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Sandia National Laboratories

Thermal and Viscoelastic Behavior of Polymer Films Used as Photovoltaic Module Encapsulants

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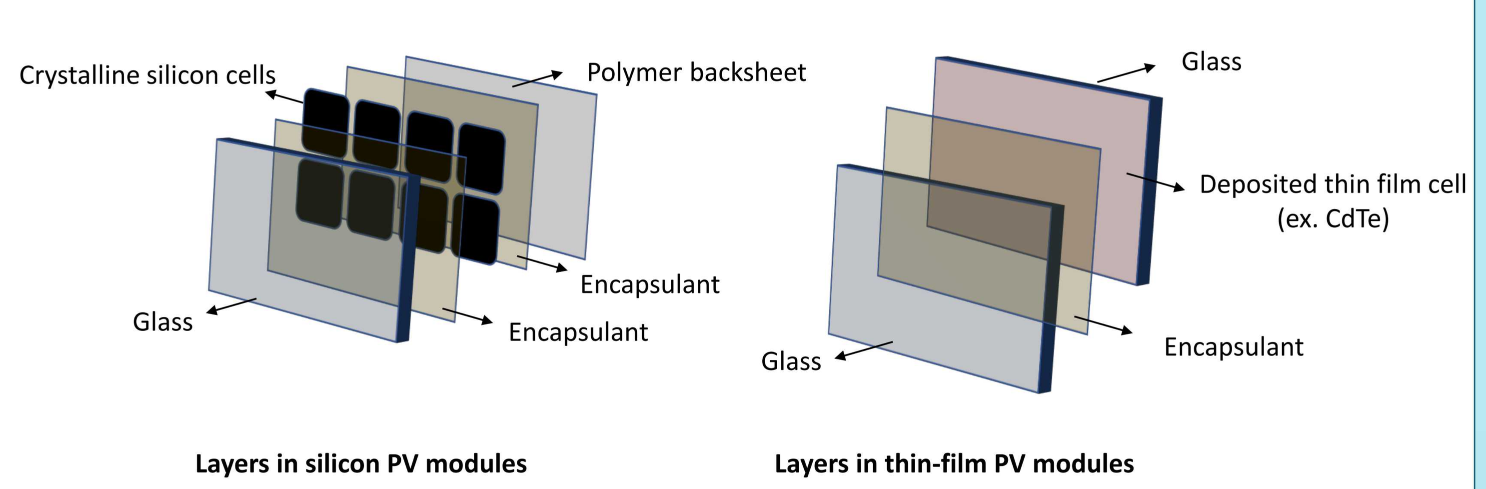
Introduction and Motivation

- As the PV industry expands and matures there has been growing interest in predicting reliability and system lifetime
- Sandia's work to address this need is part of the Durable Module Materials Consortium (DuraMAT), a Department of Energy (DOE) Energy Materials Network (EMN)
- This work is part of an ongoing predictive modeling effort developing multi-scale thermal-mechanical finite element models to better understand how module deployment environments induce the damaging stresses that lead to module degradation (*below*)

- The viscoelastic nature of polymer encapsulants is suspected to be a key factor affecting component stress states, and further experimental characterization was needed to populate a representative constitutive model

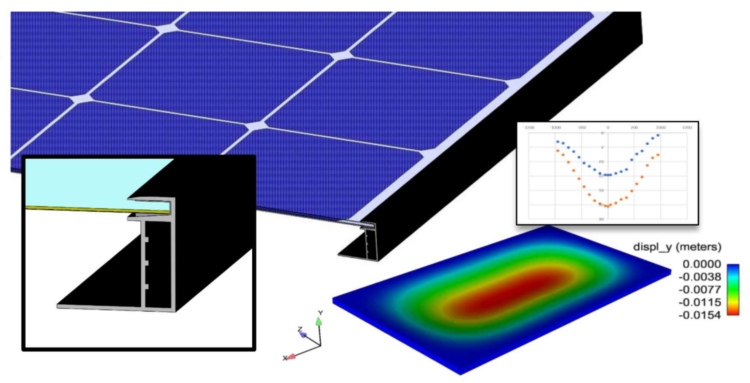
Encapsulants in Photovoltaic Modules



- The polymer layers used as encapsulants in both crystalline silicon and thin film PV modules provide:
  - protection from moisture and particulates
  - efficient optical transmittance of UV light
  - mechanical stability between glass and electronic components
- The two most common materials in commercial use are ethylene vinyl acetate (EVA) and polyolefin elastomer (POE) films
- Films produced for the PV industry include proprietary copolymer formulations and additives such as UV blockers, UV stabilizers, and peroxide crosslinking agents

