DuraMAT
Durable Module Materials Consortium

Overview of encapsulant materials in photovoltaic modules

Ashley Maes – Sandia National Laboratories

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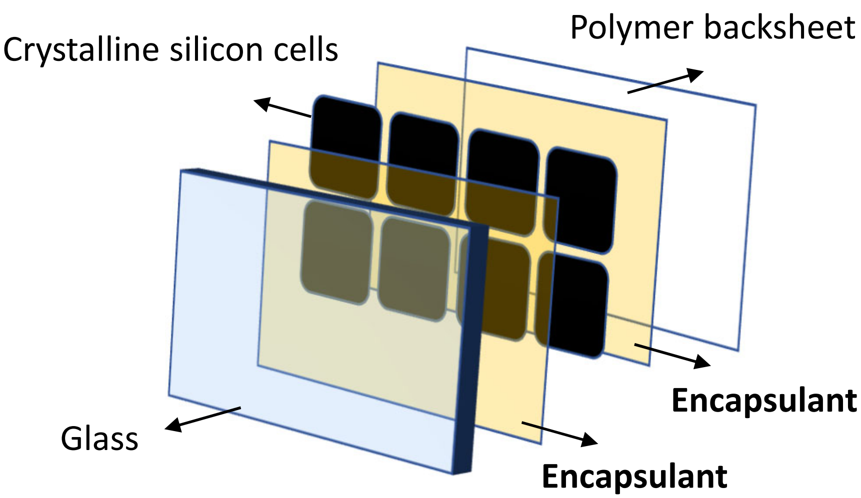
SAND2019-8246 PE

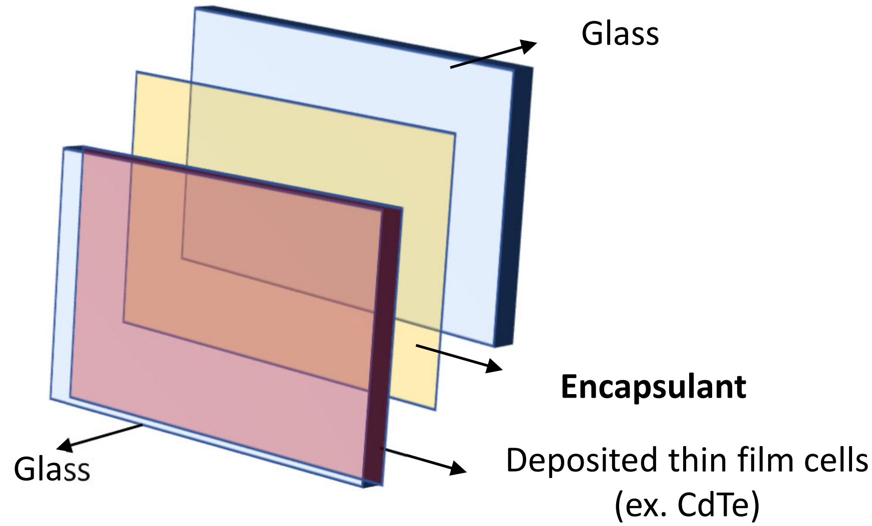
Outline

- 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



Layers in silicon PV modules



Layers in thin-film 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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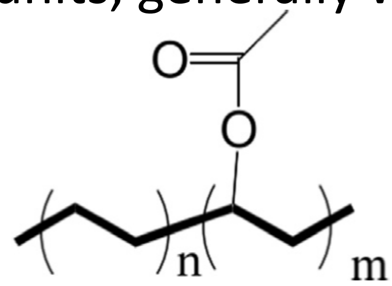
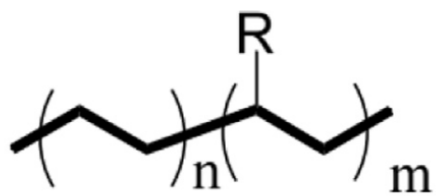
Types of Encapsulant Materials

