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Module Packaging Research and Reliability: Activities and Capabilities

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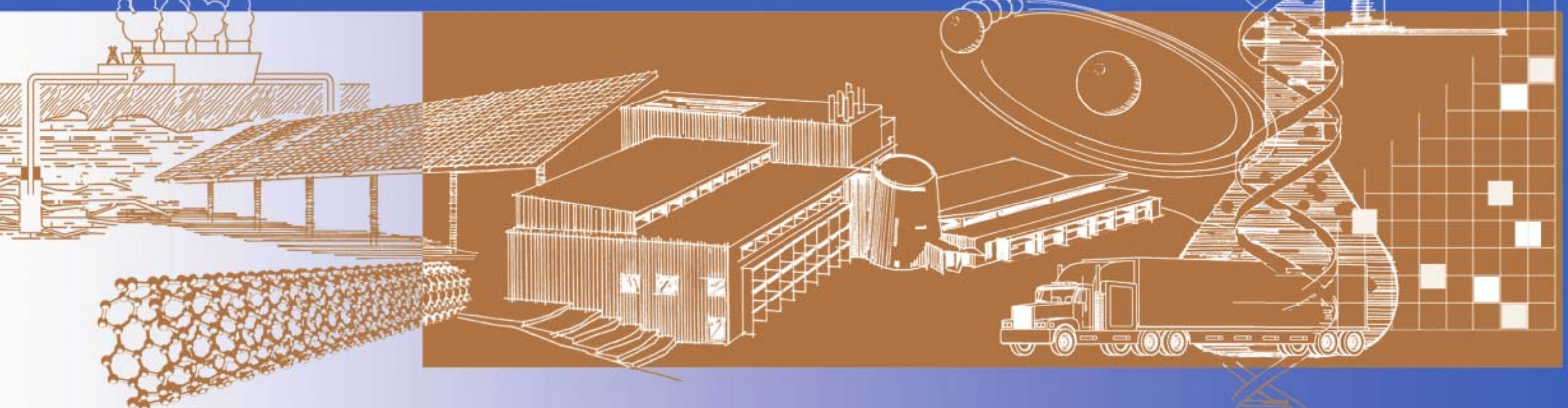

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ABSTRACT

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 are 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 due to 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 National Center for Photovoltaics.

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, wet adhesion, barrier integrity under wet conditions, and temperature. 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 Backsheet.

Candidate encapsulant studies were conducted on silicones, butyls, 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 chemical vapor deposition(PECVD) 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 T-F 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 F.J. Pern.

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] Additionally, M. Kempe will report on the rheological and mechanical considerations for PV encapsulants at this meeting[7].

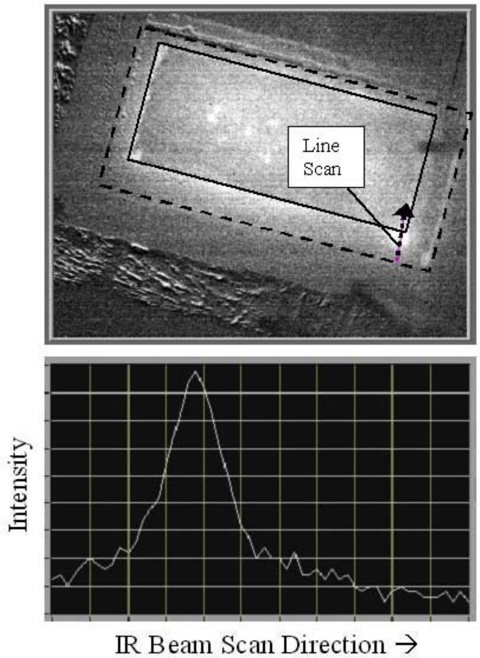

Fig. 1. Thermal image difference taken for cell #177D: (bottom) IR thermography line scan taken from the non-metallized CdTe "margin" over the metallized back contact. The peak in emission occurs at the boundary defined by the metal contact, and cannot be associated with edge leakage. The perimeters of the CdTe margin are artificially highlighted in the figure. IR imaging specifics are discussed elsewhere[8,9].

