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HARNESSING LIGHT FOR

WEARABLE TECH

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FEATURES

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Neurophotonic strategies for observing and controlling neural circuits
» spie.org/PW18_DL1

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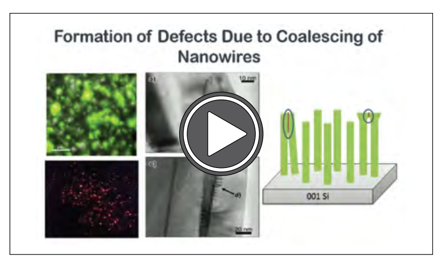

III-Nitride nanowire LEDs and diode lasers: monolithic light sources on (001) Si emitting in the 600-1300 nm range
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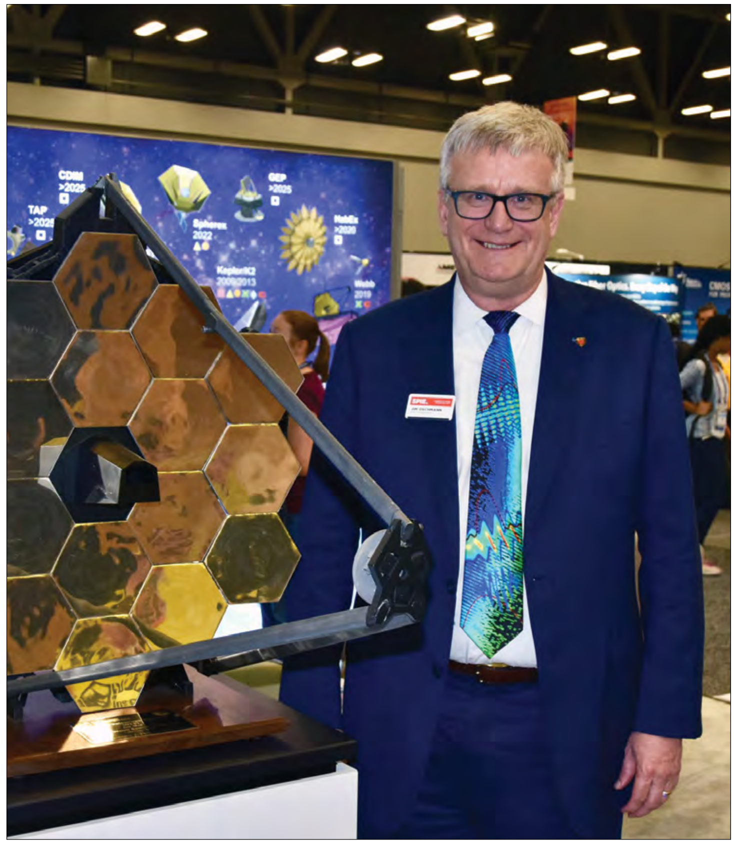
Making Light Visible in 2019



SPIE, in cooperation with many other organizations, has played a substantial role in the public's awareness of the impact of optics and photonics. SPIE was a major force behind the 2015 International Year of Light and continues to promote the resulting International Day of Light, which occurs each year on 16 May. SPIE also continues to promote optics education, outreach, and advocacy through such efforts as the National Photonics Initiative. SPIE awards, scholarships, and travel grants recognize achievements and support the future scientists, engineers, educators, and leaders in our industry. As we begin 2019, we celebrate the $4 million SPIE provided in support of the optics and photonics community last year in the form of education and outreach programs, marking the seventh consecutive year SPIE has spent over $3 million on altruism. Still, there's work to be done to increase public interest in photonics.

The good news is that our industry continues to expand, with many emerging and exciting applications for light-based technologies. As SPIE strives to increase its value to this growing community, we look for new technologies and applications to highlight through our international meetings, publications, education, outreach, and advocacy efforts.

This issue of *SPIE Professional* has some great examples of expanding uses of light-based technologies as it focuses on applications for AR/VR and biophotonic wearables—both technologies that are supported by SPIE meetings like Photonics West. As I looked into our AR/VR session at Photonics West last year, attendees filled the conference room beyond capacity, spilling into the doorways. This explosion in interest is fantastic. I think that one of the interesting upcoming AR/VR uses is in complex systems design. It helps the designers "see" how systems might be assembled and function. Allowing the viewer to immerse themselves within the system in three dimensions (virtual or augmented reality) not only helps the designers, but can also be an effective communication tool to customers "seeing" how the system will perform prior to using the actual hardware produced. These and other potential applications have the opportunity to make augmented and virtual reality real in how they help further improve our lives.

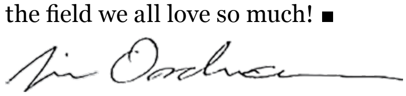
Photonics West has many such examples of research transitioning to application. Optical sensors integrate with wearable devices to provide real-time health feedback. Advances in efficient, reliable, robust, and cost-effective lasers and detection systems are advancing the potential for higher speed free-space communications over the vast distances of space. Holographic components are being integrated into head-up displays in the automotive industry. Photonics West will showcase the state-of-the art research into these and many, many other photonic technologies.

LET ME INTRODUCE MYSELF

Prior to my retirement in 2018 as an executive from SPIE Corporate Member Ball Aerospace, I worked in the aerospace industry on lasers, communications, and remote sensing for civil science and other applications. I have been lucky enough to engage in a fascinating career spanning from small companies, to not-for-profits, to large corporations. Later in life, I'm finding fulfilling opportunities to give back to the optics and photonics community through volunteer roles.

Serving as 2019 SPIE President is my current priority. My role follows many other interesting volunteer opportunities that have allowed me to appreciate the creativity and strength of groups made up of people from diverse backgrounds, including gender, race, age, sector, and culture. As SPIE President, I hope to both learn and contribute to our efforts to promote diversity in all forms. I also want to strengthen the beneficial ties between academia, government, and industry, while working with the fantastic SPIE staff and volunteers to increase awareness of light-based technologies throughout the world.

I am looking forward to expanding my understanding of our world of optics and photonics in its many important arenas. What a chance to continue to learn and give back through the honor of serving the SPIE community! I look forward to 2019 as we continue this exciting path from discovery to application. Let's continue to be leaders in furthering public awareness of the field we all love so much! ■



Jim Oschmann, 2019 SPIE President

Wearables Move Beyond the Consumer...and Into the Clinic?

By **Stephen G. Anderson**
SPIE Director of Industry Development

Despite skepticism when it was launched in 2015, the Apple Watch quickly became a best-selling wearable device, and today is a poster child for consumer wearables. Since then, combined sales of all smartwatches have grown into a ~$13 billion market segment that represents more than 40% of the worldwide wearable device business for 2018. The smartwatch segment alone is projected to increase another 32% to almost $18 billion by 2021, according to market research portal Statista.

The term wearables encompasses not just smartwatches, but a host of other electronic devices that can be worn on, or in close proximity to, the human body. Other device examples include smartglasses, contact lenses, fabrics, headbands and hats, jewelry such as rings or bracelets, and hearing aid-like devices (hearables). Not all of these devices use optical-sensing technology, but many do, and incorporate lasers or LEDs with detectors.

While the markets for wearables include gaming and entertainment, health and fitness applications—like activity trackers and smartwatches—currently dominate. These applications will account for more than half of all wearable devices sold in 2019, according to industry analyst firm CCS Insight, with significant continuing growth.

Wearable devices require high levels of engineering innovation to make them convenient, fashionable, and price competitive. Together with a growing list of capabilities, including monitoring heart rate, glucose levels, sleep quality, and so forth, these attributes are driving the current popularity of wearables among consumers, which is a key factor behind the projected market growth.

Fitness and activity trackers extend well beyond wrist-worn devices and can monitor many physiological indicators. Future devices with greatly expanded capabilities aimed at healthcare professionals will likely monitor blood pressure, blood glucose levels, brain activity (EEG), and other vital signs, while seamlessly streaming that information to your electronic health record in real time. Some current advances in this field based on optical sensing will be presented at Photonics West 2019 in San Francisco, CA; see spie.org/bios.

The fact that many wearables also embody optical technologies means many potential opportunities for optical researchers and components suppliers as the market grows. Many wristbands and watches use optical sensing, but more sophisticated wearables are also benefiting from photonics. Companies at the forefront of health wearables include startup Profusa, which is pioneering tissue-integrated biosensors scanned by an optical reader to monitor body chemistry; Artinis, which provides a portable cerebral oxygenation monitoring system based on fNIRS; and CareWear—2nd Place winner of the Photonics West 2018 Startup Challenge—which offers an FDA-approved wearable therapeutic light patch. And on the research front, some recent developments will be presented at SPIE Photonics West/BIOS 2019 in San Francisco, California.

An artifact of this drive for ongoing capability and performance improvement at the consumer level is technological convergence of consumer-grade wearables with professional medical equipment. While there is real technical overlap between wearables designed for healthcare professionals and the consumer devices that may appear to perform a similar role, some medical professionals are highly skeptical of the unregulated devices, suggesting they may confuse patients, impede care, and waste physicians' time. This raises the question, when is a wearable a regulated medical device?

In an effort to address this ambiguity, the United States Federal Food and Drug Administration (FDA), which regulates equipment designed for healthcare professionals and oversees the sale of medical devices, issued a guidance document dealing with this topic in 2016. Entitled "General Wellness: Policy for Low Risk Devices," the FDA document defines general wellness products as products that: (1) are intended for only general wellness use, as defined in the document, and (2) present a low risk to the safety of users and other persons.

Generally speaking, as long as wellness products do not make claims about disease prevention, treatment, mitigation, or cure, but instead claim only to sustain or offer general improvement to conditions and functions associated with a general state of health, the FDA will not enforce compliance with medical device regulations. These distinctions are not always straightforward however, and a detailed assessment of a device and its marketing claims may be needed to determine if it is in fact subject to regulation or not.

INTO THE CLINIC

The technical distinction between wellness products and medical devices seems likely to become even more blurred as advances in sensors and processors drive performance gains in both arenas. Such gains are an essential facet of addressing the healthcare needs of the world's aging population with the increasing prevalence of chronic diseases such as obesity, diabetes, and cardiac disorders—all of which require some form of continuous monitoring.

At the World Economic Forum in Davos, Switzerland, earlier this year, Rajeev Suri, CEO of Nokia, discussed wearable devices that will do more than existing fitness trackers by clinically monitoring heart rate, blood pressure, and other vitals. "We believe in a world where you can move from reactive care to continuous monitoring and really move to preventive care," Suri said. "At Nokia, we are trying to work on noninvasive wearable sensory devices so you can continually monitor the human body."

Continuous monitoring of vital signs raises a key point in the fight to win acceptance of wearables by medical professionals: medical wearables companies will need to do more than reliably collect data. They will also need to develop the capabilities to make sense of it all.

Meanwhile the latest incarnation of the Apple Watch highlights the potential evolution of wearables from consumer-level fitness trackers to certified health-monitoring devices: the new watch includes an electrical heart sensor that will eventually work with an app to provide an electrocardiogram, used to diagnose heart problems. The app has been approved by the FDA. ■

New U.S. Law Addresses Control of Emerging Technologies

Legislation could affect the future trade and growth of emerging photonic technologies

By **Jennifer Douris O'Bryan**
SPIE Government Affairs Director

The current political and security climate has spurred interest in maintaining control of emerging technologies developed in the United States. How this is accomplished was a point of contention recently, as legislation titled the Foreign Investment Risk Review Modernization Act (FIRRMA) moved through the U.S. Congress and was passed into law.

The debate and final outcome of this legislation should be of great interest to the companies and researchers working with technologies likely to be covered, such as artificial intelligence, autonomous vehicles, and quantum technologies. Though it is unknown at this time what technologies will be identified as "emerging" or "foundational," or what levels of control will be placed on identified items, the movement of this bill and the debate that surrounds its passage strongly indicates that additional controls are likely.

Additionally, a provision in this new law requires any new controls adopted by the U.S. as part of this process to be brought to the Wassenaar Arrangement, the international body setting control standards for 42 other countries, and therefore has the potential to have a global effect on export controls for emerging technologies.

FIRRMA INTRODUCTION

Introduced by Senator Cornyn and Representative Pittenger, FIRRMA expands the authority of the Committee on Foreign Investment in the United States (CFIUS). As originally introduced, the bill would have added new authority to CFIUS to conduct an outbound technology review for any type of arrangement with a foreign person, such as a joint venture.

Currently, outbound technology transfers are approved through the U.S. export control system, which primarily falls under the jurisdiction of the Department of Commerce, Department of State, and Department of Defense. The proposed change would have added another layer of control, requiring approval through CFIUS at the Department of Treasury for certain technology identified as "emerging." Many companies and industry representatives, including SPIE, expressed strong concerns with this proposed new layer of review outside of the current process for export controls.

During an 18 January 2018 hearing before the Senate Banking Committee on FIRRMA, IBM Vice President Christopher Padilla testified that the bill "would duplicate and seriously undermine the existing U.S. export control regime, result in a flood of cases that would quickly overwhelm [CFIUS], and could constitute the most economically harmful imposition of unilateral trade restrictions by the United States in many decades."

IBM Vice President Christopher Padilla testified that the bill "would duplicate and seriously undermine the existing U.S. export control regime, result in a flood of cases that would quickly overwhelm [CFIUS], and could constitute the most economically harmful imposition of unilateral trade restrictions by the United States in many decades."

Due to the objections expressed by stakeholders, the U.S. Senate and House of Representatives amended their respective bills to remove the provision giving CFIUS authority to review outbound technology, and as a compromise added provisions to identify and control "emerging" and "foundational" technologies through the current export control system.

NEW EMERGING AND FOUNDATIONAL CONTROLS

The emerging and foundational technology review established in the bill would begin with an interagency process to identify the list of technologies considered "emerging" or "foundational."

The Department of Commerce would retain primary authority over deciding the level of control imposed on the technology identified in this review process. However, congress prescribes some minimum control levels in the bill, requiring a license for items identified as "emerging" or "foundational" to any "country subject to an embargo, including an arms embargo, imposed by the United States." This notably includes China, as they are an arms embargoed country.

THE ADMINISTRATION

The Trump administration threatened to issue an executive order to add controls to emerging technologies on 30 June 2018, but backed off of this approach at the last minute and chose to defer to Congress to pass FIRRMA and the agencies to control these items as written in the FIRRMA bill. However, it is clear the administration has great interest in the issue of emerging technology controls, and will be closely monitoring the agencies as they implement this new law.

OUTLOOK

The provisions of the FIRRMA bill were attached to the National Defense Authorization Act, which became law on 13 August 2018. However, the law that was passed simply requires a process for identifying and controlling emerging and foundational technologies, but does not prescribe what these technologies are or largely how they should be controlled outside of the minimum requirement of a license to arms-embargoed countries.

As is often the case, details such as these are the most important in terms of impact to the community and will be decided through an interagency process. Therefore, focus will now shift to implementation of the provisions at the agencies involved, which will be primarily shepherded by the Department of Commerce in consultation with the Department of State and the Department of Defense.

