Overview of encapsulant materials in photovoltaic modules

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Outline

• Role and Requirements of Encapsulants
• Types of Encapsulant Materials
• Degradation
• Characterization Methods
• Overview of DuraMAT projects
• Summary and References
Roles of Encapsulants in PV Modules

- The module stack is heated and pressed during the vacuum lamination step of manufacturing.
- Encapsulants must perform several key roles including: protect cells and metallization from water and other environmental stresses, maintain electrical insulation, provide adhesion between layers of the laminate, and maintain high transparency through PV-relevant wavelengths.
Key Material Parameters of Encapsulants

• Materials data sheets generally include the following information about encapsulants at their beginning-of-life
  – Melting temperature
  – Volume resistivity
  – Moisture volume transmission rate
  – Light absorption
  – Young’s modulus
  – Glass transition temperature
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• Edge Seal Materials
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Types of Encapsulant Materials

- Poly(ethylene-co-vinyl acetate) (EVA)
  - Copolymer of ethylene and vinyl acetate units, generally with vinyl acetate weight percent of 27 to 33
  - Most common PV encapsulant choice

- Polyolefin elastomers
  - Ethylene copolymers

- Silicones
  - Many options have been researched including curing and non-curing

- Ionomers
  - Reduce time/temperature of lamination step
Common Additive Compounds

- UV-stabilizers
- UV-absorbers
- Radical scavenger
- Crosslinking agents
- Adhesion promoter

Carvalho de Oliveira (2017) Renewable and Sustainable Energy Reviews
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Encapsulant Role in Degradation

- Trends in silicon module failures

- Stresses that lead to loss of desired properties include:
  - UV, water and oxygen ingress, temperature

*Fig. 63: Cumulative distribution of normalized failures over time periods between installation and inspection dates for fielded silicon PV modules. Soiling is not included in this graph.*
Encapsulant Role in Degradation

- Trends in thin-film module failures

![Graph showing failure types over time](image)

- Stresses that lead to loss of desired properties include:
  - UV, water and oxygen ingress, temperature

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Fig. 64: Cumulative distribution of normalized failures over time periods between installation and inspection dates for fielded CdTe and CIGS modules. Soiling is not included in this graph.
Identified Degradation Modes

- Degradation in EVA encapsulants

J. Tracy (2018) Progress in PV
Identified Degradation Modes

- Role of oxygen in EVA degradation reactions

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Characterization Methods: Crosslinking

- Soxhlet extraction – gel content
- Differential scanning calorimetry – specific energy of x-linking reaction
- Raman spectroscopy – CH-bond stretching region

Ch. Hirschl (2013) SolMat
Characterization Methods: Yellowing

- Spectrocolorometer
- UV-fluorescence imaging:

<table>
<thead>
<tr>
<th>UV-cut Mini-module</th>
<th>UV dosage</th>
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<td>0 kWh/m²</td>
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<td>UVC-3 (High T) 78°C</td>
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Fig. 7. UVf images of UVC mini-modules at different temperatures and UV dosage levels under accelerated UV testing.

TamizhMani (2018) IEEE-PVSC
Characterization Methods: Mechanical Properties

- Rheology – viscoelastic behavior, glass transition temperature

- Elongation at break

![Image of mechanical testing apparatus with graphs illustrating rheology and elongation at break.](image-url)
Characterization Methods: Crystal Fraction

- Differential scanning Calorimetry (DSC):

- Small and wide angle X-ray scattering (SAXS/WAXS) can also measure morphology and spacing of crystal regions

Fig. 2. Typical DSC thermograms of uncured (sample S0) and partially cured (sample S10) EVA (stacked plot).
Characterization Methods: Adhesion

- Lap-shear test
- Cantilever beam

Fig. 8. Optical images through the glass laminate visualizing the delaminated interface and debond front for (a) 100% EVA with Gc, > 500 J/m² and (b) 0% EVA with Gc, < 500 J/m². Each image is accompanied by a cartoon illustrating the interpreted character of the failure, associated cohesive zone and measurement of debond length, a.

N. Bosco (2019) IEEE-JPV
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• **Overview of Related DuraMAT projects**
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Overview of Related DuraMAT Projects

• Capabilities:
  – Predictive Simulation - Thermal Mechanical Model (James Hartley)
  – Materials Forensics (Laura Schelhas)
  – Accelerated Lifetime Testing (Peter Hacke)
  – Non-destructive Testing of Fielded Modules (Bruce King)

• Projects:
  – New Concepts for Reliable Low-Cost Module Encapsulation and Barrier Technologies (Reinhold Dauskardt)
  – Discovering New Materials for PV Encapsulation (Kurt Barth)

• SPARKs:
  – Cohesive Zone Model to Simulate PV Encapsulant Delamination (Nick Bosco)
  – Degradation Mechanisms in Fielded Modules w/ Luminescence and Thermal Imaging (Sulas)
Summary

• Encapsulant polymers perform several critical roles within PV module packaging

• Encapsulant degradation can lead to direct power loss (loss of transmittance), but usually the loss of desired properties leads to secondary failures (delamination, corrosion)

• DuraMAT consortium is working to add to body of knowledge using predictive simulation, developing new accelerated stress tests, developing destructive and nondestructive materials forensics methods
Questions?

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