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Module Design, Materials, and Packaging Research Team: Activities and Capabilities

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T.J. McMahon, J. delCueto, S. Glick, G. Jorgensen, M. Kempe, C. Kennedy, J. Pern, and K. Terwilliger

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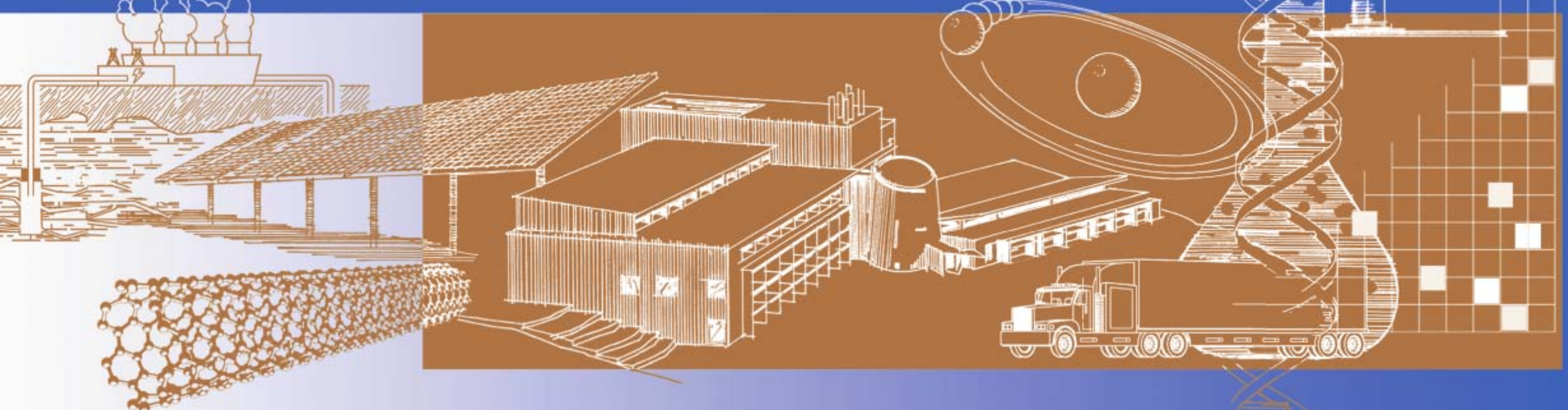

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ABSTRACT

Our team activities are directed at improving PV module reliability by incorporating new, more effective, and less expensive packaging materials and techniques. New and existing materials or designs are evaluated before and during accelerated environmental exposure for the following properties: (1) Adhesion and cohesion: peel strength and lap shear. (2) Electrical conductivity: surface, bulk, interface and transients. (3) Water vapor transmission: solubility and diffusivity. (4) Accelerated weathering: ultraviolet, temperature, and damp heat tests. (5) Module and cell failure diagnostics: infrared imaging, individual cell shunt characterization, coring. (6) Fabrication improvements: SiO_xN_y barrier coatings and enhanced wet adhesion. (7) Numerical modeling: Moisture ingress/egress, module and cell performance, and cell-to-frame leakage current. (8) Rheological properties of polymer encapsulant and sheeting materials. Specific examples will be described.

1. Objectives

Improved packaging materials and strategies are required to increase reliability of thin-film (T-F) PV modules. The Solar Program Multi-Year Technical Plan [1] states that a major impediment for flat-plate PV systems is the limitation in cost and reliability of module packaging. Both the crystalline silicon and T-F technologies require advanced module packaging to survive in harsh operating environments.

The objectives of this research are to (1) identify new, cost effective packaging materials that demonstrate improved moisture barrier and adhesion properties with weathering, (2) provide relevant performance measures for new and existing packaging materials at all relevant temperatures, before and after stress, (3) model moisture ingress and egress for module structures, (4) where possible gather outdoor test data at different test sites to correlate with indoor accelerated testing, (5) develop an acceleration constant relating use site to accelerated weathering chamber tests for important failure mechanisms, (6) identify specific failure mechanisms from field and accelerated weathering chamber testing using diagnostic methods available within our team and the NCPV.