As announcements are published by the U.S. government seeking input on this matter, SPIE will continue to provide this information to its constituency. For the community of stakeholders working in the area of technologies likely to be impacted, engagement will be necessary to ensure execution of this process does not hamper growth in many exciting fields of photonics research. ■

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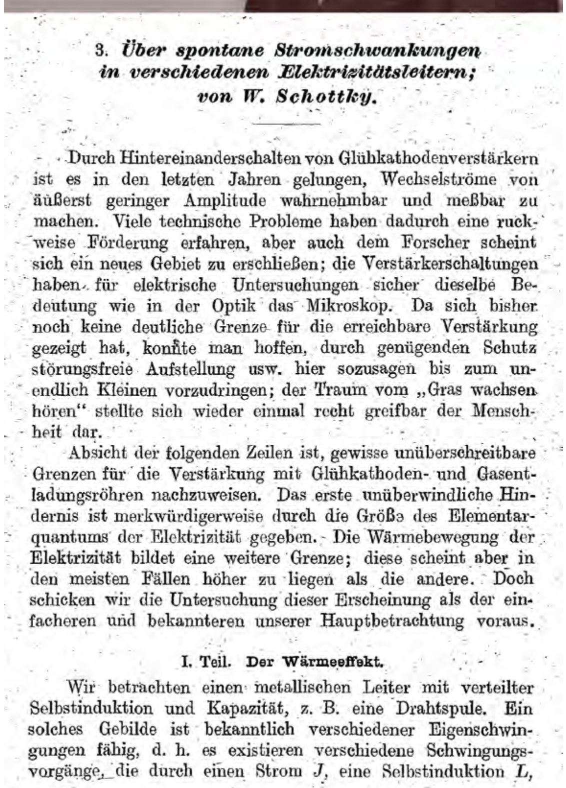
Seminal Paper Translated to English
100 Years Later

In 1918, Walter H. Schottky, a student of Max Planck and Heinrich Rubens, wrote a paper for *Annalen der Physik* called "Über spontane Stromschwankungen in verschiedenen Elektrizitätsleitern," describing the stochastic effect in electronic devices. In that paper, Schottky described a new type of electronic noise called shot noise, a concept that is a growing and prevalent challenge for today's lithography industry. The evolution of semiconductor manufacturing, often described in terms of Moore's Law, has become increasingly reliant on shorter wavelengths and higher photon energy, increasing the impact of the Schottky-observed stochastic effects.

Chris Mack, editor in chief of the SPIE *Journal of Micro/Nanolithography, MEMS, and MOEMS* (JM^3), has long been concerned that stochastic effects may limit the progress of miniaturization using lithographic techniques. Mack wanted to acknowledge the significance of Schottky's seminal work but did not want to cite a paper written in a language that he does not understand, so he asked Martin Burkhardt, a German editorial board member for JM^3 and research staff member at IBM, and SPIE Fellow Anthony Yen from ASML, to translate Schottky's seminal paper into English.

"Considering this paper is still being cited, mostly by people who likely don't know German, I suspect that there is a demand for an English version," says Burkhardt, who agreed to work on the translation in collaboration with Yen. The translation was published in a special section of JM^3 on control of integrated circuit patterning variance, with a focus on pattern roughness, local uniformity, and stochastic defects. The rights to publish this open-access English-language translation were generously granted by John Wiley & Sons, publisher of *Annalen der Physik*.



3. ***Über spontane Stromschwankungen in verschiedenen Elektrizitätsleitern;***
von W. Schottky.

Durch Hintereinanderschalten von Glühkathodenverstärkern ist es in den letzten Jahren gelungen, Wechselströme von äußerst geringer Amplitude wahrnehmbar und meßbar zu machen. Viele technische Probleme haben dadurch eine ruckweise Förderung erfahren, aber auch dem Forscher scheint sich ein neues Gebiet zu erschließen; die Verstärkerschaltungen haben für elektrische Untersuchungen sicher dieselbe Bedeutung wie in der Optik das Mikroskop. Da sich bisher noch keine deutliche Grenze für die erreichbare Verstärkung gezeigt hat, konnte man hoffen, durch genügenden Schutz störungsfreie Aufstellung usw. hier sozusagen bis zum unendlich Kleinen vorzudringen; der Traum vom „Gras wachsen hören" stellte sich wieder einmal recht greifbar der Menschheit dar.

Absicht der folgenden Zeilen ist, gewisse unüberschreitbare Grenzen für die Verstärkung mit Glühkathoden- und Gasentladungsröhren nachzuweisen. Das erste unüberwindliche Hindernis ist merkwürdigerweise durch die Größe des Elementarquantums der Elektrizität gegeben. Die Wärmebewegung der Elektrizität bildet eine weitere Grenze; diese scheint aber in den meisten Fällen höher zu liegen als die andere. Doch schicken wir die Untersuchung dieser Erscheinung als der einfacheren und bekannteren unserer Hauptbetrachtung voraus.

I. Teil. Der Wärmeeffekt.

Wir betrachten einen metallischen Leiter mit verteilter Selbstinduktion und Kapazität, z. B. eine Drahtspule. Ein solches Gebilde ist bekanntlich verschiedener Eigenschwingungen fähig, d. h. es existieren verschiedene Schwingungsvorgänge, die durch einen Strom J, eine Selbstinduktion L,

SCHOTTKY'S LEGACY

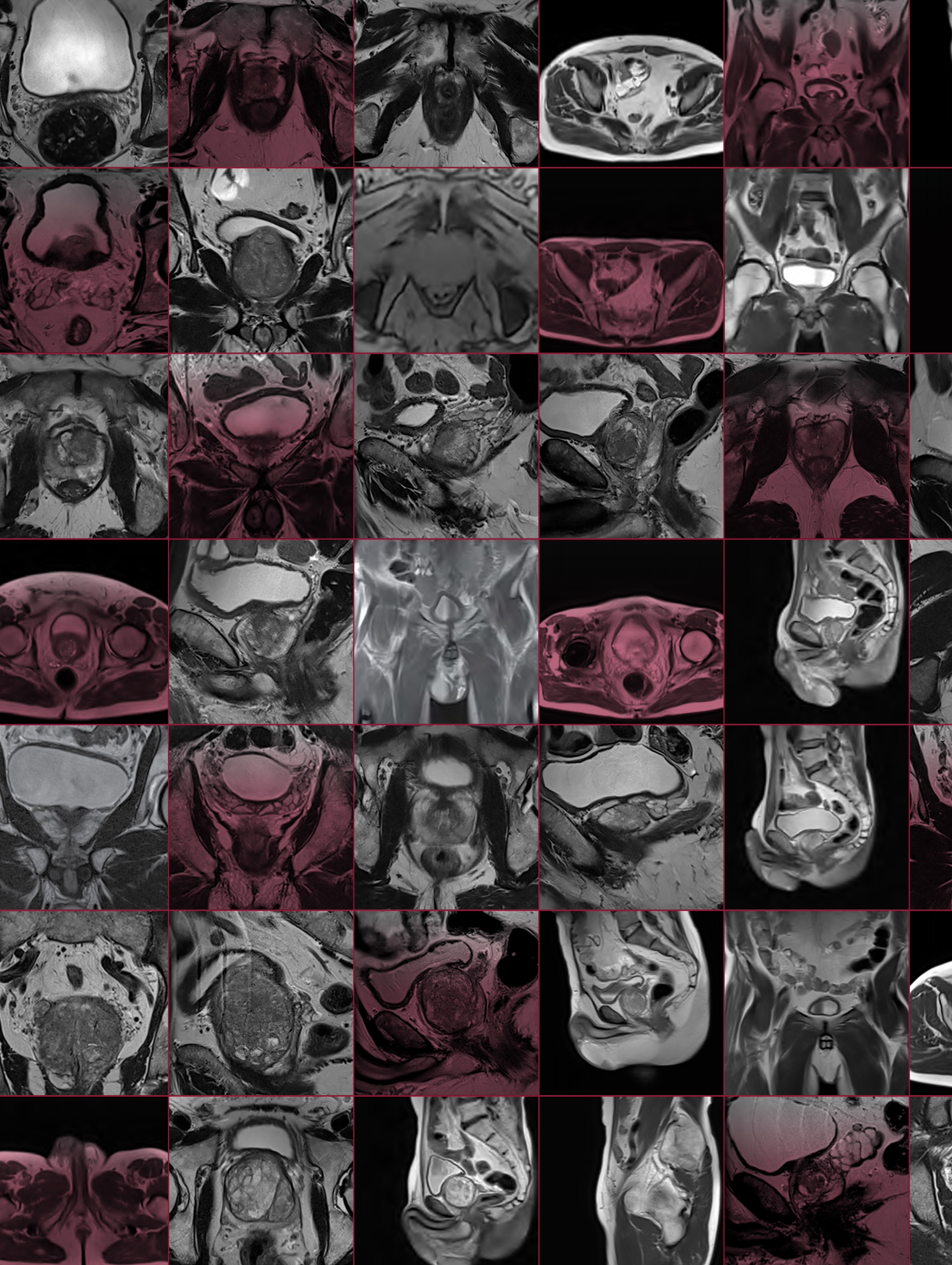
Schottky was perhaps best known for his theory of electron and ion emission and his work on vacuum tubes. Understanding of electron emissions was needed for the invention of the Schottky diode, using what is now known as the Schottky barrier. Understanding of electron and ion emissions in vacuum through what is now called the Schottky-Nordheim barrier was critical in explaining thermionic emission and in the development of modern scanning electron microscopes. However, the topic of shot noise, and subject of the translated paper, remains very important to the field of lithography.

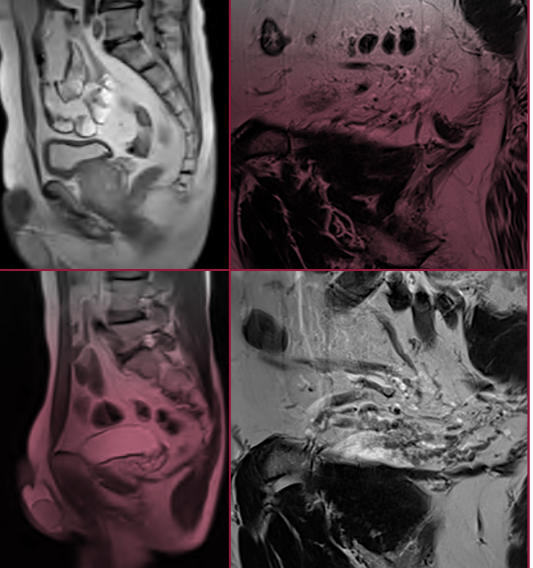
Burkhardt explains that the importance of Schottky's seminal paper lies in the description of the statistics that can be applied to incoming photons absorbed by a photoresist. "Today, we see evidence of stochastic effects in lithographic patterning because a single layer of contact holes or vias can contain tens of billions of holes," says Burkhardt. "No redundancy in those holes can be assumed—every one of them is supposed to be used for making an electrical connection—and each such hole has to be exposed in photoresist with the right number of photons so that, after development, the hole in the photoresist is of the target size."

Although Mack, Burkhardt, and Yen did due diligence to discover if another English translation exists, there's no way to be sure. "This work may have some strategic/military significance, so it is possible that it has been translated internally somewhere, perhaps during [World War II], as was done with many other papers. On the other hand, up to the end of WWII most physicists likely had a glancing knowledge of German and may have read the paper in the original language," says Burkhardt.

This translation also marks the centenary of this much-cited article, which has played such a significant role in understanding shot noise in lithography. In the same special section of JM^3, Mack also published a paper that reviews the history of shot noise, which can be traced to the work of Robert Brown, James Maxwell, Ludwig Boltzmann (of Maxwell-Boltzmann fame), and Albert Einstein, all before Schottky identified the "Schroteffekt," or shot effect, in 1918. Mack then looks at how ideas of shot noise have been applied in lithography for semiconductor manufacturing over the last 40 years.

Both papers can be read in the SPIE Digital Library: **spie.org/shotnoise** ■





Solve for X
Lessons Learned from PROSTATEx

The latest Grand Challenge co-sponsored by SPIE, AAPM, and NCI is the BreastPathQ. Challenge results were released to participants on 4 January 2019, and a workshop will take place as part of the 2019 SPIE Medical Imaging Conference in February: spie.org/BreastPathQ

In 2016, the American Association of Physicists in Medicine (AAPM), National Cancer Institute (NCI), and SPIE, partnered together to issue a challenge—a Grand Challenge—to the medical imaging research community: come up with a method to automatically classify prostate lesions as either clinically significant or not, based on images acquired from MRI. In other words, we'll give you the datasets, you submit the results of your computerized method.

On the heels of the first challenge, a second part was announced in 2017, with the task of developing a computerized method to determine the Gleason Grade Group in prostate cancer based on those same MRI images. Prostate cancer cells are classified into Gleason Grade Groups 1 to 5 based on how closely the cancerous cells resemble normal healthy prostate tissue. A close match is a 1, very abnormal cells are a 5.

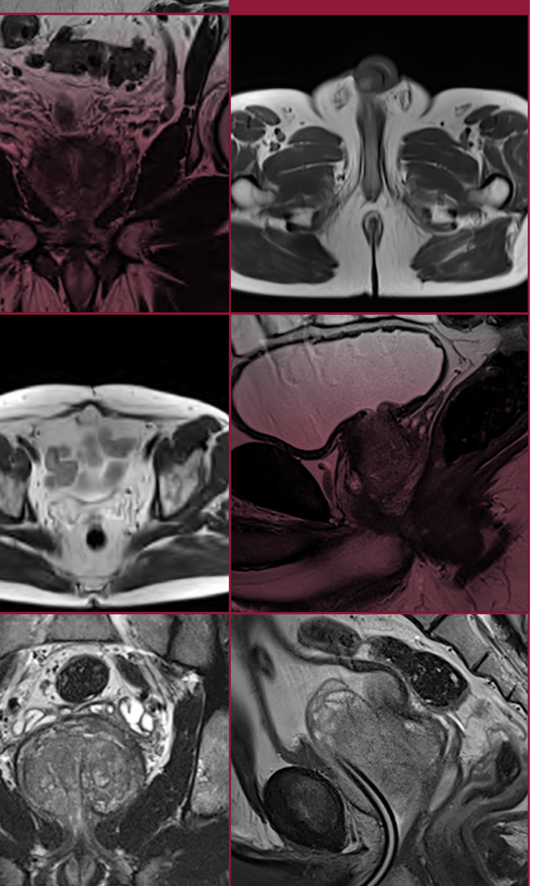
The purpose of these Grand Challenges is not to find one algorithm to rule them all, but to provide an opportunity for the comparison of perhaps dozens of algorithms through a specific and well-defined infrastructure. Sam Armato, SPIE Member and one of the organizers of the two-part PROSTATEx Challenge, believes that these challenges foster interest in the task and encourage innovation in the field.

Now that the challenge has concluded, Armato, along with other challenge organizers, has published a paper summarizing lessons learned and opportunities for the future:

1. Of the 71 methods submitted to the first part of the challenge—the one tasked with classifying prostate lesions as clinically significant or not—the majority of those methods outperformed random guessing, and the four best-performing methods could not be statistically distinguished. The conclusion: automated classification of clinically significant cancer seems feasible.
2. Of the 43 methods submitted to the second part of the challenge—the one computationally assigning lesions to a Gleason Grade Group—only two did marginally better than random guessing. The conclusion: it's very difficult for computerized methods to differentiate one of five possible pathological grades. This result demonstrates that there is a novel line of investigation on this subject that is open for creative ideas.
3. The relatively small size of the test datasets (204 in the first challenge and 99 in the second) made it difficult to achieve statistically significant conclusions. More images in future datasets will improve the likelihood of drawing such conclusions.
4. Dataset quality can be a problem for challenges—sometimes annotations are ambiguous, and sometimes the reference standard has inherent variability. These issues must be minimized as much as possible by challenge organizers.
5. Grand Challenges for medical imaging shouldn't be one-and-done. There's a need to keep the challenges going, even after the competition deadlines have passed.

Answering the last lesson learned, the challenge lives on at **prostatex.grand-challenge.org**. New methods can be added at any time, and researchers can continue to receive objective feedback.

The paper summarizing these results can be found in the *Journal of Medical Imaging* on the SPIE Digital Library: **doi.org/10.1117/1.JMI.5.4.044501** ■



A Proceedings Evolution

Conference presentation recordings provide a content-rich multimedia experience that's almost like being there.

By **Eric Pepper,**
SPIE Director of Publications

Conference proceedings have been the backbone of SPIE's publishing activity since 1963. In that time, we have published 450,000 technical papers spanning 11,000 proceedings volumes, garnering tens of thousands of patent and literature citations and global recognition of their value to advancing cutting-edge photonics research. Add to that more than 33,000 journal articles and 350 eBooks, and the SPIE Digital Library has become "the world's largest collection of optics and photonics applied research."

