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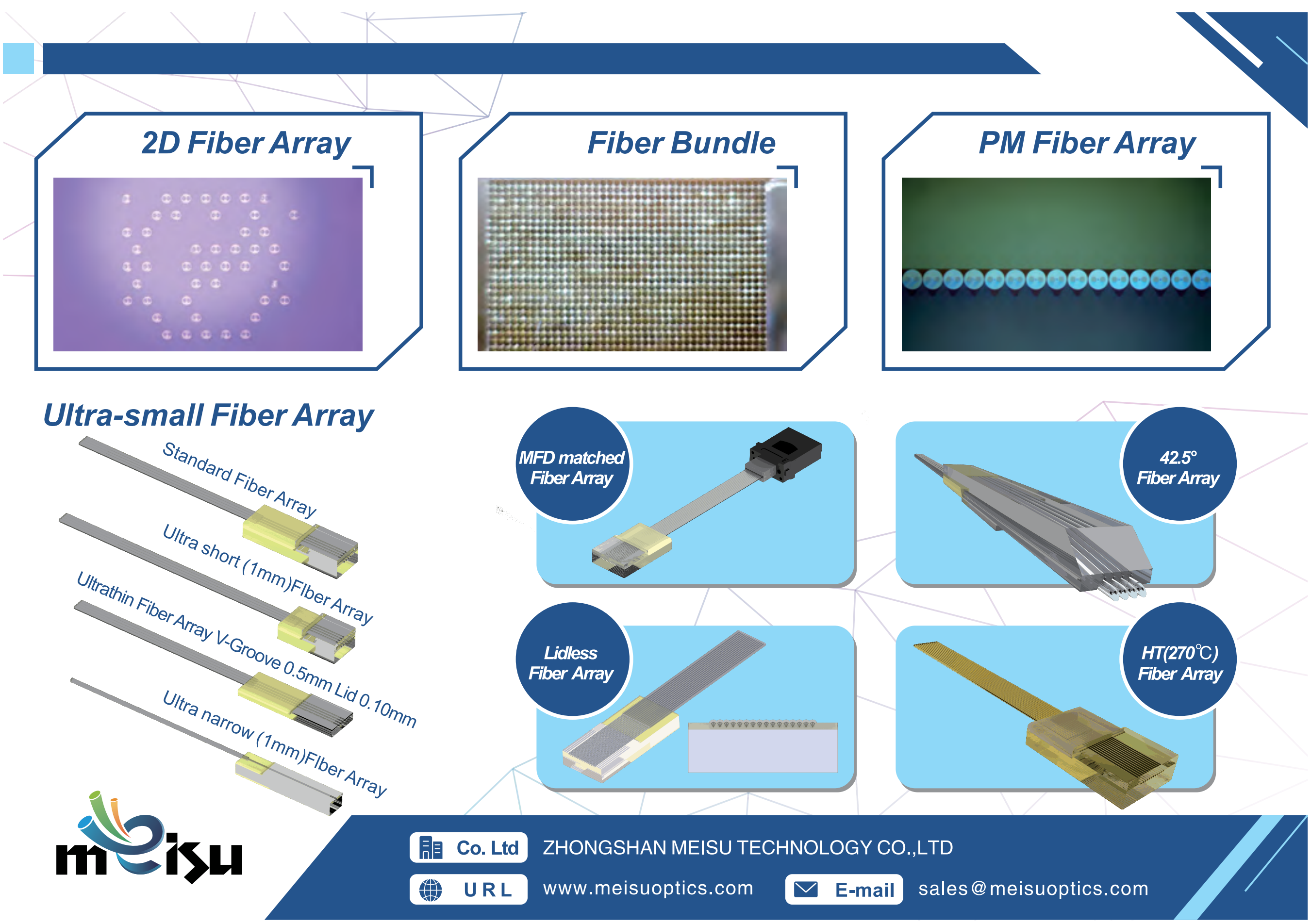
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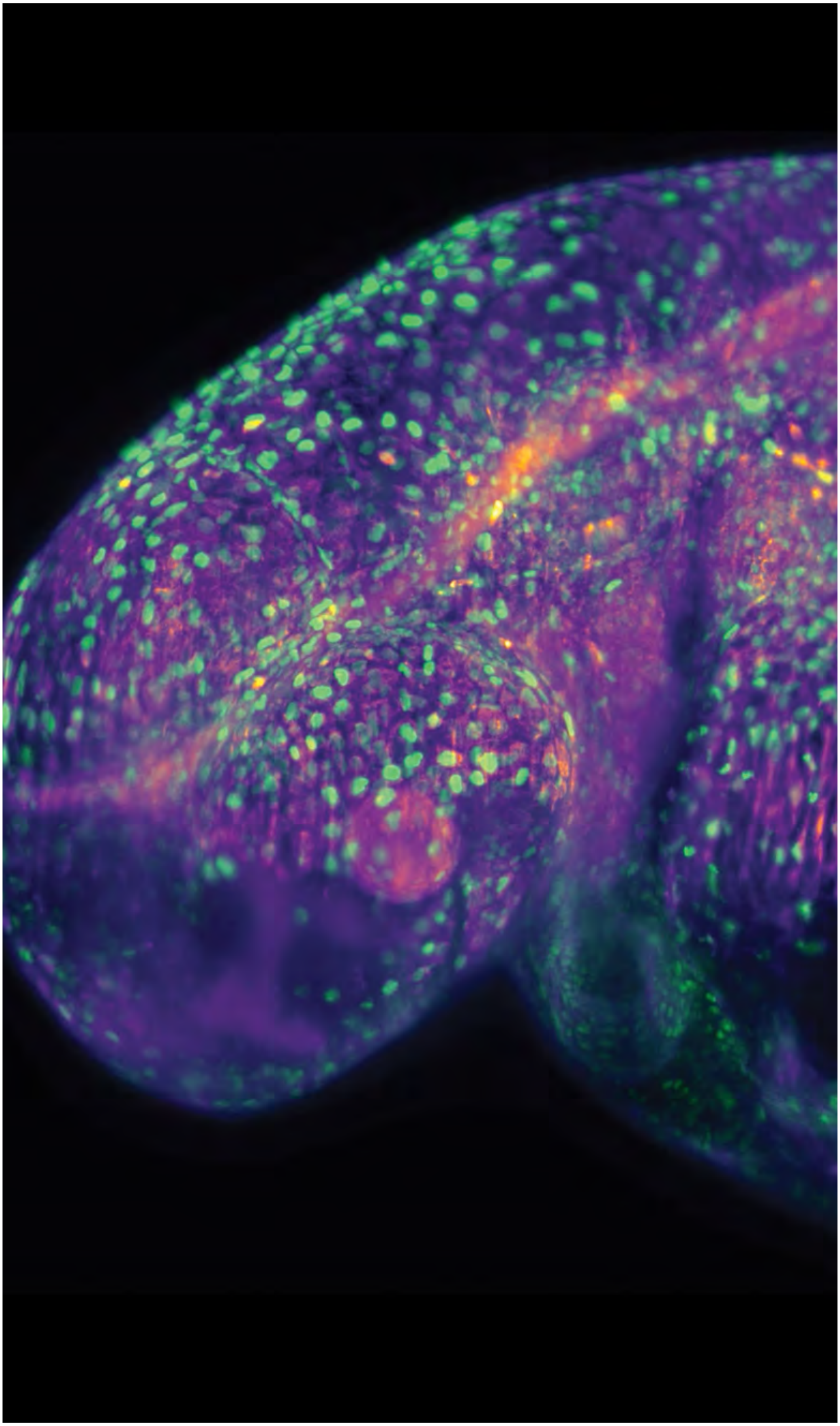

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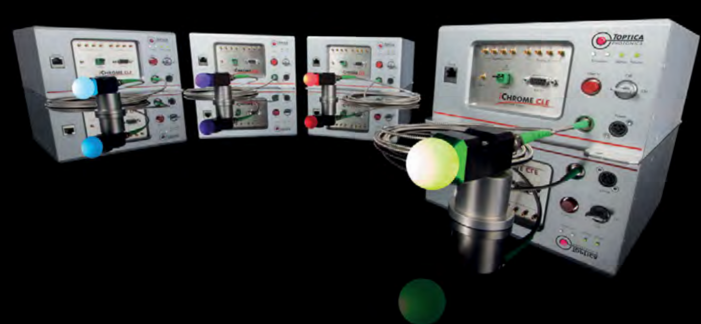
Photo Credit: Alyssa Graves and Jan Huisken, Morgridge Institute for Research



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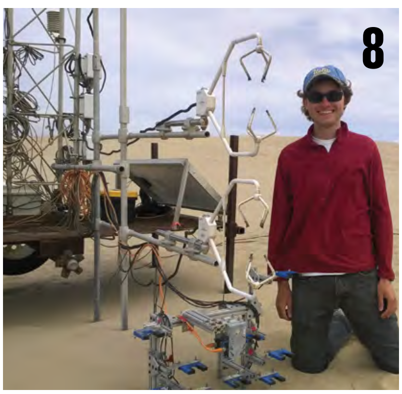

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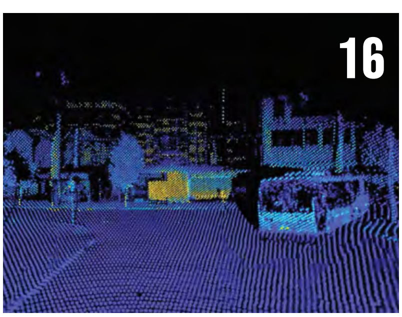

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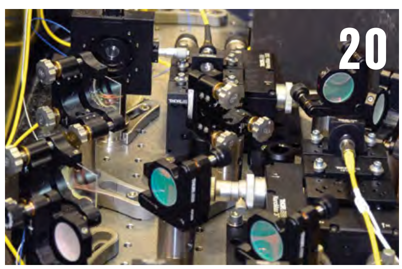

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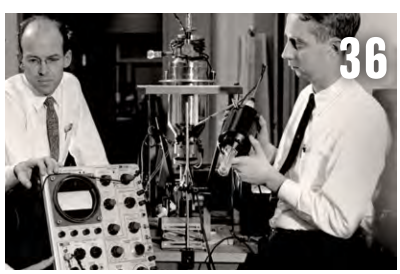

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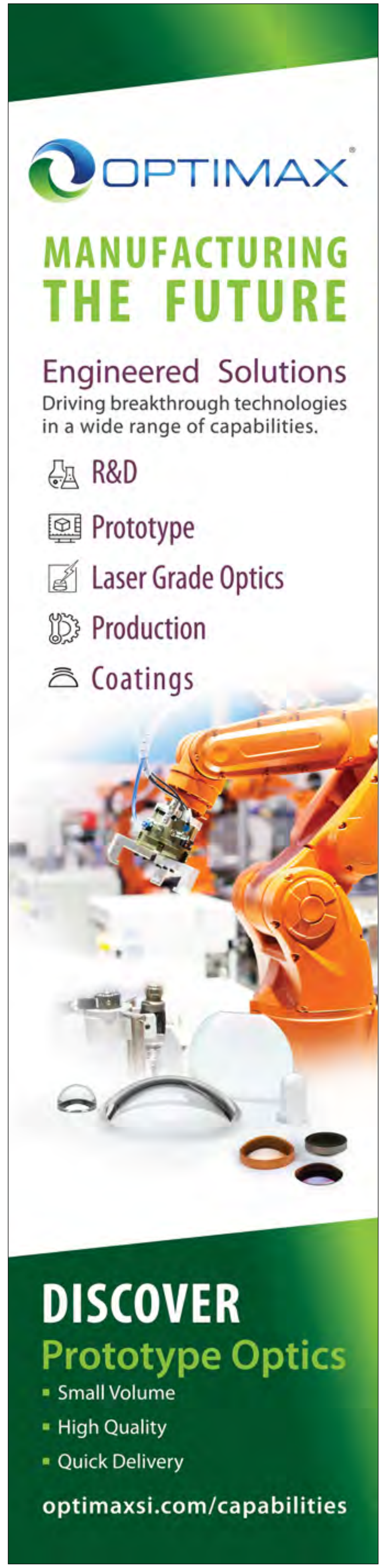

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Errata: In the final October–December 2019 issue of *SPIE Professional*, the image description on p. 5 was reversed. The bottom image showed an image of a sample pill, and the top image showed the same surface imaged with terahertz frequencies.

On p. 39, Naomi Halas's affiliation was accidentally omitted. Naomi J. Halas is the Stanley C. Moore Professor in Electrical and Computer Engineering, professor of biomedical engineering, chemistry, physics & astronomy, and director of the Laboratory for Nanophotonics at Rice University.

Let's Start Again

YOU'RE HOLDING IN YOUR HANDS the first issue of *Photonics Focus*, the new SPIE magazine, which is free for all SPIE Members and replaces *SPIE Professional*. Why do we need a new magazine? Quite a few reasons, and we have you, our readers, to thank for the idea.

In fall 2018, we gathered your feedback about *SPIE Professional* and learned what you liked, what you didn't, and what type of content would compel you to read the magazine.

You said you wanted more rich visuals. You said that the quarterly publication frequency was too infrequent. You asked for more high-level, accessible stories about photonics technology—because if you want in-depth technical detail, you're going to read a journal article. Some of you want to receive new issue alerts by email so you can read it online, and others want the magazine in print because you get too much email.

When we asked you what types of articles you most want to read in a magazine about optics and photonics, these were your top responses:

1. Feature articles on technology
2. Optics and photonics industry updates
3. Histories about how a field evolved, or a key figure in history
4. Professional development information, including soft skills articles and job postings
5. Updates on SPIE mission, goals, and achievements.

Taking all of these ideas into account, we considered a reboot of *SPIE Professional* to better meet your needs, but ultimately decided that the *SPIE Professional* scope and title were no longer aligned with what SPIE Members and advertisers want from a magazine. We decided to start anew, and *Photonics Focus* is the result. The new sections—Sources, Bandwidth, Field of View, Luminaries, and SPIE Community News—are intended to deliver the content you asked for in a fresh, visually driven layout. The features about photonics-enabled technology and applications will be the sort of immersive stories that you want to read on a plane or on your morning commute.

In addition to an increased frequency—from four issues per year to six—you also now have control over how you receive your subscription. You can receive it in print, via email, or both, and that preference can be changed by logging into your SPIE account on **spie.org**. And, the articles will all be freely available at **spie.org/photonicsfocus**.

I'll check in with you at the end of the year to ask if we're better meeting your needs and where we still need to improve. If you want to get in touch before then, you can reach me at **photonicsfocus@spie.org**.

The first issue of *Photonics Focus* celebrates the 60th anniversary of the invention of the laser. We look back at the contributions of a laser luminary, marvel at today's laser research, and look forward to the laser capabilities of the near future.

Thanks for reading,

Gwen Weerts

GWEN WEERTS, ***PHOTONICS FOCUS*** **MANAGING EDITOR**

Reader feedback on *SPIE Professional*

" If each issue focuses on one subject at a time, which it appears to, I would call it something like SPIE Focus, not Professional. Professional doesn't say anything."

" It comes infrequently enough that I forgot the SPIE magazine existed."

" I would like to see something like how to be a more effective communicator, or how to be more effective at some type of soft skill. It's not technical, but this type of information makes you a better human. Better, and more effective."

" We all like lots of pictures!"

" 'Professional' feels very different than what looking through this magazine looks like. It feels just sort of like a relaxed overview of things, which I like, but 'professional' feels not relaxed."

" I'm interested in inventions resulting in real products, manufactured and adopted, to make a practical difference in people's lives."

" *SPIE Professional* needs more articles about popular optics, as well as articles related to the industry and the optics applications."

" It's a bit dry, some more colorful (no pun intended!) and personal stories would be more interesting."

Ten Simple Steps to Writing a Scientific Paper

Andrea Armani's 10-step formula for writing a scientific paper is useful to anyone who feels the dread of the blank page looming

1. WRITE A VISION STATEMENT

What is the key message of your paper? Be able to articulate it in one sentence, because it's a sentence you'll come back to a few times throughout the paper. Think of your paper as a press release: what would the subhead be? If you can't articulate the key discovery or accomplishment in a single sentence, then you're not ready to write a paper.

The vision statement should guide your next important decision: where are you submitting? Every journal has a different style and ordering of sections. Making this decision before you write a single word will save you a lot of time later on. Once you choose a journal, check the website for requirements with regards to formatting, length limits, and figures.

2. DON'T START AT THE BEGINNING

Logically, it makes sense to start a paper with the abstract, or, at least, the introduction. Don't. You often end up telling a completely different story than the one you thought you were going to tell. If you start with the introduction, by the time everything else is written, you will likely have to rewrite both sections.

3. STORYBOARD THE FIGURES

Figures are the best place to start, because they form the backbone of your paper. Unlike you, the reader hasn't been living this research for a year or more. So, the first figure should inspire them to want to learn about your discovery.

A classic organizational approach used by writers is "storyboarding" where all figures are laid out on boards. This can be done using software like PowerPoint, Prezi, or Keynote. One approach is to put the vision statement on the first slide, and all of your results on subsequent slides. To start, simply include all data, without concern for order or importance. Subsequent passes can evaluate consolidation of data sets (e.g., forming panel figures) and relative importance (e.g., main text vs. supplement). The figures should be arranged in a logical order to support your hypothesis statement. Notably, this order may or may not be the order in which you took the data. If you're missing data, it should become obvious at this point.

4. WRITE THE METHODS SECTION

Of all the sections, the methods section is simultaneously the easiest and the most important section to write accurately. Any results in your paper should be replicable based on the methods section, so if you've developed an entirely new experimental method, write it out in excruciating detail, including setup, controls, and protocols, also manufacturers and part numbers, if appropriate. If you're building on a previous study, there's no need to repeat all of those details; that's what references are for.

One common mistake when writing a methods section is the inclusion of results. The methods section is simply a record of what you did.

The methods section is one example of where knowing the journal is important. Some journals integrate the methods

section in between the introduction and the results; other journals place the methods section at the end of the article. Depending on the location of the methods section, the contents of the results and discussion section may vary slightly.

5. WRITE THE RESULTS AND DISCUSSION SECTION

In a few journals, results and discussion are separate sections. However, the trend is to merge these two sections. This section should form the bulk of your paper—by storyboarding your figures, you already have an outline!

A good place to start is to write a few paragraphs about each figure, explaining: 1. the result (this should be void of interpretation), 2. the relevance of the result to your hypothesis statement (interpretation is beginning to appear), and 3. the relevance to the field (this is completely your opinion). Whenever possible, you should be quantitative and specific, especially when comparing to prior work. Additionally, any experimental errors should be calculated and error bars should be included on experimental results along with replicate analysis.

You can use this section to help readers understand how your research fits in the context of other ongoing work and explain how your study adds to the body of knowledge. This section should smoothly transition into the conclusion.

6. WRITE THE CONCLUSION

In the conclusion, summarize everything you have already written. Emphasize the most important findings from your study and restate why they matter. State what you learned and end with the most important thing you want the reader to take away from the paper—again, your vision statement. From the conclusion, a reader should be able to understand the gist of your whole study, including your results and their significance.