Thermal-Mechanical Finite Element Modeling

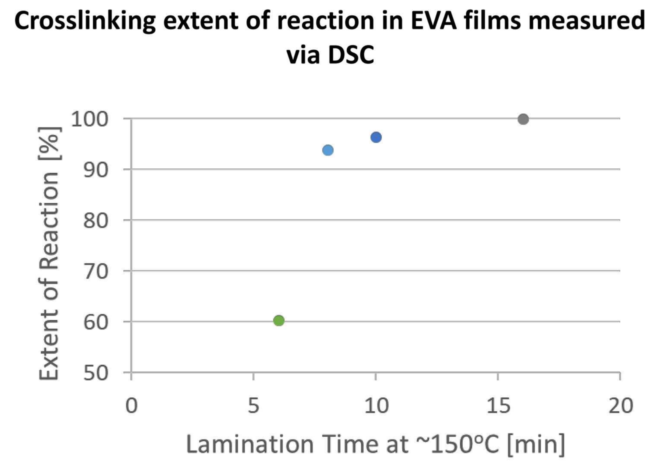
- Module-scale modeling has focused on three commercial module designs validated against loaded deflection data (*right*)
- A cell-scale parametric study was conducted to correlate geometric and material inputs with cell-level stresses [JY Hartley et al. IEEE PVSC, 2018]

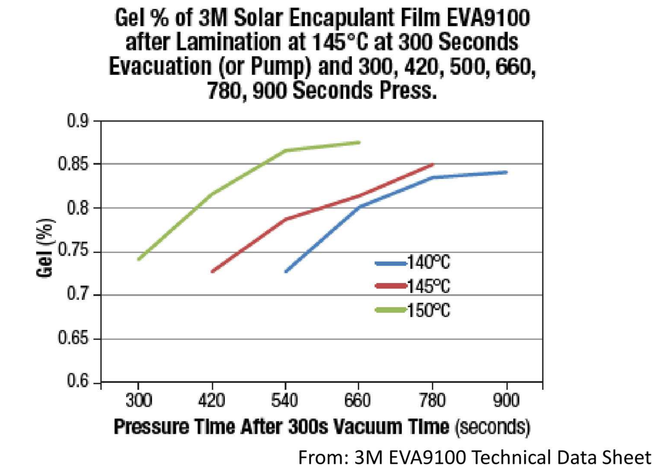


- The above efforts relied on single temperature and frequency moduli for encapsulant materials, missing the viscoelastic behavior of these polymers

Recreating Manufacturing Lamination Process

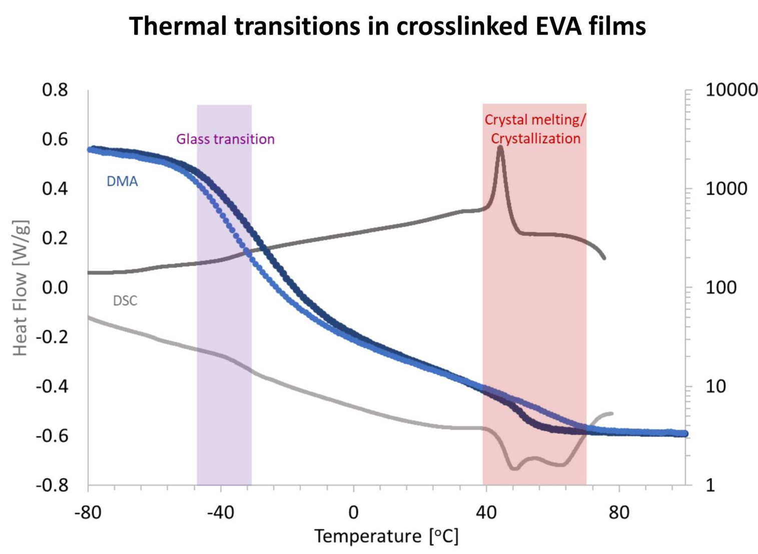
- During manufacturing, the module layers are pressed between heated platens while under vacuum to promote flow into voids, adhesion between layers, and crosslinking in systems using EVA
- Free standing samples were produced by mimicking above process in a vacuum oven with PTFE-coated release fabric on each side of the encapsulant film. Degree of crosslinking (*left*) measured by DSC matches tech. datasheet guideline plot (*right*)