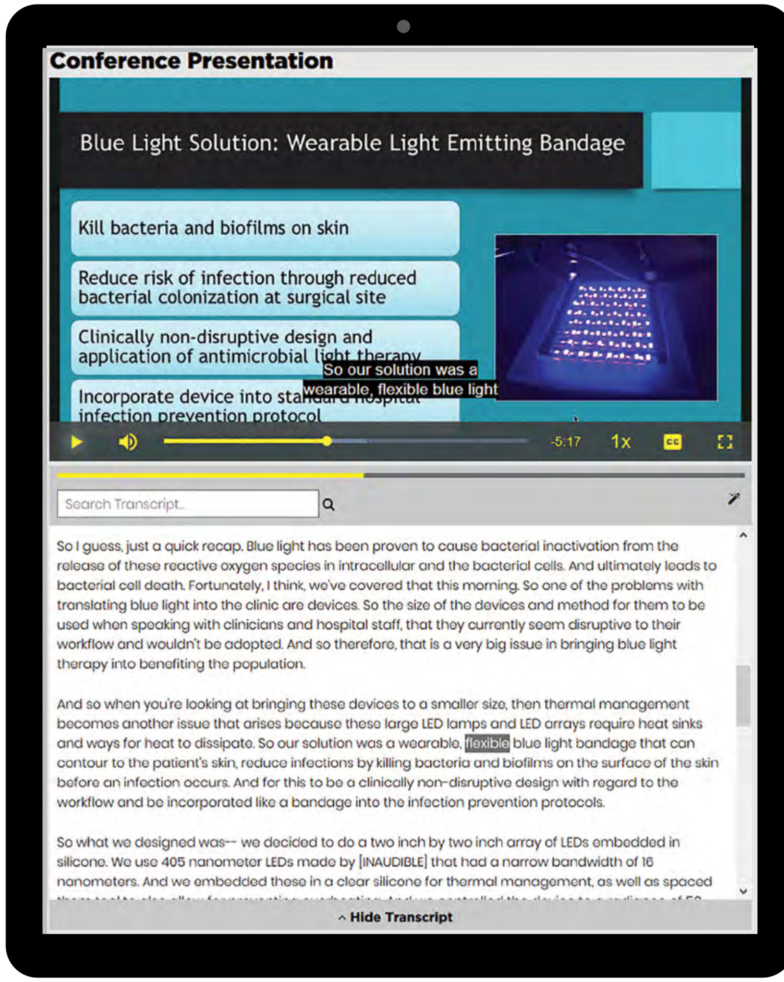
That's SPIE's publishing legacy. More recently, responding to changing data about publication preferences and use of proceedings, and enabled by advances in publishing technology, SPIE initiated a full-scale program to record the oral presentations at our major technical symposia in the U.S. and Europe and, with author permission, publish the recordings on the SPIE Digital Library as part of the conference proceedings. Today, that collection of recordings has grown to more than 16,000 content-rich presentations that showcase the thought and expertise of the participating speakers.

Each recording includes the audio of the presentation synchronized with video of the slides as projected onto the room display, although the audience Q&A discussion is not included; you have to be present to hear that portion of the sessions. Many presentation recordings are accompanied by an abstract and written paper.

Multimedia has become an effective and widely adopted means to convey and consume information. The recordings augment the conference papers by giving readers additional information about the topic, including animations, 3D images, and video demonstrations that are not typically possible in a written paper.

SPIE has further enhanced the recordings with interactive, searchable transcripts. This feature enables users to browse or search and efficiently and quickly navigate to content of interest within a presentation. Closed Captioning (CC) is also available, making the presentations ADA compliant, as well as offering that option to users who value having the written text displayed while listening to the speaker.

Another useful feature is the ability to instantly translate both the transcript and CC text into a variety of languages using Google Translate. This capability should be especially valuable for users around the world for whom comprehension will be better in their primary language.



SPIE presentation recordings include searchable transcripts, in addition to closed captions and translation options.

Typically, presentations are available on the SPIE Digital Library 2–4 weeks after a conference. Conference attendees have full access to the written papers (PDF and HTML) and may also view the presentation recordings as part of their online proceedings subscriptions, and institutional and personal SPIE Digital Library subscribers can watch the recordings as well. SPIE has decided to make all plenary presentations open access as a benefit to the community.

Capturing and archiving the many outstanding presentations given at SPIE conferences is a major enhancement to SPIE's conference proceedings. For those who are able to attend the events, they provide a way to review the talks that caught your interest or to hear and see the ones you missed. For others, this rich technical content is now available to the global research community in a format that is almost like being there.

These presentation recordings bring a new dimension to SPIE's proceedings and Digital Library, and it is an evolution that serves the community well. ■

A Day in the Life of an SPIE Professional

In 2019, the #FacesofPhotonics series in *SPIE Professional* will focus on people who have taken different career paths in optics and photonics, from industry, to starting a new company, to academia, to government. These profiles will give SPIE Members a glimpse at a day in the life of an SPIE Professional.

Leslie Kimerling

CEO and Co-founder of Double Helix Optics

Leslie Kimerling has spent much of her career working with early stage and growth companies. In fact, she describes herself as a "serial entrepreneur." She has worked with founders who have a passion for their invention, but without a clear idea about how to commercialize it. That's where Kimerling comes in: she knows how to take an invention and figure out where it fits in the marketplace and build a company around it.

"What's most interesting is when there's an amorphous idea that's potentially very powerful, and turning it into something that's tangible and usable by more than a few—it's really a fun process for me," says Kimerling.

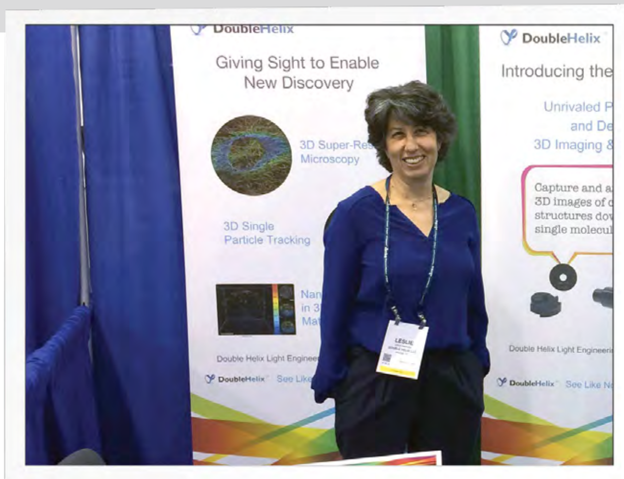
Most recently, Kimerling has partnered with Dr. Rafael Piestun to cofound Double Helix Optics (doublehelixoptics.com), a company that develops products that create vivid 3D nanoscale images, allowing you to see structures down to the single molecule level. Double Helix won the 2016 SPIE Startup Challenge and the $1 million top prize in the Luminate accelerator program and competition in Rochester, New York in July 2018.

Why did you decide to launch Double Helix Optics?

My cofounder, Dr. Piestun, was a friend in Boulder, Colorado, and he was talking to me about an innovation that he thought had significant market potential. But, he didn't come from a business background, and he wasn't sure how to bring technology to the marketplace. We spent a good chunk of time sitting together in the coffee shop, walking through what it would take to turn the double helix 3D imaging technology from concept to a usable product with potential commercial opportunity. After working together for about nine months, we decided to launch Double Helix.

What does a typical day in your job look like?

Some days are about finances and company strategy, and other days I work with the team to solve a technical issue related to a product in development. I travel often for the company—to visit customers and potential customers, meet with partners and potential partners, as well as represent Double Helix Optics at conferences, workshops, and other industry-related events. I work to strike a balance between product sales and service for our existing product line, the SPINDLE® and phase masks for 3D microscopy, and the development of new 3D imaging technologies. No day is ever quite the same, but each day brings variety along with new opportunities and challenges.



What skills are most necessary to run your company?

As CEO, I bring a set of business-related skills to the company—finance, organization, strategy, sales and marketing, business development, and fundraising. My role on the technical side of the business is to ensure we stay on path with product development, R&D, manufacturing, and identifying the right technical partners to help us advance our company.

Someone reading this article is working on a technology with the potential to be a good commercial product. What advice do you have for that person?

There's a line of thought that "If I have a new technology and patent it, then I have a product." But there's a big difference between publishing a paper, filing a patent, and having a product. You must have a lot of patience to launch a successful commercial product, and you must be willing to put the time and effort into doing what I'll call the "commercialization work," that goes beyond R&D and traditional lab/bench work. Having someone with a business background involved with your startup can significantly increase the probability of success and reduce the number of headaches you, as the technical lead, have to take on yourself.

Closing thoughts about your role as CEO of a photonics startup company?

I'm the company's advocate and number one fan. I am so proud of what our small company has accomplished in its short tenure. I am consistently impressed by the ingenuity of the team and our ability to manage our way through each challenge we face as we advance our 3D sensor and imaging capabilities. The future of 3D imaging is, I think, boundless at this stage. ■

CAREER

Removing Barriers

SPIE promotes diversity and inclusion in STEM

By **Karen Thomas**

"Diversity is the key to the future of engineering," said Sabrina Stierwalt of Caltech during a plenary talk at SPIE Astronomical Telescopes + Instrumentation in June. "The inclusion of women and other minorities in technical fields has proven to be crucial to innovation, talent recruitment, profits, and global competitiveness. While more diverse workplaces are clearly the future, some engineering programs and companies still struggle to keep up."

That Stierwalt was speaking on this subject at an SPIE plenary presentation points to the importance of the work being done to diversify science and engineering. Just as important as solving a critical lens-design issue, making strides in diversity and inclusion in STEM will impact science and engineering for generations to come.

To address some of the persistent gender equity challenges in the optics and photonics (O&P) community, SPIE formed a Gender Equity Task Force (GETF) (**spie.org/WiO**) in 2015 to identify how the professional environment and culture of the O&P industry can be improved such that O&P professionals are offered opportunities, rewards, and recognition independent of gender. The primary products of the GETF efforts were a Strategic Plan and a Feasibility Study, which together outlined recommendations of what the Society should do (Strategic Plan) and how the Society should do it (Feasibility Study).

SPIE DIVERSITY & INCLUSION AD-HOC COMMITTEE

The committee defines diversity as the inclusion of all individuals represented in the fields of science and engineering, regardless of their race, gender, ethnicity, lifestyle, economy, and geographic location.

To develop a set of strategies to improve and enhance diversity and inclusion in all aspects of SPIE, the Diversity & Inclusion (D&I) group was formed first as a Presidential Task Force in 2016 and converted to an Ad-hoc Committee on Diversity and Inclusion for 2017–2019.

As a policy, SPIE does not preclude membership or participation to any group in the O&P community. However, implicit bias and a lack of conscious planning can result in a lack of recognition of colleagues from diverse backgrounds. While gender is only one aspect of diversity, the goal of the D&I committee has been to address and increase all diversity and support inclusion in SPIE activities.

The membership of the committee comprises SPIE members from academia and industry, including students such as Perla Marlene Viera-González of Universidad Autónoma de Nuevo León in Mexico.

"It's been hard for me to get recognition in science in my country," says Viera-González. "My work is better recognized in international societies such as SPIE than in my local community."

Viera-González notes that in her culture, women are seen as primary caretakers of the family while men are considered the provider and ultimate authority.

"My family believed my career choice was just a phase and one day I would choose a more 'home-friendly' career path," she says. "In the end, they understood that I wanted to be a scientist and I enjoyed doing experiments, getting dirty in the lab, and other cool stuff."

As part of the D&I committee, Viera-González says she learned that diversity goes beyond gender and origin, and "sadly, there is a lot of discrimination for various reasons in the world. But thanks to this committee, we can create a diverse community in optics and photonics."

CHANGING THE CULTURE

To promote diversity, the D&I committee has developed several activities including increasing the diversity in SPIE committees, nominations in SPIE programs, and programs for family friendliness. The D&I committee developed a multi-pronged approach to "change the culture," which will "likely to take time to see full fruition."

Steps include encouraging members of the Society to consider diversity in nominating a colleague and hosting more D&I events at a variety of SPIE conferences. These efforts have led to some improvements such as increasing the diversity in the nomination pool for Senior members (2018 – 10% women), Fellows (2017 – 14% women) and Awards (2018 – 15% women).

According to the D&I Ad-hoc Committee's report to the Board of Directors, research reveals that the "baby penalty" negatively affects women's, but not men's, career mobility, with even larger penalties for women of color. By promoting a parent-friendly environment and culture, professional societies would send a strong message of support and inclusiveness that could help retain parents in their academic or industrial fields. This year, SPIE will begin offering grants of up to $500 U.S. per family, per calendar year, to assist SPIE Members who need financial assistance to attend SPIE conferences (see sidebar).

The Awards Committee took the inclusivity message to heart, renaming a few existing SPIE awards and creating new awards that encourage and support diversity. These include the SPIE Diversity Outreach Award and the SPIE Maria Goeppert-Mayer Award in Photonics. Renamed awards include the SPIE Maria Yzuel Educator Award and the SPIE Aden and Marjorie Meinel Technology Achievement Award.

NO SILVER BULLET SOLUTION

In 2018, SPIE participated in a national-level study of members of STEM-related professional organizations and societies. Funded by the National Science Foundation, the STEM Inclusion Study (**www.steminclusion.com**) provided comprehensive diversity and inclusion insights about the experiences of women, racial/ethnic minorities, persons with disabilities, and LGBTQ persons in the United States.

> **"If we value a diverse and equitable workplace, we need to do something different."**
> —Sabrina Stierwalt

The study found that "personal experiences of harassment in general are relatively low, and respondents across demographic groups generally felt their work is respected by their colleagues and that their supervisors treated them with respect." But, the study also pointed to "several concerning trends regarding the marginalization and professional devaluation of under-represented members of this organization."

There were "pervasive gender differences in workplace experiences: women had significantly more negative experiences on nearly every measure in our analysis, net of variation by age, education level, employment sector, and other demographic factors. Similarly, LGBTQ respondents, and racial/ethnic minority respondents reported significantly more negative experiences than their peers across a number of different marginalization and professional devaluation measures." In other words, we're not there yet.

The summary also notes that SPIE's participation in the STEM Inclusion Study is "an important signal of its willingness to consider and confront diversity and inclusion issues among its membership. Inequality in STEM is an intractable problem that has no silver bullet solution. It will take deliberate and sustained effort to help move the needle in this and other STEM-related professional organizations."

As Stierwalt noted in her plenary talk, the academic programs and tech companies that recruit from a diverse talent pool are proving to be more competitive.

"If we value a diverse and equitable workplace, we need to do something different," she said. "Luckily for us as scientists, engineers, and innovators, doing something different is what we do. If our ultimate goal is having the best and brightest minds working on the next space mission or the next ground-based telescope, then I think what we are really after is removing barriers so that STEM is accessible to everyone." ■

Thanks to SPIE's family-friendly meeting policy, Mónica López Sáenz enjoyed attending 2018 Defense and Commercial Sensing with her son.

SPIE Photonics West

CHILD CARE GRANT

Last year, SPIE announced its new 2019 SPIE Photonics West Child Care Grant, which was applauded by the SPIE Gender Equity Task Force (GETF) as a direct response the GETF Feasibility Report recommendations. Such grants will directly benefit SPIE Members with young children by enabling them to remain engaged in conferences, an essential component of professional development.

Participation in scientific conferences is widely acknowledged as essential to STEM career development. Traveling to conferences for primary caregivers, even when employers cover employee costs, is often difficult. Childcare grants covering expenses to bring care providers to conferences or hire local childcare will enable more primary caregivers to participate in SPIE conferences.

SPIE plans to offer similar grants for other conferences later in the year.

Read more in the SPIE Newsroom
spie.org/childcare

VIRTUAL AND AUGMENTED REALITY TECH

Joins the Fight against Crime

By **Rebecca Pool**

Tucked away in a small corner of South Wales, United Kingdom, police officers are using a larger-than-life technology to tackle domestic abuse. Some 1,200 frontline officers from Gwent Police Force have already used a "virtual reality cave" to interact with a virtual victim, honing skills to identify controlling and coercive behavior.

