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Calling for Quantum Engineers
New opportunities in the wake of the National Quantum Initiative

By Kent Rochford, CEO of SPIE

On 21 December 2018, the President of the United States signed the National Quantum Initiative (NQI) Act into law after the House overwhelmingly voted to approve the Senate’s amended version of the bill. The act directs the Department of Energy to establish between two and five competitively awarded National Quantum Information Science Research Centers, each to be funded at up to $25 million annually over five years. The act also directs the National Science Foundation to establish between two and five Multidisciplinary Centers for Quantum Research and Education, funded up to $10 million each year through 2023. Finally, the National Institute for Standards and Technology (NIST) will create an industry-focused quantum consortium and expend up to $80 million per year toward this and quantum science R&D.

The National Photonics Initiative (NPI)—an SPIE- and OSA-led collaborative alliance that includes industry, academia, and government actors to raise awareness of optics and photonics—worked for over a year toward this result. NPI produced a white paper in 2017 at the behest of the House Science Committee. Since then we’ve worked tirelessly to brief decision makers and comment on bill language to support legislation that can make a major impact on our community.

Just as it enables many technologies, photonics will play a major role in the emerging quantum applications. For example, many see the emergence of quantum sensors as the first commercial application, and this area makes great use of photonics as many sensor technologies exploit the slight changes in optical transitions from perturbations to be measured. In addition, quantum communications and quantum key distribution use a host of sophisticated optics, lasers, detectors, and fibers.

While much of the excitement around quantum is focused on computing or simulation—of which many incarnations use lasers and optics for trapping, entangling, preparing, or probing of qubits, or for the transduction of signals—this technology is in early stages. The excitement is justifiable given the potential to solve currently intractable problems that could make revolutionary impacts. At Photonics West 2019, the word “quantum” appeared in the program 411 times, and included a presentation on potential markets, courses on quantum technologies, and a seven-conference “Advanced Quantum and Optoelectronic Applications” track. In addition, many exhibiting companies announced and displayed components and light sources specifically for quantum applications.

I was particularly pleased that NQI made the development of technology an important goal. Research in this area is important, and more needs to be done, but I believe that the development of a technology ecosystem to support the transition from research to commercialization is necessary. To exploit the many benefits of quantum science, we need to turn experiments into products, and this requires a new field, quantum engineering. Many of us in photonics had little or no training in quantum science, yet advancing this field will require a host of new practitioners—quantum engineers—to develop, design, test, and manufacture quantum-based products.

But what is a quantum engineer? NIST has selected SRI International to lead the Quantum Economic Development Consortium (QEDC) to help with that and other commercialization issues. This public–private partnership will seek to identify workforce needs, propose technology solutions for filling gaps in research or infrastructure, and provide a forum for industry to increase coordination and share views on development of a quantum economy. SPIE hosted a panel at Photonics West to introduce the QEDC to our community, with a discussion on photonic technologies that are enabling the emerging quantum industry, as well as important gaps in certain enabling photonics technologies. We plan to work closely to increase engagement of the photonics community with the consortium and other activities.

In addition, SPIE is working to ensure that researchers and companies get appropriate export controls guidance. The Commerce Department recently released an advanced notice for proposed rulemaking, a “Review of Controls for Certain Emerging Technologies” that includes quantum technologies. Blanket control of a technology area can have a significant negative effect on the advancement of that technology. Furthermore, too early or far-reaching controls may undermine the development of commercial applications that could drive substantial economic growth. SPIE is working with the Commerce Department to ensure an appropriate balance that does not negate the tremendous possibility of the NQI.

There’s still work to be done for NPI and SPIE. The National Quantum Initiative Act authorizes agencies to do this work, but now it needs to be funded. NPI will now push for an appropriation that funds DOE, NSF, and NIST to undertake this important work. The NQI bill was strongly supported by the tech industry—from major companies and startups—so we think momentum is on our side.
So, You Attended a Conference. Now what?

You got approved to present a paper at a conference. You worked hard to prepare your slides or poster and booked your travel. You showed up, presented, met lots of people, fielded some good questions about your research project, heard some interesting talks. Then you returned to school or your job, and...mostly forgot about the conference.

Here are a few ways to get more mileage out of your conference experience:

1. FOLLOW UP.
   You probably came home with a dozen or more business cards, and maybe a few pictures of conference badges. Before you toss them in a desk drawer or archive the photos, follow up with the person you met by connecting on social media or sending an email. Did you see an interesting talk? Send them a LinkedIn request with a note about how much you enjoyed it.

   Matthew Posner, optoelectronics process engineer at Excelitas Technologies, often follows up with his new acquaintances by asking a simple question that he thinks they'll enjoy answering. “Or, depending on our initial conversation, I might give them an update on my future projects, like changing jobs or searching for new opportunities,” he says.

2. WRITE UP YOUR EXPERIENCES.
   Once you return to the daily grind, it can be easy to forget what you learned and heard. When you get back from a conference, take 30 minutes to write up a few notes about your major takeaways. Don’t wait more than a week—the details are going to get fuzzy. Share your experiences on a blog, on social media, or in a company or lab newsletter. These notes will come in handy if you’re asked to...

3. GIVE A PRESENTATION TO YOUR SUPERVISOR, LAB GROUP, OR STUDENT CHAPTER.
   Even if you’re not required to report back to anyone following a conference, consider volunteering to do it anyway. Reporting back on what you learned and experienced demonstrates that you were actively engaged in the technical content—and not just there for the drink tickets. It also gives you the opportunity to share the knowledge you gained with your colleagues, which extends the benefit of your experience to others. Institutions want to know that the expense of sending people to conferences is money well spent, and they won’t know unless you tell them.

PRO TIP:
"After swapping business cards, write what you were talking to them about on the back, so you can remember the person. Then, when you follow up a few weeks later, remind the person what you talked about."

—Laura Tobin, SPIE Member
4. FIX YOUR PRESENTATION.
You might be glad that it’s over, but don’t put that conference presentation behind you just yet. Did you stumble over part of the presentation? Did someone ask you a question you couldn’t really answer during Q&A? Talk to a supervisor or colleague, and then make notes about what would have made it better. This exact presentation may be over and done, but you’ll likely present at another conference someday, and a postmortem of your presentation can help you do better next time.

5. DOWNLOAD THE PAPERS.
Your SPIE conference registration came with access to all of the papers published in a proceedings volume of your choice. Those papers are often closely related to your research area, so take a look at the online table of contents and download relevant papers (and show courtesy to your fellow attendees by submitting your own proceedings paper—someone might be looking for it). 80% of authors give SPIE permission to publish presentation recordings, so you’ll also be able to watch presentations you might have missed.

“During the conference, I wrote notes from talks that were relevant to my group. Three months later, my supervisor asked me to give an overview. Make sure you also keep the conference proceeding so you can go through the list and see what you have forgotten.”

—Katie Chong,
Research and Development Engineer,
Finisar Corporation

Before you toss your business cards into a desk drawer, use a mobile app to scan them and quickly add them to your contacts.

5 Business Card Scanner Apps for Apple and Android:

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Open competition with substantial prize-based incentives is a tool used by DARPA since 2004 to promote innovative solutions to national security problems. The original competition, DARPA’s Grand Challenge for Autonomous Vehicles (2004, 2005, 2007), grew out of the United States Defense Authorization Bill for fiscal year 2001, which codified the goal of fielding unmanned ground combat vehicles for the US Armed Forces. In order to get US military personnel out of harm’s way, that bill specified that one third of operational ground combat vehicles should be unmanned by 2015.

While that specific goal may have proven elusive, the process of open competition, which entails incentivizing the wider community to come up with a solution to the stated problem, was hugely successful according to Dr. Timothy Grayson, director of the Strategic Technology Office at DARPA and one of the judges for the original competition.

“I think the original Grand Challenge and the sequence of the self-driving challenges after that are a good example of why DARPA is doing the challenges,” he said. “What I witnessed first-hand on those original self-driving car Grand Challenges, there was so much advancement in such a short time, it was almost mind-boggling.”

“What that Grand Challenge pointed to was, if you just put the problem out there, and then unleash the innovation and creativity across all communities, some people will go home and work in their garages at night, absolutely titillated and motivated by the freedom to just explore on their own. It’s all about immersion, experience, and trying things. That unfettered creativity is the huge benefit of the Grand Challenges.”

The Challenges can be a boon for industry, too. While early ideas for a self-driving car date back to the 1920s, and Mercedes road-tested a self-driving van in 1986, the DARPA Challenge initiated significant development activity on multiple fronts and has spawned an industry that is forecast to grow at a compound annual rate of almost 40% to reach $557 billion in 2026.

Many of the newer commercial entities in this field, like Waymo and Uber, have links directly back to the DARPA Challenge, and there are now more than 20 commercial enterprises globally, including the traditional automakers, developing autonomous vehicles. New technology providers also have emerged as a direct outcome of the quest for a self-driving vehicle. These include many that offer photonics-based sensing systems, like the SPIE Prism Award–winning LiDAR companies Luminar and Blackmore.

THE CHALLENGE OF CHALLENGES
Despite the undoubted benefits of these Challenges in terms of producing innovative technology solutions in a relatively short time, translation of these solutions into the national security world is anything but straightforward. By their nature, dual-use solutions developed commercially, while perhaps developed with a military problem in mind, are generally unaligned with a specific program or with the integration needs of a
“It’s all about immersion, experience, and trying things. That unfettered creativity is the huge benefit of the Grand Challenges.”

specific military system. As such, it can be extremely difficult for the Department of Defense (DoD) to incorporate them into its operational infrastructure.

Consider the application that motivated the original Challenge, robotic logistic convoys. What are all of the other things that a robotic logistics truck would have to plug into? At the very least, they would include several different command and control systems, each with different architectures. “Even if we had a perfect autonomous self-driving vehicle, you have a huge challenge integrating that with the rest of what you might call a system of systems architecture,” noted Grayson, “and oh, by the way, there are humans involved too. How are the soldiers that are in the convoy going to be trained to interact with these self-driving vehicles?”

Monolithic systems and rigid architectures that take decades to develop characterize much of today’s defense infrastructure. The challenge of the Challenges, so to speak, is how can the DoD take full advantage of rapidly developing technology solutions from the commercial world—solutions that may be appearing at rates that are orders of magnitude faster than the DoD is set up to deal with?

According to Grayson, DARPA is looking at this, considering ways to allow new capabilities to be ingested in smaller “baby steps,” enabling faster uptake but with appropriate risk management. Typically, the reliability and security of a novel system must be proven up front, but what if continuous monitoring could ensure that any legacy capabilities remain uncompromised as the new capability comes online? Grayson cites the example of a new camera with an image format different from what the DoD legacy system expects. A software tool can automate translation between the data formats, but they also need a way to monitor how the new camera data is affecting the legacy platform.

