Synergistic effect discovered in layered quantum dot solar cells

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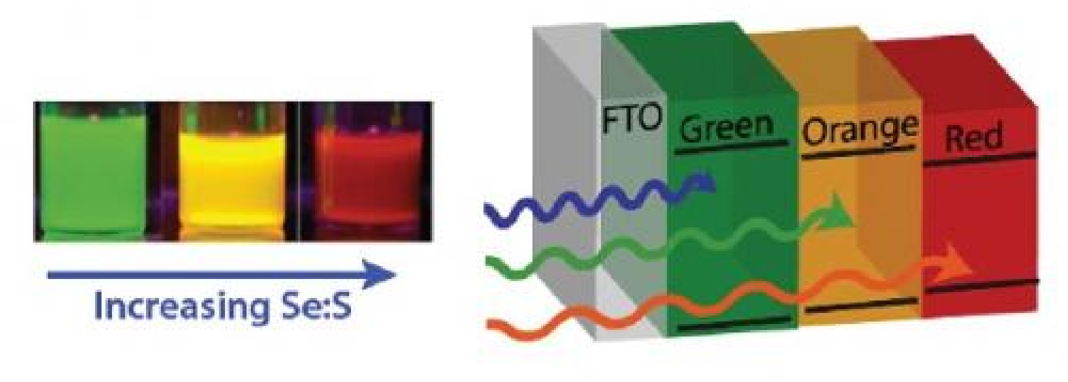

(Left) Photographs under UV light of quantum dots with different ratios of selenium to sulfur, resulting in different colors. (Right) Illustration of the quantum dot layers absorbing different wavelengths of light as the photoanode in a solar cell. Credit: Santra, et al. ©2013 American Chemical Society

(Phys.org)—Scientists have discovered that a solar cell consisting of two or three layers of quantum dots, with each layer tuned to a different part of the solar spectrum, has an efficiency that is 40-60% higher than the sum of the efficiencies of separate solar cells each made of one of the individual layers. The synergistic effect of the layered architecture could lead to new ways of designing quantum dot solar cells with high efficiencies and broad-spectrum absorption.

The researchers who designed and fabricated the new solar cells, Pralay

K. Santra and Professor Prashant V. Kamat at the University of Notre Dame in Indiana, wanted to test the previously proposed concept of a rainbow solar cell, which can harvest photons of all "colors" or wavelengths of the visible spectrum.

In order to fabricate a rainbow solar cell, scientists need to incorporate light-harvesting components with various properties to capture different parts of the spectrum. One way to do this is by using quantum dots, which can be tuned to capture specific wavelengths of light. The typical way of tuning a quantum dot's band gap to capture a particular wavelength of light is to control the dot's size during synthesis.

Here, the researchers chose a different way to tune the dots' band gaps: by controlling their composition. All of the quantum dots they used were roughly the same size (4.5 nm) and made of cadmium, selenium, and sulfur, but the amount of selenium in each dot was varied. Quantum dots with the smallest amounts of selenium had the largest band gaps and captured the shortest wavelengths of light. Based on this relationship, the researchers synthesized three kinds of quantum dots: green, which had the largest band gap; orange, which had an intermediate band gap; and red, which had the smallest band gap.

After synthesizing the quantum dots, the researchers deposited them onto a TiO_2 film one layer at a time, starting with the green dots, followed by orange, and finally red. The tandem-layered film was then used as a photoanode, which collects incoming light in a solar cell.

"To the best of our knowledge, this is the first systematic approach of depositing two or more layers of dots to sequentially harvest photons in quantum dot solar cells," Kamat told *Phys.org*. "The tuning of the quantum dots' band gaps by varying the composition is a relatively new idea and is being explored by a few groups."

When experimenting with different versions of this new tandem-layered solar cell, the researchers found they could achieve the best performance with just two layers: one layer of orange dots followed by a layer of red dots. This composite cell exhibited an efficiency of 3.2%, while a cell that included the green dots had a slightly lower efficiency of 3.0%

Even more interesting is the synergistic effect the scientists discovered in these cells. The orange/red-layered cell's observed efficiency of 3.2% is 41% higher than the expected efficiency of 2.27%, which is calculated by adding the efficiencies of two separate cells, one with orange and one with red dots. And the observed efficiency of a cell with all three colors of dots, 3.0%, is 60% higher than the estimated additive efficiency of 1.87%.

Although the scientists aren't exactly sure what causes the synergistic effects, they have two ideas. One possibility is that the dots' band energies align in such a way as to allow an electron transfer cascade from larger-band-gap dots to smaller-band-gap dots, where electrons accumulate. The other idea involves energy transfer from the larger-band-gap dots to the smaller-band-gap dots, where excitation is concentrated. In both scenarios, the electrons or excitations enhance the electron transfer process, which leads to increased power generation and higher efficiencies. The scientists suspect that both of these pathways may work together to improve performance.

"The significance of tandem-layered quantum dot solar cells is yet to be realized fully," Kamat said. "This is our maiden effort and it opens new ways for designing higher efficiency solar cells. The tandem structure allows selective absorption of light, thus maximizing the efficiency of light energy conversion. Energy losses arising from thermalization of excited electrons can be greatly minimized by this simple approach."

Building on these ideas, the scientists hope to further improve the solar cells' performance in the future.

"We still need further improvements in power conversion efficiency," Kamat said. "We have now initiated a multipronged approach to improve the efficiency of tandem quantum dot solar cells by incorporating quantum dots of different materials (copper indium sulfide, cadmium selenide and lead selenide) and extend the photoresponse further into the infrared. Spectroscopic measurements are underway to establish the synergetic effects in tandem quantum dot solar cells."

More information: Pralay K. Santra and Prashant V. Kamat. "Tandem-Layered Quantum Dot Solar Cells: Tuning the Photovoltaic Response with Luminescent Ternary Cadmium Chalcogenides." *Journal of the American Chemical Society*. DOI: 10.1021/ja310737m

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