- 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



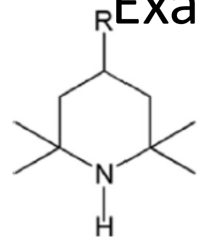
R= $-CH_3$, $-(CH_2)nCH_3$, others

- Silicones
  - Many options have been researched including curing and non-curing
- Ionomers
  - Reduce time/temperature of lamination step

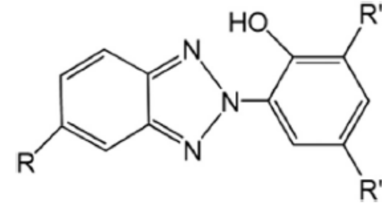
Common Additive Compounds

Example Structure:

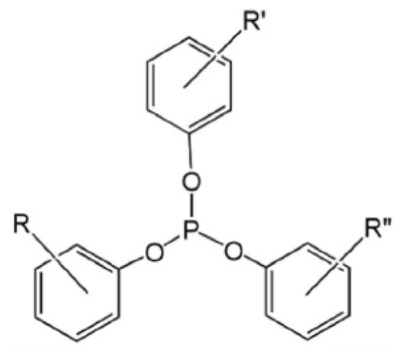
- UV-stabilizers



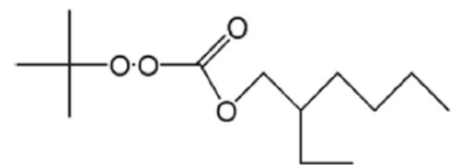
- UV-absorbers



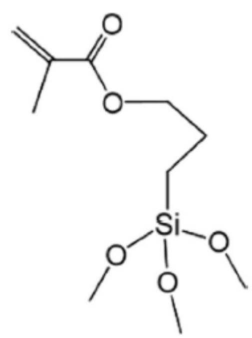
- Radical scavenger



- 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

IEA – PVPS Report (2017)

