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Into the Deep

WATER IS THE FOUNDATION OF BIOLOGICAL LIFE. That’s why it was so exciting, in 2019, when two independent teams of astronomers, using Hubble Space Telescope data, observed transiting exoplanet K2-18b with water vapor in its atmosphere. Maybe a little, maybe a lot. Of the thousands of exoplanets observed in recent years, this was the first promising candidate for harboring life.

And yet, even as we send telescopes into deep space to investigate the mysteries of galactic water, there’s a surprising amount we don’t know about our own terrestrial water. Only 20 percent of the oceans have been mapped, and marine biologists estimate that as much as 90 percent of oceanic species are yet to be discovered.

The plants and animals that have been discovered are astounding. See, for example, the giant clam and its unique symbiotic relationship with algal cells, which it farms at high densities, millimeters deep in its mantle tissue in neat, ordered rows. Vast numbers of oceanic species are thought to utilize bioluminescence to attract food, find mates, and evade predators. Others, like the self-evidently named fangtooth fish, have evolved to become “ultra-black;” that is, they completely absorb photons, usually those emitted from predators on the hunt or just-consumed prey.

But just as the Earth’s oceans are a frontier for discovery, they’re also full of untapped resources, including metal-rich layers of ore on the ocean floor known as polymetallic nodules. These nodules contain nickel, cobalt, titanium, tellurium, and yttrium—metals that are hard to mine on land, and yet crucial to a green-energy future. Tellurium is a component in thin-film solar panels, and electric vehicles rely on batteries containing cobalt and nickel. Yttrium is a common element in solid-state lasers used in modern manufacturing, dentistry, and medicine.

There are a lot of these nodules on the seafloor. Tons of them. Enough that several companies have applied for permits to begin mining them at large scale—a process that’s bound to disturb, displace, and even destroy oceanic habitats and species.

The heat is on to learn as much as we can about the oceans. Fiber optic cables that crisscross the ocean floor are ushering in a new era of ocean science that includes measuring earthquakes thousands of miles away. Underwater imaging, first popularized by Jacques Cousteau in the 1950s, has matured into an alliance between scientists and cinematographers to develop underwater imaging instruments with unique requirements for pressure, refraction, and lighting. These modern sensors, along with advanced robotics and unmanned underwater vehicles, may yet reveal unimagined mysteries in the deep.

After all, we never would have known that the fangtooth fish absorbed more than 99 percent of photons if someone hadn’t tried to take a picture of it—with a flash.

GWEN WEERTS, EDITOR-IN-CHIEF
A Scientist’s Guide to Social Media: Twitter

Can you summarize your research findings in less than 200 words? Describe your PhD using nothing but emojis? Dance the “Renegade” while reciting your thesis? While these may not seem like make-or-break skills for an optical engineer or laser scientist, you might be surprised at just how much impact social media can have on your work or research.

Most frequent users will tell you social media will extend your reach more than simply publishing a paper and crossing your fingers.

IN THE SECOND SEGMENT OF OUR SERIES on social media for scientists, we explore the fascinating world of Twitter.

For many, the mention of Twitter elicits anxiety, eye rolling, and cautioned excitement. On the surface level, the popular micro blogging platform has been associated with negative press, trolling, and internet wars. But dive a little deeper, and not only will you find a tight-knit science and technology community, but you will see that the potential for meaningful interactions and powerful conversations is far greater than what appears at the surface.

What Twitter lacks in worldwide users (300 million monthly active users, compared to Facebook’s 2.8 billion and YouTube’s 2 billion), it makes up for in community-building and networking, which are key for engineers and scientists. Mikhail Kats, associate professor at University of Wisconsin-Madison, finds the platform to be “a significant net positive” for his career explaining:

“I think it’s an important space to be in... Almost all professional journal editors are on Twitter, and are happy to openly discuss their editing process, how papers get selected, and other relevant topics. Science writers and journalists are on Twitter; funding agencies tweet their calls for proposals; fellow scientists discuss research. Many students are also on Twitter, and you can learn about challenges they face and concerns they have.”

FROM THE TOP

How do you start connecting with the scientific community on Twitter in a meaningful way?

As with LinkedIn, to build a strong presence on Twitter you first need to craft a bio. Cover the basics—a clear headshot, accurate display name, engaging header photo, research field—but don’t forget to have fun. Unlike LinkedIn, emojis are commonplace on Twitter. Use them to convey your interests: the telescope emoji for astronomical instrumentation, the microscope emoji for microscopy. Unfortunately, there still isn’t a laser emoji.

FINDING FOLLOWERS

Focusing on quality over quantity is important, but on Twitter the more followers you have the better chance your content, such as your latest research publication, will be noticed and retweeted among the community.

One way to find relevant people is by keyword searching. For example, if you are seeking other optical engineers to connect with, type “optical engineer” into the search field, filter by “people,” and find users who list optical engineering as their job or research focus. If you have similar keywords in your bio, odds are those people will want to follow you back.

Another way to amass followers is by tweeting while you attend a science conference. Use the conference hashtag to live-tweet plenary talks, share photos, and talk about your experience. Claire Park, a PhD candidate in medical biophysics at Western University, says, “By initiating dialogue or continuing conversation from hot topics discussed at conferences and meetings, you can gain the latest insights from those with similar research interests.”

TWEET, TWEET

While known for its brevity and ephemeral nature, there are several impactful ways to showcase your research on Twitter. Getting people to “stop the scroll” can be challenging; switching up your format will be an asset in getting your work amplified.
First, you can feature your research in a thread of tweets as Kats suggests: “Screenshot some of the figures, highlight your collaborators and funding agencies (they love to be acknowledged), and explain in simple terms what you did and why.”

Or choose a simpler route: a single tweet with a link to your work, combined with a strategic array of hashtags and tags (@) of coauthors, funding agencies, and institutions.

Research astrophysicist at NASA Goddard Space Flight Center Greg Mosby calls attention to the public engagement element. “You must put your work in context on Twitter—distill it down to the central problems you are trying to address so that anyone can understand. As researchers, this process is valuable. We get clarity and accomplish the goal of sharing our knowledge, and the public can reap the benefits of that knowledge.”

Just like all social media platforms, to be successful you must diversify your feed—don’t just Tweet about yourself. The following post ideas from Kats will help build your reputation as worthy of following.

**HELPFUL TIPS**

- “Did someone you know publish a good paper, or get a new position or award? Congratulate them! Spread some positivity.”
- “Can you make cool scientific animations describing important concepts? These are highly valued online, especially if they clarify things that people are confused about.”
- “Did you teach an interesting concept in a class, or show a demo? Tweet about that. The more schematics, GIFs, and graphics, the more people will want to engage with your post.”

Join conversations with popular hashtags, such as #ScienceTwitter, and offer your advice, opinion, or a story. When you are recognized as an active contributor to the community, you will gain followers who want to hear more from you, thus attracting visibility for your research and achievements.

**BE RESOURCEFUL**

Even if you choose not to use Twitter to network or promote your research, creating an account still has benefits for your career. Twitter is an excellent tool for discovering educational resources, ideas for outreach activities, volunteer and job opportunities, and more. In a recent r/AskAcademia reddit thread, one user comments, “One big plus [of having a Twitter account] is when you need to recruit students. I have a low follower count but my ‘need a PhD student’ tweet got over 15,000 views. Got a lot of quality applicants from that.”

Melissa Skala, investigator at the Morgridge Institute for Research, also finds value outside of posting. “People share their ideas on research questions, best mentoring practices, and career development, so it’s a great way to learn from others. I encourage people to look at #ScienceTwitter—smart people are talking about big ideas, so it really is intellectually enriching.”

Next in the series we cover visual platforms: YouTube, TikTok, and Instagram.

**EMILY POWER is the social media manager for SPIE.**
Ruggedized Optics for Harsh Environments

Industry design processes can protect and ensure smooth functioning of instruments of the lens. Lower optical pointing stability usually results in significant amounts of pixel shift.

Stability ruggedized imaging lenses, like industrial ruggedized imaging lenses, also feature as few complex moving components as possible, but the optical elements within have been glued to the barrel to maintain optical pointing stability and minimize pixel shift.

Ingress protection (IP) ruggedization seals off the internal optical components from liquid and debris intrusion. Movable internal components are extremely susceptible to damage from moisture and solid intrusion.

Industrial ruggedized lenses are designed and manufactured with as few moving parts as possible in order to withstand shock and vibration. For example, standard imaging lenses typically feature an adjustable iris composed of thin metal leaves with ball detents and are used to adjust the overall light throughput in the system by changing the f-number and size of the aperture. Repeated movement of the dynamic mechanics from shock and variation, however small in scale, can cause damage over time and result in part failure. For industrial ruggedized imaging lenses, this iris is replaced with a fixed aperture stop.

While shock and vibration may destroy standard imaging lenses, and industrial ruggedized imaging lenses can withstand these effects, imaging systems that rely on highly accurate, repeatable performance and must maintain sensor calibration may fail in particularly high shock and vibration environments. This is because the lens elements that sit within the inner bore of the barrel of an imaging lens assembly are surrounded by a bore gap of around 10 microns, between the outer diameter of the lens and the inner diameter of the barrel. Though this bore gap is very small, the effects of tip, tilt, and decenter from only a few microns can sum to reduce the optical pointing stability as such, IP lens designs feature the same design reductions as industrial ruggedized lenses. Protection from intrusion is in the form of O-rings and RTV silicone applied to susceptible points within the assembly. In addition, many IP lenses feature hydrophobically coated windows and/or lens elements.

IP is available in varying options and degrees of protection. Products with IP are given ratings which correspond to these. IEC 60529 is the international standard that provides the test conditions for each rating. An IP rating is specified with two characters. The first character tells the user if the product has been tested against solids intrusion and to what degree. The second character tells the user if the product has been tested for intrusion against liquids.

Managing the thermal effects of an optical design must be done at early stages in the design process as adjusting the temperature of the application environment may not be possible. All matter expands or contracts related to the coefficient of thermal expansion and the refractive index of transmissive materials changes related to the temperature coefficient of refractive index as temperature changes. These properties are
empirically determined and reported by material manufacturers. Over narrow temperature ranges and for most standard performance imaging systems, these thermal effects often are negligible. However, for environments with extremely hot, cold, or variable temperatures, for example, space-grade equipment, or for extremely high-performance imaging systems, specially designed athermal imaging lenses are needed.

Athermalized designs fall into two categories. The first is called active athermalization in which lenses are designed to withstand environmental temperatures and not become critically damaged, though the lens may not perform at optimal or even nominal specifications. This type of athermalization may require manual adjustments to focus to find the optimal operating condition.

