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2048 x 2048 Spatial Light Modulator

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- Visible wavelengths
- Dedicated drive boards

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International Day of Light

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Cover photo credit: Getty Images: FernandoAH
Luminous Luminaries

SOMETIMES WHILE RESEARCHING AN ARTICLE OR EDITING AN ISSUE, I stumble across a character who so captures my imagination that I can’t help but follow the rabbit down its hole.

That is exactly what happened when I read the first draft of Jeff Hecht’s Luminary article about Gerald Pearson and his work to create the first silicon solar cell. The story contained a short reference to a paper authored by one Mária Telkes of Massachusetts Institute of Technology (MIT) in 1947—clearly a woman and a scientist, in a decade when the combination was rare. “Who was she?” I wondered.

A few Google searches later, I was excited enough to start gushing to family and strangers about Mária Telkes. We added a second luminary article to this issue just to share her interesting story—one of pluck and perseverance in the face of good ‘ol’ boys clubs, xenophobia, and McCarthy-era suspicions of anyone who didn’t subscribe to midcentury social norms.

Telkes clashed ideologically with her supervisor at MIT, Hoyt Hottel, who saw solar research as just an interesting engineering problem. In the mid-20th century, petroleum was abundant and cheap; he couldn’t envision an economic—or environmental—reason to seriously consider anything else. Telkes, on the other hand, saw solar research as a societal imperative.

Today, the imperative is obvious, and most people working in solar research are in Telkes’s camp. Researchers are driven to halt the damage done by humanity’s heedless overconsumption of coal and petroleum— an interesting and difficult engineering problem, with a more pressing humanitarian and economic purpose.

The pages of this issue of Photonics Focus should remind us how much scientific progress has been made in a short time. Solar cell efficiency has increased from the six percent that Pearson achieved in 1954 to a useful 25 percent today. Photovoltaic (PV) panels have become affordable and ubiquitous. They are installed in remote communities disconnected from the utility grid to provide electricity where none was previously available.

While today’s PV efficiencies are functional, researchers keep finding ways to improve them through new materials, designs, and construction methods. Innovative companies are laminating quantum dots into window glass to create transparent photovoltaics, which will increase the surface area of buildings available to harness sunlight for conversion to usable energy.

Other researchers are looking not to the sun, but to water as a source of renewable energy. If water’s hydrogen and oxygen molecules could be quickly and cheaply teased apart, as plants manage so easily through photosynthesis, then the world’s most abundant natural resource could be converted to a liquid hydrocarbon, which could replace the energy-dense liquid fuel needed to power jet engines or heat homes.

Luminaries like Telkes and Pearson had the foresight to look beyond the abundance of fossil fuels in their own lifetimes, and the courage to pursue an alternative. Their curiosity and early experiments laid the groundwork for advances in renewable energy. They are the giants upon whose shoulders today’s solar researchers stand.

GWEN WEERTS, PHOTONICS FOCUS EDITOR-IN-CHIEF
WHEN I WAS A PHD STUDENT working in photonics, I often felt uncertain about my professional identity. When my advisor wanted my lab mates and me to rely on our ingenuity to get an optical measurement experiment working, he would admonish us to “think like engineers.” When he thought we needed to return to the underlying science of our work to understand what was happening, he would urge us to “think like physicists.” The feeling of occupying this liminal space between engineering and the sciences did not dissipate as I began my career as a faculty member. Though all my degrees, bachelor’s through PhD, were in electrical engineering, and my first faculty appointment was in an electrical engineering department, one colleague opined that my research was solely the domain of the physicists in the building next door.

And yet, it was the interdisciplinary nature of photonics that first drew me to the field as an undergraduate student, and that I use to excite my own students. I tell them that photonics sits at an intersection of engineering, physics, and materials science, and so requires knowledge across disciplines. This interdisciplinary quality may be one reason for a higher proportion of female graduate students in photonics than other fields of engineering and science. Engineering education research papers and policy documents often propose that interdisciplinary studies are particularly attractive for underrepresented minorities and women. And the numbers in photonics, where 33 percent of PhD students in the US are female, compared to 16 percent in electrical engineering and 19 percent in physics, would seem to bear this out.

Photonics education is as difficult to characterize as the field itself. Depending on the university, photonics graduate students regularly take classes offered by multiple academic departments. There are few degree-granting optical engineering programs, and most people working in photonics have physics or engineering degrees. The majority have advanced degrees: 57 percent have PhDs and 20 percent have a master’s degree, which is when the bulk of photonics education takes place.

Because of these unique aspects of photonics education, it is difficult to identify what improvements or innovations are required in the way we teach and mentor future photonics professionals. Engineering education has been a growing field of research, and it is where my own research program is now largely...
PHOTONICS SITS AT AN INTERSECTION OF ENGINEERING, PHYSICS, AND MATERIALS SCIENCE, AND SO REQUIRES KNOWLEDGE ACROSS DISCIPLINES.

PHOTONICS FOCUS

July/August 2021

focused. Physics education is a similarly robust area of scholarship. Though photonics education is rarely specifically studied, we can look to the engineering and physics education research to identify possible changes that would better serve our students. The following suggestions might make a good start.

### Focus on Graduate Education

For those who research and design curricula for engineering and physics education, graduate-level education must be taken into consideration. If we are concerned about the so-called STEM pipeline, we need to devote time and resources to understanding effective and equitable ways to educate and mentor our graduate students. This is especially relevant to photonics because a graduate degree is often required to work in this discipline.

### Champion Interdisciplinary Work

Since I began graduate school 15 years ago, I have heard numerous colleagues malign interdisciplinary work. While I understand that this is not a view shared by all in academia, and certainly not by many in industry, the messages we give our students about what “counts” as engineering or physics matter deeply, especially as they develop professional identities as engineers or scientists. Moreover, research at the intersection of multiple disciplines may be particularly attractive for underrepresented minorities and women whose professional identities are more frequently challenged by others. We need to communicate to all students that the ability to work across disciplines is valuable and important.

### Professional Identity

Student branches of professional membership societies, such as SPIE, can help students create connections with peers, faculty, and industry professionals. When I was a PhD student, our school’s student-run optics organization was a valuable way for me to strengthen my own identity in photonics.

### Social Responsibility

These topics are not often discussed in photonics education, at least not in my experience. And yet, as we look to technology to address some of humankind’s most pressing problems, we also must seek out responsible and just solutions in our own work. For example, I have in recent years collaborated with an anthropology colleague to explore how we can blend themes from corporate social responsibility into a semiconductor device course. Because of this collaboration, my students get to wrestle with topics such as materials sourcing, labor conditions, equitable access to technology, and the unavoidable tradeoffs involved in creating sociotechnical solutions.

Advances in photonics still excite me as much today as when I first entered the field. With increased attention on how we educate and support students, we can continue to recruit the next generation of photonics professionals, work on exciting breakthroughs, and contribute responsibly to society.

**Stephanie Clausen** is an assistant professor in the School of Engineering at San Francisco State University.
A Scientist’s Guide to Social Media

LinkedIn

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 THIS FIRST SEGMENT OF OUR SERIES on social media for scientists and engineers, we start with the most professional platform of the bunch, LinkedIn.

With nearly 740 million members, LinkedIn is the largest social media site serving professionals. LinkedIn users are found in 200 countries, which is a good benefit for researchers looking to collaborate across disciplines, institutions, and regions. LinkedIn is also one of the few international social media sites available in China.

Technical lead at Lam Research, Anuja de Silva, says she uses LinkedIn to bolster her network and stay up to date. “It’s the easiest way to keep up with the semiconductor industry, or any professional area. I can build my network, follow industry trends, and leverage the platform to connect with people I haven’t yet met but am interested in having in my network.”

Just how do you achieve success on LinkedIn as a researcher? Let’s dive in.

SET UP YOUR PROFILE FOR SUCCESS

One way LinkedIn determines if your posts are high-quality—and worthy of showing to more people—is by looking at the profile from which they came. This indicates to the LinkedIn algorithm that you are not a bot, are invested in the platform, and therefore worthy of reaping the benefits of content amplification.

Profile pictures—LinkedIn’s research shows that having a clear profile photo makes your profile 14 times more likely to be viewed by others. Choose a photo of yourself that conveys professionalism, and avoid using one that is outdated. If someone met you at a conference, would they be able to identify you in your profile picture?

You don’t need to have a professional headshot to have a great profile picture. Recruit a friend to snap a picture in front of a background that is free of distractions. Bonus points for good natural lighting, which will brighten up your photo without using a filter.

Banner images—LinkedIn has a variety of banner images to choose from, or you can pick something more personal. Maybe an image from a past conference, a photo of the tech in your lab, or one of the many SPIE International Day of Light social media banner images: spie.org/idlsocial

Headline—This is prime real estate. Focus on your research and use buzzwords that people may be searching. A strong headline adds to your credibility and shows up next to your name when you comment on posts in your feed.

Publications and patents—Linking your published works and patents on your LinkedIn profile is great way to show off your work to potential collaborators, future employers, and colleagues.

CONNECT

LinkedIn is all about making connections. The more relevant connections you have, the broader your reach. The broader your reach, the more people can learn about your research. You may even find people interested in collaborating.

Start simple: connect with coworkers, lab mates, past and current professors, and colleagues from school.
a strong foundation, branch out. Network and connect at conferences; send a connection invitation to speakers whose presentations you attend. Just be sure to include a personal note:

“Hi [Name]. I saw your talk at Photonics West this week, and was really interested in what you are doing with pulsed lasers. I’d love to follow along with your research. Let’s stay connected.”

A note should be included on each new connection you send, even if you think that person will remember you. This helps differentiate a quality connection from spam.

Now that you have added connections and optimized your profile, you need to actually post something. This can feel daunting. You are faced with a blank slate, a tiny box asking you: What do you want to talk about? A good first step is writing posts that discuss your recent or upcoming publications.

HELPFUL TIPS

• Do more than simply drop a URL in the text box—add your thoughts. People want to know what they are clicking on before they click. Write a short summary of your work, encouraging people to read the paper to learn more.

• Use popular technical hashtags. While hashtags can increase your chances of being discovered by people outside your first-degree connections, they also provide a succinct way to describe your post, like #MedicalImaging and #QuantumComputing.

• If an eye-catching image does not populate when you include the URL, add one! Take a screenshot from the article to show off your favorite figure or chart. Prioritize accessibility by taking a minute to write alternative text that describes the image.

• Mention relevant parties. Tagging (@) your co-contributors or your department can expand your reach significantly. If others like, share, or comment on your post, it will broadcast to their entire LinkedIn network—creating a LinkedIn snowball effect.

IT’S NOT ALL ABOUT YOU

Do you enjoy meeting up with that friend who only talks about themselves? Probably not. After a while, you may stop seeing them altogether. The same happens on social media. Treat your LinkedIn feed as a conversation. After a post about yourself, share the space with a colleague and share their recent work, or an article about the achievements of another lab in your field.

Comment on people’s posts, but make them real—not the quick, robotic LinkedIn autofill suggestions. Ask a question, share an opinion, offer sincere congratulations. The more you comment, share, and engage with the posts of your connections, the more they will be inclined to engage with your posts.

Start small, set goals, and learn from mistakes. Have fun with social media, and find pleasure in the brevity of communication that isn’t found in traditional scholarly places.

Next up in the series: Twitter.