7. NOW WRITE THE INTRODUCTION

The introduction sets the stage for your article. If it was a fictional story, the introduction would be the exposition, where the characters, setting, time period, and main conflict are introduced.

Scientific papers follow a similar formula. The introduction gives a view of your research from 30,000 feet: it defines the problem in the context of a larger field; it reviews what other research groups have done to move forward on the problem (the literature review); and it lays out your hypothesis, which may include your expectations about what the study will contribute to the body of knowledge. The majority of your references will be located in the introduction.

8. ASSEMBLE REFERENCES

The first thing that any new writer should do is pick a good electronic reference manager. There are many free ones available, but often research groups (or PIs) have a favorite one. Editing will be easier if everyone is using the same manager.

References serve multiple roles in a manuscript:

1) To enable a reader to get more detailed information on a topic that has been previously published. For example: "The device was fabricated using a standard method." You need to reference that method. One common mistake is to reference a paper that doesn't contain the protocol, resulting in readers being sent down a virtual rabbit hole in search of the protocol.
2) To support statements that are not common knowledge or may be contentious. For example: "Previous work has shown that vanilla is better than chocolate." You need a reference here. Frequently, there are several papers that could be used, and it is up to you to choose.
3) To recognize others working in the field, such as those who came before you and laid the groundwork for your work as well as more recent discoveries. The selection of these papers is where you need to be particularly conscientious. Don't get in the habit of citing the same couple of papers from the same couple of groups. New papers are published every day—literally. You need to make sure that your references include both foundational papers as well as recent works.

9. WRITE THE ABSTRACT

The abstract is the elevator pitch for your article. Most abstracts are 150–300 words, which translates to approximately 10–20 sentences. Like any good pitch, it should describe the importance of the field, the challenge that your research addresses, how your research solves the challenge, and its potential future impact. It should include any key quantitative metrics. It is important to remember that abstracts are included in search engine results.

10. THE TITLE COMES LAST

The title should capture the essence of the paper. If someone was interested in your topic, what phrase or keywords would they type into a search engine? Make sure those words are included in your title.

ANDREA MARTIN ARMANI *is an SPIE Fellow and the Ray Irani Chair in Engineering and Materials Science and Professor of Chemical Engineering and Materials Science at the USC Viterbi School of Engineering.*

Read the full article online (**spie.org/sciencewriting**)

OPTICS DOES THAT?

Seeing the World in a Grain of Sand

IMAGINE—YOU HAVE DISCOVERED a distant planet, and you can see that parts of it are covered by rolling sand dunes. Dunes are formed by wind, which means the planet has an atmosphere! You want to know more about this atmosphere, but how? It's time to call aeolian geomorphologist, Dr. Raleigh Martin.

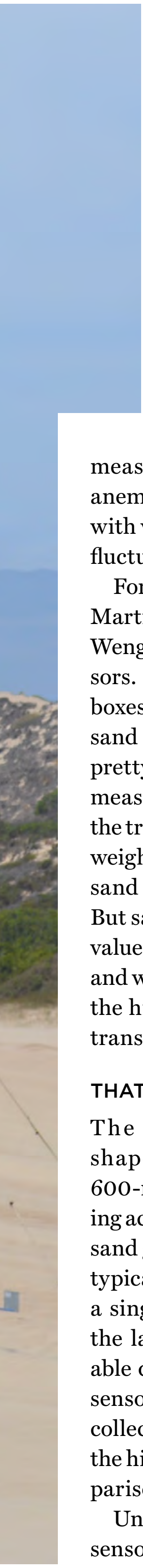
Geomorphology is the study of physical features on a planet's surface, and aeolian geomorphology is the study of wind-created landforms (aeolian comes from Æolus, the Greek god of the wind). Sand dunes and how they form was the subject of Martin's postdoctoral research at UCLA in the Department of Atmospheric and Oceanic Science. "I was trying to understand the relationship between the strength of the wind and the movement of the sand that forms the dunes," says Martin. Knowing how dunes form is important for beach restoration and coastal protection, and it has applications in climate and planetary science.

Martin set up instruments in the field to study coastal dune formation. For Martin, "the field" means at the beach. Sounds like a good excuse to get a tan, right? Not for the kinds of measurements Martin was taking. "The wind has to exceed a certain threshold strength before the sand starts moving. So, we would set up our instruments on days when the wind was high," says Martin. As an official expert on wind and sand movement on the beach, Martin recommends enjoying the beach on days where the wind speed does not exceed 10 to 15 miles per hour, the approximate speed at which sand begins moving.

The goal of Martin's research was to measure wind behavior simultaneously with sand movement, in order to examine the relationship between them. The challenge in making these measurements is that wind speed is not a static value, either temporally or spatially. Wind is turbulent, and it gusts; it also varies by its distance from the ground. Martin

Field setup showing the 10-meter tower with sonic anemometers.

Photo Credit: Raleigh Martin



HIS MEASUREMENTS DEMONSTRATED THAT THE WIND SPEED NECESSARY TO GET A PARTICLE MOVING IS HIGHER THAN THE WIND SPEED NECESSARY TO KEEP A PARTICLE MOVING.

measured wind behavior with a sonic anemometer, which is “able to tell you with very high temporal resolution what fluctuations there are in the wind.”

For measurements of sand movement, Martin used two devices: sand traps, and Wenglor YH03PCT8 photoelectric sensors. Sand traps are triangular-shaped boxes placed near the ground to collect sand that is blown into them. “They’re pretty foolproof,” says Martin. Once the measurement period is over “you empty the trap into a bag, take the bag to the lab, weigh it, and then you know how much sand moved over that period of time.” But sand traps only provide an averaged value over the measurement time period, and what Martin wanted to examine was the high-frequency fluctuations in sand transport.

THAT’S WHERE OPTICS COMES IN!

The Wenglor devices are fork-shaped attenuation sensors, with a 600-micron-diameter laser beam passing across the gap to a photodetector. The sand grains Martin was measuring were typically 300 to 500 microns in size, so a single grain of sand passing through the laser beam could create a measurable drop in transmission, allowing the sensor to record its passage. Data was collected at a rate of 25 Hz, generating the high-resolution data needed for comparison to wind measurements.

Unfortunately, this particular optical sensor wasn’t designed for a sandy, outdoor environment. Aeolian geomorphology is a very niche field, and as such, the market isn’t large enough for there to be a wide variety of dedicated measurement tools. So Martin had to use instruments designed for other purposes. The Wenglor device was created for a manufacturing environment, which is not as clean as a laboratory, but nothing like a windy beach. Dust accumulating on the device could cause measurement drift, as could changes in ambient light. By using the sand traps in conjunction, Martin was able to provide a robust calibration for the optical measurements.

“One thing we found, which had been theorized but never directly shown from field data, is that there’s a hysteresis,” says Martin. His measurements demonstrated that the wind speed necessary to get a particle moving is higher than the wind speed necessary to keep a particle moving. “We know when the wind is really strong, a lot of sand is moving. When the wind is really weak, there is no sand moving. But what is that wind speed above which you go from nonmoving sand to moving sand? We were able to tease that out by having this high-frequency signal.”

So now you know. Aeolian geomorphology: optics does that.

CHRISTINA C. C. WILLIS *is a laser scientist and writer living in Washington, DC, where she is currently serving on Capitol Hill as the 2019–2020 OSA and SPIE Arthur H. Guenther Congressional Fellow.*

Read the full article online (**spie.org/aeolian**)

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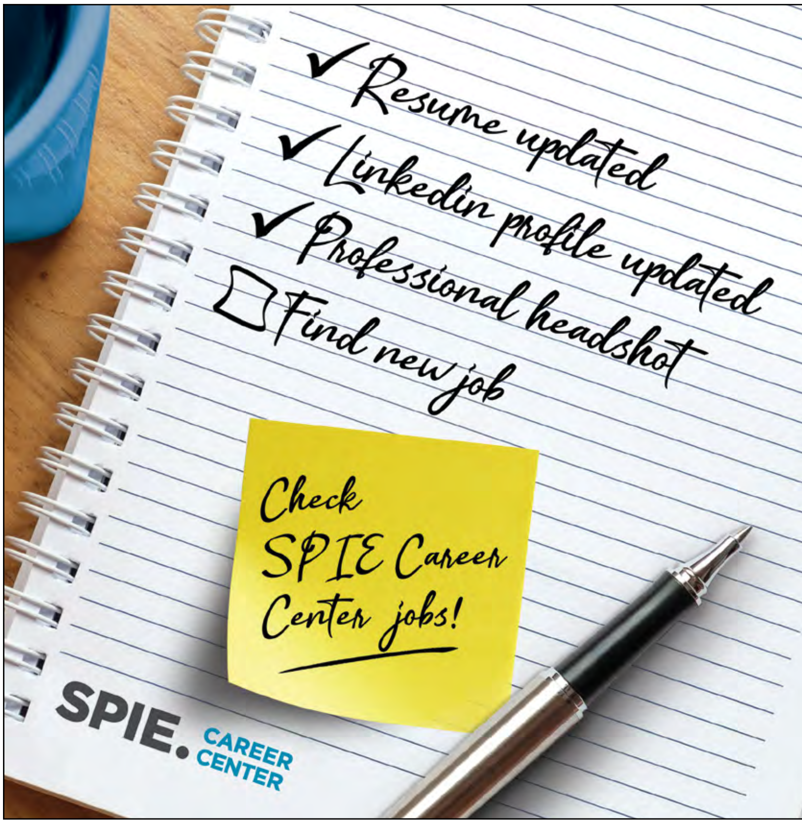

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Where Is the New Collar Workforce?

Optics companies large and small face a hiring shortage for skilled technicians

OPTICAL ENGINEERS are commonly defined as people with advanced degrees who design new products and systems, whereas technicians are the people working with their hands to create those systems. The optics economy depends on technicians to bring products to market, but there's a serious workforce shortage.

Laser company Coherent is familiar with the issue. "About 20 years ago we went through the telecom boom and everyone was hiring, and it was very difficult to get trained technicians, so we hired people that didn't have enough skill level," says Norman Hodgson, the vice president for technology and advanced research at Coherent. "Because we had unskilled technicians building lasers, we then had a bunch of warranty issues about a year later. It became very obvious that there's a need to have more skilled people building lasers."

The reasons for this labor shortage are many, but most agree that the stigma of not pursuing a four-year college degree is one of the biggest barriers.

"In the US there's a cultural idea that if you don't go to university, you're a failure," says Erick Koontz, director of engineering at FISBA US. "We should be showing students that they can still earn quite a lot and have a great career in optics without going through the intermediate purgatory of being saddled with crazy amounts of student loan debt."

Skilled jobs like optical technicians and electrical engineers are often referred to as "new collar." These jobs bear little resemblance to industrial assembly line manufacturing jobs of sixty years ago, because they are often skilled, rewarding, and well paid, with opportunities for advancement and continued training. But getting the word out about these technical career paths remains a challenge.

Alexis Vogt, endowed chair and associate professor of optics at Monroe Community College (MCC) in Rochester, New York, is well aware of the PR effort needed to make optics part of high school student vocabulary. She says, "The biggest obstacle is getting the word out. No high schooler is thinking 'I'm going to be an optics technician.'"

The outreach about the availability of high-tech jobs may need to begin with parents and high school guidance counselors, both of whom have a lot of influence over high school students' post-secondary education.

In addition, adults considering a career change, including veterans and immigrants, might find a career as an optics and photonics technician an attainable option. Last year, Coherent worked with San Jose City College (SJCC) to create a 30-second video to promote the SJCC Laser Technology Program. The trailer played for two weeks in eight movie theatres in the San Francisco Bay Area.

If a convincing message can stimulate a new wave of technicians, the workforce will be ready for them. Last year, 17 program graduates from MCC entered the optics industry, but that number doesn't begin to meet the regional need. According to Vogt, 574 technician jobs are needed per year in the Finger Lakes area of New York alone, and 97 percent of skilled optics technician job openings go unfilled.

In the meantime, companies are getting creative about addressing their shortage. In 2016, Optimax took advantage of federal funding to develop an apprenticeship program. Their strategy is to hire for unskilled entry-level positions, then offer apprenticeships to build employees' skills. Apprentices take classes at MCC while working at Optimax.

Coherent, based in San Pablo, California, takes a different approach. They partner with the Laser Technology Program at SJCC, where they help design the curriculum and donate equipment, like breadboards and laser systems. Coherent and other Bay Area laser companies have hired many of the graduates from the SJCC laser technology program.

But it's still a drop in the bucket. "In our facility alone, we have 150 technicians," says Hodgson. "So if the SJCC program graduates 15 people per year, and there are seven laser companies in the Bay Area, it's just not enough."

"This is a huge hole that needs to be filled," agrees Koontz. "I think the community colleges in partnership with companies can and should do most of the heavy lifting. But SPIE may be useful in lighting the spark, networking between industry and academia."

GWEN WEERTS *is the managing editor of* Photonics Focus.

Photo Credit: Indian Hills Community College

National Quantum Initiative Turns One

By **Jennifer Douris O'Bryan**

AS THE NATIONAL QUANTUM INITIATIVE (NQI) passed the one-year mark on 21 December 2019, progress was clearly evident, as was excitement and hope that the initiative will be successful in providing the kind of support needed to make the United States a leader in the technology applications to come. US agencies are quickly ramping up their activities related to the NQI, and Congress is eyeing a surge of funds that will be integral to fulfilling the vision set forth for the initiative.

One of the first significant steps in implementation of the NQI was the establishment of the National Quantum Coordination Office within the Office of Science and Technology Policy (OSTP). The office is charged with overseeing interagency quantum programs, including coordination of the National Science Foundation and Department of Energy Quantum Centers. The coordination office also provides support to the National Science and Technology Council's Subcommittee on Quantum Information Science and the yet-to-be-formed NQI Advisory Committee.

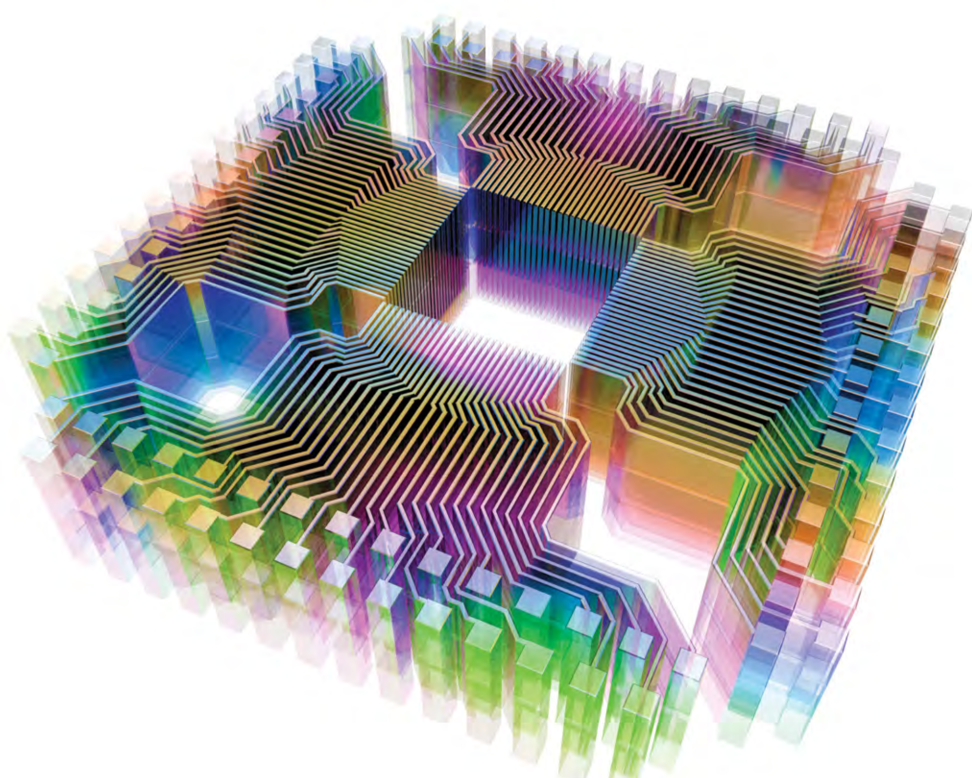
In early 2019 the Department of Energy (DOE) Office of Science sought input from the public regarding the DOE Quantum Centers and announced their intention to issue a Funding Opportunity Announcement in FY2020 to establish these centers, an undertaking that will be subject to available funds.

DOE also took the lead in assembling a NQI Advisory Committee by requesting nominations. Members of this committee will provide advice to guide US quantum programs, including "assessments of trends and developments in quantum information science and technology (QIST), implementation and management of the NQI, whether NQI activities are helping to maintain United States leadership in QIST, whether program revisions are necessary, what opportunities exist for international collaboration and open standards, and whether national security and economic considerations are adequately addressed by the NQI." Members of the committee will be picked in consultation with OSTP.

The National Science Foundation (NSF) is also moving forward in the process of establishing centers through their Quantum Leap Challenge Institutes (QLCI). These centers will include "focus areas of quantum computation, quantum communication, quantum simulation and/or quantum sensing." The solicitation also states that NSF intends for awards to be at $5 million a year for five years per center. Although the deadline for full proposals for round one of QLCI is past, Letters of Intent for round two of the solicitations for centers are due on 3 August 2020, followed by a deadline for preliminary proposals on 1 September. Full proposals are by invitation only and due on 1 February 2021.

The National Institute of Science and Technology (NIST) made quick work of establishing their Quantum Economic Development Consortium (QED-C), which began before the authorization was passed into law. According to the announcement from NIST, the QED-C "members will collaborate on precompetitive R&D such as quantum device design and prototyping, increase efficiencies while sharing resources, and leverage their own research investments with those of the federal government and other members." QED-C had 63 corporate and university members as of May 2019 and is growing fast.

Though the NQI set forth authorization amounts for quantum activities in the bill, this is not the same as providing appropriations, which is needed for the relevant agencies to see increases in



*This story will be updated online (**spie.org/NQIturnsone**) funding. Both the US House of Representatives and the Senate have passed their own funding bills covering the relevant agencies.

While both bills included positive language regarding funding of the NQI, the Senate language was more specific in directing funding amounts to these activities. For NIST, the Senate provided a $10 million increase over FY2019 funding levels. For NSF, the Senate provided $106 million towards general quantum research and $50 million for five quantum centers. For DOE, the Senate provided $120 million for general quantum research and $75 million for up to five quantum centers.

In the House, funding for DOE Office of Science and NSF Research, which are the accounts that contain funding for quantum, were increased significantly, but they did not specifically direct funding toward NQI activities, leaving it up to the agencies to prioritize NQI funding. For NIST, the House bill provided $8 million over FY19 in funding toward its quantum activities. Though the Senate bill was higher in terms of NIST funding for quantum, both House and Senate fall far below the $80 million authorized for NIST's quantum activities.

Though these significant increases in funds are a positive sign of congressional intent, there is still disagreement between the House, Senate, and the White House on how to proceed with the appropriations process in general. Until a funding agreement can be reached to allow FY20 appropriations bills to move forward, the surge of new funding being requested for the NQI will be delayed, as will implementation of the NQI as envisioned by congress and the quantum community.

