Clear view: The organic solar cell developed by UCLA researchers is transparent, but still needs contact fingers.

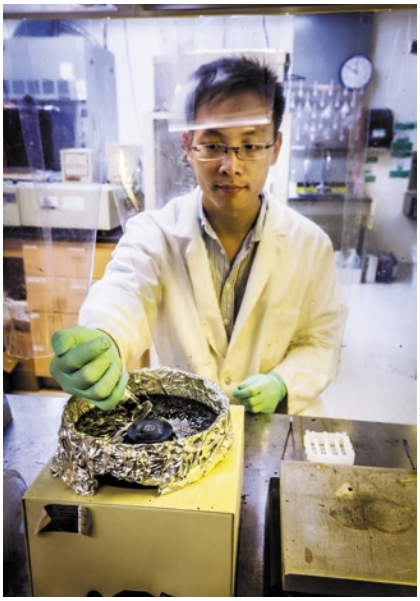
More than meets the eye

A NEW SEE-THROUGH SOLAR CELL DEVELOPED AT UCLA REVIVES OLD DREAMS OF ENERGY-PRODUCING WINDOWS

Imagine if every glass pane, on every skyscraper, in every metropolis could be converted into a solar plant, quietly and almost invisibly generating electricity. It is a distant goal that tickles the imagination, but a transparent organic solar cell developed at UCLA just brought it a little bit closer. However, a cost-competitive product based on this technology is not yet on the horizon.

It's Friday, the day that students in the organic solar cell research lab at the University of California, Los Angeles (UCLA) do their chores: sweeping the space and tidying their messes from the week's work. They are half-finished, and the lab is still dingy. Chun-Chao Chen, one of the Ph.D. students, is wearing a white lab coat with stains across the front. He slips his hands into a pair of green gloves and sits down in front of a spin-coater to demonstrate the way he adds the photoactive layer to a solar cell. He squeezes a few drops of a viscous liquid from a pipette onto a transparent substrate. The machine twirls the substrate at its center and the liquid splashes outward like paint on a spin art wheel, leaving a thin coating on the glass and a spatter of inky blue material on the surrounding foil.

This coating is the active layer on a photovoltaic (PV) device that looks like it has been brought back from the future. After a few more steps with spin-coaters and a spray gun, it will be a 4-percent-efficient solar cell that is about as transparent to the naked eye as windshield glass. Maybe that is where this technology will end up. Perhaps it will become a suburban skylight, a greenhouse or the skin on a skyscraper. »Someday,« says Yang



Chun-Chao Chen uses a spin-coater to add the photoactive polymer.

Yang, the professor leading this research group, »those are going to be covered in our technology.« In the meantime, a 4-percent-efficient, fully transparent solar cell in a lab remains state of the art. But it works, and it is clear.

Putting it all together

The solar cell that Chen paints onto a substrate at the UCLA School of Engineering and Materials Science is the combined product of several innovations that overcome common challenges for organic solar cells of this type. The technology relies on micron-long nanowires and photoactive polymers, both hot research topics at UCLA and elsewhere. Groups at Stanford and at the University of Washington are working on similar projects, and UCLA is the first to put it all together in a stable, transparent PV device. This solar cell is the product of 2 years of research by the UCLA group, which first published its findings in July. It is also the cumulative result of years of work by these and others in the UCLA organic solar research group.

Two major innovations made it possible to finally put the pieces together.

The photoactive layer of this solar cell came from Letian Dou, another Ph.D. student. Dou invented it at his workstation in the chemistry lab, behind drawings of molecular structures he has sketched on the protective glass with a dry-erase marker. Dou says that he has designed between 30 and 50 photoactive polymers at this lab. For this one, he used two commercially available monomers – molecules that can bind to other molecules – and bound them in a specific structure to make a large molecule, also known as a polymer. »I always imagine he's sort of like a chef,« Chen says. »You buy the ingredients, you make the dish.« The polymer Dou cooked up absorbs light in the near-infrared and ultraviolet spectrum and is transparent in the spectrum visible to the human eye (see chart, p. 59). Chen then came up with the process for applying it to a solar cell and covering it with silver nanowires.

