SSCP: Optimization and Characterization of the Encapsulation Stack

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Background

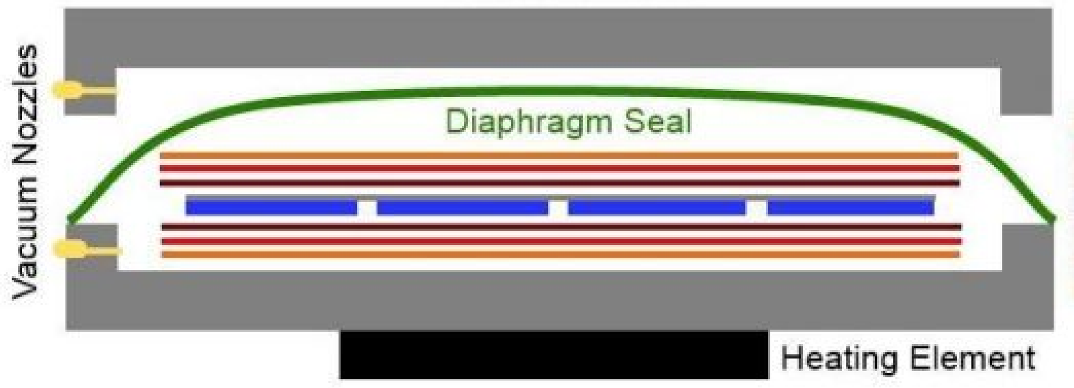
The Stanford Solar Car Project (SSCP) is an undergraduate student group which aims to train the next generation of engineers as they design and build cars to race in the World Solar Challenge, a 2,000-mile race across the Australian Outback. Stanford's vehicles achieved fourth and sixth place finishes in 2013 and 2015, respectively.

Introduction

In the World Solar Challenge, a team's race potential is greatly affected by the performance of the solar array. The Stanford Team prides itself in creating the car with as little outsourcing as possible. Therefore, determining the optimal encapsulation stack is crucial. Encapsulation, in essence, is a way to protect the fragile solar cells as well as maintain or even improve the efficiency.

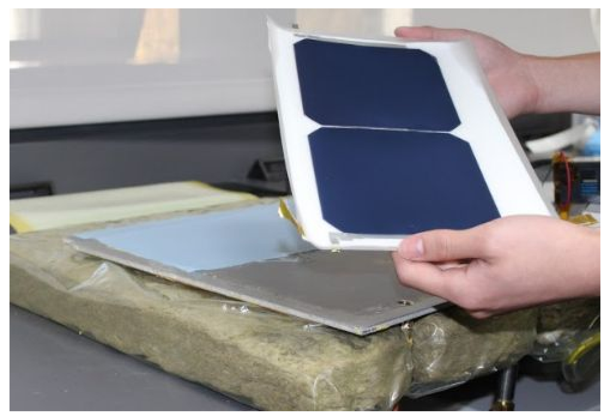
Encapsulation Stack

The encapsulation stack is composed of several layers-the components being: the topsheet, backsheet, encapsulant, and solar cells. The encapsulation method is to apply vacuum pressure and heat the stack, allowing the encapsulant to flow and cure, thereby laminating the cells.



Process

Pictured above is a diagram of the layers of materials used in lamination. The combination of these materials is known as the 'encapsulation stack'. Generally, this stack includes a top sheet which is laid down first then encapsulant, solar cell, encapsulant, backsheet, and then breather cloth to allow even vacuum across the entire surface. The layers are enclosed within a silicone diaphragm and hot plate sealed with vacuum tape. Vacuum is pulled and temperature is increased to the flow temperature for the encapsulant.

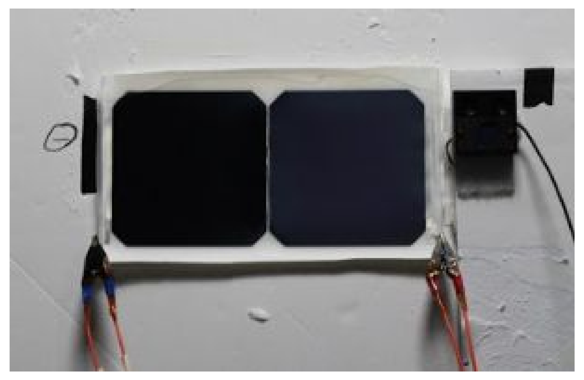


Materials

Topsheets: FEP, ETFE, 3M
Encapsulants: Mitsui Polyolefin, STR EVA, 3M Polyolefin, Dow Corning Silicone, Dupont Ionomer
Backsheets: Flexcon KPE, Flexcon PPE, Akalight, Dymat PYE, Madico RLight, Madico RLean, Madico R

