Discovery of a 'dark state' could increase maximum theoretical efficiency of solar cells from 31 to 44 percent

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The efficiency of conventional solar cells could be significantly increased, according to new research on the mechanisms of solar energy conversion led by chemist Xiaoyang Zhu at The University of Texas at Austin.

Zhu and his team have discovered that it's possible to double the number of electrons harvested from one photon of sunlight using an organic plastic semiconductor material.

"Plastic semiconductor solar cell production has great advantages, one of which is low cost," said Zhu, a professor of chemistry. "Combined with the vast capabilities for molecular design and synthesis, our discovery opens the door to an exciting new approach for solar energy conversion, leading to much higher efficiencies."

Zhu and his team published their groundbreaking discovery Dec. 16 in *Science*.

The maximum theoretical efficiency of the silicon solar cell in use today is approximately 31 percent, because much of the sun's energy hitting the cell is too high to be turned into usable electricity. That energy, in the form of "hot electrons," is instead lost as heat. Capturing hot electrons could potentially increase the efficiency of solar-to-electric power conversion to as high as 66 percent.

Zhu and his team previously demonstrated that those hot electrons could be captured using semiconductor nanocrystals. They published that research in Science in 2010, but Zhu says the actual implementation of a viable technology based on that research is very challenging.

"For one thing," said Zhu, "that 66 percent efficiency can only be achieved when highly focused sunlight is used, not just the raw sunlight that typically hits a solar panel. This creates problems when considering engineering a new material or device."

To circumvent that problem, Zhu and his team have found an alternative. They discovered that a photon produces a dark quantum "shadow state" from which two electrons can then be efficiently captured to generate more energy in the semiconductor pentacene.

Zhu said that exploiting that mechanism could increase solar cell efficiency to 44 percent without the need for focusing a solar beam, which would encourage more widespread use of solar technology.

The research team was spearheaded by Wai-lun Chan, a postdoctoral fellow in Zhu's group, with the help of postdoctoral fellows Manuel Ligges, Askat Jailaubekov, Loren Kaake and Luis Miaja-Avila. The research was supported by the National Science Foundation and the Department of Energy.

Science Behind the Discovery

• Absorption of a photon in a pentacene semiconductor creates an excited electron-hole pair called an exciton.

• The exciton is coupled quantum mechanically to a dark "shadow state" called a multiexciton.

• This dark shadow state can be the most efficient source of two electrons via transfer to an electron acceptor material, such as fullerene, which was used in the study.

• Exploiting the dark shadow state to produce double the electrons could increase solar cell efficiency to 44 percent.

Provided by University of Texas at Austin