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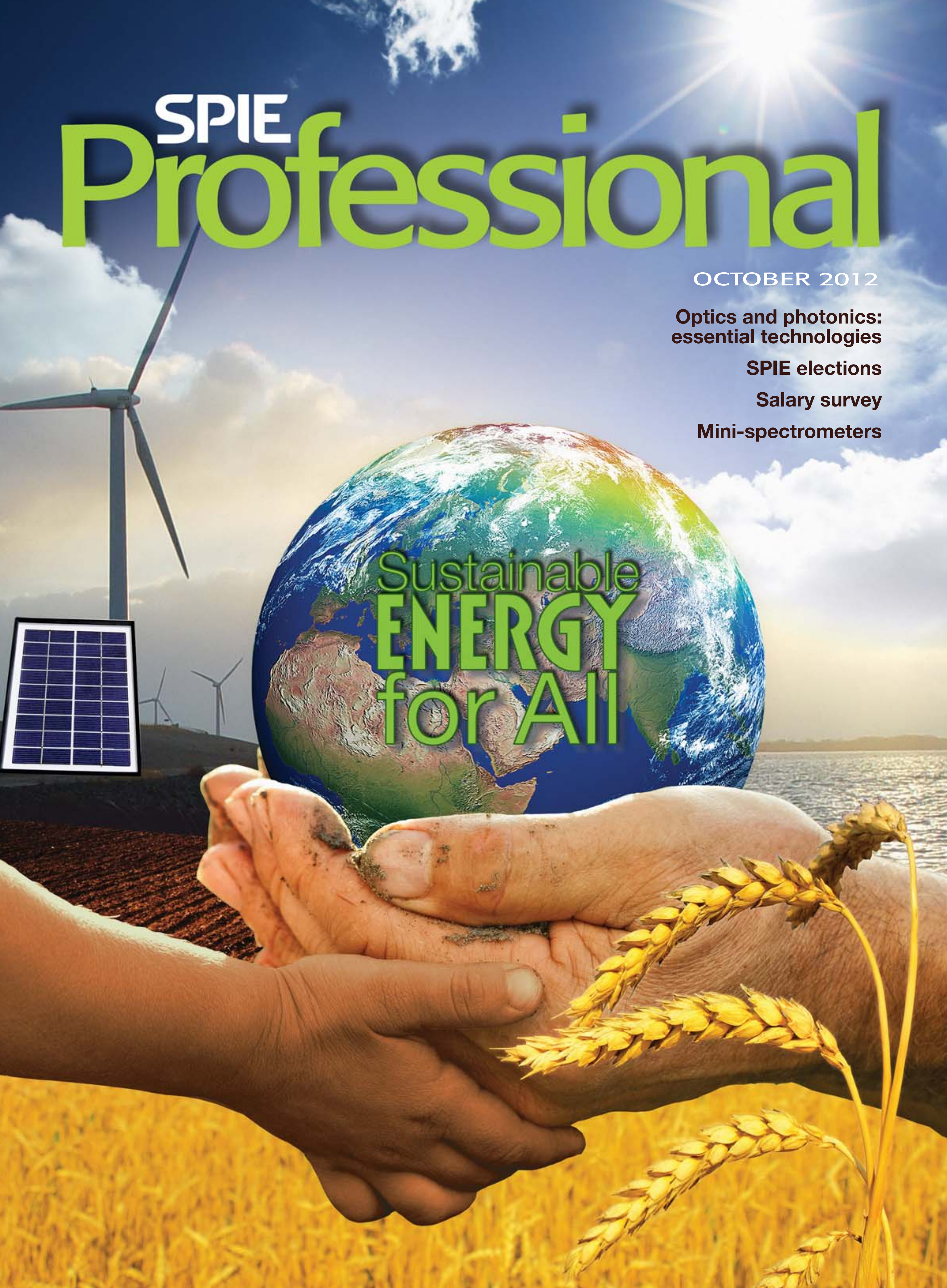


Sustainable ENERGY for All

Optics and photonics are enabling the expansion of sustainable energy.