SPEED TO LAUNCH

Meanwhile, the DARPA Challenges continue to drive innovation. On 18 April last year at the 34th Space Symposium in Colorado Springs, Colorado, DARPA formally announced its Launch Challenge. Competitors will vie for a top prize of more than $10 million based on their performance in two separate launches of small satellites at different launch sites on short notice. The idea is to incentivize industry to deliver launch systems with the capability to be both flexible and responsive, anticipating emerging DoD needs and changing the paradigm from years of launch preplanning and preparation to days.

Short launch cycles could also pave the way for rapid deployment of small satellites carrying imaging systems for things like disaster response (search and rescue) or severe weather observation. Rapid turnaround would likely also enable testing and iteration of new technologies, such as imaging systems or chips, and communications hardware prior to deployment on larger and more critical full-fledged satellite missions.

Today, it can take a decade to build, test, and launch a spacecraft. If the Launch Challenge is successful, decades may become days. While that may seem like an impossible goal, the success of the original Grand Challenge and subsequent autonomous vehicle challenges would suggest that “... unfettered creativity ... across multiple communities” has a strong chance of successfully reaching that goal.

Grayson will expand on this idea of speed and adaptation of technology by the DoD during his plenary presentation at the upcoming SPIE Defense and Commercial Sensing event in Baltimore, Maryland (spie.org/DCS). He will introduce DARPA’s mosaic warfare concept, and discuss both key technology enablers and challenges that will need to be addressed to make it a reality.

Luminar is partnered with Toyota Research Institute, which unveiled the P4 Autonomous Driving Test Vehicle at the Consumer Electronics Show 2019 in Las Vegas, Nevada, demonstrating state-of-the-art LiDAR technology.
n the early 2000s, the Internet disrupted several major industries, including music, travel, retail, and publishing. Scholarly publishing was no exception, so society and commercial publishers began the work of converting print subscriptions to digital archives. While they were immersed in the logistics of digitizing content, the question of access became a hot topic: if the Internet was free and open, and scholarly articles could be accessed on the Internet, why shouldn’t that research be free and open to read as well?

This universal-access question kicked off publishing’s open-access movement. In 2003, the Berlin Declaration on Open Access to Knowledge in the Sciences and Humanities was released, outlining steps to make the Internet the primary medium for disseminating knowledge. In the United States, a 2008 mandate by the US National Institutes of Health (NIH) required that all NIH-funded research be made open access within one year of publication. In 2013, an Office of Science and Technology Policy (OSTP) mandate expanded on the NIH model by requiring that all other federally funded research be made publicly available within one year. Similar mandates were instituted by European funders.

Publishers adapted to these requirements as they arose, building new workflows to deposit articles in the required repositories, and re-examining subscription-based business models in preparation for a future when library subscriptions might disappear.

PUBLISHING IN THE 21ST CENTURY

Many journal publishers, including SPIE, adopted a “hybrid” model: authors could, as usual, publish in a subscription journal for free or they could pay for open-access publication, making the article available online for anyone to read. For most journals, the open-access fee—or article processing charge (APC)—covered the expense of paper submission, peer review, and publication. Many researchers and funders imagined this hybrid model as a transitional stage toward the inevitable dissolution of the traditional subscription model.

Other publishers responded to the growing interest in open access by promoting existing (or launching new) all-open journals, like PLoS One and Optics Express.

Both models gained critics. Hybrid journals come under criticism for “double dipping,” the assertion that the journal is collecting fees for articles twice: once from the library or individual sub-
scon, and again from the authors who pay open-access fees. *(See the sidebar for information about SPIE’s hybrid model.)*

Meanwhile, open-access journals are criticized for being one more sponge absorbing researchers’ grant funding—especially those journals that charge high APCs. The past decade has also seen the proliferation of open-access “predatory journals” that conduct cursory—or no—peer review: researchers pay a fee to have their paper published in a journal that purports to be legitimate, but lacks most of the characteristics of reputable journals.

In spite of detractors, both models have become standards in the scholarly publishing landscape. And yet, the “inevitable” hasn’t yet taken place: the Internet didn’t kill off journal subscriptions. They remain a large portion of library budgets, and statistics indicate that author interest in open-access publication has plateaued. For SPIE journals, author-choice open-access publication stabilized at around 20%.

Interest in open-access publication also sees considerable variation between research communities. The SPIE journals *Neurophotonics* and *Journal of Biomedical Optics*, for example, have had a substantial percentage of authors opt for open access; in response, SPIE converted both journals to full open access in 2019, including the backfiles. Low author uptake of open access in SPIE’s other technical communities—like lithography, electronic imaging, and remote sensing—indicates that these research fields are less concerned with open access publication.

“Our journals serve the many authors who do not need, want, or cannot afford open access and who should be able to publish in their journal of choice,” says SPIE Director of Publications Eric Pepper. He also noted that SPIE has maintained a liberal “green” open-access (OA) policy for over two decades, allowing authors to post their papers in appropriate repositories with no embargo. “SPIE believes our hybrid OA program is an author- and institution-friendly shared approach to open access.”

The author-choice model of open-access publication is now 15 years old, and the urgency for scholarly publishers to “out with the old” has been tempered. The system seems to be working, and researchers have a range of publishing options to meet their needs.

But for some, progress toward all-open science isn’t moving fast enough.

**PLAN S: “SCIENCE, SPEED, SOLUTION, SHOCK”**

On 4 September 2018, a gong called “Plan S” sounded, calling the open-access movement back into the center ring of scholarly publishing conversation. A group of 11 European research-funding organizations supported by the European Commission and the European Research Council—dubbed cOAlition S—issued a new plan with a primary principle: “By 2020 scientific publications that result from research funded by public grants provided by participating national and European research councils and funding bodies, must be published in compliant Open Access Journals or on compliant Open Access Platforms.”

It was the strongest open-access mandate issued by a funding body to date. Among its ten key tenets: authors should retain copyright of their publication with no restrictions; funders will pay the APCs for publication in open-access journals, although open-access APCs should be “standardized and capped”; funders will monitor compliance and sanction noncompliance; and, notably for many publishers, the hybrid model of publishing is not compliant with these principles.

*(bit.ly/cOAlitionS)*

Robert-Jan Smits, the European Commission’s special envoy on open access and one of the Plan S architects*, anticipated some resistance to this idea. “The ‘S’ in Plan S can stand for ‘science, speed, solution, shock,’” he said.

Soon after the announcement, the London-based Wellcome Trust and Seattle-based Bill and Melinda Gates Foundation also endorsed Plan S, a clear signal of the cOAlition S effort to expand this all-or-nothing philosophy beyond continental Europe.

**WHAT DOES THIS MEAN FOR PUBLISHING IN OPTICS AND PHOTONICS?**

Although cOAlition S is accepting feedback from the scholarly community on the implementation of Plan S through early 2019, there are some significant ramifications to future scholarly output as currently outlined in the plan.

First, it’s important to note that 80% of journals globally are either subscription-only access or hybrid, meaning they would not meet the requirements of Plan S as originally conceived. Eight out of eleven of SPIE’s journals are hybrid, as are many of the highest impact-factor journals, including *Nature, Cell*, and *Journal of the American Chemical Society*. In effect, Plan S would block publication in journals known for rigorous peer review and high-quality research output.

In response to Plan S, more than 1,500 scientists from all career stages, including Nobel Laureates, have signed an open letter of appeal calling Plan S “a serious violation of academic freedom.” Since the academic evaluation system rewards publication in top-tier journals, they argue that the provi-

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*Smits finished his mandate on 28 February. Robert Kiley will act as interim coordinator of cOAlition S.*
The International Day of Light is a global initiative highlighting to the citizens of the world the importance of light and light-based technologies in their lives, for their futures, and for the development of society.

SPIE supports the International Day of Light and its annual celebration on 16 May.

**SPIE IDL GRANTS**
SPIE provides seed funding up to US$3,000 to organizations creating Day of Light activities.

**IDL RESOURCES**
SPIE encourages communities to plan their own annual celebration on 16 May and provides various resources to help create an event.

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Amateur and professional photographers alike should submit photos demonstrating the vital role that light plays in our lives for a chance to win US$2,500.

New technology and science category in 2019, a chance to win $750. Sponsored by: lightsource.org

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CAREER

sions of Plan S could negatively impact careers by preventing researchers from publishing where they choose.

According to the appeal, the original funders who belong to cOAlition S account for only 3.3% of global scientific output, but this small group could change the entire publishing ecosystem. cOAlition S knows that the Plan S guidelines are radical, and believes they will stimulate creation and adoption of new open research models for publishers, scholarly societies, libraries, universities, and researchers. They’re relying on the collaborative and multidisciplinary nature of scientific research to cause a ripple effect far beyond the small sphere of their immediate funding influence.

However, one consequence may be that researchers avoid collaborating with scientists in Europe so that they don’t have to be told where they can and cannot publish. Lynn Kamerlin, a biochemist at Uppsala University, Sweden, who coordinated the letter of appeal, says, “As the plan is written now, it’s a huge gamble. If the rest of the world doesn’t come along, European researchers are going to pay the price.”

**SOFTER LANGUAGE, SMALL CONCESSIONS**
Smits’ response to the letter of appeal has been mulish. In a phone conference between Kamerlin, the Plan S architects, and other authors of the appeal, Smits was quoted as saying, “Why is Plan S necessary? Because researchers are irresponsible. They still chase the journal impact factor.”

When queried about the impact of the plan on scholarly societies, who are the standard-bearers for rigorous peer review and often utilize publishing revenues to sponsor outreach, scholarships, and policy activities, Smits said, “I talked a lot to scholarly societies. They are a noble group, but they will have to bite the bullet and go open access.”

While these may sound like fighting words, it does seem as though the research community’s concerns are being heard: cOAlition S relaxed their stance on some of their key principles in late November. For example, they declared that a transition period will be allowed beyond the original 1 January 2020 deadline, giving hybrid journals time to achieve compliance with Plan S, and released a call for consultants to propose alternative business models to help society publishers “transition to a financially sustainable, Plan S-compliant publishing model.” The revised guidelines suggest that unembargoed deposits of scholarly articles in certain open-access repositories (green open access), may be acceptable—a shift from the initial declaration.

It remains to be seen where this conversation will end. If Plan S garners more support from funding agencies in the United States, Europe, and Asia, then these groups could overturn the scholarly publishing world in a way that will affect research output across all disciplines. Alternatively, three years from now Plan S might be barely remembered as a blip of turbulence in the vast ocean of scholarly publishing.

