Semiconductor Nanocrystal Inks for Printed Photovoltaics

James Mueller

Chemical Engineering, University of Michigan – Ann Arbor

NNIN REU Site: Microelectronics Research Center, University of Texas, Austin, TX
NNIN REU Principal Investigator(s): Brian A. Korgel, Chemical Engineering, University of Texas
NNIN REU Mentor(s): Matthew G. Panthani, Chemical Engineering, University of Texas
Contact: jamesmue@umich.edu, korgel@che.utexas.edu, mgp424@che.utexas.edu

Abstract:

In this study, photovoltaic solar cells were fabricated using a solution-processable route. These devices were comprised of several metallic or semiconducting layers, all of which were solution-processed from colloidal nanocrystals. Conventional copper indium gallium selenide (CIGS) solar cells (made through vapor deposition and sputtering of metal or semiconductor targets) typically have a stacked structure of an evaporated metal back electrode, co-evaporated semiconducting layers, and a sputtered transparent conductive oxide top contact such as indium- tin oxide (ITO). Rather than sputtering or evaporating these layers, we sprayed dispersions of nanocrystals using an airbrush purchased from a local art supply store. In this study, we used a back contact of gold (Au), semiconductor layers of zinc oxide (ZnO), cadmium sulfide (CdS), and CIGS, and an ITO top electrode. Devices were prepared on both glass and flexible plastic substrates, and annealed in a tube furnace or on a heating stage. The power conversion efficiency of the completed devices were tested to assess the feasibility of implementing devices made in this manner.

Introduction:

The world is in an energy crisis right now. We are using non-renewable resources to create energy, but now these resources are disappearing and energy prices are skyrocketing. Most of these non-renewable resources are carbon based products, such as coal and oil, and produce greenhouse gases (CO_2 and NO_x). These greenhouse gases lead to many negative environmental impacts such as acid rain and global warming.

Solar power is becoming a sought-after alternative to carbon based energy. Harnessing solar energy has been considered for a long time, but it was never thought of as a good alternative to fossil fuels because of the large price of solar panels. On average, a solar panel will cost around $20,000 for a typical home. Our goal is to reduce that number to $2000 per panel.

In this project, we will be using colloidal nanocrystal dispersions to create "inks" that can be used to spray coat all the layers needed for a photovoltaic cell. The light-absorbing semiconductor will be CIGS nanocrystals. CIGS is an attractive material because it has a bandgap suited well to the solar spectrum and has a high absorption coefficient [5], enabling it to absorb most of the incoming light with a very thin (~ 1 μm) layer. In laboratory scale-devices, it has shown power conversion efficiencies approaching 20% [6].

Experimental Procedure:

There were five layers to the solar cells we made. We used Au and indium tin oxide (ITO) as top and bottom electrodes, respectively. These would extract the charge carriers from the semiconductor layers. Copper indium gallium selenide (CIGS) was used as the p-type absorber layer. Lastly, cadmium sulfide (CdS) and zinc oxide (ZnO) was used as the n-type semiconductors. The CIGS – CdS, ZnO layers were used to make a p-n junction that would create a difference in electronic potential which would cause positive and negative charge carriers to separate, creating a current. Each of these materials were synthesized, expect ITO was bought from Sigma-Aldrich in a 20% wt dispersion in isopropyl alcohol. ZnO and ITO nanocrystals were dispersed in isopropyl alcohol (IPA), and CIGS, Au, and CdS nanocrystals were dispersed in toluene. The nanocrystals were synthesized using the following methods: Au via the Brust method [1], CIGS via the Panthani method [2], CdS with the Shieh procedure [3], and ZnO via the Greene method [4].

The nanocrystals were then dispersed to 5 w/v% (20 mg/mL) in the solvents described above. These were the "inks" we used. We used an artist's airbrush to spray this ink on a glass substrate.

To make the full device, we sprayed each layer, and then after each layer, we annealed in a vacuum oven at 100°C for 2 minutes. After the full device was sprayed and each layer was annealed, we annealed the completed device at 200°C for 5 minutes.

