SOLAR ENERGY

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Global Climate & Energy Project
STANFORD UNIVERSITY

Nanostructures for Light Trapping in High-efficiency, Low-cost Silicon Solar Cells

Investigators

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Objective

This work aims to develop a new pathway to achieve light scattering and trapping in silicon solar cells to increase efficiency. Dielectric and semiconducting materials, such as silicon and titanium dioxide, will be engineered into nanosize spheres, domes and wires, then placed on silicon thin film cells to create light-scattering, resonant cross-sections that promote light absorption. The engineered meta-surfaces are expected to demonstrate optical properties beyond conventional materials. The goal is to create a thin film cell with a light-to-energy conversion efficiency of approximately 20%.

Background

Thin film crystalline silicon deposited on an inexpensive substrate can help lower the manufacturing costs of solar cells. However, the conversion efficiency of these cells is often reduced due to the recombination of electrons and holes in the defective silicon layers, and poor absorption in the red and infrared portions of the solar spectrum. To address the problem, researchers have begun testing a variety of nanophotonic light-trapping techniques. Photonic nanometallic crystals were initially studied but were found to exhibit parasitic losses. The use of Mie-resonance theory in high refractive index dielectrics represents a new approach. Photonic crystals use wavelength-scale variations in the refractive index, in contrast to Mie-scattering nanostructures, which can trap deep sub-wavelengths of light that increase conversion efficiency. Combining very thin semiconducting layers with complex nanostructures creates more sophisticated optics capable of manipulating light in radically different ways that are not well understood.

Approach

The project is a collaborative effort of three leading research groups in nanophotonic and solar cell science. The researchers will focus on three key tasks: 1) design and realization of nanostructured dielectric light-trapping layers; 2) integration of these layers with ultra-thin crystalline silicon foils; and 3) fabrication of prototype solar cells.

To determine the optimum design, the research team will investigate an arrangement of nanostructures deposited as a continuous film on a thin planar cell using 3D full-field electromagnetic simulations. In addition, 3D finite element device simulations will be used to study and compare how light is affected by nanoarrays of spheres, domes, cylinders and wires of different shapes and sizes.

Initial results using these methods and materials for enhanced light trapping have shown promise. For example, Figure 1 shows how coupling the resonant modes of dielectric nanospheres on a solar cell can enhance its absorption, photocurrent and efficiency. Figure 2 shows how suitably engineered arrays of silicon nanocylinders on a silicon substrate act as anti-reflection coatings; incident light is stored in the nanostructures by driving a Mie resonance. The ultimate goal is to create ultra-thin silicon wafers that demonstrate very high efficiencies by applying fundamental insights from the behavior of light scattering and adsorption of dielectric meta-surfaces.

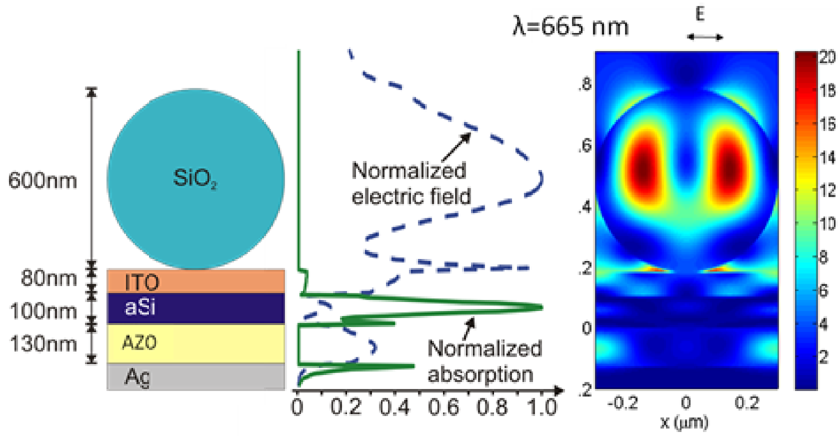

Figure 1. The resonant modes of dielectric silicon dioxide (SiO_2) nanospheres atop a solar cell can enhance its absorption, photocurrent and efficiency. [Atwater *et al.*, *Adv. Mater.* 23, 1272 (2011)].

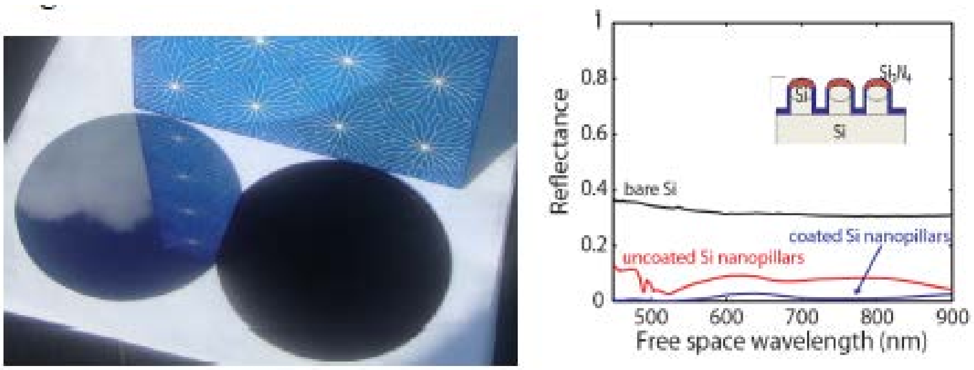

Figure 2. *Left:* Photograph of a standard silicon wafer (left) and a black wafer with silicon nanoparticle Mie scatterers. *Right:* The measured diffuse and specular reflectance of a standard silicon wafer (black line) and Si wafer with Mie scatterers (red and blue) [adapted from Polman *et al.*, *Nature Comm.* 3, 692 (2012)].

Fabrication using soft-imprint nanolithography and nanosphere self-assembly can create meta-surfaces that enhance absorption beyond well-known limits. The research team has developed a substrate-conformal imprint lithography (SCIL) technique that uses a stamp-and-mold method, which enables extremely high control over the patterned features. The team will also fabricate sphere arrays for colloidal assembly with a high degree of perfection. These small sphere arrays can accept light over a wide range of incident angles and serve as excellent in-coupling elements.