The Cave Automatic Virtual Environment comprises three screens to give a wraparound virtual experience for a growing number of exercises, including vital "golden hour" training to increase rape convictions and a virtual custody suite complete with detainees, detention officers, nurses, and lawyers.

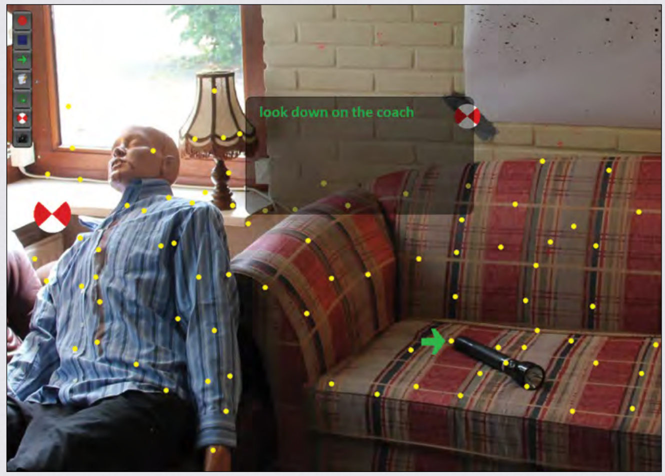
"We've got plans to build ten scenarios," says Superintendent Vicki Townsend. "Constables, sergeants, and detectives have all used [the cave] and the feedback has been wholly positive."

Gwent Police Force is hardly alone in its foray into the virtual world. The rise of VR and AR to fight crime follows years of worldwide research by forensic scientists, many of whom have developed prototype systems for reconstructed crime scenes. The Netherlands has been a hive of activity in this arena with computer scientists, systems engineers, and police professionals collaborating on a host of projects.

One such project known as CSI: The Hague launched at the turn of this decade and set out to digitize the crime scene. At the scene of any crime, all traces of evidence must be identified and secured as quickly as possible. With this in mind, the project turned to augmented reality to create a virtual version of the crime scene that would always remain intact so forensic investigators could revisit it time and time again.

To create the virtual crime scene, a first investigator at the actual crime scene would wear a head-mounted display receiving 3D video from attached cameras, controlled by a laptop in a backpack. In this way, he or she could see the surroundings, but also overlay and virtually tag objects using hand gestures. Blood stains and bullet holes could be documented, and projectile trajectories reconstructed, to build a clear record of the scene in 3D video before evidence was removed.

As Professor Stephan Lukosch from the Delft University of Technology recalls, "We had mounted two depth cameras onto a Carl Zeiss Cinemizer headset and used a simultaneous localization and mapping (SLAM) algorithm to [analyze]



Fighting crime with "On the Spot": user interface for a remote investigator in a forensic investigation scenario.

Credit: TU Delft

motion. Our end result was far from a detailed 3D model that you could run around and interact with, but back then it was really good."

A later project, "On the Spot," brought in the Port of Rotterdam fire brigade to collaborate with police in a number of virtual scenarios including a forensic investigation and ecstasy lab discovery. 3D video footage of the crime scene was streamed from an on-site police officer's body camera to a remote forensic expert.

The AR system, also using a SLAM algorithm, hand-tracking, and gesture recognition, allowed the remote expert to augment the scene with notes, geometric shapes, arrows, and more. In this way, the local police officer could view these virtual annotations via a smartphone or a head-mounted device and use them to collect the evidence at the actual crime scene, as directed by the expert.

However, according to Nick Koeman, Strategic Innovation Advisor from The Netherlands' National Police, the technology still wasn't mature enough in 2015. Visual tracking software couldn't keep pace with more complex tasks, and the Google Glass-type headsets weren't usable under direct sunlight. But, he adds, "We realized the potential of augmented reality here."


On the Spot: the on-site investigator at the crime scene.

Credit: TU Delft

And so Koeman and Lukosch, in collaboration with Dragoş Datcu from the AR organization Twnkls, started work on a third relatively low-key project, ARPro. This time, field officers would head to a potential crime hotspot, such as a suspicious building. Once there, and thanks to a localization system developed by Twnkls, they would instantly receive notes and images from previous investigations at that site to better assess the situation.

Having only recently ended, the project was not as technologically sophisticated as past AR setups, but as Datcu highlights, he and colleagues can reach tens of thousands of officers, massively enhancing collaboration. "The Dutch police has some 40,000 operational agents all with smartphones, and we can inject the right information to the right people at just the right moment," he explains.

What's more, Datcu is confident a good app for fighting crime will reach police forces in a few years. "This will be used to take images, extract meaningful evidence about markers, clues, and traces, store the semantic annotations related to the crime scene, and then present this when needed to the user," he says. "It could even detect license plates, recognize faces, and process fingerprints, giving you in-depth information about crime hotspots within moments."

Lukosch also believes that state-of-the-art mixed-reality smart glasses, such as Microsoft HoloLens, and virtual retinal display Magic Leap One will soon herald systems with a better user experience.

And for Koeman of the Dutch Police, AR and VR are the future. "Our ambition is to integrate these technologies and enhance training and our operations," he says. "We might want to act out an evacuation in a fire scenario in a government building, and we can't really light up Parliament just for a training exercise, can we?"

Credit: AUGGMED

BEYOND THE SCENES

Just as AR and VR infiltrate shady criminal worlds, the technologies are also beginning to tackle terrorism. On 7 April 2017, in a Stockholm shopping center, a hijacked lorry was deliberately driven into crowds before being crashed into a department store. Five people were killed, and fourteen others seriously injured.

Philip Engström presented on key design guidelines for crime scene visualizations using VR at SPIE Defense + Commercial Sensing in 2018. Watch his presentation on the SPIE Digital Library: doi.org/10.1117/12.2304653

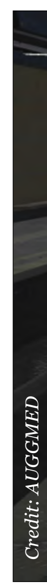
Philip Engström, SPIE Member and head of the sensor technology group at the Swedish National Forensic Centre, has reconstructed the terrorist attack. Using a cutting-edge 3D laser scanner from the 3D measurement company FARO (Florida, USA), he carried out around 100 laser scans and collected some 800 million data points from the scene to create several videos from different perspectives. His work was broadcast in a Sweden courtroom.

"The prosecution wanted to show what it was like having this truck drive at 60 km an hour towards you," he says. "The video didn't include people, was as clean as possible...but everything was clearly based on fact."

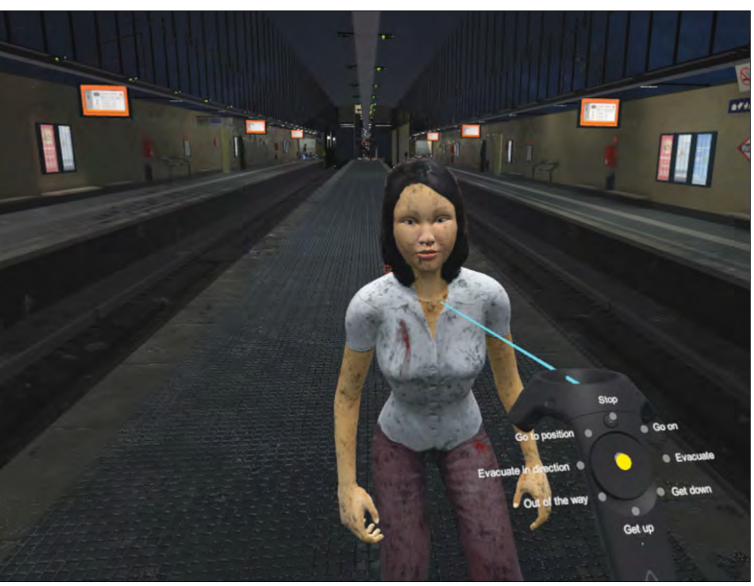
The Swedish National Forensic Centre has been developing 3D sensing technology for crime scene investigations for a decade, with Engström now heavily involved with its VR development. Like The Netherlands researchers, he has been experimenting with VR headsets as well as using real-time streaming 360° cameras as data sources. Since acquiring the laser scanner in 2017, he has rapidly reconstructed some 15 crime scenes as well as the tragic Stockholm terror attack, and he is excited about the future use of VR to counter crime and terrorism.

"It's so easy to see the big role that virtual reality can play here," he says. "After discussions with the prosecutors who watched our video as well as the police, we know that many people think it has vast potential."

Indeed, big and vast aptly describe what is around the corner for AR and VR. Researcher and serious games developer Jonathan Saunders from the Centre of Excellence in Terrorism, Resilience, Intelligence and Organised Crime Research at Sheffield Hallam University, United Kingdom, concurs, and has



Credit: AUGGMED



(Above) In this AUGGMED airport attack simulation, rendered crisis scenarios were made to be as close to reality as possible. (Below) Players can directly interact with agents via hand gestures or spoken commands to take control of a situation in a way that resembles a real-life scenario.

been instrumental in developing a platform to train law enforcement agencies to respond to terrorist and organized crime threats.

As he puts it, "Augmented and virtual reality are still experimental but very useful for when you've got to make critical decisions under pressure, say during a terrorist attack or even a crisis such as a flood or earthquake."

His platform is part of the pan-European project AUGGMED—Automated Serious Game Scenario Generator for Mixed Reality Training—which set out to enhance the 3D simulation tools already used in police and paramedic training for extremely complex scenarios. "Simulations evolve depending on what the users do," explains Saunders. "During training, one user could choose to start an evacuation immediately, which has a very different effect than exploring a scene and trying to find the suspect first."

AUGGMED's key training pilot featured a terrorist attack at the Port of Piraeus in Greece. Here, HTC Vive VR headsets, with additional cameras to extend the field of view, provided video footage rendered with VR explosions, weapons, and hostages. And, as Saunders adds, "We also used custom-haptic feedback vests that would heat up if you walked too closely to the virtual fire, and you'd feel a thump on your chest if you were shot."

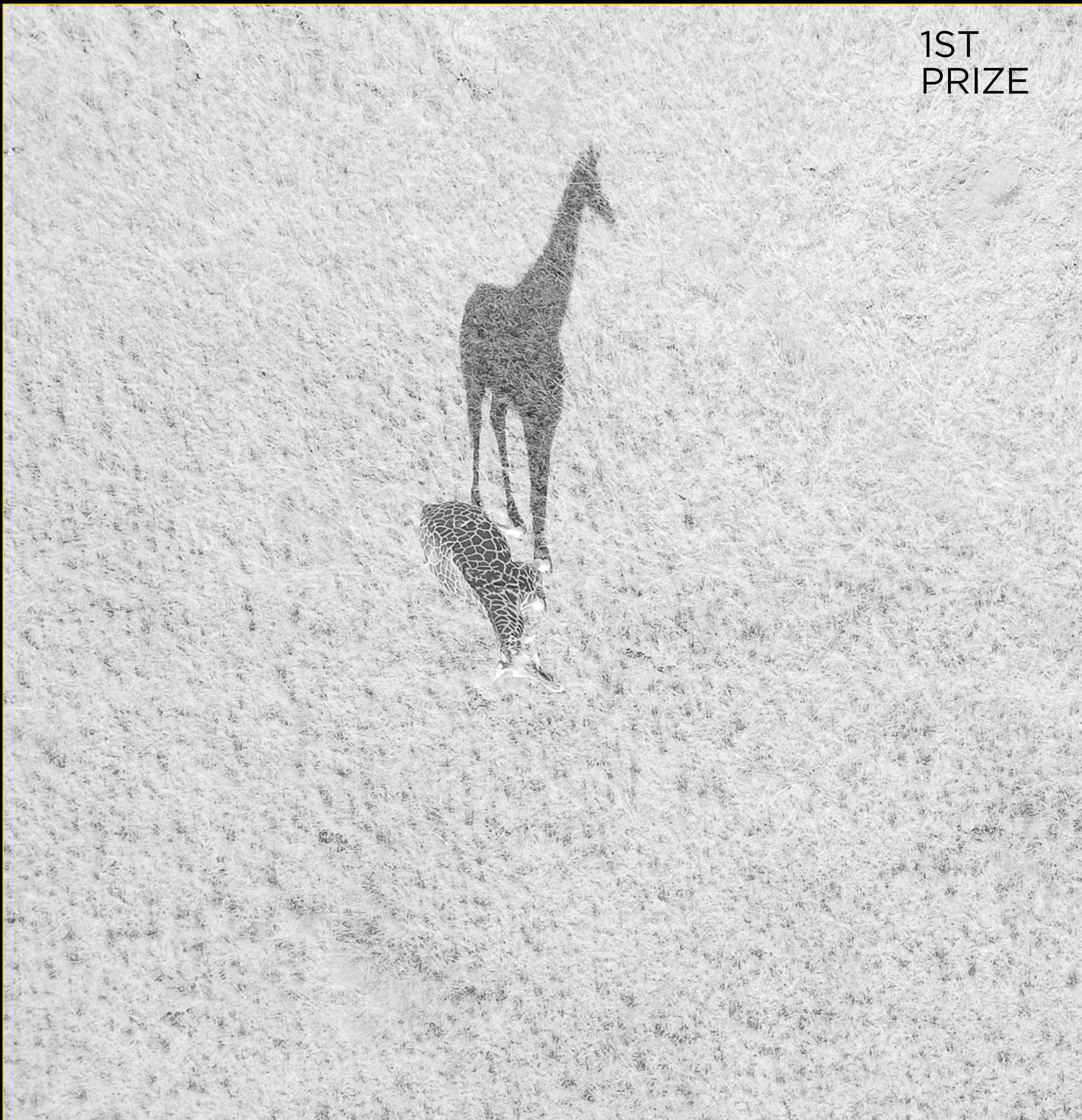
With the mediated reality platform now deemed a success, commercial development could ensue, but in the meantime, Saunders is already working a new Advanced Training, Learning, and Scenario (ATLAS) simulation for the United Nation's International Organization for Migration. Commissioned after two civilian staff were killed during a convoy attack in South Sudan, the simulations are training staff to respond to life-threatening situations.

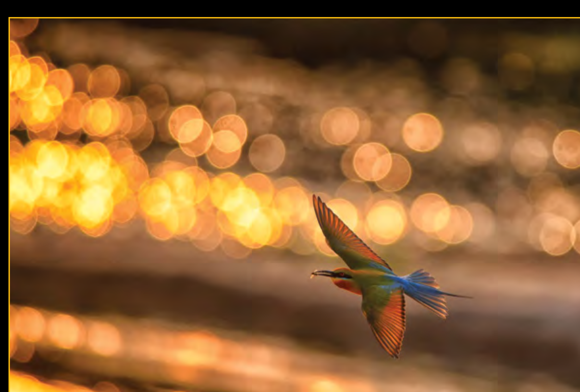
"This time, we've used methods to reduce the motion sickness experienced by those using the VR headset," highlights Saunders. "A post-processing effect on the camera—virtual reality tunneling—subtly reduces peripheral vision by slowly darkening the edges, and stops you feeling uncomfortable and unwell during motion."

Given the rapid progress, Saunders is sure both VR and AR will feature in crime and the fight against terror.

Back in Gwent, Superintendent Vicki Townsend agrees. "I think ultimately this is something that we all need to do," she says. "Virtual reality is giving us the best opportunity to deliver consistent quality training, and the sooner we can take this forward, the better." ■

In addition to new uses of AR and VR for crime scene investigations, VR simulation technology has produced encouraging results when applied to clinical settings across a wide range of health conditions. Skip Rizzo, director of MedVR at the USC Institute for Creative Technologies will speak at SPIE Defense and Commercial Sensing in April and try to answer the question, "Is clinical VR ready for primetime?" spie.org/DCS


1ST
PRIZE



2ND PRIZE

3RD PRIZE

International
Day of Light

16 May

2018 Photo Contest WINNERS

This annual photo contest seeks to raise awareness about the International Day of Light and show the world how light impacts cultural, economic, and political aspects of our global society. You can see more honorable mentions and contest details on our website: spie.org/contest

1ST PRIZE ($2,500):
"Big Shadow" by Thomas Vijayan

2ND PRIZE ($1,000):
"Starlight" by Manfred Hager

3RD PLACE ($500):
"Scaffolding Cafe" by Leyla Emektar

HONORABLE MENTIONS (Left to Right):

"Hamnoy at Night" by Kevin LaPresle

"A Symphony of Lights" by Kallol Mukherjee

"Strength of Light" by Waiphyo Aung

"Congregational Prayer with Candle Light" by Noor Ahm Gelal

Image Credit: Cliff Nass/Stanford School of Engineering

Hardwiring the BRAIN

fNIRS technology creates an increasingly sophisticated connection between brain and computer

By **Sophia Chen**

Inside a building on the northwest side of Stanford University (USA) sits a lineup of unusual cars: a self-driving white Audi and a squat, shiny red vehicle plastered with gray sunlight-harvesting silicon squares, to name a couple. The facility, with an exterior painted green to match the surrounding California oaks, is a garage dressed up as a laboratory.