By **Steve Eglash** and **Kara Fisher**


Eglash


Fisher

Energy is fundamental to health, safety, comfort, and progress for all seven billion people on this planet, but access to energy varies widely depending on whether people live in a wealthy or a poor country. In order to provide adequate energy for everyone without destroying the planet, sustainable ways must be found to generate, convert, store, and use energy.

The fields of optics and photonics are playing an important role in developing these solutions. The importance of sustainable energy was reinforced when the United Nations declared 2012 as the International Year of Sustainable Energy for All (www.sustainableenergyforall.org).

WE SUPPORT SUSTAINABLE ENERGY FOR ALL

This declaration has three major themes: universal access to energy, energy efficiency, and renewable energy.

Three billion people — more than 40% of the world's population — use wood, coal, charcoal, or animal waste for cooking and heating, and 1.5 billion people lack access to electricity. The human, social, economic, and environmental costs of this inequity are tremendous.

The optics and photonics community is addressing this problem on several fronts.

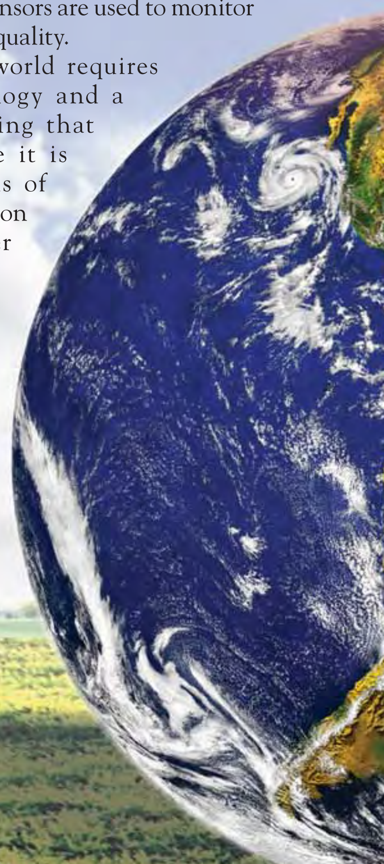
Light-management techniques are making thin-film solar cells more efficient and less expensive. Better light emitters, phosphors, and lenses are making LEDs brighter and more efficient.

Wind turbines use LIDAR to "see" wind gusts and lulls moments before they arrive. Improved display screens using LCDs or OLEDs are expanding the functionality of cell phones, which are often a person's primary or only access to the modern information economy. Video cameras enable smart energy-efficient buildings. Optical sensors are used to monitor air, water, and food quality.

Changing the world requires the right technology and a means for deploying that technology where it is needed Two-thirds of the world's population has an annual per capita income less than US$10,000 equivalent and


Courtesy Rune Hansen/UNDP

Solar panels provide clean energy in many remote places around the world.



Courtesy Paolo Patruno for Solar Sisters

Students in Uganda study by the light of a single solar-powered lantern, easier and safer than a kerosene lamp.

one-third has less than US$1,000.

Such severely constrained economics make it very difficult to get sustainable energy solutions to the people who need them the most.

Nonetheless, optics and photonics researchers are finding opportunities in both developed and resource-poor parts of the world to build better and cheaper solar cells; get industry and academia to work together on sustainable energy for all; and devise new business models so that solar cells, batteries, and LED lights reach some of the poorest people on the planet.

Better performing solar cells

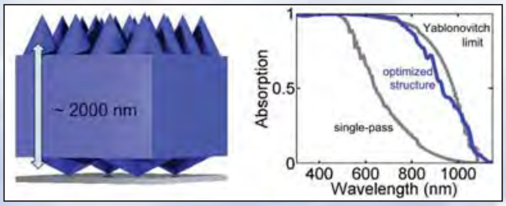
Solar photovoltaic panels can be a major part of a global sustainable-energy solution, but advances are needed in performance and cost. It is well known that anti-reflection coatings can maximize the amount of sunlight transmitted into and absorbed by a solar cell. The optical absorbing layer in bulk silicon solar cells is thick enough to assure that all incident light is absorbed.

