A more efficient, lightweight and low-cost organic solar cell

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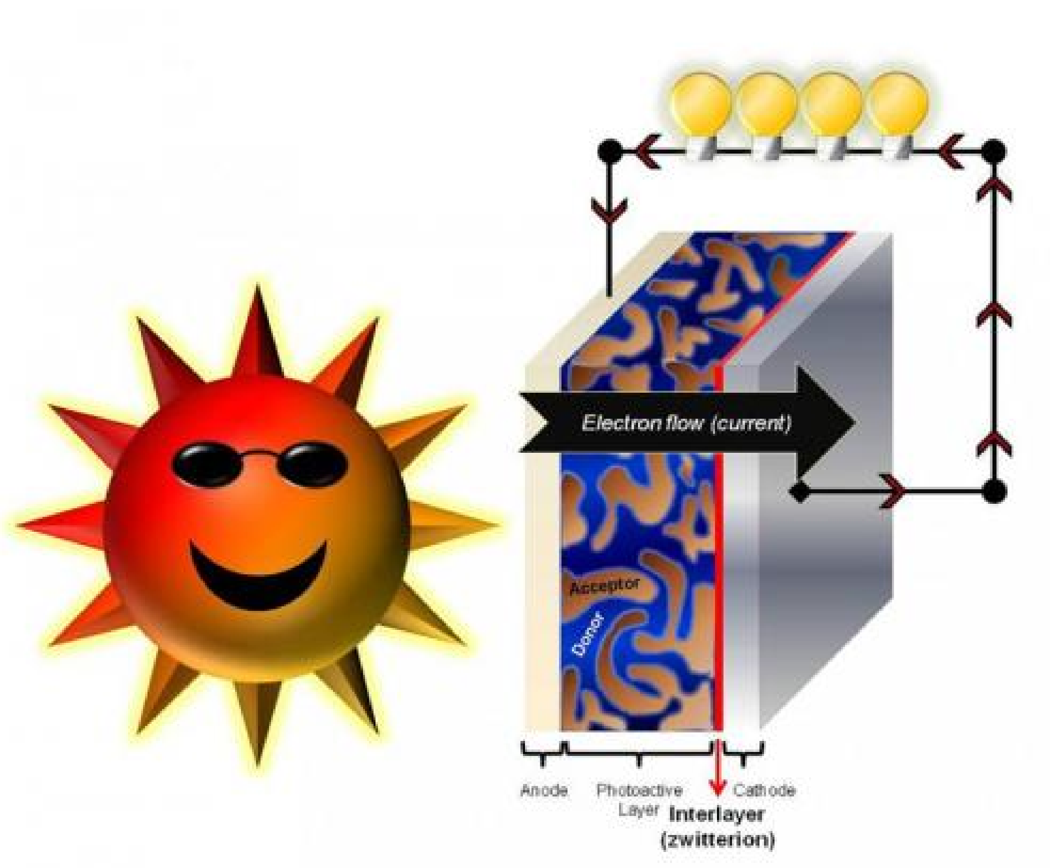

UMass Amherst researchers apply a layer of zwitterionic fullerenes to allow the use of any type of metal electrode in a more efficient, lightweight and low-cost organic solar cell. The advance overcomes a decades-old barrier to improving the power conversion efficiency of organic solar cells, which had been hampered by the inherent drawbacks of metal electrodes, such as their instability and susceptibility to oxidation. Credit: UMass Amherst

For decades, polymer scientists and synthetic chemists working to improve the power conversion efficiency of organic solar cells were hampered by the inherent drawbacks of commonly used metal electrodes, including their instability and susceptibility to oxidation. Now for the first time, researchers at the University of Massachusetts Amherst have developed a more efficient, easily processable and lightweight solar cell that can use virtually any metal for the electrode, effectively breaking the "electrode barrier."

This barrier has been a big problem for a long time, says UMass Amherst's Thomas Russell, professor of polymer science and engineering. "The sun produces 7,000 times more energy per day than we can use, but we can't harness it well. One reason is the trade-off between oxidative stability and the work function of the metal cathode." Work function relates to the level of difficulty electrons face as they transfer from the solar cell's photoactive layer to the electrode delivering power to a device.