The second type is passive athermalization, which requires no additional adjusting or compensation for the temperature over the specified working temperature range. The passive athermalization of imaging lenses has long been modeled in raytracing software used in lens design. The simulation has been rather reliable for predicting the focus change and modulation transfer function (MTF) performance, and for a long time was the standard used for verifying the performance over temperature.

In recent years, applications particularly in the automotive industry have pressed the need for tested performance. This has expanded the use of MTF testing over temperature. Testing MTF at temperature is a complex task but has slowly become an available option for validating simulations in raytracing. For actively athermalized lenses where survivability is of greater concern than MTF performance over temperature, simulations have typically been very difficult. However, testing is simple, and it has long been the case that parts get validated by thermal cycling and inspecting for damage. Because of the very tight fits used in many high-performance imaging lenses, cold temperatures can be a real concern for potential damage, as the metal barrels will shrink faster than the glass optics, causing them to compress and possibly fracture.

Ruggedization options for imaging lenses are as numerous as the applications for which they are used. As automation continues to improve, imaging systems will continue to be integrated into harsh or extreme application environments. As such, advances in ruggedization technologies are extremely important and have never been more relevant. The environmental conditions of the application will not only dictate exactly what performance specifications are needed, but also which types of ruggedization are required. Note that thermal compensation in lens design is different to resolve in application, thus thermal effects must be managed at the earliest stages of optical design. Subsequent ruggedization types—industrial, stability, and IP ruggedization—can be factored into the lens design in later phases of the design process.

Kyle Firestone is a technical marketing engineer at Edmund Optics.

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Beyond the Looking Glass: Patenting optical inventions in the world of Alice

IN THE EARLY DAYS OF OPTICS, optical inventions were instruments designed to view an object with the human eye. Whether such instruments could be patented in the US turned mainly on whether they were novel and nonobvious in the eyes of US patent law. There was never a serious question of whether the instrument constituted patentable subject matter since it clearly qualified as a machine under the patent laws.

Nowadays, the typical optical invention incorporates a digital detector and an electronic processor configured to perform digital processing of an image or optical signal. This digital evolution of optical inventions and the legal evolution of US software patents intersect at a 2014 US Supreme Court case Alice Corp. v. CLS Bank International, 573 US 208, known in patent circles simply as “Alice.” Inventors of optical devices should be familiar with the basics of this case in order to avoid patenting pitfalls and optimize their chances of winning intellectual property protection for their work.

Alice involved a portfolio of four software patents directed to computerized, that is, software-based methods of managing the payment of debts through escrow. The validity of these patents was challenged, and the US Supreme Court ruled the patents invalid as being directed to an abstract idea—namely, to the general notion of managing escrow accounts, which had been done previously without computer management.

The Court held that performing abstract ideas on a computer does not transform the abstract idea into one of the available types of patentable subject matter—a machine, a process, an article of manufacture or a composition of matter.

A rephrased version of the Court’s test regarding potentially abstract patent claims is as follows:

If a patent claim appears to be directed to an abstract idea, does it include an inventive concept sufficient to transform the abstract idea into patentable subject matter?

The Court and subsequent lower courts have ruled that the inventive concept needs to be described using meaningful additional features in the claim beyond those words used to establish the underlying abstract idea.

The risk of Alice being invoked for an optical invention depends on where the additional features reside relative to the detector. For simplicity, I refer to three categories of inventions.

A category one invention, where the additional features reside entirely within the optical system, constitutes an all-hardware based optical instrument like those of yore. Consequently, a properly worded claim

...
to a category one optical device invention should not run afoot of Alice.

A category two invention constitutes a mix of hardware and software. In this case, it is important to tie the upstream hardware additional features to the downstream algorithm software additional features and show how they operate to define a new and improved optical device. Here, it can be worth discussing the shortcomings of prior art optical devices in the patent application and explain how the invention overcomes them.

It can also be helpful to draft the category two claim so that it looks more like a hardware invention than a software invention. This can be done by downplaying the downstream additional features, such as by avoiding the use of equations or algorithm-intensive language and instead use descriptive and functional terms. The Alice risk for a category two invention is medium, but can vary based on the balance of upstream and downstream additional features.

A category three invention resides entirely within the algorithm-based software and so presents the highest Alice risk. A category three claim needs to include sufficient additional features of the digital processing steps to properly demonstrate the inventive concept. Many inventors and attorneys fall short here by thinking category three claims can be drafted in nebulous and overbroad terms. Connecting upstream hardware to downstream algorithm steps can help focus the claim and cast the invention as an apparatus. Eschewing mathematical expressions is useful to avoid a knee-jerk Alice rejection.

The description of the invention should include copious algorithm details in case they are needed later during patent examination. That said, the claims of a patent application are what are scrutinized by the US Patent and Trademark Office for patentability, not the description set forth in the specification. Claiming any type of invention too abstractly can elicit an Alice rejection.

Because virtually all modern optical devices employ detectors and algorithm software, there is a risk that Alice may be invoked to declare an optical device invention ineligible subject matter for patenting when at least some of the inventiveness resides in the algorithm software.

Drafting patent claims on an optical device with an appreciation of where the additional features that define the inventive concept reside and how it improves the technology can help avoid an Alice rejection while creating a stronger patent for licensing and enforcement.

JOSEPH E. GORTYCH is an intellectual property attorney specializing in optics, photonics, and imaging technologies at Downs Rachlin & Martin PLLC. He is a Member of SPIE, an OSA Fellow, and author of the book Consider a Spherical Patent: IP and Patenting in Technology Business published by CRC press.

## Industry Updates

### M&A

- Fiberon Technologies, Inc. acquired by Sanwa Denki Kogyo Co., Ltd. for an undisclosed amount effective June 7, 2021.
- Diversified Technical Systems, Inc. acquired by Vishay Precision Group, Inc. for $47M effective June 2, 2021.
- Redflex Holdings Ltd. acquired by Verra Mobility for A$146.1M effective June 18, 2021.
- Kyliya and Muquans acquired by iXblue SAS for an undisclosed amount effective May 20, 2021.
- Zetron, Inc. acquired by CODAN Ltd. for an undisclosed amount effective May 7, 2021.
- Cubic Corp. acquired by Veritas Capital Fund Management, LLC and Evergreen Coast Capital Corp. for $3B effective May 25, 2021.
- MKS Instruments, Inc. to acquire Atotech Deutschland GmbH for $5.1B. Closing date TBA.
- Luminar Technologies, Inc. to acquire OptoGration Inc. for an undisclosed amount. The transaction is expected to close by the end of September 2021.
- Benedetto Vigna to step down as President of the Analog, MEMS and Sensors Group of STMicroelectronics effective August 31, 2021 to become CEO of Ferrari.
- Honeywell Quantum Solutions to merge with Cambridge Quantum Computing Ltd. The merge is expected to be completed in Q3 2021.
- Biosynex Group to acquire Avalun SAS for an undisclosed amount. Closing date TBA.
- Tecan Group Ltd. to acquire Paramit Corp. for $1B. Closing date TBA.
- Excelitas Technologies Corp. to acquire PCO AG for an undisclosed amount. Closing date TBA.

### Executive Updates

- Randall Warnas appointed CEO of Autel Robotics effective June 1, 2021.
- Jennifer Cable appointed president of Thorlabs, Inc. effective June 7, 2021.
- Ryuji Maruyama appointed Chairman & CEO of Toshiba America, Inc. effective July 1, 2021.
- Richard Powell General Manager of Brunson Instrument Co. to retire from the company after 21 years. He will remain until a replacement is found and brought on board.
- Anand Gopalan CEO of Velodyne Lidar, Inc. has stepped from his role effective July 30, 2021. He remains in an advisory role while a replacement is found.
- Christopher Kubasik appointed CEO of L3Harris Technologies, Inc. effective June 30, 2021. He succeeds William Brown who is now Executive Chair of the Board.
**Generating Twin Photons for Quantum Light**

**IT TAKES TWO TO TANGO, AS THE SAYING GOES.** But for photonics computation and simulation, it might be more accurate to say it takes two—photons, that is—to reach entanglement.

Sources of quantum light, in particular correlated photon pairs, are the fundamental resource for these operations. Although such sources have been recently realized using integrated photonics, they offer limited ability to tune the spectral and temporal correlations between generated photons because they rely on a single component, such as a ring resonator.

Now, a research team at University of Maryland's Joint Quantum Institute reports a tunable source of indistinguishable photon pairs using dual-pump spontaneous four-wave mixing in a topological system comprising a two-dimensional array of resonators. They exploited the linear dispersion of the topological edge states to tune the spectral bandwidth and thereby to tune quantum interference between generated photons by tuning the two pump frequencies.

The team says the nature of the formation of the new photons provides the desired quantum characteristics. The photons are quantum mechanically entangled due to the way they were generated as pairs; their combined properties—like the total energy of the pair—are constrained by what the original photons brought into the mix, so observing the property of one instantly reveals the equivalent fact about the other. Until they are observed—that is, detected by the researchers—they don’t exist as two individual particles with distinct quantum states for their frequencies. Rather, they are identical mixtures of possible frequency states called a superposition. The two photons being indistinguishable means they can quantum mechanically interfere with each other.

The research team says their demonstration could lead to on-chip generation of novel quantum states of light where topological phenomena are used for robust manipulations of the photonic mode structure and quantum correlations between photons. Moreover, they say the work could lead to tunable, frequency-multiplexed quantum light sources for photonic quantum technologies.

(K. Mittal et al., Nat. Photon. 2021, doi: 10.1038/s41566-021-00810-1)

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**Faster Fluorescence Microscopy in Live Cells**

**LIGHTING UP LIVING CELLS** with fluorescence microscopy for biological research has two distinct advantages: target specificity and compatibility. Yet there are performance limits. For multitarget imaging, bandpass filters to deal with the broad spectral width of molecular fluorescence accommodate only three to four well-separated channels in the visible range. Meanwhile, imaging fast dynamics in live cells for multiple targets is often impeded by the slow mechanical switching of filter sets.

Now comes spectral imaging, says a team of researchers led by Ke Xu at University of California, Berkeley. They show that by using a standard epifluorescence microscope with a single emission band and a white lamp at about 10 nm resolution, six subcellular targets, labeled by common fluorophores of substantial spectral overlap, can be simultaneously imaged in live cells in the wide field with low crosstalk and high spatiotemporal resolutions. The ability to unmix and quantify different fluorescent species in the same sample via the excitation spectrum enables them to devise fast, quantitative imaging schemes for different modes of fluorescent biosensors in live cells, as well as their multiplexing with multiple additional fluorescent tags.

