DEMONSTRATION OF THE BENEFITS OF SILICONE ENCAPSULATION OF PV MODULES IN A LARGE SCALE OUTDOOR ARRAY

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Abstract: Based on the historical performance of silicones in both the construction and electronic industries, silicones are known for their superior performance in outdoor applications. This performance makes silicone materials well suited for solar photovoltaic (PV) modules in their application as a semiconductor device made for outdoor use. Silicone applications within the module include encapsulants, potting materials, and junction box and frame sealants. Dow Corning has developed a number of silicone-based products for use in PV module construction including the *Dow Corning*® PV-6100 Cell Encapsulant Series product line launched in 2009. To demonstrate the product line performance in real-world conditions, 15 kilowatts of mono-crystalline matrices were purchased from SunPower Corporation, San Jose, California, USA under the United States Department of Energy Solar America Initiative Program. The matrices were encapsulated on the Pilot Line in Dow Corning's Solar Solutions Application Center in Freeland, MI USA. The silicone-encapsulated modules were installed as part of a 30 kW PV array at the Dow Corning corporate headquarters in Auburn, Michigan in 2009. The balance of the array was constructed using 15 kW of EVA modules purchased from SunPower Corporation, using identical cell and glass technology to compare efficiency and durability.

Keywords: Silicone, Solar Cell Efficiency, Solar Cell Durability, Encapsulation

1. INTRODUCTION

While silicones for PV module encapsulation have been used since the 1970's, the market has historically been dominated by organic materials such as ethylene vinyl acetate (EVA). However, these organic materials typically utilize UV-blocking agents that have been shown to reduce overall energy conversion efficiency between PV cells and modules[1][2]. Silicone encapsulants have the potential to overcome this disadvantage with the proper product design in combination with processing, and equipment engineering.

As reported in previous EU PVSEC conferences, Dow Corning has been working to develop a new generation of silicone encapsulants to leverage the advantages of silicones while also creating a product and process combination that meets or exceeds industry requirements. The *Dow Corning*® PV-6100 liquid encapsulant series has been the result of this effort, and this material was officially launched at the 2009 24^{th} EU PVSEC in Hamburg, Germany. A key milestone in the commercialization of this product line has been the demonstration of this product/process combination at full production scale, and the subsequent creation of a significantly large array of PV modules that demonstrate the performance of PV-6100 series products in real-world conditions. This demonstration also included an array of organic (EVA) containing modules for comparative assessment of efficiency and durability.

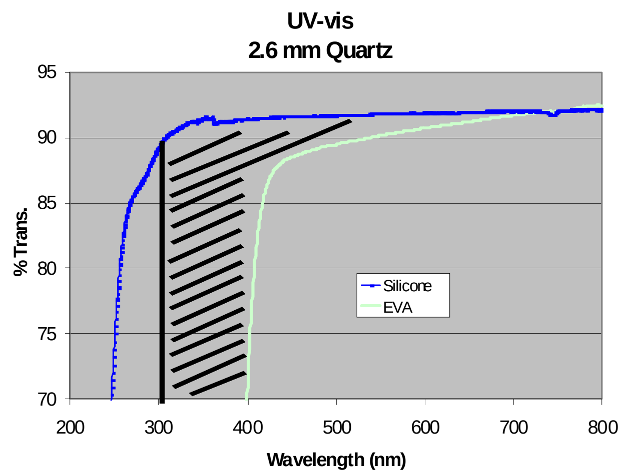
The comparative study was done in collaboration with SunPower Corporation under the Solar America Initiative. The study utilized 15 kilowatts of SunPower mono-crystalline matrices that were encapsulated with the *Dow Corning*® PV-6100 Cell Encapsulant series, and 15 kilowatts of SunPower mono-crystalline EVA encapsulated modules using identical cell and glass technology. Both sets of modules were installed side by side in a 30 kW PV array at the Dow Corning corporate headquarters in Auburn, Michigan in July of 2009. The silicone-encapsulated PV modules for this array were produced at Dow Corning's Solar Solutions Application Center in Freeland, MI USA.

2. SILICONE ENCAPSULANT EFFICIECNY GAIN

The study of silicone as encapsulants in PV modules has been underway for decades in arrays that have been installed at BP Solar, formerly Solarex, in Frederick, Maryland, USA and at Georgetown University in Washington, D.C., USA. These arrays have been successful at showing the durability of silicone encapsulated modules[1], but no study has been done to compare module efficiency gains of silicone encapsulation over EVA modules.