Most likely, the reality will fall somewhere in the middle, and Plan S funder mandates will become yet one more obstacle that researchers and publishers must navigate in an increasingly complex ecosystem.

--Gwen Weerts is the managing editor of SPIE Professional.
MEDIAN SALARY IS $74,000*
Up 3% from $71,748 last year.

CURRENCY MATTERS
Performance of median salaries paid by currency type vs. last year.

WOMEN ARE PAID LESS
Median salaries are 29% higher overall for men than for women. Gaps in median pay are smaller during early career stages.

SALARY DISPARITY
Median salaries are greatest in military/defense, followed by for-profit companies. Educational institutions pay the least.

AEROSPACE IS (STILL) ON TOP
Aerospace has held the top spot for all nine years that the survey has been conducted.

WORKING HARD OR HARDLY WORKING?
Most survey respondents work between 40 and 50 hours per week, while 1 in 5 spend 50+ hours per week at their jobs.

MONEY CAN BUY HAPPINESS
The highest earners enjoy their work the most.

STARTUP VS. TRADITIONAL
Startups account for just over 13% of workers at for-profit organizations.

Download the full report: spiecareercenter.org

*Salary information is in US dollars.
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.

Christopher Wilcox
Electrical engineer for the Air Force Research Laboratory in Albuquerque, New Mexico

SPIE Senior Member Christopher Wilcox runs the Aerophotical Effects Laboratory (AEL), which includes a wind tunnel capable of supersonic speeds. Optical windows allow his research group to access an 8 in. × 8 in. test section to study the effect of high-speed airflow on aircraft systems with high-energy lasers, laser communications, or imaging equipment that needs to maintain high resolution over very long distances.

Describe a typical day in your lab
Yesterday, I went into my office and checked my work email to see if there were any high-priority items. I had a planned experiment with the AEL wind tunnel for the afternoon, so I went to my lab and checked the alignment of the optical system with a colleague and graduate student, after which we took a quick break for lunch. In the afternoon, my team and I ran the wind tunnel and collected several sets of data for further analysis. The data collected was schlieren imagery, which can image optical inhomogeneities or pressure differences in a transparent material, such as the supersonic flow of air in our wind tunnel. We collected the schlieren image data with a high-speed camera, acquiring the 768 × 768 pixel images at a rate of 25,000 frames per second. Once analyzed and reduced, this data will provide us with a viewing of the shock waves from our experiment in our wind tunnel that were changing at rates much faster than the human eye can detect. After our data collection campaign was complete, we covered our optics, shut down our systems, and broke off for the day.

Share a memorable career story
I was working on a next-generation space telescope as a research fellow at the Naval Postgraduate School. It is a technology demonstrator platform for the James Webb Space Telescope called the Segmented Mirror Telescope. It has six segments of hexagon-shaped adaptive mirrors to make the overall 3.2-m primary mirror telescope. We had a control loop that would modulate each of the 196 actuators of each mirror and measure and build an influence function that could correct for aberrations. The code was complex and running lots of subroutines, and there was a hangup in between a bunch of calculations, so it was taking two to three days to complete! I dug deep into the code to figure out what was going on and was able to attribute the problem to a memory leak that caused the system to hang and eventually resulted in a software crash. We were able to reduce the calibration routine to just two to three hours after that, which hugely increased the fidelity of the system.

How does a person pursue a career working in a government lab?
Many government research labs have programs that students can take advantage of, like the Science, Mathematics, and Research for Transformation (SMART) Scholarship program from the US Department of Defense (DoD). Students pursuing degrees in STEM fields can receive a full scholarship and a job with the DoD after getting a degree. Or, we have the AFRL Summer Scholars program, which offers internships that help you get your foot in the door.

What do you like about working in a government lab?
We have many cutting-edge problems and projects and we get to work with small businesses and universities to help solve those problems. There’s a program called Small Business Innovative Research (SBIR), which is a good way for the government to interface with small businesses that may have a good idea that would also be useful in our lab. For example, for the wind tunnel in the AEL, we put out bids for SBIRs that can measure the volume of airflow and take “snapshots” at high rates, essentially measuring the volume of the air that’s moving through the test section many times per second. We have several companies working on different approaches to be able to perform this. In supersonic wind tunnels, air is traveling at many hundreds of miles per hour. The update rate for the camera systems has to be very high. It’s cutting-edge technology!
Industry Leaders Meet at Photonics West to Discuss Export Controls

By Jennifer Douris O’Bryan
SPIE Government Affairs Director

In a series of meetings at Photonics West 2019, SPIE facilitated discussions on a myriad of topics related to export controls as they apply to optic and photonic technologies. US Department of Commerce (DOC) officials were present for these discussions, which were open to university and industry stakeholders.

The discussion items included the anticipated additional controls on emerging and foundational technology, an industry proposal to decontrol certain infrared imaging cameras, and follow-up discussions regarding proposals to clarify or update the Commerce Control List (CCL).

EMERGING AND FOUNDATIONAL EXPORT CONTROLS

During the Sensors and Instrumentation Export Control meeting, participants heard updates on the process to control emerging and foundational technology in the United States. This effort was instigated due to the passage of legislation in August 2018 mandating that a process to identify and control these technologies be established.

An Advanced Notice of Public Rulemaking (ANPRM) was released for public comment by the DOC on 19 November regarding emerging technologies, with a deadline for comment by 10 January. SPIE submitted comments during the open comment period reflecting input from the optics and photonics community (see sidebar).

DOC officials revealed that about 250 public comments were received for this ANPRM. Officials are in the process of reviewing the input, and the DOC expects to publish a proposed rule on some subset of the emerging technologies listed in the ANPRM in the “coming weeks to months.” The DOC made clear that any proposed controls would take the approach of using specific performance parameters, as opposed to blanket control of a technology area.

There will also be a process to identify and control foundational technology. DOC Deputy Assistant Secretary Matthew Borman revealed that this process will begin with an ANPRM similar to the one published on emerging technologies. However, it was not revealed specifically what technologies would be covered in the foundational ANPRM.

UNCOOLED THERMAL IMAGING CAMERAS

An additional topic of discussion at both the Sensors and Instrumentation Export Control meeting and the Detectors & Cameras Working Group meeting was a US industry proposal to decontrol uncooled infrared (IR) imaging cameras that are at resolutions 640×580 and below. US industry reported multimillion-dollar financial losses as a result of current US export controls on these technologies.

The argument made for a reduction of controls included the significant rise in manufacturing capabilities in countries that do not adhere to the international export controls established through the Wassenaar Arrangement. In particular, China has made great strides in recent years in manufacturing high-resolution uncooled IR imagers, as well as focal plane arrays.

With the significant growth projected for sales of these mid-level uncooled IR cameras, largely fueled by the likely utilization of this technology in autonomous vehicles, US companies want to be positioned to compete in this rising market, which will require export of this technology.

OUTDATED CCL PROPOSALS

During the Working Group meetings for Lasers, Lenses & Optics; and Detectors & Cameras, university and industry representatives presented on proposals submitted during the Requests for Proposals that was open for public comment from August to October 2018. This effort by the Technical Advisory Committees of the DOC was to gather input from the public regarding specific CCL entries that were in need of clarity or updates. Follow-up discussions regarding these proposals are likely to be scheduled for the upcoming Sensors and Instrumentation Technical Advisory Committee meeting at the DOC in Washington, DC, on 30 April.

SPIE will continue to work on these and other export control-related activities in conjunction with the Technical Advisory Committees at the DOC.
GLASS HALF FULL?

How to make a glass of water store light for longer

By Chris Lee

When optics researchers get together over coffee to discuss their favorite cavities, attention turns to microtoroids, tiny glass spheres, and photonic crystals with defects. These cavities all have a few things in common: they are all really good at storing light, and they are high-precision devices.

Physicists use a number, called Q, to characterize how well an optical cavity stores light: the higher the Q, the longer light stays confined in the cavity. You do not, it turns out, go blithely into your local fab and turn out a high-Q cavity. It takes a lot of practice and trial and error to create a high-Q optical cavity.

But, it turns out that it doesn’t have to be as complicated as previously thought. Writing in Advanced Photonics (doi.org/10.1117/1.AP.1.1.016001), Andre Bogdanov and colleagues have reported a new take on high(ish) Q cavities. Their approach draws inspiration from the physics of bound states in the continuum. Yet, perhaps a simpler way to envision this is to think about interference between loss channels.

The short summary of their finding is that a cavity may leak light in different ways, called channels. But, if the light waves from different channels destructively interfere, then no light leaks from any of the channels. Hence, a high-Q cavity is born.

POWERED BY INTERFERENCE

Bogdanov and colleagues considered a simple cylinder modeled as two different cavities. Light is stored by reflecting back and forth between the end facets, called a Fabry–Perot mode. At each facet, some light leaks from the cylinder. Light can also be stored by reflecting around the perimeter of the cylinder in a mode called a Mie mode. As with the Fabry–Perot mode, light leaks out of the Mie mode at each reflection.

Light shined on the cylinder will be stored in the Fabry–Perot and Mie modes. Left to its own devices, the light in both modes will quickly be lost; neither mode stores light very well. These are cavities with a Q so low we usually don’t even think of them as cavities.

However, Bogdanov and colleagues noted that the light emitted from the cylinder via the Fabry–Perot and Mie modes. Left to its own devices, the light in both modes will quickly be lost; neither mode stores light very well. These are cavities with a Q so low we usually don’t even think of them as cavities.

So, how do you make a high-Q cavity from a cylinder? The key is to ensure that the radiation from the two modes destructively interferes with each other. When that happens,
the light stored by the cylinder in the two modes cannot easily be emitted.

The result is a mode with a Q of a few thousand. Eventually, light leaks from the cylinder anyway, but that happens in a completely different way. Essentially, the light has to be scattered out via some imperfection in the cylinder.

Not content with only calculating the properties of their new cavity, the researchers also performed an experiment using a cylinder of water and microwaves. They obtained remarkably good agreement between their calculations and experimental results.

A PICKY CYLINDER

An interesting facet of the research is something called the mode spacing. In a normal optical cavity, the modes are determined by the relationship between the dimension of the cavity and the wavelength of light. The result is a regularly spaced set of wavelengths that match the cavity. Light with these wavelengths will be stored in the cavity.

But, in order for the light to be stored, destructive interference between the two different cavities is required. The wavelength has to have the right relationship with the length of the cylinder and with the perimeter of the cylinder. This thins out the regularly spaced set of wavelengths, leaving only a few lonely leftovers that match the combined cavities.

