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# Photothermal Stability of an E-Beam Pre-Crosslinked EVA Encapsulant and Its Performance Degradation on a-Si Submodules

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## ABSTRACT

We studied the photothermal stability of a special type of ethylene-vinyl acetate (EVA) encapsulant using accelerated exposure testing (AET) and analyzed the causes of its performance degradation on amorphous silicon (a-Si) modules. The Sovlux EVA films are used on a-Si modules in a Tefzel/EVA/a-Si encapsulating configuration. AET of the Tefzel/EVA/Tefzel laminates under a solar simulator resulted in no discoloration of the Sovlux EVA due to photobleaching but substantial loss of ultraviolet absorber (UVA), whereas heating in an oven at 85°C produced light yellowing. Adhesion strength of the EVA to glass increased substantially as a result of the AET treatments. Coherent tearing of the EVA of low gel content (~61%) under Tefzel superstrate film was attributed to the formation of bubbles and delamination on the a-Si submodule as a consequence of thermal relaxation of mechanical stress from a 200-thermal-cycle between 90°C and -40°C.

## 1. Introduction

The work was a continuation from studies of earlier Sovlux EVA films as part of a NREL/ECD/Sovlux CRADA project [1]. The current study was designed to investigate the photothermal stability of Sovlux EVA laminated between two thin layers of Tefzel (samples provided by Sovlux), focusing on the changes in EVA transmittance (discoloration), UV absorber concentration, and gel content. The results were compared to the performance reliability of the commercial EVA formulation, fast-cure 15295. Additionally, we examined the Sovlux EVA on an a-Si submodule that degraded with substantial bubble formation and delamination under the Tefzel film after the submodule was subjected to a thermal-cycle qualification test.

## 2. Experimental

**Samples.** The Sovlux EVA formulation contains additives similar to the commercial formulations of regular-cure EVA A9918 and fast-cure EVA 15295, except for the absence of a curing peroxide and optional use of a silane primer. The Sovlux EVA films are pre-crosslinked by e-beam irradiation and have a gel content (degree of cross-linking) of ~54%-65% on earlier films and ~63%-68% on later films, apparently due to various degrees of e-beam irradiation. The latter films were used in this study. In addition to the Tefzel/Sovlux EVA/Tefzel laminates

provided by Sovlux, laminates of superstrate-borosilicate glass/EVA/substrate-Tefzel, where EVA was Sovlux EVA or fast-cure 15295, were also made and studied for comparison.

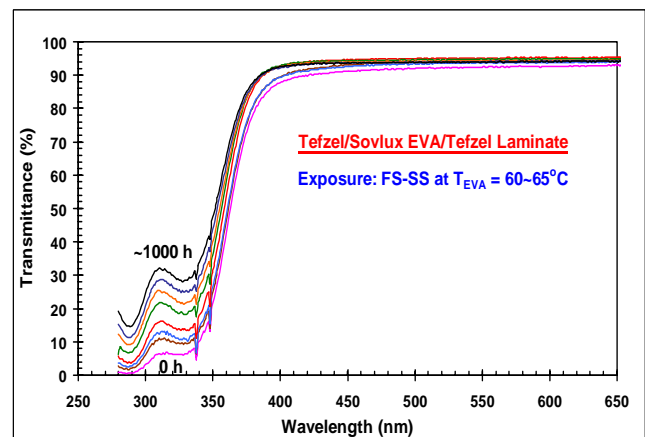
**Accelerated Exposures.** Samples were tested for ~1000 h either by light exposure under an Oriel full-spectrum solar simulator (FS-SS) of ~6.5 UV suns in the 300-400 nm range at a black panel temperature of EVA,  $BPT_{EVA}$ , of ~60°-65°C, or heating in an oven at 85°C in the dark. A borosilicate plate was placed over the samples of Tefzel/EVA/Tefzel laminate exposed under FS-SS to filter out the UV <285 nm.

**Analytical Characterizations.** Samples before and during exposures were characterized with integrated transmittance, fluorescence emission, and color index measurements. Periodically, a small specimen was removed from each sample for destructive analyses for remaining concentration of UV absorber, [UVA], Cyasorb UV 531<sup>®</sup>, and gel content.

## 3. Results and Discussion

### 3-A. Photothermal Stability of Tefzel/Sovlux EVA/Tefzel Laminates.

Light exposure resulted in a ~31%–39% loss of UVA by photodecomposition, as shown in Fig. 1, below 350 nm, and a ~2%–7% increase in transmittance integrated over the 285-800 nm range. The more permeable Tefzel/EVA/Tefzel configuration caused greater photooxidative loss of UVA

