Cadmium Selenide Semiconducting Nanorods Vertically Aligned to a Conductive Substrate for Solar Cell Application

Emily Norvell
Materials Engineering, California Polytechnic State University, San Luis Obispo

NNIN REU Site: Nanotech @ UCSB, University of California Santa Barbara
NNIN REU Principal Investigators: Martin Moskovits, Galen Stucky, Department of Chemistry and Biochemistry, University of California Santa Barbara
NNIN REU Mentor: Martin Schierhorn, Department of Chemistry and Biochemistry, University of California Santa Barbara
Contact: enorvell@calpoly.edu, MLPSDean@LTSC.ucsb.edu

Introduction:

The current design of P- and N- doped silicon solar cells lacks the efficiency to adequately contribute to the existing energy demand. Because of this, researchers are exploring new solar cell designs. The design explored in this paper is called "Nanostructured Inorganic Donor/Acceptor Photovoltaics" and is intended to be an improvement on similar work recently published in *Science* [1].

In this design, an electron current is produced by the donor/acceptor photovoltaic method of electron diffusion between CdTe and CdSe. These semiconducting materials were selected because the CdTe has conduction and valance bands that are offset in energy compared to those of CdSe in such a way that electron and hole diffusion are optimized but recombination is minimized. Solar radiation excites electrons to the conduction band but they aren't free to move because they are attracted to the hole they left behind. The electrons in the CdTe conduction band are freed by falling to the lower energy conduction band of CdSe. The electron does work in a circuit and is returned to it's hole to start the process over again.

The design of the device presented here consists of a large array of CdSe rods infiltrated with CdTe quantum dots, as schematically illustrated in Figure 1. This report focuses on the fabrication and characterization of CdSe nanorods. The design provides a very high surface contact area for the CdSe nanorods and the CdTe quantum dots material. Furthermore, the nanoscale of the design boasts a short distance for the electron to travel to be separated from its hole, and the organized structure of the rods allows a direct path for the freed electron to travel to the electrode, so recombination is minimized.

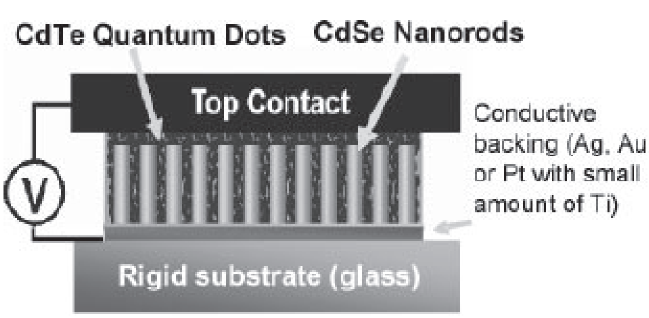

Figure 1: Side view of our nanostructured inorganic donor/acceptor photovoltaics design.

Procedure:

A solution of H_2O, H_2SO_4, 0.3 M $CdSO_4$, 2.8 mM SeO_2 was prepared and used to deposit in an electrochemical cell with a Pt mesh as the cathode. The anode was nanoporous alumina oxide (PAO) with a conductive backing which was a template for the formation of rods. We achieved the best results when we evaporated at least 10 μm of Ti before we evaporated the conductive backing of either Ag, Au or Pt and when we had the conductive back on the barrier layer side. We deposited in the PAO template using a method called cyclic voltammetry to achieve a 1:1 Cd:Se ratio so that the rods could be composed of a pure material. If straight DC voltage is used, an excess of Se will be deposited. The voltage was swept between -357 mV to -757 mV vs. a Ag/AgCl reference electrode. CdSe and Se were deposited from -357 mV to -736 mV. At -736 mV, Cd^{2+} was reduced, depositing an excess of Cd in the template which reacted with the Se precursor to form CdSe. At -656 mV, all the Cd+ that didn't form CdSe was oxidized, leaving a layer of CdSe. The CdSe was deposited layer by layer for either 600, 1200, or 1800 cycles.

Results:

An approximate 1:1 ratio of Cd:Se was confirmed with energy-dispersive x-ray (EDX) for the 0.3 M $CdSO_4$: 2.8 mM SeO_2 ratio (almost 100 fold excess of Cd ions). This ratio means our rods were made of pure CdSe. The length of the rods was controlled by the number of voltage cycles. 1200 cycles yielded ~ 1 μm.

