions, components, instruments, and system providers from around the world

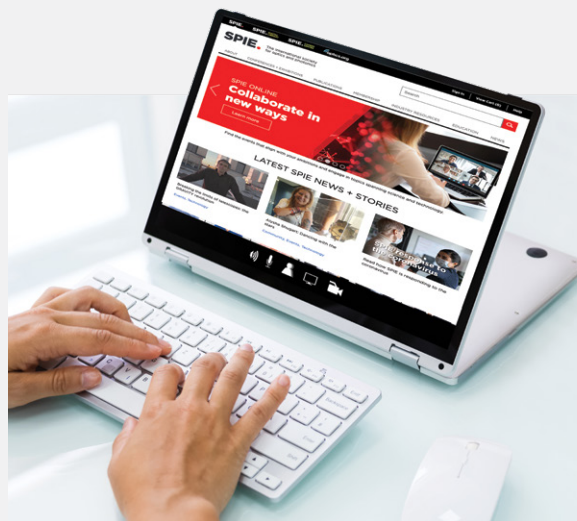
- BiOS Expo and Photonics West
- Product demos and tutorials
- Quantum West one-day workshop -*New*
- Industry Program

SEE THE WEBSITE IN JANUARY FOR PRICING AND REGISTRATION INFORMATION

Get a free preview in January

25-28 January 2021

Register now for the **Photonics West Preview**. A series of webinars featuring presentations and discussions on hot topics, as well as product launches and announcements from the leading photonics companies. spie.org/pw-preview



Upcoming SPIE Digital Forum Events

SPIE Medical Imaging
February 2021

SPIE Advanced Lithography
February 2021

SPIE AR, VR, MR
March 2021

**SPIE Smart Structures +
Nondestructive Evaluation**
March 2021