The authors say their results show the exceptional opportunities excitation spectral microscopy provides for highly multiplexed fluorescence imaging. While the work reported focused on a facile system based on a lamp-operated epifluorescence microscope with a single emission band and a white lamp at about 10 nm resolution, six subcellular targets, labeled by common fluorophores of substantial spectral overlap, can be simultaneously imaged in live cells in the wide field with low crosstalk and high spatiotemporal resolutions. The ability to unmix and quantify different fluorescent species in the same sample via the excitation spectrum enables them to devise fast, quantitative imaging schemes for different modes of fluorescent biosensors in live cells, as well as their multiplexing with multiple additional fluorescent tags.

The work reported focused on a facile system based on a lamp-operated epifluorescence microscope, the fast multifluorophore and quantitative biosensor imaging capabilities they demonstrated should be readily extendable to other systems, including light-sheet fluorescence microscopy and structured illumination microscopy.

**Holograms Help Harness Solar Energy**

**SUMMER SUNSEEKERS WOULD UNDERSTAND.**
Capturing as much sunlight as possible on a surface is critical to efficient harnessing of solar energy. Using holograms, researchers at University of Arizona have developed an innovative technique to capture unused solar energy that falls on solar panels. Their method can reportedly increase the amount of solar energy converted by a solar panel over the course of a year by about five percent.

Solar cells work best when certain colors of sunlight fall on them, and when the whole area is covered by photocells. However, some panel area is needed to connect the cells, and the solar-cell shape may not allow the remaining panel area to collect sunlight, thus decreasing efficiency.

The research team’s holographic light collectors are inserted into the solar panel package where they separate the colors of sunlight and direct them to the solar cells within a panel. The light collectors combine a low-cost holographic optical element with a diffuser. The optical element is situated symmetrically at the center of the photovoltaic module to obtain the maximum effective light collection.

The research team computed the annual energy yield improvement for Tucson, Arizona, using their holographic light collector. They presented a reproducible method for evaluating the power collection efficiency of the light collector as a function of the sun angles at different times of day, in different seasons, and at different geographical locations. The five percent improvement in annual yield of solar energy enabled by their technique could have large impact when scaled to even a small fraction of the hundreds of gigawatts of photovoltaics being installed around the world.


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**One-Direction Light Control**

*NEAR-FIELD LIGHT, LIKE PEOPLE, does better traveling in a single direction. New research that experimentally verifies such highly efficient photonics routing may have applications for integrated optical devices, wireless power transfer, switching, filtering, and more.*

Controlling in one direction the propagation of near-field light, which is invisible light at the subwavelength scale, has been an ongoing challenge in photonics physics. That such control would significantly advance so many applications is also part of the appeal.

Successful efforts to achieve unidirectional control of near-field light have focused on specific interactions between the electric dipole and the magnetic dipole in a system, but this leads to complexities in device design.

In the new work, researchers from China’s Tongji University demonstrated an all-electric scheme able to flexibly control the propagation direction of near-field light. They used hyperbolic metamaterials (HMM), which have the unique ability to control near-field light by enabling subwavelength confinement of electromagnetic waves.

HMM are an important class of artificial anisotropic material with hyperbolic isofrequency contours. Large wave-vector modes in HMM are of particular interest because those modes are easier to integrate and have a smaller loss of energy at transfer. According to the team’s results, selective near-field coupling HMM is enabled by discrete electric dipoles with different phases, which serve as a metasource composed of all-electric components and with a symmetry-associated inner freedom. Their research not only addresses the need for an all-electric experimental design scheme for near-field photonics, but also contributes fundamentally valuable symmetry-based excitation principles.

HEDY LAMARR
From Hollywood glamour to frequency-hopping, a film star’s enduring legacy

By Rebecca Pool

FROM BEGINNING TO END, the life of 1940s Hollywood film star Hedy Lamarr, was extraordinary. She rose to fame in hit movies alongside the likes of Clark Gable and James Stewart, but perhaps less well known was her wartime invention of torpedo guidance based on a phenomenon known as radio frequency-hopping. In fact, Lamarr has been dubbed the “Mother of WiFi” because of the ongoing relevance of her extraordinary scientific work.

Lamarr married six times, had three children, and led the kind of life most people can only imagine. Despite her silver screen stardom and the spectacular legacy her invention left the world of wireless communications, she died quietly in 2000 without any compensation for her engineering efforts.

Lamarr’s daughter Denise Loder-DeLuca says that if her mother had been born at a later time, the outcome would be different. “What my mother achieved is now a triumph, but she didn’t see a penny for it,” Loder-DeLuca says. “Hedy wasn’t business-minded, she was just incredibly creative, and while I’m sure women struggled then, it’s outrageous she wasn’t taken seriously—she was told just go back to being pretty, go back to your movies.”

Born in Austria in November 1914, Hedwig Eva Maria Kiesler was catapulted into the public eye in 1933 when she frolicked naked in Ecstasy, a Czech feature film later denounced by the Pope and Adolf Hitler. A year later, she married Viennese arms merchant, Friedrich Mandl, reportedly Austria’s third richest man. Four years on, she’d left that marriage, but not before sitting in on many a dinner party where, according to Richard Rhodes’ biography, Hedy’s Folly, much discussion on weaponry took place.

On leaving Mandl, Hedy set off for London, where she met Louis B. Mayer of Metro-Goldwin-Mayer (MGM) who was scouting for talent across Europe. He persuaded her to change her name to Hedy Lamarr and introduced her to Hollywood where she swiftly became an acting sensation.

Around this time, she also encountered aviation tycoon Howard Hughes. Recognizing her inventive streak, he lent her two chemists and others so she could develop a Coca Cola tablet to mix with water to replicate the much-loved soda drink at home. The cola tablet didn’t work out, but as Lamarr recounted to Forbes journalist Fleming Meeks, she took the opportunity to suggest that Hughes streamline the design one of his airplane’s square wings to speed up flight. He did.

Crucially, in 1940, Lamarr also met George Anthiel at a party. He was an experimental concert pianist, having composed the incredibly complex Ballet Mecanique, and she was harboring a wealth of fundamental munitions knowledge. Together they devised a secret communications system for ships and torpedoes that they hoped would help defeat Nazi Germany.

At the time, Germany’s U-boats were devastating the Allied forces and evading British torpedoes, which, guided by radio transmission on a single frequency, could be intercepted by enemy forces. To counter this, Lamarr came up with the idea that a radio signal could instead be transmitted over multiple, rapidly changing, or hopping, frequencies, making torpedo jamming much more difficult.

Harnessing frequency hopping to guide torpedoes was all well and good, but those shifting frequencies had to also take place in exact time-synchronization with the radio transmitter guiding the torpedo. Enter Anthiel. The composer had already experimented with synchronizing 16 player pianos using punched tape, and he and Lamarr applied a similar principle to their radio guidance system.

They proposed using a pair of synchronized, perforated rolls, controlled by calibrated clockwork motor drives, to switch the signal between the transmitter and torpedo. These drives could be triggered simultaneously by a locking pin that would release the moment the torpedo was fired.

Working with Caltech’s Professor Samuel Mackeown, Lamarr and Anthiel detailed their invention in US patent 2292387A, which stated, “In a conventional player piano record there may be 88 rows of per-
about time.” In 2014, she was inducted into the National Inventors Hall of Fame for helping to create an early form of wireless communications.

Experts disagree on the significance of Lamarr and Antheil’s scientific contributions. According to Robert Walters, author of *Spread Spectrum: Hedy Lamarr and the Mobile Phone*, “Their idea was good and had some influence on wireless communications... but I think the main thing Lamarr and Antheil have added to the whole boring world of frequency hopping and steering torpedoes is glamour.”

Without doubt, Lamarr and Antheil’s invention was ahead of its time. Anthiel reportedly claimed that their invention’s mechanisms could ‘be fitted inside of dollar watches.’ A patent was granted in 1942, but according to Rhodes, the US Navy simply filed it away, claiming the guidance system was too heavy.

Investigations by Alexandra Dean, writer of the 2017 documentary *Bombshell: The Hedy Lamarr Story*, suggest the Navy wasn’t willing to take the work of an actress and a pianist seriously. According to Dean, the US government seized the patent as the “property of an enemy alien” because Lamarr was Austrian.

Lamarr and Antheil’s idea was revisited in the 1950s, with an electronic version of frequency hopping developed for a sonobuoy, a device dropped from an airplane to detect submarines via sonar and securely transmit that data back to the plane. The concept was also used by the US Navy during the 1962 Cuban Missile Crisis. American ships armed with torpedoes were guided by a frequency-hopping system.

Loder-DeLuca believes her mother was at her brightest when working on her secret communication system. “My mother was tough—she always stuck up for herself, had a spunky attitude, and never felt sorry for herself, but I think her story would be totally different today,” she adds.

Indeed, in 1997, an 84-year-old Lamarr received the American Electronic Frontier Foundation’s Pioneer Award. When notified of the honor, reportedly she said, “Well, it’s about time.” In 2014, she was inducted into the National Inventors Hall of Fame for helping to create an early form of wireless communications.

Experts disagree on the significance of Lamarr and Antheil’s scientific contributions. According to Robert Walters, author of *Spread Spectrum: Hedy Lamarr and the Mobile Phone*, “Their idea was good and had some influence on wireless communications... but I think the main thing Lamarr and Antheil have added to the whole boring world of frequency hopping and steering torpedoes is glamour.”

Glitz or no glitz, Lamarr’s frequency-hopping idea came about during a very different era for women. Markstrom’s colleague, Professor Asta Pellinen-Wannberg of the Swedish Institute of Space Physics, emphasizes that women were not supposed to be both beautiful and clever in the 1940s.

“I also think they [Lamarr and Antheil] had this power—they were not from that [technical] field, so they could look at a problem differently,” Pellinen-Wannberg says. “We see inventions that were made ahead of their time by the wrong people—and I think if Lamarr was born 40 years ago, she would probably be a professor now.”

Lamarr died peacefully on 19 January 2000 in Florida. Towards the end—in the internet era informed in part by Lamarr and Antheil’s ideas—Loder-DeLuca says, her mother hadn’t truly realized the impact her patent had on the world. But it did, and Lamarr’s ideas and concepts live on.

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**LAMARR HAS BEEN DUBBED THE MOTHER OF WiFi**

**BECAUSE OF THE ONGOING RELEVANCE OF HER EXTRAORDINARY SCIENTIFIC WORK**

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*REBECCA POOL is a science and technology journalist based in the UK.*
Art and science go hand in hand when it comes to putting eyes on the underwater world.
Creating immersive underwater cinema can require close encounters with the oceans’ apex predators.

IN THE TITLE OF THEIR CELEBRATED 1956 documentary film, ocean explorer Jacques Cousteau and cinematographer Louis Malle famously dubbed the realm beneath the seas The Silent World. Using phosphorous torches for lighting and an ultra-wide-angle lens, they created an international cinema sensation—one of the first underwater films ever to be shown in living color.