Why does any of this matter? High-Q cavities are great for many applications: think of lasers with really sharply defined wavelengths, very sensitive sensors, or high-precision filters. The simple cylinder described in this paper isn’t ready for any of these applications yet, but it is headed in that direction.

Read the article in Advanced Photonics on the SPIE Digital Library: doi.org/10.1117/1.AP.1.1.016001

—Chris Lee is a physicist and writer living and working in Eindhoven, The Netherlands.
Researchers deploy fiber-optic cables to sense subtle vibrations deep in the earth as permafrost thaws, causing costly damage to infrastructure.

By Sophia Chen

Listening with Light
After the long, snowy winter in Fairbanks, Alaska, the summer tries to apologize. The sun lingers in the sky as long as 21 hours per day. During daylight hours, temperatures routinely climb higher than 70°F—and the surface thaws.

In 2016, during this mild season, a team of geoscientists drove a tractor called a Ditch Witch over a field maintained by the US Army Corps of Engineers. With a three-foot chainsaw rotating on its front, the Witch dug a narrow trench less than a foot deep. Nate Lindsey, a UC Berkeley graduate student, trudged after it, laying fiber-optic cable in its wake. After five days in the dirt, Lindsey’s team buried four cables, each about the length of two football fields, in a rectangular grid.

The network lay underground among untamed tree roots from a nearby forest. To lay the fiber, Lindsey had to snake his hands through the sharp, subterranean thicket. “It was a massive undertaking,” says Lindsey.

This fiber network did not transmit e-mails or cat GIFs: instead, the scientists designed it to pick up sound, like an ear to the ground. “It’s measuring nanostrains,” explains geophysicist Jonathan Ajo-Franklin of Lawrence Berkeley National Laboratory, who works with Lindsey. The cable could pick up tiny vibrations that compress a meter of dirt by as little as a nanometer. They wanted to listen for vibrations in still-frozen earth four meters further underground—the so-called permafrost, on which the vast majority of Alaska sits.

Academic geoscientists like Ajo-Franklin and Lindsey have only begun exploring this fiber-based technology, known as distributed acoustic sensing (DAS), in the last few years. But they’re getting results quickly: researchers have already demonstrated that in some circumstances, optical fiber can sense earthquake signals as sensitively as conventional sensors known as geophones—and it could be a lot cheaper. They want to use the technology to study structure and motion underground, not just for science, but to protect infrastructure and improve earthquake warning systems.

One reason for their rapid success: they’re not starting from scratch. In their experiments, Ajo-Franklin and Lindsey used decades of DAS research that originates from military, telecom, oil, and gas industry applications.
The technology originated with scientists at the US Naval Research Laboratory (NRL) and defense contractor TRW, who were developing next-generation sonar.

In 1977, the NRL and TRW experiments revealed that optical fibers could pick up subtle vibrations. They began to invest in these hair-thin fibers, which were lightweight and insensitive to electromagnetic noise, as a potential upgrade for classic ceramic-based sonar sensors. In the 1980s, the NRL tested optical fiber arrays that ships could tow in the water to sense enemy submarines.

The NRL then developed supporting technology—directional couplers for manipulating acoustic signals, for example—to improve the fibers' sensing capability. “It was so pioneering they left everybody in the dust for a long time,” says Arthur Hartog, the author of An Introduction To Distributed Optical Fibre Sensors. Today, the US Navy’s newest type of attack submarine, dubbed the USS Virginia class, carries an array of optical fiber on its hull for detecting acoustic vibrations.

To sense vibration, you measure how light scatters inside the fiber. An infrared laser sends a light pulse down the fiber. Most of the light flows right through, but because of imperfections in the glass core, some light scatters back through the fiber to hit a detector. “You have to imagine these microscopic changes in density throughout the glass,” says Hartog. “They change the index of refraction in the fiber very slightly. It creates a tiny bit of scatter, and you capture some of it on the way back.” In fact, companies design fiber specifically for sensing; unlike telecom fiber, which is engineered for as little scattering as possible, sensing fiber contains specifically designed impurities.

Sound waves compress or stretch the fiber, which changes the scattering signal. By timing when the detector registers the signal, researchers can pinpoint the location of the impurity where the light scattered. Then, for example, the submarine crew can analyze the signal to register the presence of an unknown ship, or geophysicists can infer mechanical properties about the soil near the impurity.

Also in the 70s, telecom researchers developed acoustic sensing further—somewhat indirectly. They investigated the science of how light scatters in fiber, a field now known as optical time-domain reflectometry (OTDR). They found that scattering signals could help them detect breaks in fiber. Today, telecom companies perform routine network maintenance by measuring scattering signals. But their studies reaped benefits beyond their industry. All DAS signal analyses now incorporate the lessons they learned from watching light bounce around in broken fibers.

Then, academic researchers made another key development: using the entire length of an optical fiber as an extended sensor. In the 80s, they demonstrated they could survey large areas using a single fiber—and distributed sensing was born. Today, a 10-kilometer fiber can function as 10,000 individual point sensors, if you divide it into 1-meter sections and monitor the scattering from each section. Geophysicists now record strain data over an entire fiber, as opposed to relying on discrete geophone data points that might be spaced several kilometers apart. “This is really the strength of the method,” says Ajo-Franklin.

In the 2000s, the oil and gas industry took distributed sensing further. They started using DAS to discover new deposits. DAS is useful for exploration because optical fibers are robust, says Thomas Coleman of Silixa, a US- and UK-based company that makes DAS equipment. The fibers function well in extreme environments of high temperature and pressure, especially compared to conventional sensors.

The industry also began using the technology to tackle an ongoing problem: oil theft. Thieves dig under pipelines to tap them, and then sell the oil on the black market. This oil amounts to billions of dollars lost: Nigeria, for example, lost $13 billion due to pipeline sabotage in 2016. Oil theft is not only a business issue: this January, news agencies reported that a gasoline pipeline in Mexico exploded after being illegally tapped, killing more than 90 people.

While working at oilfield services company Schlumberger, Hartog collaborated with global energy company BP to use fiber sensing to better secure pipelines. These systems could detect vibrations indicating the potential presence of intruders and are widely used to secure pipelines today.
In the last decade, academic geophysicists began exploring the potential of DAS. Ajo-Franklin and Lindsey are using their network in Alaska to study permafrost, ground that has been frozen for two years or longer.

Because of rising global temperatures, permafrost is thawing at an accelerated rate, which portends future problems.

Lindsey compares the permafrost to a frozen steak. As the steak thaws, it begins to rot, and “microbes take over and respire carbon dioxide into the atmosphere,” he explains. Some researchers estimate that the permafrost contains twice as much carbon as the current amount in the atmosphere. As it thaws, microbes convert that carbon into carbon dioxide and methane. If this gas is released, it could be a “massive” driver of climate change, says Lindsey.

In addition, the ground becomes spongy because of permafrost thaw, which damages infrastructure. Environmental engineer Anna Wagner of the US Army Corps of Engineers, one of Lindsey’s collaborators, says that engineers can use DAS data to monitor changes in soil strength due to thaw to prevent infrastructure damage.

To study the thaw, Wagner’s team actually heated an area of permafrost slightly smaller than half a basketball court and 1.5 meters deep. They thawed the permafrost by jamming 121 steel rods into the ground and running 60 watts of electricity through them for 63 days. They used DAS to measure seismic vibrations in the dirt, to infer how the earth’s hardness and elasticity changed during thaw. They now have some data that could improve models of permafrost thaw, says Wagner.

DAS could lower the cost of seismic monitoring because fiber is far cheaper than conventional sensors. But the exact cost reductions aren’t clear, says Lindsey. The instruments that detect scattering signals, called interrogators, are expensive to buy outright, which means academics usually rent them. Lindsey’s group leases a Silixa interrogator called iDAS.

Eileen Martin, a computational geophysicist at Virginia Tech, is pursuing another potential cost-saver: working with telecom companies to adapt their so-called dark fiber networks—unused infrastructure they’ve already laid—for vibration sensing. Martin recorded seismic data using components of a dark fiber network under the Stanford University campus. The signals are noisier than conventional seismographs, but Martin thinks adapted dark fiber infrastructure could improve seismic monitoring and earthquake warnings in cities. “In the past, we’ve had very sparse data in urban areas,” says Martin. “It’s a huge opportunity, now that there’s the ability to use fiber already in place.”

However, data management will be a big challenge, says Martin. The permafrost project and her Stanford project can each collect more than 10 terabytes a week. So Martin is working on compression techniques to condense the data.

Another related challenge is how to store the data. A local DAS network could produce at least a thousand times more raw data than its seismograph counterpart, says Martin. Historically, academic geophysicists archive their data publicly using government and university resources—but if DAS takes off, they’ll need vastly more storage space.

Even so, DAS promises geophysicists the ability to monitor seismic activity in far more detail than currently exists. The technique is catching on among her colleagues, says Martin, especially as they develop and share more data-processing methods specifically for academic geoscience. It helps, too, that some infrastructure has already been laid—and that they stand on the shoulders of researchers from years past.

–Sophia Chen contributes to WIRED, Science, and Physics Girl. She is a freelance science writer based in Tucson, Arizona.
In 2014, Eric Betzig won a Nobel Prize for breaking the law. Specifically, Abbé's Law, which set a limit to how deeply optical microscopes could peer into their subjects. Betzig's workaround used fluorescent molecules to light up living cells from the inside. But, breaking one closely held assumption wasn't enough for Betzig. In his acceptance lecture to Stockholm University, Betzig told the audience that optical microscopy must free itself from petri dishes and cover slips. “That’s not where cells evolved; we need to look at them inside the whole organism,” he said. That is, by peering into dense, living tissue. This was no idle call to action. Using technology borrowed from astronomy, his lab had already witnessed neurons firing in the brain of a live mouse.

That technology is called adaptive optics, and it’s one of the marquee stories in the annals of tech transfer. First theorized in the 1950s, adaptive optics is, at its most basic, a two-part system: a sensor reads distortion on incoming light, and a deformable mirror changes shape to match that distortion, unscrambling the photons while reflecting them to the objective viewer. Simple as that sounds, even the most rudimentary models took decades to develop. Many of the essential technological innovations took place in classified military programs—notably, the oft-maligned “Star Wars” defense initiative. When declassified in the early 1990s, that work reinvigorated civilian astronomy.

