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Florida Solar Energy Center

Neelkanth Dhere
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Author

Neelkanth G. Dhere

1679 Clearlake Road

Cocoa, Florida 32922, USA

(321) 638-1000

www.floridaenergycenter.org

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Comparison of the Modes and Mechanisms of Degradation of Experimental c-Si PV Modules with Various Encapsulants

NREL Project, UCF/FSEC Account No. 2012-6117

Report: October, 2016

Seven modules with different encapsulants, provided by the National Renewable Energy Laboratory (NREL), were installed at the Florida Solar Energy Center (FSEC) outdoor test facility for long-term durability testing in the hot and humid climate of Florida. Along with the modules, NREL also provided corresponding load resistors, junction boxes, and module connections. The modules were installed at latitude tilt, on a south facing rack on March 20, 2014.

During project different types of tests such as visual inspection in environmental conditions and infrared imaging and I-V characterization were carried out on the seven modules: 110412-NRE-EVA, 110413-NRE-EVA-NC, 110413-NRE-TPU, 110420-NRE-TPO1 (2), 110512-NRE-PVB, 110628-NRE-ION and NRE-PDMS. Type of defects, origins of hot spots, cracks in the cell, browning/ discoloration occurring near the bus bar/cell interconnects and the snail trails, and blistering were studied.

I-V characteristics were measured under standard test conditions (STC) conditions of 1000 W/m^2 and 25 ^oC using the Spire 4600 solar simulator in September 2016. I-V data compared was compared to baseline data taken in 2014. From the last two years of data, significant degradation has been observed in two modules; 110413-NRE-TPU and 110628-NRE-ION. Minimal degradation was observed for other modules, however visual discoloration was observed in 110413-NRE-EVA-NC and 110512-NRE-PVB during the most recent visual inspection.

CURRENT-VOLTAGE RESULTS

Table 1: Baseline I-V data from April 2014.

IV-Data 4/1/2014									
Normalized Module Data With Calculated Power and Fill Factor									
Name	Site	Temperatur	Irradiance	Power	Isc	Voc	Ipeak	Vpeak	Fill Factor
110412-NRE-EVA	FSEC	25	1,000	159.61	8.34	25.84	7.80	20.46	74.05
110413-NRE-EVA-NC	FSEC	25	1,000	157.71	8.24	26.05	7.67	20.55	73.42
110413-NRE-TPU	FSEC	25	1,000	145.97	8.21	25.75	7.35	19.85	69.01
110420-NRE-TPO1(2)	FSEC	25	1,000	157.45	8.23	25.92	7.67	20.53	73.85
110512-NRE-PVB	FSEC	25	1,000	155.70	8.19	25.85	7.61	20.47	73.53
110628-NRE-ION	FSEC	25	1,000	150.27	8.30	26.09	7.20	20.86	69.36
NRE-PDMS	FSEC	25	1,000	216.05	8.40	36.26	7.72	28.00	70.90

Table 2: I-V data collected in September 2016.

IV-Data 9/20/2016									
9/20/2016 Module Data at standard test conditions - Indoor Spire 4600									
Name	Site	Temperature	Irradiance	Power	Isc	Voc	Ipeak	Vpeak	Fill Factor
110412-NRE-EVA	FSEC	24.30	1,000	158.824	8.257	25.747	7.767	20.449	74.706
110413-NRE-EVA-NC	FSEC	23.73	1,000	158.454	8.204	25.826	7.747	20.453	74.781
110413-NRE-TPU	FSEC	24.01	1,000	126.061	8.160	25.789	6.943	18.158	59.900
110420-NRE-TPO1(2)	FSEC	23.99	1,000	157.749	8.219	25.818	7.707	20.468	74.339
110512-NRE-PVB	FSEC	23.95	1,000	157.245	8.148	25.725	7.713	20.386	75.017
110628-NRE-ION	FSEC	23.93	1,000	136.175	8.243	25.796	6.303	21.608	64.043
NRE-PDMS	FSEC	23.93	1,000	212.620	8.172	36.192	7.539	28.204	71.886

Table 3: Comparison of September 2016 data to April 2014 baseline data.