As one of the founding members of the National Photonics Initiative (NPI), SPIE has led in the effort to pass the NQI Act and is currently lobbying to fund the initiative. The NPI is co-founded by SPIE and OSA, along with the support of APS, IEEE Photonics, and LIA.

JENNIFER DOURIS O'BRYAN
is the SPIE Director of Government Affairs.

Industry Updates

M&A

» **AMETEK, Inc.** acquired **Gatan, Inc.** from **Roper Technologies, Inc.** for $925M on October 31, 2019.

» **Carinthian Tech Research AG** acquired by **Silicon Austria Labs GmbH** for an undisclosed amount effective June 25, 2019. CTR is now called Silicon Austria Labs GmbH.

» **DiniGroup** acquired by **Synopsys, Inc.** for an undisclosed amount effective November 15, 2019.

» **Finisar Corp.** acquired by **II-VI Inc.** for $3.2B, effective September 25, 2019. The combined company will be organized into two segments: Photonic Solutions and Compound Semiconductors.

» **FLIR** acquired the intellectual property and tethered drone operating assets of **Aria Insights, Inc.** on October 3, 2019. The terms of the deal are not disclosed.

» **FocalSpec Ltd.** acquired by **TKH Group NV** for an undisclosed amount effective October 31, 2019.

» **ThorLabs, Inc.** acquired **KMLabs** Y-Fi™ portfilio of fiber laser products for an undisclosed amount effective October 28, 2019.

» **Minifab (Australia) Pty Ltd.** acquired by **SCHOTT AG** for an undisclosed amount effective June 5, 2019.

» **Nanometrics Inc.** and **Rudolph Technologies, Inc.** have merged to form **Onto Innovation Inc.** effective October 21, 2019.

» **Nutronics** acquired by **nLight** for $33.3M cash-plus-stock, effective November 14, 2019.

» **Operations Technology, Inc. (OPTEK)** acquired by **Thorlabs, Inc.** for an undisclosed amount effective October 14, 2019. OPTEK will form a new Thorlabs entity called **Thorlabs Measurement Systems**.

» **QinetiQ Group PLC** to acquire **MTEQ, Inc.** for $105M and is expected to close in the second half of 2020.

» **Silicon Microstructures, Inc.** acquired by **TE Connectivity Ltd.** from **ELMOS Semiconductor AG** for an undisclosed amount effective October 7, 2019.

Executive Updates

» **Constantin Häfner** named new director of **Fraunhofer ILT**, effective November 2019. He succeeds **Reinhart Poprawe** who is retiring.

» **James Schreiner** appointed Sr. VP and COO of **MKS Instruments, Inc.** effective September 16, 2019.

» **Karl Lamprecht** appointed President and CEO of **Carl Zeiss AG** effective April 1, 2020. He will succeed **Michael Kaschke**.

» **Yves Maitre** appointed CEO of **HTC Corp**. effective September 17, 2019. He succeeds **Cher Wang**.

» **Alexander Davern** to step down as CEO of **National Instruments Corp.** effective January 21, 2020. He will be succeeded by current CFO **Eric Starkloff** effective February 1, 2020.

» **Sang Beom Han** stepped down as CEO of **LG Display** effective September 17, 2019.

2020 Prism Awards

Finalists

WINNERS WILL BE ANNOUNCED AT SPIE PHOTONICS WEST 2020

COMMUNICATION
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Cailabs
Innolume

ENERGY / EFFICIENCY
Innovations in Optics
Osram
Prisma Photonics

HEALTHCARE
Modulight
Norlase
PhotoniCare

LIFE SCIENCES
CellOptic
Hamamatsu
TERA-print

MANUFACTURING
Inspekto
IPG Photonics
TRUMPF Lasertechnik

QUALITY CONTROL
CCS & EFFILUX
CloudMinds
Si-Ware Systems

SAFETY & SECURITY
Allied Vision Technologies
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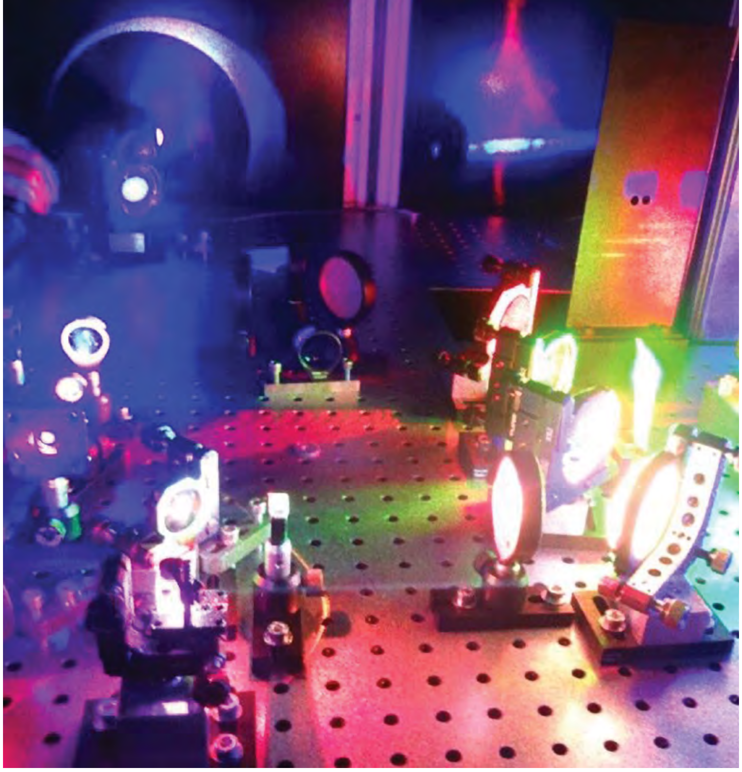


Ultimate Holography Creates Images of "Unprecedented" Quality

French firm's Chimera printer may obviate costly lasers, slow printing, limited FOV, and unsaturated color

RESEARCHERS IN FRANCE HAVE developed a new type of optical printer that produces digital 3D holograms with what they call "an unprecedented level of detail and realistic color." The printer can make high-resolution color recreations of objects or scenes for museum displays, architectural models, fine art, or advertisements without requiring glasses or viewing aids.

"Our 15-year research project aimed to build a hologram printer with all the advantages of previous technologies while eliminating known drawbacks such as expensive lasers, slow printing speed, limited field of view, and unsaturated colors," commented team leader Yves Gentet from Ultimate Holography in Bordeaux, France. "We achieved this by creating the Chimera printer, which uses low-cost commercial lasers and high-speed printing to produce holograms with high-quality color that spans a large dynamic range."

The new printer creates holograms with wide fields of view and full parallax on a special photographic material they designed. Full parallax holograms reconstruct an object so that it can be viewed from all directions, in this case with a field of view spanning 120 degrees.

The printer can create holograms from 3D computer-generated models or from scans acquired with a dedicated scanner developed by the researchers. The high-quality holograms can even be used as masters to produce holographic copies.

When developing the new hologram printer, the researchers carefully studied two types of previously developed holographic printer technologies to understand their advantages and drawbacks.

"The companies involved in developing the first two generations of printers eventually faced technical limitations and closed," said Gentet. "Our small, self-funded group found that it was key to develop a highly sensitive photomaterial with a very fine grain rather than use a commercially available rigid material like previous systems."

The Chimera printer uses red, green, and blue low-power commercially available continuous-wave lasers with shutters that adjust the exposure for each laser in a matter of milliseconds. The researchers also created a special antivibrating mechanical system to keep the holographic plate from moving during the recording.

Holograms are created by recording small holographic elements known as hogels, one after another using three spatial light modulators and a custom designed full-color optical printing head that enables the 120-degree parallax. After printing, the holograms are developed in chemical baths and sealed for protection.

The hogel size can be toggled between 250 and 500 µm and the printing rate adjusted from 1 to 50 Hz. For example, if a hogel size of 250 µm is used, the maximum printing speed is 50 Hz. At this speed it would take 11 hours to print a hologram measuring 300 × 400 mm, which is about half of the time it would take using conventional hologram printing systems based on pulsed lasers.

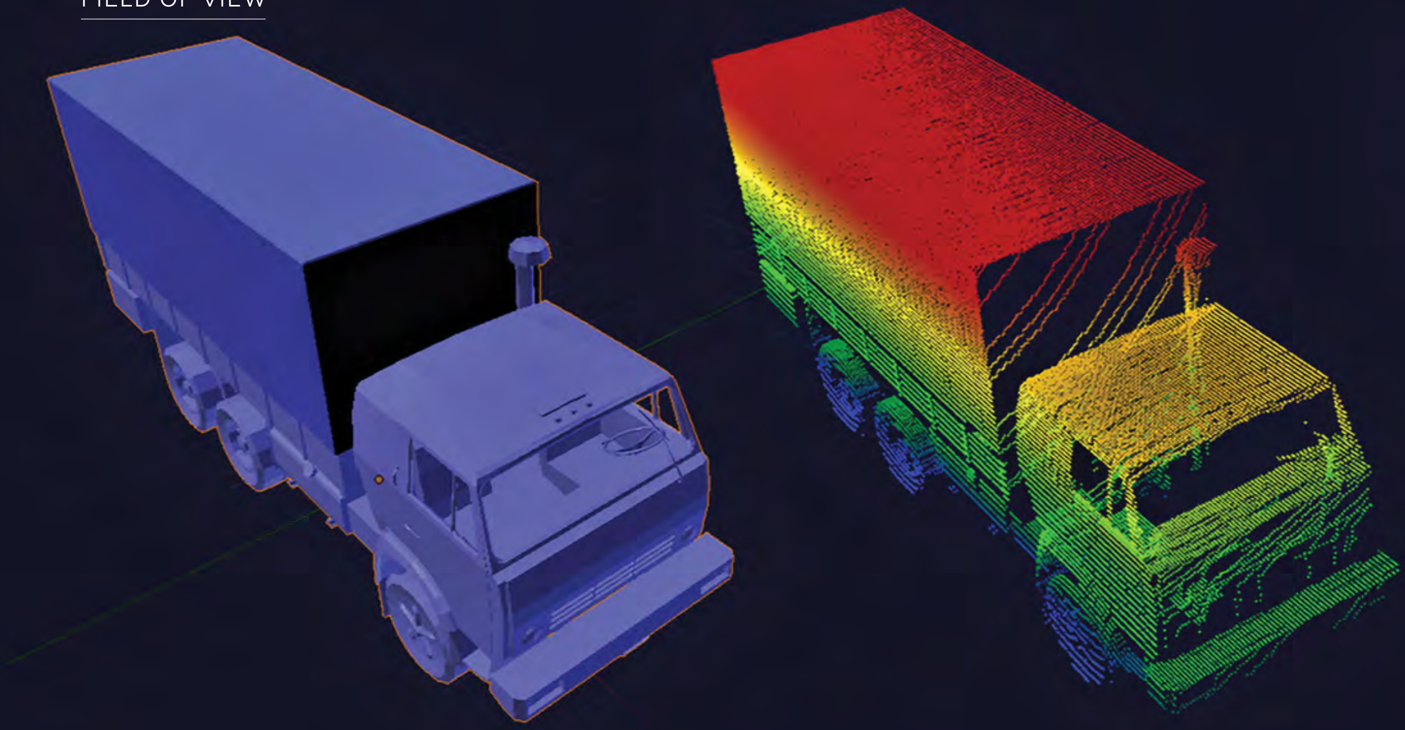
The team used the new technology to print holograms that measured up to 600 × 800 mm showing various color objects including toys, a butterfly, and a museum object.

"The new system also offers a much wider field of view, higher resolution, and noticeably better color rendition and dynamic range than previous systems," said Gentet. "The full-color holographic material we developed provides improved brightness and clarity while the low-power, continuous-wave lasers make the system easy to use."

The researchers say that as technology improves, especially 3D software, it may be possible to expand their hologram printing approach to medical or other advanced applications.

This article first appeared on optics.org.

Photo Credit: C. Gentet



Lidar System Partnership Intends to End Toll Road Delays

Cepton Technologies and MechaSpin collaborate to deliver laser-based traffic monitoring and billing system

A new technology partnership is set to transform road tolling for both providers and motorists alike by utilizing a combination of lidar technology and data analytics. Cepton Technologies has collaborated with MechaSpin, an industrial perception and machine-learning systems developer, to create a lidar-based solution that produces detailed 3D classification of vehicles in real time for automated tolling applications.

The solution combines Cepton's Sora-P60 with MechaSpin's MSx software to enable immediate profiling and classification of vehicles traveling at highway speeds in a wide range of weather and lighting conditions.

Conventional road tolling systems often depend on physical infrastructure to reduce vehicle speed, or tollbooths to allow for manual processing, which can cause congestion and frustration amongst motorists. Advanced systems that allow for faster tolling, however, are often subject to abuses such as leakage, while road-based sensors often fail due to wear and tear.

Cepton and MechaSpin's solution addresses these challenges by eliminating the need for physical infrastructure while providing accurate data, such as vehicle velocity, size, and axle count, in a format that can be integrated with other sensor, data capture, and billing systems. The hardware is designed for aerial installation and contains minimal moving parts, reducing the likelihood of failure.

Neil Huntingdon, Cepton's VP of business development, commented, "This partnership will bring major innovations to the tolling industry. Our Sora-P60 lidar delivers an unrivaled scan speed at 380 Hz, making it possible to profile vehicles as they pass at highway speeds. Our partnership with MechaSpin will allow for faster, more accurate, and lower cost management of our transport infrastructure as the number of vehicles continues to grow globally."

Danny Kent, MechaSpin's president, added, "The tolling industry lacks an integrated end-to-end solution for deploying 3D lidar for vehicle classification and tracking. MechaSpin and Cepton have partnered to deliver a solution for this need. Cepton's lidar technology coupled with MechaSpin's MSx Processing Engine offers a robust solution for tolling, intermodal, and other transportation industry applications."

Cepton says its Micro Motion Technology (MMT) is unlike conventional beam-steering technologies, such as spinning lidar and MEMS. Instead Cepton's MMT architecture enables a mirrorless, frictionless, and rotation-free system to increase the durability of the product, while delivering accurate 3D sensing. The company showcased its lidar solutions at the 26th Intelligent Transport Systems World Congress in Singapore in October 2019.

This article first appeared on optics.org.

Photo Credit: Cepton Technologies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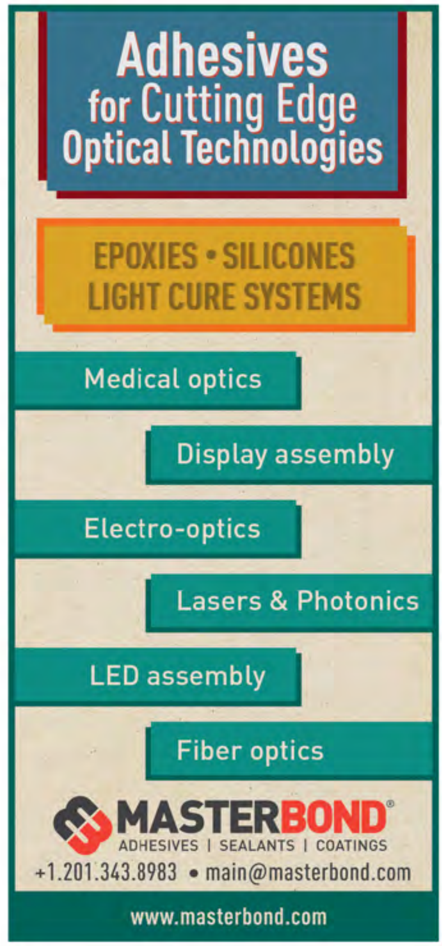
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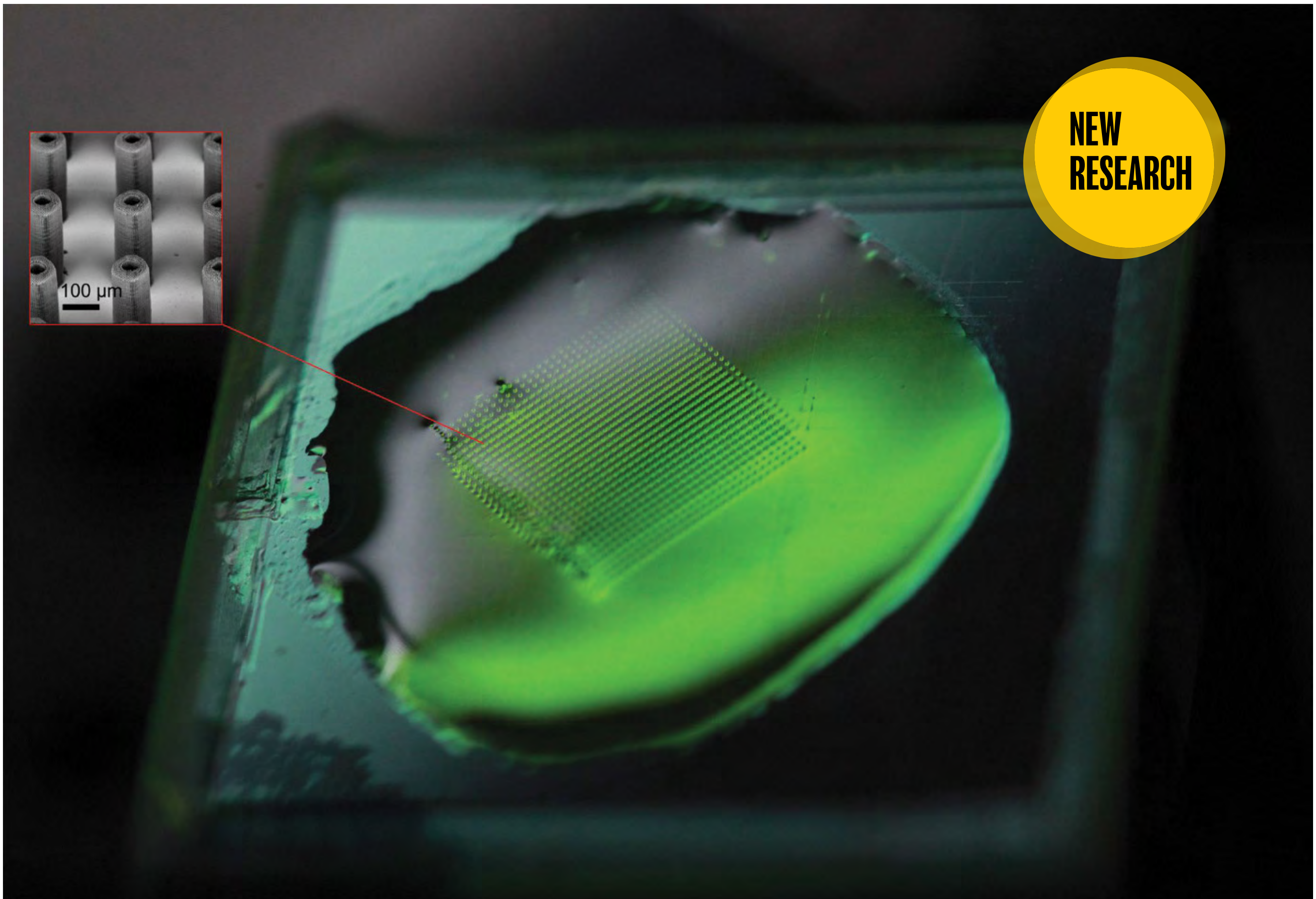


Nanoscale 3D Printing Gets a Boost

3D PRINTING ON THE NANOSCALE HAS traditionally required a tradeoff between speed and resolution. The existing additive method uses a single spot of high-intensity light to convert a photopolymer material from liquid to solid—a process that can take hours to produce miniscule complex 3D structures. The slow production speed limits the ability to scale up the technique for practical applications, of which there are many, including bioscaffolds, flexible electronics, and components for consumer devices like smartphones. If only they could do it faster.