Stanford neuroscientist Jennifer Bruno runs brain experiments using the Toyota Avalon in the back. The black matte sedan, stripped of its engine and rigged with a computer, is parked in front of enormous monitors that stretch from floor to ceiling. To do the experiment, Bruno's team turns on the monitors to project a driving simulation. Press on the brake in the driver's seat, and the pixels of the avatar car will respond exactly as a real car would. You're essentially playing a gigantic 270-degree arcade game. "You get a very immersive, realistic driving experience," says Bruno—as realistic as you can get without risking collisions.

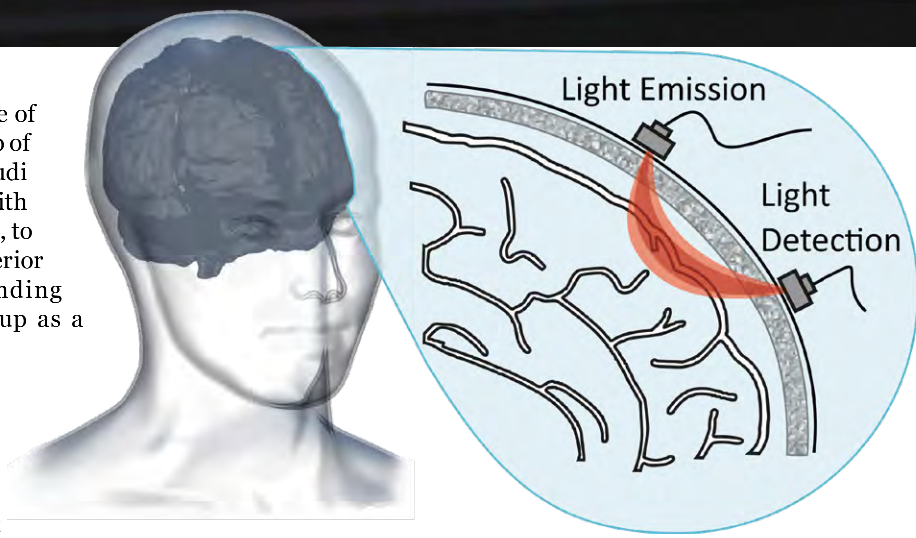


Image Credit: Alexander von Lühmann

The fNIRS mechanism: near-infrared light enters the skull and scatters back out to be measured by sensors. The amount of light absorbed can tell you about brain activity in a specific region.

In 2015, Bruno and her collaborators performed a study to observe the brain activity of humans driving a car. In a series of trials spanning about 30 minutes per person, they instructed study participants to change lanes as they drove in the simulation. In random trials, the steering wheel behaved in reverse: rotate it to the right, and the simulated car would swerve to the left. Bruno's team would monitor the driver's brain activity as they adapted to different steering settings, in hopes that the results could help the automotive industry design a safer car.

To monitor the participants' brains, Bruno's team used a device resembling a shower cap embedded with a network of LEDs and sensors. Recruits for the study donned the cap, clambered into the Toyota's driver's seat, and pretended to drive along a city street or a simulated forested highway. Each LED on the cap, pressed against the wearer's scalp, beamed

Image Credit: Drexel University

light onto their head with roughly the brightness of a laser pointer. Some of that light could enter the wearer's skull and bounce back out. Meanwhile, detectors on the cap measured the light that scattered back out.

The technology exploited in the cap is called functional near-infrared spectroscopy, or fNIRS (pronounced "eff-nears"). FNIRS devices use multiple wavelengths of near-infrared light to detect changes in the levels of hemoglobin, the protein in blood that transports oxygen, in the brain. When neurons fire in the brain, oxygen-flush blood flows to that area. That oxygen is bound to hemoglobin proteins. Oxygenated hemoglobin absorbs infrared light differently than unbound hemoglobin. Thus, fNIRS devices exploit that difference to determine the amount of oxygenated and deoxygenated hemoglobin in particular regions of the brain. Higher levels of oxygenated hemoglobin indicate more brain activity.

The technique was pioneered in 1977 by Duke University biologist Frans Jöbsis, who first identified this capability of near-infrared light by applying light-carrying optical fibers to the shaved temples of cats. Like magnetic resonance imaging (MRI), fNIRS monitors brain activity noninvasively.

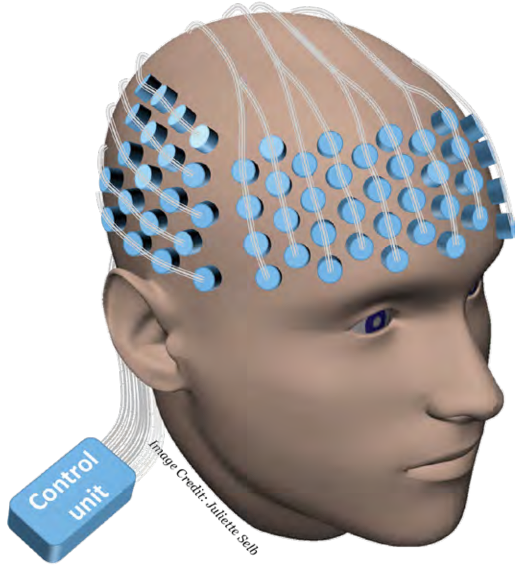
But unlike MRI, which requires a hulking machine, fNIRS has gained popularity as a brain-imaging technique because of its small size. Cap and headband-sized models are commercially available. And, unlike the MRI machine, fNIRS is not limited to use in clinics and laboratories. "The portability is super important," says Bruno. Because of fNIRS miniaturization, for the first time, researchers are measuring brain activity of people in more realistic environments rather than artificially controlled lab settings.

Today, portable fNIRS devices consist of a network of light sources and detectors placed on a person's head. The sources beam near-infrared light, 650 to 900 nanometers in wavelength, past the scalp, and into the brain. This particular range of wavelengths can penetrate biological tissue much more deeply than visible light and is known as the "optical window." The device measures the amount of light that scatters back to each detector. Using this information, it can calculate the amount of oxygenated versus deoxygenated hemoglobin in the area.

Despite a decades-long history, fNIRS devices have only become miniaturized in the last handful of years, says David Boas, director of the Neurophotonics Center at Boston University and editor in chief of the SPIE journal *Neurophotonics*. When Boas first started working in the field in the 90s, machines applied infrared light via long heavy fiber-optic cables. But as electronics shrank, especially devices for digitizing optical signals, the light sources could be directly affixed to the person's head, and fNIRS systems became more portable.

The fNIRS cap used in Bruno's car study, for example, hooked up to a tablet that the researchers placed in the backseat of the car. "Researchers who study brain activity are getting excited because they can have their subjects doing more natural tasks. They can even be walking around," says Boas. "It really increases the number of studies you can do." But by some definitions, Bruno's cap doesn't qualify as a wearable because it still needs to connect to a tablet. Boas's group began developing a true wearable fNIRS device two years ago. Such designs mostly sit on the head and hook up to a smaller, smartphone-sized control unit, either via electric wiring or even wirelessly, that you can put in your pocket or elsewhere on the body.

The devices' portability also permits Bruno to collect brain data out of the lab. She and her team have set up a station in a hospital about a 90-minute drive south of Stanford in the heavily agricultural Salinas Valley, California, where much of the U.S.'s lettuce crop is grown. They have collected fNIRS data on the brains of about 150 children and adolescents in the area to find out how pesticide use might affect their development, says Bruno.



David Boas and his collaborators are integrating a network of sensors and LEDs onto a mesh cap for portable brain imaging.

These increasingly portable designs have enabled the budding field of neuroergonomics, "studying the brain at work in everyday life," explains biomedical engineer Hasan Ayaz of Drexel University. Neuroergonomics researchers study how the brain functions outside of controlled lab settings to improve their product designs. Ayaz has worked with a coffee machine company, for example, to observe brain activity as a user interacts with the device. The company wanted to use the data to improve its user interface, says Ayaz.

In addition, Ayaz and his collaborators think that fNIRS could be used to help people whose jobs require them to digest and apply a lot of information quickly, such as airplane pilots, surgeons, or air traffic controllers. They have already begun studying pilots' brains using fNIRS. In one study, they split the pilots into two groups, where one group flew an actual plane, while the other used a flight simulator on the ground. Both groups wore a battery-operated, headband-shaped fNIRS device, which was originally developed by Ayaz's lab and is now commercially available via a spinoff startup, the Maryland-based fNIR Devices.

Curiously, Ayaz's group found that the brains of pilots flying the real plane were more active than those participating in the simulation. Researchers generally don't understand how differently people's brains behave in natural versus controlled settings. The study provides evidence that lab-based results do not necessarily translate into real-world situations.

One eventual goal of the studies is to use fNIRS to create a dynamic user interface for the pilots that changes depending on their mental state. Ayaz is using fNIRS to study the pilots' so-called cognitive workload, a number derived from physical signals that quantifies the pilots' brain activity. For example, if an fNIRS signal indicates that the pilot's brain is extremely active, the various devices in the cockpit could be programmed to present less information to the pilot. "We want to inform the machine about the operator's state so it can adapt itself to the user," says Ayaz.

Researchers also want to use fNIRS signals to directly control machines known as brain-computer interfaces (BCIs) developed for people with ALS or other mobility issues. These systems could be programmed to display "yes" or "no" or used to move a robotic arm based on specific fNIRS signals. "Right now we are at the proof-of-concept stage, demonstrating that [fNIRS BCIs] are feasible," says Ayaz. "There is still a lot of work to be done to create reliable systems for everyday use."

Ayaz's group recently performed a study where participants listened to a story while wearing an fNIRS device. Analyzing the resulting signals, they could identify which speech audio clips the person heard 75 percent of the time. This cracks open the door toward BCIs capable of transcribing perceived speech, they write in a 2018 paper published in *Frontiers in Neuroscience*.

FNIRS technology builds on conventional BCIs based on electric encepha-

Image Credit: ISAE-SUPAERO

A pilot wears an fNIRS device during a flight simulation.

lography (EEG). EEG devices, which can be worn on the head like Bruno's device, measure electric signals produced when neurons fire. An fNIRS device, on the other hand, measures oxygenated blood that has rushed to the region of the brain a few seconds after the neurons fire. Thus, EEG measures brain activity more directly and rapidly than fNIRS.

However, fNIRS has some advantages over EEG. It's more difficult to determine precisely where electric signals originate compared to optical signals. EEG devices can be more complicated to use, too. Most electrodes in EEG devices also require a sticky gel to make good electrical contact, whereas fNIRS sensors can work directly on skin. In addition, because of its slow response, an fNIRS signal might be more trustworthy as input for an on-off switch in a BCI, says SPIE Member Alexander von Lühmann, a biomedical engineer at the Technical University of Berlin, Germany. EEG signals change rapidly and are more likely to mistakenly toggle a machine on and off.

Ultimately, the two methods complement each other rather than compete, says von Lühmann. They measure different things, so one technique can help confirm the measurements of the other. The techniques are also sensitive to different noise: fNIRS sensors pick up ambient light and fluctuations in blood pressure, while EEG devices pick up electric signals produced by the wearer's contracting muscles, so one technique can compensate for the noisiness of another. Researchers like von Lühmann are building wearable brain-imaging devices that take both EEG and fNIRS signals simultaneously, in the hopes that the resulting data will be cleaner to interpret. "The hardware is more complicated, but in the end you have more information that you can exploit in signal processing," says von Lühmann.

Von Lühmann has built a prototype headset that combines EEG with fNIRS, a model he calls M3BA. The device can be integrated into any wearable, such as a cap or a headband, with a moveable battery pack that can rest on the user's neck. The system can talk to a computer via a Bluetooth connection.

A big challenge is processing and interpreting the measured signals. Researchers are developing algorithmic methods to sort artifacts from real signals. Von Lühmann's hybrid device includes two accelerometers, whose measurements can be used to remove motion artifacts from raw data.

They could identify which speech audio clips the person heard 75 percent of the time. This cracks open the door toward BCIs capable of transcribing perceived speech.

Signal-processing techniques vary depending on the application. For example, researchers developing BCIs do not necessarily need to understand the biological activity that produces the signals. To execute a binary command, the BCI just needs to discriminate one type of brain signal from another. To that end, von Lühmann is developing machine-learning algorithms to classify different types of signals.

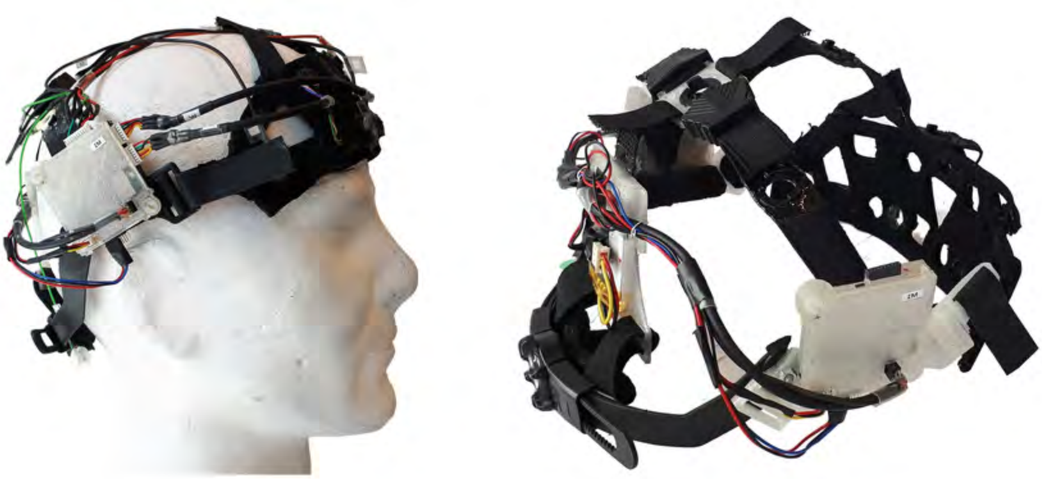


Image Credit: Alexander von Lühmann

Von Lühmann's M3BA wearable device combines fNIRS with EEG imaging capability.

On the other hand, physiology researchers do need to trace signals to biological origins or function. In Bruno's study, her team managed to locate changes in the drivers' brain activity as they drove. They are also looking to connect brain activity to other physiological responses: they could detect the drivers' pupils dilating when the drivers' brains are more active, for example. "We are still in the process of better understanding the fNIRS signals themselves," says Ayaz.

And while Bruno's cap suffices for her car study, she's still looking for a better design. FNIRS can only image the surface of the brain, so she'd like something that could see deeper. And it's still not comfortable enough for some of the studies that Bruno wants to do, such as studies of brain activity in children with autism. "For a child who has autism, a tag on a shirt can be irritating," she says. "These caps are way better than an MRI machine, but they're still little discs on your head. It gets irritating after a while."