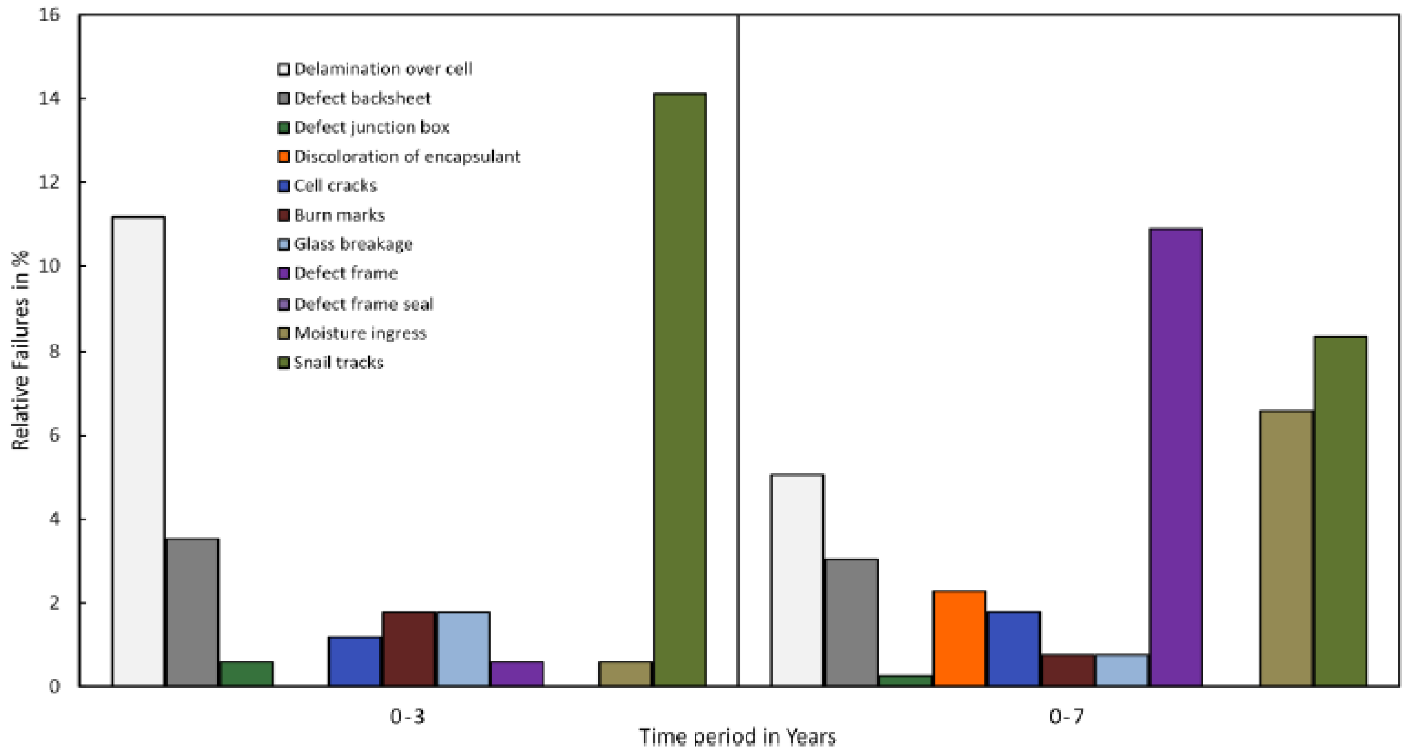

Fig. 63: Cumulative distribution of normalized failures over time periods between installation and inspection dates for fielded silicon PV modules. Soiling is not included in this graph.

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

Encapsulant Role in Degradation

- Trends in thin-film module failures

IEA – PVPS Report (2017)

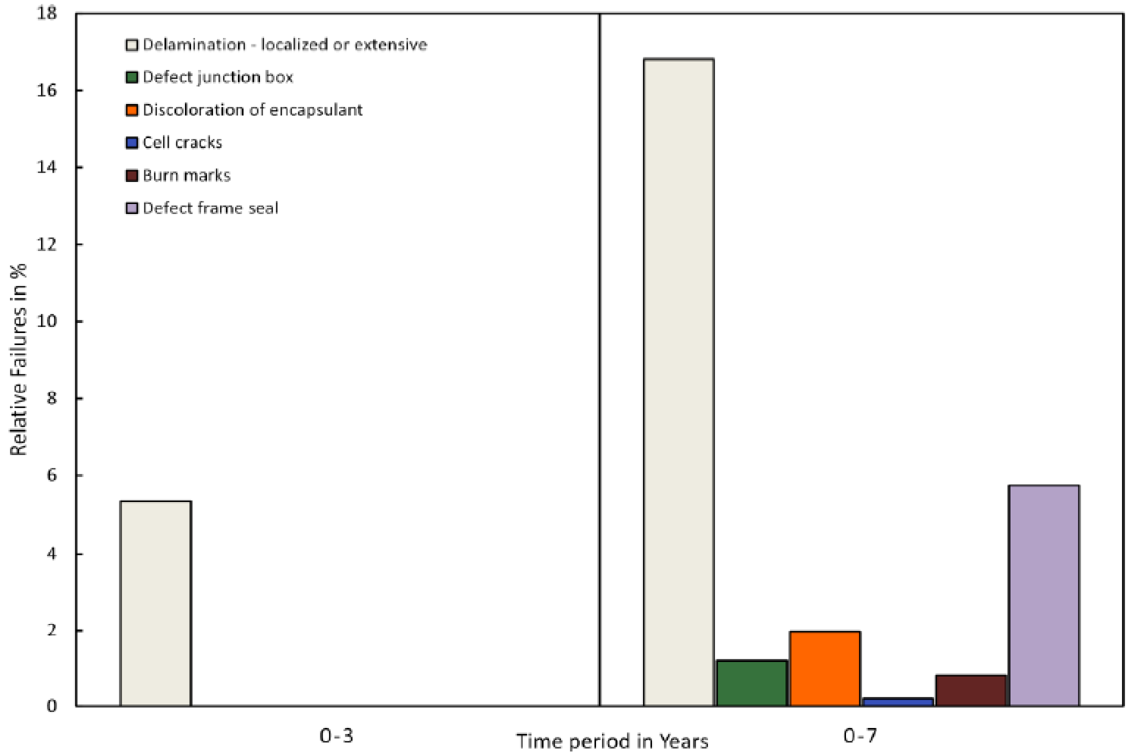

Fig. 64: Cumulative distribution of normalized failures over time periods between installation and inspection dates for fielded CdTe and CIGS modules. Soiling is not included in this graph.