Flash Tester Set-Up

Flash testing is a unique and powerful way of testing the efficiency of solar cells. For this research project, the flash tester lamp was placed on a table and aligned so that the flash pulse would go directly through a window to illuminate the solar cells within the dark room. There the cells were mounted on an angle-adjustable wooden frame with a thermocouple probing the back of the solar module (ensuring that the temperature was at the standard 25℃). When the light hits the cells, measurements such as the short circuit current (Isc), the open circuit voltage (Voc), series resistance (Rs), and the efficiency are taken. For each set of measurements, the flash tester software plots a point on a IV curve in order to graphically show the power output of the module. A reference cell is also used to monitor the light intensity for the measurements (which was kept constant throughout the experiment at 1 sun).

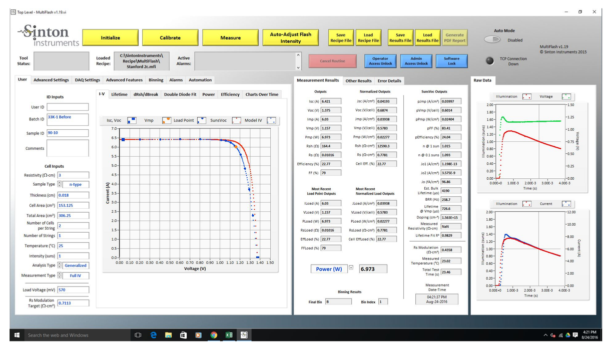


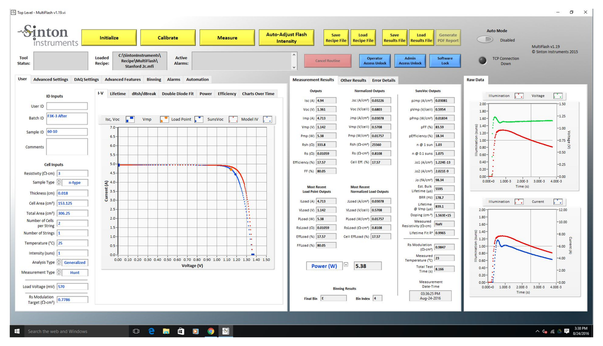
Series Resistance of High-Efficiency Solar Cells

It can be difficult to obtain accurate flash measurements for high efficiency cells due to their large capacitive effects. This is caused by the cells charging on the rising edge of an illumination pulse or discharging on the falling edge. This charging and discharging of the cell capacitance alters the current measured and thereby affects other parameters used to characterize the cell's electrical performance. In order to counter this capacitive effect, the flash tester uses a special technique that includes applying a small voltage modulation throughout the duration of a flash pulse, thereby keeping the cell's carrier concentration constant i.e putting the cell into a steady-state condition which then allows for full and accurate IV characterization of the cell/module being tested.

Method

For this project, 1x2 solar cell modules were tested. Before each test, the system was calibrated with a reference module and at each angle (90 through to 50 degrees with respect to the horizontal), the Rs modulation target value was adjusted to be within 10% agreement with the Rs and the Rs modulation. For each encapsulation stack, 2-3 modules were tested and for each module, 10 iterations of testing was done at each angle and the results were then saved according to which encapsulation stack the module was associated with. In order to determine the change in efficiency/power output, the modules were soldered and tested before encapsulation, as well as tested after encapsulation. For each angle the results were averaged separately for before and after testing routines, then these averages compared in order to determine which encapsulation stack led to minimal efficiency loss / maximum efficiency gain at the different angles tested.





Final Results

After analyzing the data, these were the best encapsulation stacks for each angle.

Stack	Degree	Change in Efficiency
FEK	90	-1.345%
FEK	80	-1.05%
3EK	60	-0.2478%
F3K	50	-0.37875%

Further Investigation

This project could be extended to test other combinations of topsheets and encapsulants. It could also be extended to complete testing on the different combinations of backsheets with encapsulants/backsheets with topsheets, as well as testing the effects of other techniques such as dicing or texturing on the electrical performance of solar cells/modules.

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