Silicon Heterojunction Photovoltaic Cells

Hans Banerjee

Electrical and Computer Engineering, University of Illinois at Urbana-Champaign

NNIN REU Site: Microelectronics Research Center, The University of Texas at Austin, Austin, TX
NNIN REU Principal Investigator: Prof. Sanjay Banerjee, Electrical and Computer Engineering, University of Texas at Austin
NNIN REU Mentors: Emmanuel Onyegam and Sayan Saha, Electrical and Computer Engineering, University of Texas at Austin
Contact: banerje8@illinois.edu, banerjee@ece.utexas.edu, onyegam@utexas.edu, sayan.saha@utexas.edu

Abstract and Introduction:

A key advantage of silicon heterojunction photovoltaic cells over conventional cells is that they have potentially higher efficiencies [1]. They can be made using remote plasma chemical vapor deposition (RPCVD), a low temperature process that prevents carrier lifetime degradation and thus improves open-circuit voltage (V_{oc}) [2]. Both single (SHJ) and dual (DHJ) heterojunction cells were fabricated by depositing a-Si:H onto n-type silicon wafers using RPCVD. SHJ cells were fabricated with and without intrinsic silicon "i-layers," and with different thicknesses of p-doped a-Si:H at the front.

According to I-V testing, the SHJ cells with an i-layer produced a higher V_{oc} than those without one, suggesting the i-layer aids in passivation. Thicker p-doped layers resulted in lower short-circuit current density (J_{sc}), due to absorption in the p-doped layer reducing quantum efficiency at short wavelengths. DHJ cells were fabricated with varying back surface field (BSF) layer thicknesses. A 30 nm BSF layer produced a similar V_{oc} and J_{sc} to one of 20 nm, indicating that thicker BSF layers do not significantly reduce back surface recombination. The SHJ and DHJ cells showed similar efficiencies (~15%). This may be due to non-optimized doping of the BSF layer in the DHJ cells, or their lack of an i-layer leading to lower quantum efficiency.

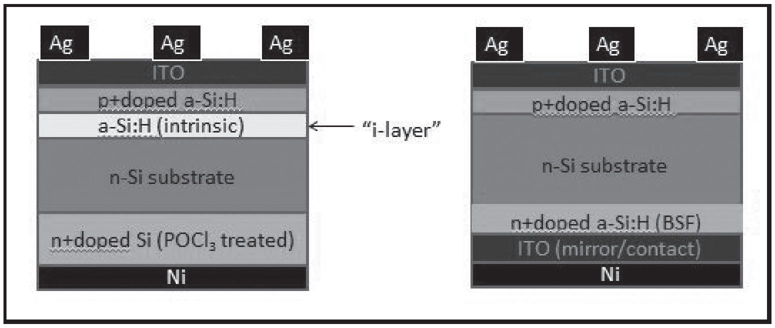

Figure 1: Schematic diagram for SHJ (left) and DHJ (right) cells.

Single HJ

Cell	i-layer	Front p+	V_{OC}	J_{sc}	Fill Factor	Eff.
No I	0 nm	18.6 nm	632 mV	30.9 mA/cm^2	77.0%	15.1%
718-2	6 nm	11 nm	637 mV	32.0 mA/cm^2	77.5%	15.8%
719-2	7 nm	17 nm	637 mV	30.3 mA/cm^2	78.8%	15.2%

Dual HJ

Cell	Back n+	Front p+	V_{OC}	J_{sc}	Fill Factor	Eff.
716-2	20 nm	18.6 nm	616 mV	31.6 mA/cm^2	77.3%	15.0%
716-3	30 nm	18.6 nm	619 mV	31.9 mA/cm^2	77.9%	15.4%

Figure 2: Physical and electrical measurements of fabricated cells.

Experimental Procedure:

Three SHJ and two DHJ cells were fabricated using RPCVD. Schematic diagrams of these cells are given in Figure 1. The SHJ cells were constructed with and without intrinsic a-Si:H i-layers, and with different thicknesses of p+doped a-Si:H at the front. The DHJ cells were fabricated with varying back surface field (BSF) n+doped a-Si:H layer thicknesses. The doping concentration of the p-doped and n-doped a-Si:H layers was held constant for all cells through constancy of the relevant RPCVD parameters. I-layers were not incorporated into the DHJ cells due to time constraints; the effect of the i-layer on PV cell characteristics was studied solely through the SHJ cells. Physical characteristics of the five cells are shown in Figure 2. All cells were metalized with nickel at the back and screen printed with silver paste at the front to improve electrical contact.