The absorbing layer in thin-film solar cells made using silicon, CdTe, CIGS, or GaAs, however, might be too thin to absorb all light in one or two passes, so advanced light-management techniques are needed to maximize absorption and reduce cost.

Recently, the U.S. Department of Energy funded the creation of three research consortia to develop advanced technologies for the PV manufacturing industry.

One of these is the Bay Area Photovoltaic Consortium (bapvc.stanford.edu) (BAPVC), comprising universities, national labs, and industry. As part of BAPVC's optics and photonics R&D program, university researchers are developing light-trapping techniques, transparent metal electrodes, and other advanced optical materials and structures.

Professors Shanhui Fan and Yi Cui at Stanford University, for example, are working on the theory and experimental application of photon management in nanostructured solar cells.



Courtesy of Fan Group

At left, a silicon structure for simultaneous anti-reflection and light trapping. The 3D structure has the same amount of silicon as a flat film with a thickness of 2 microns. At right, the absorption spectrum of the structure is compared to the single-pass and the Yablonovitch limit spectra. The structure generates a short circuit current of 34.6 mA/cm^2, close to the Yablonovitch limit of 35.5 mA/cm^2.

Enhancing optical absorption is important for improving efficiency and reducing cost for ultrathin-film solar cells. With an active layer thickness of only a few microns or less, efficient light absorption requires both broadband anti-reflection coatings and effective light-trapping techniques, which often have different design considerations.

The Fan group has shown that by employing a double-sided grating design, they can simultaneously optimize the geometries for anti-reflection and light-trapping purposes to achieve broadband light absorption enhancement. The

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SPIE supports UN initiative

SPIE is among numerous organizations endorsing the U.N. Sustainable Energy for All initiative (www.sustainableenergyforall.org).

Ensuring that all people across the globe have access to modern energy services by 2030 is fundamental to addressing nearly every major challenge and opportunity humanity faces today, according to a U.N. task force supporting universal access to energy.

"Be it jobs, security, climate change, the empowerment of women, food production or household income, access to sustainable energy for all is essential for strengthening economies, protecting ecosystems and achieving equity," the task force said in an April technical report.

"Access to energy that is sustainable, secure and affordable is a critical catalyst for economic growth and development."

Sustainable Energy for All

◀ *Continued from page 21*

Energy Affiliates at Stanford

The Energy and Environment Affiliates Program (eeap.stanford.edu) is Stanford University's industry liaison for interactions with faculty in energy, environment, materials, chemistry, and sustainability.

The program creates a single point-of-contact and gateway for organizations interested in energy and environment research at Stanford and helps industry and faculty to engage with each other.

The Affiliates Program is primarily about establishing a relationship and the exchange of ideas. Companies benefit from access to emerging technology, out-of-the-box thinking, and innovative problem solving. Stanford benefits from exposure to practical real-world problems, constraints, and opportunities.

UN Photo/Mark Garten

UN Secretary-General Ban Ki-moon gets a first-hand look at the solar test facility at the National Renewable Energy Laboratory in Colorado (USA).

Photo courtesy Jeff Schmidt, Simpa Energy

A pay-as-you-go Simpa Solar Home System outside of Kundapura, Karnataka, India, can charge mobile devices and power a small fan and 2-3 LED lights.

photocurrent generated by the proposed thin-film absorber is close to the Yablonovitch limit that assumes perfect anti-reflection and perfect light trapping for silicon thin film at the thickness of 2 microns (See figure on page 21).

Facilitating connections

Sometimes advances come from technical innovation, sometimes from innovative business models, and sometimes from the social sciences, but connections are critically important in every case.