“I started using LinkedIn during undergrad as an online CV. For many years, I only updated my profile when I looked for new positions or attended conferences. Now, I find it a great way to interact with people I meet in different professional settings. I find many interesting research projects and papers through Twitter and LinkedIn, and sometimes those bring new inspirations. It is a great place to promote my research and connect with researchers outside my field.”

Linhui Yu, research fellow at Harvard Medical School

“Think of it like compound interest. Even a small, initial gain in the number of researchers and scholars that your research reaches in the early days of publication can, in the long run, make a significant difference. I find that sharing our research progress through LinkedIn helps our team in other impactful ways, too. It creates new opportunities for collaboration and assists with recruitment of team members to our lab.”

Aydogan Ozcan, Chancellor’s Professor at UCLA

“I can’t post too much about my work [online] because I’m in the private sector, so I tend to steer away from original technical posts, but I have been trying to build a personal brand to show my attitude and work ethic.”

Katie Chong, optical engineer for Baraja

EMILY POWER is the social media manager for SPIE.
ORGANIC LIGHT-EMITTING DIODES (OLEDs) are mono-
lithic, solid-state devices that consist of a series of organic
thin films sandwiched between two thin-film conductive
electrodes. When electricity is applied to an OLED, under
the influence of an electrical field, charge carriers (holes
and electrons) migrate from the electrodes into the organic
thin films until they recombine in the emissive zone forming
excitons. Once formed, these excitons, or excited states,
relax to a lower energy level by giving off light (electrolu-
minescence) and/or unwanted heat.

The basic OLED cell structure consists of a stack of thin
organic layers sandwiched between a conducting anode
and a conducting cathode. They are manufactured by depositing
the chemicals on a glass substrate between an anode and
cathode by using vacuum thermal evaporation or inkjet
printing depending on whether the chemicals are in a solid
or soluble form. The current is provided by an active matrix
using either low-temperature polysilicon, indium gallium
zinc oxide, or a combination of the two.

Compared to LCDs, OLED displays are thinner, have
higher contrast, faster response time, wider viewing
angles, more accurate color representation, and weigh less.
Depending on the application, OLED panel prices may
be the same as an LCD or be more expensive. While LCD
displays must keep the backlight on all the time, OLEDs
power subpixels independently, so the display only uses
power when a subpixel needs to be lit. Most videos average
around 20 percent of the pixels on, so for TVs, OLEDs use
less power than LCDs. A similar construct exists for smart-
phones. But monitors and notebooks use office applications,
which are heavily tilted to white space, where OLEDs tend
to use more power than LCDs, which is why OLEDs have
low penetration in those markets.

Samsung Display has been the dominant supplier of
small/medium displays and enjoys a 70 percent market
share. The Chinese display makers—BOE, CSoT, Tianma,
Visionox, and EverDisplay—have almost as much capacity
as Samsung, but they have struggled with yields and quality.
However, in 2020 they crossed the performance threshold
and are expected to ship more than 100 million displays
in 2021. Recently, BOE qualified to be a supplier to both
Samsung Mobile and Apple. LG Display is the only panel maker
producing TV-size displays, but they will be joined by Samsung,
CSoT, and BOE over the next three years.

In 2020, OLED displays were used in smartphones, TVs,
smartwatches, notebooks/tablets, and automotive monitors.
But smartphones make up 80 percent of the OLED display
revenue. Total panel shipments were 800 million, up 18 per-
cent year-over-year, despite the pandemic. In 2021, growth is
projected to be 21 percent.

Revenues rose steadily from $9.5 billion in 2015 to $31.8
billion in 2020. As the shipment volume grows, so will the
revenues, which are forecast to hit $40 billion by 2022—a 33
percent share of the total display market.

OLEDs are also used in microdisplays for headset applica-
tions like night vision, fighter pilot headsets, and augmented
reality. They can be produced with fields of view of over 100
degrees and produce luminance levels of 7,000 cd/m². How-
ever, the luminance levels will have to grow to 30,000 cd/m²
to provide sufficient light in high ambient conditions, given the
need to offset light losses from the required lens, color filters,
or circular polarizers.
OLED technology is constrained by the lifetime of the organic material and therefore has limits in terms of luminance. The harder the device is driven, the shorter the lifetime. The lifetime issue is most significant for TVs, where the current luminance is on average 800 cd/m² and 1,000 cd/m² peak, with lifetimes of 50,000 hours. Much effort is going into making the material more efficient in order to increase lifetimes and peak luminance. High-end smartphones have peak luminance in high ambient conditions of over 1,500 cd/m² in order to make them sunlight readable.

OLEDs are unique in that they can be folded or rolled to give product designers wide choices in form factor. A new range of products have been developed based on OLED displays, including folded and rolled smartphones that also serve as tablets; folded laptops, where one display can serve the dual purpose of a display or a keyboard; and TVs that fit in a small container when not used, and then roll out into a 65-inch display when needed.

In addition to foldable and rollable architecture, OLEDs offer a range of new design features, such as transparency that allows viewers to see through the display at up to 50 percent visibility; cameras placed under the display to eliminate the notch and still preserve the ability to take selfies; the use of ultra-thin glass (<100 µm) that serves as both a barrier and cover lens; and under-panel fingerprint readers to minimize the display thickness.

In the coming years, OLED technology is expected to advance by adding a more efficient blue emitter, which would improve efficiency (which means battery life) by 25 percent, eliminate components, and improve lifetime. Moreover, JOLED in Japan has developed a mass-production process that inkjet prints the organic layers, reducing the material costs by approximately 10 percent, because it is more than twice as efficient as VTE in terms of material utilization. TCL, the second-largest global panel maker, is investing approximately $5 billion to build a Generation 8.5 OLED fab to enter the TV market using this technology.

In addition to foldable and rollable architecture, OLEDs offer a range of new design features, such as transparency, that allows viewers to see through the display at up to 50 percent visibility.
The curved 38-inch OLED display on the 2021 Cadillac Escalade.

OLEDs are the first technology to challenge LCDs in over 30 years and have taken more than 25 percent share of the revenue. The improvements being made to OLED technology in terms of cost reduction, efficiency improvements, and higher luminance should drive market share to more than 33 percent by 2025 and 50 percent before the end of the decade. Moreover, display capital expenditures are predominantly for OLEDs, meaning the capacity will grow, while LCD capacity remains flat or goes down. The threat to OLEDs beyond 2025 is MicroLEDs, which promise to outperform OLEDs, but have unsolved technical challenges that contribute to costs two to four times that of OLED panels.

BARRY YOUNG is CEO of the OLED Association, LLC a nonprofit that supports the OLED industry. Previously, he was a cofounder, senior analyst, and CFO of DisplaySearch.
Industry Updates

M&A

» Amplitude Systèmes and sister company Amplitude Technologies have merged and now operate under the name Amplitude.

» BAE Systems Rokar was acquired by Elbit Systems Ltd. for $31M effective April 1, 2021.

» Varian Medical Systems, Inc. was acquired by Siemens Healthineers for $16.4B effective April 15, 2021.

» MTS Systems Corp. was acquired by Amphenol Corp. for $1.7B effective April 7, 2021.

» Northrop Grumman’s IT and Mission Support Services businesses was acquired by Peraton Corp. for $3.4B effective February 1, 2021.

» Inphi Corp. was acquired by Marvell Technology Group Ltd. for $10B effective April 21, 2021.

» Abaco Systems, Inc. was acquired by AMETEK, Inc. for $1.35B effective April 30, 2021.

» Multiphoton Optics GmbH was acquired by Heidelberg Instruments Mikrotechnik GmbH for an undisclosed amount effective March 30, 2021.

» Hitachi, Ltd. to acquire GlobalLogic, Inc. for $9.6B and is expected to close by the end of July 2021.

» ATS Automation Tooling Systems, Inc. to acquire BioDot, Inc. for $106M. The transaction was expected to close in Q2 2021.

» DiaSorin S.p.A. to acquire Luminex Corp. for $1.88B. The transaction is expected to close in Q3 2021.

» Snap has agreed to buy WaveOptics for more than $500M. Closing date TBA.

Executive Updates

» Valentin Gaponstev will step down as CEO of IPG Photonics and become executive chairman. Eugene Scherbakov will become the CEO.

» Scott Rudder was appointed President and CEO of OptoSigma Corp. effective April 15, 2021. He succeeds Guy Ear who is now Chairman of the Board.

» Nobuaki Kurumatani has resigned as CEO of Toshiba Corp. effective April 14, 2021. Chairman and former CEO Satoshi Tsunakawa will return to the CEO position on an interim basis.

» Randy Chatman was appointed CEO of ThermoTek, Inc. effective April 14, 2021.

» Neil Mitchill was appointed CFO of Raytheon Technologies Corp. effective April 9, 2021.

» Wai Kuen Chiang CFO of Dialight plc stepped down effective June 30, 2021.

» Dan Caruso was appointed Executive Chairman and Interim CEO of ColdQuanta, Inc. effective March 15, 2021.

» Joseph Broz was appointed VP, Quantum Growth and Market Development of IBM effective March 15, 2021.

» Rob Bechtold was appointed VP of OptiPro Systems, LLC effective April 6, 2021. He will also continue in his role as CTO for the time being.

» Brian Soller was appointed CFO of Luna Innovations Inc. effective April 28, 2021. He was previously VP and GM of the Lightwave Division at Luna.
A Conversation About Solar

For this energy-themed issue of Photonics Focus, the primacy of solar energy in the renewables mix stood out. We wanted to know more, so we asked David J. Feldman an economist, financial analyst, and solar-energy markets guru for the National Renewable Energy Laboratory. Here’s what he had to say:

WHAT DOES THE NATIONAL RENEWABLE ENERGY LABORATORY (NREL) DO, AND HOW DOES ITS WORK IMPACT THE SOLAR INFRASTRUCTURE IN THE US?

NREL is the only federal laboratory dedicated to clean energy research and development. We help identify, develop, engineer, and design manufacturing processes for new photovoltaic (PV) products, as well as products that might support accelerated PV deployment, such as energy storage. We also help advance the deployment of solar infrastructure in the US through work designed to lower costs, improve solar integration onto the grid, and provide technical assistance for state and regulatory authorities.

SOLAR ACCOUNTED FOR 43 PERCENT OF ALL NEW ELECTRICITY GENERATING CAPACITY IN 2020—FIRST AMONG ALL TECHNOLOGIES FOR THE SECOND YEAR IN A ROW. WHAT IS THE PRIMARY DRIVER OF THIS SUCCESS?

There are four primary drivers of the acceleration of solar adoption. First, the rapid drop in price has made solar competitive with traditional sources of power generation in large parts of the US. NREL estimates that from 2010 to 2020, the cost of energy for US utility-scale PV systems dropped 83 percent. Second, the federal government extended the investment tax credit (ITC), first in 2015, and then again in 2020. They also revised it to drop over time, from 30 percent all the way down to 10 percent. The idea is to create incentives to deploy PV systems while the ITC is still available. Third, many states have set aggressive targets, requiring electricity supplied within their state to come from renewable energy sources, and/or set up regulations encouraging commercial and residential PV deployment. Many utilities now have mandates to procure a certain amount of electricity from renewable sources, which goes up over time. So that’s even more reason to lock in solar now. What’s more, most commercial and residential customers in the US now have the ability to feed electricity into the grid from their solar-energy systems and get retail credit for the energy. Finally, as part of their environmental sustainability plans, many corporations have procured a large amount of solar energy from both onsite and offsite sources.

WHAT ROLE HAVE INCENTIVES PLAYED IN THE UPTICK OF COMMERCIAL AND/OR RESIDENTIAL SOLAR?

