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Long-term durability of transparent backsheets for bifacial photovoltaics: An in-depth degradation analysis

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Abstract

Bifacial modules with a glass/transparent backsheet (G/CB) structure offer many advantages, such as lighter weight, smaller heat capacity, and higher anti-soiling ability, over their glass/glass (G/G) counterparts. However, compared to traditional opaque backsheets, transparent backsheets can be more susceptible to degradation because UV light can more easily go through the transparent outer layer into the backsheet core and inner layers. Therefore, a better understanding of the degradation mechanism and long-term durability of emerging transparent backsheets is needed. In this study, the G/CB laminated coupons constructed with silica glass, polyolefin elastomer encapsulant (POE) and three types of fluoropolymer-based transparent backsheets were subjected to accelerated weathering under ultraviolet (UV) light at 65 ° C and 50% relative humidity (RH) for up to 3600 h with additional 200 thermal cycles. The maximum UV dose (1800 MJ/m2) is equivalent to approximately 45 years of field exposure in Arizona, assuming a 12% albedo for reflected light on the backside of a PV module. The transmittance of the coupons was characterized by UV – visible spectroscopy periodically during UV exposure. Cross-sectional characterization of optical, chemical, and mechanical degradation was conducted on the transparent backsheets of the aged and unaged coupons using confocal fluorescence microscopy, microscale infrared spectroscopy, and nanoindentation, respectively. Results showed that superficial outer layer cracking occurred on coupons constructed with a polyvinyl fluoride (PVF)-based backsheet (G/CB1) at the end of the exposure.Local delamination appeared near a corner of the coupon with a polyvinylidene fluoride (PVDF)-based backsheet (G/CB2). However, the coupon containing a fluoroethylene vinyl ether (FEVE)/polyethylene terephthalate (PET)/ethylene-vinyl acetate (EVA)-based transparent backsheet (G/CB3) showed the greatest yellowing, as well as substantial backsheet cracking. Significant degradation was not only

observed on the FEVE outer layer but also in the PET core layer of CB3. The depth-dependent degradation was seen in fluorescence, micro-IR and nanoindentation mapping of the aged CB3. This study suggests that, although the application of transparent backsheet is promising, careful considerations of the long-term UV durability are needed when designing and selecting backsheets for 50-year bifacial modules.

Introduction

Solar photovoltaic technology has emerged as a significant contributor in the renewability field, accounting for 57% of newly installed renewable energy capacity in 2019 [1]. Initially developed in the 1960's by Hiroshi [2], bifacial modules collect light from both sides of the module; leading to higher energy production compared to a monofacial modules with the same footprint. According to researchers, bifacial modules can improve power output from 25% to 50% [3]. Increased power output leads to a reduced levelized cost of energy (LCOE), which is a major obstacle in the adoption of PVs as a primary energy source for terrestrial applications [4]. The increase in power output of bifacial modules is dependent on numerous factors such as tilt angle, array spacing, ground albedo and installation elevation [5,6]. Kreinin et al. found a bifacial gain of 20% for a module with an installation angle of 30° and a ground albedo of $\approx$ 50% [7]. Muehleisen et al. found up to a 20% yield gain is possible for transparent backsheet bifacial modules compared to modules with a black backsheet [8].

Currently, the most common configuration for bifacial modules consists of a glass-glass structure with a sheet of glass replacing the traditional opaque backsheet of conventional modules. The use of glass on both sides of the module allows for a more resilient module that is resistant to unfavorable weather conditions along with demonstrating durable waterproof abilities and strong anti-potential induced degradation (anti-PID) [9,10]. However, the use of glass as the rear backing has some disadvantages, such as the trapping of encapsulant degradation products, which can accelerate discoloration and corrosion within the module [11]. Compared to its glass/glass counterpart, glass/transparent backsheet modules have the advantages of having lower weight, smaller heat capacity, strong anti-soiling ability, high light transmittance, and effusion of the gaseous by-products in the laminate [11]. Though, the current research on transparent backsheets is limited, previous work done by Kempe et al. [12] found that all seven of the transparent backsheets cracked after the standardized IEC 62788-7-2 test followed by a mandrel bend test. Smith et al. [13] also suggested a fluoropolymer-based free-standing transparent backsheet went through substantial yellowing, delamination and cracking after extensive aging. Polymer backsheets are susceptible to damage from ultraviolet (UV)-light, heat, moisture and thermal mechanical stresses. Compared to traditional opaque backsheets, transparent backsheets can be more vulnerable to degradation because UV light can go through the transparent outer layer into the backsheet core and inner layers. Previous work showed most of the degradation happened due to chain scission and post-crystallization of the core PET layer after exposure with UV dose up to $\approx$1000 MJ/m2 [13].