Researchers from Lawrence Livermore National Laboratory and the Chinese University of Hong Kong have defied this engineering tradeoff. Instead of projecting a single point of light into the liquid polymer, they projected a million points simultaneously, thus generating an entire plane of projected light. Using a digital mask to control a high-intensity burst from a femtosecond laser to create the desired pattern in the polymer material, they built the object layer by layer. When the liquid polymer is rinsed away, the solid object remains. The group reduced production time from several hours down to eight minutes using this method.

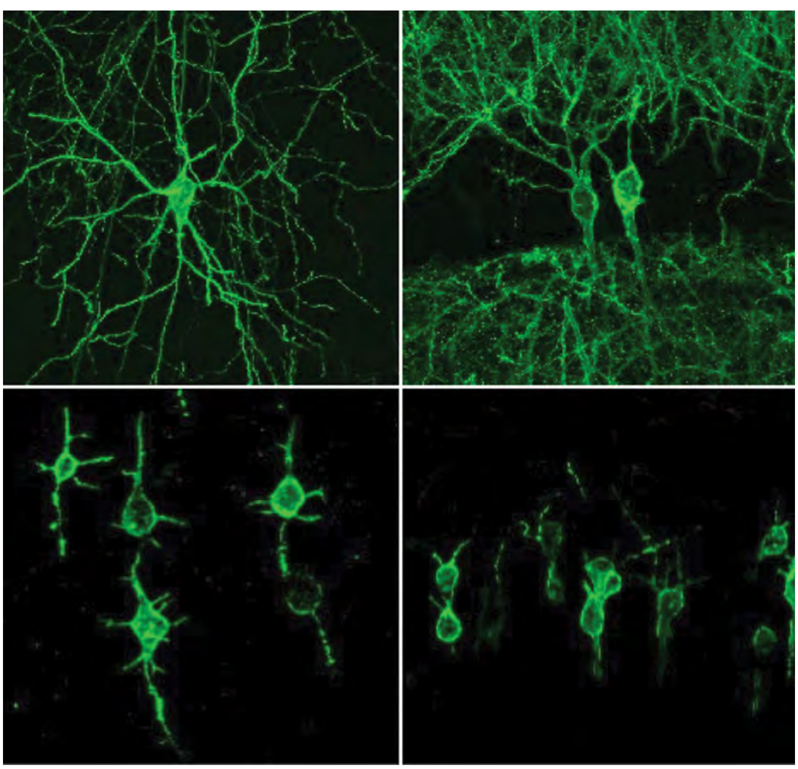
This approach allows creation of suspended 3D structures, such as bridges and 90-degree overhangs. It can also generate even smaller 3D features than the focused light spot method can produce. Next, they'll explore printing with other materials to expand potential applications. *(S. K. Saha et al., Science 2019 doi: 10.1126/science.aax8760. Foundational research was presented at SPIE Photonics West.)*

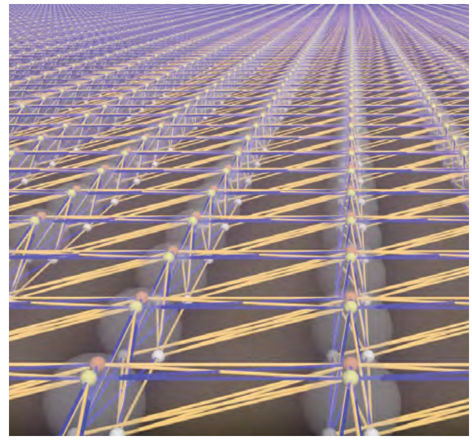
Voltage Sensor Lights Up Living Brain

NEUROSCIENTISTS HAVE HAD SUCCESS RECORDING electrical activity from individual neurons via electrodes implanted into the brain, but have struggled to find a method that allows them to record the activity of larger populations of neurons. Since neurons work together as a network in living animals, single-neuron recording limitations have hampered progress in brain research. Multielectrode arrays and calcium imaging have both tried to tackle this issue, but both have limitations.

Ed Boyden's lab at MIT, partnered with Xue Han, associate professor of biomedical engineering at Boston University, developed a fluorescent probe that allows imaging the activity of many neurons at once in mice brains. They used a voltage-sensing molecule called Archon1 that can be genetically inserted into the cell membrane of neurons. When the neuron's electrical activity increases, the molecule fluoresces.

Previous studies in Boyden's lab demonstrated successful use of Achron1 to image electrical activity in mouse brain slices, but they wanted to use it in living, awake mice engaged in specific behavior to see what they could learn. Modifications to the molecule allowed them to see each cell in the network as a distinct sphere, enabling them to image activity in a region of the mouse brain that plans movement. Using a simple light microscope, they were able to visualize the activity of the brain's circuits and link them to the animal's movements. This is the first demonstration of a voltage sensor that works in a living mammalian brain. *(K. D. Piatkevich et al., Nature 2019 doi: 10.1038/s41586-019-1641-1. Boyden will present on optical tools for analyzing and controlling the brain at SPIE Photonics West 2020.)*



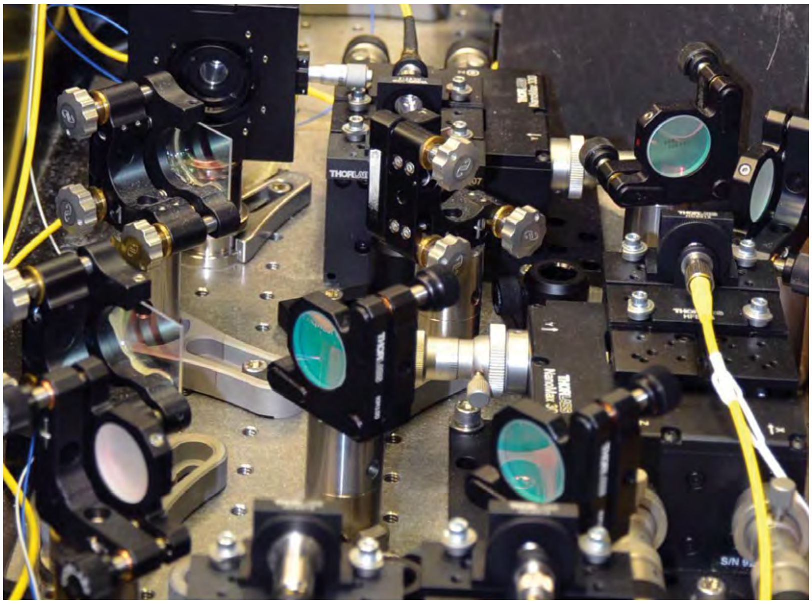


Cluster Luck Advances Quantum Computing

QUANTUM COMPUTING PROMISES TO solve difficult problems at blazing fast speeds, but current quantum processors are not large enough or accurate enough to deliver on the future of computing as envisioned by quantum engineers. Quantum computing utilizes cluster states—a large collection of entangled quantum components—to perform quantum computations. But previous attempts to create cluster states have struggled to achieve the necessary scale and are prone to errors.

An international team of scientists from Japan, Australia, and the US have succeeded where previous attempts have failed: they built a large-scale quantum processor made of laser light. The processor is extremely scalable, a trait that will eventually allow it to outperform classical computers on difficult problems.

The researchers used specially designed crystals to convert ordinary laser light into a type of quantum light called "squeezed light," which is then weaved into a cluster state by a network of mirrors, beamsplitters, and optical fibers. In their prototype, the levels of squeezing are still too low to solve practical problems, but the design is compatible with approaches to achieve state-of-the-art squeezing levels. This system demonstrates the first large-scale cluster state with a structure that enables universal quantum computation. *(W. Asavanant et al., Science 2019 doi: 10.1126/science.aay2645. Foundational research presented at SPIE Photonics West and Optics + Photonics.)*



Photon Pairs You Can Count On

PHOTONS MOVE QUICKLY AND EXHIBIT QUANTUM phenomena at room temperature. These properties make photons excellent candidates to serve as qubits for quantum computing. The other quantum candidates, including trapped ions and superconducting currents, are only stable in extremely cold conditions, a drawback that creates a lot of design challenges for quantum engineers. The downside to using photons as qubits is the challenge of quickly and reliably producing single photons. It's not easy.

In order to get a single usable photon, a pair must be generated by splitting a single high-energy photon into two low-energy photons. The creation of pairs is essential, because you have to be able to detect one—destroying it in the process—to realize the existence of the other. Since quantum processes are inherently random, efforts to split a photon can produce nothing, one pair, or even two pairs. The reliability of producing just one pair is quite low.

However, physics professor Paul Kwiat of the University of Illinois at Urbana Champaign and his former postdoc Fumihiro Kaneda have figured it out. They built an efficient single-photon source that can reliably and quickly generate single photons. If an application required a 12-photon source, for example, then their method could produce 4,000 12-photon events per second. To put this accomplishment in perspective, the best competing experiment prior to theirs was only able to generate one 12-photon event once every two minutes. They have realized a 500,000× efficiency.

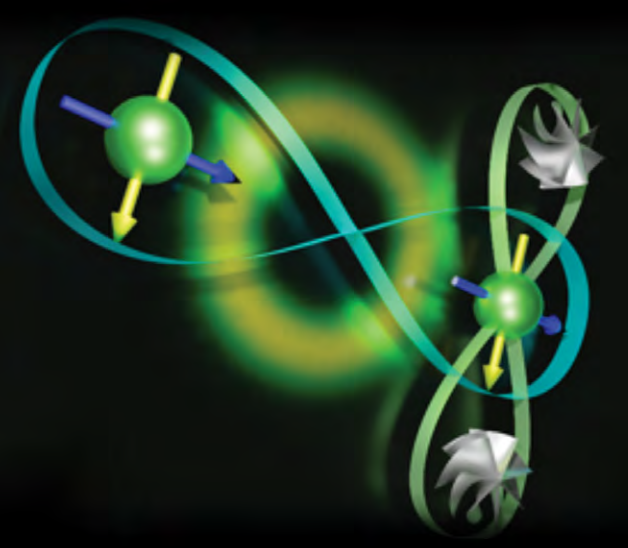
They accomplished this feat by pulsing a spontaneous parametric down-conversion source 40 times and utilizing "time bins" to efficiently store and release one of a photon pair. By pulsing the source 40 times, they are guaranteed that at least one photon pair will be produced from the process, in spite of the frustratingly random nature of the quantum process. When the stored photons are released, they are coupled into a single-mode optical fiber at a high efficiency—the state that photons need to be in to be useful in quantum information applications. *(F. Kaneda and P. G. Kwiat, Science Adv. 2019 doi: 10.1126/sciadv.aaw8586. Foundational research presented at SPIE Defense and Commercial Sensing and SPIE Security + Defence.)*

Robust Light Source for SRS/CARS Microscopy

COHERENT RAMAN SCATTERING (CRS) imaging is based on a multi-photon scattering process that employs two near-infrared laser pulses to excite Raman modes in the midinfrared spectral range. Its label-free chemical selectivity has earned CRS a wide scope of applications in biomedical microscopy, including live cell, tissue, or DNA imaging. The most prominent representatives of CRS are coherent anti-Stokes Raman scattering (CARS) and stimulated Raman scattering (SRS). In both cases, two beams—the so-called pump and Stokes beams—interact, giving rise to the generation of a new frequency (CARS) or to an energy exchange between the two beams (SRS).

A team of scientists from University of Stuttgart and University of Glasgow has developed an ultra-low noise fully automated laser system for coherent Raman scattering microscopy. Based on solid-state femtosecond technology, combined with optical parametric frequency conversion, their multicolor system reaches the shot noise limit at modulation frequencies of 1 MHz and above. Three output beams are inherently synchronized, and the Stokes and pump beams are spatiotemporally overlapped with a precisely controllable temporal delay. The unique robust frequency conversion design requires no active stabilization electronics, which can negatively affect the system stability, noise, and handling.

In order to evaluate the system performance, the team recorded the spectrally very broad SRS response from a D_2O and H_2O mixture, as well as the narrow response of acetone. To demonstrate the capability of the novel light source with respect to imaging applications, they investigated a mixture of micrometer-sized polystyrene and PMMA in a basic confocal scanning microscope setup. With this proof of concept, the team showed that the proposed system allows chemical-selective imaging with video frame rates. *(H. Linnenbank et al., Adv. Photon. 2019 doi: 10.1117/1.AP.1.5.055001)*



Entangled Optical Vortexes Survive Trial by Fiber

QUANTUM COMMUNICATION RELIES ON TWO PHOTONS, split from the same parent photon, that retain correlated states, even across long distances. Information must be encoded between two quantum states of a photon that are orthogonal to each other, such as polarization and orbital angular momentum (OAM). But when you send one photon down an optical fiber (the traditional medium for optical communications), OAM is easily destroyed by the slightest bend in the fiber. Moreover, temperature variations and stresses in an optical fiber can change polarization unpredictably. If one photon changes polarization or OAM state and the other doesn't, the quantum correlation is broken.

Fortunately, a team led by Oxenløwe and Sciarrino, from Denmark and Italy, have demonstrated an important development for quantum communication via optical fiber. They used an air-core fiber, designed such that the travelling photon cannot scatter into a different OAM mode even when the fiber is stressed or bent. The team showed that the quantum states of two entangled photons were nicely preserved, even after one travelled down a five-meter-long optical fiber—a distance long enough to communicate between a quantum memory unit and a quantum processor.

The results constitute a building block for future exploration of quantum entanglement involving polarization and orbital angular momentum. The scalability of the approach also widens the range of applicability for the transmission of complex states of light. With development of improved fibers, entangled states may be preserved over longer and longer distances. *(D. Cozzolino et al., Adv. Photon. 2019 doi: 10.1117/1.AP.1.4.046005)*

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National Ignition Facility beamlines entering the laser facility's target chamber.

BACK IN THE POWER GAME

The US is building one of the most powerful lasers in the world that could eventually break the quantum vacuum and produce matter from nothing

By **Rebecca Pool**

IT'S NO SECRET THAT THE US HAS TRAILED THE REST of the world when it comes to high-power ultrafast laser science. While North America well and truly led the petawatt pack at the turn of this century, the intense laser science scene has since shifted towards Europe and Asia.

But this is about to change. In September 2019, Karl Krushelnick, director of the Gérard Mourou Center for Ultrafast Optical Science (CUOS) at the University of Michigan, revealed he and colleagues had won $16 million from the National Science Foundation to build a world-class high-power laser that he believes will bring the US back on track.

As he says, "This laser will have the highest peak power in the US and will be among the world's most powerful laser systems for the next decade." The CUOS team will be drawing on the US's high-power laser heritage alongside decades of photonics innovation worldwide.

In the race for laser power, Lawrence Livermore National Laboratory (LLNL) set the standard back in 1996, when a beamline at its Nova facility broke the petawatt barrier, generating nearly 100 times the world's total energy

Photo Credit: Damien Jemison/LLNL

"THIS LASER WILL HAVE THE HIGHEST PEAK POWER IN THE US AND WILL BE AMONG THE WORLD'S **MOST POWERFUL LASER SYSTEMS** FOR THE NEXT DECADE."

consumption rate in a fleeting half a picosecond. LLNL physicist Michael Perry and colleagues had harnessed chirped-pulse amplification, a method pioneered by Nobel laureates Gérard Mourou and Donna Strickland, to amplify an ultrashort laser pulse to this mighty million-billion watt level.

Nova made history, yet in a bid to achieve fusion ignition, the facility was swiftly succeeded by the National Ignition Facility (NIF). Today, this stadium-sized energetic laser facility can generate mammoth 2.15 MJ energy pulses to take deutrium-tritium fuel capsules to fusion temperatures. But because of its relatively long laser pulses, the mighty NIF does not exceed a petawatt (PW) of power.

In the interim, tens of facilities from the US to the UK and China to Japan have reached and even exceeded the petawatt threshold. Right now, all eyes are on Eastern Europe's $875 million Extreme Light Infrastructure (ELI), which can generate pulses that pack a formidable ten petawatts of peak power on its ultrahigh intensity laser system.

Meanwhile, in Asia, China hosts a 5.3 PW laser at its Shanghai Superintense Ultrafast Laser Facility and plans to build an unimaginable 100 PW laser by 2023. And South Korea's Center for Relativistic Laser Science (CoReLS) is now home to a 4 PW laser.

Thankfully, this growing power gap did not go unnoticed by US science. In December 2017, the National Academies of Sciences, Engineering, and Medicine released a report stating the US was losing ground in intense ultrafast laser science and called on the government to fund at least one high-power laser facility.

The call didn't fall on deaf ears. With the latest NSF $16 million grant, CUOS researchers have already started to build ZEUS, the Zettawatt-Equivalent Ultrashort Pulse Laser System. CUOS plasma physicist Alexander Thomas is excited.

"The National Ignition Facility is a very, very impressive facility, but it's not a short-pulsed laser and just doesn't do the same physics [as facilities such as ELI are designed to do]," he says. "But now, we're building a laser system that can perform at a world-class level, and because of our design, we're going to be able to do things that other people can't."

ZEUS will also serve as a high-power laser user facility for all US scientists, as well as the wider international research community. Thirty weeks a year have been set aside for external user experiments, and requests for beamtime will undergo an open and transparent external review process.

"We'll be doing frontier science with ZEUS, but it also has so many practical applications," adds Thomas.

• • •

ZEUS WILL BE BUILT AROUND CUOS's existing high-intensity HERCULES laser. The latter currently occupies several rooms at CUOS, but once ZEUS is complete, it will sprawl across an incredible 7,500 square feet.

▲ LLNL staff modified one of Nova's existing arms to build an experimental chirped pulse amplification laser that generated the world's first petawatt pulse in 1996.

"HERCULES will serve as a front-end for ZEUS, and in part, this is why we're getting a lot of bang for the buck here," says Thomas. "We're not starting from scratch; we're leveraging some $20 million dollars of past investment into HERCULES, mainly from the National Science Foundation, over the last twenty years."

He adds, "We also have a team of world-class experts in high-power ultrashort pulse laser technology, led by research scientists Anatoly Maksimchuk and John Nees, which is why we are able to build ZEUS here."

Slava Lukin, program director of plasma physics from the Division of Physics at the NSF agrees that ZEUS's relatively cheap price is largely due to the HERCULES legacy and team. "The CUOS team is not inventing a laser here, but is bringing together a combination of many lasers to build a very powerful system in a reasonable timeframe and at a reasonable price tag. This wouldn't have been possible five years ago, but it is now, and having one of the most experienced teams in the world bringing this together is unique." But as he also highlights, "We are not operating in a vacuum, and given the interest worldwide in high-intensity lasers, some of the necessary technology is now semi-commercial, and quite frankly, also cheaper."