I would differentiate between incentives and regulatory structure. Certainly, state incentives have played a large role in US PV deployment and still drive demand. However, some states, such as California and Hawaii, have large levels of deployment despite many state incentives phasing out. That’s due to their high electricity rates and sunny skies. However, another key element driving demand is regulatory structure. The vast majority of commercial and residential PV systems feed some of their electricity to the grid. How they are compensated for that exported electricity can have a big impact on the competitiveness of many solar-energy systems.
ARE TAX INCENTIVES AND GRANTS STILL NEEDED TO ENCOURAGE ADOPTION OF SOLAR?

All forms of energy are incentivized in some way by federal and state governments—from exploration and production of fuel, to electricity generation. Many states, which once offered incentives and grants no longer do, yet still have robust solar-energy markets. That said, as solar becomes a larger share of the electricity mix, its relative value decreases. Some of this can be mitigated, but the cost of solar energy will have to continue to fall or it may become oversaturated in some regions.

WHAT TECHNOLOGICAL CHANGES/IMPROVEMENTS IN SOLAR PV ARE SPURRING RESIDENTIAL AND COMMERCIAL ADOPTION?

Solar panels continue to get cheaper and more efficient, requiring less labor and supporting material for the same amount of energy at a cheaper price. Some of this is due to technology advances by companies with support from the government, and some of it is due to the increasing size of the solar supply chain. There have also been innovations and improvements in the design of other equipment used for a solar-energy system, such as inverters and racking, which has lowered their costs and potentially decreased installation times. Companies have come up with innovative solutions for acquiring customers, such as group purchasing programs. Some jurisdictions have improved their processes to permit and interconnect a PV system, saving installers time and money.

WHAT IS THE IMPACT OF GEOGRAPHY ON THE RATE OF INSTALLATION OF RESIDENTIAL SOLAR PVs?

Geography plays an important role in residential PV installation. PV panels do produce more electricity in places like Arizona. Still, PV can be competitive in regions with less sun depending on other factors, such as the cost of retail electricity in that area. Washington state gets a significant portion of its energy from very inexpensive hydropower, for example, whereas New York City has an old, expensive distribution grid.

DOES NREL HAVE A TARGET PERCENTAGE FOR RESIDENTIAL ENERGY BEING PROVIDED BY SOLAR?

We do not set targets for solar adoption; we analyze the feasibility of scenarios under many different modeling lenses. Still, NREL estimates that residential rooftops in the US have the potential to produce 1,000 TWh a year, or about 25 percent of what the US consumes. (bit.ly/nrelest).

HAVE ELECTRIC UTILITIES BEEN NEGATIVELY IMPACTED BY INDIVIDUAL HOMEOWNERS INSTALLING SOLAR PVs? THAT IS, ARE THE UTILITIES EXPERIENCING A DROP IN REVENUE BECAUSE PEOPLE ARE ADOPTING SOLAR?

Behind-the-meter PV systems operate in many ways like an energy efficiency device. That is, if a homeowner is sourcing a portion of its power from the PV system, it’s as if they are consuming less electricity from the utility’s perspective. Many utilities earn a return based on how much electricity they sell, so residential PV systems effectively cause them to sell less, which can affect profit. However, there are alternative business models that encourage utilities to perform services that are more in-line with activities that support residential PV while still earning a profit. We are seeing a switch to these models across the country from New York to Hawaii.

IF YOU COULD SAY ANYTHING TO THE PV RESEARCH COMMUNITY, WHAT WOULD IT BE?

Keep up the good work. Research can take a while to get to the marketplace, but we continue to see decades of research and development coming online and lowering the cost of solar electricity.

WILLIAM G. SCHULZ
is managing editor of Photonics Focus.
**Towards Fully Automated Optical Design**

**UNDER THE HEADING** “computers can’t replace everything,” one might list optical design. Experts say that even with powerful optimization algorithms, the practice is considered both an art and a science, requiring skilled human guidance to achieve successful outcomes.

Indeed, since the introduction of computer-aided design, and despite increasing degrees of automation, design without human intervention is generally considered impossible.

But maybe not, says a team of researchers led by Jun Zhu, a professor in the Department of Precision Instrument at China’s Tsinghua University. They report the development of a result-diversified automatic design method for freeform optics. They say they have obtained automatically—with field-of-view, focal length, and entrance pupil diameter as the only input specifications—a variety of three-mirror freeform imaging systems that have various structures and diffraction-limited high-imaging qualities.

The researchers describe a five-phase, computer-based calculation process that explores the solution space of three-mirror freeform systems and design imaging systems working in the visible and long-wavelength infrared bands. When complete, they say the process gives multiple-choice results of various optical power distributions and various structures meeting the design requirement.

With their five-phase process, the team developed a program using MATLAB which they performed on a high-performance computing platform at Tsinghua to generate two examples.

“Rather than spend time finding initial solutions and performing optimizations, the designer only needs to determine the optical specifications and constraints, and then input them into the computer and wait for the results,” the team writes. “The majority of the designer’s work will involve browsing through and analyzing the multiple optical systems that are obtained and selecting the appropriate system as the final design.”

(Jun Zhu et al., Light: Sci. App. 2021, doi: 10.1038/s41377-021-00510-z)

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**MEMS Device Offers Less Leaky Optical Switching**

OPTICAL SWITCHES WOULD BE AN IDEAL SOLUTION for handling the workloads from artificial intelligence and machine learning tasks. They would improve utilization of computing resources as well as reduce latency and energy consumption. But today’s silicon photonic switches have a big problem—they leak too much light, limiting their scalability for data centers, cloud hyperscalers, and high-performance computers.

Now, a group at University of California, Berkeley, reports a $32 \times 32$ silicon photonic microelectromechanical system (MEMS) with both grating and gap-adjustable-directional couplers. With the former, light is coupled to the chip. Directional couplers guide the light path on the chip by controlling the gap spacing of each coupler.

The group previously demonstrated MEMS-based silicon photonic switches with moving waveguides. However, these multilayer devices were made with custom fabrication processes not commonly accessible.

The new, single-layer switch “exhibits high uniformity, and the power consumption is several orders of magnitude lower than thermo-optic switches,” the authors write in the *Journal of Optical Microsystems*. They note that the fabricated device has a more-than-acceptable maximum on-chip loss rate of 7.7 dB. What is more, they say, the chip is readily fabricated at a commercial CMOS foundry on 200-mm wafers. This means the switch can be intimately integrated with other silicon photonic integrated circuits and it may be a promising route to building programmable photonic circuits.

“This switch is fully compatible with the standard silicon photonics process offered by commercial foundries,” says co-author Ming C. Wu. “This means they can be readily integrated with existing designs to add new functions or improve the performance of silicon photonic integrated circuits.”

Doubling Up on Microresonators

TWO IS OFTEN BETTER THAN ONE, and so it is with microresonators.

Researchers at Chalmers University in Sweden describe a new kind of microcomb-on-a-chip based on two microresonators in an arrangement known as a photonic molecule. That’s because the microresonators interact with each other in a manner similar to atoms binding together to form a diatomic molecule.

“The reason why the results are important is that they represent a unique combination of characteristics, in terms of efficiency, low-power operation, and control, that is unprecedented in the field,” says Óskar Bjarki Helgason, a PhD student at Chalmers, and first author of an article describing the technology.

The Chalmers researchers are not the first to demonstrate a microcomb on a chip, but their method overcomes several common limitations in the field. The key factor is the use of two optical cavities—microresonators—instead of one. Placed on a chip, the microcomb would fit on the end of a human hair.

Since almost any measurement can be linked to frequency, the microcombs offer a wide range of potential applications. They could, for example, radically decrease the power consumption in optical communication systems, with tens of lasers being replaced by a single chip-scale microcomb in data center interconnects. The microcombs could also be used in lidar, measuring distances for autonomous driving vehicles, for example.

Another possible use for the dual-action microcombs would be calibration of spectrographs used to search for Earth-like exoplanets, extremely accurate optical clocks, health-monitoring apps for mobile phones, and analyzing exhaled air to diagnose diseases at an early stage.

(Mosk et al., Nature Photon. 2021, doi: 10.1038/s41566-020-00757-9)

Seeing Clearly through Disordered Media

THE MOST SUCCESSFUL STRATEGY for obtaining clear images through a disordered medium is the filtering of ballistic light. But ballistic photons with a scattering-free propagation are rare, and no known method has been able to increase their proportion.

Now, two research teams in Europe report the creation of a new set of optical states they term scattering invariant modes (SIMS) whose transmitted field pattern is the same, irrespective of whether they propagate through a disordered or a homogenous medium.

To find SIMS, they first characterized a distorting medium—zinc oxide—by shining light signals through the powder and measuring them at a detector behind the sample. With this result, the team could conclude how any other wave would be changed by the medium. Next, they calculated a specific wave pattern that would be changed by the zinc oxide layer as if wave scattering were absent.

Co-authors Allard Mosk at Utrecht University, the Netherlands, and Stefan Rotter at TU Wien, Austria, say the research teams were able to show that SIMS are a special class of light waves that can produce the same pattern at the detector, regardless of whether they were sent through air or disordered media. They say the experiment—they projected an image of the Big Dipper—demonstrates that zinc oxide powder does not change the shape of SIMs other than they get a little weaker.

The remarkable properties of SIMS make them an attractive new set of tools for research and practical applications such as medical imaging.

(Mosk et al., Nature Photon. 2021, doi: 10.1038/s41566-021-00789-9)
IF THERE IS A SURFACE THE SUN CAN SHINE ON, THERE OUGHT TO BE SOME KIND OF COATING, PANEL, WINDOW, OR OTHER MEANS TO CONVERT THE ENERGY OF SOLAR PHOTONS INTO ELECTRICITY.
A Billion Windows on Quantum Dots

Tiny engineered nanocrystals may give windows renewed purpose

WALK ALONG THE SUNNY SOUTHEAST façade of Boulder Commons, a pioneering net-zero energy (NZE) development project that opened in 2017 in Colorado, and you will see four-story walls clad with 655 photovoltaic (PV) panels. Taking the place of what would have been the metal panels, brick, and glass on the other external walls of the roughly 100,000 square-foot complex, these dark silicon PV panels generate 205 of the complex's 575 kW power-generating needs. This was a crucial, albeit unpretty, design innovation because the 370 kW delivered by the additional 1,072 roof-installed PV panels would have been insufficient for the complex to achieve NZE.

Halfway around the world in 2019, a development firm built an "entrance porch" at the Warwick Grove Shopping Centre in Perth, Australia, to test an assembly of 18 solar windows supplied by the local firm ClearVue PV. Largely transparent even as they generate modest amounts of electricity, the windows have undergone testing to identify what improvements remain to be achieved before these so-called building-integrated photovoltaics can be deployed in the constructed landscape.

What materials scientist Lance Wheeler of the US Department of Energy's National Renewable Energy Laboratory (NREL) in Golden, Colorado, sees in demonstrations like these are baby steps toward realizing the "energy everywhere" mantra he embraces. Wheeler believes that if there is a surface the sun can shine on, there ought to be some kind of coating, panel, window, or other means to convert the energy of solar photons into electricity.