- Stresses that lead to loss of desired properties include:
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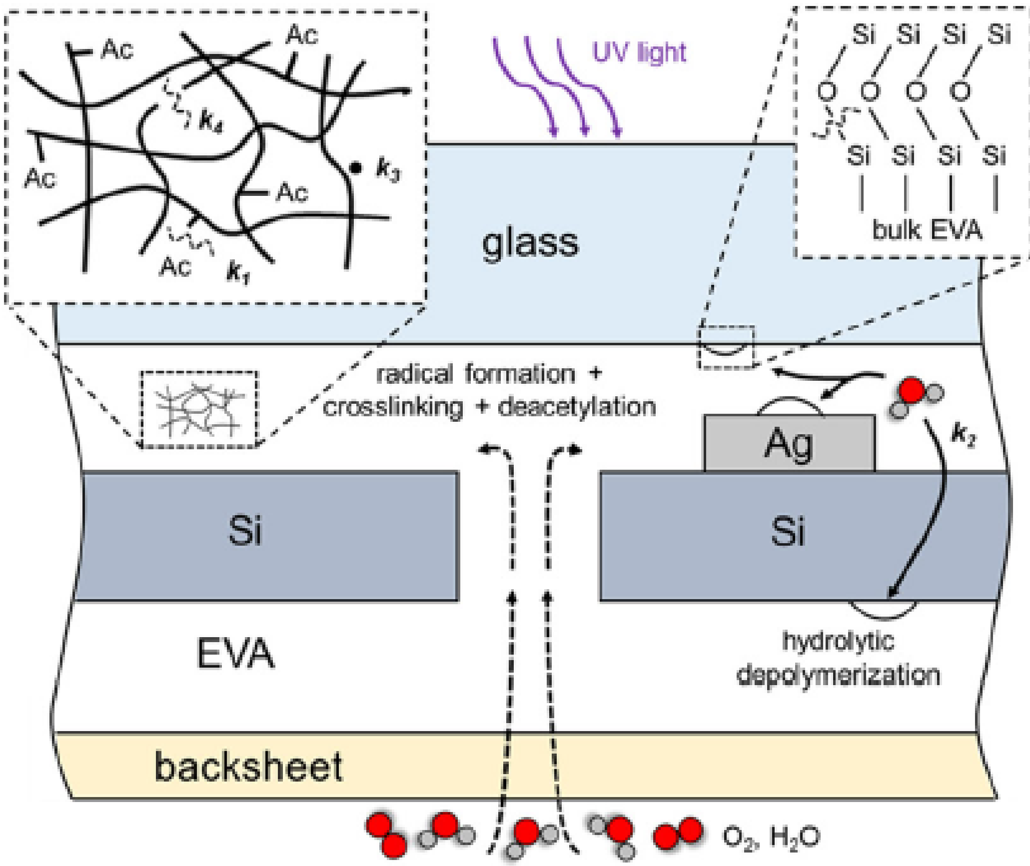
Identified Degradation Modes