Rods deposited in the alumina templates stood unsupported and did not clump together when the template was etched away with NaOH and dried in super critical CO_2. Nanorods that are vertically aligned to the

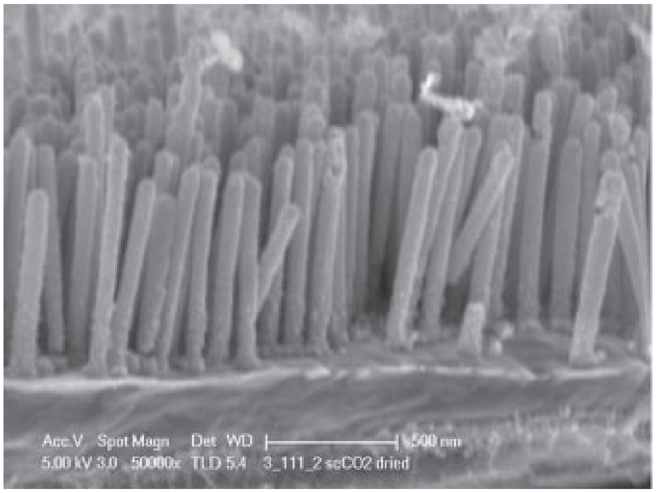

Figure 2: Nanorods vertically aligned to conductive substrate.

conductive substrate can be seen in Figure 2.

In preliminary work, CdSe was deposited onto slides of Pt. When the CdSe films were annealed at 300°, 400°, 500°, and 600°, an increase in characteristic crystalline CdSe peaks was shown with analysis of the slides with x-ray diffraction (XRD). XRD was done on the rods but inconclusive data resulted due to the random orientation of the crystallinity of the rods.

As-deposited rods were examined with a transmission electron microscope (TEM), which can be seen in Figure 3. The rods appear grainy, which was confirmed with selective area electron diffraction (SAED) to mean that the rods are polycrystalline, characterized by rings on the diffraction pattern. The spacing of the rings matched those of hexagonally oriented CdSe. Rods were annealed at 600°C and examined with TEM, shown in Figure 4. They look more uniform and smoother than the unannealed rods. SAED showed bright points on the diffraction pattern which indicated that annealed rods were more crystalline. These results confirmed that the crystallinity of CdSe nanorods increased when annealed.

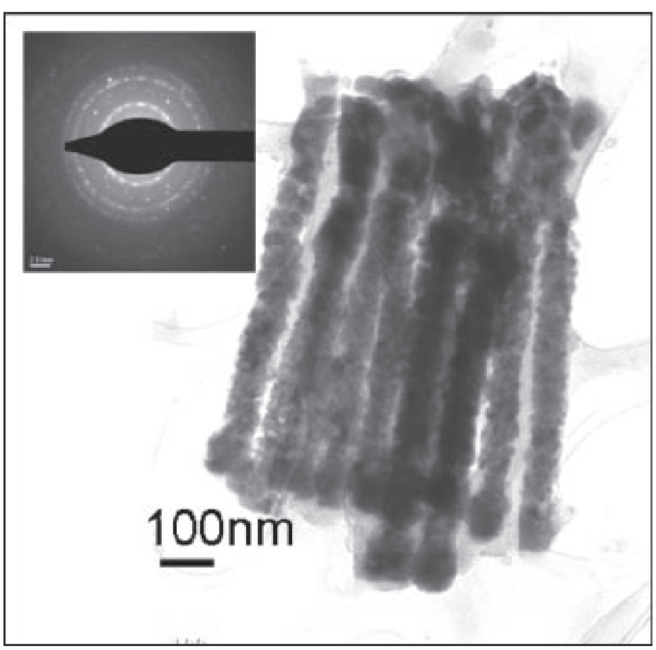

Figure 3: TEM of unannealed rods (inset): SAED of rods.

Future Work:

As more data is collected, a ratio of length per voltage cycles can be determined. Different materials for semiconductor rods and conductive backings will be tested for their effectiveness. Eventually solar devices can be assembled and tested for their efficiency.

Conclusion:

We successfully produced CdSe rods with the desired characteristics towards the production of photovoltaic devices with potentially greater efficiencies than current solar cells. We were able to produce pure CdSe material from Cd and Se precursors in solution. Vertically aligned rods were fabricated that made good contact to a conductive substrate and provided a large surface area for contact with sensitizing quantum dots. The as-deposited rods were poly crystalline and became more single crystal after annealing, which was desired for good electron transport to the electrode.

Acknowledgements:

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References:

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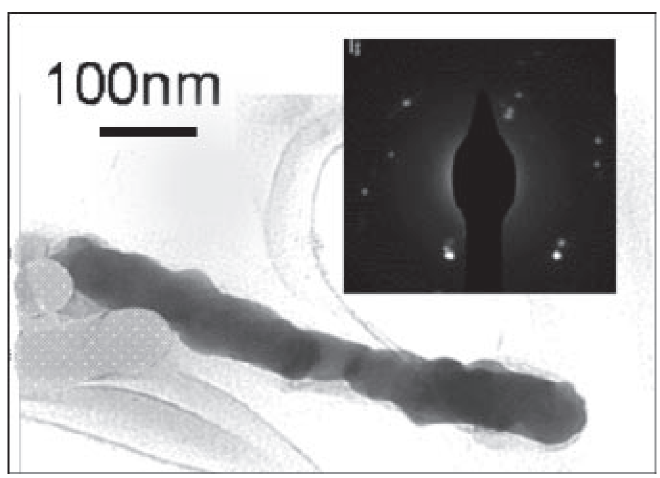

Figure 4: TEM of annealed rods (inset): SAED of rods.