Material Characterization in PV Modules

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Goals: Performance, Durability & Safety Testing

- Identify the critical material properties needed for long term durability, reliability and safety in a photovoltaic module.
- Establish testing protocols to address the stability of these critical properties under accelerated and use conditions.
- Produce and test modules for performance, durability and safety.
- Develop materials and module analysis diagnostics tools to provide insight into degradation mechanisms.
- Apply analysis methods to modules exposed under accelerated durability test conditions and modules from the field and compare their performance
- Relate changes in material properties to module performance.

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Durability Test Conditions

- Typical durability test conditions are based on the performance and safety qualification test conditions (IEC61215, UL1703) including damp heat, UV, thermal cycling and humidity freeze.
- Module manufacturers typically test from 1.25 to >3x qualification exposure times.
- Several reliability groups are advocating combination tests which test backsheets, laminates and/or modules under combined conditions either simultaneously or in sequence.
- Test-to-failure methods are being studied.
- Comparison to outdoor testing is needed to validate acceleration conditions or test to failure protocol.
- DuPont is testing beyond qualification exposure, investigating combined stress exposure and using extended UV exposure to better understand long term durability.

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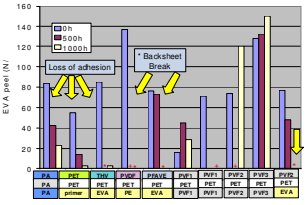
Mechanical Properties: EVA Adhesion After Damp Heat



Issues with Accelerated Exposure

You not only test the integrity of interfaces, you test the integrity of the base materials as well.

For most backsheets, damp heat is particularly damaging to core layer.

At some point, the limit of performance is not adhesion chemistry, but the material chemistry of the core layer.

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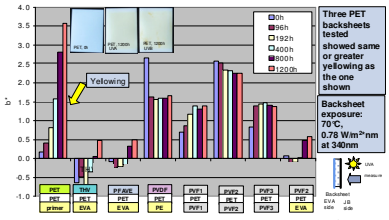
Optical Properties: Color Changes with UVA Exposure



Three PET backsheets tested showed same or greater yellowing as the one shown

Backsheet exposure: 70°C, 0.78 W/m²-nm at 340nm

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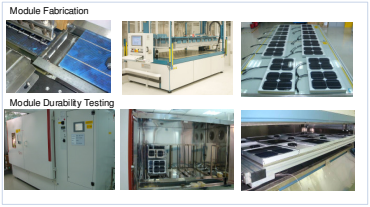
Module Fabrication and Durability Testing



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Module Durability after Damp Heat

- EL image of modules showing cell degradation after 3000h damp heat for modules using TPT™ and PPX backsheets. Modules with TPT™ lost 15% power, modules with PPX lost 50% power.
- Cracking, delamination and failure at junction box in PET/PET backsheet
- Cracking near frame edge for FPX backsheet
- Yellowing of FPX backsheet
- Cracking of the underlying PET layer in TPT™ observed without delamination.

• Differences in module performance with different backsheet materials
• Visual changes consistent with materials test results in damp heat

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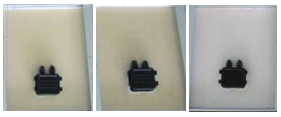
Module Durability after UV Exposure



PPX1 PPX2 TPT™

Yellowing in modules with PET/PET backsheets after 5x IEC UV pre-conditioning exposure from back side of module

• Differences in module performance based on backsheet material
• Visual changes consistent with materials test results after UVA exposure

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Analysis of Commercial Modules from the Field

- Program to evaluate modules from the field for their performance, durability and safety
- Apply non-destructive analysis to identify localized degradation and failure sites
- Apply destructive analysis methods to better understand degradation mechanisms
- Compare performance to degradation and failure mechanisms observed under accelerated durability test conditions
- Understand the relationship between materials, design, process, installation and environment

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Materials and Module Analysis Methods

Module ⟷ Material Analysis

- Metals Analysis
- Mass Spectrometry
- Microscopy
- Molecular Weight
- NMR
- Physical Measurements
- Separations
- Spectroscopy
- Surface and Particle Science
- Thermal Analysis
- Wet Chemistry
- X-Ray

Stage One – Non Destructive Analysis

1. Visual Inspection and Documentation
2. Power Output Measurement (IV Curve)
3. Electroluminescence (EL) Imaging
4. Thermal Imaging under forward bias
5. Wet Leakage Current or Dry Insulation Test

Stage Two – Destructive Analysis

1. Sample extraction via back side core
2. Physical layer profile (SEM)
3. Chemical layer profile (IR/SEM)
4. Defect pathways (X-Ray)

Photovoltaic Module Performance and Durability Following Long-term Field Exposure D. L. King, M. A. Quintana, J. A. Kratochvil, D. E. Ellibee and B. R. Hansen, Prog. Photovolt: Res. Appl. 2008; 16:241–258

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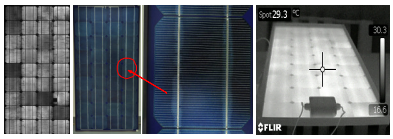
Example #1: Fielded Module



- **Module construction and exposure:** glass/EVA/Si/EVA/TPT™, residential rooftop array.
- **Visual inspection:** some localized frontside encapsulant delamination at tabbing wires.
- **EL imaging:** fine line interruptions and a few cells not operating at optimum efficiency, contributing to the small amount of power loss.
- **Wet leakage current testing:** good electrical insulation.
- **Thermal imaging:** no hot spots.

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Example #2: Fielded Module

- **Module construction and exposure:** glass/EVA/Si/EVA/PPX, residential rooftop array
- **Visual inspection:** localized delamination between PET-PET backsheet interlayers
- **EL imaging:** fine line interruptions and many cracked cells.
- **Wet leakage current measurement:** resistance of <1MOhm/m²
- **Thermal imaging:** temperature non-uniformities but no excessive hot spots.

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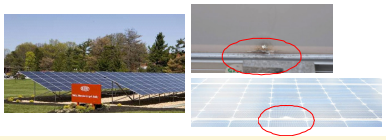
Example #3 : Installation Damage in PV Array

40kW ground mounted system

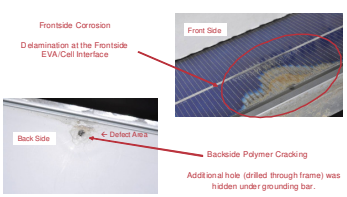
173 W c-Si Module – **Damage during installation** initiated corrosion and delamination

Locus of Failure – Characterization & Analysis

- Depth profile, chemical analysis, and X-Ray tomography to understand compromised module



Visual Identification of Module Defect



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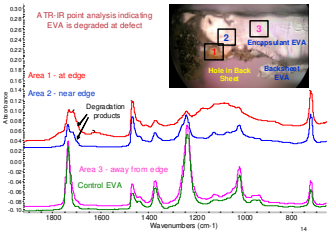
Encapsulant EVA Oxidation at the Defect



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Summary

- The performance and durability of a PV module is determined by a combination of materials, process and design
- Understanding material durability and interactions can provide insights into module durability
- Comparison of accelerated durability testing to fielded module performance is important to understanding relevant degradation mechanisms and validating and quantifying acceleration factors
- Fundamental understanding of materials changes under use conditions over the expected service life of the PV module is key to understanding and improving durability
- Analytical methods are being effectively applied to provide insights into chemical and physical materials changes and module performance issues

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This poster contains no confidential information.