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Packaging Materials and Design for Improved PV Module Reliability

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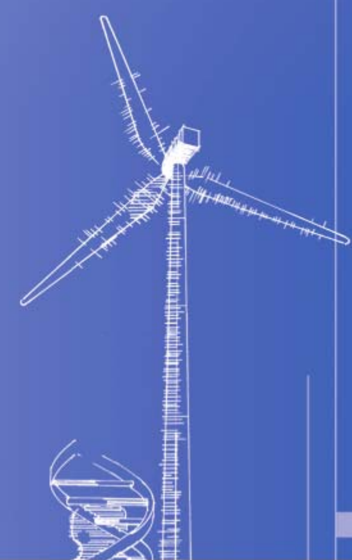

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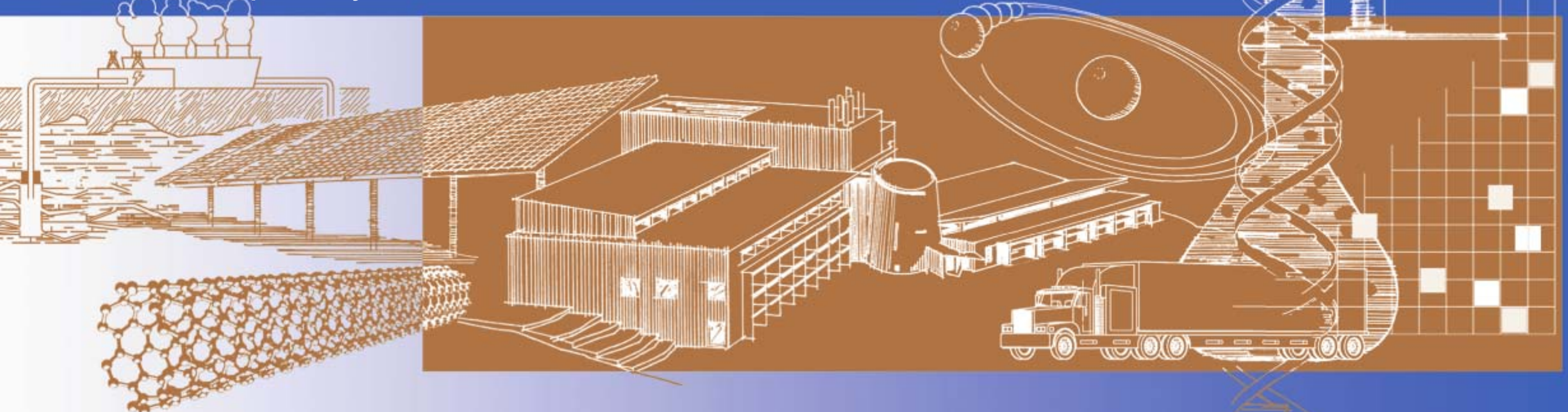

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ABSTRACT

A number of candidate alternative encapsulant and soft backsheet materials have been evaluated in terms of their suitability for photovoltaic (PV) module packaging applications. Relevant properties, including peel strength as a function of damp heat exposure and permeability, have been measured. Based on these tests, promising new encapsulants with adhesion-promoting primers have been identified that result in improved properties. Test results for backsheets provided by industry and prepared at the National Renewable Energy Laboratory (NREL) have suggested strategies to achieve significantly improved products. The ability of glass/glass and glass/breathable backsheet constructions laminated with various encapsulant and/or edge seal materials to protect thin-film aluminum coatings deposited onto glass substrates was assessed. Glass/glass laminate constructions can trap harmful compounds that catalyze moisture-driven corrosion of the aluminum. Constructions with breathable backsheets allow higher rates of moisture ingress, but also allow egress of deleterious substances that can result in decreased corrosion.

1. Objectives

Improved packaging materials are required to increase reliability of thin-film PV modules. As discussed in the Solar Program Multi-Year Technical Plan [1], a major impediment for flat-plate PV systems is the limitation in cost and reliability of module packaging. Both crystalline-silicon and thin-film technologies require advanced module packaging to survive in harsh operating environments. The objective of this research is to identify new, cost-effective packaging materials that demonstrate improved moisture barrier and adhesion properties with weathering. Candidates include both commercial and experimental materials provided by the private sector, and experimental materials developed in-house.

2. Technical Approach

A number of new encapsulants and backsheets have been evaluated as improved packaging materials. The primary properties of interest were adhesion (using an Instron 5500R mechanical testing unit) as a function of damp heat exposure and moisture transport (measured with a Mocon Permatran-W 3/31 instrument). Peel strength measurements (both 90 and 180) have been made to allow screening of alternate encapsulant formulations and to test the durability of interfacial adhesion. By measuring the time-dependent permeability of backsheets and encapsulants, the diffusivity and solubility of these materials can be derived and used to compute moisture ingress time scales [2]. Finally, the ability of combinations of packaging components to protect PV devices from corrosion was assessed.

3. Results and Accomplishments

3.1 Encapsulants

Candidate encapsulants were compared with a control material, namely, a standard fast-cure ethylene vinyl acetate (EVA) product (designated 15295P) from Specialized Technology Resources, Inc. (STR). Samples included silicones and primers from GE and Dow Corning, an experimental material from BRP Manufacturing (BRP-C), an experimental fluorocarbon from Saint-Gobain (THV), and several in-house formulations.