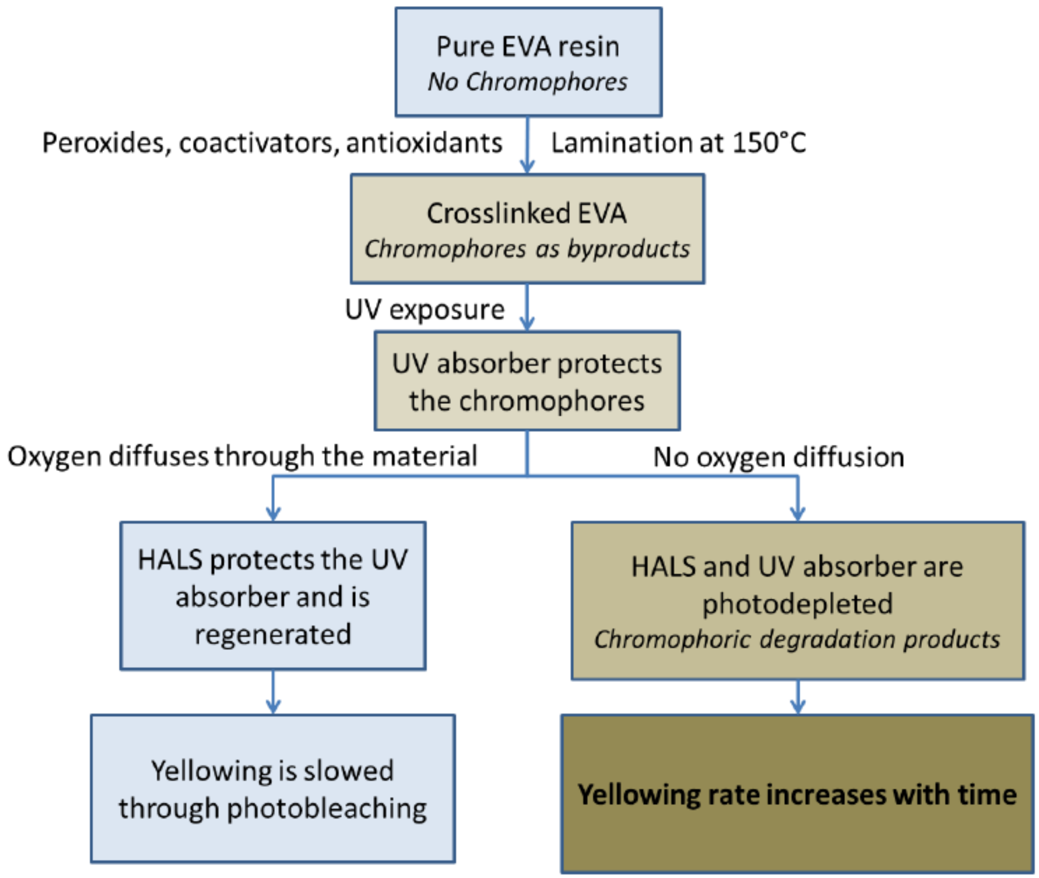
- Degradation in EVA encapsulants



J. Tracy (2018) Progress in PV

Identified Degradation Modes

- Role of oxygen in EVA degradation reactions



IEA – PVPS Report (2017)

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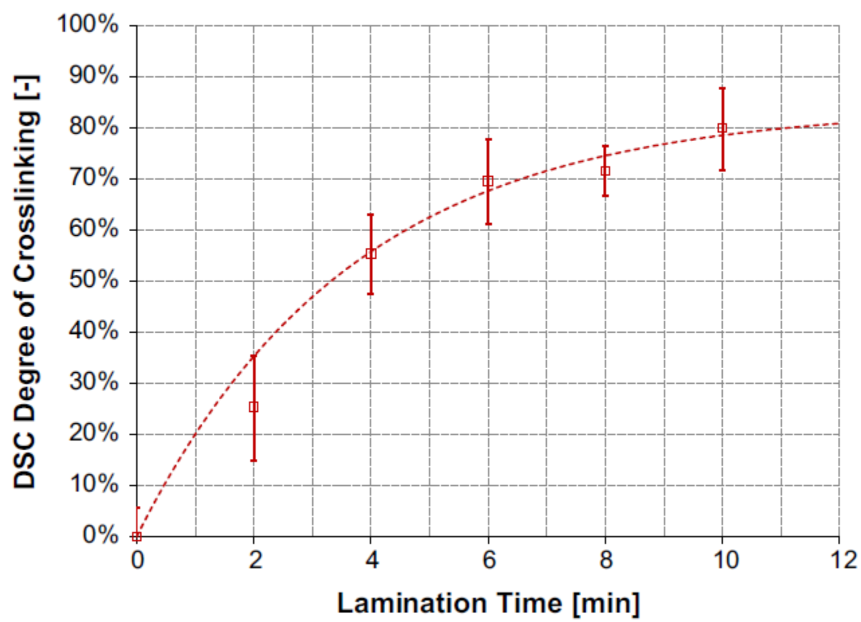
Characterization Methods: Crosslinking