This is an aspiration with many potential solutions, and Wheeler is among a cadre of green-energy researchers who are bullish on the role that some of the tiniest engineered crystals on the planet will play. Known often as quantum dots (QD), these are nanoscale crystals of semiconductor compositions whose knack for photonics play first became apparent in a materials science laboratory in Russia in 1980. Research since then has revealed that these nanocrystals, which are comparable in size to viruses and contain hundreds to thousands of atoms, can pull off fantastic photonics and electronic abracadabras. Beginning around the turn of the millennium, entrepreneurially minded quantum-dot players began to see their science undergird commercial technology in applications that now range from televisions and tablets, to cellular labeling agents and medical therapeutics.
For their part at NREL, Wheeler and colleagues have been investigating the synthesis of photoactive nanomaterials, including quantum dots, and how to use these in green-energy applications, such as solar windows. Solar windows must pull off a seemingly incompatible double feat: they have to be see-through, because that’s the raison d’être for windows, while also intercepting sunlight to generate electricity. Now think of billions and billions of square feet of solar windows on skyscrapers and buildings all over the constructed landscape and you begin to see how nanometer-scale quantum dots could participate in solving global-scale environmental threats.

“PV windows could become a great solution” for achieving NZE buildings like those in the Boulder Commons complex, says Wheeler. After all, he noted, “buildings account for 70 percent of electricity use.” There are challenges ahead. If you’re in the solar window game and you have any realistic hope that architects, developers, the construction industry, and building occupants will embrace novel technology, then your products will have to hit a sweet spot that combines power efficiency, transparency, affordability, good aesthetics, durability, reliability, and industry certifications, among others. No one has done that quite yet.

ANYBODY WHO, LIKE WHEELER, intends to deploy some of the material world’s smallest structures to heal one of the planet’s largest and most troubled structures—an overheating atmosphere due to rising carbon dioxide levels—can draw a line from their current work to about 1980. That’s when Alexei Ekimov, a materials scientist at the Vavilov State Optical Institute in St. Petersburg, was investigating the origin of color in filter glass whose formulations included semiconductor ingredients, such as cadmium sulfide and copper chloride.

Ekimov traced the color to nanoscale crystal inclusions of those semiconductors. He also noticed that these nanocrystals had the curious property of absorbing light of shorter wavelengths than expected from the behavior of these same materials in bulk formats. Ekimov teamed with theoretician Alexander Efros, at the nearby Ioffe Institute. The two scientists showed that the absorption and emission spectra of nanocrystals were determined by their sizes, not their compositions. It was as though one lightbulb filament could be made to emit any color just by making the filament bigger or smaller. “It is an amazing and wonderful property,” says Efros, who since 1993 has been studying nanomaterials at the US Naval Research Laboratory in Washington, DC.

In the same timeframe, Louis Brus, then working on colloidal syntheses of cadmium sulfide nanocrystals at Bell Labs, managed to produce a series of nanocrystals with sizes down to just a few nanometers. Working with him were young scientists, including Paul Alivasatos (named in February as the next president of the University of Chicago) and Moungi Bawendi, Massachusetts Institute of Technology (MIT), who would become giants in the field of semiconductor nanocrystals. Alivasatos would also help initiate an early wave of quantum-dot commercialization by cofounding in 1999, the Quantum Dot Corporation (now part of Fischer Scientific) for cancer diagnostics and medical research, and Nanosys in 2001, which opened the way for quantum-dot-enhanced TV and electronic displays.

What the quantum-dot pioneers were learning was that the very same chemical substance, if embodied as nanocrystals, could emit any wavelength in and around the visible range just by controlling the size of the nanocrystal. The smaller particles, when energized with ambient light, emit toward the blue side of the spectrum. The large nanocrystals emit toward the redder side. Nanocrystals with intermediate diameters fill in the rainbow. This set nanocrystals apart from chunks, wafers, and other bulk forms of semiconductors, whose bandgaps are of set energies and whose absorption and emission spectra are therefore also unchanging.

Because the behavior of electronic and photonic energies in the different-sized nanocrystals resembles the quantized behavior in atoms, semiconductor nanocrystals garnered the nickname from some as “artificial atoms,” and more commonly as “quantum dots.”
This prototype of a QD-infused solar window can harvest sunlight for conversion into electricity. Photons make their way to solar cells at the edges to generate electricity for powering the structure hosting the window. It remains mostly transparent, with a slight tint. The windows have since moved beyond prototypes and have been installed in buildings.

**MATERIALS SCIENTIST** and quantum-dot entrepreneur Hunter McDaniel pegs some of his embrace of quantum dots to his purchase in 2014 of one the first commercial QD products: an Amazon Kindle Fire tablet whose brilliant color display was made possible with quantum-dot technology from Nanosys. It was a hold-in-your-hand demonstration that quantum dots had become commercial technology and helped inspire McDaniel to take his own entrepreneurial leap by launching UbiQD, based in Los Alamos, New Mexico, where at the time he had been a postdoctoral research associate at Los Alamos National Laboratory (LANL). The company’s name is the short version of the phrase “ubiquitous quantum dots” and pronounced as “ubiquity.” The technological foundations and intellectual property for UbiQD’s R&D and first products emerged from research at LANL, MIT, the University of Washington, and Western Washington University.

The design of the company’s experimental solar windows, and pretty much any other solar window now under development, goes something like this:

- Infuse one or more layers of a window glass assembly with quantum dots, organic dyes, or another photoactive material that absorbs some of the sunlight and converts it into a glow of infrared photons.
- Trap the near-IR glow in the plane of the window by internal reflection.
- Guide the photonic glow to photovoltaic cells in the edges of the window.
- Use that energy to run the building’s systems and, if you have made enough power, to feed into the grid and even power up tenants’ electric vehicles.
In its experimental solar windows, UbiQD’s quantum-dot systems consist of copper-indium sulfide cores clad in zinc sulfide shells. These core/shell quantum dots provide a nontoxic alternative to the lead- and cadmium-containing QDs that started the QD era but that McDaniel felt would prove problematic for large-scale commercial QD applications. A pivotal physics nuance of the CuInS/ZnS quantum-dot materials resides in their favorable so-called Stokes shift. This means that the absorption spectra and emission spectra of these QDs do not overlap, thereby preventing one quantum dot in the window from absorbing the emission of another—a fatal flaw in other solar window designs.

Last summer, McDaniel and UbiQD colleagues reported that they had taken a step toward commercial solar windows that could, in theory, provide up to 40 percent of a building’s energy needs. Combine that, McDaniel says, with a building full of next-generation, energy-efficient, smartly controlled systems, and you have a pathway to an era of NZE buildings.

The UbiQD team has been experimenting with assemblies of low-iron commercial glass, which allows more infrared light to transmit through it than higher-iron glass, with luminescent solar concentrator (LSC) glass layers infused with their CuInS$_2$/ZnS quantum dots. The team reports that their best assemblies so far deliver an NREL-certified 3.6 percent power conversion efficiency (of sunlight to electricity), which the UbiQD team rates as “a new champion efficiency for this technology.” That’s much less than commercial silicon PV panels, which deliver efficiencies in the range 15–20 percent, but enough to begin making sense for solar windows that can generate much of a building’s energy needs even as they let most of the sunlight pass through. To offset the maple-syrup tinge their QDs impart to the windows, the team added a blue pigment, thereby producing a more marketable color-neutral window. But that fix added an unwelcome “haze” that reduced the amount of light reaching the windows’ PV cells attached at the edges.

McDaniel acknowledges there is a lot of optimization work ahead, but the incentives are compelling enough to push on. “There is an $80-billion annual market for windows in new construction,” McDaniel says. “Retrofitting existing buildings could amount to another $10 billion in potential market for each major urban center.” The global green-energy win would be earned by converting as many of these buildings as possible from being loads on the grid to being assets. “The only way to do that is with glass,” says McDaniel, noting there simply is not enough roof real-estate available on buildings for rooftop solar cells to do the job themselves.

To remain alive as it moves toward realizing a solar window vision, UbiQD has been selling its first commercial product (by way of the spinoff company UbiGro) for the vast greenhouse agriculture market. They infused QDs into plastic film that reconditions sunlight passing through it—the UVs and blues get converted into growth-promoting oranges and reds. The film ends up amplifying greenhouse
There is an $80-billion annual market for windows in new construction. Retrofitting existing buildings could amount to another $10 billion in potential market for each major urban center.

crop yields and increasing profits for the greenhouse owners. The company’s wide-eyed projections puts the total accessible market in the greenhouse sector for their QD films at about $4 billion per year.

McDaniel welcomes the growth in sales for the company’s greenhouse films. But, he says, “we always have thought windows would become our best market for the material.” That’s where those baby steps come in. This year, UbiQD will be installing test windows in several buildings, including their own headquarters, a Holiday Inn Express, and another undisclosed venue.

ClearVue also has demonstration projects in the works. With some of the greenhouse market in its sights, for one, the company joined Murdoch University, with an announcement in April of the opening of what these partners claim is “the world’s first clear solar glass greenhouse.”

UbiQD and ClearVue are among the more visible players in the competition to bring solar windows to market, but there are others in the game. One of these, Ubiquitous Energy, based in Redwood City, California, told Forbes contributor Scott Snowden that it could begin marketing architectural solar windows by late 2022. Their technology relies on organic-dye-based solar coatings, rather than quantum dots, to convert a portion of solar energy entering the window into electricity. This approach to solar windows is a reminder of another threat that confronts entrepreneurs like McDaniel who commit to one solution among others that could end up getting to the finish line first. A study published in 2018 in Renewable and Sustainable Energy Reviews by scientists in Malaysia and Japan compared nine transparent solar photovoltaic technologies, among them ones based on QDs, organic dyes, and thin layers of up-and-comer PV materials known as perovskites. The conclusion? None performed well enough for large-scale commercialization.

It’s why a mix of chutzpah, perseverance, and steely nerves on the part of solar-window champions might be the most important indicator of potential success. “There’s always a risk of a new technology and that you might be scooped,” McDaniel says. “I try not to worry too much.”

Ivan Amato is a writer, podcaster, and crystal photomicrographer based in Hyattsville, Maryland.
Will Artificial Photosynthesis Ever See the Light of Day?

By Bob Whitby
Despite intensive research, we can’t yet reliably or cheaply convert sunlight into energy-dense fuel. But the goal is in sight—and still out of reach.

IN 1912, ITALIAN PHOTOCHEMIST GIACOMO CIAMICIAN laid out a remarkable vision of a world powered by the Sun.

“On the arid lands there will spring up industrial colonies without smoke and without smokestacks,” Ciamician wrote in a paper published in Science, “forests of glass tubes will extend over the plains and glass buildings will rise everywhere; inside of these will take place the photochemical processes that hitherto have been the guarded secret of the plants, but that will have been mastered by human industry which will know how to make them bear even more abundant fruit than nature, for nature is not in a hurry and mankind is.”

Coal fueled the Industrial Revolution, but Ciamician had already spotted a problem: though stores were vast, they weren’t inexhaustible. (He said nothing about the environmental consequences of mining and burning coal, an insight for a later time.) “Modern civilization is the daughter of coal,” he wrote, “for this offers to mankind the solar energy in its most concentrated form ....”

What solar lacked in energy density it more than made up for in abundance, he argued. By his calculations, the Sahara Desert received a daily dose of solar energy equivalent to that contained in six billion tons of coal. All that was necessary was to harness it the way plants do. More than a century later, Ciamician’s future is both tantalizingly close and frustratingly elusive. Solar energy is a reality in ways he could not have predicted. But the Sun still has an inconvenient tendency to set every day. Plants don’t wither and die at night because they’ve converted sunlight, water, and carbon dioxide into chemical bonds, glucose in this case, to fuel growth.