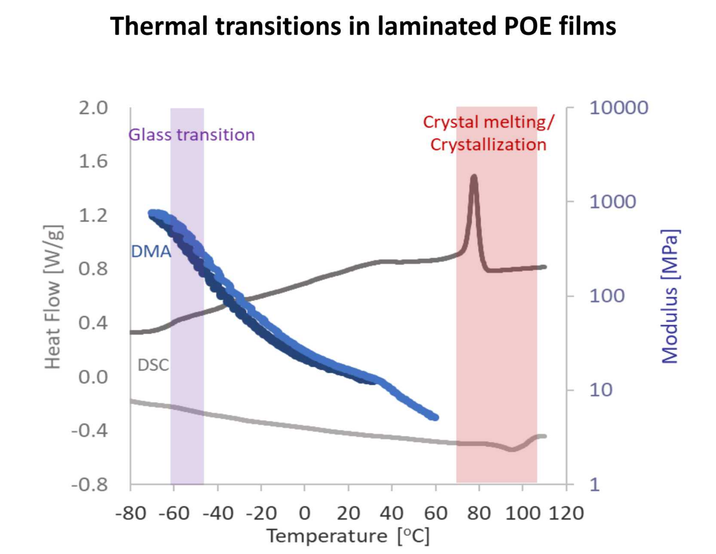




Thermal Transitions

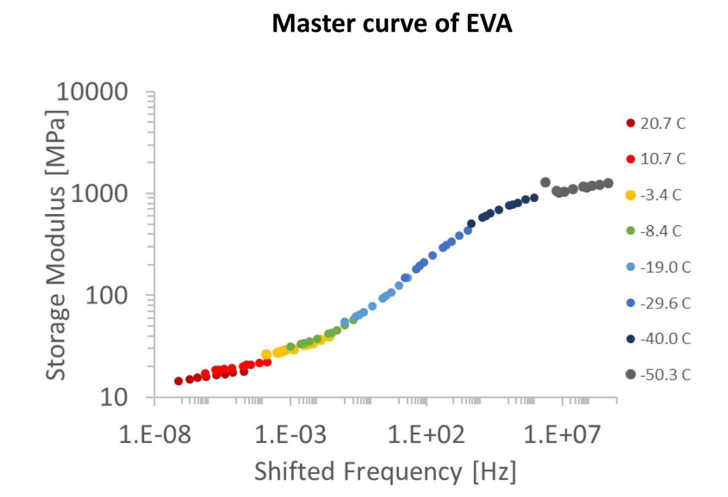
- Dynamic mechanical analysis was performed on a Netzsch DMA 242 Artemis instrument in the tension configuration and differential scanning calorimetry (DSC) was performed on a TA Instruments Q200
- Key thermal transitions are seen in EVA and POE with both experimental methods