- 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:

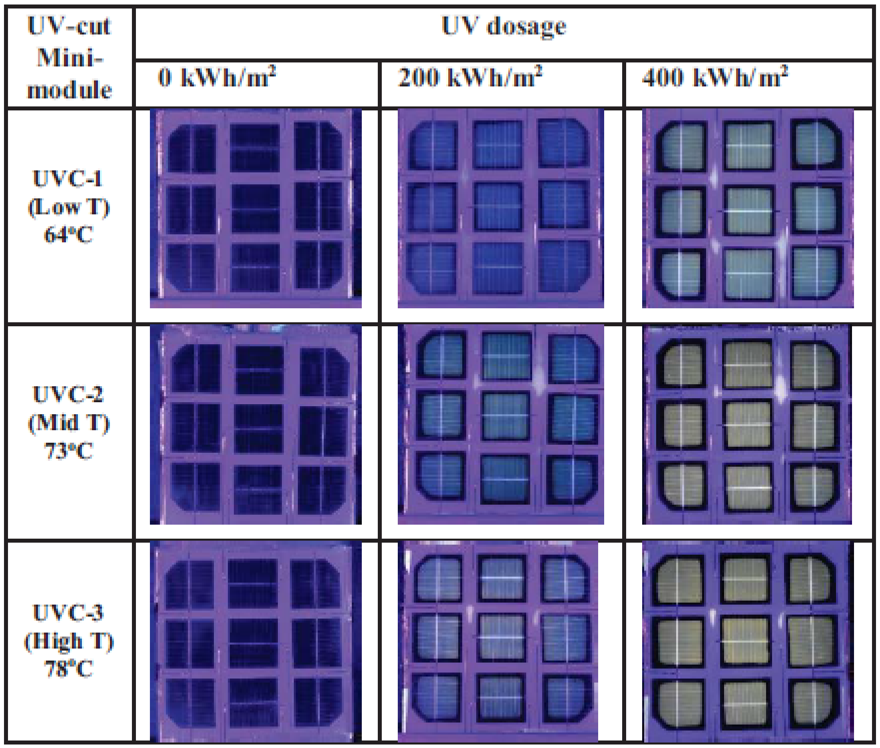


Fig. 7. UVf images of UVC mini-modules at different temperatures and UV dosage levels under accelerated UV testing.

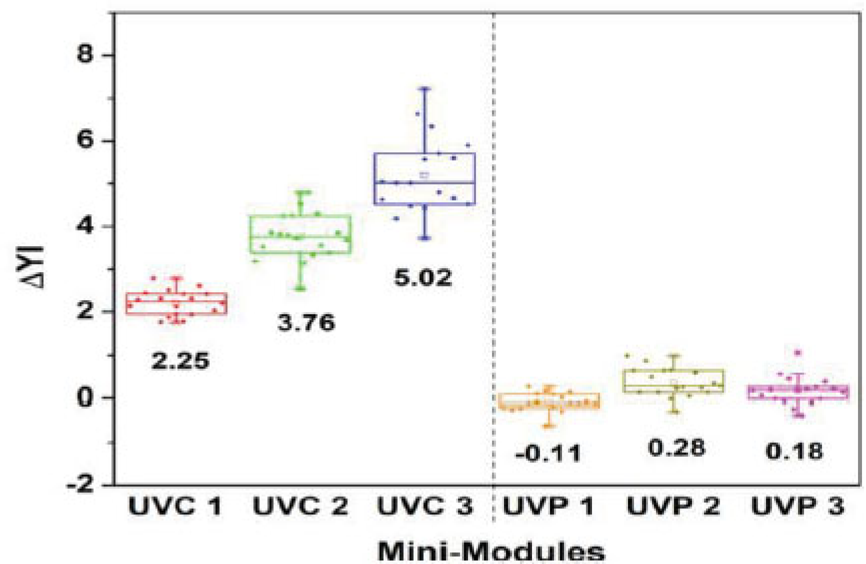
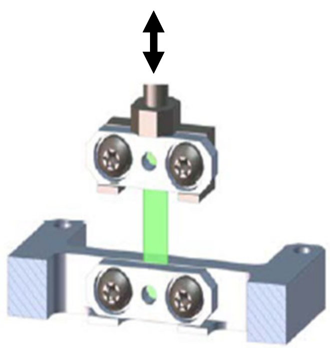