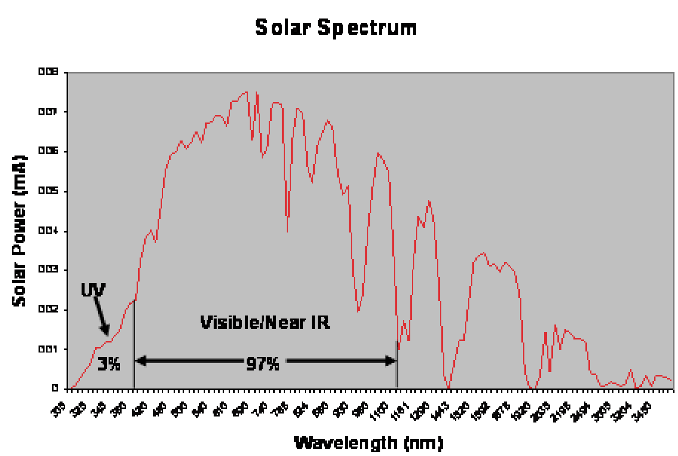
The study of silicones potential efficiency gains has been reported by comparing the percent of light transmission of silicones and EVA versus wavelength [1][2]. From the graph shown in Figure 1, it was quite apparent that silicones were significantly more transparent over the range of 250 to 400 nm.

Figure 1: Comparison of Silicone and EVA Percent Light Transmission from 200 to 800 nm



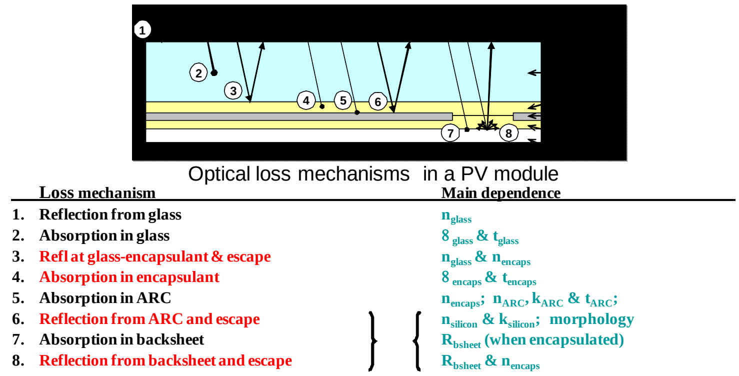
When comparing this data to the solar spectrum it was apparent that the EVA was cutting off approximately 3% of the useable spectrum for crystalline PV solar cells [3] as shown in Figure 2.

Figure 2: EVA UV cut off of Solar Spectrum



To expand this demonstration of the silicone advantage, a collaborative study was started with Australia National University. In this study, the optical properties of silicone and EVA were measured and utilized in a Ray Tracing Simulation created by ANU. The basis of the simulation software is shown in Figure 3.

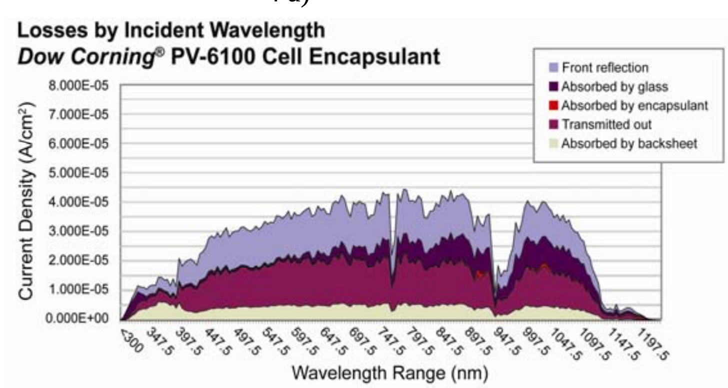
Figure 3: ANU Ray Trace Modeling of Optical Loss Mechanisms in crystalline PV Modules[3].



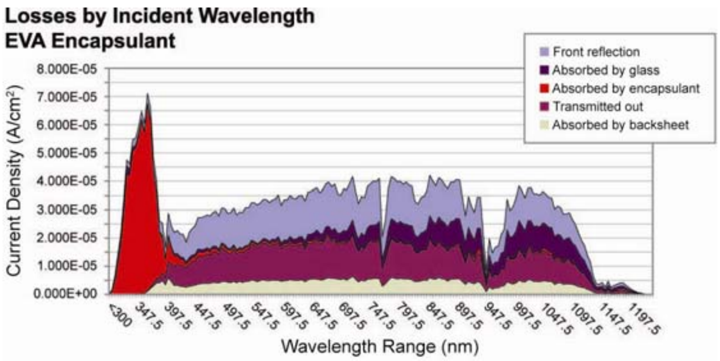
The model combined External Quantum Efficiency Data for cells and the optical properties of silicone to generate a simulation of J_{sc} losses over the spectrum functional for crystalline PV cells. This analysis confirmed the observation of EVA cutting off the UV portion of the spectrum. The output of the analysis is shown in Figure 4.