Comparison to 4/1/2014 Data									
Name	Site	Temperature	Irradiance	Power	Isc	Voc	Ipeak	Vpeak	Fill Factor
110412-NRE-EVA	FSEC	25	1,000	0.995	0.990	0.996	0.995	1.000	1.009
110413-NRE-EVA-NC	FSEC	25	1,000	1.005	0.995	0.991	1.010	0.995	1.018
110413-NRE-TPU	FSEC	25	1,000	0.864	0.993	1.002	0.944	0.915	0.868
110420-NRE-TPO1(2)	FSEC	25	1,000	1.002	0.999	0.996	1.005	0.997	1.007
110512-NRE-PVB	FSEC	25	1,000	1.010	0.995	0.995	1.014	0.996	1.020
110628-NRE-ION	FSEC	25	1,000	0.906	0.993	0.989	0.875	1.036	0.923
NRE-PDMS	FSEC	25	1,000	0.984	0.973	0.998	0.977	1.007	1.014

The most notable result in this comparison is that two modules showed significant degradation while the other modules showed little to no problems. For module 110413-NRE-TPU the degradation is largly due to a reduction in fill factor. This is likely series resistance due to the failed interconnect discussed previously. 110628 NRE-ION also shows a reduction in fill factor. The degradation appears to be caused from shunting in one cell that shows up as a hot spot during infrared imaging.

VISUAL INSPECTION

Module 110413-NRE-TPU:

Snail Trails:

Snail trails have been identified on this module previously, however it seems they are more pronounced as of the most recent visual inspection. Several examples are shown in Figure 1.

