Quantum Dots Promise to Significantly Boost Solar Cell Efficiencies

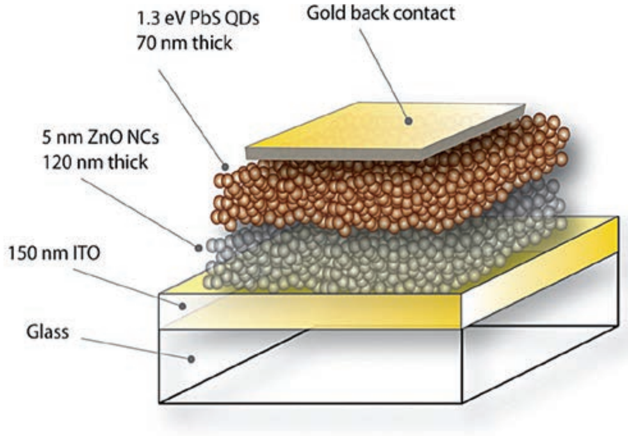
The solar power industry has a problem: researchers have pushed the efficiencies of the current generation of solar cell technologies close to their practical limits, so achieving significant new gains in solar photovoltaic efficiencies will depend on the development of new technologies. In the search for a third generation of solar-cell technologies (as a follow-up to silicon and thin-film solar cells), a leading candidate is the use of "quantum dots"—tiny spheres of semiconductor material measuring only about 2–10 billionths of a meter in diameter.

Quantum dots have the potential to dramatically increase the efficiency of converting sunlight into energy—perhaps even doubling it in some devices—because of their ability to generate more than one bound electron-hole pair, or exciton, per incoming photon. Today's solar cells produce only one exciton per incoming photon, but the "multiple exciton generation" (MEG) effect of quantum dots promises to wring more energy out of each photon.

In addition, varying the size of quantum dots effectively "tunes" them to respond to different wavelengths of light. As quantum dots get smaller, the light spectra that they absorb will shift to the blue, which represents greater energy or shorter wavelength. The smaller the dot, the greater the shift.

Using detailed thermodynamic calculations, NREL has shown that quantum-dot solar cells operating under concentrated sunlight can have maximum theoretical conversion efficiencies twice that achievable by conventional solar cells—up to 66%, compared to 31% for present-day first- and second-generation solar cells.

But before technologically significant quantum-dot solar cells become a reality, scientists must first learn how to split the excitons created by quantum dots and collect the resulting free electrons and holes with high efficiency. Therefore, NREL is pursuing a better understanding of the fundamental science of MEG processes to develop solar cells with predicted high efficiencies. NREL has produced quantum dots using colloidal suspensions; then, using molecular self-assembly, they have been fabricated into the first-ever quantum-dot solar cells. While these devices operate with only 4.4% efficiency, they demonstrate the capability for low-cost manufacturing.



In 2011, NREL researchers certified the first all-quantum-dot solar cell, which combines a 70-nanometer-thick layer of lead sulfide quantum dots (QDs) with a 150-nanometer-thick layer of zinc oxide nanocrystals (NCs). Current is collected from the transparent conductive oxide layer, formed from indium tin oxide (ITO), and the gold back contact. The top of the solar cell, shown face down in this illustration, is protected with a layer of glass.

Quick Facts

In 2001, NREL predicted that quantum dots would be capable of generating more than one exciton, or electron-hole pair, from a single photon of light. The effect was later proven experimentally.

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In 2011, NREL researchers certified the first all-quantum-dot photovoltaic cell, which was based on lead sulfide and demonstrated reasonable solar cell performance, along with good stability. Quantum-mechanical effects allowed it to achieve a greater open-circuit voltage than is possible from bulk lead sulfide.

In 2012, NREL researchers verified that a quantum-dot solar cell was generating more than one exciton per incident photon. The cell used lead selenide quantum dots, measuring 5 nanometers in diameter, packed tightly into a film. The quantum-dot film generated 30%–40% more electrons from high-energy photons than is possible in a conventional solar cell.

In early 2013, scientists from NREL and other labs demonstrated a process whereby quantum dots can self-assemble at optimal locations in nanowires, a breakthrough that could improve solar cells, quantum computing, and lighting devices.

National Renewable Energy Laboratory
15013 Denver West Parkway, Golden, CO 80401
303-275-3000 • www.nrel.gov

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