Here at Stanford, we have established the Energy and Environment Affiliates Program (eeap.stanford.edu) to be Stanford's industry liaison for research in energy, the environment, materials, chemistry, and sustainability. The Affiliates Program is a membership organization that facilitates communications and relationships for companies and other organizations with Stanford's faculty and graduate students.

The program works across the entire university but particularly closely with the Precourt Institute for Energy (pie.stanford.edu), the hub of energy research; the Woods Institute for the Environment (woods.stanford.edu), the hub of environmental research; and the Geballe Laboratory for Advanced Materials (www.stanford.edu/group/glam).

New business models improve access to sustainable energy

Programs like the BAPVC and Stanford's Energy and Environment Affiliates Program focus on business opportunities in the developed world, but there are also bottom-of-the-pyramid opportunities.

People without access to electricity and modern lighting must use kerosene lanterns to light their homes. Kerosene lanterns are a sensible solution for many people in resource-poor parts of the world because they are inexpensive to purchase and fuel can be bought in small increments as finances permit.

Unfortunately, kerosene lanterns are an awful solution in all other respects. They produce a poor quality, flickering light. They create indoor air pollution that leads to respiratory diseases. They can cause burns and fires. And they are expensive to operate because the cost of kerosene far exceeds the equivalent cost of electricity.

Poor people who live off grid have had no practical alternative, until now.

Engineers in optics, photonics, materials science, and other disciplines have developed efficient photovoltaic panels, high-brightness LEDs, and long-lived batteries to provide an alternative to kerosene. Such systems produce high-quality light without any of the environmental or health costs of kerosene lanterns.

As an additional benefit, these systems can also be used to charge cell phones. Currently, the rural poor must walk kilometers and then pay to charge their phones. Remarkably, despite the significant up-front cost, these photovoltaic systems pay for themselves within a couple of years as users no longer need to buy kerosene or pay third parties to charge their cell phones.

The problem is the up-front cost. Energy infrastructure is capital intensive.

Renewable energy for phones

Electricity is cheaper than kerosene in the long run, but the high initial cost is an insurmountable barrier for billions of people and for many governments.

Fortunately, the concept of microfinance for individuals and small businesses underserved by traditional financial institutions has been extended to paying for energy infrastructure. Pay-as-you-go solar energy is enabling the poor to switch from kerosene lanterns to PV panels, batteries, and LED lamps.

Organizations such as Eight19 (www.eight19.com), Simpa Networks (www.simpanetworks.com), and Angaza Design (www.angazadesign.com) buy the equipment and provide it to users who then pay on a daily or weekly basis for only the electricity they use. After a while the equipment is fully paid for and the user owns it free and clear.

The amortized cost is less than people are currently spending on kerosene, so they save money, reap the benefits of LED lighting, and build equity toward owning the complete system.

In many cases, users select larger systems that can power sewing machines, irrigation pumps, small machinery, or televisions. The pay-as-you-go concept can be applied to microgrids for providing electricity to entire villages, to water purification systems, or to other types of beneficial infrastructure. ■

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Photonics For a Better World

Read more articles and blog posts celebrating the many ways that photonics are applied in creating a better world:

- spie.org/betterworld
- PhotonicsforaBetterWorld.org

Bay Area PV group

The Bay Area Photovoltaic Consortium (BAPVC) (bapvc.stanford.edu) is a partnership joining universities, industry, and the U.S. government with the mission of developing advanced technologies to deliver high-performance PV modules at low cost.

The BAPVC is led by Stanford University and the University of California, Berkeley and is funded by the U.S. Department of Energy (DOE) with additional support from industry and universities.

The DOE is providing $25 million over five years as part of the SunShot Photovoltaic Manufacturing Initiative.

The BAPVC conducts industry-relevant R&D that will impact high-volume PV manufacturing, produce a highly trained workforce, and speed commercialization of cutting-edge PV technologies. Industry members identify areas of research emphasis, evaluate proposals, monitor research, and commercialize innovations.

All U.S. universities are eligible to respond to the BAPVC's requests for proposals.