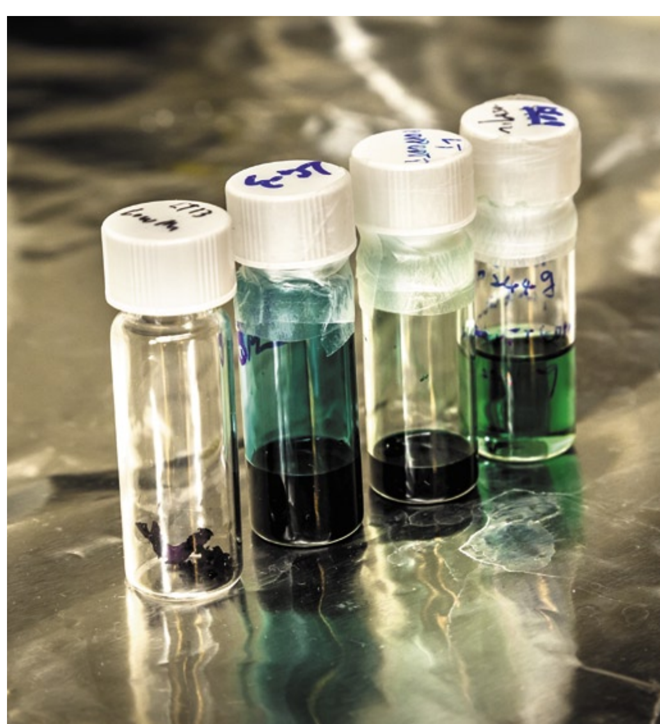
Dou, who also received a nod from the National Renewable Energy Laboratory (NREL) this year for designing polymers for the world's most efficient tandem junction organic solar cell, says the breakthrough with this cell is the combination of high transparency and relatively high efficiency. It is the first time this type of cell has demonstrated a level of efficiency that is at all feasible for a commercial product.

Dou's material absorbs energy mostly in the infrared part of the spectrum, and is mixed with a commercially available polymer that absorbs light mostly in the ultraviolet part of the spectrum. The materials are diluted into the dark blue solution that Chen puts on the glass substrate.

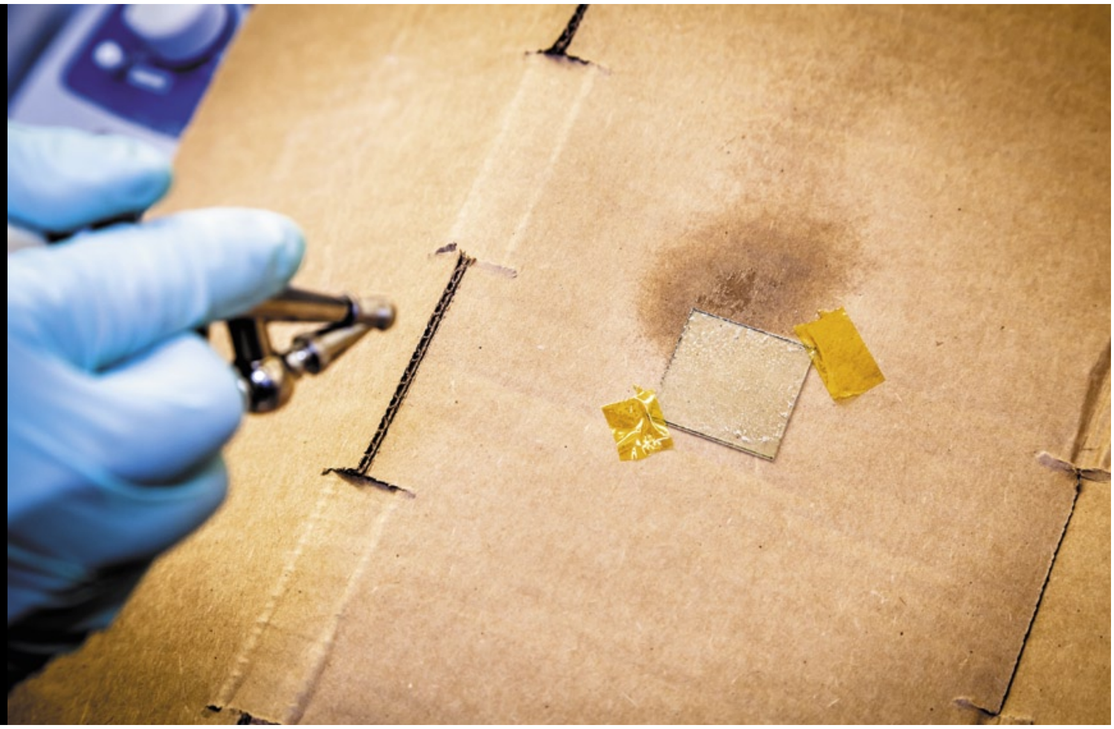
High-tech materials, low-tech fabrication

What makes this solar cell especially high-tech, oddly, is the low-tech method with which its four basic layers are applied. It requires neither a vacuum, nor temperatures above 100° C, nor a clean room. You could put it together in your kitchen. But the polymer is just one of the two core innovations that make this transparent solar cell possible.