The ability to do the same thing, with the same ingredients, is the holy grail of renewable energy. Instead of glucose, artificial photosynthesis would produce hydrogen or a liquid hydrocarbon that could serve as a direct replacement for liquid fossil fuels, using infrastructure already in place. Electric vehicles are a part of the carbon-free energy future, but batteries won’t work everywhere. Passenger planes, ships, and trains need energy-dense liquid fuel; likewise, you’ll probably never heat your home with a battery-powered furnace.

We are indeed in a hurry to replace fossil fuels. Now, science just has to make nature’s secrets bear fruit.
THOUGH DISCOVERY OF THE PHOTOVOLTAIC EFFECT dates to 1839, and Bell Labs researchers built the first photovoltaic cell that generated enough electricity to run a device in 1954, study of artificial photosynthesis really began in 1972 when University of Tokyo researcher Akira Fujishima and Kenichi Honda successfully split water into hydrogen and oxygen using only sunlight as the source of energy.

Three years later, Fujishima and colleagues reported sustained production of hydrogen from an electrochemical photocell with a titanium dioxide (TiO₂) crystal anode to produce oxygen, and a platinum cathode to produce hydrogen. The device made 1.1 liters of hydrogen per day in the August sun as it falls on Japan, an efficiency rate they calculated at 0.4 percent. That’s less than half what nature achieves, but a promising start.

Fujishima didn’t report on his device’s lifespan, but it’s safe to assume it was short. One result of splitting water is that the water itself becomes corrosive and degrades or destroys the photoelectrodes. By 1980, Fujishima realized that while titanium dioxide (TiO₂) alone wasn’t the answer for a water-splitting device, it made a great coating for glass, tiles, and other surfaces exposed to sunlight, in effect making them self-cleaning. That’s easily commercialized research, unlike artificial photosynthesis.

It would be a familiar pattern; exciting breakthroughs followed by silence as the scientific challenges came into focus. In 1998, John Turner with the National Renewable Energy Laboratory (NREL) demonstrated a device that extracted hydrogen from water at an eye-popping efficiency rate of 12.4 percent. His discovery generated an avalanche of news stories, 300 by one tally. The catch? Turner’s device used rare and expensive materials, including the noble metal platinum as a catalyst. Turner’s device cost an estimated $10,000 per square centimeter and only lasted 20 hours.

In 2011 Daniel Nocera, then a chemistry professor at MIT, made headlines with a device built out of readily available materials—mostly silicon, cobalt, and nickel—that split water at about 2.5 percent efficiency. Nocera envisioned home-based systems that collected hydrogen to power fuel cells and produce electricity, an elegant solution that could easily be deployed all over the developing world. He even formed a startup to move the idea forward. But the company eventually shelved the idea because it was too expensive to deploy as a technology, instead using some of the ideas behind it to develop batteries.

Nature makes photosynthesis look easy, but the artificial version is devilishly complicated. At minimum it requires a light absorber, catalysts, an electrolyte, and a way to keep the resulting products—oxygen and hydrogen—separate so they don’t recombine into water or worse, explode. The reaction that produces oxygen turns water acidic, while the reaction that produces hydrogen turns water basic, so photoanodes and catalysts must be stable and efficient in those conditions. Systems designers have to consider electrical resistance, chemical transport, and varying timescales in which processes occur. Pieces of the device must be mutually compatible. And the whole thing should be simple and inexpensive.

THESE ARE PROBLEMS worth solving. Hydrogen can power fuel cells in electric vehicles or be burned in a modified combustion engine. It can be used as a nonfossil chemical feedstock to make...
ammonia, vital for food production. It can be combined with carbon dioxide to make liquid hydrocarbon fuel via the Fischer-Tropsch process. Someday, scientists hope it will be the first part of an integrated device that takes in sunlight, water, and carbon dioxide and produces usable hydrocarbon fuel.

While some of the most exciting advances have been made by small teams working in a lab, it’s become obvious that real success will require a major initiative with a clearly defined goal and big money backing it. A handful of countries, including the United States, have put major resources into the effort.

Enter the Joint Center for Artificial Photosynthesis (JCAP), a US Department of Energy (DOE) Innovation Hub funded in 2010 as part of President Barack Obama’s push toward renewable energy. JCAP started with $122 million in funding over five years and brought together more than 200 scientists from Caltech, DOE’s Lawrence Berkeley National Laboratory (Berkeley Lab), University of California campuses, and SLAC National Accelerator Laboratory. It had a clear goal to develop an integrated solar-energy-to-chemical-fuel conversion system and move it from the benchtop to commercialization.

Nathan Lewis, the George L. Argyros professor of chemistry at Caltech and JCAP’s founding director, was confident that success was at hand. “We are going to build prototypes of solar fuel generators as soon as we can,” he told the Los Angeles Times in a 2011 interview. “You will be able to hold it in your hand. It will look like bubble wrap, or it might look like a membrane, similar to the material in a very good waterproof jacket.”
Lewis, who is well known in the field for his predictions of an energy-producing device that can be rolled out like artificial turf, even offered a timeline. “We are almost positive that the first prototype will not work. The second prototype will probably not work. But sometime, maybe by the sixth time, it will work. In the first five years, we’ll have working prototypes, but the first ones will be expensive. We’ll declare partial victory, but we can always invent ways to make them faster and cheaper.”

As if on cue, JCAP announced in 2015 that they’d met their goal. By coating light-absorbing semiconductors such as silicon or gallium arsenide with a nanometer-scale skin of TiO$_2$—they created photoelectrodes that were durable, efficient, and cheap. A two-nanometer layer of nickel on top of the TiO$_2$ proved to be an effective catalyst for the photoanode which was grown onto a photocathode that used a nickel-molybdenum catalyst. A special plastic membrane kept the resulting gases separate but allowed ions to flow between the two sides. The prototype was a one centimeter square, 10 percent efficient, and lasted 40-plus hours—a record at the time. Was our clean-energy future finally here?

That’s a rhetorical question. Despite demonstrating real progress toward splitting water to produce hydrogen, the DOE cut JCAP’s funding by 40 percent in its second five-year period, and also changed its mission. Instead of moving water-splitting out of the lab and into the world, the new mission goes many steps beyond, to the difficult fundamental science of creating liquid solar fuels.

The mission change ultimately impacted the research team more than the reduction in funding. “We had a goal and a vision, and inspiration from President Obama to go do this moon shot,” said Lewis, about their first mission to split water. “And then you get close to the Moon they say, ‘No, we’re going to slingshot you out to Mars…’ You know, how you split water is not the same thing as how you selectively reduce CO$_2$. Not even close. Well, it literally was like taking the spacecraft when it was in lunar orbit and ready to find the lander and then diverting it. All hands on deck, we’re going to Mars tomorrow.”

“We were very close on the water-splitting side,” Lewis added. “I think it’s disappointing.”

“MARS” IS A NEW $100-MILLION INITIATIVE from DOE announced in July 2020. The money will fund two new research centers: the Liquid Sunlight Alliance (LiSA), led by Caltech in association with Berkeley Lab; and the Center for Hybrid Approaches in Solar Energy to Liquid Fuels (CHASE), led by the University of North Carolina at Chapel Hill. LiSA’s goals are to tailor molecules and materials to better understand transport and activity, make discoveries in light excitation and catalytic processes, and develop models for evaluating the durability of components and interfaces.

CHASE is tasked with researching photoelectrodes that combine semiconductors for light absorption with molecular catalysts. “Mechanistic investigations will provide unparalleled depth in the understanding of the light-driven chemistry at material-molecule-solution interfaces,” the researchers wrote in a recent paper outlining the center’s approach.

One challenge is developing catalysts that are both active in creating fuel and selective in the fuel they create. While the only products from splitting water are oxygen and hydrogen, reducing carbon dioxide can produce a range of products, some useful and some less so. The trick, CHASE believes, is to combine catalysts to create a multistep reaction sequence, or cascade, that spits out the desired fuel.

It’s extremely challenging science and it’s going to take time. “We’re not trying to do this to put it in a device in our five-year plan,” said Jillian Dempsey, associate professor of chemistry at the University of North Carolina, Chapel Hill, and CHASE deputy director. “I’m not promising you liquid solar fuels in 10 years. I’m trying to be optimistic that in 10 years we’re going to be ready for translational science with robust systems, because we will have addressed all of these fundamental challenges associated with selectivity and durability.”
In other words, we are closer than ever to solar fuels, but still a long way away. We now understand this relatively “simple” process is anything but. And we know it’s a solution whose time has come.

Giacomo Ciamician got that part, too.

“If our black and nervous civilization, based on coal, shall be followed by a quieter civilization based on the utilization of solar energy, that will not be harmful to progress and to human happiness,” Ciamician wrote in his 1912 paper. “The photochemistry of the future should not however be postponed to such distant times; I believe that industry will do well in using from this very day all the energies that nature puts at its disposal. So far, human civilization has made use almost exclusively of fossil solar energy. Would it not be advantageous to make better use of radiant energy?”

BOB WHITBY is a science writer based in Fayetteville, Arkansas.
OFF THE GRID

Renewable energy microgrids can provide sustainable power in remote communities as well as critical backup in areas where the power grid may be threatened by climate change

By Nancy Averett

GRIPPING A MICROPHONE, Apu Miguel stood on the concrete pad of a newly built open-air community center high in the mountains of Peru. “American brothers and sisters, as the leader of this community I want to thank you for the support you have given us on this project,” said the compact muscular man, oblivious to the row of fidgeting boys seated at a table behind him. “We are really happy,” Miguel added, “not just because of what this means to us, but what it means to our children.”

The cause for celebration on this spring 2019 morning was the electrification of Miguel’s tiny village, Mushuk Lamas, thanks to the installation of a photovoltaic (PV) battery microgrid that takes energy from the Sun and stores it in lithium-ion batteries so that the residents can have power around the clock. The electricity powers an internet tower, laptops, refrigeration for medicine—even flood lights for the soccer field. When volunteers first flipped the switch at the community center, Miguel exclaimed, “We have light!”

Microgrids—power installations that can run independently from the wider electricity grid—have been around for decades. Traditionally they were built in places where power lines could not easily go— islands, mountaintops—or where energy security is necessary, such as at hospitals or military bases. Until recently, however, most relied on fossil fuels such as diesel-powered generators.

But shipping fuel and then storing it in remote places is expensive, and as renewables have dropped in price in the past 20 years, more communities are integrating them into their microgrids. Now, experts say these sustainably powered systems—which can be solar alone, solar and wind, solar and...
“People are coming to see that the grid as we know it—it was good for when it was built, but it’s 100 years old.”

Photo credit: Twende Solar
hydrogen, or even, someday soon, solar and biogas—are poised to become more common both in developing countries where rural enclaves are hungry for electricity, and in developed countries where communities want better resilience from climate change-induced natural disasters that can wreak havoc on the larger electrical grid.

Two recent examples, says Jorge Elizondo, chief technology officer at Heila Technologies, were the recent prolonged power outages in Texas sparked by unusually cold weather that resulted in energy rationing, and in California wildfires that have led to blackouts.

“People are coming to see that the grid as we know it—it was good for when it was built, but it’s 100 years old,” says Elizondo, who started Heila, which makes a control system to manage renewable energy microgrids, as a doctoral student at MIT. “We need to do something better. We have to.”

Still, alternative-energy powered microgrids are not without their challenges. Researchers say these systems must have complementary technology to overcome several key issues—the highly variable nature of sun, wind, and other renewable energy sources, and their low inertia and voltage instability.