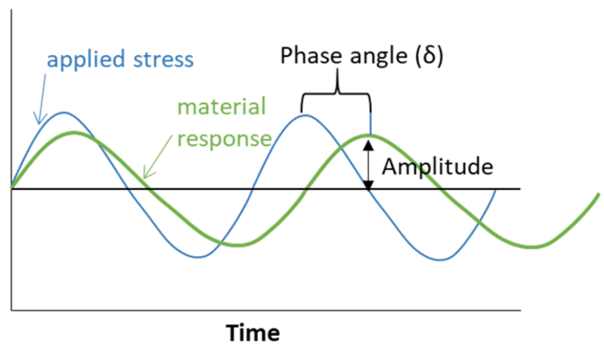
Fig. 12. ΔYI of mini-modules after 400 kWh/m^2 UV exposure in the chamber testing at low, mid and high temperatures.

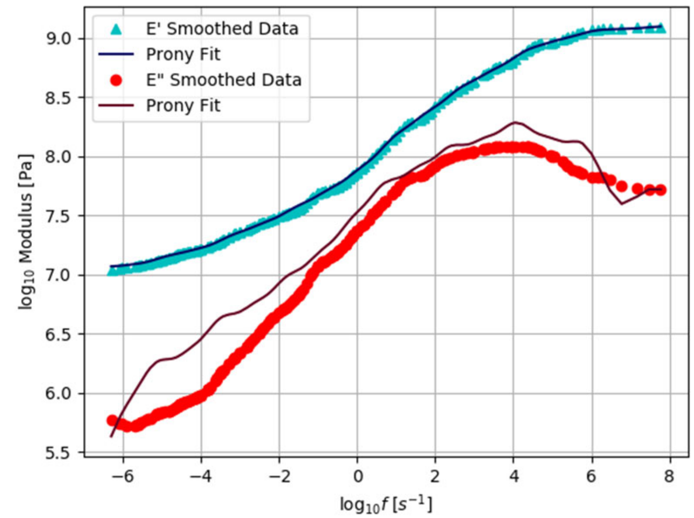
TamizhMani (2018) IEEE-PVSC

Characterization Methods: Mechanical Properties

- Rheology – viscoelastic behavior, glass transition temperature







Loss and Storage Modulus of EVA

- Elongation at break

Characterization Methods: Crystal Fraction

- Differential scanning Calorimetry (DSC):