The second major innovation is the use of silver nanowire as a conductor on the top layer of the cell. Typically, high conductivity and high transparency are at odds. However, the researchers at UCLA found a way to use a web of tiny silver nanowires, sprayed onto the surface of the cell and covered in transparent conductive oxide (TCO). They use an interlayer of the TCO between the nanowires and the active layer to get around a common challenge for organic solar cells: keeping the silver from causing a reaction that would damage the polymer. The process for adding the nanowires and oxide is important, too. These oxides are typically sputtered – a process in which charged particles are fired at a target in a specialized vacuum chamber, releasing material to be deposited on a substrate. This process not only requires special machinery, but also it



THE PHOTOACTIVE LAYER OF THE CELL IS DEPOSITED AS A LIQUID SOLUTION. DEPENDING ON THE DILUTION, THE POLYMER MIXTURE TAKES ON DIFFERENT COLORS.



SILVER NANOWIRE FLOATING IN ALCOHOL IS SIMPLY SPRAYED ONTO THE SOLAR CELL.

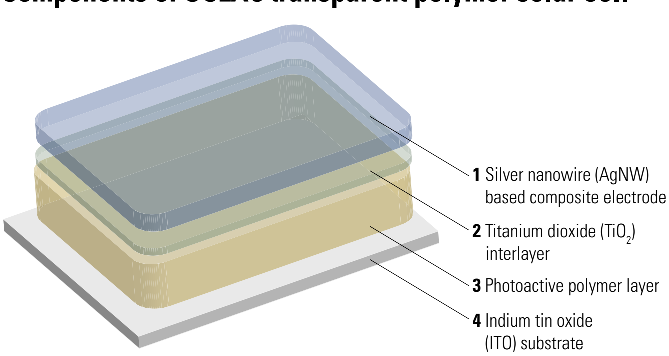
causes damage to the soft polymers. The silver nanowire helps boost conductivity, which allows the TCO to be spin-coated instead of sputtered.

While the concept has been proven, there is still plenty of work to do be done before transparent solar modules become a reality. Organic solar cells are not a new concept, and it is a tough market for new technologies competing with ever-cheaper crystalline silicon products. Konarka Technologies Inc., the Massachusetts-based startup with technology similar to the cells at UCLA – though not transparent – filed for bankruptcy in June. A clear module may offer slightly different benefits, but Yang estimates that real-world applications are probably still 5 to 7 years out.

How to get up the efficiency?

The main challenge now is getting these cells to produce more electricity in less space. With a cell efficiency ranging from 3.82 to 4.02 percent, depending on which surface the light is hitting, a product would still have to be made at incredibly low cost in order to sell at a competitive price. To put it in perspective: to power a 50 W light bulb under standard test conditions, you would need 0.25 m² of high-efficiency monocrystalline modules from Sunpower Corp. Cadmium-telluride thin-film modules from First Solar would need 0.35 m². To do this with the UCLA solar cell would take 1.34 m² of cell surface area. And more than just the cell needs to be bigger: a larger cell area increases costs for racking, cabling and mounting. The need for high efficiency or very low cost is even more important because these products are designed for integrated applications in buildings or consumer products, so they will have to produce power even at sub-optimal orientation, often being exposed to the sun at a 90° inclination.

Components of UCLA's transparent polymer solar cell



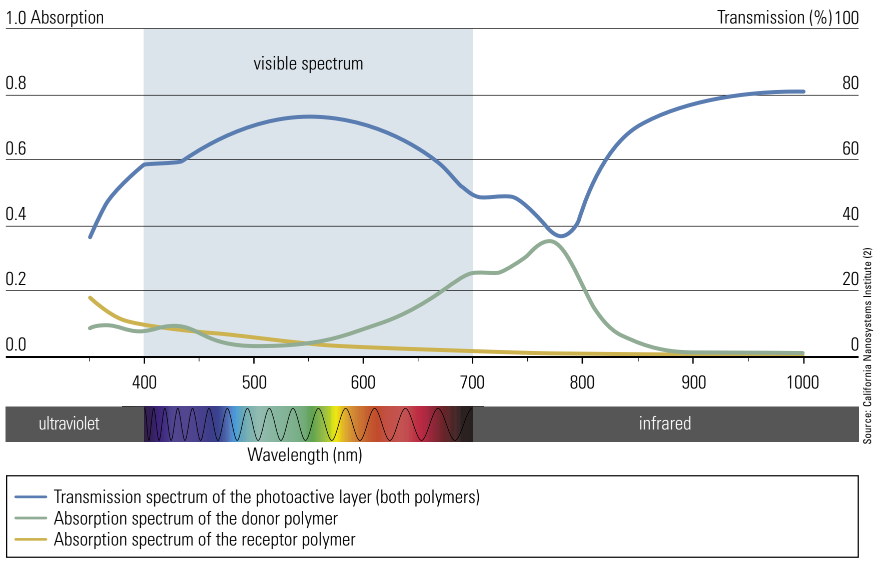
1 Researchers spray-coat nanowire composite onto the interlayer using an alcohol-based solvent. A titanium dioxide (TiO_2) gel is applied as a treatment to enhance the connections between the nanowires and to bind them to the polymer. A transparent conductive filler – made of indium tin oxide (ITO) nanoparticles – is added by spin-coating and fills in the gaps between nanowires. It makes a smooth surface and completes the composite electrode.