Cousteau, who became a tireless advocate for marine animals and ecosystems, understood that most of what lies beneath the seas—some 80 percent of the world’s oceans, according to the US National Oceanic and Atmospheric Administration (NOAA)—remains unseen by human eyes. His 1960s television series, The Undersea World of Jacques Cousteau, shot from aboard the Calypso, pushed the bounds of new optics and lighting technology to bring a window on Earth’s oceans into the homes of millions of people around the globe.

Today’s filmmakers are no less inspired by the sometimes strange, often captivating beauty of the underwater world. They have an array of imaging technologies to choose from, but like Cousteau, passion and a knack for making things happen also drives their work.
NOAA National Marine Sanctuaries filmmaker Nick Zachar started diving when he was 11 years old and says, “I have been diving ever since.” He studied biology as an undergraduate, but then, after seeing documentaries like BBC’s Blue Planet series, he enrolled in film school.

For a thesis project, Zachar decided to make a film about the underwater world surrounding the tiny island of Saba in the Caribbean. But with little money and a diver's do-it-yourself sense of adventure, “I made it all on a GoPro—fake it till you make it.”

Now, Zachar works with 360-degree virtual reality (VR) cameras to produce NOAA’s 360 degree: Explore the Blue immersive virtual reality films showcasing the US National Marine Sanctuaries. They can be viewed on a PC or a VR headset.

For Cousteau, “making it” came from his close association with another pioneer, Harold “Doc” Edgerton, a professor at Massachusetts Institute of Technology (MIT) whose mid-20th century optics inventions, like the use of powerful strobe lighting, resulted in such iconic photos as a bullet at the instant it tears through a piece of fruit. According to MIT’s online Edgerton memorial and archive, the underwater world, for Doc, held special interest. Indeed, his deep-sea strobe light enabled the first images of the deep ocean and seafloor.

Both artistic creativity and scientific curiosity continue to drive optics and photonics innovations that enlarge our window on the ocean world. Torches have been replaced by LED lighting—if lighting is even needed by some of today’s professional video cameras from Sony, RED, and other manufacturers, that record with high fidelity in even very low-light conditions.

And from TV and movie screens, directors and cinematographers now hope to bring viewers new immersive and VR experiences via technology like multicamera arrays for 360-degree filming underwater.

Scientists have graduated from simple still and video cameras locked in underwater housings, to optics innovations like laser line scan underwater imaging, robots that can track and film elusive creatures in the mid-ocean twilight zone, and handheld or fixed underwater microscopes to image plankton and other animals in the water column where they live, to name just a few.

“Science probably leads the technology,” says Evan Kovacs, an underwater cinematographer and CEO of Marine Imaging Technologies, who began his professional life as a lighting designer for “Jazz at Lincoln Center” in New York City. Today, his long list of daring underwater film projects includes both 2D and 3D imaging of iconic deep-water shipwrecks, the Titanic and her sister ship, the Britannic.

His work has shown him that “Usually science has a question,” Kovacs says, “and so okay, how can we solve it via imaging?” Once the scientific community comes up with a way to capture the type and
A VRTUL 360-degree camera system by Casey Sapp.

Cinematographer and 360-degree camera inventor Casey Sapp says his company, VRTUL (Virtual Reality Technology Underwater Limited), “specializes in prototypes that are purpose built for VR headsets and large-format screens.” When asked to create images of hundreds of millions of pixels at 60 frames-per-second, he says, “there’s no [off-the-shelf] camera that shoots at that. We buy cameras and then build software and pipelines to reach what’s available and make it work.”

Working at the cross section of cinema and science, Sapp’s inventions include the first 360-degree 3D underwater camera system; the first remotely operated vehicle/VR piloting system in partnership with the Monterey Bay Aquarium Research Institute; the first 360-degree cinematic camera on a submarine; and, he says, in 2019, the highest resolution underwater cinematic camera system in the world.

It’s a high-stakes game to shoot immersive film productions that are unique in every way, Sapp says. Diving has inherent dangers, while expensive cameras, lights, and other equipment add to the risk. He says the nature of his projects—which require specialized software to stitch together images from multiple cameras and make it all look seamless—rest on big budgets and narrow windows of opportunity to get the shot.

But he also describes the reward: images he will share with the world of baby humpback whales as they are birthed in the waters off Tonga in the South Pacific, for example, or great white sharks on patrol in the ocean near Guadalupe Island in Mexico.

However sublime the experience, shooting still or motion pictures in the world’s oceans—whether for Hollywood hits or scientific expeditions to hydrothermal vents—requires an understanding of key differences with the surface world, says Stan Logan of Deepsea Power & Light. He notes a substantial divide between shallow- and deep-water photography.

“The dive market is the largest user of underwater lighting and filming, and that goes back to the 1960s and 70s, in particular with James Bond,” Logan says. “The technical challenges of course are much simpler at diver depths of 100 feet where lighting is also less of a problem.”

However, in deep-ocean imaging, every piece of equipment must be able to withstand high pressure and account for the way light behaves underwater.

Water has a higher refractive index than air—it bends the light more. As such, filmmakers must make careful equipment choices, such as camera-housing dome ports that allow rays of light to enter camera lenses unrefracted, eliminating upper limits on the field of view, versus flat ports, which narrow the field of view and make the image appear magnified.

Water absorbs wavelengths of light, with long wavelengths the first to go—red, orange, yellow. In fact, colors disappear with depth in the same order as the spectrum. Lighting a scene underwater can bring the color back, though marine biologists now recognize that artificial light can drive some animals away while attracting others by providing a spotlight on prey.

In the 20th century, two major technical advances propelled underwater imaging, says oceanographer Jules S. Jaffe of the Scripps Institution of Oceanography and University of California, San Diego. First was the development of the film camera, and then the Aqua-Lung, Cousteau’s invention with Émile Gagnon, that gave rise to scuba diving as a popular sport.

A new revolution in underwater optical imaging began in the mid-1980s. Jaffe cites, for example, the towed sled, ARGO, developed by Robert Ballard at Woods Hole Oceanographic Institution (WHOI).
Ballard and his crew watched in real time as video cameras sent live images via cable of the discovery of the Titanic. Today, interested people can join Ballard virtually on a deep-sea marine science expedition which includes live video feeds from the seafloor.

Jaffe’s own research has been part of the revolution, attesting to his interest in using new technology to observe ocean phenomena. Or, as he puts it, “optics in service to global ecology.” He is inventor or coinventor of instruments such as the benthic underwater microscope (BUM), a diver-deployed imaging system capable of near-micrometer resolution. Jaffe describes the device’s three principle optical components: a long working distance microscope objective lens, a shape-changing electrically tunable lens, and focused LEDs to provide reflectance illumination.

Recording images with up to 2.2 µm resolution, the BUM can capture images of fine anatomical details, like dinoflagellates or zooxanthellae living symbiotically inside coral. Jaffe and his team used it to examine various levels of coral bleaching—which is really expulsion of the zooxanthellae. The instrument, he says, is handheld, or it can be left in place for autonomous time-sequence imaging, the only constraints being battery life and biofouling.

“They get all schmutzed up,” Jaffe says of the gunk that builds up on the instrument.

The importance of imaging these fine details is “an intrinsic need to more fully characterize small marine organisms with small microscopes,” Jaffe continues. For example, his lab has supported or codeveloped instruments like the in-situ plankton assemblage explorer, an inexpensive underwater imaging system to study zooplankton, as well as a video velocimeter that uses a particle image correlation technique to reconstruct underwater bulk flow velocity—an important measurement, since ocean currents determine the fate of many marine organisms.

Visual information from such instruments, Jaffe says, can aid understanding of larger scale ecological processes and events like coral bleaching and algal blooms.

He sees a role for AI in helping to process the rich visual data stream captured by today’s optics technologies.

ALAN ADAMS, a former MIT physics professor and string theorist, now ocean-optics designer, says oceanography as a discipline needs to step back from its historic reliance on highly specialized, one-of-a-kind imaging and exploration devices and perhaps embrace mass production.

Adams says researchers see a growing need to have many cameras—mass-produced cameras—that would provide, for example, very wide-area monitoring of changing coastlines, ecological restoration projects, or to keep a close eye on aquaculture operations.

The needs of science and commerce, Adams says, should be strong incentives to build mass-produced camera systems.

“There’s so many reasons that we need good cameras underwater and the problem is not that we’re too stuck to do it properly,” he says. “You must start with the assumption that you’re going to build hundreds of thousands of cameras. And then it’s possible to build a device that really ought to be built.”

For other ocean researchers, there is a need for instruments that fall somewhere between the extremes of microscopes and minisubs. That’s especially true of the twilight zone of the world’s oceans—anywhere from 200- to 1,000-meters deep. Marine scientists say it’s an area teeming with life—a vast biomass of giant larvaceans,
Helmet jellyfish (*Periphylla periphylla*) can be damaged by the Sun’s rays and so have a sensory organ that lets them know when to retreat to darker waters, left; Glass squid (*Cranchia scabra*) born in light-filled surface waters are fully grown at four months and ready for life in the much deeper waters of the ocean twilight zone, right.

Many innovative underwater imaging devices, like the benthic underwater microscope, shown here, have been developed in Jules Jaffe’s lab at the Scripps Institution of Oceanography.

Dinner-plate size jellyfish, krill, zooplankton, and more. These animals, probably some of the most surreal lifeforms on Earth, are thought to move up and down in the water column, rising to feed at night near surface waters, then submerging with daylight to evade predation.

“By scuba diving, we could make the kind of behavior observations and collections that were hard to do other ways,” says marine biologist and twilight zone expert, Laurence Madin. “That was all great, but eventually your air ran out and you had to go back up and you lost track of whatever you were looking at,” the former WHOI deputy director and vice president for research recalls telling his friend, WHOI robotics expert Dana Yoerger.

“I said, it’d be great if there was some kind of machine that would either carry on past the time when the diver’s air ran out, or better yet, go ahead and go deeper,” Madin recalls.

Yoerger continues the story, “And so Larry asked me, he said, Dana, can you make me a robot that can show me what I missed when I ran out of air?” Yoerger laughs. “And that started the whole project. I said, oh yeah, we can make a robot, it can even follow the animals around.”

Enter Mesobot, a new-this-year autonomous underwater vehicle developed at WHOI with primary funding from the US National Science Foundation.

Yoerger and colleagues seemingly thought of everything. Lights used on Mesobot are in red or infrared wavelengths to which deep sea animals have minimal sensitivity. Its thrusters are designed to minimize noise and water disturbances, and the vehicle has an overall unobtrusive profile that maybe doesn’t quite fit in with the locals, but on test runs they don’t seem to mind, either.