To better understand the degradation mechanism and the long-term performance of emerging transparent backsheets for bifacial application, three fluoropolymer-based transparent

backsheets as a part of glass/polyolefin elastomer (POE)/transparent backsheet coupons were constructed and subjected to accelerated weathering conditions. Coupons were placed on the NIST SPHERE (Simulated Photodegradation via High Energy Radiant Exposure), at 65 ° C and 50% RH with UV irradiance of 140 W/m2 for up to 3600 h. The total UV dose for 3600 h of exposure is equivalent to approximately 45 years of field exposure in Arizona given a 12% albedo for reflected light on the backside of a PV module. Additionally, coupons were subjected to 100 thermal cycles ranging from - 40 ° C to 85 ° C after SPHERE exposure in two rounds, one was after ≈2000 h, and the other was after ≈3600 h of exposure. Chemical changes of the surface of the coupons, as well as certain cross-sections, were characterized using micro-scale attenuated total reflectance Fourier transform infrared (micro-ATR-FTIR) spectroscopy. The cross-sections of the unexposed and aged coupons were further characterized using confocal fluorescence mapping and nanoindentation. Results indicate that following exposure, all three coupons showed multiple degradation modes including yellowing, cracking and delamination, but at very different levels. The correlation between optical, chemical, and mechanical degradation of transparent backsheets will be discussed.

Section snippets

Materials

Silica/encapsulant/transparent backsheet (G/CB) coupons (75 mm × 100 mm) used in this study were composed of the following components: a 3 mm thick polished fused silica wafer with a transmittance of around 95% between 250 nm and 800 nm, top and bottom encapsulants used for lamination were a UV-transparent polyolefin elastomer (POE-T) and a POE with UV cut-off at ≈ 380 nm (POE-UVA). The components of the fluoropolymer backsheets (CB1, CB2, CB3) are listed in Table 1. A more detailed discussion

Discoloration and delamination of coupons

After ≈3600 h of UV exposure and 200 thermal cycles, there are notable optical changes to all three coupons. Compared to those without exposure, all coupons yellowed to varying degrees. G/CB3 (Fig. 2c) showed the most yellowing, turning a dark yellow at the end of testing conditions. The other backsheets showed some yellowing from their initial state but not as significant as G/CB3. This change in yellowing can also be easily seen in the change in the yellowness index over the duration of

Conclusion

The durability of the backsheets of three glass/encapsulant/transparent backsheet coupons were studied using the NIST SPHERE under UV/65 ° C/50% RH for up to approximately 3600 h (1800 MJ/m2) and 200 thermal cycles. Characterization of the changes of these coupons and their multilayer polymer backsheets were conducted by UV – vis spectroscopy, micro-FTIR and LSCM as a function of exposure. The cross-sectional backsheet samples before and after exposure were characterized by spatial resolved

*Disclaimer

Certain commercial products or equipment are described in this paper to specify adequately the experimental procedure. In no case does such identification imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that it is necessarily the best available for the purpose.

CRediT authorship contribution statement

Soshana Smith: Formal analysis, Data curation, Investigation, Writing – original draft, Writing – review & editing. Stefan Mitterhofer: Formal analysis, Data curation, Investigation, Writing – original draft, Writing – review & editing. Stephanie L. Moffitt: Investigation, Writing – review & editing. Song‐Syun Jhang: Data curation. Stephanie S. Watson: Methodology, Writing – review & editing. Li‐Piin Sung: Resources, Conceptualization, Writing – review & editing. Xiaohong Gu: Supervision,

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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