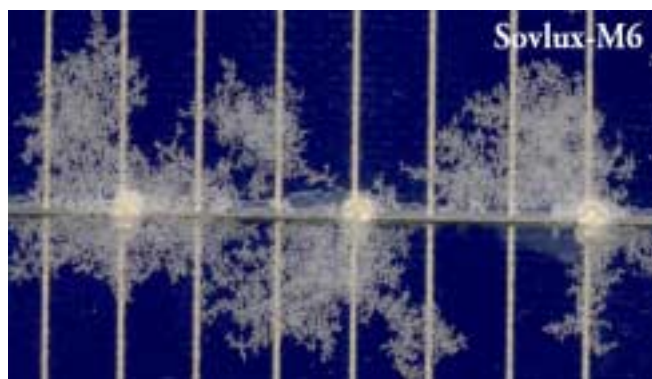


**Fig. 1.** Transmittance spectral changes as a function of light exposure for a Tefzel/Sovlux EVA/Tefzel samples.

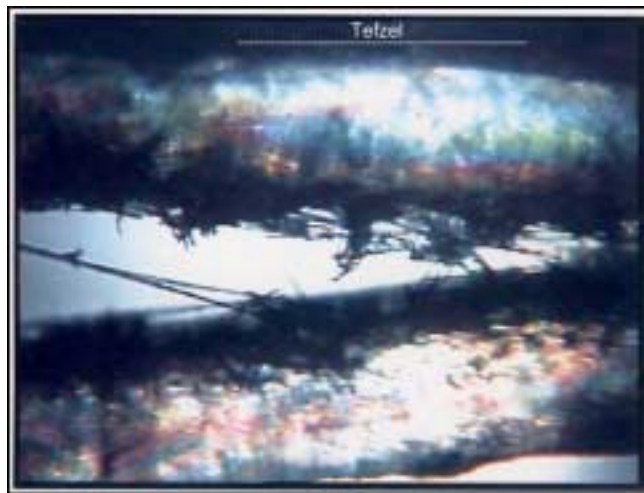
than that of the borosilicate/EVA/Tefzel configuration. Loss of UVA by thermal evaporation from oven-heated samples was not obvious. No discoloration was seen due to photobleaching of the curing-generated, UV-excitable,  $\alpha$ , $\beta$ -unsaturated carbonyl chromophores [2], as evidenced by the rapid decreases of the initial fluorescence emission peak intensities at  $\sim 420$  nm for all UV-exposed samples with Tefzel super- or substrates. Light exposure also caused an increase of gel% from an original  $\sim 63\%$  to  $\sim 75\%$ , with a small decrease in yellowness index. In earlier studies, the Sovlux EVA in glass/EVA/glass laminates have shown a better long-term stability than EVA 15295 against UV-induced yellow-browning [3]. Oven-heated borosilicate/Sovlux EVA/Tefzel and Tefzel/Sovlux EVA/Tefzel samples exhibited light yellow color while borosilicate/15295 EVA/Tefzel sample remained visibly clear, suggesting that thermal stability of Sovlux EVA is poorer than that of 15295 EVA when encapsulated with Tefzel. Observed qualitatively, the adhesion of the Tefzel film to EVA and the EVA to glass increased significantly as the accelerated exposure time increased, as evidenced by the increased difficulties in removal of the Tefzel films from EVA layer and the EVA from glass for [UVA] and %gel analyses.

### 3-B. Analysis of the Degraded a-Si Submodule

The Sovlux a-Si submodule (ID No.: M6), among others, was subjected to a PV module qualification test that imposed 200 thermal cycles between  $90^{\circ}\text{C}$  and  $-40^{\circ}\text{C}$  in the dark with a forward bias equivalent to 1-sun exposure at NREL's Outdoor Test Facilities. Aside from a loss of  $\sim 50\%$  of maximum power, the submodule showed localized sponge-like bubble formation and delamination in the front Tefzel/EVA layer around the solder joints and neighboring areas of bus wires, as seen in Fig. 2. Results of detailed optical microscopic examinations indicate the bubbling and delamination had occurred in the EVA bulk layer under the Tefzel film, as seen in Fig. 3, a probable consequence of mechanical stress relaxation in the region of a relatively low degree of cross-linking ( $\sim 61\%$  gel found). The EVA layer on the backside became wrinkled (figure not shown), likely a consequence of melt-reflow of the low-crosslinked EVA ( $\sim 57\%$  gel found) during the thermal cycles because the uncrosslinked EVA has a moderate melting point at  $\sim 70^{\circ}\text{C}$ .



**Fig. 2.** Sponge- or fern-like bubble formation and delamination on the a-Si submodule specimen. The large, round, white spots are the solder joints.



**Fig. 3.** Cross-section micro-photograph (60X) of Tefzel/EVA layers, showing the coherent tearing in the bulk EVA layer under the Tefzel film (which is roughly above the dash line), where sponge-like bubbling/delamination patterns are present as in Fig. 2.

### 4. Conclusions

Light exposure of the Sovlux EVA in the superstrate-Tefzel/EVA laminates would cause no discoloration because of photobleaching reactions, but substantial loss of protective UV absorber, and some increase of gel content. Heating at  $85^{\circ}\text{C}$  caused light yellowing. In borosilicate/EVA/borosilicate laminates, Sovlux EVA performed better against browning than fast-cure 15295 on the long term basis. To reduce or eliminate the bubble formation and delamination problems on Tefzel/Sovlux EVA/a-Si modules, we suggested to Sovlux a substantial size reduction of the solder joints and an increase in the cross-linking degree (gel content) by e-beam irradiation from the present  $\sim 53\%$ - $68\%$  to  $75\%$ - $80\%$  or higher.

### 5. Acknowledgement

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### 6. References

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- [2] Pern, F. J., "Ethylene-Vinyl Acetate (EVA) Encapsulants for PV Modules: Degradation and Discoloration Mechanisms and Formulation Modifications for Improved Photostability," *Die Angew. Makromol. Chemie*, 252 (1997) 195-216.
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