Extended Accelerated Stress Testing (EAST) of Glass/Glass, Glass/Backsheet and Glass/Transparent Backsheet PV Modules: Influence of EVA and POE Encapsulants

Preprint

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Extended Accelerated Stress Testing (EAST) of Glass/Glass, Glass/Backsheet and Glass/Transparent Backsheet PV Modules: Influence of EVA and POE Encapsulants

Akash Kumar[1], Ashwini Pavgi[1], Peter Hacke[2], Kaushik Roy Choudhury[3] and GovindaSamy TamizhMani[1]

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***Abstract*— This paper presents the indoor extended accelerated stress testing (EAST) results of glass/glass (GG), glass/backsheet (GB) and glass/transparent backsheet (GT) modules having identical cells and two different encapsulant types, ethyl-vinyl-acetate (EVA) and polyolefin-elastomer (POE). Six 4-cell modules having the above-mentioned construction combinations were subjected to extended ultraviolet (UV; 600 kWh/m^2), damp-heat (DH; 2000 hours) and thermal-cycling (TC; 600 cycles) tests. The post-stress UV fluorescent imaging, electroluminescent imaging, reflectance spectrophotometry and colorimetry results indicated that the grid finger degradation and encapsulant browning are slightly higher in the GG modules compared to the GB modules. The post-stress IV test results indicated, in general, that the GG/EVA modules tend to perform inferior to the GG/POE modules with the EAST evaluation.**

Keywords- indoor accelerated stress testing, glass/glass, glass/backsheet, EVA, POE, reliability

I. Introduction

Glass/Glass (GG) photovoltaic modules are claimed to offer several advantages compared to the conventional glass/backsheet (GG) modules and the percentage of market share for GG modules has also steadily increased over the recent years. By having glass as both superstrate and substrate, the modules are reported to offer better mechanical support and humidity/temperature tolerance [1]. Further, more than 90 % bifacial modules (GG and glass/transparent backsheet, GT) employ ethylene vinyl acetate (EVA) and polyolefin-elastomer (POE) encapsulants. Considering an estimated market share of over 35% by 2030 [2], it becomes critical for the industry to understand the reliability of GG modules compared to the well-established glass/backsheet (GB) modules with common encapsulants such as EVA and POE .

We recently reported two reliability studies related to field-aged (10-35 years) GG modules with different cell technologies/manufacturers and two different encapsulant types of EVA and ionomer [3], [4]. The primary degradation modes observed in the field-aged GG/EVA modules were encapsulant browning and delamination. The GG/ionomer modules did not suffer from the browning issue, but they experienced significant corrosion and delamination issues. Other studies indicated some limitations of GG modules in terms of weight and operating temperature.

This paper focuses on an indoor extended accelerated stress testing (EAST) per IEC 63209 [5] of GG, GB and GT modules having identical cells and two dominant encapsulant types, EVA and POE. In this study, six 4-cell modules having the above-mentioned construction combinations were subjected to extended UV, damp-heat and thermal-cycling tests to determine the degradation modes and degradation magnitude for each of the module construction combination.

II. Methodology

A. Module Construction

In this work, 6 monofacial 4-cell crystalline silicon (PERC) modules with three different substrate types and two different encapsulant types (two types of encapsulant per substrate type) were used for the extended accelerated stress (EAST) testing. In addition, we also constructed control modules for each of the three combinations. The three different substrate types are: glass-glass (GG – 3.2 mm substrate), glass- polymer backsheet (GB – TPT backsheet) and glass-transparent backsheet (GT – Tedlar PVF clear backsheet). The two encapsulant types are: EVA and POE. To be consistent with the current industry practice, we used UV pass (UVp) encapsulant above the cell and UV cut (UVc) encapsulant below the cell in all module constructions. All the six modules were subjected to the following three extended stress tests in parallel with 2 modules (one with EVA and the other with POE) per test: UV (600 kWh/m^2 at 60 ºC; beyond Qualification Plus testing per NREL protocol), thermal cycling (TC) with 600 cycles between 40 ºC and +85 ºC per IEC 63209 standard, and damp heat for 2000 hours at 85º C/ 85 % RH per IEC 63209 standard. All the test and control modules were characterized before and after the stress tests, and they include: EL, IR, UVF, spectral reflectance and colorimetry.

III. Results and Discussions

Due to space limitation of this extended abstract, only EL, UVF, reflectance and colorimetry results are analyzed and presented. Detailed I-V performance results will be presented in the full paper.