At the heart of HERCULES lie titanium-sapphire crystals. Light pumped into these discs is then bounced through a system of mirrors and lenses, getting stretched, energized, and squeezed via chirped pulse amplification into powerful 500 TW pulses that are focused using adaptive optics to tremendously high intensities.

Back in 2008, the mighty system was classed as the highest intensity laser in the world, squeezing 20 J of energy into a 1.3 micron focal spot to deliver a whopping 2 × 1022 W/m^2, or 20 billion trillion W/m^2, if that's easier to wrap your head around, for a duration of only 30 femtoseconds.

Photo Credit: Lawrence Livermore National Laboratory

At the time, this intensity was two orders of magnitude greater than ever achieved before.

Clearly, ZEUS has good credentials, but the best is yet to come. As Thomas points out, using additional pump lasers and a longer chain of amplification stages, he and colleagues will raise the peak pulse power of the HERCULES laser from 500 TW to an impressive 3 PW, but the laser's pulses will remain at 30 femtoseconds in length.

"Adding more power to any high-powered laser system really is a case of adding more amplifiers or pump lasers," says Thomas. "We recently upgraded HERCULES from 300 TW to 500 TW by replacing its homemade pump lasers with commercial versions, and now we're extending this further with the amplification stages and pump energy, which is a big part of the cost."

What's more, the plasma physicist reckons that by using adaptive optics in the form of deformable mirrors with a controllable reflective surface shape, he and colleagues will be able to focus ZEUS's beam to a 1 micron focus spot, giving intensities approaching an incredible 1×10^{23} W/m^2. This is an order of magnitude larger than HERCULES's record-breaking 2×10^{22} W/m^2.

"With many of these high-powered laser setups, the amplification system causes imperfections in the wavefront that can limit the focusability of the laser," says Thomas. "This isn't unique to ZEUS, but by using these deformable mirrors, the wavefront is adjusted to compensate for imperfections and maximize the intensity."

But crucially, ZEUS's 3 PW laser will be joined by a second beamline that will be used to generate an extremely bright GeV energy electron beam. And this is where things get exciting.

In this "dual beamline" configuration, the high-energy electron beamline will shoot its charged particles directly at the high-intensity 3 PW laser light coming from the opposite direction to create the system's namesake zettawatt-equivalent ultrashort pulses, that is, 1×20^{21} W pulses.

This method of mimicking a much more powerful laser by colliding with a high-energy electron beam relies on a plasma physics phenomenon known as laser wakefield acceleration. Laser wakefield acceleration uses a laser pulse to create charge separation, or a "charge wake," in the sea of ionized gas or plasma that trails the laser. The electric field in this wake imparts oscillatory energy to electrons, accelerating the particles to higher energies, so in effect, the electrons are picking up energy while "riding" this plasma wake.

In the case of ZEUS, the massive electric fields generated by its mighty multi-petawatt laser will impart enormous oscillatory energy to the electrons in its plasma wake, propelling the particles to speeds approaching the speed of light.

Alongside Michigan colleagues, research scientists, Anatoly Maksimchuk and John Nees are set to construct ZEUS from CUOS's 500 TW system, HERCULES.

"When we collide our GeV electron beam with our principal laser, the electrons are going to experience a huge electric field, and 'feel' an increase in [energy] intensity of around a million times," says Thomas. "So, from the point of view of these accelerating electrons, the petawatt laser now actually feels like a zettawatt laser, which of course motivates 'zettawatt-equivalent' in ZEUS."

And of course, the implications are profound. Using ZEUS, Thomas and colleagues hope to study strong field physics and relativistic plasma as never before, testing the limits of the theory of quantum electrodynamics in super-strong electromagnetic fields and learning how the universe operates at the subatomic level.

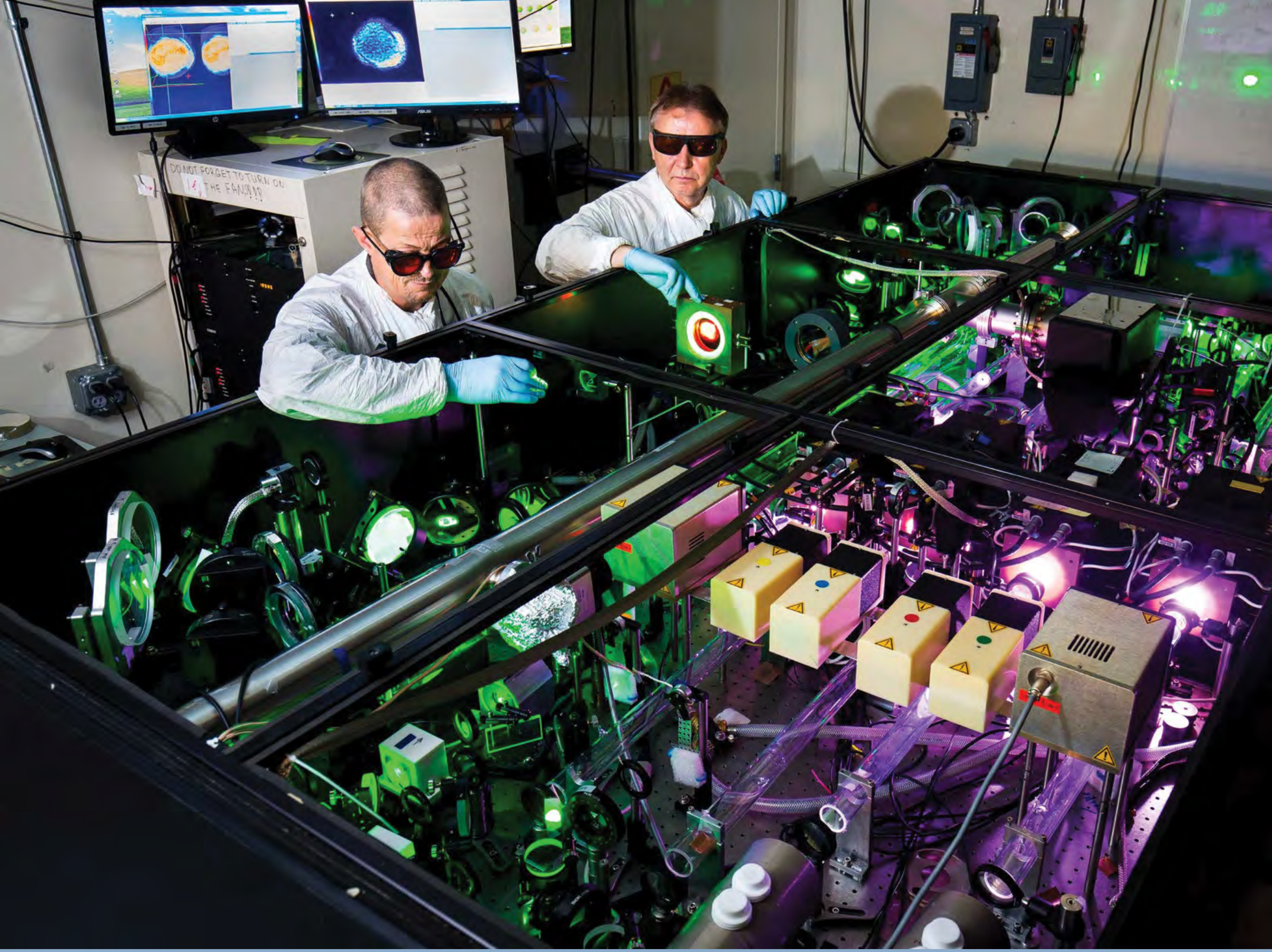
"By making use of ZEUS' multiple-laser arm system, we are effectively able to explore intensities that are six orders of magnitude higher than a single laser beamline," he adds. "And so we can probe quantum electrodynamics at the extremes of field strength, which is where you can get these exotic and more uncertain effects."

As part of their investigations, the researchers hope to look at the quantum vacuum, essentially the underlying fabric of spacetime. Theory predicts that the quantum vacuum isn't actually empty, but instead contains matter and antimatter (electron–positron) pairs that fleetingly flicker into existence before annihilating each other.

Given the power and intensity of ZEUS, the researchers intend to eventually harness the laser's strong electric field to break the attraction between electron–positron pairs in a vacuum, so the particles escape mutual annihilation, and matter and antimatter are created from nothing.

"If we fired ZEUS's three petawatts into a vacuum, not much would happen," says Thomas. "However, if we interact this laser with the electron beam [in a vacuum] then we could perhaps start to rip the vacuum apart, and start to produce matter and antimatter out of almost nothing."

Thomas concedes that breaking the vacuum directly isn't going to happen right away, but clearly every increase in laser power and intensity brings researchers closer to this holy grail of 21st-century laser physics. In the interim, ZEUS will also be used for "a whole laundry list of scientific applications" as Thomas puts it. The plasmas generated by the laser system will be similar to those believed to exist in astrophysical bodies, so researchers will be able to study



the conditions predicted to exist in stars and around black holes.

As NSF's Lukin points out, laboratory astrophysics can't come soon enough. "Amongst astronomy researchers is this general recognition that to understand and continue to interpret [space] observations, more laboratory work is needed as they really need to understand the plasma physics here," he says.

Meanwhile, the fact that ZEUS can accelerate electrons to blisteringly fast speeds in mere centimeters instead of the kilometers demanded by conventional particle accelerators will make it a powerful, compact synchrotron light source. What's more, being able to shrink the size of the accelerators that generate proton beams and radioactive isotopes opens the door to bedside cancer therapies.

And because the only thing better than more lasers is yet more lasers, the laser system will also have a third, longer-pulse laser to enable pump-probe experiments so researchers can, for example, use x-ray spectroscopy to study atomic-scale processes in materials across ultrashort timescales.

Photo credit: Joseph Xu, Univ. of Michigan College of Engineering

"With multiple lasers that provide multiple options for researchers, ZEUS is going to have a real impact on the [academic] community...once constructed, this user facility will provide 30 weeks every year to external users," says Lukin. "I really do believe in what we are doing here, and right now really is the right time to do this."

Thomas couldn't agree more.

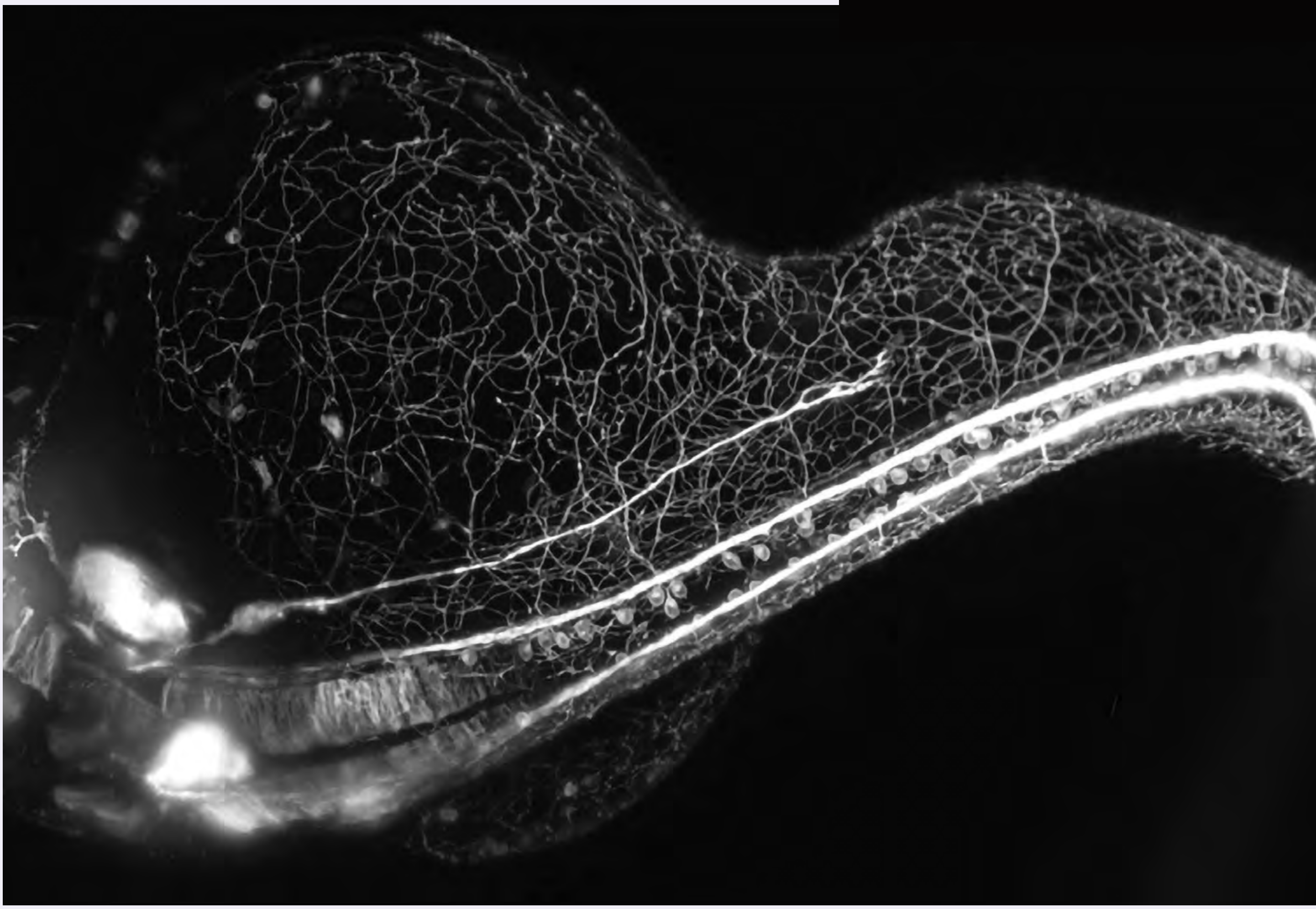
"With ZEUS, the science is so interesting as we're dealing with plasma physics mixed with ultrafast optics, relativity, and particle physics, and yet it also provides this multitude of applications," he says. "So we have this perfect combination, and that's why I'm in the game."

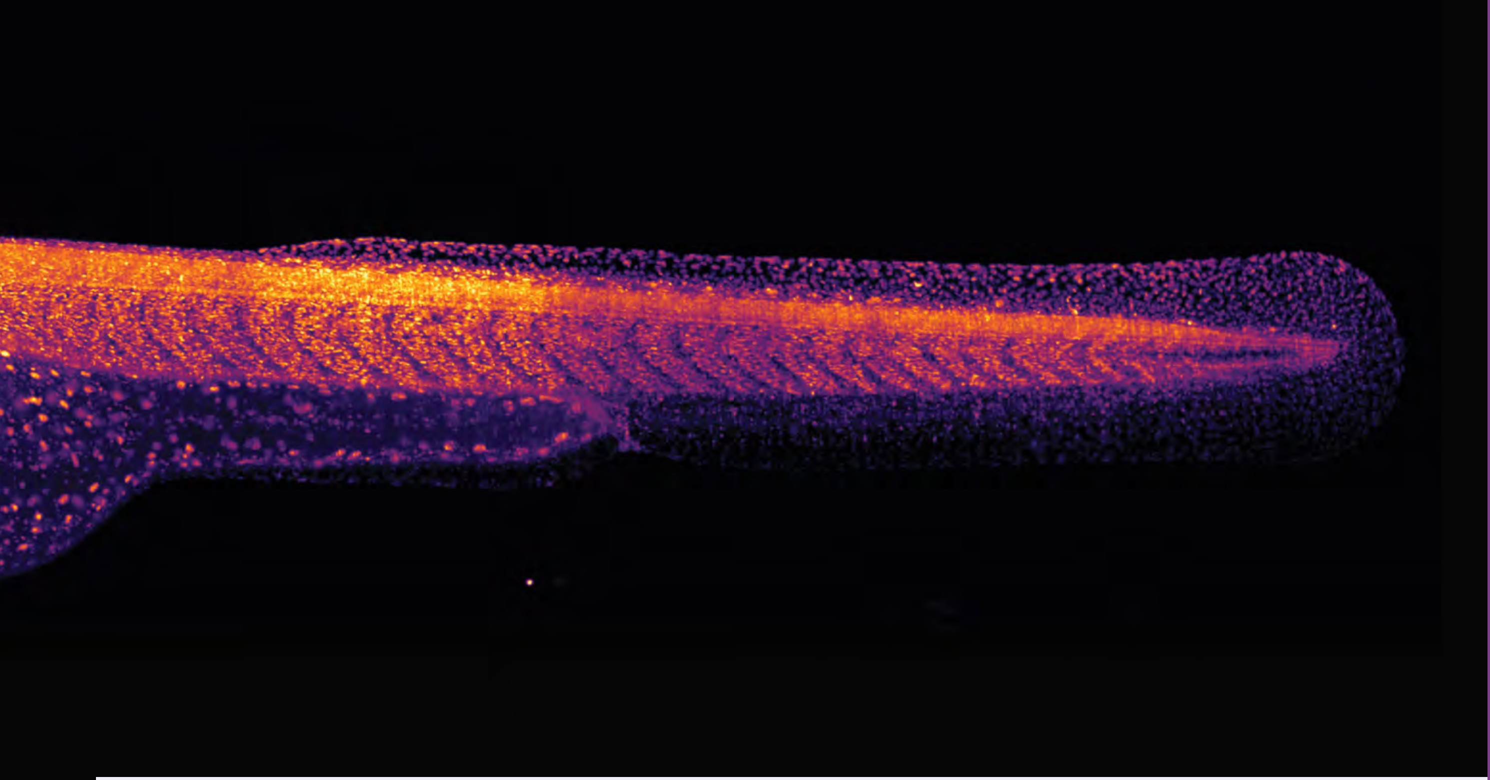
REBECCA POOL *is a science and technology writer based in Lincoln, United Kingdom.*

NO LIBRARY CARD NEEDED

Enhancing collaboration with portable light sheet microscopes

By **Debbie Sniderman**





MARY HALLORAN'S LAB STUDIES ZEBRAFISH embryos to determine how their nervous system develops, including axon and neuron branching patterns. For Halloran, a professor at the University of Wisconsin-Madison's Department of Integrative Biology, light sheet microscopy is the only tool for the job. Whereas traditional confocal imaging zooms in on just a small region of an embryo or nervous system, light sheet imaging allows them to zoom out and look at the entire embryo rapidly, with a high resolution close to the quality of a higher magnitude objective.

Unfortunately for Halloran, whose lab has just five to seven full-time people, commercial light sheet microscopes are prohibitively expensive. Fortunately for Halloran, there is now an option for labs like hers.

A new light sheet microscope, developed at the Morgridge Institute for Research, a private, nonprofit biomedical research institute at the University of Wisconsin-Madison, uses compact light engine (CLE) technology from TOPTICA Photonics, Inc. to create a system so small and portable it can easily travel to users. Its flexible modular setup and portability is the basis for a new microscope lending initiative called INVOLV3D, where collaborators can request fleets of light sheet microscopes to be sent out for research on a temporary basis.