Results and Conclusions:

In Figure 1, you can see the full device as prepared. The Au contacts are the shapes that look like fingers that stretch the whole width of the device. Nickel paint was put on top of the contacts to protect them and those are the circular spots on the left of the figure. The stack of all the nanocrystals is located on the right of the figure.

Figure 2 shows a scanning electron microscope (SEM) micrograph of a completed device that was cracked in half. Different layers can be seen on the image and this suggests that we made device with all the layers intact.

A power conversion efficiency test was run to determine if any photocurrent would be produced from the device. No photocurrent was found. This could be from a few things, including nonuniformity of sprayed layers. It is important to have complete and discontinuity-free layers to prevent shorts.

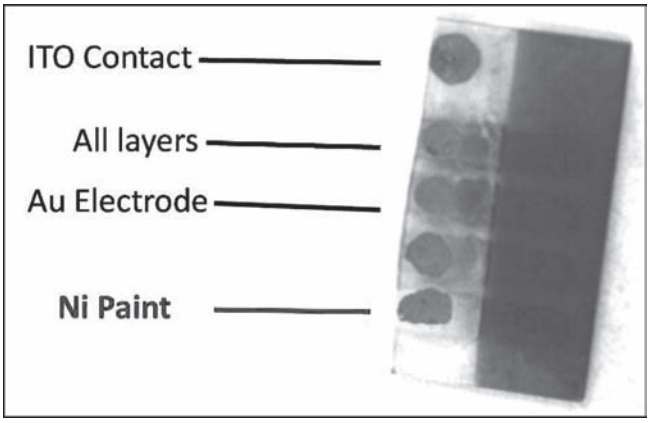

Figure 1: Fully prepared device.

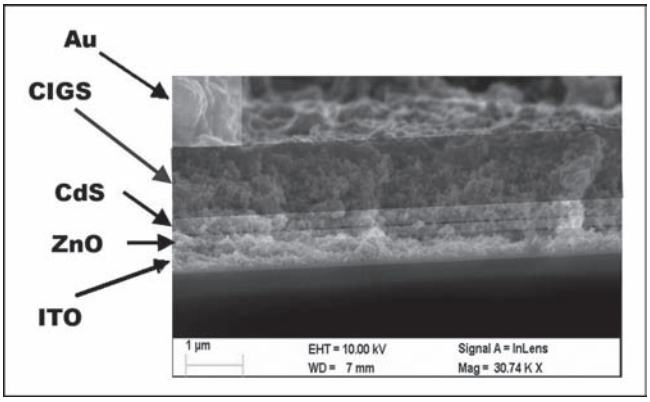

Figure 2: SEM of cracked device.

Future Work:

Different techniques of creating continuous films should be explored. Spraying continuous and complete layers are vital to create a current through the device. Other techniques should be explored to spray the nanocrystals onto the substrate. Our method for synthesizing ZnO caused discontinuous films to form. Other ways to deposit ZnO should be explored. Different annealing methods should also be explored.

Acknowledgements:

National Nanotechnology Infrastructure Network Research Experience for Undergraduates Program, the National Science Foundation, Dr. Brian A. Korgel, Matthew G. Panthani, Vahid Akhavan, Brian Goodfellow, the Korgel Group, Jean Toll, the University of Texas at Austin, and the University of Michigan.

References:

[1] Brust et al, J. Chem. Soc., Chem. Commun., 1994, 861.
[2] Panthani et al, J. Am. Chem. Soc., 2008, 130 (49), pp 16770-16777.
[3] Shieh et al, J. Phys. Chem. B, 2005, 109 (18), pp 8538-8542.
[4] Greene et al, Nano Lett., 2005, 5 (7), pp 1231-1236.
[5] Rockett et al, R. W. Journal of Applied Physics, 1991, 70, R81-R97.
[6] Repins et al, Progress in Photovoltaics: Research and Applications, 2008, 16, 235-239).