Spray-Deposited CdS/PbS Solar Cells

Nagendra Dhakal, Seth Calhoun, Robert E. Peale, Saiful Khondaker
Physics, University of Central Florida, Orlando FL 32816
Isaiah O. Oladeji
Sisom Thin Films LLC, 1209 W. Gore St. Orlando Fl 32805

Abstract

We demonstrate photovoltaic action for a thin-film CdS/PbS heterojunction solar cell fabricated by aqueous spray deposition using earth-abundant elements as a potentially flexible, low-cost solar-cell technology. The structure comprises borofloat glass substrate, fluorine-doped tin oxide as transparent current collector, CdS window layer, and PbS absorber layer. Gold is deposited as ohmic contact to the PbS and light is incident through the substrate. The IV curves are diode-like with ~ 0.7 V threshold. Under 1 sun, the short circuit current density ~ 0.5 A/m^2, the open circuit voltage ~ 0.14 V, the max power ~ 21 mW/m^2, and the fill factor ~30%.

Introduction and motivation

Silicon-based solar cell dominant the market due to economy scale and the earth-abundance of Si. CdTe and CuInGaSSe cells struggle to compete due to expensive vacuum growth methods and scarcity of In, Ga, and Te elements. This paper explores a low cost, scalable, aqueous deposition technique to grow a complete thin-film solar cell from abundant elements, which can potentially reduce cost per Watt below that of Si cells.

CdS and PbS are excellent heterojunction partners due to compatible electron affinity [1]. Indeed, there have been several recent reports of CdS/PbS junction thin-film solar cells [2-5], many deposited from aqueous solution. We explore a different spray-on aqueous deposition based on heterogeneous reaction and nano-crystal growth at hydroxyl nucleation sites on hydrophilic substrates. The entire cell structure comprising four distinct materials is grown by the same method.

Figure 1 presents the cell structure, which comprises SnO_2:F, CdS, $Pb_{1-x}Cd_xS$, and PbS:Se, grown in that sequence on a borofloat glass substrate. These layers are completed by a metal contact. The front current collector is the transparent conducting oxide Sn_2O:F (FTO). CdS is an established n-type window layer. PbS, a p-type semiconductor with 0.42 eV bandgap, is the absorber. All the elements involved are abundant compared to In, Ga, and Te.

The simple CdS/PbS structure is unlikely to have good photovoltaic properties, because the PbS conductivity usually exceeds that of CdS, so that the depletion and built-in field would lie mostly within the window layer. The photogenerated carriers in the PbS absorber would therefore be poorly separated. This motivates our choice to insert an insulating $Pb_{1-x}Cd_xS$ layer between the CdS and PbS layers. The bandgap of the $Pb_{1-x}Cd_xS$ layer needs to be ~1.5 eV to match the solar spectrum.

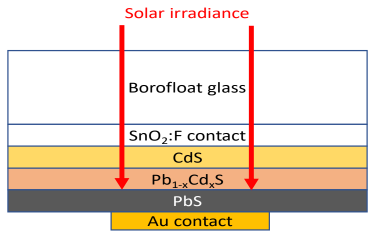

Figure 1: Solar cell structure

Methods

Experimental details

The aqueous-spray thin-film growth method is Streaming Process for Electrodeless Electrochemical Deposition (SPEED). Substrates are borofloat glass. The chemistry and properties of SPEED-grown FTO are described in [6-9], where nano-crystalline growth is done at 500° C substrate temperatures. CdS growth by SPEED is a spray variation of chemical bath deposition [10] that avoids wasteful homogeneous reactions. PbS growth was described in [11]. PbCdS growth is similar. Physical characterization included scanning electron microscopy (SEM) of the surface morphology. For photo response measurements gold contacts of 75 mm^2 area were evaporated on the PbS surface using a shadow mask. Current-voltage (IV) measurements were performed in the dark and under 1 sun illumination, which was produced by a solar simulator with 1.5 air mass filter.

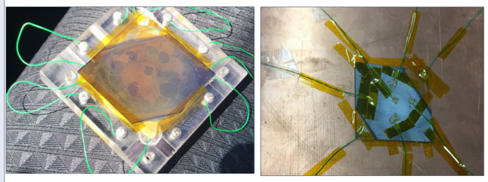

Fig.2: Photographs of solar cell samples.

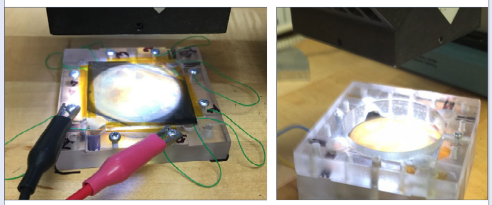

Fig.3: Solar cell exposed to 1 sun from solar simulator.