In his book The Adaptive Optics Revolution, historian Robert Duffner calls adaptive optics, “the most revolutionary technological breakthrough in astronomy since Galileo pointed his telescope skyward to explore the heavens 400 years ago.” And adaptive optics is still revolutionizing science, at both macro- and microscopic scale. Biologists use adaptive optics to see cellular interplay in live tissue; vision scientists use it to map individual eyeball aberrations; lithographers can now etch transistor circuitry inside deeply refractive crystal; and, as recently as January of this year, astronomers used it to see what they believe is the birth of either a neutron star or a black hole.

It all started with the twinkle of the stars. After being flung from burning globs of gas, stellar photons cross the universe unmolested. That is, until they reach Earth’s atmosphere. The mix of warm and cool air up there creates a turbulent mess for light, which will bend its path to travel through relatively dense mediums.

In 1953, astronomer Horace Babcock came up with an idea to untwinkle the stars. In the journal Publications of the Astronomical Society of the Pacific, he described a “seeing compensator” that compared dis-
torted stellar light against light generated by a bright “control star.” His original concept called for bouncing the incoming light off an Eidophor—a mirror covered in a thin layer of electrified oil. Inner gadgetry would produce a schlieren image, showing distortion in the incoming light waves. This schlieren image would then pass through a type of television tube called an orthicon, which would transmit the perceived distortion levels back to the Eidophor mirror. The electric impulses controlling the surface tension of the oily mirror would distort the Eidophor so it matched the incoming distortion. And, this would be a closed-loop feedback, constantly reading and morphing to match the distorted photons. Given how quickly atmospheric turbulence shifts, this last bit was essential. If it all worked perfectly, the astronomer would get a clear view of their desired celestial object.

Alas, contemporary technology couldn’t meet Babcock’s specs. It was another decade before anyone began designing rudimentary adaptive optics systems. But military and aerospace researchers, rather than astronomers, picked up the thread. Sputnik—launched in 1953—sparked a reconnaissance race between the US and USSR. As each nation covertly tried to keep tabs on its rival’s armaments, both sides launched hundreds of satellites. “This was a time when the US was very interested to know what the Soviets were getting up to in space,” says Robert Fugate, a retired senior scientist with the Air Force Research Laboratory in Kirtland, New Mexico, who spearheaded many of the military’s later classified efforts with adaptive optics. By the mid-60s, some US defense thinkers thought Babcock’s ideas might help them get a better look at those Soviet satellites. It also might be able to see other threats, like incoming missiles. Some even thought these techniques might someday translate into laser energy weapons capable of shooting those enemy missiles down.

The first military research took root in upstate New York, at the Rome Air Development Center. Funded by the Advanced Research Projects Agency—a government-funded civilian agency that later became DARPA—these Air Force researchers teamed up with civilian corporation Itek to tackle the basic systems behind adaptive optics: the wavefront sensor, deformable mirror, and processor capable of relaying the constant signals between the two. The groups also gathered data on light passing through the atmosphere. Some of those experiments involved flying a B-57 with a 1,200 watt tungsten light bulb over the base. Unsurprisingly, civilians living in the area concocted all sorts of stories to explain those lights, even though the research group was forthcoming about the nature of their work. By the early 70s, Rome and Itek had a prototype system capable of measuring atmospheric distortion: the real-time atmospheric compensation (RTAC).

BUILDING AND TESTING THE FIRST AO SYSTEM

Impressed with Itek’s role, in 1973 DARPA awarded the company a contract to further the RTAC concept. Once again, the company partnered with Rome’s Air Force scientists. Between 1976 and 1981, they developed the compensated imaging system and installed it on the 1.6 meter telescope atop Haleakala volcano in Hawaii. In March of 1982, they tested it for the first time. In The Adaptive Optics Revolution, Robert Duffner describes this maiden run:

“Scientists aimed the telescope at a star. The first image danced around and looked washed out and blurry. But when Don Hanson pushed the button to activate the adaptive optics on the telescope ... a dramatic change occurred: the image became much brighter, clearer, and more detailed.”

Exciting as it was, the experiments were classified, and the astronomers at that Maui telescope were sworn from telling their colleagues about the breakthrough. On top of that, the DOD didn’t seem particularly impressed with the results, at least not enough to bring adaptive optics into production. See, adaptive optics systems need a lot of light to work. Some of it goes to the wavefront sensor, so the device can measure the distortion. Many stars, and most satellites, aren’t bright enough on their own to provide the light needed for adaptive optics with enough left over for the telescope to see the image. Astronomers would work around this by imaging a second nearby star as a “guide.” Satellites were trickier. The best method was imaging the satellite just after sunset, but while near-Earth orbit was still illuminated by the sun’s light. The adaptive optics system would use the reflected sunlight to measure the atmospheric distortion.

“However, making reflected sunlight from the satellite itself the guide star for the system just is not practical,” says Fugate. For one, this limited the time a telescope with adaptive optics had to collect satellite imagery to just a few minutes each day. Also, sometimes the reflected sunlight wasn’t bright enough to correct the imaging. These drawbacks made the system too unreliable for counter-espionage purposes. But the DOD did not give up on adaptive optics. Not even close.

USING LASERS AS GUIDE STARS

“In the late spring of 1982, we were called to go brief the “Jasons” (a group of hard-nosed scientists who evaluated proposals for the DOD, cofounded by none other than Charles Townes) on using a laser to generate a guide star in the sky to make measurements of atmospheric distortion to be used in an adaptive optics system,” says Fugate. The Jasons approved this proposal.

The 1980s were heady times for Fugate. He returned to work at Starfire Optical Range in New Mexico. While refining laser guide star concepts, he continued to develop core adaptive optics systems and even managed to finagle a combined $1 million from the Air Force and Strategic Defense Initiative to get the Starfire Optical Range its own 1.5 meter telescope. And then, on 13 February 1989, he completed the first successful test of adaptive optics combined with a laser guide star, correcting atmospheric distortions in real time.

This was another amazing breakthrough for adaptive optics. The laser guide star allowed corrections that provided unprecedented views of the stars—and satellites. And, it was a breakthrough that mainstream astronomy had no idea about, thanks to national security.

However, the veil would soon lift. The Strategic Defense Initiative—which had funded a lot of Fugate’s work—was winding down. He and others set to work lobbying the military to declassify its work on adaptive optics and laser guide stars. Astronomers around the world were also working on adaptive optics and laser guide stars, but were wasting brain power trying to solve problems the US military had figured out years before.
Astronomers around the world were also working on adaptive optics and laser guide stars, but were wasting brain power trying to solve problems the US military had figured out years before.
By 1990, the Air Force decided declassifying wouldn’t give America’s enemies any real strategic advantage. It planned several avenues for releasing this information, the most important (and dramatic) of which was Fugate’s presentation at the meeting of the American Astronomical Society in 1991 in Seattle. His presentation featured a slide of side-by-side pictures: On the left, a blurry fuzz. On the right, two tightly focused shining balls of light. The pictures showed the same star system, before and after adaptive optics with laser guide stars.

Fugate’s presentation was a smash, and afterward he and his colleagues worked hard to share their work with other astronomers. His influence percolated into other disciplines as well.

ADAPTIVE OPTICS FOR VISION SCIENCE
Eyes are tempestuous little organs, and in the early 1990s ophthalmologist David Williams heard some colleagues from the University of Rochester’s optics labs discussing a new technology that might help him peer through ocular distortion. “I cold-called Fugate out of the blue and told him what I wanted to do,” says Williams. Fugate told Williams to come on down to Albuquerque—but told him to show up around midnight. “Astronomers are nocturnal creatures,” says Williams. After the visit, Williams returned to Rochester, bought a deformable mirror, and hired a grad student who knew how to build wavefront sensors. They spent the next few years building adaptive optics systems for eye science.

During the 90s, civilian astronomers were pushing adaptive optics further in their own field. One of the most proactive was SPIE Fellow Claire Max, an astrophysicist and Jones member who, at the time, was based at Lawrence Livermore National Laboratory. She had spearheaded efforts to build the first astronomical laser guide star at Lick Observatory, and wanted to continue innovating systems for larger aperture telescopes. However, she was having trouble finding funding to match the scale of her ambitions. That is, until she and her colleague Jerry Nelson at UC Santa Cruz attended a workshop given by the head of a NSF Science and Technology Center where they heard about 10-year NSF grants worth a few million each year. “This gives you time and money to do ambitious projects,” says Max. “We knew these NSF centers liked doing something that involved more than one discipline,” she says. So, Max and Nelson contacted Williams, and included his vision work in their proposal. They won the grant in 1999, and established the Center for Adaptive Optics at UC Santa Cruz, where for a decade astronomers and vision scientists spent that grant money collaboratively advancing adaptive optics in their respective fields, while also operating as an educational hub for the technology. After the government money ran dry, they secured extra funding, and the center continues its mission today. The astronomers successfully built bigger and better adaptive optics systems, such that even the largest-aperture telescopes could benefit from the technology. Meanwhile, the vision research led to significant breakthroughs in anatomy and clinical care. They were able to get 3D views of the retina in high resolution, which helped them understand more about how eyes work, and also became an important diagnostic tool.

Adaptive optics played a role in surgery, too. Williams helped Bausch + Lomb develop technology to map a person’s cornea for laser vision correction. Williams is currently using adaptive optics to develop a cure for blindness. “We can look into the eye and see on a cellular spatial scale whether our treatments are making a difference or not,” says Williams.

FROM THE EDGE OF SPACE TO THE LIMITS OF BIOLOGY
Adaptive optics got its start helping astronomers see deep into space. Over the past two decades, it’s also allowed microscopists to peer into the nuances of cellular biology. “My PhD research project 20 years ago involved some of the first work in the application of adaptive optics to microscopes,” says Martin Booth, who at the time was working under Tony Wilson and Mark Neil at Oxford University. “The major part of this work was the first demonstration of adaptive aberration correction in confocal laser scanning microscopes, which are commonly used in biomedical imaging.”

Since then, SPIE Senior Member Booth has established his own Oxford lab, where he continues to focus on developing the adaptive optics systems themselves. This has resulted in a blossoming array of applications and discoveries. For instance, traditional wavefront sensors don’t always work at microscopic scale, so he has developed an image-based aberration measurement scheme. And, he believes this discovery could cross back over into telescopes to help maintain the active alignment of the mirrors used in the cameras of Earth-facing satellites.

Eric Betzig was introduced to adaptive optics in 2006 when he was a new hire at Janelia Research Campus. Though he’d been working on fluorescent schemes to light up single cells for superresolution (the same work that earned him a Nobel Prize in 2014), most of his new colleagues were focused on the brain. So, he got on board and hired his first postdoctoral researcher. Na Ji was part neuroscientist, part physicist, and was already using adaptive optics by the time she came to Betzig’s lab.