As both hardware and software improve, fNIRS will be used not just for brain research, but also to help people do their jobs or create user-adaptable household products, says Ayaz. In the future, the technology could enable signals from your brain to enhance everyday experiences. ■

–Sophia Chen contributes to Wired, Science, *and* Physics Girl. *She is a freelance science writer based in Tucson, Arizona.*

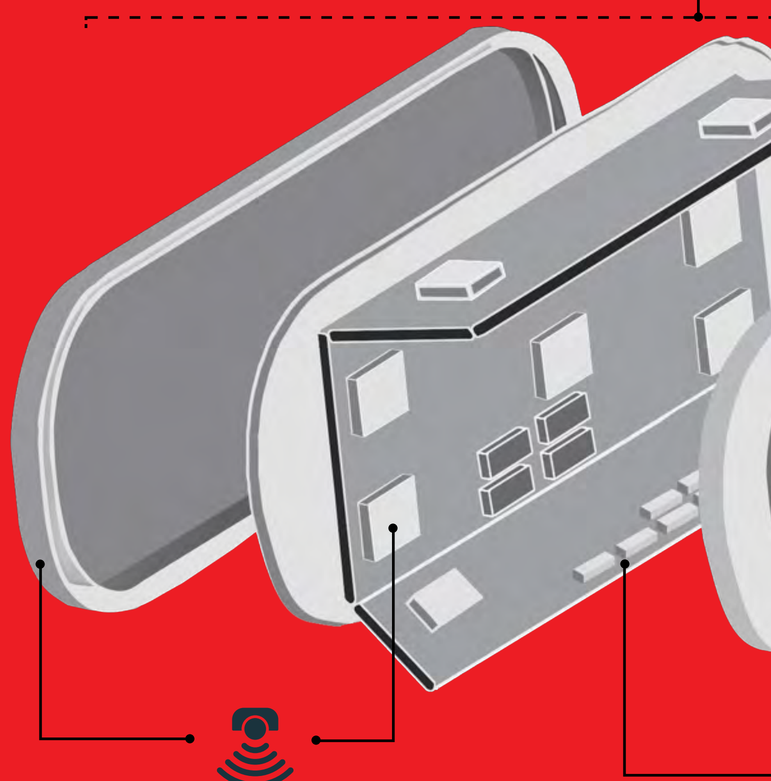
Thanks to Allan Reiss of Stanford University for providing helpful background information for this article.

Making the VIRTUAL become REALITY

Photonic technologies enable virtual and augmented reality devices. The core elements of state-of-the-art headset design and functionality have been discussed in SPIE conferences, courses, and publications for decades. The oldest paper on virtual reality in the SPIE Digital Library was published in 1965—it discusses simulation of space scenes for research and training for space ventures. **spie.org/VRin1965**

System Design

Before any AR/VR headset goes to market, many thousands of hours go into the design, testing, and validation of the system. These headsets are full of many intricate and discrete parts, but at their core all of them include optical components, displays, sensors, and processors. Putting them all together into a functional and comfortable unit takes innovative system engineering and design. The two-day **Augmented, Virtual, and Mixed Reality Conference** at SPIE Photonics West features presentations, a headset demo session, and a student design challenge. This event draws together all of the industry professionals who make up the ecosystem of AR/VR design. The **Conference on Digital Optics for Immersive Displays** at Photonics Europe, chaired by Bernard Kress from Microsoft, also contributes to this growing body of research.

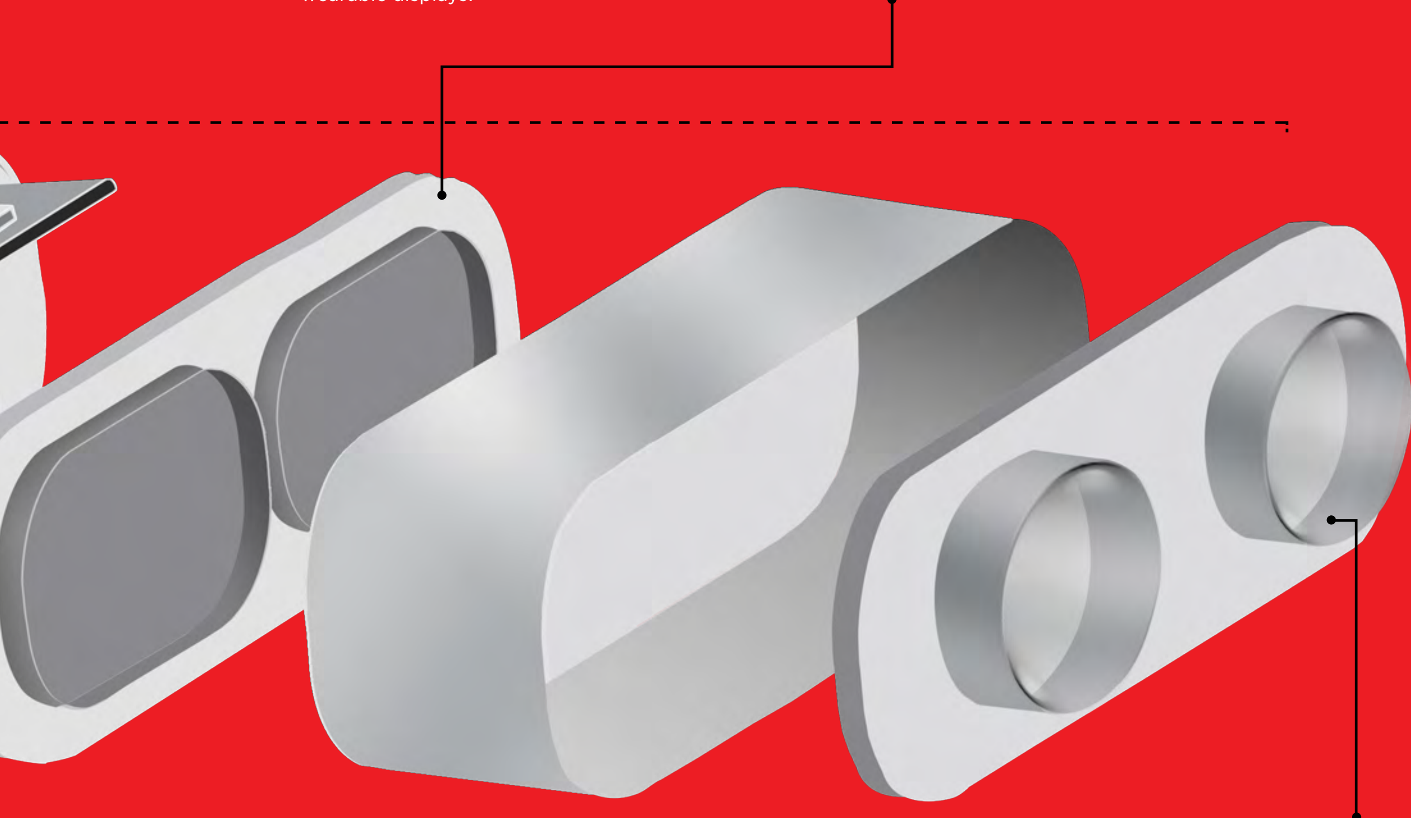


Sensors

Interactivity is what makes AR/VR systems so immersive, and without sensors tracking the users' body and eye movements, the technology fails. Image sensor technologies used in VR headsets, including infrared sensors, are featured in the **Conference on Image Sensing Technologies: Materials, Devices, Systems, and Applications**. The **Three-Dimensional Imaging, Visualization, and Display Conference** deals with image-sensing systems for a variety of applications—including AR/VR. Both of these conferences take place at SPIE Defense + Commercial Sensing, where a number of companies showcase image sensors and display technology at the Expo.

Displays

High-resolution displays are at the heart of every AR/VR experience. Creating bright displays that don't damage or tire the eye, while fitting a particular form factor, are just some of the key drivers in display technology for AR/VR. SPIE Optics + Photonics covers many aspects of display technology: in the **Organic Photonics Symposium**, engineers learn about the latest materials used in VR headset displays; a conference on **Emerging Liquid Crystal Technologies** covers the latest materials for 3D, head-mounted, and near-eye displays; and **Advances in Display Technologies** features papers on AR/VR, head-up, near-to-eye, and wearable displays.



Electronics

Processing power and smaller electronics are key drivers for many, if not all, new technologies, and AR/VR video would still be clunky and lagging without recent improvements in chip manufacturing. Microcontrollers and other chip-level components housed in the headset can be tied to conferences that take place at SPIE Advanced Lithography: **Novel Patterning Technologies for Semiconductors, Advances in Patterning Materials and Processes**, and **Advanced Etch Technology for Nanopatterning**. Companies working on chip technology present their latest work toward the mandate for smaller, lighter, and faster.

Optical Components

Lenses, prisms, spatial light modulators, and diffractive optical elements are just a few of the optical component used in headsets. Smaller, lighter, less-expensive and more specialized functionality are driving the production of novel optical components for use in AR/VR systems. The SPIE course **Optical Technologies and Architectures for Virtual Reality, Augmented Reality, and Mixed Reality Head Mounted Displays** provides an overview of the optical components and architecture for AR/VR displays. The exhibit at Photonics West features companies whose optical elements are key to the commercialization of this growing field.

Augmenting Reality Poses Challenges for Optics

By **Neil Savage**

At the beginning of 2019, many people have probably already tried a virtual reality (VR) headset. They're available in stores for video gamers and have been integrated into rides at Disney World. But when it comes to VR's more advanced cousin, augmented reality (AR), there's still a lot of development needed before the world sees commercially viable visors.

According to Bernard Kress, the partner optical architect for the HoloLens team at Microsoft and SPIE Board Member, "Everybody agrees, the optics aren't ready for primetime." And yet the tech industry is fully invested in tackling those technical hurdles, from large companies like Google and Microsoft, to smaller businesses like Florida-based Magic Leap.

In VR systems, the main goals are to improve the optical performance and bring the price down. For AR, the challenge is greater. The aim is to make headsets that look and feel a lot like sunglasses, that can show you the real world but overlay additional images or information, and to do so in a way that doesn't cause eye fatigue or cost too much. "When you do augmented reality you want to have a thin window in front of your eye through which you look at the real world," says SPIE Fellow Jannick Rolland, professor of optical engineering at the Institute of Optics at the University of Rochester, New York, and director of the National Science Foundation's Center for Freeform Optics. "And then that window is also a way to send the virtual image to your eye."

While virtual reality attempts to immerse the user in an artificial world, augmented reality tries to add to the real world. Possible applications include the ability to lay an MRI or x-ray image over a patient so a surgeon can see where she's operating, or projecting a wiring schematic on top of a bulkhead for an engineer. Crime investigators in The Netherlands have already used AR to project images from a crime scene to experts back in a lab, who then make annotations visible via a headset worn by the onsite investigator (see story on p. 16).

In AR, some of the challenges include designing optics that will pass most of the light from the outside world, while controlling the light from the display so that the image doesn't suffer from chromatic aberration or stray light, making sure the virtual image appears to be the right distance from the eye, and having a wide enough field of view that the image doesn't vanish when the wearer's eyes move. The optics have to be relatively easy to manufacture at commercial scales, without driving the cost of the headset higher than consumer comfort.

Further, the whole system has to take aesthetics into account. “No one wants to walk around with a bucket on their head the whole day,” says SPIE Fellow Mark Brongersma, a professor of materials science and engineering who leads the Plasmonics and Photonics group at Stanford University. That’s much less a factor in VR, Rolland says. “In virtual reality, you are in your home or training or something, so you don’t care as much,” she says.

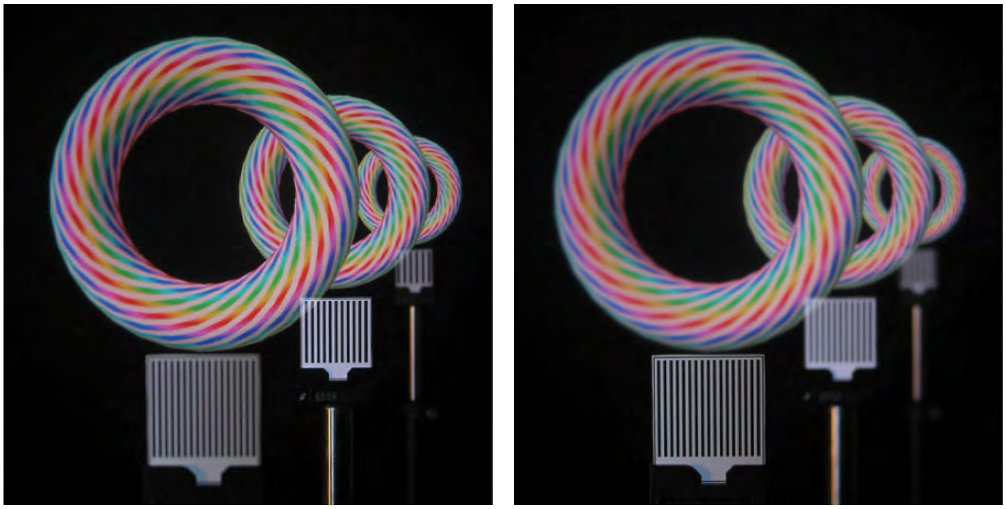


Image Credit: Courtesy of Hong Hua

Example of focus cue mismatch between physical and virtual objects in a conventional optical see-through head-mounted display.

All those factors drive the specifications the optics will need to meet. Once a designer has settled on the architecture for a display system, engineers can turn to emerging optical technologies to build the necessary components. Among those new technologies are freeform optics and metasurfaces.

GOING FREEFORM

Freeform optics is the practice of designing individual surfaces of optical components without rotational or translational symmetry, unlike the spherical or aspherical surfaces in traditional optical elements. The most well-known component may be a freeform prism, commonly used to fold the path of light in head-mounted displays: light from a display is coupled into the prism through one surface, guided through the bulk through total internal reflection—perhaps in combination with a reflective coating—and then sent on through another surface of the prism. “Each of the surfaces is not a simple surface but a freeform surface to do aberration correction,” says SPIE Fellow Hong Hua, a professor of optical sciences at the University of Arizona in Tucson. The shape of each surface is individually defined to perform better wavefront correction than would be available by using a series of traditional lenses.

A freeform eyepiece would be preferable to using a stack of multiple lenses to deliver an image from a microdisplay worn on a person’s temple, Hua says. A stack would be too thick and block too much light from the outside world. Instead, Hua has been working on a design in which she folds optical surfaces into a waveguide, bending the optical path through multiple refractions.

Another issue optical engineers are trying to address with freeform optics is the problem of vergence accommodation conflict. The human eye naturally adjusts its focus based on how far away it perceives an object to be. So if an AR headset projects an object a fraction of an inch from the eyes, but it seems to be much farther away, the eye will try to change its focus. This problem can lead to headaches and eye strain.

To help with this common problem, Hua has developed a multifocal plane, essentially a lens with different concentric focal planes. “The idea is instead of having one focus for the system, you can basically create a stack of focus,” she says. A spatial-light modulator projects an image onto each focal plane in sequence while blocking the others out. If the switching happens fast enough, the eye doesn’t notice that it’s happening but still has the ability to focus at different distances.

Image Credit: Magic Leap

Magic Leap One, which is now available for purchase for developers, gives you an idea of the form factor that designers are hoping to achieve for AR headsets.

GOING WIDE

Another challenge for AR headsets is having a large enough field of view (FoV), which is how wide of a scene the eye can see. Barmak Heshmat, a research scientist at Massachusetts Institute of Technology in Cambridge, Massachusetts, says the ultimate goal would be to have an FoV of 154 degrees for each eye, and Rolland says the minimum acceptable is 60 degrees. There are tradeoffs, however. For one thing, a wide FoV means more optics, adding bulk to the system. For another, a wider field of view results in a smaller eye box, which is the volume of space near the eye where the eye can scan without wandering too far away from the AR projection and having the image vanish. "You want a wide field of view and you also want a large eye box," Rolland says, "and the challenge is to get both."

One way some engineers are addressing the problem is by using holograms. Microsoft, for instance, argues that holographic displays solve many of the problems in AR headsets, allowing lightweight displays with less aberration and multiple focal planes in a wide field of view. Microsoft researchers described their work at the SIGGRAPH computer graphics conference in 2017.

Their design offers an 80-degree FoV horizontally. The hologram consists of a series of smaller "sub-holograms" that each focus light at a different depth of the scene, allowing them to focus each pixel individually. The design is flat and compact, and uses the holographic projector to correct aberrations.