FOR EXAMPLE, WHEN A COMMUNITY DECIDES to add renewables to an already established system or, as in the case of Mushuk Lamas, create one from scratch, the first thing they must think about is how they are going to ensure a reserve of energy for cloudy or windless days. Some renewables systems retain a diesel generator for that purpose, but this can be problematic, says Mariko Shirazi, a professor of electrical engineering at the University of Alaska Fairbanks, news.uaf.edu/expertsguide/mariko-shirazi. Such generators must be left on all the time—to avoid a delay in power as the system switches from renewables to diesel—yet run at a very low setting. The former is expensive, and the latter is bad for the generator’s motor.

Installing a battery is often a better solution, says Shirazi. “When the sun shines or the wind goes up, the battery absorbs power. When it’s cloudy or the wind dies down, the battery injects power into the system.”

But batteries also have drawbacks. They work well in the short term, but for longer-term energy storage, the number of batteries needed increases rapidly—and so does the price.

However, battery efficiency could be improved, and costs lowered, says Venkat Subramanian, an advanced materials science and engineering professor at the University of Texas at Austin. For example, most microgrid control systems are designed to draw only low amounts of power from the battery, to prevent it from overheating, which would reduce the battery’s life and pose a safety risk. But that conservatism leaves a lot of potential power untapped.

A more dynamic control system, Subramanian says, would allow two-way communication between the battery and the controller. “So, the battery could say ‘No, I’m not going to take this charge from you today because if I take the charge, then I’m going to compromise on durability and so forth.’” To do that, he says, it’s necessary to create more sophisticated physics-based algorithms for grid control, something that the current grid designers believe is too complicated. “We’re working to change that,” he says.

Another option for energy storage is to convert it to hydroelectric. On El Hierro, one of Spain’s Canary Islands, excess energy from wind turbines pumps water into a reservoir located at high elevation. When the wind dies down and the system needs more energy, the water is released into a lower reservoir. As the water moves from one reservoir to the other, it powers turbines that supply power to the system.

What is more, hydrogen electrolyzers can split water into oxygen and hydrogen, and the latter can be stored in fuel cells and tapped when needed. Elizondo says this type of hydrogen storage was included in his company’s signature project—creating a microgrid control system for Stone Edge Farm, a Sonoma, California winery—because during the summer months the PV system was creating more energy than the system’s batteries could hold. “You can use that excess energy in the winter,” he says, “when solar production is about a third of what it is in the summer.”

In addition to energy storage, microgrid designers must also consider how to maintain system strength, which is the ability of a grid to preserve the correct voltage waveform if something unexpected happens, such as a lightning strike or fallen transmission line. In the traditional grid, large spinning machines convert mechanical energy into electricity and help provide system strength through the concept of inertia.

At a coal-fired electricity plant, for instance, the burning coal creates steam that causes a turbine to spin and generate electricity. If the steam suddenly goes out, the turbines will keep turning for a while due to Newton’s first law of physics. There is no electricity disruption for consumers, at least in the short term, and any shocks to the grid, such as a big step up in demand, get smoothed out because the system can easily speed up or slow down to absorb them.

Apu Miguel’s daughter was the first to plug a device into the community’s new microgrid, powered by solar.
“We’ve built our power system, hung our hat, on the physics of that inertia,” says Shirazi. “Diesel generators, steam plants, nuclear plants, they’re all using synchronous machines.”

Renewables, however, do not have grid inertia, which makes maintaining system strength trickier. Some systems contain software programmed to mimic inertia. Others have what’s called a synchronous condenser, which spins like a turbine but not for the purpose of generating electricity. Instead, it rotates to adjust conditions on the grid by generating or absorbing power—which is what keeps electrical voltage at a constant level and helps stabilize the system.

In time, researchers believe the controllers for renewables will be sophisticated enough—using algorithms, machine learning, and other computational techniques—to provide system strength without inertia. “A big topic of research right now is how do you get to a point where you no longer need synchronous machines?” says Shirazi. “Because as we move toward more and more renewables, it’s starting to be possible to imagine that scenario.”

IN ADDITION TO TECHNICAL CHALLENGES, installing renewable-powered microgrids requires considerations such as anticipating and addressing community interest, as well as concerns about how a new system will be maintained. In rural Alaska, for example, four Native American tribes decided that the only way they could move from a fossil fuel-based microgrid to a renewable one was to teach themselves how to install and maintain one, leading to the formation of the Chaninik Wind Group in 2005.

Volunteers with the nonprofit Twende Solar, which helped bring electricity to Mushuk Lamas, always make sure to include representatives of local solar companies to help in their installation projects. “They speak the language, they can source products, and parts, and they have skilled experienced labor to fix these systems if anything goes wrong,” says John Grieser, a renewable energy engineer in Portland, Oregon, who co-founded Twende and travelled to Peru to help install the Mushuk Lamas microgrid.

Grieser says that communities need to show a real interest in having a renewable microgrid system for it to succeed. He makes sure that when Twende approaches a community about installing a free solar-energy system that the residents contribute something in return. In the case of Mushuk Lamas, residents constructed a waterproof structure that holds the system’s batteries and controller. They also helped wire the buildings that would have power—the community center, communal kitchen, and medical post—installing lights, switches, and outlets. In addition, they dug trenches to run power to those buildings.

Mushuk Lamas residents did not help with the installation of lights along the community’s soccer field because Grieser and his volunteers wanted that to be a surprise. “We turned it on and made these big bright ‘Friday Night Lights’ on the soccer field,” Grieser says. “And it was like something out of a movie. It’s raining and the chief, who’s like 65 years old, is standing on the soccer field, water dripping from his face and he just looks up and yells out, ‘We have light!’”

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NANCY AVERETT reports on science, technology, and the environment from Cincinnati, Ohio.
MÁRIA TELKES
All Hail the Sun Queen

By Gwen Weerts

MÁRIA TELKES, WHO WOULD LATER COME TO BE KNOWN as “The Sun Queen,” was born in Hungary in 1900 where she attended school and obtained a PhD in physical chemistry. In 1925, she emigrated to the United States to work as a biophysicist. Aside from these facts, little is known about her early life, except that she must have been plucky.

Telkes loved the practical applications of scientific research. Working as a research engineer at Westinghouse Electric in the late 1930s, she studied energy conversion and thus heard about a promising new research project in Boston that revolved around her favorite source of energy, the Sun.

In 1938, Boston industrialist Godfrey Lowell Cabot gave Massachusetts Institute of Technology an endowment to study how humans might harness solar energy. MIT faculty were asked to bring forward proposals to utilize this gift, but 25-year-old assistant professor Hoyt Hottel was the only one who had an idea. He was thusly appointed chairman of the new Solar Energy Committee charged with developing a new field of research.

Hottel's first project was an experimental solar building, completed in 1939, the same year that Telkes was hired for the new MIT solar program. The building, named Solar I, would be used to investigate various methods of trapping solar energy and storing it as heat. Although it looked like a house, Hottel was careful to emphasize that Solar I was a research laboratory.

Soon after Telkes joined MIT, however, the team's efforts were redirected as the US entered World War II. For her part, Telkes invented an inflatable plastic solar distiller that could make seawater potable—a life-saving invention intended for use in the war’s Pacific theatre. But Hottel shopped around the design to so many different manufacturers that the desalinators were not delivered to the Air Force until after the war was over. Nonetheless, many consider Telkes’s invention the most significant of her 20 patent claims, which also include a functional solar oven.

Following the war, the Solar Energy Committee resumed interest in solar houses and began work on Solar II, which was meant to move the group closer toward the goal of a model solar-heated home—one that people could live in.

With Solar I, the team dabbled in different methods of heat storage. For Solar II, the idea was to pick one method and go all-in. The team had some success using water tanks to store heat in Solar I, but Telkes noted that the method required big heavy tanks with limited heat-storage potential. She thought phase-changing materials, those that store and release heat when they change from liquid to solid, were the path forward. Hottel read her proposal and thought it was promising, so Telkes's method was selected for Solar II.

Telkes's design used Glauber's salts, or sodium sulfate decahydrate, which melts at 90°F, just like coconut oil. Her calculations showed that, at least in theory, the salts would be more efficient at heat storage than water.

Unfortunately, the Glauber's salts used in Solar II tended to stratify after repeated phase changes, and they corroded their custom metal bins resulting in leaks. Worse, the salts rarely heated up more than 90°F in winter. In the end, Glauber's salts proved to be no more efficient than water at storing heat. The Solar II house project removed the salt tanks and returned to a water tank system. In so doing, they effectively removed Telkes from the solar fund as well.

Telkes, however, was determined to build a livable, solar-heated house, with or without funding from MIT. And she remained convinced that phase-changing materials were the way to go.

Telkes was also media savvy. She knew that research programs would only fully embrace solar research if the public got excited about it. She frequently appeared in popular magazines and newspaper articles, where she voiced her enthusiasm for solar.

The publicity helped her connect with modernist architect Eleanor Raymond, who agreed to work with Telkes to build the house she had envisioned. Together, they secured private financing from Boston philanthropist Amelia Peabody and built what came to be known as the Dover Sun House in 1948.

The Dover Sun House included a large south-facing sun collector, which looked like large black windows. The apparatus trapped heat in an air pocket that was sandwiched between a double layer of plate glass in front, and a black sheet of metal in the back. Fans
circulated the warmed air into metal bins that contained the Glauber's salts, and then throughout the house.

MIT, meanwhile, went to work building Solar III, which would use a water heat-sink method and, this time, also human inhabitants. But it was the Dover Sun house that wowed the press—perhaps in part because it was an unusual collaboration between three women—and it was featured on a 1949 cover of Popular Science.

The house's solar-heating system functioned for three years before the Glauber's salts corroded the metal containers and made them leak. Nonetheless, the project succeeded in capturing the imagination of the public, who now had "solar heat" and "solar energy" in their vocabulary.

Meanwhile, at MIT, friction arose between Hottel and Telkes. He was frustrated by her dogged pursuit of Glauber's salts in the face of negative results, and annoyed by her cozy relationship with the media. A review of Cabot's solar fund in 1953 by MIT Dean George Harrison blamed Telkes for the lackluster results of the program, stating that she "is a person of strong opinions which she expresses forcibly, who does not submit willingly to direction, and she has for some time been at outs with the committee, and especially with Professor Hottel." Telkes was fired from MIT.

This dismissal does not seem to have phased Telkes, because she continued her solar-energy research. By 1971, she and a team at University of Pennsylvania built a house that generated both heat and electricity from the sun using CdS/Cu₂S solar cells.

While Telkes remained a lifelong and vocal advocate for the practical uses of solar energy, Hottel's interest had always been more academic. He saw solar-energy systems as mere engineering problems. Given the cheap abundance of fossil fuels, what was the imperative to move the technology forward? Toward the end of his life, Hottel was interviewed by the Chemical Heritage Foundation, where he said, "We're kidding the public about the sun. It's not worth as much as claimed. The cost of doing something using the sun has always been a little higher than if you do it some other way."

Hottel was wrong about that. In 2021, silicon photovoltaics are now the cheapest way to generate electricity. Telkes's ideas for harnessing the energy of the sun were visionary, even if the methods were initially flawed. Although active solar-heating technology has largely been abandoned, Telkes's lifetime of advocacy for research into solar energy rightfully earned her moniker "The Sun Queen."

Ave, Mária.

GWEN WEERTS is the Editor in Chief of Photonics Focus.