And, as Yoerger promised, Mesobot can, indeed, find and track target animals with low-res stereoscopic cameras and, for scientific imaging, a high-res cinema-quality video camera.

“Now, you could go for something really seriously sensitive,” says Adams, who consulted with Yoerger on Mesobot, “but that fails the beautiful image problem, because you’re not just interested in science, you’re also interested in making beautiful, compelling, powerful images that communicate the science.”

WILLIAM G. SCHULZ is managing editor of Photonics Focus and a PADI Open Water Scuba Instructor.

Mesobot, a new-this-year autonomous underwater vehicle developed by the Woods Hole Oceanographic Institution.

Read a transcript of Jacques Cousteau’s 1968 plenary talk at the SPIE conference on Underwater Photo-Optical Instrumentation Applications.
By Bob Whitby

Photo credit: S. Rossbach
Giant clams are recognizable by their iridescent purple and blue lips.

Unique animal-plant symbiosis inspires innovators in solar cell and optical wireless communications

ONE OF THE FIRST THINGS YOU DO when you are an adorable giant-clam larva floating in sun-blasted shallows around the western Pacific or the Red Sea is to capture and store within your tiny Troidaeidae self a couple of the Symbiodinium algal cells floating throughout your habitat. You may be no larger than a dust speck, but you now have the symbiotic partners you need to drop to the ocean bed, find a good place to stick yourself, and grow into a giant clam. You could end up living longer than a century, spanning four feet in length, and weighing as much as 500 pounds.

That’s plenty of molluscan wow to ensnare a marine biologist’s attention, but it’s the giant clams’ voluptuous blue and purple iridescent lips that Alison Sweeney, a professor of physics and of ecology and evolutionary biology at Yale University, could not resist. That was close to a decade ago when, as a postdoc at the University of California, Santa Barbara (UCSB), she went to Palau, an archipelago in Micronesia, to study iridescence in sea creatures.

Since then, she and other giant clam biologists have helped unveil just how elegant natural photonics technology can get and how, in the case of giant clam/algae symbioses, it appears to be central to the performance of one of the most efficient photosynthetic systems on the planet. What’s more, as the biologists have been teasing out more of the clams’ biophotonic wonders, engineering-minded collaborators have been adapting lessons from the clam biophotonics to high-tech applications, among them solar cells and optical wireless communication.
Sweeney is happy her work is inspiring technology developers, but it's the light-mediated symbiosis of the clams and their algal partners that widens her eyes the most. She thinks of the giant clams as algae farmers. As a clam larva matures into an adult and giant status (when it's the size of praying hands), it domesticates photosynthetic *Symbiodinium* cells on industrial scales. "It grows the one or two or three algae cells it scoops up early on into this dense monoculture array within its skin," Sweeney says. "It grows the algae cells at much higher densities than otherwise would happen for the algae [in the open ocean]. And the clam takes care of them just like a farmer by building a biophotonic infrastructure that provides them with a goldilocks amount of light to make photosynthesis run at an optimum rate and efficiency."

Biophysicist Amanda Holt, a Yale colleague of Sweeney's, calculates that mature giant clams harbor some 100 million algal cells per cubic centimeter of mantle tissue, which is the often brilliantly colorful tissue lining the clam's two fluted shell halves. These algae reside in pillared arrangements—like dense rows of soybeans, Sweeney points out—that penetrate several millimeters into the mantle. At those depths, the algae shouldn't be able to efficiently photosynthesize. They shouldn't be able to produce the glycerol, glucose, and other molecules the clam needs to live—unless there is some way of shunting sunlight arriving at the mantle surface to even the deepest algal cells.

This is where the clam biophotonics story comes in. In a 2014 paper in the *Journal of the Royal Society Interface*, Sweeny, her USCB research supervisor, Dan Morse, Holt, and colleagues from NASA Ames Research Center and the University of Pennsylvania (U. Penn.) described how the star of the biophotonics show is a cleverly organized population of light-manipulating cells known as iridocytes. The same type of cell that confers iridescence in squid dye, they reside in the top millimeter or so of giant clam mantle tissue. "It is a solar panel that, instead of making electricity, makes energy rich molecules by shunting sunlight to hundreds of millions of symbiotic algal cells," Sweeney says.

Also found in squid, octopus, hatchetfish, and other sea creatures, iridocytes are loaded with stacked layers of photon-engaging proteins. Like Bragg filters made of a grid of tightly spaced lines, these stacked layers do wonders with light. Using light-measuring probes that Holt developed in her garage, the researchers managed to gather and measure the intensity and wavelengths of light at different depths of mantle tissue. The researchers observed that the iridocytes scatter photosynthetically productive light sideways and downward such that it illuminates the entire length of the algal pillars. Meanwhile, the Bragg-mirror structures dominating each iridocyte's volume back-reflects otherwise damaging ultraviolet (UV) light away from the clam and algal symbionts. That's also where the alluring lip colors come from.

Using a double-probe technique, they have measured photosynthetic efficiency at varying depths in the clams' tissue. One probe flashes controllable wavelengths and intensities of blue light into the algal pillars, while the other probe measures light that emerges from the same hyperlocal neighborhoods of tissue. In this protocol, Sweeney explains, "the more red fluorescence there is, the more the light is going to nonphotosynthetic pathways. The less fluorescence there is, the more efficient is the photosynthesis." Sweeney has been stunned by just how little red light emerges. As she sees it, the dimness of this red output could mean the photosynthesis of the clam/algae tag team is as good as any photosynthesis happening anywhere on the planet.

Ecologist Susann Rossbach, working with colleagues at the King Abdullah University of Science and Technology (KAUST) in Saudi Arabia, also took a deep dive into giant clam iridocytes. With poetic flare, in a paper published last year in *Frontiers*
Giant clams harbor some 100 million algal cells per cubic centimeter of mantle tissue. They reside in pillared arrangements (left) and with light manipulating cells known as iridocytes (right).

of Marine Science, they describe the iridocytes as mediating “photonic cooperation between giant clams and their photosynthetic symbionts.”

Rossbach points out where she thinks her team has added to the biophotonics story Sweeney and her colleagues already have uncovered: “Our observations indicate that, in addition to the backscattering of nonproductive wavelengths, iridocytes of giant clams are also able to absorb ultraviolet radiation and re-emit it, shifted toward longer wavelengths.” Those re-emissions, Rossbach suggests, in turn can drive up photosynthesis in the algal symbiont cells yet more.

The KAUST group’s work began in earnest on 29 August 2018, when Rossbach and coworker Silvia Arossa collected two giant clams on the Abu Shosha reef in the Red Sea, which is not far from the KAUST campus. Sweeney started her work with a pair of clams that she harvested herself. The team then made absorbance and photoluminescence measurements by shining excitatory pulses of light into successive paper-thin regions of mantle tissue and measuring the spectrum of light that emerged. The researchers observed spectral shifts of the 325-nm stimulus light toward less dangerous and potentially more photosynthetically useful wavelengths ranging between 365 and 550 nm.

Sweeney and Holt note that there are many molecules in giant clam tissue capable of causing spectral shifts. As such, they caution that the spectral shifts Rossbach’s team has observed do not necessarily mean they play a specific biological role of contributing to the photosynthetic efficiency of Symbiodinium cells.

Regardless of the uncertainty, Sweeney and Rossbach concur that the algal symbionts’ photosynthetic efficiency would be impossible without the photonic assistance of the iridocytes. Same goes for the photonic protection against damaging and photosynthesis-thwarting UV radiation (UVR). These benefits, among others, are what enable giant clams to thrive in relatively shallow water where UVR would otherwise be debilitating, Rossbach says.

Probing yet further into the basis of the iridocytes’ photonic traits, the KAUST group zeroed in on the signature multilayered stacks within the iridocyte cells. Previous research has indicated that these stacks are made of platelets of protein and crystallized guanine (one of DNA’s four nucleotide bases) alternating with sheets of cytoplasm. Based on spectral-shift measurement with pure crystallized guanine, the KAUST team argues that the intracellular guanine crystals serve as the basis of the “photonic cooperation between the bivalve host and their photosynthetic symbionts.”

Although the full account of the biophotonic properties underlying the symbiosis of Tridacnidae clams and Symbiodinium algae is yet to be revealed, the story in hand already has compelled engineering-minded investigators to steal what they can in pursuit of new technologies.

Under a recently completed US National Science Foundation (NSF) Inspire Award, which supports interdisciplinary collaborations, Sweeney joined forces with U. Penn materials scientist Shu Yang. With an eye on emulating clam iridocytes’ ability to forward-scatter sunlight, Yang’s lab synthesized artificial iridocytes as a means of redistributing light energy on micrometer and millimeter scales. Their specific tack was to synthesize nanoscale silica particles and pack them into gelatin microspheres.

The artificial iridocytes “show wavelength selectivity, depending on the size of the nanoparticles, had little loss, and a narrow forward-scattering cone, similar to that seen in giant clams,” Sweeney and Shu write in a report to NSF. They add, “The Yang lab
created a variety of bioinspired microparticles utilizing energy-downhill mechanisms seen in cells and assembled light-responsive nanoparticles that demonstrated photothermal effect and solar transparency, which could potentially be applied to improve solar-cell performance.” The duo also outline the potential of using the synthetic iridocyte structures, and their tunable photonics properties, to tailor the transparency and thermal insulation of windows.

In parallel, Rossbach and her biology colleagues at KAUST teamed with technology developers in the university’s photonics laboratory who took a stab at applying giant clam biophotonic manipulations to the cause of optical wireless communication. Reporting in *Optical Materials Express*, the researchers peg their interest on the intensifying need for high-capacity optical communication links as the Internet of Things undergoes explosive growth. The iridocytes’ natural ability to manipulate light, including UV wavelengths, is tantalizing to the researchers because the higher-frequency light can accommodate high-bandwidth optical communications and data transfer.

In the same paper, an interdisciplinary team of 14 KAUST researchers, including Rossbach but led by Boon Ooi of the photonics laboratory and biologist Carlos Duarte, report a series of optical measurements using iridocytes embedded in mantle tissue of Red Sea giant clams. Based on the data, they say, iridocytes could be used “as a high-speed color converter for mid-deep UV photodetection, well-suited to application in mid-deep UV optical wireless communication.”

Researchers want to know more about giant clams iridocyte cells and their natural ability to manipulate light.
Iridocyte cells mediate photonic cooperation between giant clams and their photosynthetic symbionts.

The iridocytes’ biologically useful property of down-converting ultraviolet solar photons to lower-frequency photons could point a way toward clam-inspired optical components, Ooi and his team say. The iridocytes, or artificial photonic structures based on them, could both detect high-frequency ultraviolet signals and then convert them into visible wavelengths for which silicon photodetectors are especially responsive. So, the Ooi team says, combining iridocyte-inspired UV photodetection with silicon-based optical components could provide a novel approach to designing optical communication systems for Internet-of-Things devices, among them wearable health monitors and wireless inventory trackers.