2 This layer conducts current to the nanowire-based electrode while preventing the silver from coming into contact with the soft polymer and causing damage.

3 This photoactive layer is composed of two polymers that capture light in the non-visible spectrum. The new molecule developed by UCLA acts as the electron donor. A commercially available polymer serves as the electron receptor.

4 A commercially purchased indium tin oxide (ITO) on-glass substrate is spin-coated with a modifying polymer to make it compatible with the active polymer.

Light absorption and transmission



The transparent solar cell transmits most of the sun's visible light and absorbs more of its ultraviolet and infrared light. This chart shows the areas where the most light is absorbed and the most light is transmitted. At 800 nm, for example – outside the visible spectrum – the UCLA-developed polymer absorbs the greatest amount of light. This is also where the cell is least transparent.

Dou thinks he can get his polymers to higher efficiency with some more lab time. He is already working on tweaking the chemical structure of the material he used for the transparent solar cell, and he says there is potential for new polymers with both similar and very different chemical structures to perform better than this one.

Yang says his team has not done any analysis of the actual production cost of the cells, but they suspect the greatest expenses to be the silver and the polymer. As Michael McGehee, the professor who leads the organic solar cell research team at Stanford, points out, more complex polymers are more expensive. »It's routine chemistry,« he says, but every step adds cost. Dou's polymer takes seven different chemical reactions to get to the final product, and each step is followed by purification to separate out byproducts. It takes between 2 weeks and a month to synthesize it.

McGehee has also looked into the cost of the silver, which he says should be less of a concern. He estimates that, based on a silver price of \$879 per kg, the nanowire portion embedded in the oxide should cost about 18¢ per m^2. For the UCLA solar cell at its current efficiency level, this would be about 0.5¢ per W, in addition to the cost of the silver contact grid that would still be screen-printed on. McGehee and Yang agree that scaling up the module is also not a daunting challenge. Roll-to-roll printing is a proven technology for applying even layers to organic solar cells.

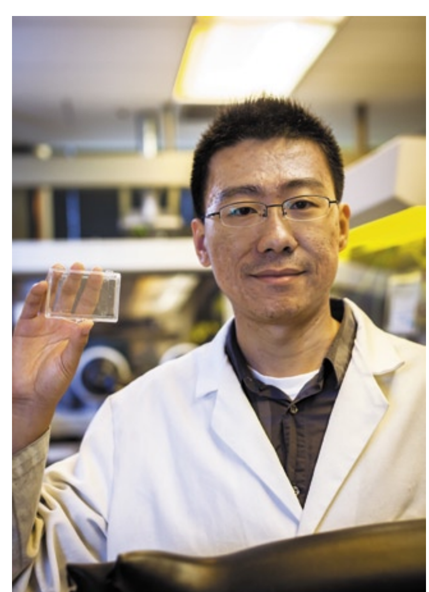
Dreams of commercialization

Then there is the question of reliability. »To recover the cost,« McGehee says, »you would need this to work 20 to 25 years. Right now, maybe we could do 5-year lifetimes.« McGehee says that very small amounts of impurities can cause organic solar cells to degrade, especially when they are exposed to light. The UCLA researchers have yet to closely evaluate the stability of their transparent solar cells. Yang says the polymer itself is stable – or, at least, has a stable shelf life. The researchers have been keeping it in the lab for several months now, testing it every few weeks, and it is not degrading. Long-term testing under sunlight, however, could tell a different story.

Looking forward, Yang says that he envisions the end product as a plastic laminate film that would adhere to windows. The layers can easily be applied with roll-to-roll printing or spray coating. The final product would still need contact fingers, which Yang says could be printed on with silver paste that would leave a light-visible grid on the surface. So far, the group has been working under US Government research grants and is now looking for private-sector sponsors. Ultimately, they would like to license the technology. Yang adds that while the UCLA team will continue working on improving the efficiency of their polymers, commercialization will have to be handled by the industry.

For the researchers at UCLA, the cell they have developed still represents progress. Yang leans back in his office chair, looking up at a beautifully crafted, written piece of artwork in Chinese calligraphy. According to his translation, it says – roughly – that studying is like medicine: it cures ignorance. »We try to do things that are groundbreaking,« he says. »That's why we have a much higher failure rate: because we try things. We dream.«

Melissa Bosworth



Letian Dou designed the infrared-light-absorbing polymer that makes the transparent solar cell possible.

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