Ch. Hirschl (2013) SolMat

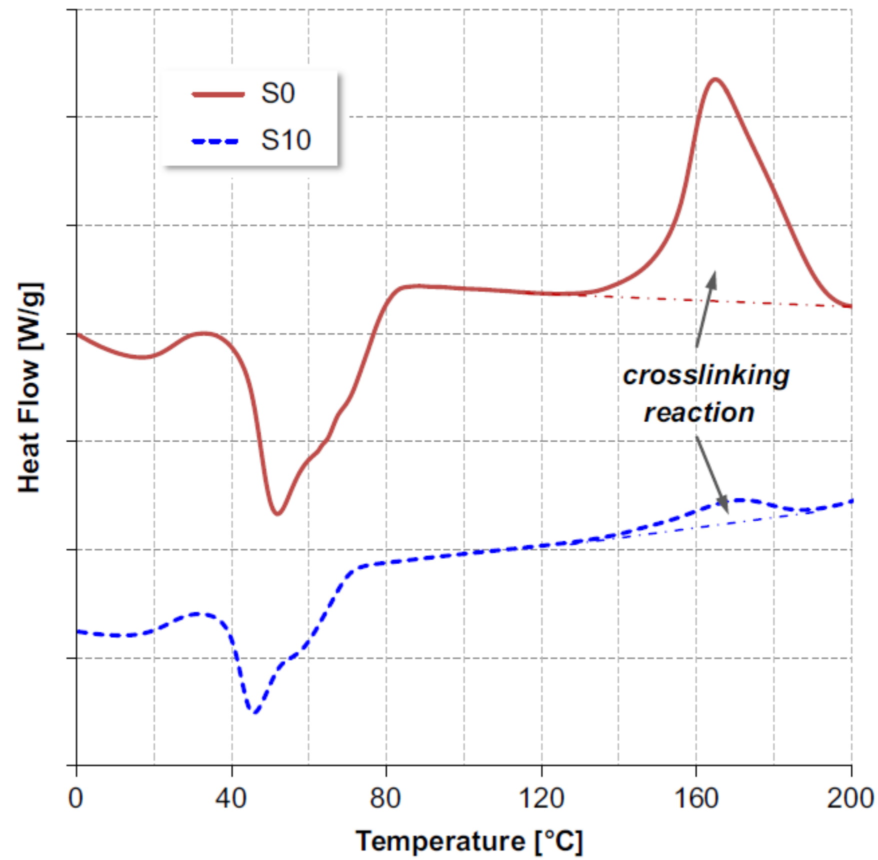


Fig. 2. Typical DSC thermograms of uncured (sample *S0*) and partially cured (sample *S10*) EVA (stacked plot).

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

Characterization Methods: Adhesion

- Lap-shear test
- Cantilever beam

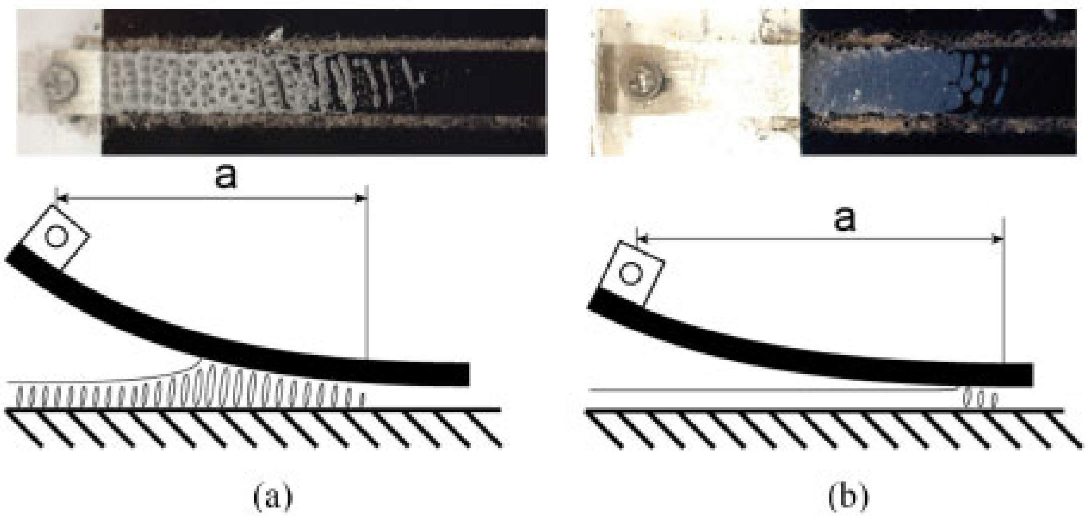


Fig. 8. Optical images through the glass laminate visualizing the delaminated interface and debond front for (a) 100 % EVA with Gc, > 500 J/m^2 and (b) 0% EVA with Gc, < 500 J/m^2. Each image is accompanied by a cartoon illustrating the interpreted character of the failure, associated cohesive zone and measurement of debond length, a.

N. Bosco (2019) IEEE-JPV

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Overview of Related DuraMAT Projects

- 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?

Acknowledgements:

DuraMAT network, especially James Hartley, Christine Roberts, Josh Stein

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