Figure 4: PV module Ray Trace Modeling Results a) EVA optical losses b) Silicone Optical losses

4 a)



4 b)



The losses shown in the model output show a significant absorption of the available light below 400 nm for EVA with most other optical losses being equal. This information coupled with the External Quantum Efficiency data for mono-crystalline cells indicated a >1% relative gain in cell efficiency[1].

An experiment to confirm the potential efficiency gains was conducted at a single cell level with SunPower Corporation under the NREL PVMR&D program. The results of this study, demonstrated under flash testing at STC, that cells encapsulated with silicone had ~ 1.7% advantage in J_{sc} losses when utilizing non-Anti Reflective (AR) coated glass and ~1.5% when using AR coated glass[1].

3. OUTDOOR ARRAY SILICONE TO EVA COMPARISON

Armed with the confidence from the simulations and actual cell measurements, a decision was made to demonstrate these gains in an outdoor, large scale array. This array was constructed in collaboration with SunPower Corporation. SunPower supplied completed EVA modules along with 72 cell matrices (unencapsulated), glass, frames and junction boxes. Dow Corning encapsulated the matrices with PV-6100 Cell Encapsulant Series on the pilot line located in Freeland, Michigan, USA shown in Figure 5.

Figure 5: *Dow Corning*® PV-6100 Cell Encapsulant Series Module Assembly Pilot Line Freeland, Michigan, USA

The modules were then characterized by IV using a Spire 4600 Sunsimulator and Electroluminescence (EL) for total power output and production quality. Comparison of the Pmax of the modules indicated a lower power output for the silicone encapsulated modules at an average of 220.4 watts vs. 222.6 watts for EVA. Since the cells were chosen for similar performance this difference was determined to be caused by matrix damage due to shipping and handling by EL analysis. To correct for this discrepancy, the analysis of the array power output was conducted on a W/W_p basis. Once characterized, the modules were then installed at a site on the grounds of Dow Corning's Corporate Center in Auburn, Michigan, USA in July of 2009. The array was erected in two halves in same location, at a 45^o angle with no shading. The east half (EVA): Inv #1: 4x9 modules; Inv #2: 4x8 modules. The west half (Si): Inv #3: 4x8 modules; Inv #4: 4x9 modules. Shown in Figures 6 and 7.

Figure 6: 30 Kw Array at Dow Corning Corporation, Auburn, Michigan, USA

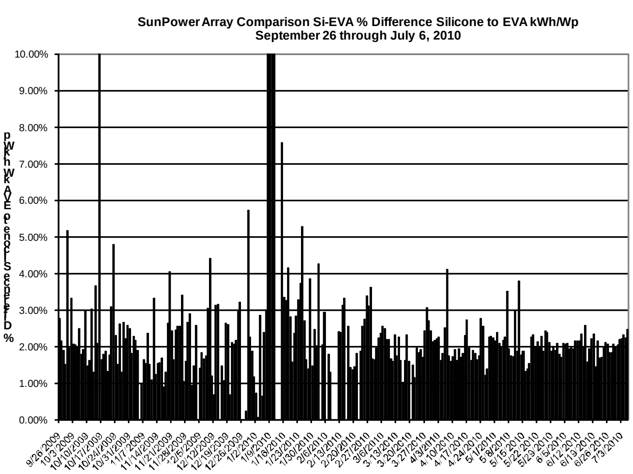
Figure 7: Fronius Inverters for power collection and performance monitoring

The strings were coupled with 4 Fronius 7.5 Kw inverters. The Fronius data acquisition software was used for data collection.

The installation was completed in July 2009. The system was brought on line in September, and data acquisition started later that month. The arrays have been on line since that time and the modules have experienced temperatures from approximately 95° F to -10° F, and sun, rain and snow. Regular inspections have shown that the appearance of both Silicone and EVA modules continues to be very good.

The power output performance has been constantly monitored and regularly evaluated since September. The graph shown in Figure 8 is a summary of the comparison for the last year.