Results

Figures 2 and 3 present photographs of the sample and experiment. Figure 4 presents an SEM image of the cell surface without metal contacts. The surface is continuous without cracks. There are structures with 1-5 micron length scale that can internally scatter incident solar radiance, and thereby increase absorption.

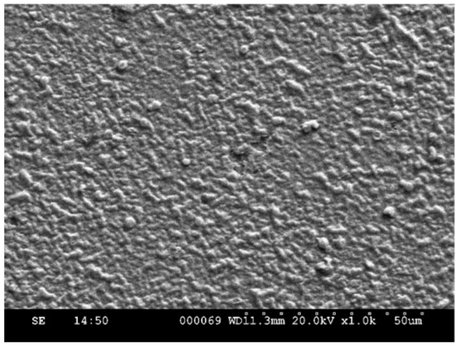

Figure 4: SEM images of the solar cell surface

Figure 5 presents the diode-like IV curve measured in the dark. The threshold voltage is ~ 0.7 V and threshold resistance is ~ 640 Ω.

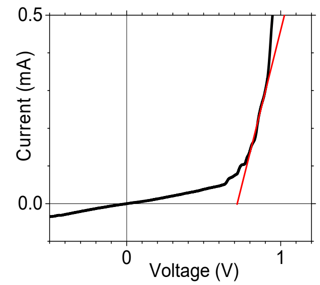

Figure 5: IV curve measured in the dark.

Fig. 6 presents an IV curve measured under 1 sun illumination. (The current scale in the forward bias portion of the IV curve is inverted with respect to the curves in Fig. 5 as is usually done.) The power I * V is also plotted. The maximum power is 1.6 µW. The fill factor is 28%. The efficiency of this first cell is very low, only about 0.002%.

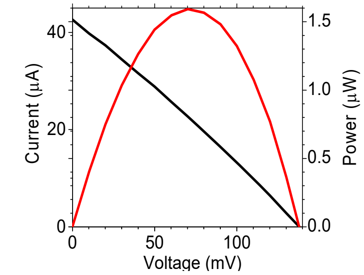

Figure 6: IV and power curves for CdS/PbS solar cell under 1 sun illumination.

Summary

Photovoltaic thin-film CdS/PbCdS/PbS heterojunction solar cell was fabricated by aqueous spray deposition. The diode-like IV curve has 0.7 V threshold. Under 1 sun illumination, the short circuit current density J_{sc} ~ 0.5 A/m^2, open circuit voltage ~ 0.14 V, max power ~ 21 mW/m^2, and fill factor ~30%.

References

1. Binbin Weng et.al. Appl. Phys. Lett. 104, 121111 (2014).
2. J. Hernández-Borja, Y. V. Vorobiev, R. Ramírez-Bon. Solar Energy Materials and Solar Cells 95, 1882 (2011).
3. H. A. Mohamed. Solar Energy 108, 360 (2014).
4. D. Saikia and P. Phukan. Thin Solid Films 562, 239 (2014).
5. A. S. Obaid, Z. Hassan, M. A. Mahdi, M. Bououdina. Solar Energy 89, 143 (2013).
6. F. Khalilzadeh-Rezaie, I. O. Oladeji, G. T. Yusuf, J. Nath, N. Nader, S. Vangala, J. W. Cleary, W. V. Schoenfeld, and R. E. Peale. MRS Proceedings. Vol 1805, pp. mrss15-2136423.
7. F. Khalilzadeh-Rezaie, I. O. Oladeji, J. W. Cleary, N. Nader, J. Nath, I. Rezadad, and R. E. Peale. Optical Materials Express 5, 2184 (2015).
8. R. E. Peale, E. Smith, H. Abouelkhair, I. O. Oladeji, S. Vangala, T. Cooper, G. Grzybowski, F. Khalilzadeh-Rezaie, J. W. Cleary. Opt. Eng 56, 037109 (2017)
9. R. Gibson, S. Vangala, I. O. Oladeji, E. Smith, F. Khalizadeh-Rezaie, K. Leedy, R. E. Peale, and J. W. Cleary. Optical Materials Express 7, 2477 (2017).
10. I. O. Oladeji and L. Chow. J. Electrochem. Soc. 144, 2342 (1997).
11. H. Abouelkhair, P. N. Figueiredo, S. R. Calhoun, C. J. Fredricksen, I. O. Oladeji, E. M. Smith, J. W. Cleary and R. E. Peale. MRS Advances 3, 291 (2018).