Results and Discussion:

I-V and effective quantum efficiency testing was conducted on the cells. The I-V data for all the cells is shown in Figure 2. The effective quantum efficiency (EQE) between the wavelengths of 300 and 1200 nm is plotted in Figure 3 for SHJ cells and Figure 4 for DHJ. One notable result of this data is that both DHJ cells performed similarly in the EQE tests. The V_{oc} and J_{sc} of both cells were comparable as well (Figure 2). It can thus be concluded that having a thicker BSF than 20 nm does not significantly reduce back surface recombination in DHJ cells.

In SHJ cells, the V_{oc} of the cells with an i-layer was slightly higher (~ 5 mV) than that of the cell without it. This shows that the presence of an i-layer aids in the prevention of front surface recombination. However, the V_{oc} of the sample with the 7 nm i-layer had the same V_{oc} as the one with the 6 nm i-layer, possibly indicating that 6 nm of a-Si:H provides sufficient passivation.

In terms of current, the cell with the thinnest front p+doped layer clearly displayed the best J_{sc}. The explanation for this becomes clearer upon viewing Figure 3 and comparing the EQE curves for 718-2 and 719-2. The cell with the thinner front p-layer (718-2) exhibits significantly higher quantum efficiency at the lower wavelengths (< 700 nm). Thus, it seems that the thicker front p-layer of 719-2 was absorbing more light at short wavelengths, which leads to lower generation of effective charge carriers. It can be concluded that an overly thick a-Si:H layer at the front junction leads to reduced EQE at short wavelengths, and therefore adversely affects current.

Future Work:

When comparing SHJ and DHJ cells, the efficiency for both types is around 15%, depending on the various parameters. At first glance, it does not seem like the DHJ cells perform any better than the SHJ. However, it is worth noting that the DHJ cells were done without i-layers, which could have increased V_{oc} and efficiency like they did for the SHJ cells. Also, the doping concentration of the BSF layer in the DHJ cells may not be optimal. Future experiments with DHJ cells will be conducted with the i-layer thickness and BSF layer doping concentration as variables. Finally, texturing the surface of PV cells helps efficiency by reducing surface reflections and trapping light inside the cells for longer, leading to more generated carriers and higher current [3]. Texturing was omitted for the sake of time in this brief study, but can be performed to achieve higher efficiencies on future cells.

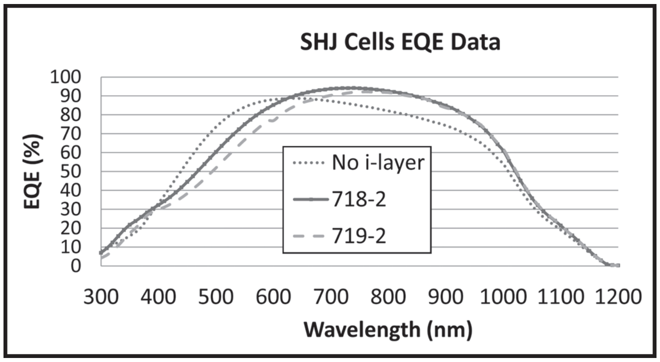

Figure 3: Quantum efficiency graph of SHJ cells.

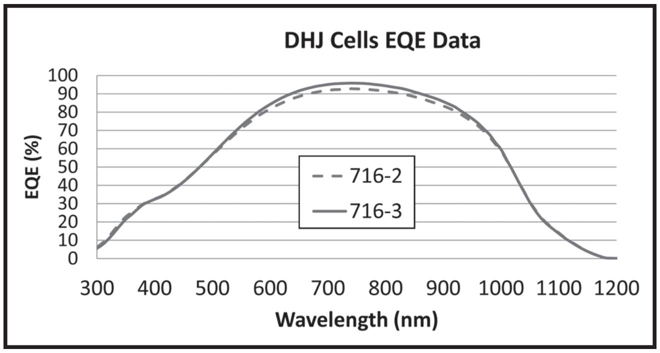

Figure 4: Quantum efficiency graph of DHJ cells.

Acknowledgements:

I would like to acknowledge the National Nanotechnology Infrastructure Network Research Experience for Undergraduates Program and the National Science Foundation for selecting me and funding me for this prestigious research opportunity. I would also like to thank my mentors Emmanuel Onyegam and Sayan Saha, my P.I. Dr. Sanjay Banerjee, and everyone at the Microelectronics Research Center for all of their help.

References:

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[2] D. Sarkar, et al.; "Remote Plasma Chemical Vapor Deposition for High Efficiency Ultra-thin ~25 Microns Crystalline Si Solar Cells," 38th IEEE PVSC, June 3-8, 2012.

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