Russell likes to use a lock-and-dam analogy to talk about electron transfer. "People have thought you'd need to use tricks to help electrons, the water in the lock, over an obstacle, the electrode, like a dam. Tricks like sawing the dam apart to allow the flow. But tricks are always messy, introducing a lot of stuff you don't need," he says. "The beauty of the solution reached by these synthetic chemists is to just move the dam out of the way, electronically move it so there is no longer a difference in energy level."

Synthetic chemist and polymer science professor Todd Emrick agrees, "That challenge was unmet and that's what this research is all about." He and polymer chemistry doctoral student Zak Page in his lab had been synthesizing new polymers with zwitterions on them, applying them to several different polymer scaffolds in conjugated systems, also known as semiconductors, in the inter-layer of solar cells. Zwitterions are neutral molecules with both a positive and negative charge that also have strong dipoles that interact strongly with metal electrodes, the scientists found.

Emrick asked Page to see if he could synthesize conjugated polymers, semiconductors, with zwitterionic functionality. With time, and by enlisting a system of multiple solvents including water, Page was able to prepare these new "conjugated polymer zwitterions," or CPZs.

Emrick explains, "Once we could make CPZs, we were able to incorporate any conjugated backbone we wanted with zwitterionic functionality. That allowed us to make a library of CPZs and look at their structure-property relationship to understand which would be most important in electronics. In particular, we were interested in electron transport efficiency and how well the CPZ could modify the work function of different metals to help move electons across interfaces towards more powerful devices.

In choosing a metal for use as an electrode, scientists must always negotiate a trade-off, Page says. More stable metals that don't degrade in the presence of water and oxygen have high work function, not allowing good electron transport. But metals with lower work function (easier electron transport) are not stable and over time will degrade, becoming less conductive.

Guided by UMass Amherst's photovoltaic facility director Volodimyr Duzhko in using ultraviolet photoelectron spectroscopy (UPS), Page began to categorize several metals including copper, silver and gold, to identify exactly what aided electron transport from the photoactive layer to the electrode. He and Emrick found that "if you want to improve the interlayer properties, you have to make the interface layer extremely thin, less than 5 nanometers, which from a manufacturing standpoint is a problem," he says.

To get around this, Page and Emrick began to consider a classic system known for its good electron transport: buckyballs, or fullerenes, often used in the photoactive layer of solar cells. "We modified buckyballs with zwitterions (C60-SB) to change the work function of the electrodes, and we knew how to do that because we had already done it with polymers," Page points out. "We learned how to incorporate zwitterion functionality into a buckyball as efficiently as possible, in three simple steps."

Here the synthetic chemists turned to Russell's postdoctoral researcher Yao Liu, giving him two different fullerene layers to test for electron transfer efficiency: C60-SB and another with amine components, C60-N. From UPS analysis of the zwitterion fullerene precursor, Page suspected that the amine type would enhance power even better the C60-SB variety. Indeed, Liu found that a thin layer of C60-N between the solar cell's photoactive layer and the electrode worked best, and the layer did not have to be ultra-thin to function effectively, giving this discovery practical advantages.

"That's when we knew we had something special," says Page. Emrick adds, "This is really a sweeping change in our ability to move electrons across dissimilar materials. What Zak did is to make polymers and fullerenes that change the qualities of the metals they contact, that change their electronic properties, which in turn transforms them from inefficient to more efficient devices than had been made before."

Russell adds, "Their solution is elegant, their thinking is elegant and it's really easy and clean. You put this little layer on there, it doesn't matter what you put on top, you can use robust metals that don't oxidize. I think it's going to be very important to a lot of different scientific communities."

More information: "Fulleropyrrolidine interlayers: Tailoring electrodes to raise organic solar cell efficiency" *Science*, 2014: www.sciencemag.org/lookup/doi/ … 1126/science.1255826

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