A key finding by the Kaust team was that the iridocytes have short photoluminescence decay times of about a nanosecond. That, in turn, enabled the team to show that the cells can modulate light from UV LEDs with a 22 MHz bandwidth, which Rossbach explains could translate into data-transmission rates of tens of megabits per second.

“Our colleagues are now trying to either extract pure iridocytes from the mantle tissue or artificially synthesize such materials, which would be a first step toward an optimization strategy,” says Rossbach, who recently became environmental chemical science manager with the Red Sea Development Co.

Pleased as she is by the possibility that the evolving story of giant clam biophotonics could lead to new technologies, Sweeney says she is most wowed by how the more she and her scientific partners learn about the clam’s photosymbiotic system, the more efficient the algal photosynthesis seems to be.

“Clams are way better than soybeans. They are even better than Iowa corn, and that is saying a lot. They are on par with spruce forests, which are very efficient,” Sweeney says. “As far as we can tell,” Sweeney says of giant clam mantle, “this small bit of tissue might be the most photosynthetically productive ecosystem on Earth.”

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IVAN AMATO is a writer, podcaster, and crystal photomicrographer based in Hyattsville, Maryland.
BEYOND TELECOMMUNICATIONS
Subsea Fiber Optic Cables Now Enable Deep-Ocean Science

By Mara Johnson-Groh
WHAT GOES ON IN THE OCEAN is largely a mystery. An estimated 91 percent of oceanic species are yet to be discovered and only 20 percent of the ocean floor has been mapped.

Part of the reason is that sending instruments into the deep is expensive and difficult. For example, crewed submersibles can cost tens of thousands of dollars a day to operate. As a result, oceanic expeditions are typically feasible only for short durations, leaving gaps in scientists’ knowledge of rare events and long-term processes.

“Seventy percent of the Earth’s surface essentially is unmonitored,” says Giuseppe Marra, a frequency metrologist at the National Physical Laboratory (NPL) in the United Kingdom. “There is a huge lack of data.”

But that’s starting to change as increasingly sophisticated photonics technology reaches the seafloor. Today, there is a network of more than one million submerged kilometers of fiber optic cables crisscrossing the world’s oceans, pulsing with light as data is passed from one continent to another. First laid for telecommunications, fiber optic cables are now also finding expanded use by oceanographers. From measuring earthquakes to monitoring climate change, fiber optic cables are ushering in a new era of ocean science.

Oceans “basically govern the health of our planet,” says Deborah Kelley, a marine geologist at the University of Washington. Along with new power systems, “Fiber optic cables are really transforming how we do oceanography.”

Fiber optic cables were first placed along the ocean floor in 1988. They added to the bundles of telecommunications cables already stretching across the deep, dating back to the first transatlantic cables installed in the late 1850s. With those cables, the first transatlantic message sent by England’s Queen Victoria took 16 hours to transmit. Today, fiber optic cables allow messages to pass at nearly the speed of light, crossing the Atlantic in milliseconds.

While we typically think of transcontinental data being sent to the cloud, it’s actually passing through the ocean. In 2015, an estimated 99 percent of data sent between continents was transferred through submarine fiber optic cables. Though more and more investors are exploring satellite constellations for data communications, oceanic fiber optic cables remain the fastest and cheapest way to send information. Even still, laying new oceanic fiber-optic cables can cost hundreds of millions of dollars. Telecommunications companies have historically banded together to split the costs, but today a handful of tech giants like Google, Microsoft, Facebook, and Amazon own or are building their own networks.

Similarly, ocean scientists have come together to build their own networks. Deborah Kelley is one such marine geologist. She is director of the US National Science Foundation’s (NSF) Ocean Observatories Initiative Regional Cabled Array, a network of scientific instruments linked by 900 km of fiber optic cables, situated off the coast of Oregon in the US.

The NSF array hosts 150 scientific instruments—such as chemical sensors, hydrophones, thermometers, fluorometers, current meters, and digital cameras—that measure geologic, chemical, and biologic properties in the ocean. The backbone of the array is fiber optic cables, which transfer the collected data to shore. A copper lining in the cabling pulses with 10,000 volts to power all the instruments.

Through an internet platform, the data from the scientific instruments are almost instantly available to anyone with an internet connection. Thanks to 24/7 monitoring provided by fiber optic cables, that amounts to more than a terabyte of data every day.
It’s kind of like getting your first satellite in space,” Kelley says. The array “gives us new insights into the ocean.”

The array proved its usefulness early on in 2015 when several instruments in the array, including pressure recorders, captured a massive eruption of the Axial Seamount, a submerged active volcano 300 miles off the coast of Oregon. The event dropped the sea floor seven feet and created a 400-foot-thick lava flow. With 70 percent of volcanism on Earth occurring in oceans, this data helps scientists understand the mechanism behind subsea eruptions and gas explosions.

“The emergence of both fiber optic cables and the internet really allowed these types of measurements to emerge and provide much more powerful technologies than we had before,” Kelley says.

Before fiber optics, oceanographic research instruments, like those in the Regional Cabled Array, had to rely on battery power, which resulted in limited observations and data gaps. Today, some instruments in the network can make more than 200 measurements per second, all of which is streamed in real time via fiber optic cables and made publicly available on the internet. This data can now be used to answer questions, such as how microbial communities on deep sea vents change over time, that could not previously be studied.

“You can be sitting in your living room and watch one of the most extreme environments on Earth with really incredible, amazing animals, seeing how they move around over time,” Kelley says.

In addition to permanent subsea cables, fiber optic cables are being dropped into the ocean to provide live data transmissions from submersibles. However, it’s a complicated endeavor. Load-bearing fiber optic cables can weigh several pounds per foot and sending a fiber optic-connected submarine instrument down to the ocean floor requires industrial scale boats and winches.

“If you want to go 4,000 meters deep in the ocean, you’re looking at [a winch] the size of a dump truck to run it,” said Brennan Phillips, an ocean engineer at the University of Rhode Island.

Phillips started brainstorming ways to make lighter cables that could transmit live data and was inspired by one of his pastimes—fishing. Working with Nautilus Defence, an engineering consultancy, Phillips and his colleagues redesigned a flexible braided fishing line to house a strand of fiber optic cable threaded through the center. The braided design of the line allows the system to support the weight of an instrument yet remain lightweight. Instead of an industrial winch, the new ultralight system can be easily deployed and retrieved with a standard fishing reel.

“What that means is I can use really small boats to do my work. And I can go fly somewhere else, where I might be doing my research, with a suitcase essentially,” Phillips says. “It opens up all kinds of operational modes that weren’t available beforehand. And it’s just a lot of fun.”

Phillips has tested the line in the waters of Rhode Island’s Narragansett Bay in the US, where it enabled live-streamed video of fish, shrimp, and anemones from the ocean floor. In Bermuda, the reel worked down to a tested depth of 780 m, though he’s created enough line to reach twice that distance.

As well as connecting scientific instruments, the new line can also be an instrument itself. Fiber optic cables are affected by environmental strains—due to factors like changes in pressure and temperature in their surroundings. These strains add noise and degrade signal strength, so scientists have worked to minimize and remove these effects. But in recent years, scientists have realized that those noises can be seen as signals.

In his work as a frequency metrologist, NPL’s Giuseppe Marra tests the timing and frequency of atomic clocks. In 2016, he was testing fiber optic cable linking atomic clocks in England when he noticed an unusual signal. Often environmental vibrations, including local traffic, cause noise signals in data, but this one was different.

Marra eventually pinned the noise to earthquakes that occurred 1,400 km away in central Italy. He was struck by the realization that the noise previously perceived as an annoyance could be a useful signal.

Seismometers have detected earthquakes for centuries, but their use in the oceans is still highly limited by the expense of ocean bottom sensors. Marra realized that hundreds of thousands of existing fiber optic cables could be used as oceanic seismometers.

“You have the possibility of turning the existing submarine telecommunication infrastructure into a giant detector for underwater earthquakes and seismology in general,” Marra says.

The technique works by turning submarine networks into giant interferometers. Using an instrument connected to a cable on land, a laser pulse is sent down a fiber optic cable line. If there is an earthquake along the cable line, it will put a strain on the cables, causing a disturbance in the signal. When the light pulse loops back, this effect can be seen as a phase change when
compared to a laser signal that remained locally on land. One such measurement can identify a line where the earthquake may have occurred, and measurements from multiple cables can be used to triangulate its epicenter.

With a million-plus-kilometer-long network of fiber optic cables already in the oceans, implementing this technique could massively expand earthquake monitoring worldwide. The technology needed for these fiber optic sensors is relatively straightforward. Only a few dedicated hardware pieces on land and some spare bandwidth are required.

In addition to interferometric sensing, other groups are similarly using fiber optics with a technique called distributed acoustic sensing. This method works in a similar manner by looking for changes in light signals caused by strain to the fiber optic cables. But instead of looking for returned signals, it probes backscattered signals.

Fibers in cabling are designed to be perfect so that they can transmit light with the highest efficiency. But as with any manufacturing, there are always small imperfections and in fiber optic cables, these imperfections cause light to be scattered backwards by Rayleigh backscattering. Looking for changes in this backscattered light, scientists can pinpoint locations where the fibers have been strained—such as by earthquakes.

Developed by the gas and oil industry as a monitoring system, distributed acoustic sensing is showing promise in measuring a wide range of environmental disturbances in the ocean, from earthquakes to swells and currents. Already, scientists have used it to sense earthquakes in California, Iceland, and Alaska.

A similar technique called distributed temperature sensing, which uses Raman backscattering, can even probe strains on fiber optic cables caused by changes in temperature. Phillips is hoping to use this technique with his fiber optic fishing line since the permeable design exposes the fibers to the ocean water.

“The systems I have in the lab are able to sense a 10-kilometer-long fiber optic line for temperature every quarter meter,” Phillips says. “That’s 40,000 temperature sensors.”

Because a backscattered signal is inherently weak, distributed acoustic sensing can only probe out about 50 km offshore, though some think that could be extended up to 100 km. In comparison, disturbance sensing using interferometry has almost no limits. Early in 2021, a group of researchers at the California Institute of Technology and Google found multiple earthquakes and pressure changes due to ocean swells along a cable stretching 10,000 km from Los Angeles, California, to Valparaiso, Chile.

In the study, the scientists detected the earthquakes by measuring shifts in the polarization of light sent through the cables instead of phase changes. While polarization measurements aren’t as sensitive as phase measurements, they are regularly collected by modern systems, which makes implementation much easier in the short term while hardware for phase measurements improves.