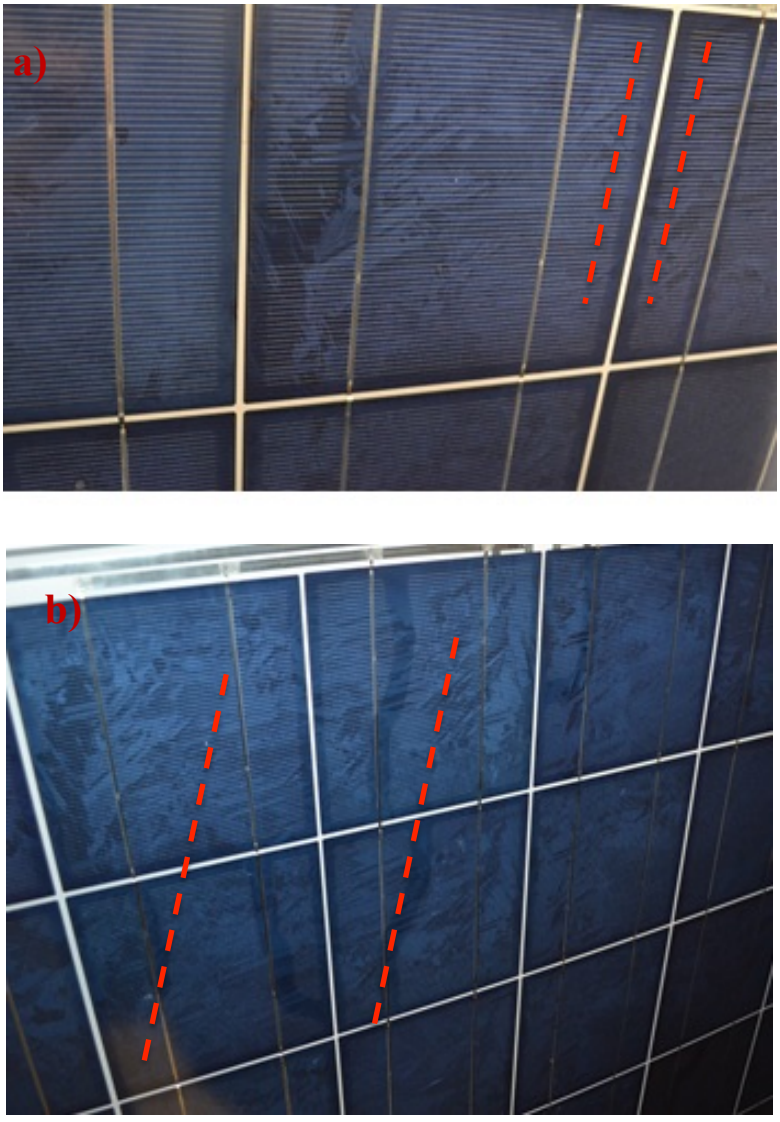

Figure 1: Visual image of 110413-NRE-TPU showing the formation of snail trails on several cells at bus bar and cell interface (a) and the between solar cell active area (b).

Module 110413-NRE-TPU:

Blistering and Yellowing:

This particular defect was aslo observed in 2014 and 2015 visual inspection. It has become more severe in 2016 shown in Figure 2. This hot spot also resulted in severe hot spot during previous infrared inspections as shown in Figure 3.

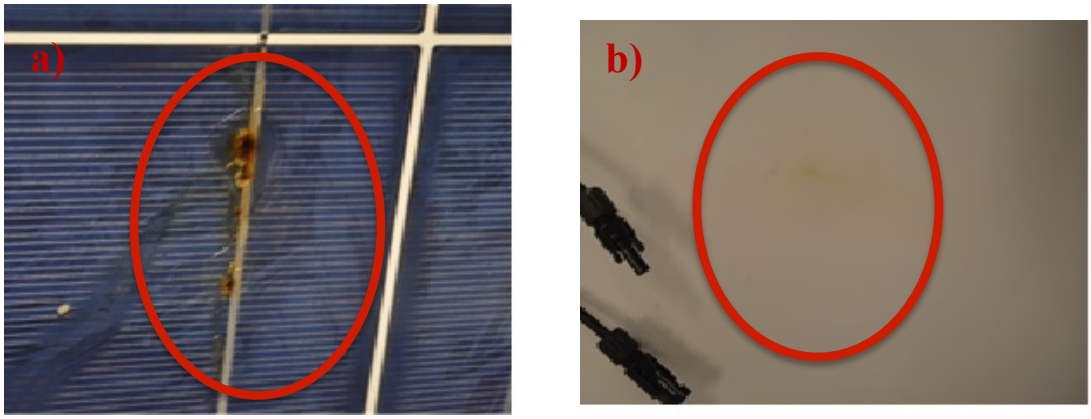

Figure 2: Blistering and yellowing was observed (a) and directly behind the blistering (b) of module 110413-NRE-TPU

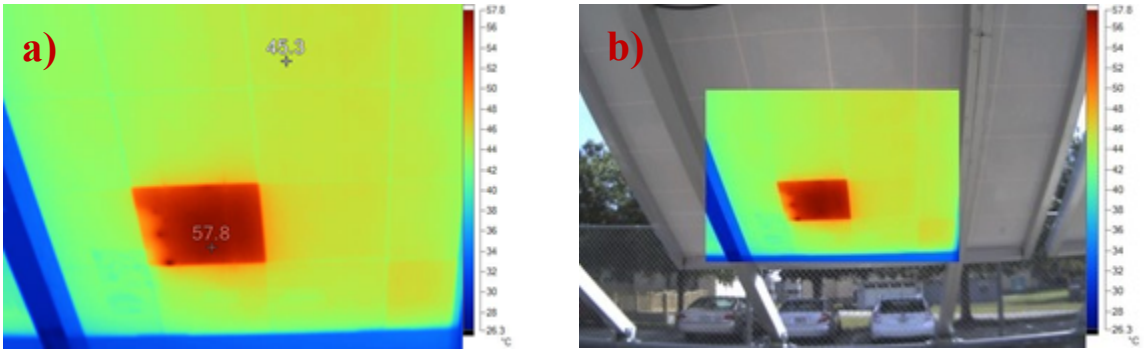

Figure-3: Temperature at specific locations, including the hottest spot are highlighted (a). Detail view of the hotspot from the back side (b) of module 110628-NRE-ION.