However, as Booth had also learned, adaptive optics doesn’t translate directly from astronomy to microscopy. “The challenge in astronomy is the rapid fluctuations,” says Ji. “You have to make a feedback loop between the wavefront sensor and the deformable mirror thousands of times a second.” In biology, the distortion doesn’t fluctuate, it’s just very dense. “I don’t know if you’ve ever seen a brain, but they look like a blob of tofu,” she says. Ji and Betzig came up with several highly technical alternative methods for peering through tissue. One involves a homebrewed wavefront sensor that works like an astronomical wavefront sensor in reverse. They also used fluorescent molecules inside the brain like internal guidestars and near-infrared light to penetrate into the flesh.

Betzig says he’s close to retiring from microscopy. His final project is building a microscope he calls an “adaptive optics Swiss Army knife.” This machine will pair every type of modern optical microscopy—confocal two photon, structural illumination, superresolution localization, expansion, lattice light sheet—with an optimized adaptive optics system. “It’s still the early days of adaptive optics microscopy, and most people aren’t aware of what it can do,” he says. He predicts that within the next 10 to 20 years every commercial microscope will come standard with adaptive optics. “Just like with telescopes, it will make no sense to use one without it.”

—Nick Stockton is a freelance writer based in Pittsburgh, Pennsylvania. He contributes to WIRED and Popular Science.
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23 Years Later

This material’s unique optical properties make it attractive for applications in both defense and consumer technology

By Mark Crawford

In 1996 Eric Mazur, SPIE Member and a physics professor at Harvard University in Cambridge, Massachusetts, and several of his graduate students discovered a material they later called “black silicon.” The group placed a silicon wafer in a vacuum chamber, filled it with chalcogen-containing gas, and irradiated the silicon with ultrashort pulses from a femtosecond laser. Upon examination, the team discovered the blackened surface was covered with a vast array of nanoscale spikes.

This altered material eventually proved to be much more sensitive to light than a standard silicon chip. It was announced to the world at the American Physical Society Centennial meeting in 1999 in Atlanta, Georgia. In 2003, Mazur and his team built the first black silicon photodetector. Additional testing of black silicon revealed its high light absorption at wavelengths between 400 nm and 2.5 µm—far beyond the infrared response of regular silicon.

Mazur and then-graduate student James Carey of Harvard University founded the startup SiOnyx in 2006, with the intent of using black silicon to improve the infrared sensitivity of silicon-based photodetectors and
image sensors in low-light and night-vision applications, suitable for a wide range of industries.

“What Mazur and SiOnyx discovered is that the increase in light absorption could lead to a useful gain in detectable electrical current, resulting in a highly sensitive photodetector that includes infrared wavelengths (lower photon energies) that silicon usually does not absorb,” says SPIE Fellow David Dickensheets, a professor of electrical and computer engineering at Montana State University in Bozeman. “Their end goal goes beyond simply absorbing all the light to actually converting those absorbed photons into useful electrons.”

SiOnyx’s black-silicon-based technology is a significant breakthrough in the development of smaller, lower-cost, and higher-performing photodetection or optoelectronic devices for a variety of applications. In 2012, SiOnyx received venture funding from Coherent and In-Q-Tel, the venture wing of the US Central Intelligence Agency (CIA). A year later SiOnyx developed a night-vision camera for the US Army that achieved its expected performance goals when operated in lab conditions that simulated a moonless night. Building on these successes, in 2018 SiOnyx brought to market the Aurora camera, which captures high-definition video in near total darkness.

“It has been quite a long road,” says Mazur. “The idea has always been for black silicon technology to benefit consumer technology. Early support from the Department of Defense helped make the transition from prototype to proven technology possible. The research we did for the Army Research Office validated our work—there was a lot of skepticism initially.”

That’s not the case now: a search for “black silicon” on Google Scholar will show nearly 9,000 records.

With the increased sensitivity of black silicon detectors in the near infrared, the most obvious commercial applications are for low-light situations.

“Any market that benefits from near-infrared-enhanced performance and/or better low-light sensitivity is a target for our technology,” adds Carey, now principal engineer for SiOnyx. The number of applications continues to grow and includes commercial applications (night vision, machine vision, automotive, gesture, time of flight, security, defense, and spectroscopy) and military applications (night vision, targeting, laser “see-spot”). “The increased near-infrared sensitivity of our products provides value in all of these markets,” he states.

The Aurora camera is the first SiOnyx product specifically aimed at the consumer electronics space. While most commercial night vision cameras capture images in grayscale or monochromatic green, black silicon technology can uniquely produce full-color photos and video in low-light conditions, including near-total darkness—ideal for a variety of military, security, and consumer applications. High-end night vision technology is either based on analog intensifier tubes or thermal sensors that cost thousands of dollars, and sometimes tens of thousands of dollars—the Aurora is a digital alternative that is based on complementary metal–oxide–semiconductors (CMOS).

In April 2018 the company launched a Kickstarter™ campaign to support the future launch of the camera. “We felt that using Kickstarter was a great way to engage our new consumer audience,” says Carey. “It is a perfect platform to get early customer feedback, prioritize features, market products that are still in a formative stage, and create advocacy through the enthusiastic backers that use Kickstarter.”

After the first four days of the launch SiOnyx had tripled the $50,000 goal it had hoped to meet for that time period. The crowdsourcing campaign raised a total of about $300,000 and generated more than 600 backers.

“We were both humbled and extremely excited by the incredible response Aurora has received through its Kickstarter,” indicates Stephen Saylor, president and CEO of SiOnyx. “Aurora is tapping into the massively underserved market for action cameras with real night vision at consumer prices and we are grateful to our current and future backers for helping us continue this journey forward.”
The term “black silicon” actually dates back at least to the 1980s as a generic term for describing high-aspect-ratio features formed on the surface of silicon.

Black silicon can be formed in a variety of ways, including wet etching, dry etching, and laser ablation. The resulting geometry of the nanotextures can vary dramatically; small changes at the nanoscale can have large impacts on performance at the macroscale. The spikes (also called silicon nanowires) can be customized for parameters such as diameter, density, and length, which can significantly alter the optical reflection and absorption of the module.

All black silicon increases light absorption and decreases reflectivity; however, some black silicon is blacker than others. With the explosion of interest in nanowires for studying 1D and quantum materials, several other “black” materials have been created, including carbon nanotubes. However, when compared to these other materials, silicon still holds its own in overall light absorption and “blackness” and is very straightforward to process.

A possible competing technology to black silicon is graphene-based near-infrared detectors; however, graphene-based optoelectronic devices face significant challenges with scaling up, including the production of low-cost and high-quality graphene. Carey notes, “Other materials, such as SiGe and InGaAs, have high near-infrared and shortwave infrared sensitivity, but don’t enjoy the scale and low cost that a silicon-based technology does.”

At Montana State University, Dickensheets has incorporated nanotextured black silicon as an optical absorbing material into silicon-based micro-optomechanical systems (MOEMS) to reduce stray light and increase optical contrast during imaging. “Inadvertent reflections are often a problem in MOEMS devices,” he says. “A direct and practical use for black silicon is as a light absorber or baffle that can be patterned with micron-scale precision and built into a device, as a self-aligned aperture around the active optical surface.”

Dickensheets and his graduate student Tianbo Liu are impressed by how black this material can be. The black silicon they make using cryogenic ICP-RIE etching has much less light scatter (less than 1 percent of incident optical power) and specular reflection (less than .001 percent reflectivity) compared to black paints or other commercial “black” flocking materials.

Black silicon can also be cast into a polymer film spun onto the wafer after the black layer is made. “If the wafer is then etched from the bottom, until all the solid silicon is gone, the nanowires will remain embedded in the polymer film, forming a black layer there,” says Dickensheets, describing work done in the NSF-supported Montana Nanotechnology Facility by former graduate student Mohammad Moghimi. “This could be useful for creating highly absorbing features in flexible optical devices. Naturally occurring optical systems, like insect eyes, rarely occur on a rigid substrate, so flexible optical platforms may open up all kinds of new applications.”

One of the biggest trends in photovoltaic manufacturing today is using black silicon to increase efficiency. SPIE Member Fatima Toor, assistant professor of electrical and computer engineering at the University of Iowa in Iowa City, has developed various techniques to improve the front- and back-surface performance of nanostructured black silicon solar cells, with up to a 23% increase in short wavelength (400 to 600 nm) internal quantum efficiency and an increase in the external quantum efficiency in the long wavelength (>900 nm) region of up to 11%. Her team is also working on utilizing black silicon for biosensing and tandem PV applications.

Although black silicon is more than two decades old, Toor believes it is just now reaching its commercial glory. She points out that Trina Solar, one of the largest photovoltaic cell and module manufacturers in the world, recently released its black-silicon-based PV modules that are higher efficiency over wide view-of-angle than traditional solar cells that are pyramid textured and coated with vacuum-based silicon nitride antireflection coatings. Toor says, “Given that black silicon is highly versatile and silicon-based, I believe more commercial products based on black silicon will continue to enter the market.”

Scanning-electron microscope image of the surface of a black silicon wafer.

Credit: Tianbo Liu, doi.org/10.1117/1.JMM.16.4.045501
SiOnyx R&D activities continue to focus on improving the sensitivity of its sensors and designing image sensors for future applications.

In January 2019 SiOnyx announced a $19.9-million deal with the US Army to deliver digital night-vision cameras. These will be part of the Integrated Visual Augmentation System (IVAS) program, which provides individual soldiers with head, body, and weapon technologies. The army is eager to gain a combat advantage by improving low-light detection of people at a distance of 150 meters. The contract, which was awarded through the army’s specialist Night Vision and Electronic Sensor Directorate (NVESD), calls for SiOnyx to deliver low-light camera modules within two years.

“This is an exciting new development for SiOnyx,” says Carey. “The application is aimed at providing tremendous low-light imaging capability, in a smaller form factor, than is currently possible. There are plenty of challenges in making digital night vision small, such as optics design, thermal management, and sensor performance. State-of-the-art night vision today is analog and the form factor for the [current military-issue night vision goggle] PVS14 is considered compact. For digital night vision, the Aurora is significantly smaller than previous offerings—the cameras we will build for IVAS will be even smaller.”

This new contract with the US Army brings the government’s early work with SiOnyx full circle. While the Department of Defense’s early interest and support of their technology ultimately allowed SiOnyx to enter the consumer market with the Aurora night vision camera, this latest contract with the US Army will allow the government to benefit from the technology advancements and lessons learned during SiOnyx’s years developing for the commercial market. “We always intended our black silicon image sensors to be dual-use technology,” says Carey. “There is tremendous value in improving the low-light and night-time imaging performance of silicon image sensors, for both military and commercial purposes.”