In addition to enabling scientific advances in oceanography, these fiber optic detection techniques could also provide advanced tsunami warnings. With ongoing monitoring, it could provide coastal residents advance warning of tens of minutes—instead of just a few minutes with current systems.

Current applications with fiber optic sensing seem unlimited. Temperature and ocean swell monitoring could aid climate change studies, geologic indicators could provide insights into understanding Earth’s interior, and even whale migrations could be monitored with fiber optic cables.

“I think these techniques can really be revolutionary,” Marra says. “And we’re working hard to prove that.”

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

Action-at-a-distance is a concept deeply embedded in physics, as indeed it has been since the earliest scientific accounts of magnetism. The later emergence of a more comprehensive science of electrodynamics laid to rest, finally, any idea that vision itself could require tangible interaction between an object and the eye of the beholder—contrary to arguments once advocated by ancient Greek schools of philosophy.

Strangely enough, the most consistent modern understanding of seemingly noncontact interaction has echoes of those earlier notions. Particles, even though massless, are indeed at work between observer and the observed. And just as vision requires the propagation of light in the form of photons, so too, we now understand the forces that operate over nanoscale distances to be mediated by so-called virtual photons—those not directly observed. As Feynman, Casimir, and others have shown, the forces between electrical charges, and even between electrically neutral bodies, are mediated by these virtual particles.

Of course, as a descriptor the word virtual now finds many more applications. In optics and photonics, virtual reality, along with augmented and mediated reality, are at the cutting edge of transformative technologies as witnessed by the spectacular growth of these subjects at SPIE conferences. But the past 18 months have accelerated other connotations, as virtual or digital meetings have sustained society connections at every level, from one-to-one videocalls between friends and family members, to the highly sophisticated teleconferencing platforms deployed for scientific meetings.

The challenges of lockdowns and restrictions, imposed on us all in times of global pandemic, have resurfaced the landscape of human connections. Harnessing modern IT and communication channels, ingenious new ways have been found for scientific symposia and meetings to stay alive. In-house expertise has put SPIE at the forefront of innovations for hosting high-quality meetings, and the experience gained will assuredly be a legacy that informs future events. And yet, the very term virtual reminds us that even our finest digital symposia lack direct human contact.

Sociologists and mental health experts increasingly emphasize just how much we need direct contact with one another. Most of us also know that in-person contacts, either planned or serendipitous, can lead to career-enhancing changes in our professional lives. And so, it is a pleasure, and a relief, to see the first fruits of a return to in-person SPIE meetings. It will take a while for the reset to have full effect, but you can be sure that as we go forward together, our Society will be energetically waving the banner at the front.

David Andrews
2021 SPIE President
SPIE
Deadlines and Events

**September**

1: Abstracts due for SPIE Advanced Lithography 2022  
3: Applications due for SPIE-Franz Hillenkamp Postdoctoral Fellowship  
8: Abstracts due for SPIE AR|VR|MR 2022  
13-16: SPIE Optical Systems Design Digital Forum  
13-16: SPIE Remote Sensing Digital Forum  
13-16: SPIE Security + Defence Digital Forum  
15: Nominations due for SPIE Fellows  
16: Submissions due for SPIE International Day of Light Photo Contest  
27-1 October: SPIE Photomask Technology + EUV Lithography Digital Forum  
28: Manuscripts due for SPIE Optifab  
28-30: SPIE Space, Satellites, + Sustainability, Glasgow, UK  
28-30: SPIE Photonex + Vacuum Expo, Glasgow, UK  
29: Manuscripts due for SPIE Laser Damage

**October**

1: Prism Awards applications due  
6: Abstracts due for SPIE Defense + Commercial Sensing 2022  
8: Applications due for Nick Cobb Memorial Scholarship  
10-12: SPIE/COS Photonics Asia, Nantong, Jiangsu, China  
17-20: SPIE Laser Damage, Rochester, New York, USA  
18-21: SPIE Optifab, Rochester, New York, USA  
20: Abstracts due for SPIE Photonics Europe 2022  
27: Manuscripts due for SPIE Future Sensing Technologies

**November**

17-19: SPIE Future Sensing Technologies, Tokyo, Japan  
19: Finalists announced for 2022 PRISM Awards

**December**

13-16: Advances in 3OM: Opto-Mechatronics, Opto-Mechanics, and Optical Metrology (3OM), Timisoara, Romania  
29: Manuscripts due for SPIE Photonics West 2022
SPIE A.E. Conrady Award in Optical Engineering

SPIE FELLOW DAVID AIKENS, president of Savvy Optics, in recognition of his world leading expertise, training, and development of optical engineering and optical standards. Aikens’ career has had influence across optical engineering. His seminal work on mid-spatial frequency errors continues to lead to significant advances in multiple areas from high-power laser optics to freeform surfaces. He turned a disorganized US delegation for ISO/TC 172 (Optics and Photonic Technical Committee) into a thriving body of experts engaged with other world-standards leaders in optics. Since 2012, he has been a critical contributor to the SPIE IR Materials Working Group, helping to organize and direct the group toward concrete results. Throughout his career—with Hughes Aircraft, at Lawrence Livermore National Laboratory, at Zygo, and now with Savvy—Aikens has shared his knowledge with the wider optics community.

The SPIE A. E. Conrady Award in Optical Engineering is presented in recognition of exceptional contributions in design, construction, testing and theory of optical and illumination systems and instrumentation.

SPIE G.G. Stokes Award in Optical Polarization

NIRMALYA GHOSH, professor of physical sciences at the Indian Institute of Science Education and Research (IISER) in Kolkata, in recognition of his extensive research in the field of Mueller matrix polarimetry. His work has included developing applications of Mueller matrix polarimetric spectroscopy and imaging for interdisciplinary fields including quantum optics, space optics, biomedical optics, chemistry, materials science, and fluorescence spectroscopy.

Ghosh’s work has impacted multiple areas of optical sciences from quantum, space, and biomedical optics to material sciences and fluorescence spectroscopy. He developed novel concepts of weak measurement in classical optics and introduced these to the domain of plasmonics. As well, he has made key contributions to studies of spin orbit interaction of light generating new insights into polarization optical effects.

The SPIE G.G. Stokes Award in Optical Polarization is presented for exceptional contribution to the field of optical polarization. The award may be presented for a specific achievement, development, or invention of significant importance to optical science and society, or it may be given for lifetime achievement.

SPIE Mozi Award

SPIE FELLOW XIANG ZHANG, president and vice chancellor of the University of Hong Kong, in recognition of his seminal contributions to optical physics and experimental research into the so-called optical perfect lens.

Zhang’s experimental demonstration of the first optical super lens was a breakthrough that opened a new field of deep subwavelength photonics with applications in ultraresolution imaging for complex biomolecular machinery, optical communication at the subwavelength scale, and nanolithography. He has also contributed key discoveries regarding the magnetic response of metamaterials in far-infrared, research that expanded the field of optical metamaterials, and offered the first demonstration of 3D bulk metamaterials with a negative refractive index.

The SPIE Mozi Award, established by the Taiwan Information Storage Association (TISA) and SPIE in 2017, is named in honor of the Chinese philosopher, scientist, and engineer, Mozi (468–391 BC), the first person in recorded history to mention the simple principles behind the concept of camera obscura. This award is presented for outstanding discoveries, scientific and technical achievements, or inventions in the field of optics.

See the entire list of SPIE Award winners at spie.org/2021awards
SPIE FELLOW RENU TRIPATHI, a professor of physics and engineering at Delaware State University (DSU), is the inaugural recipient of the IBM-SPIE Historically Black Colleges and Universities (HBCU) Faculty Accelerator Award in Quantum Optics and Photonics. The announcement was made 1 August, during the opening plenary event at SPIE Optics + Photonics.

The $100,000 annual award supports and promotes research and education in quantum optics and photonics within IBM-HBCU Quantum Center member institutions, currently 23, including DSU. The IBM-SPIE agreement stipulates a joint annual award year through 2025, with each organization providing $50,000 per year for a shared total of $500,000 over five years.

"Receiving this prestigious inaugural award from IBM and SPIE will highlight and bring national prominence to our distinctive quantum science research program at DSU," said Tripathi. "It also allows us to broaden the scope of quantum-sensing research, education, and training at the university so that both undergraduate and graduate students will have direct experiential educational exposure to advancements in quantum science and technologies."

Tripathi’s winning proposal seeks to demonstrate “a quantum gyroscope with a high rotation sensitivity, suitable for inertial navigation applications.” She says she will use the award to develop quantum science education curricula and teaching practices at DSU, including providing hands-on experience and training to DSU students through summer research programs and workshops.

Tripathi has given several invited talks at SPIE conferences, served as an organizing committee member for the Optical and Quantum Sensing and Precision Metrology conference at SPIE Photonics West since 2019; participated in the ’Increasing Diversity and Inclusion in Sciences & Engineering’ panel at SPIE Optics + Photonics in 2016; and was featured in the 2010 SPIE Women in Optics Planner. What’s more, she helped found the SPIE Student Chapter at DSU, and is an active mentor to its students.

Acknowledging the inequities in previous technology nodes and supporting workforce developments, SPIE and IBM are working together to ensure the technologies of the future leverage the qualities and experiences of a diverse community. Quantum photonics and its related technologies will be at the forefront of technology advancements and the economies of the future. SPIE and IBM believe the impact of these technologies will be stronger with the inclusion of the ideas and work of the diverse student-bodies found at America’s HBCUs.

"By supporting quantum research programs and education at HBCUs, we hope to contribute to a truly diverse scientific and engineering community," said SPIE President David Andrews. “Quantum is a rapidly growing area that is already proving critical to technological innovation. We want to make sure that the field is open, accessible, and inclusive for the current and future generations of optics and photonics students, and this new program will contribute to delivering that objective."

For more on the IBM-SPIE HBCU Faculty Accelerator Award in Quantum Optics and Photonics, including the next award cycle, visit spie.org/hbcu-award
IN JUNE, SPIE and The Optical Society (OSA) announced the selection of Brandon McMurtry as the 2021–22 Arthur H. Guenther Congressional Fellow. He will serve a one-year term in Washington, DC, as a special legislative assistant for a member of the US Congress or as a staff member for a congressional committee beginning in September. SPIE and OSA are co-sponsors of the fellowship.

McMurtry is a PhD candidate in the Department of Chemistry at Columbia University, studying solution-phase crystal growth mechanisms in the lab of Professor Jonathan Owen. As a graduate student, his research has focused on improving the synthesis of colloidal semiconductor nanocrystals for use in solid-state lighting applications. Prior to graduate school, he received a BS in chemistry from the University of Hawai‘i at Mānoa in Honolulu.