Applications like Halloran's fragile, fluorescently labeled samples are perfect for light sheet fluorescence microscopes (LSFM). Their high speed and low phototoxicity are used to create 2D or 3D images of living structures such as cells, tissues, or other biological organisms. LSFM shines laser light on a specimen from the side and exposes only a thin volume of a sample around the plane of interest. Fluorescence is collected with a sensitive camera to optically section a sample. Because of its low-power lasers and exposures in the millisecond range, it's a gentle high-speed technique with less toxicity, photobleaching, and damage to tissues than traditional confocal imaging methods.

Confocal microscopes, which are well-established in labs, rely on beam scanning to raster across an entire sample. This method is slow and inefficient, and over time fluorescence fades away. After hours of imaging, cells, tissues, or embryos show the effects of laser exposure. 3D imaging multiple planes is problematic as light always shines through the entire specimen perpendicular to the image plane, exposing every plane to the light.

The advantages of LSFM are quite clear. Because they cause less damage to tissues, experiments using LSFM can run for much longer. It's possible to image developmental processes in intact small animals, keeping organisms alive for many days with the right sample preparation. Wide-field objectives and the latest sCMOS or EMCCD camera technologies can be used to capture fast phenomena in the focal plane, like a beating heart or neuronal activity, or rapidly acquire an entire stack of images in a living embryo.

COLLABORATORS CAN REQUEST FLEETS OF LIGHT SHEET MICROSCOPES TO BE SENT OUT FOR RESEARCH ON A TEMPORARY BASIS.

Photo Credits: Bottom—Mary Halloran, University of Wisconsin; Top—Alyssa Graves and Jan Huisken, Morgridge Institute for Research

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TYPICALLY, UNIVERSITIES NEED TO USE ADVANCED fluorescence microscopes only for a few weeks to gather substantial data. A handful of research groups can afford to purchase commercial light sheet microscopes, and a number can build their own. In between, there are significant numbers who don't have time, expertise, or knowledge to build one, or don't yet have funding to buy one. This new lending library initiative creates a bridge for those users.

Jan Huisken, director of medical engineering at the Morgridge Institute for Research and visiting professor in integrative biology at the University of Wisconsin-Madison, is one of the developers of light sheet microscopy technology and the father of the Flamingo Project. Researchers at Huisken's Lab use LSFM to study tissue dynamics at the cellular level of biological processes in the early development of zebrafish and other organisms.

Huisken says the challenge for most microscopists is disseminating developed technology. After building a novel tool on an optical table in a research lab, publishing results, and getting publicity, typically no one can use the tool other than those at the lab or those willing to pack their specimens and come visit.

"Many biologists wish they had that recently published microscope in their own lab or could travel to use it. Unfortunately, we are not well equipped to host outside samples in our microscopy lab. With a modular, customizable, and portable framework we can now bring the latest technology to the biologists," he says.

Together with TOPTICA, he incorporated a CLE into a modular system developed as a traveling microscope framework and whimsically named it Flamingo, because it looks like the microscope is standing on one leg.

Light sheet microscopes allow users to build up volumetric data sets from very thin slices and create time lapse images over long periods of time, so laser robustness and stability at low power are critical. The CLE offered by TOPTICA is thermally robust and has well-known stability. It is integrated into a variety of OEM products where stability is critical, and is popular in light sheet microscopes.

Its frequency-doubled diode laser technology creates four color wavelengths in one integrated device, making a compact efficient light source that works up to 50 mW without producing a lot of waste heat or needing an external modulator.

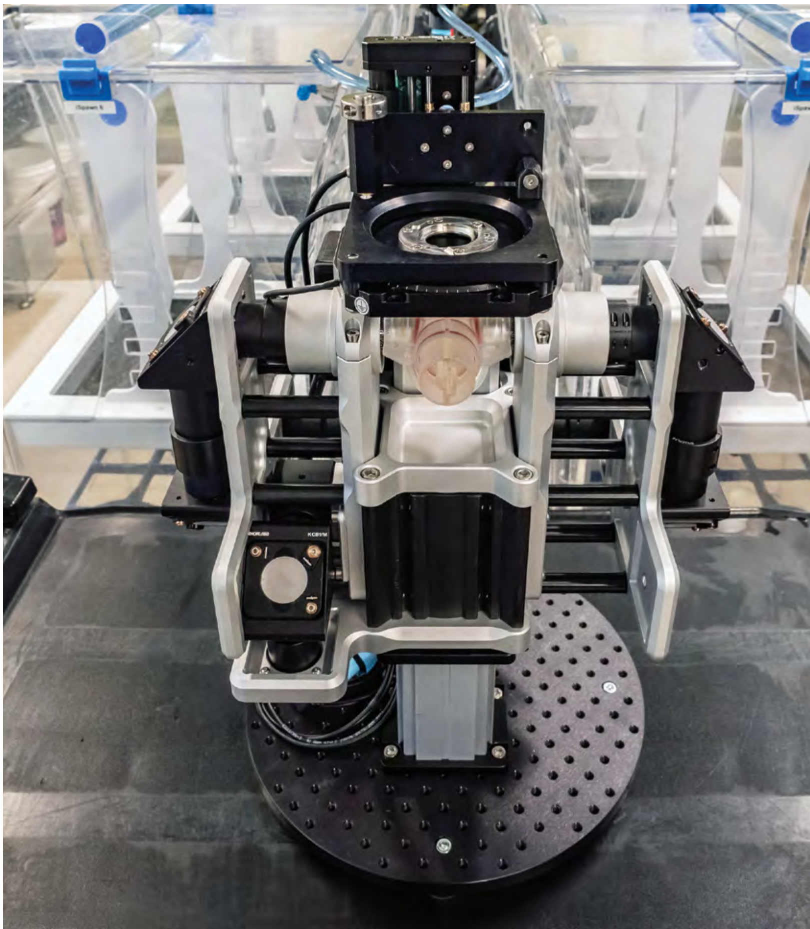
Huisken says, "We found the CLE to be perfect for the Flamingo. It has the right power, all the laser lines needed to excite the typical fluorophores in biology, and it is robust and small enough for a compact travel microscope. TOPTICA was an obvious partner, and their service department helped integrate the components into a scope from the software side as well. They were a natural fit for us."

Whereas typical optical setups built on breadboards and optical tables aren't easily packaged or intended to move, the Flamingo prototypes are compact enough to travel to the user by car or plane, and the microscope, electronics, and minicomputer fit in two suitcases.

It's not only portable, it's also configurable. Biologists now realize the importance of looking at cells in the context of intact tissues, as opposed to extracted on a cover slip. The Flamingo system's configurability allows researchers to look deeper into intact tissues and use larger samples and a greater variety of specimens than traditional microscopes, which are limited to flat small samples.

Flamingo provides the ability to turn the lenses or the whole scope around to look at samples from the top, side, or bottom. This new flexibility for the scope and samples means biologists can get perfect images of not only fixed tissues, but things that are alive, growing, and moving around. Whole organism imaging has been a huge driver in the field.

There are other ways to customize, beginning with the lenses. There are a variety of objective lens configurations in LSFM, ranging from one to four lenses for illumination and detection. Lenses are chosen to fit desired sample sizes into the field of view with the desired magnification, numerical aperture, and working distance. Options also exist for illumination, filters, and cameras needed to match the objective lenses to have enough FOV, pixel size, sensitivity, and frame rates for various applications.



Flamingo light sheet microscope in a zebrafish room at Harvard University.

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HUISKEN WANTS INVOLV3D, HIS LENDING LIBRARY initiative of which Flamingo is the first instrument, to remain a collaborative initiative. He believes sharing benefits the community and has no plans to commercialize the Flamingo technology.

"Sharing also makes sense from a funding perspective, since tools aren't sitting in a basement unused after an experiment is completed. And from a scientific basis, getting tools into the field allows for rapid adoption of user feedback to make improvements to make everyone happy," says Huisken.

Flamingo is built with high-end lasers, stages, cameras, and opto-mechanical components, but is packaged differently from typical experimental setups. It's not spread out on an optical table but is wrapped around a central post. Several Flamingos could be built for the same cost of a single commercial system, which can cost three to eight times more, depending on the configuration. "The support of several manufacturers helped us reduce the costs," he explains.

The instrument also helps reproduce scientific results produced with other instruments. "Most journal readers don't have or can't afford to purchase expensive commercial systems. Anyone can request the same Flamingo configuration to reproduce published papers using it," Huisken says.

Creating a tool that can be passed back and forth between labs, like Flamingo, has shown there's a different way to collaborate. "Alternatively to commercializing the technology or making it open source, making multiple copies of the technology, sharing it, and allowing people to test it can be better than conventional models for the community," he says.

Thanks to close proximity to Huisken, Halloran's lab at the University of Wisconsin was one of the first to benefit from Flamingo. "We've done a lot of light sheet imaging with the Flamingo in its standard configuration holding one sample in a capillary tube, and created lots of data-rich movies with this setup. Huisken's lab helped design software for us to provide quick automatic quantitative feedback while imaging. We're still collaborating and beta testing the new setup, and we expect it will be extremely useful to look at a large set of genes rapidly and do something we couldn't otherwise do," she says.

For Duygu Özpolat, principal investigator and cell and developmental biologist at the Marine Biological Laboratory in Woods Hole, Massachusetts, the Flamingo's ability to travel and low photo toxicity solved her biggest problems. Her lab used the Flamingo for a couple weeks to image live segmented worms similar to earthworms and test different configurations.

"Normally a lab like mine couldn't purchase equipment like this since it's too expensive. We'd need to try to

WHOLE ORGANISM IMAGING HAS BEEN A HUGE DRIVER IN THE FIELD.

find someone to share and visit their tool. But that's not possible with the samples we have. It's not easy to carry animals around to places where microscopes are and keep them alive. It's nice when a high-end tool can come visit your lab. Not having to travel is a big advantage, and our most important reason for using it," she says.

Her initial impressions were that it is flexible, easy to use without being a microscopy expert, and the system's light didn't cause toxicity, alter biological processes, or damage while imaging large areas. "Light sheet scopes image samples much faster than confocal scopes. Typically it takes five minutes to go through a 60-micron-thick sample with a confocal scope. But with light sheet, you go through the same thickness in seconds. This made it possible to visualize a thicker portion of an animal without the fluorescence dimming and image for longer," says Özpolat.

As of the beginning of 2020, there are five systems in use in the field—three in Madison and two in Boston, where another team member lives. He travels with the microscope to different labs around the area to facilitate collaborations and reports back on how it works and how to improve it. While the Flamingo is the instrument they plan to replicate, the team can come up with new designs if needed.

The group will continue to use these systems for the coming years in their own lab and in many exciting collaborations. Pending funding, Huisken hopes to build many more Flamingos in 2020. He is seeking partners willing to collaborate and funding opportunities to make more systems, and already has a long waiting list of labs interested in trying the system.

In the future, Huisken envisions the microscopes will travel to remote field locations, like volcanos and oceans, without support infrastructure. He hopes to obtain grants in other countries and find partner labs to help build systems there for more widespread use around the world.

DEBBIE SNIDERMAN *is CEO of VI Ventures LLC, an engineering consulting firm.*

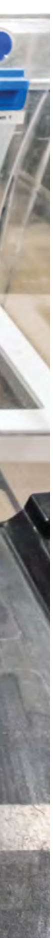
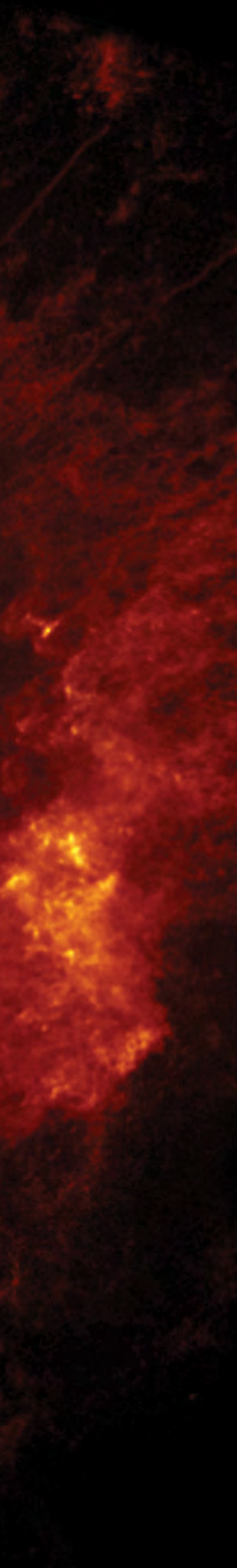


Photo Credit: Michael Weber, Jan Huisken

ALIEN LIGHT

Violent tempests in outer space produce natural lasers

By **Sophia Chen**



Eta Carinae. Photo credit: NASA, ESA, and the Hubble SM4 ERO Team

THE STORY BEHIND THE INVENTION OF the laser typically goes like this. Theodore Maiman, a 32-year-old physicist working at the Hughes Research Laboratories in California, built the first working prototype in 1960. The heart of this device, a synthetic ruby crystal that emitted red light, exploited the new science of quantum mechanics describing a nano-verse of photons, electrons, and other particles. Today, researchers and engineers have developed the technology into models ranging from the gentle red spot of a laser pointer to the behemoth x-ray laser in Germany called the European XFEL, which produces light more intense than all of Earth's solar radiation focused onto a fingertip.

But the laser, it turns out, is not uniquely a product of human engineering. "It would be more exact to say that … lasers have not been invented but discovered," writes physicist Mario Bertolotti in his 2004 book, *The History of the Laser*.

Indeed, as a series of astronomical observations would confirm beginning as early as the 1970s: lasers exist in nature.

Experts dispute which astronomical object qualifies as the first discovery of a natural laser. But one oft-cited observation is the 1976 discovery of unusually bright infrared light in the atmospheres of Mars and Venus. Led by Nobel laureate Charles Townes, a group of University of California, Berkeley astronomers deduced that atmospheric carbon dioxide produced this light, and that it brightened and dimmed in sync with sunrise and sunset.

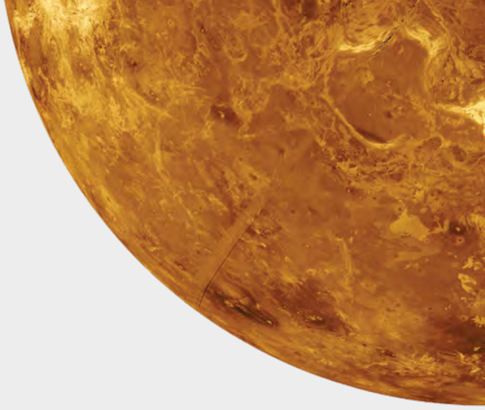
This light, as confirmed by NASA-affiliated researchers in the 1980s, was amplified via the same mechanism that a lab laser produces a beam. They determined this using further observations and models of atmospheric processes on the two planets. In a 1981 paper in *Science*, they wrote that Mars's infrared light was, to their knowledge, "the first definite identification of a natural infrared laser."

Unlike lab lasers, however, these natural ones did not form clearly defined beams. Instead, the light resembled a diffuse glow. If you photographed Mars's horizon with an infrared camera, the laser "would look like a bright edge to the planet," says NASA astrobiologist Michael Mumma, who helped confirm the two planetary lasers. Analyzing the vertical profile of the light from the ground to the sky, they found that the glow peaks in brightness 75 kilometers above Mars's surface.

Still, Mumma's team referred to the glows as lasers because of how they produced light. The letters of the word "laser" refer to this mechanism: light amplification by stimulated emission of radiation. Some circumstance in Mars's atmosphere, just like in a lab laser, amplified the light like a photon megaphone.

The amplification involves the interaction between two key components known as the pump and the gain medium. The pump is the energy source that fuels the amplification: Maiman's pump was a xenon lamp, while the planetary lasers run on sunlight, which is why the amplified light exists only in the planets' daytime regions. The gain medium is a material that absorbs the pump's energy to emit light. Maiman's was his ruby crystal, while Mars's and Venus's consist of carbon dioxide molecules.

The gain medium fluoresces at specific wavelengths determined by the material's nanometer-scale structure. Maiman's ruby laser emitted red light at 694 nanometers, whereas carbon dioxide emits several wavelengths around 10 microns. With enough energy from the pump, the gain medium can produce light in a process called stimulated emission, in which one photon interacts with the material to emit a new identical photon, thereby amplifying the total light. A human-engineered laser situates the gain medium between mirrors, resulting in further amplification as a single photon traverses through the gain medium multiple times.



To identify a natural laser, astronomers examine the spectra of astronomical objects for unusually intense light. Stars and planets typically emit colors of light in predictable proportions in a spectrum known as a blackbody distribution, explains astronomer Dainis Dravins of Lund University in Sweden. A laser amplifies specific wavelengths, which make themselves known by poking out conspicuously from a measured spectrum.

The carbon dioxide lasers on Mars and Venus amplified the 10-micron light up to 7 percent, compared to the intensity of light without lasing. Mumma says that this amplification is comparable to that of a photon making a one-way trip between the mirrors of a laboratory laser that also uses carbon dioxide as a gain medium.

In 1996, astronomers made another notable discovery—the first natural laser beyond the solar system. This object, another infrared laser, proved to be much more extreme than the ones on Mars and Venus. Searching from an airplane known as the Kuiper Airborne Observatory, Vladimir Strelnitski and his colleagues found the light was produced in the ionized gas disk around the star MWC349A in the constellation Cygnus. This laser, originating about 4,500 light years away, amplified 169-micron light about a thousand times compared to a blackbody distribution—four orders of magnitude more amplification than Mars and Venus. Because the light amplification on Mars and Venus is so low, Strelnitski, now the director emeritus of Maria Mitchell Observatory, claims MWC349A as the first natural laser.

These discoveries weren't a shock. Researchers predicted the existence of natural lasers as early as 1937. Although humans had yet to invent lasers, astronomer Donald Menzel pointed out that such light amplification could theoretically occur in the universe. At the time, however, he speculated that the extreme environments needed to amplify the light would "probably never occur in practice."

Another hint came in 1965, when astronomers discovered the first natural maser, produced via hydroxyl molecules from the direction of the constellation Orion. A maser amplifies microwave radiation instead of infrared and higher energy radiation like a laser, but their physics is identical. In fact, Strelnitski considers the natural maser a more fundamental scientific discovery than the laser. But masers, which exclusively emit radiation invisible to humans, fail to capture the public's imagination. "When you say 'maser,' people don't know what it is," he says. "They know what a laser is because they see it in the supermarket."

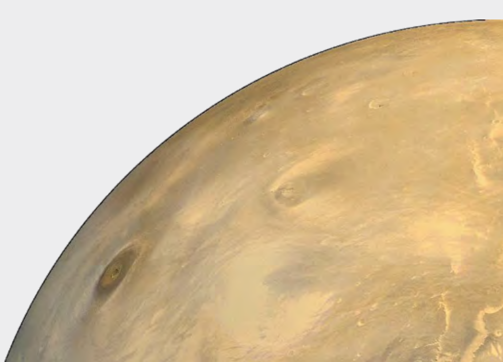
Natural masers occur much more frequently than lasers because they require less extreme conditions to form. This is because it takes less energy for a molecule to emit a microwave photon versus an infrared one. In planetary atmospheres such as Jupiter's, collisions with nearby particles can impart molecules with enough energy to produce and amplify microwave radiation.