EFFORTS TO CAPTURE SOLAR ENERGY for human use began decades before Gerald L. Pearson was born in Salem, Oregon, in 1905. His father was a fruit farmer with a fourth-grade education who insisted that Gerald and his two brothers go to college. Pearson studied physics at Willamette University in Salem, then earned a master’s degree at Stanford University.

By the time Pearson was hired by Bell Labs in 1929, 90 years had passed since French physicist Edmond Becquerel, then a 19-year-old in his father’s laboratory, measured a small voltage between platinum electrodes in an acidic solution containing silver chloride illuminated by sunlight. British engineer Willoughby Smith later discovered photoconductivity in selenium in 1873, and in 1883 American inventor Charles Edgar Fritts applied gold leaf to selenium to make the first solar cell. However, its anemic efficiency, less than one percent, made it impractical.

An important experiment in silicon physics at Bell Labs in 1940 also marked a big step in solar cells. Russell Ohl was studying how impurities affected silicon properties when he found that illuminating a cracked sample of silicon with different impurity levels on two sides produced a surprisingly strong voltage across the crack. It led to Ohl’s observation of the first junction of silicon regions doped with positive and negative impurities—a key to the junction diode and transistor—as well as the first silicon solar cell.

Bell Labs made military projects top priority during World War II, but turned back to semiconductors in 1946, transferring Pearson into the program. After five years of war work, Pearson told historian Lillian Hoddeson, “we felt free as the wind.”

Pearson was interested more in the scientific aspects of semiconductors than in making transistors. He did not work on the point-contact transistor that was the first type invented, but his research on semiconductor behavior and p–n junctions contributed to the junction transistor which came next. Pearson did develop the first useful silicon field-effect transistor, which he described at a 1953 meeting.

Meanwhile, a practical problem roused Bell Lab’s interest in solar power. The dry cell batteries used to power remote telephone equipment degraded quickly in humid regions, and in 1952 Bell asked engineer Daryl Chapin to study other possible power sources. Chapin thought solar cells might work, but wanted more efficiency than selenium could offer, so he asked Pearson, a personal friend, about alternatives.

Pearson and Calvin Fuller had been studying how impurities affect silicon’s properties, important for transistors and other semiconductor devices. Fuller gave Pearson a silicon sample doped with gallium to give it positive charge carriers, and suggested that Pearson dip it into hot lithium to add negative carriers. After connecting an ammeter to the sample, they turned on a lamp and saw the highest current flow ever recorded in a solar cell.

Pearson walked to Chapin’s office and told him to drop selenium and switch to silicon. Yet, problems emerged: lithium migrated through the silicon and good electrical connections to the semiconductor were hard to make. First, they replaced the lithium with phosphorous, which helped but was not enough.
Then they tried a new recipe suggested by Fuller: doping the silicon with arsenic as negative carriers, then applying a very thin layer of boron to make positive carriers and form the p–n junction very close to the surface. Those changes also made good electrical contacts, allowing them to convert six percent of the solar energy into electricity, beating the one percent that solar-energy pioneer Mária Telkes, then at MIT, had reported for thermoelectric conversion in 1947. Six percent was the target for the telephone application, though Chapin calculated that an ideal silicon solar cell could reach 23 percent of sunlight into electricity.

Chapin, Fuller, and Pearson submitted a letter to the *Journal of Applied Physics*. Around the same time, the front page of the 27 January 1954 *New York Times* heralded an “atomic battery” produced by the RCA Corp. in which electrons emitted by radioactive strontium-90 generated electricity from a p–n junction in silicon. The RCA Corp. invention produced a microwatt of power per square yard of solar cell.

Bell Lab’s solar cell made the front page of the *Times* shortly after on 26 April 1954, appearing between announcement of the first large-scale test of the Salk polio vaccine and a gangland killing in New York. A square meter of Bell’s solar cell converted six percent of the incident solar energy into electricity, effectively leaving RCA’s atomic battery in the dust. The *Times* projected solar cells might someday harness the “almost limitless energy of the sun for the uses of civilization.”

Bell managers told Pearson the solar cell had received “the best newspaper publicity coverage ever in the history of the Bell system.” But Pearson was not as impressed by the publicity, noting that the invention of the transistor earned only six inches on the *Times* obituary page. He told Hoddeson the solar cell “was the most important publicity-wise, but I think scientific-wise it may not have been.”

Pearson measured success by how much his inventions were used. When he totaled up sales of his inventions in 1969, they had reached $260 million (nearly $1.2 billion today). His best-selling invention at the time was the silicon rectifier at $154 million, followed by p–n–p–n devices at $65 million, $18 million in thermistors, $20 million in field effect transistors, and only $5.8 million in solar cells, just over two percent of the total.

Yet solar cells captured the public’s imagination. Edmund Scientific sold them in their catalog in the 1960s—you can see my own here, which I purchased for $2.25. Crucially, solar cells powered the space race, since all satellites built to last more than a month required solar power. Looking back, Pearson acknowledged, “The scientific equipment on the Moon and on Mars wouldn’t function if it weren’t for solar cells.”

Pearson died in 1987, too early to see solar rooftops, solar-power farms, or solar cells with efficiency above the 23 percent limit that Chapin predicted 67 years ago. If he was around today, the tremendous growth of solar power and its importance in controlling climate change might have changed his mind.

*JEFF HECHT is an SPIE Member and freelancer who writes about science and technology.*
2021 | The Power of Light

THIS ISSUE PUTS A SPOTLIGHT on the myriad ways that humans harness light. The conversion of light energy supports every form of life whose food chain traces down to photosynthetic organisms of some kind. The Sun powers our lives and, with other stars by night, reveals our visual world. Beyond the weak natural sources of light on Earth—bioluminescence in the marine and insect world, the phosphorescence of some minerals—only fire and flame provided any other possibility for illumination, until recent times with the introduction of incandescent bulbs.

The whole field of lighting experienced a major advance with the arrival of solid-state sources providing single-color emission. The first LED based on semiconductor electroluminescence, reported in 1927, led some 60 years later to OLED technology. The challenge of achieving usable output at the blue end of the visible spectrum led to development of high-brightness GaN emitters in the early 1990s, paving the way for revolutionary new forms and applications of solid-state lighting. Combining red, green, and blue LEDs, or using an adjunct phosphor, these new simulations of daylight have rapidly displaced the much less efficient, earlier forms of light bulb.

Many modern forms of display technology utilize the activation of individual colors, supplemented by quantum dots in the last decade, while a facility to modify the spectrum of radiant illumination leads to other applications. In our homes we can now have controllable mood luminaries; in agriculture, lighting optimizes the growth of specific crops with suitably engineered wavelengths.

Beyond the numerous applications in electrical lighting, it is interesting to observe the flip side of the coin: the conversion of light into electrical energy. All are familiar with carbohydrate synthesis in photosynthesis, but studies now indicate a possible future for artificial leaves in synthesizing fuel. In both respects, light-driven electrical charge separation drives the underlying molecular mechanisms.

Since the development of the first semiconductor-based forms of the solar panel, the steady improvement in designs and efficiency has progressively led to its domination of global energy harvesting. Solar power is now a major contributor to national power grids straining to address energy demand. Microgrid implementations secure power for communities too remote for connection to urban networks, while solar lamps can provide night-time power in even less well-endowed communities. Interconversion between electrical energy and light continues to blaze new paths of application, empowering human lives and transforming societies.

On a final note, I am delighted that after a hiatus of more than a year, we can return to in-person conferences, resuming operations in San Diego for SPIE Optics + Photonics, 1-5 August. There is a valuable legacy in the sophisticated digital operations that can now sustain conferences for remote participants, and our online meetings have been warmly welcomed by SPIE constituents. But zooming becomes wearisome; there is no way to replicate the experience of an exhibition floor, the serendipitous encounters, live lecture-floor interactions, receptions, and networking events. Large-scale meetings simply don't translate to an online format. We have heard loud and clear the message that no experience can match meeting in person; the freedom to do so is, indeed, a cause for real celebration.
SPIE
Deadlines and Events

July
1: Nominations due for SPIE Awards
14: Manuscripts due for SPIE Optics + Photonics
12-16: Photonics for Quantum Digital Forum
22: Voting closes for the SPIE 2021 election

August
1-5: SPIE Optics + Photonics in San Diego, California
2: SPIE Annual General Meeting in San Diego, California
18: Abstracts due for SPIE Photonics West 2022
18: Abstracts due for SPIE Medical Imaging 2022
18: Manuscripts due for SPIE Remote Sensing
18: Manuscripts due for SPIE Security + Defence
18: Manuscripts due for SPIE Optical Systems Design
25: Abstracts due for SPIE Smart Structures + Nondestructive Evaluation 2022
30: Manuscripts due for SPIE Photonex + Vacuum Technologies
30: Manuscripts due for SPIE Space, Satellites + Sustainability

September
1: Abstracts due for SPIE Advanced Lithography + Patterning 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, Madrid, Spain
13-16: SPIE Remote Sensing, Madrid, Spain
13-16: SPIE Security + Defence, Madrid, Spain
15: Nominations due for SPIE Fellows
16: Submission deadline for SPIE International Day of Light Photo Contest
26-30: SPIE Photomask Technology + EUV Lithography, Monterey, California
28: Manuscripts due for SPIE Optifab
28-30: SPIE Space, Satellites, + Sustainability, Glasgow, UK
28-30: SPIE Photonex + Vacuum Expo, Glasgow, UK

October
1: Applications due for Prism Awards
4: Abstracts due for SPIE Defense + Commercial Sensing 2022
8: Applications due for Nick Cobb Scholarship
10-12: SPIE Photonics Asia, Nantong, Jiangsu, China
17-20: SPIE Laser Damage, Rochester, New York
18-21: SPIE Optifab, Rochester, New York
SPIE Awards Announced

SPIE Gold Medal

SPIE FELLOW HUGO THIENPONT, a professor with the Faculty of Engineering at the Vrije Universiteit Brussel, in recognition of his profound and durable impact on society and his pioneering vision for photonics. The different disruptive instruments he developed and implemented during the past decades have generated a tangible impact on education, research, innovation, and societal well-being in Flanders, Europe, and beyond.

In the 1980s, Thienpont was one of the first European researchers to recognize the potential impact of the science and technology of light. As such, he was one of the first to actively promote photonics as both a new research and engineering discipline and a key enabling technology. Many of his scientific results—in areas such as microlasers; organic materials for nonlinear optics, optical fiber sensors, optical lab-on-chips and organ-on-chips, and freeform optics—are utilized across industry via medical endoscopes, augmented- and virtual-reality goggles, head-up displays, microscopy, space telescopes, and microsatellites.

The SPIE Gold Medal is the highest honor the Society bestows and is awarded in recognition of outstanding engineering or scientific accomplishments in optics, photonics, electro-optics, or imaging technologies or applications.

SPIE Directors’ Award

SPIE FELLOW MARYELLEN GIGER, the A.N. Pritzker Professor of Radiology at the University of Chicago, for her outstanding service to SPIE and the optics and photonics communities. Giger has been a key voice in data-driven approaches, including how we serve the community, and an active leader in advancing the Society’s equity, diversity, and inclusion efforts.

Giger is the inaugural editor-in-chief of the Journal of Medical Imaging and one of the founding chairs of the Computer-Aided Diagnosis Conference at SPIE Medical Imaging. Her NIH-funded research in machine-learning, image-based analyses of breast cancer for risk assessment, diagnosis, prognosis, response to therapy, and biological discovery has yielded various translated components.