–Mark Crawford is a science and technology writer based in Madison, Wisconsin.

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SPIE Fellows are Members of distinction who have made significant scientific and technical contributions in the multidisciplinary fields of optics, photonics, and imaging. They are honored for their technical achievement and for their service to the general optics community and to SPIE in particular. More than 1,400 SPIE members have become Fellows since the Society’s inception in 1955.
SPIE Fellows Demonstrate Outstanding Technical Accomplishment and Service to the Community

This year, 88 Fellows from 18 different countries have been nominated by their peers for this distinction.

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Amir Amini, University of Louisville (USA)
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Vijayan Asari, University of Dayton (USA)
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Xingfa Gu, Institute of Remote Sensing & Digital Earth, CAS (China)
Mircea Guina, Tampere University of Technology (Finland)
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Anna Yaroslavsky, University of Massachusetts, Lowell (USA)
Dan Zhu, Huazhong University of Science & Technology (China)

Nominations for the 2020 class of SPIE Fellows are due 15 September.
spie.org/2020_Fellows
The Up and Coming Stars of Tomorrow

These 12 early-career professionals represent the broad spectrum and reach of photonics.

Now in its third year, the SPIE Defense + Commercial Sensing Rising Researcher program recognizes early-career professionals who are conducting outstanding work in product development or research in the areas of defense, commercial, and scientific sensing, imaging, optics, or related fields.

The honor of being identified as a Rising Researcher is hard won: these individuals must show a record of service and leadership, demonstrate how their work advances science or product development, and be able to communicate how their work fits into the broader story of science.

SPIE Fellow Tom George is CEO of SaraniaSat Inc. and was a member of the 2019 selection committee. “I believe that there are very few incentives to recognize young talent before they have accumulated a career’s worth of experience,” he says. “The Rising Researcher program is an excellent way to identify the up and coming stars of tomorrow and encourage them to continue their record of excellence in research.”

The 2019 Rising Researchers will be acknowledged at DCS in Baltimore, Maryland, in April, where they will all present papers.

“DCS is a unique symposium that covers the entire technology readiness level (TRL) scale, from low-TRL research concepts to high-TRL systems,” says George. “DCS is an excellent forum to showcase Rising Researchers because on the one hand, the low-TRL researchers can envision the new and exciting systems of tomorrow that will be enabled by their work, while the high-TRL researchers can get a glimpse of the new concepts that are “coming down the pike” for them to work on in the future. DCS is a one-of-a-kind forum hosting the entire technology development ecosystem under one roof.”

These individuals are to be congratulated for making an early impact on the optics and photonics field.

MEET THE 2019 DCS RISING RESEARCHERS:

Giulia Acconcia, Politecnico di Milano (Italy)

Paper: “Fast fully integrated active quenching circuit for single photon counting up to 160 Mcounts/s”

Giulia Acconcia received her MA in electronics engineering, and her PhD, with honors, in information technology, electronics area, both from Politecnico di Milano. She is currently a postdoc researcher at Politecnico di Milano. Her main research interests concern the design and development of integrated circuits for read-out, signal routing, and timing to achieve high-performance with single-photon avalanche diodes.

Darryl Boyd, US Naval Research Laboratory (USA)

Paper: “Fabrication of high refractive index, infrared transmitting organically modified chalcogenide (ORMOCHALC) polymers”

Darryl A. Boyd is a research chemist in the Optical Sciences Division at the US Naval Research Laboratory. His research focuses on the development of novel chalcogenide-based optical polymers for use in defense sensing and detection. Boyd received his BS in chemistry from the University of Michigan, and his MS and PhD degrees from Purdue University. Away from the lab, he runs the website www.DrBoydTheChemist.com, where he posts simple science videos geared toward inspiring young people to pursue careers in science.
Stephen Andrew Gadsden, University of Guelph (Canada)
Paper: “An adaptive smooth variable structure filter”
Stephen Andrew Gadsden is an assistant professor in mechanical engineering at the University of Guelph, where he is also the director of the Intelligent Control and Estimation (ICE) Laboratory. His team is targeting the development of new control methods that enable robustness to disturbances and uncertainties, while providing accurate and stable system control; creating and testing novel estimation strategies that provide improved performance in the presence of system and measurement nonlinearities; and developing autonomy in the area of cognitive systems by utilizing machine-learning techniques.

Stefan Heist, Friedrich Schiller University (Germany)
Paper: “Pattern projection in the short-wave infrared (SWIR): accurate, eye-safe 3D shape measurement”
Stefan Heist is the leader of a junior research group at the Institute of Applied Physics at the Friedrich Schiller University, and a research associate at the Fraunhofer Institute for Applied Optics and Precision Engineering. He received his diploma and PhD degrees in physics from the Friedrich Schiller University in 2011 and 2017, respectively. His research interests focus on the application of new wavelengths for optical 3D shape measurement, the development of high-speed pattern projectors, and the simulation-based optimization of structured-light techniques.

Juejun Hu, Massachusetts Institute of Technology (USA)
SPIE Member Juejun Hu received his BS from Tsinghua University in 2004 and his PhD from the Massachusetts Institute of Technology in 2009, both in materials science and engineering. He is currently an associate professor in MIT’s Department of Materials Science and Engineering. Prior to joining MIT, he was an assistant professor at the University of Delaware from 2010 to 2014. He has authored and coauthored more than 90 refereed journal publications.

April Jewell, Jet Propulsion Laboratory (USA)
Paper: “Advanced technology enabling CubeSat and Flagship missions”
April Jewell is a technologist at NASA’s Jet Propulsion Laboratory where she focuses on design, development, and implementation of surface-passivation techniques and thin-film coatings for silicon-based imagers that meet project/mission specific objectives. She holds a PhD from Tufts University and a BS from George Washington University, both in chemistry. Jewell has spent the majority of her career endeavoring to understand how atoms and electrons get from point A to point B, and how photons interact with matter. Her work has resulted in more than 60 publications, including three book chapters and multiple patents.

Yong Lin Kong, University of Utah (USA)
Paper: “Multiscale additive manufacturing of electronics and biomedical devices”
Yong Lin Kong is an assistant professor at the University of Utah’s Department of Mechanical Engineering. He received a BEng in mechanical engineering from The Hong Kong University of Science and Technology (2010), an MA in mechanical and aerospace engineering from Princeton (2012), and a PhD in mechanical engineering and materials science (2016), also from Princeton. His research focuses on the fabrication of biomedical devices and the printing of nanomaterial-based functional devices. He is a recipient of the MIT Technology Review Innovators Under 35 Asia Pacific Award, Materials Research Society Graduate Student Award, and the Daniel & Florence Guggenheim Foundation Fellowship.

Laura Na Liu, University of Heidelberg (Germany)
Paper: “A dynamic plasmonic system that responds to thermal and aptamer-target regulations”
Laura Na Liu is a full professor at the Kirchhoff Institute for Physics at University of Heidelberg. She works at the interface between nanoplastronics, biology, and chemistry. Her group focuses on developing sophisticated and smart plasmonic nanosystems for addressing structural biology questions, as well as catalytic chemistry questions in local environments.

Uttam Majumder, Air Force Research Laboratory (USA)
Paper: “Deep learning for radio frequency civilian vehicles classification”
SPIE Member Uttam K. Majumder is a senior electronics engineer at Air Force Research Laboratory. He earned his PhD in electrical engineering from Purdue University. His research interests include machine learning for object recognition, high-performance computing, radar waveforms and systems design, and digital image processing. He has served as adjunct faculty and taught short courses at the SPIE DCS Symposium, the IEEE Radar conference, and at other IEEE events.

Andrés Marrugo, Universidad Tecnológica de Bolivar (Colombia)
Paper: “Wide-field 3D imaging with an LED pattern projector for accurate skin feature measurements via Fourier transform profilometry”
SPIE Member Andrés Marrugo is an associate professor in the Universidad Tecnológica de Bolivar’s Department of Mechanical and Mechatronics Engineering, where he did his BEng in mechatronics engineering. He received his PhD in optical engineering and his MSc in photonics from the Universitat Politécnica de Catalunya, and was the recipient of the Honours Diploma for Young Researchers from the Spanish Optical Society. His team innovates in optical technologies and develops methods for 2D and 3D image acquisition/analysis for biomedical and industrial applications.

Thanh Duc Nguyen, University of Connecticut (USA)
Paper: “Biodegradable piezoelectric force sensor”
Thanh Duc Nguyen is an assistant professor in the University of Connecticut’s Departments of Mechanical Engineering and Biomedical Engineering. His research is focused on the manufacturing and transformation of biodegradable surgical-suture polymers into special structures with “smart” functions for medical applications. Recently, he invented a platform technology to create 3D microstructures of medical polymers for single-administration vaccines, and developed a novel biodegradable piezoelectric device that can monitor intra-organ pressures and stimulate tissue growth. His work has been published in journals (Science, PNAS) and highlighted in media such as The New York Times, The Guardian, and BBC News.

Jamie Ramsey, Rochester Precision Optics (USA)
Paper: “Experimental verification of a MWIR/LWIR 3x continuous zoom lens”
SPIE Member Jamie Ramsey is an optical designer for Rochester Precision Optics. Her current interests lie in multispectral optics with a focus on achromatization and athermalization, and an emphasis on SWAP-c. Her design experience covers a broad range of commercial and military optical systems in the visible, MWIR, and LWIR wavelength regions. She holds a PhD from Strathclyde University in electrical and electronics engineering specializing in diffractive optics, and an MSc in condensed matter and materials physics from the University of Ottawa. She supports STEM-related education, and volunteers as a reviewer for the Regeneron Science Talent Search.
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 1,600 technical presentations will be given in more than 40 conferences spanning sensors, infrared technology, laser systems, spectral imaging, radar, and lidar.

Is clinical VR ready for primetime?
Albert “Skip” Rizzo, director of medical virtual reality at the Institute for Creative Technologies is going to try to answer that question. Since the mid-1990s, a significant body of scientific literature has evolved regarding the outcomes from the use of clinical virtual reality (VR). The use of VR simulation technology has produced encouraging results when applied to address cognitive, psychological, motor, and functional impairments across a wide range of clinical health conditions. Rizzo will discuss the trajectory of clinical VR over the last 20 years and summarize the basic assets that VR offers for creating clinical applications.