Module 110512-NRE-PVB:

Discoloration:

Discoloration was observed for the first time in module 110512-NRE-PVB. It is important to note that only a single defect was observed as is shown in Figure 4.

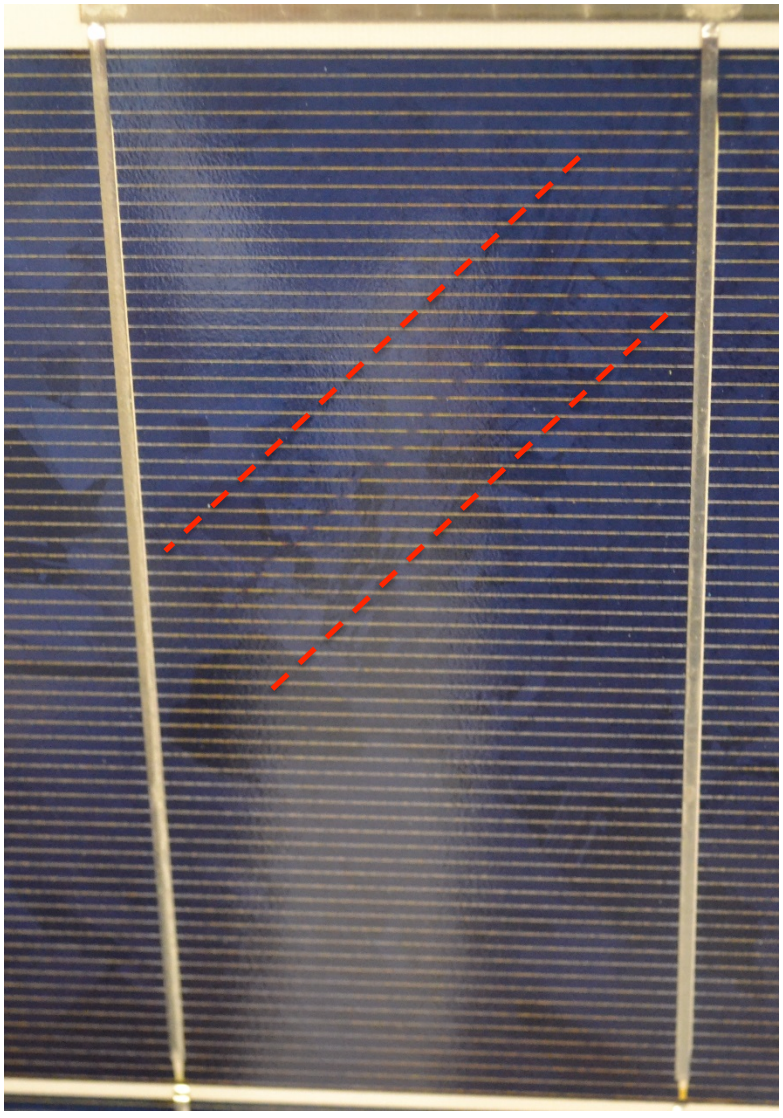

Figure-4: Visual image of the snail trail in module 110512-NRE-PVB

Module 110413-NRE-EVA-NC

Discoloration:

Discoloration was observed for the first time in module 110413-NRE-EVA-NC. The pattern seems to be about 1 inch from the edge of the cell on most cells in the module. The discoloration can be seen in Figure 5.