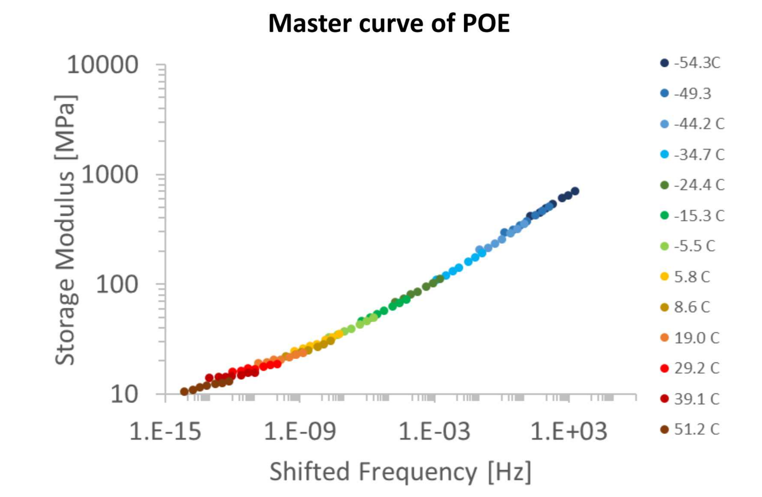




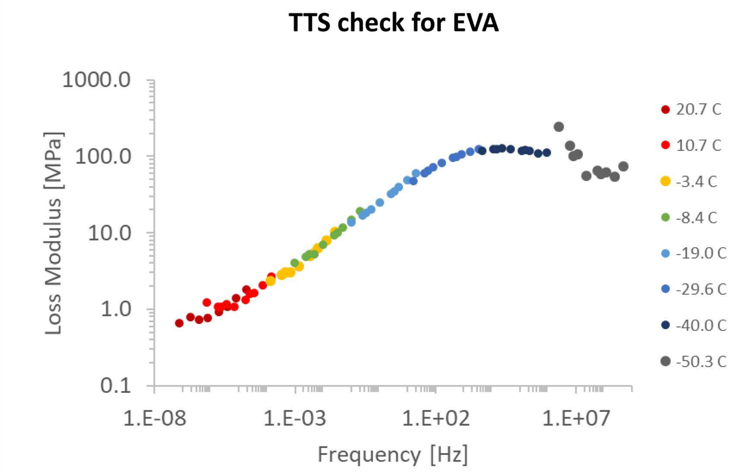
Time Temperature Superposition

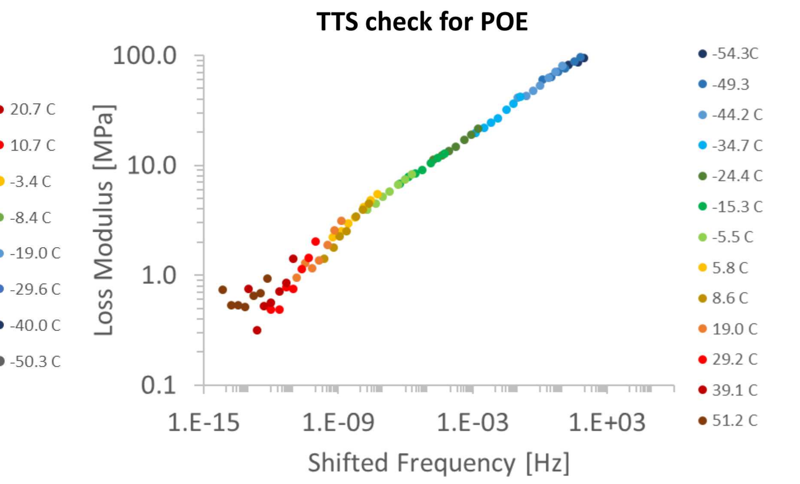
- Isothermal frequency sweeps (0.1 Hz to 10 Hz) were collected at and above the materials' glass transition regions (EVA: -40°C, POE: -60°C)
- Williams-Landel-Ferry (WLF) equation was used to find shift factors (α_T), with parameters C_1 and C_2 optimized to storage modulus (E') data
- In future work, a Maxwell Model will be used to fit each master curve





- Validity of time-temperature shift verified with loss modulus (E") data shifted with above parameters. POE data show some scatter at high temps





Additional Factors Affecting Viscoelasticity

- We have observed crystallization/melting behavior in DSC and DMA that is likely occurring in polyethylene domains
- Manufacturers are motivated to shorten lamination step, resulting in incomplete crosslinking. Crosslinking may continue slowly under field conditions
- Multiple chemical degradation mechanisms due to thermal and UV exposure have been proposed [MCC Oliveira, J. RSER, 2017]
- Future work will evaluate methods to include these effects into Sandia's Universal Polymer Model
  - Demonstrated with curing kinetics in polymer foams [DB Adolf and RS Chambers, J. Rheology, 2007]

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DuraMAT Durable Module Materials Consortium

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