Nanocrystals for the next generation of solar cells

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Collaboration with industry

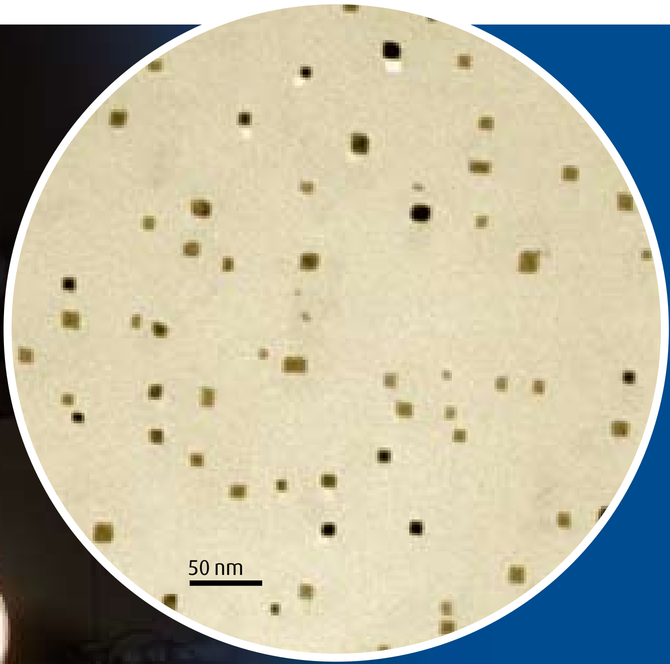
The Semiconductor Group at iNANO and Department of Physics and Astronomy collaborates closely with the Danish solar cell company RAcell Solar A/S on the development of third-generation solar cells based on nanotechnology, and with RAcell Solar A/S and the Norwegian producer of silicon feed stock material, Elkem, on the use of metallurgical grade silicon for first-generation solar cells.

Solar cells are key components in establishing a CO_2 free, sustainable energy source. Materials with incorporated nanostructures are predicted to improve the efficiency of solar cells by increasing the harvest of unused energy from the sun.

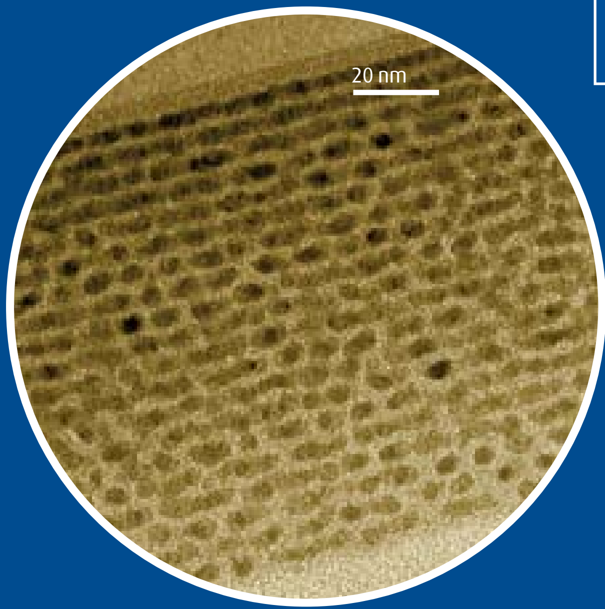
By Mads Møgelmose Kjeldsen and Arne Nylandsted Larsen

A solar cell is a device that converts sunlight directly into electricity, and solar cells are of great interest because they provide a carbon-free, sustainable energy source. The most important properties of solar cells are their cost and efficiency. The efficiency of a solar cell is the proportion of the energy in the sunlight that is converted into electricity. Thus, a good solar cell has high efficiency and/or can be produced at a low cost.

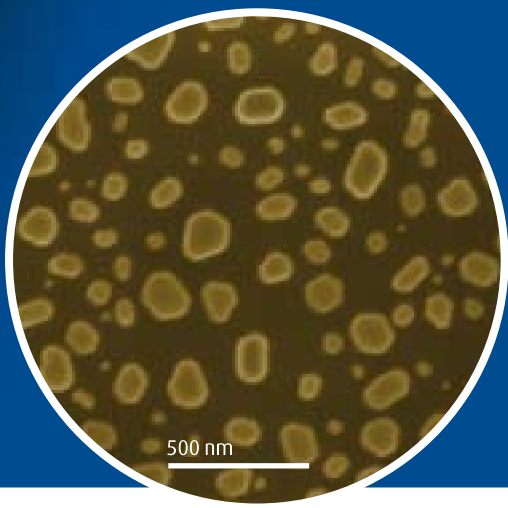
Today conventional solar cells have efficiencies at about 20 per cent. A typical price per kWh is $ 0.20, which is too high to compete with electricity produced from fossil sources - competition requires a kWh price of about $ 0.02. A reduced price per square meter or an increased efficiency is two ways to achieve this goal. The Semiconductor Group at iNANO and the Department of Physics and Astronomy undertakes research activities following both paths.



This Transmission Electron Microscopy (TEM) image shows tin nanostructures. The nanocrystals have rectangular shapes and sizes around 10 nm.



The TEM image shows a multilayer structure of germanium nanocrystals incorporated into a silicon dioxide matrix. This structure may significantly increase the generation of current inside the solar cell.



This Scanning Electron Microscopy (SEM) image shows gold nanodots on the top-surface of a silicon substrate produced by evaporation of a 10 nm thick gold layer followed by heat treatment at 500 °C for 15 min.

Today most solar cells are made of silicon because this material is abundant, has good electrical properties and the silicon technology is very advanced. However, due to its indirect band gap silicon is weak at absorbing light. This is where nanoscience comes to the rescue. In sufficiently small nanocrystals the band gap becomes quasi-direct, which gives rise to strong light absorption. Thus, the optical properties of silicon can be improved by adding nanocrystals. Our research is focused on exploring the properties of nanostructures in semiconductor materials and applying them in solar cells.

Increasing the current

Since silicon is the favourite material for commercial solar cells, we experiment with silicon-based structures containing nanocrystals of silicon or other materials. Inside the solar cell nanocrystals are used to increase the generation of current. In this context silicon and germanium are of particular interest because they are both fairly easy to work with in the laboratory and fully compatible with the silicon technology.

In silicon-based tandem solar cells the top cell is based on nanocrystals, while the bottom cell is a standard silicon cell. In such tandem cells the band gap of the top cell should ideally be around 1.6 eV. This can be achieved most easily by means of silicon nanocrystals, but light absorption is theoretically expected to be strongest in germanium.

Harvesting more sunlight

Nanostructures close to the surface of the solar cell can improve the coupling of the light into the solar cell via excitation of localized surface plasmons. Metals are useful for this purpose, and we are in particular studying the effect of silver and gold nanoparticles as their resonance frequencies match the solar spectrum. One element of special interest is tin due to the fact that tin is able to crystallize in two different structures - as a semiconductor and as a metal - depending on the processing conditions. Hence tin nanostructures might be useful inside the solar cell and on the surface as well. We can now produce both semiconductor and metal tin nanocrystals in thin layers of crystalline silicon - and currently we are studying their optical properties.

The entire solar spectrum

The greatest challenge in solar cell design is to combine materials in such a way that all the different wavelengths of the sunlight are efficiently used to generate current in the cell. In this context nanocrystals has a great advantage because their properties can be controlled by changing their size and shape. In the future the utilization of nanocrystals may make it possible to design a solar cell tailored to capture the entire spectrum of light from the sun.