The SPIE Directors’ Award is presented to an individual who has rendered a significant service of outstanding benefit to the Society.

SPIE President’s Award

SPIE FELLOW MARÍA J. YZUEL, professor emeritus at the Autonomous University of Barcelona, for her inspirational leadership in the field of optics, tireless dedication to the promotion of equity, diversity, and inclusion in science, and many years of outstanding service to SPIE and its international community.

Yzuel’s extensive work has had enormous influence in a variety of optics areas, including optical systems, optical processing of information, and polarization. Her research has yielded improvements in the use of spatial light modulators as diffractive optical elements and has been applied and developed in fields such as medical and diagnostic imaging.

The first female professor of physics in Spain and the first woman president of the Spanish Optical Society, her commitment to diversity in physics includes participation with the Association of Women Researchers and Technologists and the SPIE Women in Optics program. In 2009, she served as SPIE President.

The SPIE President’s Award is presented to an individual who, in the opinion of the President and the Board of Directors, has rendered a unique and meritorious service of outstanding benefit to the Society.

See the entire list of SPIE Award winners at spie.org/2021awards
New SPIE Photonics-Technician Scholarship

WITH THE OPTICS, PHOTONICS, AND IMAGING industry growing exponentially, and industry reports suggesting that one-fifth of experienced technicians are approaching retirement, the need for skilled optics and photonics technicians—and the need to attract capable students into relevant programs—is obvious.

The Eichenholz-SPIE Photonics Technician Scholarship provides direct support for students in technician associates’ or certificate programs. The scholarship program is primarily funded by SPIE Fellow Jason Eichenholz, a serial entrepreneur and pioneer in laser and optics-enabled innovation, product development, and commercialization.

Established for students enrolled or planning to enroll in a laser, optics, or photonics technician associate or certificate program, each of the four annual $2,500 scholarships will be awarded to offset tuition and fees, textbooks, computers, or a computer upgrade, as well as other supplies and equipment needed for courses of instruction. Scholarship winners will also receive a one-year complimentary SPIE Student Membership.

Application requirements also include technician-program information, a resume, and a personal essay.

Learn more at spie.org/technicianscholarship

SPIE Endorses Updated Endless Frontier Act

SPIE SUPPORTS a new version of the Endless Frontier Act introduced by Senate Majority Leader Chuck Schumer (D-NY) and Senator Todd Young (R-IN), and by Representatives Ro Khanna (D-CA) and Mike Gallagher (R-WI) in the House of Representatives.

The updated version of the bill incorporates community input and places a high priority on the commercialization of technology. It would establish a new technology directorate within the National Science Foundation (NSF) designed to strengthen US leadership in critical technologies through fundamental research. The bill would authorize $100 billion over five years for carrying out the mission of the new directorate.

Key technology-focus areas highlighted in the bill cover a range of optics and photonics-related technologies, from AI, biotechnology, and semiconductors, to quantum computing, advanced communications technology, and cybersecurity.

Learn more at spie.org/endorse

SPIE Annual General Meeting

The SPIE Annual General Meeting is scheduled to take place in-person on Monday 2 August, during SPIE Optics + Photonics in San Diego. Slides from the meeting will be available in the SPIE Member Lens newsletter.

AHEAD OF THIS YEAR’S INTERNATIONAL DAY OF LIGHT (IDL) CELEBRATION on 16 May, the IDL Steering Committee announced the launch of the “Trust Science” pledge, a worldwide campaign to promote support for the scientific process and to acknowledge the many benefits of science for society. Society at large is experiencing a variety of challenges impacting its trust in science. The last several months have openly demonstrated the importance of evidence-based solutions—in fields from healthcare to engineering. The Trust Science pledge invites the general public to join leading scientists worldwide to affirm confidence in the process of scientific research and discovery.

The campaign is organized by SPIE, the IEEE Photonics Society, and The Optical Society Foundation (OSAF), together with the IDL Steering Committee. To date, the pledge has seen enthusiastic support worldwide with founding signatories including Nobel laureates, UNESCO L’Oréal For Women in Science prize winners, presidents and CEOs of major scientific organizations, as well as scientists and students from more than 20 different countries. The pledge is now being shared widely to invite all interested individuals to take part.

Read more at trust-science.org
**SPIE Digital Library Subscription Price Reduction Extended**

SPIE HAS EXTENDED its 10 percent price reduction for SPIE Digital Library and SPIE journal institutional subscriptions into 2022.

The discount applies to both new and renewing SPIE Digital Library institutional subscriptions as well as institutional subscriptions to individual SPIE journals invoicing before 1 July 2022. Pricing for all other SPIE publications will remain flat for 2022.

The price reduction was originally implemented last year in recognition of the challenges facing the library and research communities during the COVID-19 pandemic. The SPIE Digital Library, the world’s largest collection of optics and photonics applied research, comprises more than 540,000 publications. SPIE is committed to enabling the broadest possible dissemination of information to researchers, engineers, and academics worldwide.

Learn more at spie.org/DLprice-reduction

**Discovering Light in English**

IN MAY, SPIE, The Optical Society Foundation (OSAF), and the Spanish National Research Council (CSIC) co-published an English translation of Discovering Light: Fun Experiments with Optics.

Originally published in Spanish by CSIC and Catarata Books in 2018 for a general audience as well as secondary-education-level students, Discovering Light is a collaboration by 14 young scientists—including project editor María Viñas-Peña—who met as researchers at Spain’s Institute of Optics (IO-CSIC). The English version of Discovering Light is the first translation of the book.

Section titles range from the basic “What is light?,” “Optical instruments,” and “Safety rules for the use of laser pointers,” to the more expansive “Light in nature,” “Light-based technologies,” and “The human eye: a biological camera.” Content includes a variety of easy-to-follow experiments related to different optical phenomena and technologies.

The book is available as an open access, downloadable eBook via the SPIE Digital Library.

Learn more at spiedigitallibrary.org/PM324

**SPIE and Vanderbilt University Announce First Recipient of $1 Million Optical Engineering Faculty Fellowship**

VANDERBILT UNIVERSITY (VU) assistant professor of biomedical engineering Yuankai “Kenny” Tao has been named first recipient of the new SPIE Faculty Fellowship in Optics and Photonics.

The fellowship is funded by a $500,000 SPIE gift that is matched 100 percent by VU. It is the eighth major SPIE gift to universities and institutes as part of the Society’s ongoing program to support the expansion of optical engineering teaching and research.

Tao received his bachelor’s degrees in electrical and computer engineering and biomedical engineering, as well as a master’s degree and a PhD in biomedical engineering, from Duke University. Prior to joining the faculty at VU, Tao was an assistant professor in the Department of Ophthalmic Research at Cleveland Clinic and director of the diagnostic imaging and biophotonics laboratory at Cole Eye Institute.

“The SPIE Faculty Fellowship will be instrumental in expanding opportunities for Vanderbilt University faculty working in optics and photonics,” said SPIE President David Andrews. “Their faculty will benefit directly from the gift, and it will positively impact the learning experience of their students. This partnership between SPIE and Vanderbilt will have a long-standing effect on generations of optics teachers, researchers, and students to come.”

The SPIE Endowment Matching Program was established in 2019 to increase international capacity in the teaching and research of optics and photonics. With this latest endowment, the program crosses the $3-million threshold for funds provided.

For more information, visit bit.ly/SPIEndow

Photo credit: Vanderbilt University
THE 2021 WINNER of the Michael Kidger Memorial Scholarship award is Geoffroi Côté, a second-year PhD candidate at Université Laval in Canada. Côté received his undergraduate degree in engineering physics from Laval in 2017. He entered the PhD program there on a fast track following the award of a master’s degree in 2019.

The Michael Kidger Memorial Scholarship was established in 1998 to honor Michael John Kidger, a well-respected educator, design software developer, and member of the optical science and engineering community. The scholarship is awarded to a student engaged in optical design including lens design, illumination design, and computational optical design.

For more information, visit kidger.com

Michael Kidger Memorial Scholarship

SPIE Journals Added to Web of Science

TWO NEW SPIE JOURNALS, Advanced Photonics and Journal of Optical Microsystems, have been recognized by the scholarly publication indexing service Web of Science.

Launched in 2019, Advanced Photonics is a highly selective, open access journal publishing innovative research in all areas of optics and photonics. Co-published by SPIE and Chinese Laser Press, the journal has been added to the Science Citation Index Expanded (SCIE) index, which means that the journal can expect to receive an impact factor in 2022. This rapid inclusion in the SCIE database is an indicator of the high-quality content published in the journal. Papers published in 2019 averaged 12 citations per paper.

At the same time, the Journal of Optical Microsystems (JOM) was added to the Web of Science’s Emerging Science Citation Index. Launched in January 2021, its early inclusion, after just one issue of publication, is a vote of confidence and a positive sign for the new journal. It publishes cutting-edge research in all aspects of optical and photonic microsystems, from materials and fabrication of micro-optical and photonic components, through assembly and packaging, to systems and applications.

Both Advanced Photonics and the Journal of Optical Microsystems are Gold Open Access journals. SPIE will be waiving all open access fees on submissions to both journals through 2021.

Learn more at spie.org/journalsWoS

SPIE Luminaries Series

THROUGH 2021, SPIE IS CELEBRATING the work of those who have "lit the way" for research in optics and photonics by featuring a different “luminary” every month. Each of these luminaries has made a significant impact on the development of a field that is core to SPIE, including biomedical optics, electronic imaging, optical systems, lens design, neurophotonics, light-based energy research, remote sensing, medical imaging, and nanophotonics.

Many luminaries have published with SPIE for decades, while others are newer to the community. To highlight their scholarly contributions, their SPIE-published research will be open access on the SPIE Digital Library during the month they are featured. Ching Tang, inventor of the OLED, is July’s luminary.

Luminaries featured to date:

• William H. “Bill” Arnold, a lifelong lithography expert and former SPIE President, who passed away in December 2020
• Chris Xu, known for his contribution to the development and invention of three-photon microscopy
• Harrison Barrett, a longtime leader in developing methods for the assessment and optimization of medical imaging
• John Pendry, a theoretical physicist and leader in transformation optics
• Wolfgang Osten, known for his significant contributions to the development of wide-scale optical imaging and metrology
• Halina Rubinsztein-Dunlop, who, with her team, produced one of the first Bose-Einstein condensates and designed and built atomic circuits using cold atoms
• Ching Tang, inventor of the OLED

Learn more at spie.org/luminaries
Reflections

A refugee carries a solar panel on her journey, which will be crucial for powering cell phones to communicate with family and social services.

Photo by Muhammad Mostafizur Rahman, head of news photography at bdnews24.com in Bangladesh.

mustafizmamun.com

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.
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. Solid-state devices composed of thin films of organic molecules that create light with the application of electricity
2. Branch of chemistry concerned with chemical effects of light
4. Silicon doped with positive and negative impurities
6. Absorbs light to initiate electrochemical transformations
8. Relating to the production of electric current at the junction of two substances exposed to light
12. Having to do with the Sun

ACROSS:
3. Material with an electrical conductivity value between materials such as metallic copper and glass
5. Changes resistance depending on the amount of light incident on it
7. Coinventor of the silicon solar cell
9. Italian photochemist
10. Material that can help increase solar cell efficiencies
11. How green plants use sunlight to make food from carbon dioxide and water
13. A material based on quantum dots
14. A decentralized source of electricity
15. Container in which chemical energy is converted into electricity for use as power source
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