3.4 Module and Cell Shunts

Here, in collaboration with D. Albin and S.H. Demstu, we report on a non-linear, metastable, shunt path loss mechanism due to cell processing that in addition to the cell edge mechanism reported last year[8,9] can cause half the degradation in performance during stress testing[10]. The physical mechanism for explaining why stability in nitric/phosphoric (NP) -etched devices is improved with thicker CdTe layers may be due to the grain boundary penetrating ability of this etch. Recently, we reported that device stability could be improved by using a perimeter margin of CdTe around the back metallization of the device such that edge shunting was removed[8,9]. Because the devices in this study use such a design feature, the shunting shown was surprising. Line-scanned infrared (IR) thermography as shown in Fig. 1 revealed that unlike the device edge shunting observed previously in non-margined cells, shunting in these "margined" devices was extending perpendicularly through the film, and always at the metallization corners. These corners are essentially the regions defined by our Kapton lift-off tape process. We now speculate that capillary trapping of the NP etch at these corners during deionized water rinse, and the resultant over-etching and formation of Te perpendicular to the substrate, are responsible for the resistive shunts observed there. In other regions of the device, where NP can be more easily rinsed away, the same physical mechanism may be responsible, in a more subtle fashion, for the inability to reduce our CdTe films without impacting stability..

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. 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 to provide increased protection for PV modules. IR camera studies have helped us determine the cause of the cell edge shunts in margined cells.

REFERENCES

[1]*Solar Energy Technologies Program Multi-Year Technical Plan, 2003-2007 and Beyond*, DOE/GO-102004-1775, U.S. Department of Energy, Washington DC, January 2004.

[2]G.J. Jorgensen et al., " Testing of Packaging Materials for Improved PV Module Reliability," *Proc. of the 31st IEEE PV Specialists Conference, 2005, Lake Buena Vista, FL*, forthcoming.

[3]G. D. Barber, G. J. Jorgensen, K. Terwilliger, S. H. Glick, J. Pern, and T. J. McMahon, "New Barrier Coating Materials for PV Module Backsheets," *Proc. of the 29th IEEE PV Specialists Conference, p.1541, 2002.*

[4]S.H. Glick et al., "Oxynitride Thin Film Barriers for PV Packaging", *Proc. of the U.S. Department of Energy's Solar Energy Technologies Program's 2005 Annual Review, 2005, Denver CO this volume, Nov 2005.*

[5]J.F. Pern and G.J. Jorgensen, "Enhanced Adhesion of EVA Laminates to Primed Glass Substrates Subjected to Damp Heat Exposure," *Proc. of the 31st IEEE PV Specialists Conference, 2005, Lake Buena Vista*.

[6]M.D. Kempe, "Control of Moisture Ingress into Photovoltaic Modules," *Proc. of the 31st IEEE PV Specialists Conference, 2005, Lake Buena Vista, FL*, forthcoming.

[7]M.D. Kempe, "Rheological and Mechanical Considerations for Photovoltaic Encapsulants," *Proc. of the U.S. Department of Energy's Solar Energy Technologies Program's 2005 Annual Review, 2005, Denver CO this volume, Nov 2005.*

[8]T.J. McMahon, T.J. Berniard, and D.S. Albin, "Non-linear Shunt Paths in Thin-Film CdTe Solar Cells," J. Appl. Phys. 97, (2005) 054503.

[9]T.J. McMahon, T.J. Berniard, D.S. Albin, and S.H. Demstu, "Excess Dark Currents and Transients in Thin-Film CdTe Solar Cells: Implications for Cell Stability and Encapsulation of Scribe Lines and Cell Ends in Modules," *Proc. of the 31st IEEE PV Specialists Conference, 2005, Lake Buena Vista, FL*.

[10]D.S. Albin, S.H. Demtsu, and T.J. McMahon, "Film Thickness and Chemical Processing Effects on the Stability of CdS/CdTe Solar Cells," submitted to Thin Solid Films Aug 2005.

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