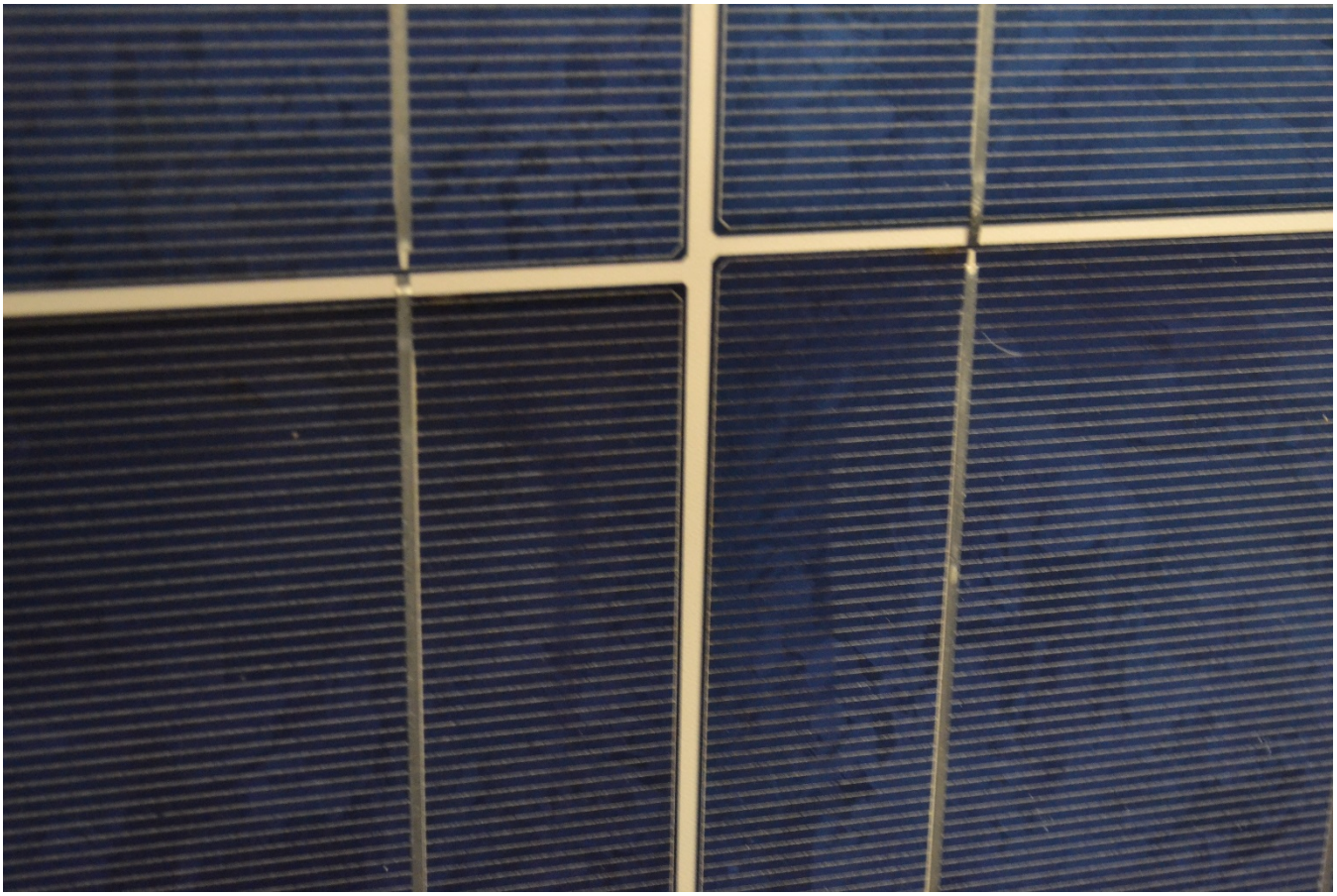

Figure-5: Visual image of the discoloration in module 110413-NRE-EVA-NC

SUMMARY

Out of seven modules with different encapsulants, two modules 110413-NRE-TPU and 110628NRE-ION showed degradation in power and fill factor according to 2016 I-V data. The degradation in 110413-NRE-TPU is attributed to interconnect failure that resulted in yellowing and blistering observed in the visual inspection. So called “snail trail” discoloration increased in 110413-NRE-TPU in terms of both size and shape. Module 110628NRE-ION there were no snail trails but the hot spot was observed and due this degradation in FF. During the visual inspection discoloration was observed in the module 110512-NRE-PVB. And 110413-NRE-EVA-NC for the first time.