SOLAR ENERGY

GCEP

Global Climate & Energy Project

STANFORD UNIVERSITY

Inorganic Nanocomposite Solar Cells by Atomic Layer Deposition

Investigator

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Objective

This project is a fundamental study into the development of low-cost, thin film solar cells. It explores the fabrication of semiconductor nanocomposites for photovoltaics using nanostructured materials and atomic layer deposition (ALD). The focus is on cells built by high-throughput techniques where multiple junctions, ultrathin layers, and nanoporous structures are used to achieve good energy conversion efficiencies at low cost.

Background

There is a strong need for the development of photovoltaic cells with low cost, high efficiency, and stability. The broad energy distribution of the solar spectrum creates a fundamental challenge for the development of devices capable of efficient photovoltaic conversion. A multiple junction approach uses stacked cells of different materials so that each different cell converts a portion of the spectrum with an efficiency approaching the 70% single wavelength conversion. In thin film technologies, there exists a common problem with conversion efficiency where the photogenerated electrons and holes can recombine and are hence lost for power conversion. If the solar cell can be made using nanoscale heterojunctions, then the problem of recombination through traps can be greatly reduced. ALD is particularly well suited for this application since it can allow for deposition on complex non-planar structures at the nanoscale level with controllable thickness. With nanoscale diffusion lengths, the materials constraints can be relaxed, and low cost deposition routes become acceptable.

Approach

The basic proposed structure for a nanostructured multijunction solar cell is illustrated in Figure 1. It consists of a nanostructured substrate that is coated with semiconducting layers through ALD. There are three major issues which must be addressed in these proposed solar cells: First is the development of the nanostructured substrates with variable pore size and morphology. Second is the issue of ALD of Ge or other material into the nanostructured substrate and

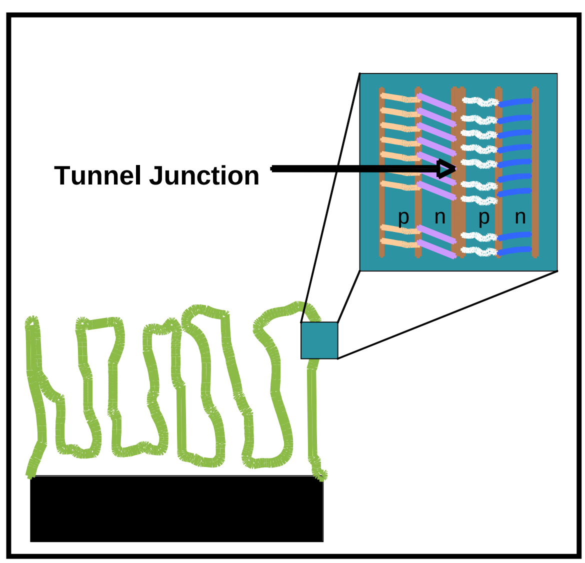

Figure 1: Schematic illustration of the nanostructured multijunction solar cell design. The nanostructured template is coated by ALD with several semiconducting layers to generate two p-n junctions separated by a tunnel junction.

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the subsequent growth of additional layers of nano-structured material, such as GaAs. The third challenge is the electrical connection and current collection from all of the nanostructured p/n junctions.

The nanostructured substrate forming the silicon layer of the heterojunction solar cell will be created by one of several approaches. These various approaches are to develop substrates with variable pore size and morphology. The following three structures will be considered: porous silicon, sintered films of silicon nanocrystals, and anodic alumina.

Atomic layer deposition (ALD) is the key enabling technology for the fabrication of the inorganic nanocomposite solar cells. The novelty of ALD is the ability to carry out the fabrication at higher throughput than that of competing inorganic solar cells designs, and hence at lower cost. ALD has the unique property of following the contours of non-planar surfaces, and the ability to deposit nanoscale films of controllable thickness in porous or nanostructured materials. The adsorption-controlled layer-by-layer reactions characteristic of ALD allows for the precise control of film thickness, excellent conformability and uniformity over large areas. Faster processing times is made possible by both the nanostructure-based design and the nature of the ALD process. Ultimately the thinner films, fast deposition, and batch processing should allow the design to be scaled up to develop a high throughput process.

In the primary structure, ALD will be used to deposit Ge onto the nanostructured Si substrate to form Ge/Si nanocrystalline p/n junctions. The ALD process is illustrated in Figure 2. It consists of an alternating series of self-limiting chemical reactions, called half-reactions, between gas phase precursors and the substrate. The precursors are pulsed into the reactor in a sequential fashion. Ge is chosen for two reasons: it has a direct bandgap just slightly above its indirect bandgap minimum and its bandgap is ~0.7eV. This combination of direct gap and its value mean that Ge will absorb a very large fraction of the IR portion of the solar spectrum. These materials form the structure of a single heterojunction solar cell.

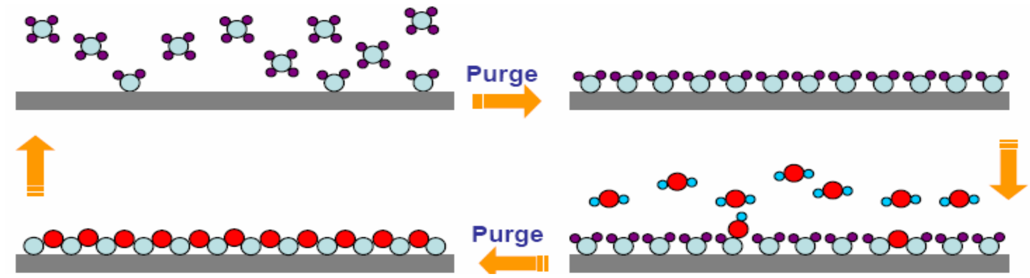

Figure 2: Schematic illustration of the ALD process. Alternating pulses of two different precursors, separated by a purge pulse of an inert gas, constitute a typical ALD cycle. Multiple ALD cycles are used to deposit a film.

Electrical connections to the nanostructured cells will need to be developed. Sputter deposited metals will be used initially, but the possibility of using selective deposition or contact printing methods to deposit metals only where desired will also be investigated. Another challenge for the multijunction approach is to achieve current matching between the two cells as the overall efficiency drops rapidly when equal currents are not present in both cells. Single nanostructured cells of each material combination will first be developed and then accurately modeled for both the optical path/absorption and electrical path/collection efficiency for photogenerated electrons and holes in each semiconductor layer. The information developed from the single heterojunction cells will be necessary to achieving current matching.