Apple might be thinking along those same lines, since it purchased Colorado-based company Akonia Holographics in 2018: a company working on holographic lenses for augmented reality headsets.

GOING META

Another technique to meet the demands of VR and AR optics is the use of metasurfaces. Metasurfaces contain periodic structures—a series of pillars, for instance—with dimensions about the same size as the wavelengths of light they're dealing with. That sets up optical resonances and gives engineers extremely fine control over light, even producing a negative index of refraction in some cases. "These structures look completely alien at first observation, but they have a much higher ability to focus light however you want," Brongersma says.

Working with researchers from Magic Leap, he's built gratings that consist of beams of silicon 30-nm wide and 75-nm thick, spaced 125-nm apart. The nanobeams act as optical antennas, redirecting the light where he wants. He's also studying other high-index materials such as titanium dioxide or gallium nitride—the refractive index determines the resonant wavelength a metasurface can achieve. The metasurfaces are coated onto a standard lens, with individual coatings for different wavelengths and polarizations. For instance, one coating could be made to pass visible light but reflect infrared light. The headset could then direct IR light to the user's cornea and collect reflections from the eye to see where the user's gaze was directed, so it can project the image to the right place.

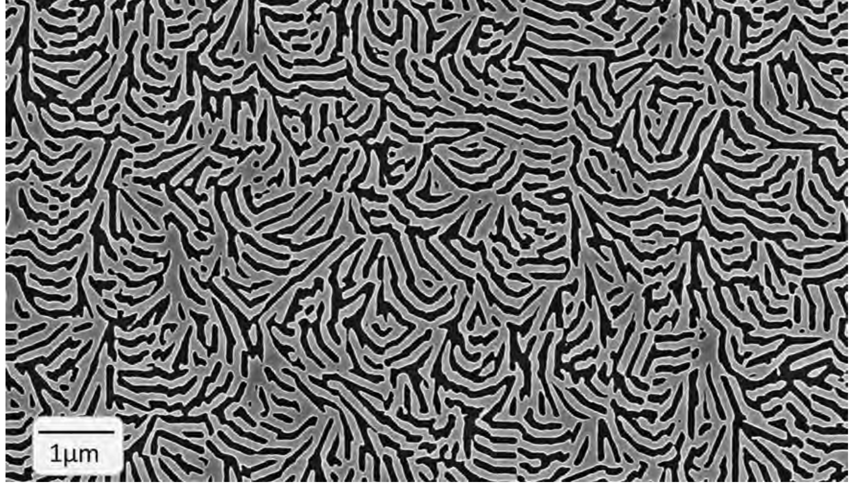


Image Credit: Courtesy of Mark Brongersma

This silicon-based metalens for 3D lightfield imaging uses an array of lenses with displaced optical axes.

Manufacturing metalenses will be a challenge for industry, according to Brongersma. He uses electron beam lithography to build his gratings over an area of roughly 100 microns, but that would be far too expensive a process to cover the couple square inches of the lens on a pair of glasses. And the structures have to be built with an accuracy below 10 nm.

Metasurfaces could have a lot of advantages for AR and VR, says SPIE Member Arka Majumdar, professor of electrical engineering and physics at the University of Washington in Seattle. "You can make a very thin lens," he says. "You can use all the light." But the surfaces are not easy to create. "Designing these things requires a huge amount of computational power," he says. Majumdar has founded a company, Tunoptix, that aims to use metasurfaces with microelectromechanical systems for both AR and endoscopy applications.

However the designs and manufacturing questions shake out, Majumdar is certain that metasurfaces will play a role. If the aim is build a pair of high-tech glasses that look like something out of *Mission: Impossible*, the only way to achieve that compactness and performance is with a metalens. "I'm not saying metasurfaces will solve it," Majumdar says. "I'm just saying without metasurfaces there is no way we are going to get to that form factor."

It's unlikely all the demands of AR headsets could be met by optics alone, so many people working on the technologies are thinking about how to marry their optical design with computational tricks. The headsets are already doing a lot of computation to produce the images or track the eyes, Majumdar says, so why not use some of that power to improve what's being sent to the optical elements? Indeed, Microsoft's SIGGRAPH paper talks of a computational approach, where the hardware is simplified and much of the wavefront control is the job of the software. Rolland agrees. "Not everything has to be done optically. Some things can be done in software," she says.

There's still a lot of work to do. In his free online SPIE Course, "Introduction to VR, AR, and MR," (see p. 37) Kress points out that Apple's CEO Tim Cook acknowledges that the quality of AR displays is "not there yet." Nonetheless, Apple is investing massively in AR. "He knows that it's not for tomorrow," says Kress, "it's for the day after tomorrow." ■

–Neil Savage is a science and technology writer in Lowell, Massachusetts.

Jannick Rolland, Mark Brongersma, and Arka Majumdar will present talks at Photonics West in February 2019. Download the SPIE Conference app to plan your schedule: spie.org/mobile

Both Achilefu and Boppart will accept their awards and give talks at SPIE Photonics West in February. spie.org/awards

Working Together to Improve Global Health

Samuel Achilefu's multidisciplinary approach to translational science wins the 2019 SPIE Britton Chance Award in Biomedical Optics

Samuel Achilefu's resume of currently held positions—mostly at Washington University School of Medicine—reads like most people's end-of-career summary: professor of radiology, professor of biochemistry and molecular biophysics; professor of biomedical engineering; professor of medicine; chief of an optical radiology laboratory; director of a molecular imaging center; co-leader of an oncologic imaging program. Any one of these roles could be a satisfying career on its own, but Achilefu manages to wear all of these hats at once.

His roles are indicative of his broad research interests, which range from cancer therapy with nanoparticles, to molecular probes for imaging, to technology development for *in vivo* clinical imaging. These different pursuits require a lot of collaboration: Achilefu's lab pulls together experts in chemistry, molecular and cell biology, biochemistry, physics, engineering, veterinary medicine, pathology, and immunology.

Achilefu finds this interdisciplinary collaboration rewarding. "It is like seeing the whole elephant," he says, "instead of guessing what it looks like by touching only one part of the animal."

This multidisciplinary approach to science with a focus on translatable outcomes has earned Achilefu the 2019 SPIE Britton Chance Award, which is awarded annually in recognition of outstanding lifetime contributions to the field of biomedical optics through the development of innovative, high-impact technologies. The award particularly honors pioneering contributions to optical methods and devices that have facilitated advancements in biology or medicine.

Achilefu's team invented one such innovative device, a head-mounted display that helps surgeons visualize cancer cells during surgeries. His fluorescence goggle system, described in a 2013 paper published in the *Journal of Biomedical Optics* (**doi.org/10.1117/1.JBO.18.10.101303**), incorporates a CMOS sensor and a see-through display that allows the physician to clearly see cancer cells that have been targeted with a molecular agent, making them glow.

The goggles grew out of Achilefu's research around molecular imaging methods, an area of central focus in his lab at Washington University School of Medicine in St. Louis. For example, his lab made the fundamental discovery that radionuclides disintegrate into daughter atoms with entirely different fluorescence enhancing or quenching properties. Copper-64 quenches the fluorescence of near-infrared dyes before it disintegrates into zinc, which, surprisingly, is a fluorescence enhancer, and nickel, which has no effect on fluorescence. This inverse relationship between radionuclide decay and fluorescence enhancement can be used to image the body noninvasively by positron emission tomography (PET), and the fluorescence enhancement generated after the rapid radionuclide decay and potentiated by the daughter atoms can guide real-time surgery in the operating room where radioactivity is not desirable.

Most recently, Achilefu's group discovered a paradigm-shifting contrast mechanism termed dichromic NIR fluorescence that can detect, monitor, and image molecular processes in cells and living organisms. The products of this research are now headed toward commercialization.

But Achilefu is not done yet. Although the Britton Chance Award is given for outstanding lifetime contributions, Achilefu still has a long career ahead of him. His research so far has been focused on improving methods to image and treat cancer, but his next interest is to prevent cancer altogether by developing point-of-care detection kits for use in high- and low-resource areas of the world.

This commitment to improving the global condition is exactly what the Britton Chance Award wishes to recognize. Lihong Wang, director of the Caltech Optical Imaging Laboratory and winner of the 2018 Britton Chance Award, has known Achilefu for more than 15 years, dating from his years at Mallinckrodt Medical, Inc. in St. Louis, where Achilefu co-led the optical imaging project as a principal scientist. "Dr. Achilefu is an outstanding researcher, teacher, and role model with unparalleled academic and research accomplishments," says Wang. "He is most deserving of this award."

Achilefu will be giving the keynote address at BIOS Hot Topics at Photonics West on 2 February 2019 on the topic "Power of Light to See and Treat Cancer." He will discuss his goggle system—a headset paired with a simple fluorescent molecule—that allows surgeons to visualize cancer in the operating room. ■

Read Achilefu's papers and watch his presentations on the SPIE Digital Library: spie.org/Achilefu

Bridging the Valley of Death in Biotech

Stephen Boppart wins the 2019 SPIE Biophotonics Technology Innovator Award

Stephen Boppart, director of the Center for Optical Molecular Imaging and head of the Biophotonics Imaging Laboratory at University of Illinois at Urbana-Champaign (UIUC), is fully committed to moving biophotonics technology from the bench to the bedside, and beyond. He encourages research faculty to drive the translation of their work into the commercial sphere—something he knows a lot about, having founded four biophotonic startup companies.

In 1998, while he was a grad student at MIT, Boppart was part of a team that co-founded LightLab Imaging, which pioneered commercialization of optical coherence tomography (OCT) for catheter-based medical imaging applications. His next company, Diagnostic Photonics, uses OCT during breast cancer surgery to assess tumor margins in real time. The third company, PhotoniCare, winner of the 2018 SPIE Startup Challenge, uses OCT to detect ear infections in children by providing real-time visualization of the middle ear. LiveBx, Boppart's fourth and latest startup, stands for "living biopsy," and focuses on nonlinear label-free imaging technology for tissue samples that are kept alive for a few hours after biopsy.

While Boppart was pursuing his PhD in medical and electrical engineering at MIT, he strongly felt that he needed to understand the tissue, disease, and patient that he was imaging, so he completed an MD in medicine as well. This dual-degree training has uniquely enabled him to both understand health problems and innovate on technical solutions. It makes sense, then, that Boppart's Biophotonics Imaging Laboratory at UIUC focuses on technologies that will have significant impact on health and society, because Boppart believes it's not enough to just move an idea from the lab to clinical trial. He says, "We need to be thinking how we can really change the world."

This track record for developing medical technology that truly impacts public health has earned Boppart the 2019 Biophotonics Technology Innovator Award from SPIE. The award is presented for extraordinary achievements in biophotonics technology development that show strong promise or potential impact in biology, medicine, and biomedical optics. On 2 February, he will accept the award at BIOS Hot Topics and he will also present three invited papers at Photonics West.

Boppart learned a few things along the way about commercializing biophotonics technology. He points out the importance of bridging the "valley of death" that most companies succumb to. One way is by developing systems friendly to the clinical environment, such as designing a clinical-looking prototype from the beginning, and having clinical data the company can run with.

At the same time, devices need to be simple. He says, "Engineers love complexity, so we tend to build these complex systems that are ultimately not practical in clinical settings. We've learned to keep things as simple as possible."

For anyone who may be taking notes, his third nugget of wisdom is to get to revenue fast. Because medical devices often have lengthy approval processes, he advises first marketing the technology to research or biotech labs while pursuing the medical device technologies in parallel. "You can get revenue quickly from the research market while waiting for the clinical market to develop," he says.

Boppart's contributions to the field of biophotonics are not limited to his successful startup companies. His lab has developed new applications for nonlinear imaging and OCT, including vibrational imaging and elastography; they have contributed to imaging of neural morphology, gastrointestinal malignancies, embryonic morphology, and engineered tissues. His team developed interferometric synthetic aperture microscopy (ISAM) and computational adaptive optics (CAO), which use computational methods to improve the resolution and quality of OCT images. This contribution has been singled out by Boppart's colleagues as an impressive technical feat that will impact biomedical applications in the future.

Adam Wax, professor and director of graduate studies in the Department of Biomedical Engineering at Duke University, has known Boppart for nearly twenty years. He notes that although Boppart's research metrics are impressive, "his experience in translational research, from developing new techniques, to seeing their clinical applications, to their commercialization, has truly set him apart as an innovator."

Anyone who has been through this process of innovation and technology transfer knows it takes many minds coming together to bring a new idea or piece of technology to fruition. Boppart emphasizes the impressive work coming out of his lab is an interdisciplinary collaboration across all career stages. He says, "One person, even an undergraduate, may say something that triggers a thought that we didn't have. Sometimes these undergrad students don't realize they play an important role, but they do. Everyone can make a contribution." ■

Read Boppart's papers and watch his presentations on the SPIE Digital Library:
spie.org/Boppart

Both Wood and Suzuki will accept their awards and give talks at SPIE Advanced Lithography in February. spie.org/awards

Two Pioneers Recognized for Contributions to Lithography

SPIE presents the Frits Zernike Award annually for outstanding accomplishments in microlithographic technology, especially those furthering the development of semiconductor lithographic imaging solutions. This year, the award is being presented to two individuals: SPIE Fellow Obert R. Wood II of GLOBALFOUNDRIES, Inc., in recognition of his pioneering contributions to EUV lithography, and SPIE Fellow Akiyoshi Suzuki of Gigaphoton, Inc., for his innovation on all phases of lithography exposure tools.

OBERT WOOD, PIONEER IN EUVL

Obert R. Wood is a principal member of the technical staff in the Strategic Lithography Technology Department at GLOBALFOUNDRIES. He was on the technical staff at Bell Laboratories for 34 years and has extensive experience in extreme-ultraviolet lithography (EUVL), ultrahigh intensity lasers, and laser surgery. He will receive the Frits Zernike Award for his pioneering contributions to EUV lithography, from conception to the threshold of high-volume manufacturing.

"If someone were to ask me to name one person who has contributed more than anyone to EUVL, I would respond without any doubt that Obert Wood is that person," says SPIE Fellow Bruno La Fontaine, Senior Director at ASML. "He has made immense contributions to EUVL."

La Fontaine notes Wood's pioneering work in the late 1980s when he built one of the first lithography systems using multilayer coated EUV mirrors, which led to the first high-quality images of sub-100-nm features in resist. This put EUVL (a.k.a. soft x-ray lithography at the time) solidly in the list of front contenders to succeed optical lithography.

During the 1990s and the early 2000s, Wood expanded his trailblazing research, publishing papers on multilayer mirrors, optical designs, optical testing, optics lifetime, aberrations and focus testing, sources, resists, masks, and metrology.

As fully integrated systems were becoming available during the late 2000s, Wood proved that EUV lithography could be successfully integrated into normal semiconductor processing to produce working SRAM devices. This was a formidable advance toward the acceptance of EUV as the main technology to follow immersion lithography.

In a series of SPIE presentations, Wood has detailed the EUV process integration and its insertion strategy from the 32-nm down to the 14-nm nodes, some of the most detailed revelations published. Today, he continues to work on EUV lithography at GLOBALFOUNDRIES in preparation for the technology's pending implementation in high-volume manufacturing.

Read Wood's papers and watch his presentations on the SPIE Digital Library: spie.org/O-Wood

AKIYOSHI SUZUKI'S CONTRIBUTIONS BOTH BROAD AND DEEP

The Frits Zernike Award will also be presented to Akiyoshi Suzuki in recognition of his innovations on all phases of lithography exposure tools, including proximity printing, projection steppers, projection scanners, 1X and reduction types, reflective and refractive types, g-line, I-line, 248 nm, 193 nm, and 13.5 nm.

During his 40-year career at Canon, Suzuki's contributions in microlithography, starting from contact to early projection systems, were pivotal. His early work on two-mirror wafer lithography systems, along with later two-mirror designs for flat-panel display lithography, have made an impressive impact on both the semiconductor and display industries. In 2014, Suzuki joined Gigaphoton as a technical advisor.

