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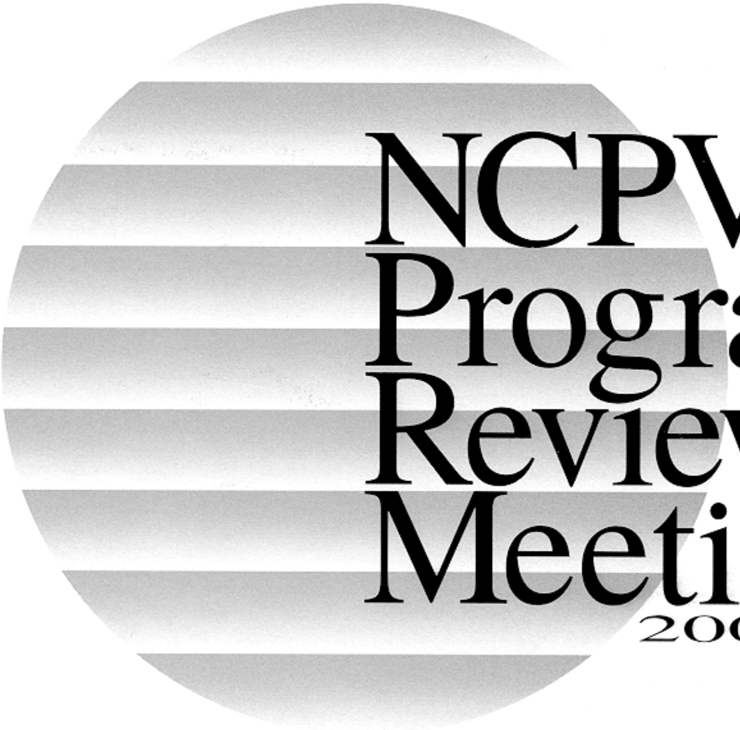

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Photothermal Stability of Various Module Encapsulants and The Effects of Superstrate and Substrate Materials Studied for PVMaT Sources

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ABSTRACT

This paper briefs the photothermal reliability studies we conducted on different encapsulation materials for some U.S. PV companies that are subcontractors of the Photovoltaic Manufacturing Technology (PVMaT) program. The results indicate that the photothermal stability of two foreign ethylene vinyl acetate (EVA) films is dependent on the formulation, curing method and condition, as well as accelerated exposure condition and time. With a Tefzel or Tedlar superstrate or substrate, no EVA discoloration was observed. Delamination and/or wrinkling were observed for some thin-film superstrate materials and non-EVA encapsulants. Silicone adhesive caused notable electrical degradation on crystalline and amorphous silicon (c-Si and a-Si) solar cell samples.

1. Introduction

Upon request by several U.S. PV manufacturers, we have conducted accelerated exposure tests (AET) in the past three years for two foreign EVA formulations, non-EVA encapsulants, and polymer superstrates and substrates. These PV manufacturers are subcontractors to the PVMaT program administrated by NREL; they are not identified in this paper for obvious reasons. The studies were to evaluate the photothermal stability of the various encapsulant materials in laminated forms that can be indicated by discoloration (e.g., yellowing), delamination, and wrinkling. Some studies also involved testing the special encapsulated solar cells supplied by the participants. All of these studies were/are carried out in line with our own research and development task activities and within our capabilities.

2. Experimental

Samples and Configurations

The samples received from the PV manufacturers varied in form, thickness, lamination, and solar cell type. The encapsulant materials included EVA of peculiar formulations and pre-cross-linking, non-EVA polyolefin, and thin layers of non-EVA adhesives. The superstrate and substrate materials used on the laminates included borosilicate glass plates and various polymer films, such as Tefzel, Tedlar, and polyester. Three laminate configurations were used: glass/encapsulant/glass (G/E/G), glass/ encapsulant/polymer (G/E/P), and polymer/ encapsulant/ polymer (P/E/P), with or without a c-Si solar cell or a-Si minimodules. Most of the encapsulant laminates without solar cells were prepared in our laboratory using a custom-built double-bag vacuum laminator. Laminates of commercial EVA formulations, the slow-cure EVA A9918 and fast-cure 15295, and NREL-developed V11 EVA formulations were also studied in parallel for comparison.

Accelerated Exposure Tests (AET)

The samples were studied using the various test equipment as described in [1]. The AET conditions were designed individually depending on the sample characteristics and agreed to by the participating companies prior to initiation of the experiments.

Analytical Characterization

The two foreign EVA formulations (Sov-NA and BS EVA) were analyzed for the presence and concentration of UV absorber (UVA) and gel content before and after particular curing conditions. Details of the analytical methods were described in [2]. The laminate samples were characterized before, during, and after the selected periods of exposure tests with several spectroscopic analyses for the encapsulant and superstrate materials and efficiency measurements for the solar cell.