2. Technical Approach

Module-level packaging issues addressed by our task are directed at alternatives to double glass lamination for thin films. Our task studies include soft backsheets and hard coat barrier films. Ethylene vinyl acetate (EVA) substitutes are being considered as a more effective and less expensive laminating polymer when transparency is not required. Environmental chamber stress testing is used to screen new materials and module designs. Past and continuing problems include T-F shunt failure, SnO_2 delamination, and cell-to-frame current isolation. Failure diagnostics are an integral part of our task. We are heavily involved with the T-F partnership team's reliability efforts. Hot/Humid survival in the field and 85%/85°C stress depend on adhesion, cohesion, and water diffusion barriers.

3. Results and Accomplishments

3.1 Encapsulants and backsheets.

Candidate encapsulant studies were conducted on silicones, butyles, and several in-house formulations, and were compared to the standard Specialized Technologies Resources(STR) fast cure EVA designated 15295P [2]. Backsheet candidates include various uncoated polymer sheets and single and multi-layer coated polyethylene terephthalate(PET) samples. Our past work on barrier coatings [3] is being extended to plasma enhanced(PE) CVD SiO_xN_y coatings [4]. NREL PECVD coated PET films are also included.

Several experiments were performed to quantify the relative effectiveness of various packaging strategies in preventing moisture-induced degradation of thin-film devices. Another objective was to determine the combined behavior of various packaging components (i.e., backsheets, encapsulants, etc.) that we have individually characterized in terms of moisture transport properties [2].

3.2 Wet adhesion studies

A number of silane adhesion promoters designed to improve adhesion of EVA to glass after damp-heat were screened by priming the glass substrates and preparing samples at NREL. Some samples were found to have a statistically significant improvement in adhesion compared to the STR control. The most promising primers are being compounded into EVA for further testing [5]. These topics are reported at this meeting by G. Jorgensen.

3.3 Moisture ingress studies

Moisture-relevant properties of polymers and coatings were measured. Using these values, M. Kempe has modeled moisture ingress and egress into and out of module structures to determine moisture content in module packages under various humidity conditions [6]. This topic is discussed in more detail at this meeting by M. Kempe.

3.4 Module and cell shunts.

Here, in collaboration with D. Albin and T. Berniard, we report on a non-linear, metastable, shunt path loss mechanism located at T-F solar cell corners (and presumably to a lesser degree, edges) that causes over half the degradation in performance during stress testing [7]. We use dark I-V curves and current transients to study the voltage switching behavior for ideal, undegraded cells and degraded cells with these shunt paths that are so devastating to performance.

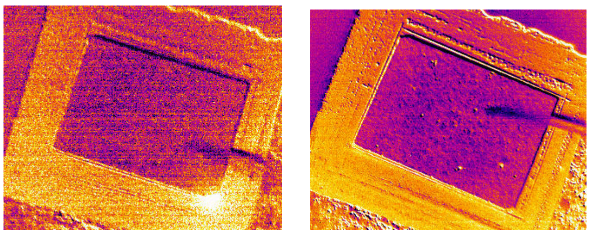

Fig. 1. Thermal image difference taken for cell #177D: (left) the reverse-bias image at -1.5 mA @ -0.45 V minus the zero-bias image. The light spot in the lower-right corner is the shunt path. (Right) the reverse-bias image at -0.0009 mA @ -0.45 V minus the zero-bias image after removing that corner.

By physically removing the micro shunt path defect, which we locate with an IR camera as in Fig. 1, and knowing exactly the light and dark I-V performance before and after its removal, we can model the electrical properties of that defect and demonstrate how devastating its presence can be to the entire device performance. One-dimensional modeling to describe such cell degradation is completely inappropriate and misleading. We point out metallic shunt defect mechanisms cited in the literature and discuss the implications for scribe lines and cell ends in fullsize modules. Effects of humidity on cell-ends and scribe-lines, with and without EVA or with new candidate encapsulants, as well as edge passivation processes, can be effectively screened for detrimental chemical reactions using the transients, as will be described in a forthcoming paper [8].

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 barrier coatings onto polymer films) are ongoing. We have used numerical modeling and mini-modules to examine the effectiveness of several combined packaging strategies/constructions to provide increased protection for PV modules. Effects of humidity on cell-ends and scribe-lines, with and without EVA or with new candidate encapsulants, as well as edge passivation processes, can be effectively screened for detrimental chemical reactions using the dark current transient and IR camera studies.

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