"Akiyoshi's portfolio of contributions is exceptionally broad and deep," says SPIE Fellow Andrew R. Neureuther of University of California, Berkeley. "This includes pioneering work on alignment, precision stages, immersion, ArF, F2, and double exposure. His nearly 100 U.S. patents and well over 100 Japanese patents, which are almost all in the field of microlithography, attest to this."

Neureuther adds that throughout Suzuki's long career, he repeatedly made technology-extending contributions to proximity printing, i-line, DUV, and even EUV. "His solutions were practical and often leveraged his mathematical modeling of the physics of lithography," says Neureuther.

Of particular note are the use of multiple wavelengths to reduce standing wave effects in contact printing, the use of 2:1 mirror radii to minimize aberrations in two-mirror systems, and the use of off-axis quadrapole to selectively enhance the printing of Manhattan geometries. When quadrapole illumination became available, there was a nearly two-fold increase in the depth-of-focus of resist materials. Resist chemists initially attributed depth-of-focus increase to their new polymers only to realize later that the increase was mainly associated with the new off-axis illumination.

"In several of these cases," says Neureuther, "Suzuki's insight came from his careful understanding of mathematical modeling, thus showing an unusual capacity to leverage the combination of theory and practice." ■

Read Suzuki's papers on the SPIE Digital Library: spie.org/Suzuki

Photonics West

2-7 February 2019, San Francisco, California

Every year, Photonics West brings together people from industry, academia, and government who are working on the full spectrum of optics and photonics technology, from biophotonics, to optoelectronics, to semiconductor lasers, to nanophotonics. But this year will feature an expanded free-to-attend two-day industry program for AR/VR, hundreds of new exhibitors, and a plenary given by a 2018 Nobel Laureate in Physics. Photonics West is the place where ideas cross-pollinate and multidisciplinary connections are made.

PLENARIES

In addition to thousands of technical talks that will be given throughout the week, the first four days of Photonics West will feature plenary and keynote "hot topics" talks given by experts in their field, including:

- 2018 Nobel Laureate in Physics **Donna Strickland**
- Pioneer of near-infrared optical imaging and tomography SPIE Fellow **Eva Sevick**
- SPIE Fellow **Samuel Achilefu**, winner of the 2019 SPIE Britton Chance Award for transformative advancements in cancer treatment and patient care
- Facebook head of Optical Technology Strategy **Katharine Schmidtke**
- **Clare Elwell**, whose research using new optical imaging techniques to understand the human brain won the 2016 WISE Research Award
- SPIE Fellow and machine-learning expert **Aydogan Ozcan**
- **Henry Hess**, whose work focuses on artificial-muscle building from molecules, and "smart dust" biosensors that detect environmental pathogens
- Jet Propulsion Laboratory's Saturn-focused Cassini Mission Project Manager—and recent Emmy recipient—**Earl Maize**

BIOS Plenary Session

Sunday, 3 February 2019

Donna Strickland, winner of the 2018 Nobel Prize in Physics.

Donna Strickland, associate professor of physics at the University of Waterloo and winner of the 2018 Nobel Prize in Physics will talk about her co-invention of a chirped pulse amplification that overcame the limitations of self-focusing and enabled the highest power lasers in existence today.

OPTO Plenary Session

Monday, 4 February 2019

Katharine Schmidtke, second on left, explains that each dot on the map is a Facebook user, and each line is a conversation.

Katharine Schmidtke, who is responsible for optical technology strategy at Facebook, will discuss optoelectronics used for data centers and networking. Facebook was an early adopter of 100G single-mode optical transceivers: they established an ecosystem of equipment that works at 100 Gb/s and defined a relaxed optical transceiver specification, CWDM4-OCP, that is optimized for data centers.

On the same morning, plenary talks will also be given by Susumu Noda, director of the Photonics and Electronics Science and Engineering Center at Kyoto University on the topic of two decades of progress for photonic crystals; and Aydogan Ozcan, who leads the Bio- and Nano-Photonics Laboratory at UCLA and will talk about deep learning optics.

LASE Plenary Session

Monday, 4 February 2019

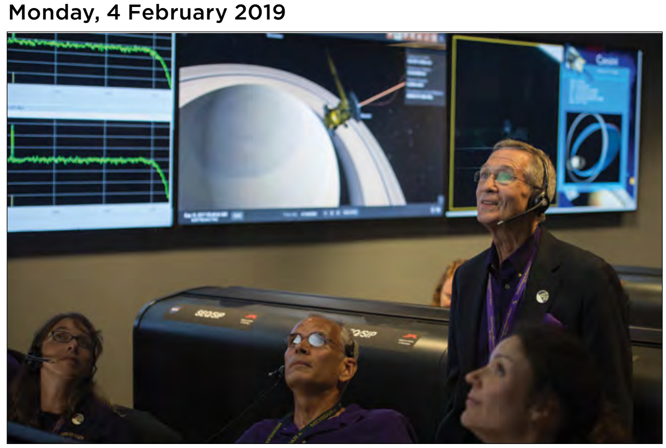


Photo Credit: NASA/Joel Kowsky

Project manager Earl Maize, right, monitors the status of NASA's Cassini spacecraft in mission control at NASA's Jet Propulsion Laboratory, in Pasadena, California.

Earl Maize, program manager of the NASA Cassini mission, Jet Propulsion Lab, will give a talk titled "Cassini's Grand Finale: Going out in a Blaze of Glory." On 15 September 2017, the Cassini spacecraft ended its 20-year voyage of discovery with a fiery plunge into Saturn's atmosphere. He will discuss the engineering and scientific rationale for the mission's final scenario and some of the complexities of an entirely new mission for an aging spacecraft. He will also present highlights from the many amazing findings from the spacecraft's 13 years of exploration in the Saturn system.

The afternoon will also feature a talk from Yuji Sano from the Japan Science and Technology Agency, who will discuss the past 25 years of development of laser peening and expanded applications. The evening plenary session will end with a talk by Günther Tränkle, director of Ferdinand-Braun-Institut in Berlin, Germany. Tränkle will present an overview detailing how power, efficiency, and beam quality of high-power laser diodes have been improved over the past 20 years and will show the path to further performance scaling.

Nano/Biophotonics Plenary

Tuesday, 5 February 2019

Credit: Andra Mihali

Henry Hess researches "smart dust" biosensors that detect environmental pathogens.

Henry Hess, professor of biomedical engineering at Columbia University will discuss engineering with biomolecular motors. Optical techniques are a key tool to interrogate and interact with nanosystems as they enable nondestructive measurements with nanometer precision as well as the control of chemical events at the nanoscale. The presentation will highlight the important contributions of photonics to the study of active nanosystems.

EXHIBITIONS

Featuring hundreds of product launches, live demonstrations, and technologies on display, the BIOS Expo and Photonics West Exhibition are both free and open to the public: the 200-exhibitor-strong BIOS Expo—with the latest technology in biomedical optics and healthcare applications—is open 2–3 February. The sold-out Photonics West Exhibition, 5–7 February, showcases the best innovations of the photonics industry from more than 1,200 international companies. ■

Real Reality (RR) Courses on AR/VR at Photonics West

Bernard Kress, the partner optical architect for the HoloLens team at Microsoft, will teach two courses at Photonics West, where he'll focus on market expectations, hardware requirements, optical technologies, and investment patterns in the AR/VR/MR industry.

Kress notes that it took 20 years for technology to advance from a cordless phone to a smartphone, but it took 50 years for a head-mounted display to develop into something like HoloLens—mostly because government research moves slowly. But now that the AR/VR research has moved into private industry, the pace of advancement is going to pick up. Fast.

"I can't even predict what we're going to have in five years," says Kress, "so don't ask me what we'll have in ten years!"

The industry is still struggling to find a less-clunky term that encompasses all of the different "reality" technologies, including smart glasses, augmented, virtual, and mixed reality. According to a tweet from Clay Bavor, head of AR and VR for Google, "VR/MR/AR/RR are not separate and distinct things. They're convenient labels for different points on a spectrum."

For now, the research community hasn't agreed on the right term to unify these different technologies any more than they have unified these technologies into a single headset. "Of course, everyone wants to merge to a single device," says Kress, "but optical technologies do not allow for such merging at this time. But this fusion of all three functionalities will happen eventually."

Kress will teach a two-hour introduction to VR, AR, MR, and smart eyewear (SC1234) and a full-day course on optical technologies and architectures for AR/VR (SC1218).

Complementary to the two courses taught by Kress is a full-day course taught by Michael Browne and James Melzer called Head-Mounted Displays for Augmented Reality Applications (SC1096), which emphasizes requirements, specifications, design and components, and human factors. It's complementary to SC1218 and people interested in learning about AR/VR would benefit from taking both.

Along with optics for AR/VR, there will be more than 70 courses and workshops to choose from at Photonics West, ranging in length from two hours to two days. Topics include LiDAR for autonomous vehicles, laser sources, nonlinear optics, biomedical spectroscopy, tissue optics, photonic therapeutics, optoelectronic materials, and more. Register for a course: **spie.org/PWCourses** ■

Defense + Commercial Sensing

14–18 April 2019 in Baltimore, Maryland

SPIE Defense + Commercial Sensing is the leading global event for experts working on materials, components, systems, and analytics for defense and commercial applications in sensing and imaging. Over 1,700 technical presentations will be given in more than 40 conferences spanning sensors, infrared technology, laser systems, spectral imaging, radar, and LiDAR. Numerous onsite courses are available, covering current approaches in lasers and applications, sensors, imaging, infrared systems, optical and optomechanical engineering.

Plenaries

Albert "Skip" Rizzo will answer the question "Is Clinical Virtual Reality Ready for Primetime?" during his plenary talk on Monday evening. He will discuss the issues involved in the design, development, implementation, and evaluation of virtual environments for use in clinical assessment and intervention. His talk will be helpful for people who want to know how VR can be usefully applied in the pro-social area of healthcare. Experts in either VR or healthcare will get an informed perspective on the state of the field moving into the future.

Philip Perconti, director of the U.S. Army Research Laboratory, and Timothy Grayson, director of the Strategic Technology Office of DARPA, will also give plenary talks on Monday and Tuesday.

Expo

The DCS Expo is a key exhibition for researchers, engineers, product developers, and purchasers who specialize in optics and photonics. Visit with 380 companies who provide everything from components to the most advanced sensor systems.

Featured technologies:

- Infrared sources, detectors, and systems
- Optical components including specialized lenses and coatings
- Chemical and biological sensing
- High-speed imaging and sensing
- High-precision optics manufacturing
- LiDAR
- Cameras and CCD components
- Photonic sensors, spectroscopy, multi-spectral, hyperspectral
- Fiber optic components, equipment, sensors, and systems
- Lasers and other light sources, laser accessories, and laser systems

Courses

Over 30 half-day, full-day, and two-day courses will be offered, taught by recognized experts in industry and academia. Courses are grouped into program tracks based on related technology topics:

- Imaging and Sensing Technologies
- Imaging and Data Visualization
- Infrared Sensors and Systems
- Defense, Homeland Security, and Law Enforcement
- Intelligence, Surveillance, and Reconnaissance
- Laser Sensors and Systems
- Next-Generation Sensors and Systems
- Sensor Data and Information Exploitation
- Imagery and Pattern Analysis
- Optical and Optomechanical Engineering

Industry

The transitioning of defense technologies to more diverse commercial markets will be the focus of the SPIE Industry Stage. Presentations and panel discussions on quantum, hyperspectral imaging, infrared technologies, autonomous vehicles, public policy, and changing global markets will be some of the topics at the free four-day event held in conjunction with the Expo. Come to hear industry veterans, government representatives, and entrepreneurs provide insight into the growing photonics markets. ■

Attend Defense + Commercial Sensing: spie.org/DCS

Advanced Lithography

24–28 February in San Jose, California

For over 40 years, SPIE Advanced Lithography has been a vital gathering of the lithography community, bringing together leaders from industry, academia, and governmental labs working at the forefront of the demanding field of semiconductor chip manufacturing. This year's Symposium promises to continue in this tradition by discussing the biggest challenges and opportunities for the semiconductor and lithography industries.

To kick of the technical program, the plenary session will feature IBM Chief Operating Officer, Dario Gil, discussing quantum computing and its role in the computing paradigm. He will be followed by two presentations on 3D NAND technology. Jeongdong Choe of TechInsights will focus on the roadmap, process, design, and challenges of the technology; while Steven Steen and Bart van Schravendijk, from ASML and Lam Research Corporation respectively, will give a combined presentation on the patterning process innovations in 3D NAND.

One of the more popular conferences, EUV Lithography, is now in its tenth year and again will be eyed closely for big announcements by source providers as well as those working in masks, resists, and modeling.

"Recent announcements from integrated chip makers confirming that EUV is moving into high-volume manufacturing is encouraging for everyone involved in the semiconductor and lithography industries," says longtime AL contributor and attendee Tony Yen, VP and Head of the Technology Development Center at ASML. "These announcements are in a way the culmination of years of R&D efforts presented and discussed at SPIE Advanced Lithography, the venue that served to disseminate the results of progress made, and network among those working in this field. Obviously, the work on EUV continues, and we have much to discuss and learn this February in San Jose."

In addition to EUV, industry leaders are giving presentations on the latest in everything from novel new lithographic approaches and patterning technologies to metrology and characterization. Complementing the technical presentations, there are over a dozen courses offered along with numerous networking events and an exhibition featuring key suppliers for the lithography industry.

The presentations and discussions at AL have long been important to the continuation of Moore's Law and the innovations in chip manufacturing. Advanced Lithography 2019 promises to build on this legacy as the work to get smaller and more complex patterns continues. ■

Attend Advanced Lithography: spie.org/AL

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EVENTS AROUND THE WORLD 2019

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For information about advertising in *SPIE Professional*, contact Melissa Farlow at melissaf@spie.org.

Upcoming events and deadlines

Check the monthly SPIE E-News for more information on and links to the items below.

JANUARY

- **11:** SPIE Photonics West early registration deadline
- **16:** Abstracts due for SPIE/OSA European Conferences on Biomedical Optics
- **30:** Abstracts due for SPIE Optics + Photonics
- **31:** Applications due for SPIE Education Outreach Grants

FEBRUARY

- **1:** SPIE Medical Imaging early registration deadline
- **2-7:** SPIE Photonics West in San Francisco, California, USA
- **7:** SPIE Advanced Lithography early registration deadline
- **15:** SPIE Smart Structures + Nondestructive Evaluation early registration deadline
- **15:** Applications due for SPIE Optics and Photonics Education Scholarships
- **16-21:** SPIE Medical Imaging in San Diego, California, USA
- **20:** Abstracts due for SPIE/SIOM Pacific Rim Laser Damage + Thin Film Physics & Applications
- **24-28:** SPIE Advanced Lithography in San Jose, California, USA

MARCH

- **3-7:** SPIE Smart Structures + Nondestructive Evaluation in Denver, Colorado, USA
- **11:** SPIE Optics + Optoelectronics early registration deadline
- **13:** Abstracts due for SPIE Remote Sensing and Security + Defence
- **15:** Applications due for the Joe and Agnete Yaver Memorial Scholarship
- **15:** Nominations due for SPIE Senior Members
- **27-28:** Photonics 21 annual meeting in Brussels, Belgium
- **29:** SPIE Defense + Commercial Sensing early registration deadline
- **31:** Applications due for the Michael Kidger Memorial Scholarship

APRIL

- **1-4:** SPIE Optics + Optoelectronics in Prague, Czech Republic
- **14-18:** SPIE Defense + Commercial Sensing in Baltimore, Maryland, USA
- **24-26:** SPIE Structured Light in Yokohama, Japan

MAY

- **1:** Abstracts due for SPIE Photomask Technology + EUV Lithography
- **16:** International Day of Light
- **16:** SPIE International Day of Light Photo Contest opens
- **19-22:** SPIE/SIOM Pacific Rim Laser Damage + Thin Film Physics & Applications in Qingdao, China
- **21-24:** 15th Conference on Education and Training in Optics and Photonics (ETOP) in Quebec City, Quebec, Canada