Strelnitski anticipated that MWC349A should contain lasers, he says, based on prior observations of masers in the star. MWC349A's gain medium consisted of hydrogen atoms, which produced laser light via two processes, ionization and then recombination. First, UV light strikes a neutral hydrogen atom, ripping away its electron to ionize the particle. Then, during recombination, the newly formed ion quickly recaptures another electron.

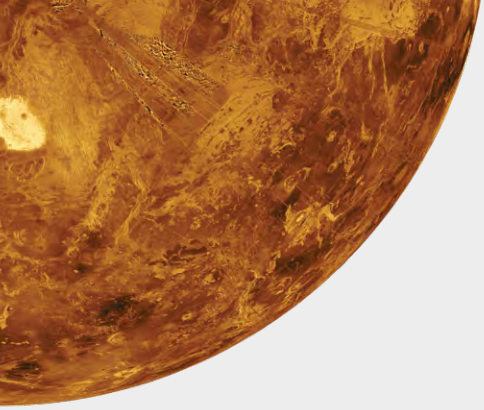
Natural lasers and masers enable astronomers to study distant objects they could not otherwise see. "The problem number one in astronomy is the lack of photons from very weak faraway sources," says Strelnitski. "If there is an amplification, then more photons will be in a spectral line." In 2018, for example, European astronomers Cristiano Cosmovici and Sergei Pogrebenko discovered water on exoplanets for the first time because they could observe masers produced by the molecules.

Natural lasers could also aid the search for extraterrestrial intelligence, says Strelnitski. To look for aliens, researchers hunt for unusual signals, especially laser light, which an intelligent civilization might have sent to transmit information long distances. To confirm alien intelligence, they would need to distinguish artificial lasers from natural ones. If it's unclear whether a natural energy source powers the laser light, "it may be a signal of extraterrestrial intelligence," he says.

Humans could also harness the natural laser light to signal to aliens. In the late 1980s, Mumma and his graduate student, Brent Sherwood, wondered whether humans could



Top Photo Credit (Venus): SSV, MIPL, Magellan Team, NASA; Bottom Photo Credit (Mars): NASA



RESEARCHERS
PREDICTED THE EXISTENCE OF
NATURAL LASERS
as early as 1937

hijack Mars' and Venus's natural lasers to transmit data into interstellar space. They developed a design that involved building mirrors in the planets' atmosphere and to exploit the surrounding carbon dioxide as a gain medium.

The project, ultimately, was just a thought experiment. "No one thought it was practical, but it was fun," says Mumma.

More recently, though, research on natural lasers has quieted. The lack of momentum could be because the objects are rare and difficult to study, says Mumma. "And once you know a laser is there, what do you do with it?" he says. "In terms of actual usefulness, it really doesn't tell you all that much about the fundamental physics [behind] the spectral lines."

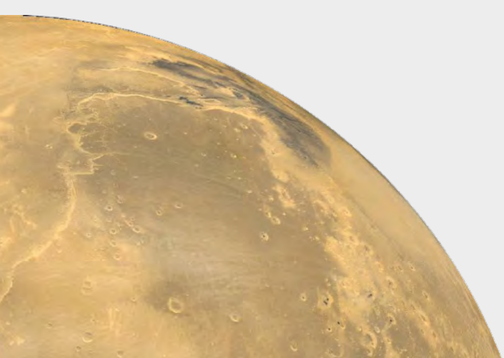
But questions about natural lasers linger. Perhaps the most bewildering case is the object Eta Carinae, located 7,500 light years away and the most luminous star known in the Milky Way.

For centuries, Eta Carinae's rapidly changing appearance befuddled observers of the southern sky. In the 1840s, the star exploded so violently that it expelled about twenty Suns' worth of matter, followed by an encore explosion fifty years later. Gas and dust ballooned outward into two lobes. The explosions also flung gas blobs that, for reasons unknown, move an order of magnitude slower than other ejected material. "If I started listing all the mysteries about Eta Carinae, it would be a real mess," says astronomer Kris Davidson of the University of Minnesota.

The star is no less temperamental now. Between 1998 and 2008, the star brightened about two orders of magnitude.

On top of all this, astronomers have debated—and never settled—whether the star produces the only known natural ultraviolet laser in the universe.

Two decades ago, Davidson was part of the team that first proposed this laser, which could explain some of the star's strange signals. Iron ions in the star's gas blobs produced thousands of different UV wavelengths, and two unusually bright colors stood out: one at 250.7 nanometers and another at 250.9.



Much of the study of this light can be credited to two researchers: Davidson's colleague, Sveneric Johansson of Sweden's Lund University, and Vladilen Letokhov of the Russian Academy of Sciences. In the 1990s into the mid-2000s, the two wrote several papers on how the star might produce amplified UV light. In the meantime, they showed that the star produced natural infrared lasers.

They later wrote, given what they understood about iron ions in the lab, the star shouldn't be able to sustain a UV laser. If the UV light didn't come from a laser, though, it's unclear what else could cause the amplification. To conclusively show it's not a laser, researchers could measure the distinctive timing that laser photons follow. Future extremely large telescopes may be capable of making these measurements, says Dravins."In principle, this is something we would like to do," he says.

But Dravins and his colleagues have no active plans to do so. Researchers may never know, as Eta Carinae is still rapidly evolving, says Davidson.

Interest in naturally occurring lasers has dwindled. Strelnitski still works with students to further study MWC349A, but he no longer researches astrophysical lasers as actively as before. Mumma, who still works at NASA, changed his research focus years ago. Johansson passed away in 2008, and Letokhov just months later, in 2009. Younger scientists have not filled their roles. It may be that, four decades after their astonishing discovery, natural lasers have receded into just another background glow in the sky.

SOPHIA CHEN *contributes to* WIRED, Science, *and* Physics Girl. *She is a freelance writer based in Tucson, Arizona.*

Robert Hall and the Diode Laser

Sometimes the first steps are the easiest

SPECULATION ABOUT THE FEASIBILITY of semiconductor lasers started even before Theodore Maiman demonstrated the ruby laser in May 1960. Yet, Robert N. Hall doubted it was possible. He had been working on semiconductors at the General Electric Research Laboratory in Schenectady, New York, since shortly after the invention of the transistor, so he was well qualified to list several likely showstoppers. At the top of the list was the pitifully tiny fraction of electrical energy released as light when current carriers recombined in a semiconductor.

However, an unexpected breakthrough at the MIT Lincoln Laboratory in Massachusetts changed his mind. Robert Rediker and Ted Quist were studying why the electrical properties of gallium-arsenide diodes with impurities alloyed into them differed from those with impurities diffused into them. To find out, they compared the emission efficiency of the two types of diodes when cooled to the same temperature as liquid nitrogen (77 K). Spectroscopist Bob Keyes found that more than 85 percent of the current carriers recombining at the junction of a diffused diode emitted light, but only a tiny fraction of the recombinations emitted light in the alloyed diodes.

Rediker reported the dramatic difference on 9 July 1962 at the Solid-State Device Research Conference in Durham, New Hampshire. Hall attended the meeting, and he was impressed by both the Lincoln Lab result and a report by Jacques Pankove of RCA, noting that the emission efficiency also increased with the current density in the semiconductor. Previously electroluminescence from semiconductors had been around 0.01% efficient, but the new results were close to 100%. "That really shook me up," Hall said in a 1985 interview. "That was the lightbulb turning on. If things are really this efficient, what can you do with it?"

The train home to Schenectady gave Hall a few hours to think through the implications of high efficiency and high power density. His rough calculations showed that they might make a laser possible after all. He theorized that passing a strong current through a semiconductor junction inside a Fabry-Perot resonant cavity could produce coherent light oscillating in a single mode—in other words, a laser. Having built his own telescope as an amateur astronomer, he envisioned making the resonator by cutting the semiconductor, then lapping and polishing the opposite faces of the crystal to make mirrors.

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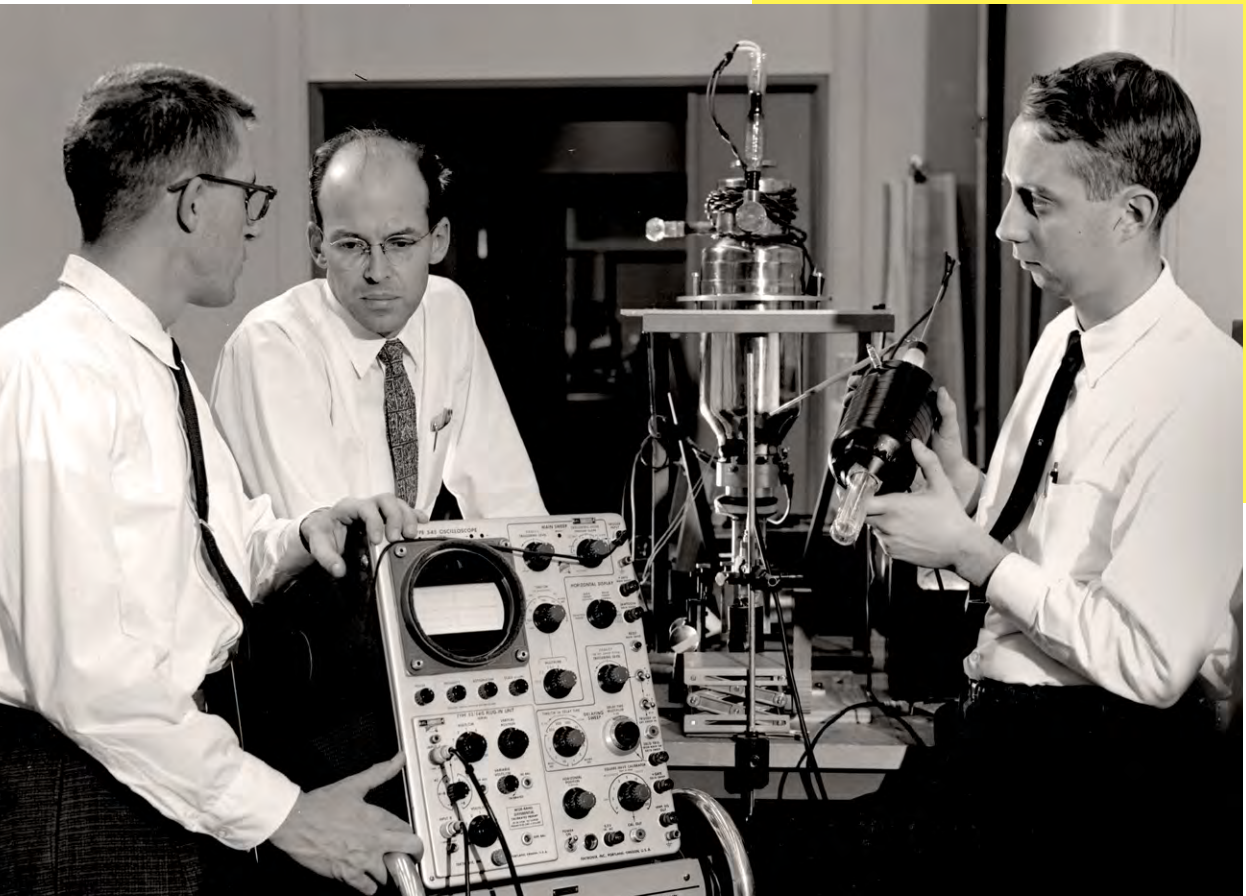
FOUNDED IN 1900 BY THOMAS EDISON, the GE lab was an industrial powerhouse of innovation with an informal structure that allowed its researchers move between projects. Hall



Left to right: Gunther Fenner, Robert Hall, and Jack Kingsley at GE Research Lab in 1962.

talked around the lab and found several others interested in making a diode laser. Then he told his boss, Roy Apker, that a little group working half time "could probably find out if the idea was good for anything in a few months." Apker gave them the go-ahead.

Light emission in semiconductors was a new direction for GE, but Hall's team had relevant experience. Ted Soltys had made tunnel diodes from gallium arsenide, so he made the gallium arsenide junctions for their experiments. Dick Carlson had experience in preparing materials. Electronics specialist Gunther Fenner set up equipment to deliver high-current pulses to the diodes without destroying them, and set up an infrared viewing system to study the infrared light they hoped to generate. Jack Kingsley had worked with other lasers, so he knew what to watch for in their experiments.

Nonetheless, Hall thought "we would stumble around" for a while before achieving anything. It took them about a month to produce gallium-arsenide diodes for Fenner to test. Some were dead shorts, and others self-destructed when the current hit them. But, others emitted light.

Fenner came into the lab to do more tests on Sunday, 16 September, and when he zapped test diode L-52 with a pulse of more than 12 amperes, he saw its emission increase rapidly in a way that he didn't understand. By Monday they "could clearly see that there were some very interesting patterns...and above a certain threshold the spectrum changed very drastically [so] you could see interference patterns and modes" with diode L-69, Hall recalled. Light emission had crossed the threshold for laser operation.

"It was a big rush from that point on," Hall said. "We found some diodes worked, but most of them didn't. Some of them did very strange things that we couldn't make much sense out of, but a few of them behaved in ways that we could understand and interpret as clear evidence for coherent light emission."

Kingsley's spectrometer showed clear spectral narrowing and multiple modes at the expected frequencies. It added up to a convincing story that they submitted to *Physical Review Letters* on 24 September, and was published on 1 November.

GE pushed for quick publication because they knew the field was about to explode. Because of the July conference, they were aware of Lincoln Lab and RCA's work on electroluminescence from gallium arsenide. They suspected the large laser group at Bell Labs was working on diode lasers. And they knew that another GE researcher, Nick Holonyak Jr. at the company's Syracuse Lab, who had also attended the Durham meeting, was working on diode lasers because he had asked Hall about them at the end of August. Sure enough, within weeks after Hall's groundbreaking publication, Lincoln Lab and Holonyak reported on their diode lasers in *Applied Physics Letters*, as did Marshall Nathan of IBM, whose report was a surprise.

The first practical devices to come from that burst of innovation were not diode lasers, but red LEDs made from gallium arsenide-phosphide, a compound Holonyak picked because its light is visible to the eye. It took major design improvements and years of additional work to make practical diode lasers. Herbert Kroemer and Zhores Alferov independently invented heterojunctions to confine current, leading to the first room-temperature diode lasers in 1970. Bell Labs spent years stretching diode lifetimes from minutes to a hundred years. New wavelengths and higher powers followed.

However, it's hard to match the heady excitement of the cascade of breakthroughs during those few weeks in the fall of 1962. While most Americans were worrying about the Cuban Missile Crisis, a new era of laser technology was dawning.

JEFF HECHT *is an SPIE Member and freelancer who writes about science and technology. The quotes in this article are from his interview with Bob Hall in 1985. Hall died in 2016, aged 96.*

Photo Credit: GE Global Research

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- continuous optimization targets
- derivative targets
- detectors
- dispersion formulas
- electric field intensity
- equivalent index
- equivalent stack
- gain materials
- global optimization
- group optimization
- illuminants
- layer sensitivity
- local optimization
- material mixtures
- multiple environments
- needle optimization
- optical monitoring
- optical density
- phase shift
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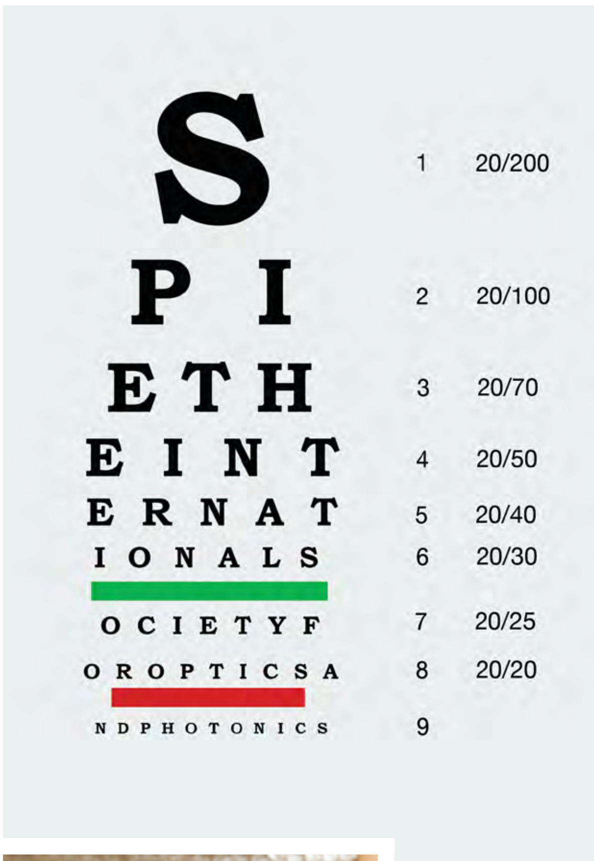


I AM EXCITED TO BEGIN MY TERM as your SPIE President. This is a significant responsibility and I pledge to represent SPIE and its members and constituents to the best of my ability. I also welcome you to the inaugural issue of our new bimonthly SPIE Membership magazine, *Photonics Focus*. We hope that this magazine will help keep you up to date with what is going on with SPIE, but more importantly, highlight some of our activities and accomplishments.

For those of you who live in countries that use imperial measures, you certainly noted that the title of this article is a play on the measurement of visual acuity. The unit 20/xx implies that you can identify a set of characters at 20 feet, when the standard observer can identify them at xx feet. In these units, 20/20 implies that you match the standard observer and therefore have good vision. If your visual acuity is 20/200, you have to be ten times closer to the target than the standard observer, indicating that your vision is degraded.

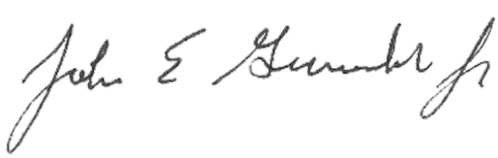
For about half of our Membership, this attempt at humor means absolutely nothing because in metric countries, a measure of good visual acuity is 6/6. Twenty feet is approximately equal to six meters. This simple situation is a great reminder that SPIE is truly an international society!

Our programs and services must meet the needs of the global community, and our international meetings are a great example of that. Of the 20 meetings and conferences that SPIE will organize in 2020, 10 of them will be held outside of the US. But that is just the start as SPIE partners with and supports conferences of many national optics societies.

Another example of our international presence is that out of our 334 Student Chapters, 254 are international as are 75 percent of our Student Members. In addition, international users account for roughly 70 percent of the downloads from the SPIE Digital Library.

We are working hard to serve the global optics and photonics community, and I invite you to contact me if there are things that we can be doing better.

So, whether it is 6/6 or 20/20, let's have a great year.