1) UV Extended (UV600)

Fig.1 shows the UVF images indicating four GB and GT modules showed the presence of fluorescence rings close to the cell edge but without covering the cell edge and of two GG modules showed the presence of fluorescence at the cell edges without any ring formation. The fluorescence pattern in all the modules is thought to originate from the bottom UV cutting encapsulant, where the additives could have migrated from backside of the cell to the front edge of the cell during the lamination process at about 150 °C. During the accelerated

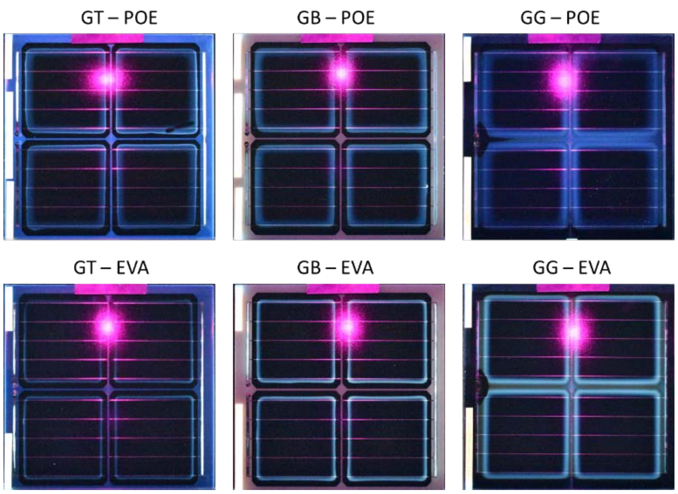

Fig 1. UVF images of 6 test modules after UV600 kWh/m^2

testing, the migrated additives from back to front of the cells are exposed to UV irradiation causing the encapsulant discoloration. The presence of oxygen bleaching of chromophores leads to the lack of fluorescence right at the cell edge in GB and GT modules. However, in the GG modules, the glass substrate doesn't allow oxygen transportation for the bleaching reaction to occur, leading to fluorescence all the way to the cell edge absent of oxygen bleaching. The fluorescence pattern in POE and EVA encapsulant were marginally different in all the modules. The POE modules exhibited a wider fluorescence ring width than the EVA modules. However, the fluorescence intensity was higher in EVA modules.

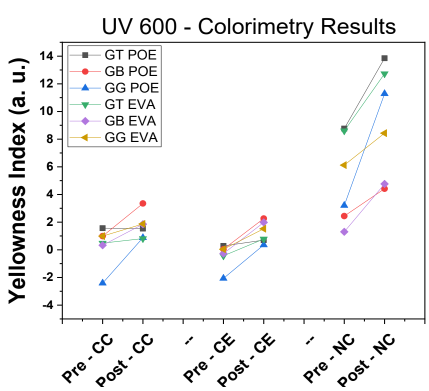

Fig 2. Pre- and post-UV600 colorimetry results of 6 modules performed at three different locations i) CC – Cell center ii) CE – Cell edge and iii) NC – non-cell location

Evidence of yellowing/browning after UV600 was also observed from colorimetry results as shown in Fig. 2. The test was performed at three different locations in the module i) CC- cell center ii) CE- cell edge iii) NC- non-cell. As shown in Fig. 2, the non-cell area displayed the highest increase in YI and the cell-center and cell-edge areas showed only small increase in YI. Additional analysis on the colorimetry results will be presented in the full paper.

2) DH Extended (DH2000)

During intermittent characterization, one module, GT/POE, shattered due to handling issue and hence the results of GT modules are not presented for the DH2000 test. The reflectance spectrophotometry was performed at same location as colorimetry. The results, as shown in Fig. 3 (inset pictures of UVF images after DH2000), indicate little or no reflectance change on the cell-center areas (bandgap absorption only) and a significant decrease in reflectance at non-cell area and cell-edge

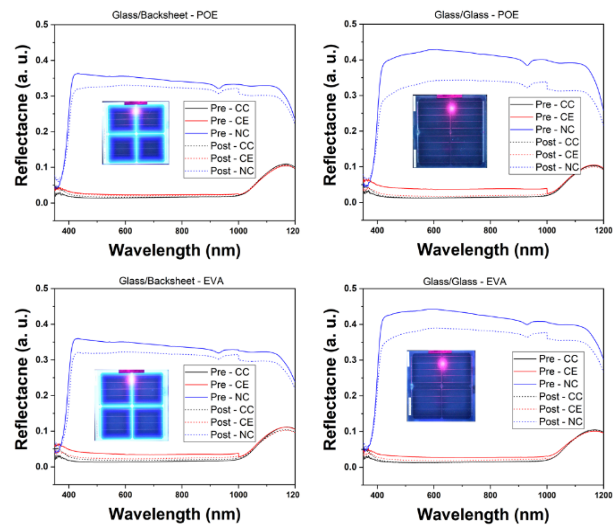

Fig 3. Reflectance results of GB and GG modules from three different locations i) CC- cell center ii) CE- cell edge iii) NC- non-cell for pre and post DH 2000 h (85 °C, 85 % RH). Inset showing the UVF images after DH2000

area in all the modules. The decrease in reflectance could be due to ingress of water vapor into the polymeric encapsulant. Moisture ingress through backsheet and/or the edges of the

