Chopping up photons

Conventional solar cells lose most of the Sun's energy as heat. *Nature Photonics* spoke to Tom Gregorkiewicz at the University of Amsterdam about his group's latest work, which may lead to cheap and efficient silicon solar cells by harnessing some of the lost energy.

The quantum-cutting team. From left to right, back to front: Tom Gregorkiewicz, Ignacio Izeddin, Salvatore Minissale, Wieteke de Boer, Dolf Timmerman, Bert Zwart, Ngo Ngoc Ha and Peter Stallinga.

Your paper is all about quantum cutting. What exactly is that?
Quantum cutting is a term used to describe the process by which a high-energy photon can be divided into two or more photons of lower energy. The photon is essentially 'cut' into several pieces and its quantum size is changed.

And what has this got to do with solar cells?
Well, to convert energy from incoming light to electricity most efficiently inside solar cells, we need to be able to harness as much of the incoming photon energy as possible. Typically, in photovoltaic devices, once the energy of the initial photon exceeds a certain threshold, it is absorbed and used to create only one electron–hole pair (or exciton). Any extra energy in the photon above that threshold is lost as kinetic energy of the exciton and converted into heat. We are interested in studying quantum cutting with a view to improving the overall efficiency of photovoltaic cells by increasing the number of electron–hole pairs that can be produced from a given photon.

What have you achieved in your latest work?
We have demonstrated space-separated photon cutting in silicon nanocrystals, for the first time. Space separation refers to the way in which the incoming photon energy is divided into two or more distinct, spatially separated excited states. We show that, thanks to quantum cutting, a silicon nanocrystal can absorb a photon and transfer some of its excess energy (that would otherwise be lost as heat) to a nearby neighbouring erbium ion or another nanocrystal. The result is a second, spatially separated exciton state that can be used to create another photon by photoluminescence. Overall, two photons are emitted for each photon absorbed.

Why is the approach attractive?
People have already shown that multiple electron–hole pairs can be generated by single high-energy photons that are absorbed in nanocrystals. But because of Auger recombination and carrier cooling effects, the excitons tend to have very short lifetimes (50–100 ps or shorter). Only the final exciton has been shown to have a lifetime that is long enough to be useful for harvesting the incident photon energy. Now we have shown that the mechanism of space-separated quantum cutting can be used very generally to create multiple excitons outside a given nanocrystal with longer lifetimes. Right now we've demonstrated the effect with two excitons, but we could show it for more. Because the extra energy (that is, exciton) is transferred to a completely different nanocrystal, the excitons cannot interact as usual and their lifetimes increase. We think we can boost the exciton lifetimes by about six orders of magnitude or so, therefore making it easier to harvest more of the photovoltaic energy.

How fast is this quantum-cutting process?
We don't know. We expect it to be of the order of 10–100 ps. The cooling of carriers in silicon nanocrystals has not been studied in great detail but it is something we want to investigate. We have two students working on this project right now.

What led you to this point?
Actually, the whole thing started as a Master's student project. Our group has been working on erbium and the erbium doping of silicon for quite some time, as well as silicon photonics. For the past three years we have focused on silicon nanocrystals and in particular the energy transfer that occurs when a photon is absorbed.

So where next for this work?
What we have shown here is a proof-of-principle demonstration. We have shown that it is possible to separate photo-excited states in space, and by doing so generate more photons and use more of the photon energy. The beauty of the work is that it's a simple measurement. One photon goes in, and we just measure how many come out. It's a basic step forward that opens up new opportunities for solar-cell technology. Looking ahead, we want to understand the underlying kinetics of the photon-cutting process, which we can do using high-resolution, ultrafast spectroscopy. That will give us a handle on how to optimize the effect. We have also initiated a collaboration with ECN (Energy Research Center of the Netherlands) to explore the potential of the space-separated quantum-cutting phenomenon for spectral shaping in solar cells.

Interview by Amber Jenkins.

Gregorkiewicz and his colleagues have an Article on quantum cutting on page 105 of this issue.