JOHN E. GREIVENKAMP
2020 SPIE PRESIDENT, president@spie.org

SPIE

Deadlines and Events

January

- **16** Abstracts due for SPIE Structured Light
- **16** Abstracts due for SPIE/SIOM Pacific Rim Laser Damage
- **17** SPIE Photonics West early registration deadline

February

- **1-6** SPIE Photonics West, San Francisco, California, USA
- **2-4** SPIE AR|VR|MR, San Francisco, California, USA
- **12** Abstracts due for SPIE Optics + Photonics
- **14** Applications due for SPIE Optics and Photonics Education Scholarships
- **15-20** SPIE Medical Imaging, Houston, Texas, USA
- **23-27** SPIE Advanced Lithography, San Jose, California, USA
- **28** Applications due for SPIE Education Outreach Grants

March

- **10** SPIE Photonics Europe early registration deadline
- **15** Applications due for the Joe and Agnete Yaver Memorial Scholarship
- **15** Nominations due for SPIE Senior Members
- **31** Applications due for the Michael Kidger Memorial Scholarship
- **29-2** SPIE Photonics Europe, Strasbourg, France

April

- **1** Abstracts due for SPIE Remote Sensing and Security + Defence
- **10** SPIE Defense + Commercial Sensing early registration deadline
- **3-5** 16th International Conference on Laser Applications in Life Sciences, Nancy, France
- **23-26** SPIE Structured Light, Yokohama, Japan
- **23-26** SPIE/SIOM Pacific Rim Laser Damage, Yokohama, Japan
- **26-30** SPIE Defense + Commercial Sensing, Anaheim, California, USA
- **26-30** SPIE Smart Structures + Nondestructive Evaluation, Anaheim, California, USA
- **29** Abstracts due for SPIE Photomask Technology + EUV Lithography

May

- **16** International Day of Light
- **16** SPIE International Day of Light Photo Contest opens
- **18-19** SPIE Translational Biophotonics in Houston, Texas, USA

SPIE COMMUNITY SUPPORT

Giving Today for a Brighter Tomorrow

In 2019, SPIE provided over $5 million in community support to help create the future.

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2020

SPIE Awards Announced

SPIE Biophotonics Technology Innovator Award
SPIE Fellow Nirmala Ramanujam, The Robert W. Carr Professor of Biomedical Engineering at Duke University, in recognition of her development of disruptive low-cost, high-performance technologies to enable see-and-treat paradigms for cervical cancer prevention.

SPIE Britton Chance Biomedical Optics Award
SPIE Fellow Steven Jacques, professor of biomedical engineering at the University of Washington, in recognition of his pioneering work in the field of biomedical optics.

SPIE Frits Zernike Award for Microlithography
SPIE Fellow Winfried Kaiser, senior vice president of product strategy lithography optics at Carl Zeiss SMT GmbH, for exemplary contributions to advancing the state-of-the-art lithographic optical systems, including EUV, that has enabled the continuation of Moore's law.

SPIE Harold E. Edgerton Award in High-Speed Optics
Alan R. Fry, senior staff scientist and director of the Laser Science and Technology division at SLAC National Accelerator Lab, in recognition of his many contributions to the laser industry, as well as industrial and scientific applications of ultrafast laser technology.

SPIE Harrison Barrett Award in Medical Imaging
Harold L. Kundel, professor emeritus of radiology at the University of Pennsylvania, in recognition of his many contributions to the field of medical image perception. His pioneering work first linked lesions in medical images to their spatial frequency spectra, a concept that forms the backbone for many of today's computer-aided detection systems.

SPIE Diversity Outreach Award
Jessica Wade, research associate in the Blackett Laboratory at Imperial College London, in recognition of her extensive public engagement surrounding the issues of science, technology, engineering, and math (STEM), and for championing gender equity and diversity in these fields.

Nirmala Ramanujam

Steven Jacques

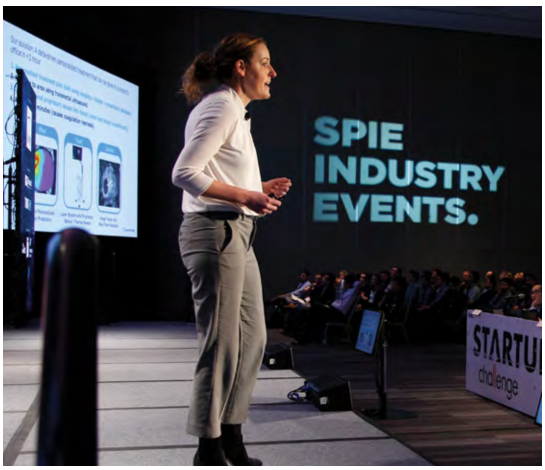
Winfried Kaiser

Alan R. Fry

Harold L. Kundel

Jessica Wade

See the entire list of SPIE Award Winners at **spie.org/2020awards**



2020 SPIE Startup Challenge and New Six-Day Entrepreneur Program

TODAY, LIGHT-BASED TECHNOLOGIES ENABLE a proliferating number of areas, from healthcare and high-speed communications, to quantum computing, AR/VR, and self-driving vehicles. To keep this entrepreneurial drive going, SPIE Photonics West holds the SPIE Startup Challenge—a high-stakes global competition where entrepreneurs with innovative, light-enabled products or applications are given five minutes to pitch their businesses to a team of expert judges and vie for over $85,000 in cash, prizes, and promotion. This year, SPIE is also offering a six-day entrepreneurial training program that includes networking events for the challenge applicants and venture investors, as well as expert-directed workshops.

Dirk Fabian, Community Lead at SPIE and well-known presenter of the Startup pitch-and-judging sessions explains, "The Startup Challenge provides a way for both rookie and veteran entrepreneurs with young photonics companies to maximize their learning, networking, and marketing with the photonics business community. Most new companies don't have the resources they need to spend on marketing and customer discovery, but this is where being at Photonics West adds tremendous power to the Startup Challenge experience."

Now in its tenth year, the 2020 SPIE Startup Challenge will feature the inaugural SPIE Venture Summit, which showcases the complete range of the Startup participants' pitches and a lineup of industry panels and speakers. Summit attendees will receive 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.

Learn more about the SPIE Startup Challenge and new programs (**spie.org/startup**).

SPIE Scholarships/Grants

SPIE Optics and Photonics Education Scholarships
Scholarships are an important component of the more than $5 million that SPIE spends on community support annually. In 2019, SPIE awarded $298,000 in education scholarships for their potential contribution to optics, photonics, or other related fields. Individual scholarships range from $3,000 to $11,000 and are available to students located anywhere in the world who are studying optics, photonics, or related fields. The deadline for 2020 scholarship applications is 14 February 2020.

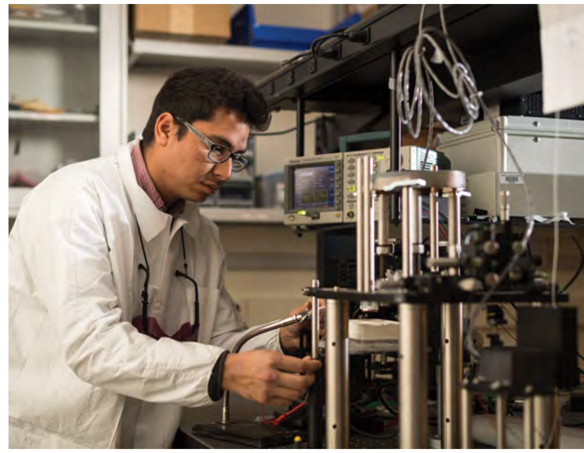
Joe and Agnete Yaver Memorial Scholarship
Former executive director of SPIE, Joe Yaver, along with his wife Agnete, built the multidisciplinary and international scope of SPIE, and were instrumental to the technical and financial success of the Society. This $10,000 award is intended for people seeking further education that will "provide the business knowledge required to facilitate the advancement and application of optics and photonics research and technology." The award is available to SPIE Members and staff seeking an advanced degree or certificate from an accredited program. Applications are due 15 March 2020.

Michael Kidger Memorial Scholarship
Michael John Kidger was a respected educator, design software developer, and member of the optical science and engineering community. Established in 1998, this scholarship provides $5,000 to a student engaged in optical design of either imaging or nonimaging systems. Applications are due 31 March 2020.

Apply online: **spie.org/scholarships2020**

SPIE Education Outreach Grants
As another piece of our educational mission, SPIE provides support for optics and photonics related education outreach activities. These $5,000 awards are intended to increase awareness of optics and photonics among students and the larger community. Many different not-for-profit organizations are eligible for these grants. Application are due 28 February 2020.

Apply online: **spie.org/outreachgrants**



2020 SPIE-Franz Hillenkamp Postdoctoral Fellowship Awarded

SPIE ANNOUNCES FERNANDO ZVIETCOVICH, currently a PhD candidate at the University of Rochester, as the winner of the 2020 SPIE-Franz Hillenkamp Postdoctoral Fellowship in Problem-Driven Biomedical Optics and Analytics. The annual award of $75,000 supports interdisciplinary problem-driven research and provides opportunities for translating new technologies into clinical practice for improving human health.

Zvietcovich's research—conducted in conjunction with Kirill Larin and Michael Twa at the University of Houston's Biomedical Optics Lab—will build on work covered in Larin's lab over the past five years. Zvietcovich will work on translating a novel biophotonics-based optical coherence elastography method into *in vivo* clinical use for human ocular disease diagnostics and treatment monitoring.

Honoring the career of medical laser pioneer Franz Hillenkamp, the SPIE-Hillenkamp Fellowship is a partnership between multiple international biomedical laboratories—the Wellman Center for Photomedicine, the Beckman Laser Institute, the Manstein Lab in the Cutaneous Biology Research Center at Massachusetts General Hospital, Medical Laser Center Lübeck, and Boston University, this year joined by the University of Houston as a hosting lab—and the Hillenkamp family. The endowment is funded through generous donations from the biomedical optics community, with SPIE contributing matching funds up to $1.5 million.

New Editors for JM^3

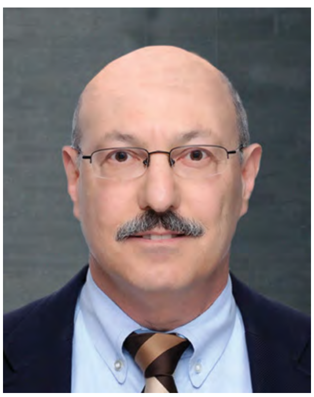
TWO NEW CO-EDITORS-IN-CHIEF WILL TAKE THE HELM of the *Journal of Micro/Nanolithography, MEMS, and MOEMS* (JM^3) starting 1 January 2020. Harry Levinson, a consultant at HJL Lithography, and Hans Zappe, the Gisela and Erwin Sick Professor of Micro-Optics at the University of Freiburg in Germany, will share editorial duties for the journal.

A longtime associate editor of JM^3, Zappe will manage the MEMS, MOEMS, and microfabrication side of the journal. Levinson, well known in the lithography community, will handle micro/nanolithography and related metrology technologies.

They succeed Chris Mack, who served as editor-in-chief since 2012.

"JM^3 is currently recognized as the world's premier journal for lithographic technologies. I am looking forward to working with Dr. Zappe to continue the commitment to technical excellence established by our predecessors," Levinson said.

"Our aim is to continue developing the profile and reach of JM^3 as a premier outlet for exciting science and engineering developments in optical MEMS and advanced lithography," Zappe said. "Supported by a strong editorial board and the resources of SPIE, JM^3 can become the go-to journal in both of these fields."



Left: Harry Levinson; Right: Hans Zappe

Fellows Announcement

SPIE WILL HONOR 72 new Fellows of the Society in 2020. Fellows are Members of distinction who have made significant scientific and technical contributions in the multidisciplinary fields of optics, photonics, and imaging. They are honored for their technical achievement and for their service to the general optics community and to SPIE in particular.

See the list of 2020 SPIE Fellows: **spie.org/fellows**

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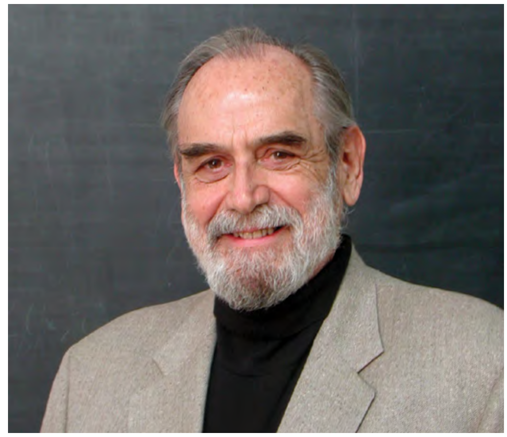
Did you know that SPIE Senior Membership is a prerequisite to becoming an SPIE Fellow? Nominate yourself or a colleague for SPIE Senior Membership and put them on a path of recognition. Senior Membership nominations are due 15 March 2020.



In Memoriam: Roland V. Shack

Professor Roland V. Shack passed away on 18 October 2019 at the age of 92

PROFESSOR EMERITUS OF OPTICAL SCIENCES at University of Arizona's (UA) Optical Sciences Center (OSC), Shack's multiple talents and contributions to the field of optics are legendary. His name can be found in many scientific publications, and his Shack-Hartmann sensor and the Shack cube interferometer are "household words." But, for many, Shack's dedication to his students and the learning process is considered one of his greatest influences on the optics community.

Shack began his teaching career at OSC in the fall of 1965—the center's academic program began operation that year with five faculty members, four graduate students, and a curriculum of seven courses. After an engineering career at Perkin-Elmer, Schack discovered his real calling at OSC—teaching. He encouraged students to be curious, to understand what was happening before their eyes, and not to take anything for granted.

An SPIE Fellow since 1984, Shack received extensive recognition for his significant contributions, including the 1998 SPIE A.E. Conrady Award in Optical Engineering, the 2003 OSA David Richardson Medal, and the 2004 SPIE Gold Medal. In 2005, SPIE published a special volume honoring Shack, along with OSC former Director and Professor Emeritus Bob Shannon, entitled, *Robert Shannon and Roland Shack: Legends in Applied Optics*.

Read more about Roland V. Shack (**spie.org/shack_obituary**).

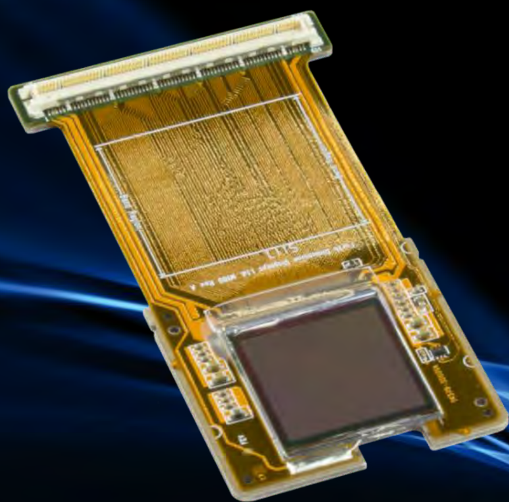
Reflections

The Brocken Spectre appears when a low sun is behind a person who is looking downwards into mist from a ridge or peak. The ghostly figure is no more than the shadow of the person projected forward through the mist. Both the shadows and the glory converge towards the antisolar point. The Brocken Spectre is a similar effect to anticrepuscular rays and cloud shadows.

Photo by Adarsh Ananthachar, @adarsh_ananthachar

Submit your own images of light properties and light-based technology to **REFLECTIONS** by mentioning @SPIEtweets ( ) or @spiephotonics ( ). Submissions can also be sent by email to **photonicsfocus@spie.org**.

2048 x 2048 pixel Spatial Light Modulator



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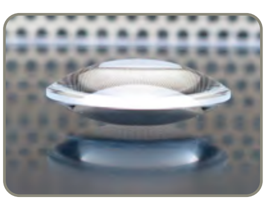

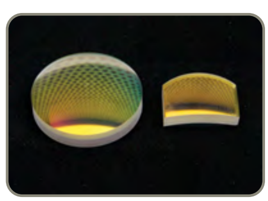




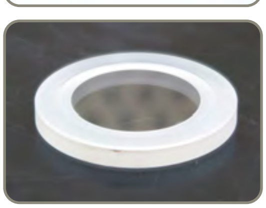
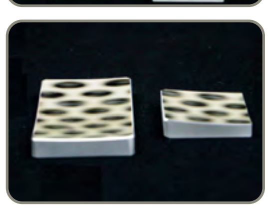

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- Having all the required testing equipment including Perkin Elmer Spectrophotometers and Fisba Interferometer.
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- Protected aluminium coated mirrors from 190nm.
- Capable of manufacturing multi-element lens assemblies in small quantity

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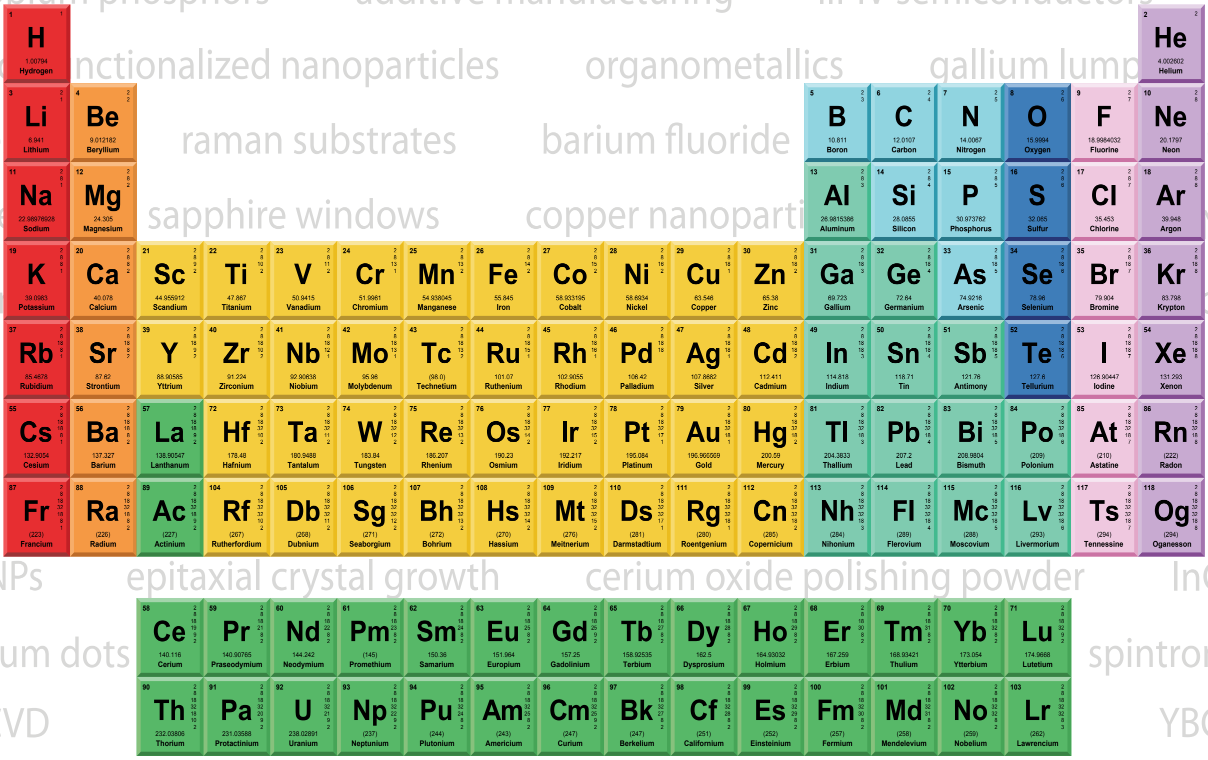

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