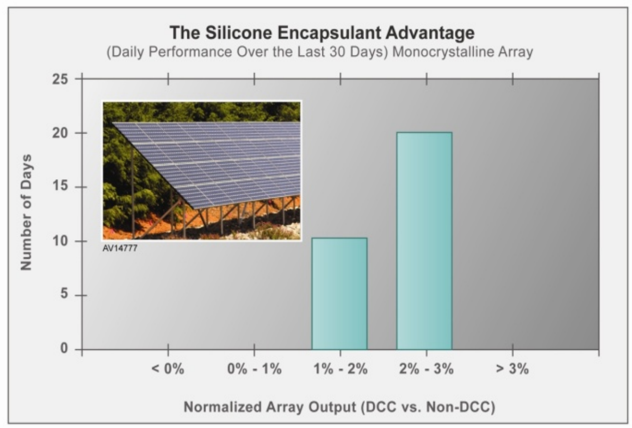
Figure 8: Daily Power Output Comparison



This data indicates consistent superior performance of the silicone array in kW/kW$_p$ performance in almost all weather conditions. There have been a few excursions of significantly greater performance of over 10% and some days of negative performance. These days are associated with very low insolation where the inverters are turning on and off throughout the day causing a large signal to noise ratio.

The average 30-day performance of the array is displayed continuously at Dow Corning Corporation. Figure 9 shows a snap shot of the typical average performance at greater than 2% kW/kW$_p$ relative efficiency gain.

Figure 9: Summary Chart of array performance

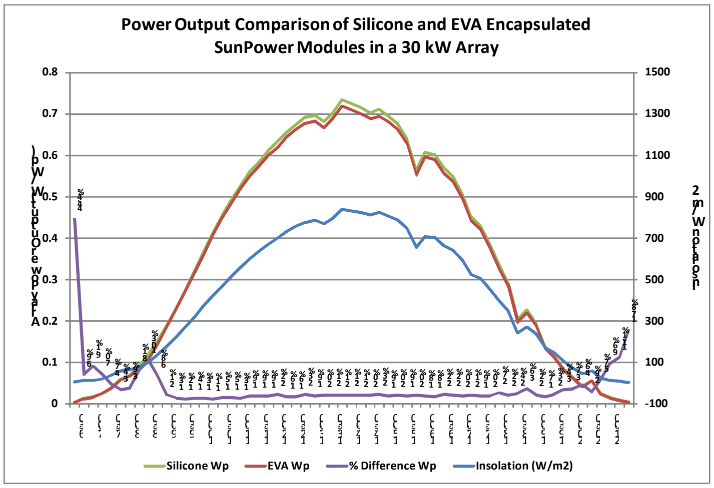


	Dow Corning 12,342W Capacity	Non-Dow Corning 12,466W Capacity	System 24,808W Capacity
Watts produced at 2:45 PM	7,312W	7,130W	14,442W
Yesterday's KWh Produced	63.8 kWh	63.1 kWh	126.9 kWh
Total KWh Produced			29,533 kWh
Normalized KWh/Wp	0.1629	0.1596	
Total Advantage DCC vs. Non-DCC	2.06%		

Monocrystalline Array at Dow Corning Corporation, Midland, Michigan

A closer analysis of a typical high insolation summer day for Michigan day is shown in Figure 10.

Figure 10: Silicone vs. EVA High Insolation Summer Day (25-June-2010)



This graph demonstrates that on this particular day the difference between silicone and EVA encapsulated modules is consistently between 1-2% kW/kW$_p$ relative efficiency gain once the insolation is greater than 100 W/m^2.

4. CONCLUSIONS

A 30 kW array to compare the performance of EVA to Silicone encapsulated modules was constructed at Dow Corning Corporation at the Corporate Center in Auburn, Michigan USA using EVA modules and matrices purchased from SunPower Corporation under the United States Department of Energy Solar America Initiative program. The silicone modules were encapsulated using *Dow Corning*® PV-6100 Cell Encapsulant Series at Dow Corning's pilot line in Freeland, Michigan, USA. The array was installed in July of 2009. Data collection on the array has been underway from September 2009. The data collection has shown silicone encapsulated modules outperform EVA encapsulated modules at greater than 2% kWhr/kW$_p$ relative efficiency gain. The modules have been exposed to all seasons experiencing temperatures from approximately 95^o F to -10^o F, and sun, rain and snow. Regular inspections have shown that the appearance of the Silicone and EVA modules continues to be very good. The array continues to be monitored for performance and appearance.

5. ACKNOWLEDGEMENTS

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