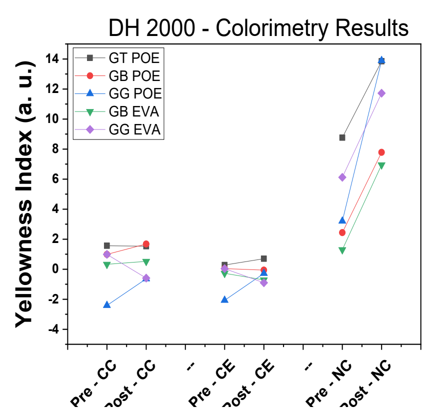

Fig 4. Pre- and post-DH2000 colorimetry results of 6 modules performed at three different locations i) CC – Cell center ii) CE – Cell edge and iii) NC – non-cell location

laminate could be associated with reflection reduction during the DH2000 test

As shown in Fig. 4, the non-cell area displayed the highest increase in YI and the cell-center and cell-edge areas showed only small increase in YI. Additional analysis on the colorimetry results will be presented in the full paper.

3) TC Extended (TC600)

The EL images of TC600 test modules are presented in Fig. 5. Severe grid finger degradation was observed in the GG/EVA module. The GT/POE module also displayed minor grid finger detachment or breakage in cells below the junction box. The failures in metal fingers might lead to increase in the series resistance (R_S), and hotspots if the degradation becomes severe [6].

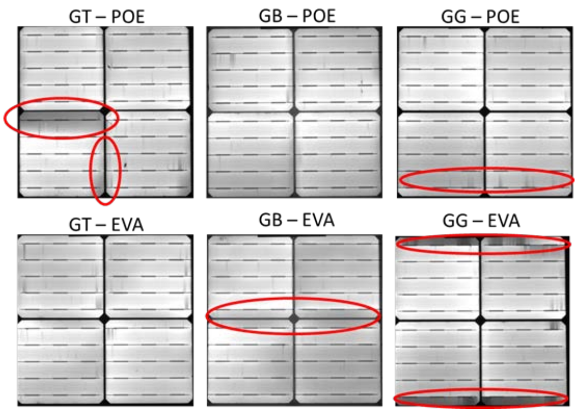

Fig 5. EL images taken at 100% Isc with 60s exposure of 6 modules after TC600

IV. Conclusion

An indoor extended accelerated stress testing (EAST) of UV600, DH2000 and TC600 was performed on 4-cell modules with EVA and POE encapsulants. Severity ranking color codes (red color>amber color>green color) for each degradation mode in GG and GB/GT is summarized in Fig. 6. The key degradation modes observed in GG are listed below:

- Encapsulant yellowness index increase in all constructions in UV600 and DH2000: Ring browning in GB and GT is attributed to oxygen bleaching. Edge browning in GG modules is attributed to absence of oxygen bleaching reaction. Even though UV transmitting encapsulant was on the top layer of cell, the additives from the bottom UV cutting encapsulant are suspected to have migrated during the lamination process causing ring/edge browning.
- Grid finger degradation in GG/EVA construction in TC600: Could possibly be attributed to the glass/glass rigidity.
- POE encapsulant appears to be better than EVA as the module displayed lesser fluorescence, sustained EL emission and lower changes in reflectance and colorimetry.

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	EAST: Degradation modes after UV 600 kWh/m^2, TC 600 cycles and DH 2000 hours				
Construction	Encapsulant Type	Encapsulant Browning	Encapsulant Delamination	Glass Breakage	Grid Finger Degradation
Glass/Glass	EVA	Edge browning	No significant sign	No breakage	Severe after TC600
	POE	Edge browning	No significant sign	No breakage	Minor after TC600
Glass/Backsheet*	EVA	Ring browning	No significant sign	No breakage	Minor after TC600
	POE	Ring browing	No significant sign	No breakage	Minor after TC600
Severity	High	Medium	Low		
* Both white and transparent backsheets					
**One of the two modules broke due to handling issue					

Fig 6. Severity ranking color codes (red color>amber color>green color) for each degradation mode observed in GG and GB/GT