Monolithic is out, mosaic is in

Timothy Grayson, office director of the Strategic Technology Office at DARPA, will present on “Mosaic Warfare,” DARPA’s strategy for conducting joint multidomain battle at speed. Instead of focusing on developing new complex monolithic platforms, mosaic warfare focuses on speed and adaptation. In this concept, the mosaic is comprised of low-cost sensors, command and control nodes, and manned and unmanned systems, which together can create a system that adapts to dynamic threats and environments. Unlike today’s rigid architectures that take decades for the military to develop, mosaic warfare will harness the power of dynamic, coordinated, and highly autonomous composable systems. Grayson will introduce the audience to this concept and discuss both key technology enablers and challenges that will need to be addressed to make it a reality.
Applications, components, and devices

The Thermosense vendor session started 15 years ago and has become a popular and well-attended event. Sixteen vendor presentations will provide an opportunity for exhibitors to highlight their latest technology and products. The session is open to anyone looking for state of the art infrared imagers, radiometric, nonradiometric, and infrared image-processing systems.

The large exhibit will give attendees the opportunity to visit with 380 companies who provide everything from components to displays to advanced sensor systems.

Learn something new

DCS will offer numerous course options (spie.org/DCS19_courses) for continuing education needs, all taught by leading experts—most of them SPIE Fellows. Two courses on the “hot topics” LiDAR for Autonomous Vehicles (SC1232) and Deep Learning Architectures for Defense and Security (SC1215) are filling up quickly, and the two perennially popular courses on electro-optical imaging systems (SC067 and SC154) will again be available.

New courses in emerging technical areas have been added to the DCS course catalogue in 2019 to engage people interested in these growing topics of research:
- Quantum Cryptography (SC1258)
- Blockchain Technologies and Distributed Ledger Systems (SC1266)
- Introduction to Quantum LiDAR and Quantum Radar (SC1267)
- Interpreting Deep Learning Networks (SC1268)

For people working in the photonics industry without a technical or research background, DCS also offers short two-hour crash courses that will help anyone feel more comfortable communicating about photonics technology:
- Basic Optics for Non-Optics Personnel (SC609)
- Infrared Imaging Basics (SC1246)
- Infrared Systems Architecture and Design for Future Market Trends (SC1269)

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Fight Bias, Embrace Diversity

SPIE seeks to cultivate a culture of openness and inclusivity. Help us eradicate bias and make the world of optics and photonics a shining example of all minds coming together to innovate regardless of gender, race, nationality, culture, educational background, politics, sexuality, body type, and age, for the betterment of life.

Educate yourself on the issues faced by a diverse workforce, challenge your own assumptions, and tap into the rich pool of talent, perspectives and ideas offered by people different from you.
Honoring Excellence
Imaging, integrated photonics, and nanospectroscopy spark the work of 2019’s Early Career Achievement Awardees

The SPIE Early Career Achievement Awards recognize young professionals’ significant and innovative technical contributions in the engineering or scientific fields of relevance to SPIE, honoring excellence in academia and industry/government. Receiving the 2019 awards are three of SPIE’s most promising stars.

EARLY CAREER ACHIEVEMENT AWARD – ACADEMIC
Sarah Elizabeth Bohndiek, University of Cambridge (United Kingdom)
For her pioneering work on optical imaging and spectroscopy, enhanced by her use of x-rays, magnetic resonance, and photoacoustics, and for making significant advances in molecular imaging for cancer research.

As a graduate student at University College London, SPIE Member Sarah Elizabeth Bohndiek studied radiation physics, assessing and exploiting the capabilities of the then newly emerging CMOS image sensors for x-ray imaging. She developed new testing methodologies for these nonlinear devices and first presented her findings at SPIE Photonics West 2007. As a postdoctoral fellow at the University of Cambridge and Stanford University, she made major contributions to the field of molecular imaging using nonionizing radiation, including magnetic resonance and optical imaging methods. Today, as a group leader appointed jointly between the Department of Physics and Cancer Research UK Institute in Cambridge, Bohndiek is developing biomedical imaging techniques to improve cancer patient management. She is an SPIE Student Chapter Advisor for the University of Cambridge, actively champions the chapter within the physics department and to local industry, and sponsors lab members to participate in SPIE meetings. For SPIE Photonics Europe 2016, she organized and delivered a Women in Optics event, as well as gave a plenary talk. Her unique perspective, built through training in physics, biochemistry, and radiology, has burnished a reputation as an emerging multidisciplinary research leader in her field.

EARLY CAREER ACHIEVEMENT AWARD – ACADEMIC
Juejun Hu, Massachusetts Institute of Technology (United States)
In recognition of his original contributions to integrated optics and photonics through innovative material and device engineering.

Juejun Hu became an independent investigator in 2010 and has been pioneering novel optical materials and their applications in integrated photonics ever since. His research, which focuses on photonic materials and devices for sensing, photovoltaics, and communications, has already impacted industry: his work on a solution processing of high-index glass optical adhesives method enabled University of...
Illinois and Semprius Inc. to fabricate stacked solar cells with the then-record efficiency of 44%. Currently at MIT, Hu leads the Photonic Materials Group in their work on novel photonic materials such as chalcogenide glasses and phase change materials, while exploring their applications in integrated photonics. Lauded as a scientist who “[thrives] in a problem-rich environment,” Hu’s more than 80 papers and eight US patents have solved major technology roadblocks in communication and sensing. An active SPIE Member, he has also served as a conference session co-organizer at SPIE Photonics West and Defense + Commercial Sensing.

EARLY CAREER ACHIEVEMENT AWARD – GOVERNMENT/INDUSTRY
Mathias Steiner, IBM Research (Brazil)

In recognition for his pioneering and influential contributions to industrial and applied optics, especially the nanometer-scale optical characterization and photonic application of one- and two-dimensional materials.

SPIE Member Mathias Steiner’s success started with his diploma thesis: the development of a Fourier transform imaging spectrometer for remote sensing applications, an industry collaboration for the European Space Agency. His doctoral thesis then combined conceptions from quantum optics, photonics, and molecular spectroscopy to develop an optical cavity that allows for spatially immobilizing molecules within a photonic structure and studying optical coupling on the level of individual emitters and single photons. During a postdoctoral fellowship at the IBM T. J. Watson Research Center, Steiner developed experimental techniques for studying optical properties of one- and two-dimensional nanostructures—including carbon nanotubes and graphene—embedded as functional components in optoelectronic and photonic devices. At Brazil’s IBM Research Lab in 2013, Steiner established an interdisciplinary effort to study the interactions of liquids and solids at the nanometer scale, research with future applications in the recovery of natural resources. Today, Steiner’s team at IBM conducts experimental and computational R&D for industrial-scale applications. As part of his ongoing efforts to strengthen optical science and engineering in Latin America, he has also initiated a collaboration between IBM Research and Brazil’s Federal University of Minas Gerais, focusing on optical nanospectroscopy for industrial applications. ■
Two Decades of Good Will

Rick Trebino wins the 2019 SPIE Maria J. Yzuel Educator Award

What do FROGs, BOAs, TADPOLES, STRIPED FISH, and GRENOUILLE have in common? Answer: They’re all found in the swamp. More specifically, they’re all acronyms for ultrashort-pulse measurement techniques developed and coined by SPIE Fellow Rick Trebino, a physicist at Georgia Tech and owner of Swamp (simply wonderful apparatus for measuring pulses) Optics.

Although the witty acronyms are memorable, Trebino is most well-known for the devices they represent. His career has been devoted to developing devices to measure ultrashort pulses, and he’s widely respected as an expert on the topic; in fact, he wrote the book on it (Frequency Resolved Optical Gating: The Measurement of Ultrashort Laser Pulses, Springer).

Trebino has also made tremendous contributions to undergraduate and graduate education in both optics and physics in the form of freely available slides and lectures on these topics. In recognition of the significance of his contribution, he has been awarded the 2019 SPIE Maria J. Yzuel Educator Award, which is presented in recognition of outstanding contributions to optics education by an SPIE instructor or an educator in the field.

Trebino’s unique sense of humor and clear communication style carry through to his teaching materials, which are colorful, self-contained, filled with detailed illustrations and animations, and include elegant and intuitive mathematical derivations.

“Rick must have invested thousands of hours in the honing of this teaching material over the years, and to give this away as he does for the benefit of the entire optics community is simply remarkable,” says Federico Capasso, SPIE Fellow and Robert L. Wallace Professor of Applied Physics at Harvard University.

All of his teaching material is placed on his website (frog.gatech.edu/talks.html), where he gives it away to anyone who needs it. Professors from all over the world have shared stories about contacting Trebino for permission to use his slides in their courses, and students have reported that Trebino’s lectures are so useful that they often ignore their textbooks altogether. His lectures have been translated into Spanish, French, Chinese, Portuguese, and partially into Arabic.

SPIE Member Mikhail Kats, assistant professor of electrical and computer engineering at University of Wisconsin-Madison, benefitted from Trebino’s open-source teaching materials during his first hectic semester when he was setting up his lab and starting his research program. He found that Trebino’s free material was much better than any other teaching materials he could find. “Rick’s notes are possibly the best free resource for optics education at the undergraduate and early graduate level,” says Kats.

Trebino continues to develop teaching innovations and is currently working on a “next-generation textbook” that will consist of open source and free lectures and slides for use on a tablet or mobile platform.

“The Maria J. Yzuel Educator Award rewards two decades of good will and altruistic contributions to the international optics community by Rick Trebino that have had tremendously positive effects for educators and students alike,” says Anderson Gomes, Universidade Federal of Pernambuco, Brazil. “It is also a springboard for his next project to make next-generation educational material freely available to students worldwide, particularly in the world’s poorer areas, where it is most needed.”

Recognize your colleagues for their contributions to biomedical research, airborne optics, optics education, medical imaging, technology innovation, microlithography, and optical design (and more) by nominating them for SPIE awards.

Award nominations for 2020 are due 1 June.

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

**APRIL**

1-4: SPIE Optics + Optoelectronics in Prague, Czech Republic

2-3: Congressional Visits Day

14-18: SPIE Defense + Commercial Sensing in Baltimore, Maryland, USA

23-26: SPIE Structured Light in Yokohama, Japan

24: Abstracts due for SPIE Laser Damage

**MAY**

1: Abstracts due for SPIE Photomask Technology + EUV Lithography

1: Abstracts due for SPIE/COS Photonics Asia

1: Abstracts due for SPIE Optifab

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

31: Applications due for SPIE Education Outreach Grants

**JUNE**

23-27: SPIE/OSA European Conferences on Biomedical Optics in Munich, Germany

24-27: SPIE Optical Metrology in Munich, Germany

24-27: SPIE Digital Optical Technologies in Munich, Germany

28-4 JULY: 17th International Photodynamic Association World Congress in Cambridge, Massachusetts, USA

**JULY**

7-9: Applied Optics and Photonics China in Beijing, China

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