A number of silane adhesion promoters designed to improve adhesion of EVA to glass were screened by priming the glass substrates and preparing samples at NREL. Their construction was: Tedlar-Polyethylene Terephthalate (PET)-EVA (TPE)/EVA/primed glass. The 90° peel strength was measured between EVA and glass as a function of damp heat exposure. Some samples were found to have a statistically significant improvement in adhesion compared to the STR control; some samples were so adherent that they did not initiate peel, even after 775 h exposure to damp heat [3]. The most promising primers are being compounded into EVA for further testing.

NREL-prepared alternate encapsulant formulations were also tested. These included EVA and an ethylene copolymer of methacrylate with glycidyl functional groups having various silanes incorporated into the base resin. Some materials were found to be similar or inferior in performance to STR's 15295P EVA. One material was quite promising; no peel initiation occurred after 743 h damp heat exposure.

3.2 Backsheets

Backsheet candidates include NREL plasma-enhanced chemical vapor deposition (PE-CVD) coated PET films [4], three commercial products from Isovolta, an experimental laminate from DuPont Teijin Films, ten PE-CVD coated PET samples from AKT, two multi-layer coated PET samples from PNNL, and an uncoated/unlaminated liquid crystal polymer (LCP). The various samples are at different stages of evaluation. Water vapor permeability was measured as a function of temperature (see Fig. 1). LCPs have very low permeability values, typically 100 times lower than uncoated PET. LCPs also provide a better moisture barrier than experimental PET films having inorganic coatings, although the sample of LCP has a higher activation energy than either the coated or uncoated PET film. However, the LCP material by itself is very fragile and may be better suited for use in a laminate construction; it is also a relatively expensive material. Polyethylene naphthalate (PEN) has been identified as a high-performance material for the food packaging industry. Although it does have better moisture barrier properties than PET, the water vapor transmittance rate (WVTR) of uncoated PEN is inadequate for PV applications. The Isovolta Tedlar-SiOx-PET backsheet exhibits barrier properties intermediate between uncoated PET and some experimental oxide/nitride coated PET films.

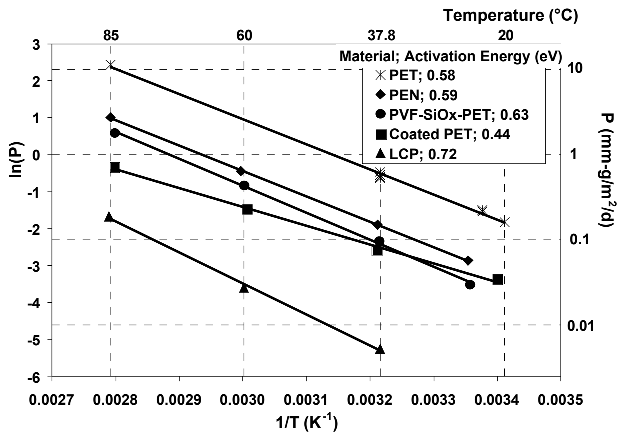

Figure 1. Arrhenius plot of permeability for backsheets at 85% RH

3.3 Combined Packaging

Several experiments were performed to evaluate the relative effectiveness of various packaging strategies and components (e.g., backsheets, encapsulants, edge sealants) in preventing moisture-induced degradation of thin-film devices. The performance of small (laboratory scale) PV devices is difficult to characterize without compromising the integrity of the protective package. However, exposure to damp heat (85°C/85% RH) aggressively corrodes aluminum, which is often used in PV modules (e.g., as interconnects). Consequently, thin-film aluminum coatings were vacuum deposited onto glass substrate test articles to simulate a PV device and provide a rapid visual indication of damage. The extent of degradation as a function of exposure time was documented with digital imagery. A number of backsheet/encapsulant combinations were laminated to the aluminized glass and were subjected to 1000 hours of damp heat exposure.

Samples with the TPE breathable backsheet provided very good protection of the Al layer. Substantial bulk corrosion of Al occurred for glass/EVA/Al-glass samples, suggesting that corrosion of the Al may be catalyzed by by-products (possibly acetic acid) within the encapsulant. Samples with the BRP-C encapsulant exhibited excellent protection of the aluminum layer, independent of the type of backsheet. Samples with the experimental DuPont Teijin backsheet did not exhibit aluminum corrosion, even though its adhesion to EVA was severely compromised by damp heat exposure. If this problem could be eliminated, this material would be an attractive advanced backsheet because the WVTR at 85°C/100% RH is below the measurement sensitivity of our MOCON instrument. Properly wetted edge seal materials demonstrated an outstanding ability to prevent moisture ingress in glass/glass constructions, even when a bead-blasted edge delete exists.

4. Conclusions

We have evaluated a large number of backsheet and encapsulant materials in terms of their moisture barrier properties and their ability to maintain good adhesion during damp heat exposure. Several promising packaging candidates have been identified. Additional efforts to develop improved encapsulants (by compounding high-potential primers into EVA for further testing) and backsheets (by deposition of high barrier coatings onto polymer films) are ongoing. We have also investigated the effectiveness of several combined packaging strategies/constructions to provide increased protection of PV modules. Glass/glass laminate constructions with EVA are believed to trap harmful compounds that catalyze moisture-driven corrosion of aluminum. Constructions with breathable backsheets allow higher rates of moisture ingress, but also allow egress of deleterious substances, thereby reducing corrosion.

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[4] S.H. Glick et al., "Dielectric Thin-Film Barriers of Silicon Oxynitride for Protecting Photovoltaic Cells and Modules," *Proc. of the 31st IEEE PV Specialists Conference, 2005, Lake Buena Vista, FL* (to be published).

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