3. Results and Discussion

Photothermal Stability of Encapsulants and Their Laminates

Samples of G/E/G configuration of the various encapsulants were used in this study. Results show that the discoloration rate is strongly dependent on the encapsulant's formulation, curing method, and condition under a given AET condition and exposure length. Figure 1 shows the net changes in yellowness index (YI) for five different EVA formulations. As expected, the slow-cure A9918 EVA discolored faster and greater than other [1]. The Sov-NA EVA formulation contains UVA and antioxidants identical to that of fast-cure 15295 EVA and was previously cross-linked with e-beam to ~50-55 gel% rather than using a curing agent in the latter for a ~80 gel%. The Sov-NA EVA samples show an earlier yellowing, but a more stable discoloration rate than the 15295 EVA after 1000 h exposure. A fast curing of Sov-NA EVA in the G/E/G lamination process produced a relatively better stable laminate than that from a 3-step, longer curing process. The fast-cure BS EVA, which contains an UV absorbing compound that is different from the UVA in the A9918, 15295 and Sov-NA EVA, was stable against discoloration within our test time frame. The BS and V11 EVA were comparable in the short-term AET study (~700 h). But a recent field observation indicated the

BS EVA turned yellow-brown after a dormant eight years. For the non-EVA encapsulant that used a polyolefin, the laminates were stable against photo-induced yellowing, much better than A9918 and 15295 EVA and similar to that of V11 EVA under a very stringent AET condition [1]. However, the encapsulant delaminated severely at a test temperature of ~110^{o}C while G/EVA/G laminates remained adhesive [1]. The polyolefin is said to have a melting point of 100^{o}-110^{o}C as compared with the ~70^{o}C m.p. for EVA.

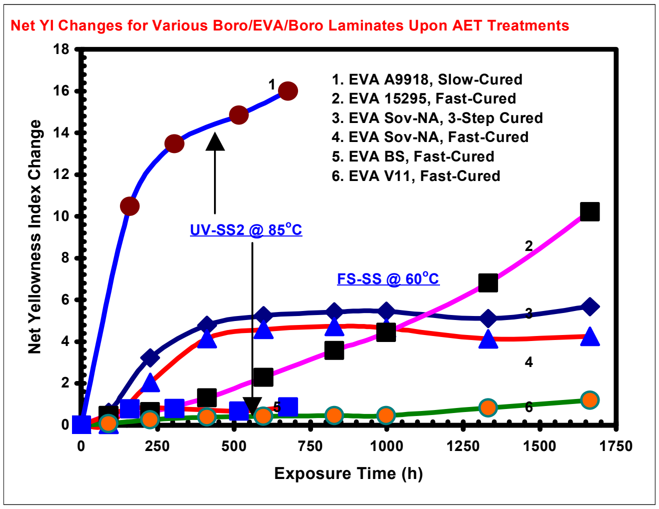

Figure 1. Net changes in yellowness index (YI) for five different EVA formulations in G/E/G configuration.

Effect of Superstrate and Substrate Materials on Encapsulant Photodiscoloration

When the laminates were in the G/E/P or P/E/P configurations, with P used either as a superstrate or substrate, low to no EVA discoloration was observed under various AET conditions. This is attributed to the photobleaching reactions when air (oxygen) was allowed through the permeable polymer films, such as Tefzel and Tedlar. For laminates using polyester or nylon superstrate, light-to-dark yellowing, delamination, and/or wrinkling were observed [1].

Degrading Effect of Silicone Adhesives on Solar Cell Performance

As seen in Table 1, significant efficiency degradation was observed for c-Si cells and a-Si minimodules encapsulated with silicone adhesives in the P/E/Si cell/E/P configurations upon AET treatments [1]. The degrading effect is tentatively attributed to the yet-unidentified chemical compounds from silicone adhesives that induced harmful reactions on the solar cell/metallic components during the photothermal exposures.

4. Conclusions

We have studied various encapsulation materials for several PVMaT subcontractors in an effort to help on the mission objectives of NCPV at NREL. This work has permitted us to make timely contributions to the advancement or development of new encapsulant materials by the U.S. PV industry. The results, also reported individually to each of the PV manufacturers, have allowed them to evaluate or determine the usefulness of, or to improve, their chosen materials.

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[2] F.J. Pern, "Factors That Affect the EVA Encapsulant Discoloration Rate Upon Accelerated Exposure," *Solar Energy Materials and Solar Cells*, **41/42** (1996) 587-615.

Table 1. Percent Changes of I-V Parameters for Polymer Films-Encapsulated c-Si Cells and a-Si Minimodules after AET Treatment in DSET Tabletop Exposure System #2 with ~1.2 UV Suns at BPT = 60^{o} - 65^{o}C [1].

Sample ID	Polymer Film	Pottant Type	Voc (%)	Vmax (%)	Jsc (%)	Jmax (%)	FF (%)	Pmax (%)
(a) c-Si cells at 1188 h								
B1-1	Tefzel	EVA	0.00	-1.26	4.63	6.04	0.12	4.74
B2-1	Tefzel	EVA	-0.36	-2.32	7.30	8.02	-1.35	5.48
D1-2	Tefzel	Silicone	-1.04	-0.65	-22.69	-15.43	9.90	-15.95
D2-1	Tefzel	Silicone	-0.36	-0.14	-23.96	-28.24	-5.46	-28.37
(b) a-Si minimodules at 1235 h								
F57S6-1	PES[1]	EVA	-1.81	-4.68	-9.38	-3.83	3.04	-8.34
F57S18-3	UV-PES[1]	PE[1]	-4.20	-7.33	-10.80	-10.76	-2.95	-17.11
F55S28-4	Nylon	Silicone	-1.69	-7.27	-14.10	-14.40	-6.00	-20.61

[1] PES: polyester; UV-PES: UV-screen polyester; PE: polyethylene thermoset adhesive.