As part of his fellowship, McMurtry will attend a comprehensive science policy and communication training and orientation session facilitated by the American Association for the Advancement of Science (AAAS). Upon training completion, he will interview with Senate, House of Representatives, and congressional committee staff on Capitol Hill and then select which congressional office or committee he wishes to serve for his fellowship year.

The Congressional Fellowship’s program mission is to bring technical and scientific backgrounds and perspectives to the decision-making process in Congress and provide scientists with insight into the inner workings of the federal government. Fellows may participate in a multitude of policymaking functions including conducting legislative or oversight work, assisting in congressional hearings and debates, preparing policy briefs, and writing speeches.

Read more here: spie.org/guentherfellow2021
**SPIE Top Scholarships Winners**

**THE SPIE D.J. LOVELL SCHOLARSHIP**, the Society’s largest and most prestigious scholarship, was awarded to Simone Eizagirre Barker, University of Cambridge.

Riley Logan, Montana State University, was awarded the SPIE John Kiel Scholarship, which was established to honor SPIE founding member John Kiel, in recognition of his significant contributions to the Society. The scholarship awards a student’s potential for long-term contribution to the field of optics and optical engineering.

The Laser Technology, Engineering, and Applications Scholarship was awarded to Murat Yessenov, CREOL, The College of Optics and Photonics, University of Central Florida. This scholarship is awarded in recognition of a student’s scholarly achievement in laser technology, engineering, or applications. Funds are provided in part by SPIE.

The Optical Design and Engineering Scholarship was awarded to Geoffroi Côté, Université Laval. The scholarship was established in memory of Bill Price and Warren Smith, both well-respected members of SPIE’s technical community. The scholarship is awarded to a student in the field of optical design and engineering.

Maryam Baker, James C. Wyant College of Optical Sciences, was awarded the BACUS Scholarship. This scholarship is awarded to a student in the field of micro-lithography with an emphasis on optical tooling and/or semiconductor manufacturing technologies. The scholarship is sponsored by BACUS, SPIE’s Photomask International Technical Group.

Samuel Ignacio Zapata Valencia, Universidad Nacional de Colombia Sede Medellín, is the recipient of the Teddi Laurin Scholarship. Photonics Media is partnering with SPIE to fund the scholarship to raise awareness of optics and photonics and to foster growth and success in the photonics industry by supporting students involved in photonics. This scholarship is in memory of Laurin Publishing and Photonics Media founder Teddi Laurin.

Meet more 2021 SPIE Optics and Photonics Education Scholarship recipients at: spie.org/2021scholarshipwins

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**EXCEPTIONAL ARTICLES** in interdisciplinary applications, theoretical innovation, and photo-optical instrumentation and design, in the *Journal of Applied Remote Sensing* (JARS) have been given best papers published in 2020. The honorees were selected by the journal’s editorial board.

“*How much benthic information can be retrieved with hyperspectral sensor from the optically complex coastal waters?”* by Ele Valtmäe, Birgott Paavel, and Tiit Kutser, of the University of Tartu, Estonia, was selected for Interdisciplinary Applications.

“*Noise reduction and destriping using local spatial statistics and quadratic regression from Hyperion images*” by Mahendra Pal, Alok Porwal, and Thorkild Rasmussen—all of Lulea University of Technology, Sweden; Pal and Porwal are also with the Indian Institute of Technology Bombay, India—was selected for Theoretical Innovation.

“*On-orbit calibration and characterization of GOES-17 ABI IR bands under dynamic thermal condition*” by Zhipeng Wang, Xiangqian Wu, Fangfang Yu, Jon P. Fulbright, Elizabeth Kline, Hyelim Yoo, Timothy J. Schmit, Mathew M. Gunshor, Monica Coakley, Mason Black, Daniel T. Lindsey, Haifeng Qian, Xi Shao, and Robbie Iaco-vazzi was selected for Photo-Optical Instrumentation and Design. JARS is published online in the SPIE Digital Library and optimizes the communication of concepts, information, and progress among the remote-sensing community. Ni-Bin Chang, professor of civil, environmental, and construction engineering at the University of Central Florida, is the editor-in-chief.

Read more at spie.org/2020JARSpapers

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**Starshade Research Helps Advance Exoplanet Imaging**

**IN JUNE**, the *Journal of Astronomical Telescopes, Instruments, and Systems* (JATIS) published a special section on the latest science, engineering, research, and programmatic advances of starshades, the starlight-suppression technology integral to extra-solar and exoplanet detection.

Section topics range from starshade programs and missions, to various aspects of related technologies, including formation flying, deployment, high-contrast imaging, and performance modeling. Together, the 19 open access articles provide an extensive overview and current status of this growing field.

“*NASA’s starshade technology development activity,*” “*Antirefection coatings on starshade optical edges for solar glint suppression,*” “*Exoplanet imaging performance envelopes for starshade-based missions,*” and “*Mapping the observable sky for a Remote Occulter working with ground-based telescopes*” are just a few of the articles featured in this collection.

Read more at spie.org/jatis-starshade
**2021 SPIE Startup Challenge**

SIX STARTUPS WON industry accolades and a share of $35,000 in prize money at the 11th annual SPIE Startup Challenge on 2 June. The pitch competition, which took place online this year, is an integral part of the industry and entrepreneurship programs of SPIE.

The Startup Challenge includes two distinct tracks: healthcare and deep tech. Finalists and semifinalists had multiple opportunities for mentorship, industry advice, and feedback from the Challenge’s network of experts as they prepared and honed their final pitches.

In the deep tech track, In A Blink, whose WINK-ol provides virtual fiber-optic technology to enable massive data transfer from public-transport and industrial vehicles to a smart grid, won first place; Owl Autonomous Imaging, whose 3D ranging thermal camera provides safer robotic mobility, came in second; and Ki3 Photonics landed third with its solutions for secure quantum communications.

In healthcare, Advanced Optronics was the top winner with its flexible surgical sensor for use with cochlear implants, while LASE Innovation won second place with its technology for improving single-cell analysis. Prebeo, whose kidney viability assessment system aims to make kidney transplants safer and more efficient, was honored with third place.

In A Blink and Advanced Optronics each took home checks for $10,000 from Jenoptik; Owl Autonomous Imaging and LASE Innovation each received $5,000; and Ki3 Photonics and Prebeo took home $2,500 each.

The SPIE Startup Challenge, which showcases new businesses, products, and technologies addressing critical needs with photonics, was supported this year by founding partner Jenoptik; lead sponsors MKS Instruments and Hamamatsu; and strategic partners Luminate and LDV Capital.

Learn more at spie.org/startupchallenge2021

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**The 2022 Women in Optics Planner is Here**

WE COULD ALL USE SOME GOOD ADVICE from time to time—along with reminders of important, can’t-miss events. The SPIE Women in Optics (WIO) planner—a well-respected linchpin of the organization’s WIO program—meets those needs and more.

Offered by SPIE since 2005, the planner was created to inspire and educate girls and young women, inviting them to consider careers in optics, photonics, and other STEM areas. The planners showcase a vibrant cohort of women scientists, engineers, researchers, and industry leaders, giving insights into their career trajectories, challenges, and successes. Each profile offers a role model for other women and girls interested in STEM fields, giving examples of the myriad opportunities available in science and science-related professions.

The 24 participants in the 2022 WIO Planner range from women at the beginning of their careers to those further along their professional paths. Each featured participant shares something of her dreams, ambitions, challenges, and successes, while offering experience-based advice. A sampling of their suggestions include:

- “Follow your intuition and curiosity when you do science. I found I enjoyed my research the most when my curiosity drove me. And enjoy the freedom of doing science.”
- “Don’t be afraid of having a sense of entitlement about what you can accomplish, and what pay and recognition you deserve for a job well done.”
- “...be adventurous...be bold...and always cherish [your] curiosity.”
- “If something excites you, even if it’s tangential to what you think you want to do or completely unrelated, lean into that.”
- “Be aware of your own unique set of skills and keep on looking for your niche. STEM is the ultimate playground!”
- “Don’t be afraid of not knowing, ask as many questions as possible.”

Packed with inspiring voices and visions, the 2022 SPIE WIO Planner also includes handy reminders for important days on the STEM calendar: Introduce a Girl to Engineering Day (24 February), International Women’s Day (8 March), International Day of Light (16 May), International Day of Women and Girls in Science (11 February), and International Women in Engineering Day (23 June).

This engaging and informative planner is available at no cost to science teachers, educators, career counselors, community clubs, students, and members of the public.

Visit spie.org/wioplanner2022 to download a PDF or request a print copy, and spend the next year with women who are transforming our world.
Film star Hedy Lamarr told this aviator to streamline the wings on one of his aircraft. Although it took 16 hours, she sent the first underwater transatlantic message. Still the fastest and cheapest way to send information between continents. Optical instruments are prone to this process after extended periods underwater. Technology considered a forerunner to WiFi and Bluetooth. Mid-ocean realm containing more biomass than anywhere else on Earth.

Snap a photo of your completed crossword puzzle and send to photonicsfocus@spie.org. One winner, drawn at random, will receive a gift!

DOWN:
1. Film star Hedy Lamarr told this aviator to streamline the wings on one of his aircraft
2. Although it took 16 hours, she sent the first underwater transatlantic message
3. Still the fastest and cheapest way to send information between continents
4. Optical instruments are prone to this process after extended periods underwater
5. Technology considered a forerunner to WiFi and Bluetooth
10. Mid-ocean realm containing more biomass than anywhere else on Earth

ACROSS:
6. Giant clam body part hosting algal symbionts
7. Co-opted as a monitoring system by the oil and gas industry
8. What happens to light rays underwater
9. With the aid of a laser pulse submarine networks can be used as this type of detector
11. Cells that shunt sunlight to giant clam algal symbionts
12. Giant clams are better at this biological process than corn or soybeans
13. Underwater colors disappear with [blank] in accordance with their order on the spectrum
14. Long before LEDs, this type of torch was used as lighting for underwater filmmaking
15. They make possible 360-degree underwater Imaging
Reflections

*Pteropods*, also known as sea butterflies or sea angels, are so-called mucus feeders that spread a sticky net around their bodies to snag passing particles and plankton.

Paul Caiger/©Woods Hole Oceanographic Institution

Submit your own images of light properties and light-based technology to REFLECTIONS by mentioning @SPIEtweets or @spiephotonics. Submissions can also be sent by email to photonicsfocus@spie.org.
Present your research and meet with your community in 2022

CONNECT WITH YOUR COLLEAGUES FACE-TO-FACE AT YOUR SPIE EVENT

Make plans to join your community at the best live conferences in optics and photonics. We welcome you to discuss and learn new ideas, network with colleagues, and amplify your results.

Contribute an abstract by the dates below to present at next year’s event. Share ideas, collaborate in-person, and innovate brilliantly.

ABSTRACT SUBMISSION DUE DATES

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