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Functional Requirements of PV Module Materials

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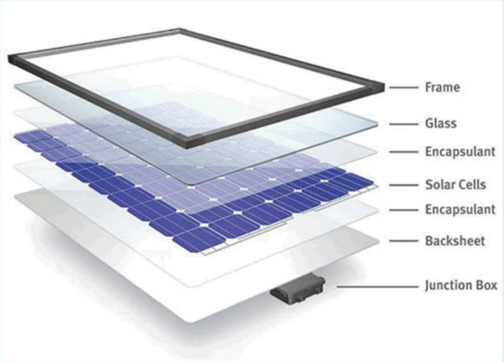
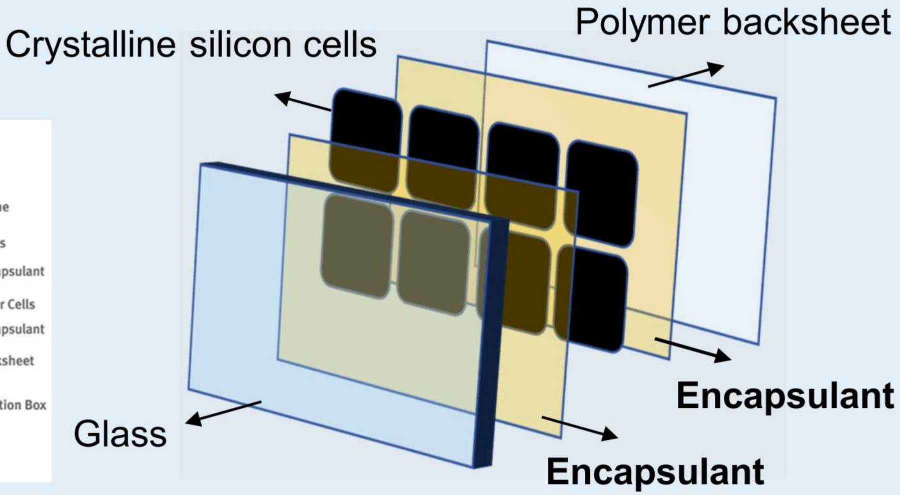
IEA PVPS Task 13 Subtask 1.1 – New Module Concepts, Designs, and Materials

- Activity Leaders
  - Gernot Oreski (PCCL, Austria)
  - Joshua Stein (Sandia, USA)
- Motivation
  - Provide global survey of innovations in PV module designs and materials
- Deliverables:
  - Report (2021) "Designing New Materials for Photovoltaics: Opportunities for Lowering Cost and Increasing Performance through Advanced Material Innovations"
  - Workshop (2019) "Innovations in Photovoltaic Materials"
- Get Involved:
  - We welcome proposals for contributions to the final report. Please contact the subtask leads with ideas.

Module Components

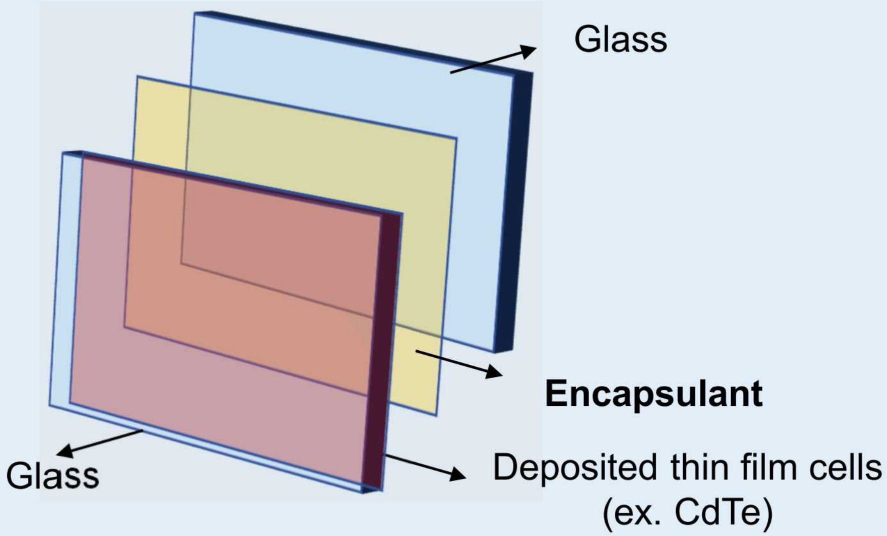
- Top sheet and Coatings
- Encapsulants and Edge Seals
- PV Cell and Metallization
- PV Cell to Cell Interconnection
- Backsheet
- Frame and Adhesives
- Junction Box, Cabling, and Connectors





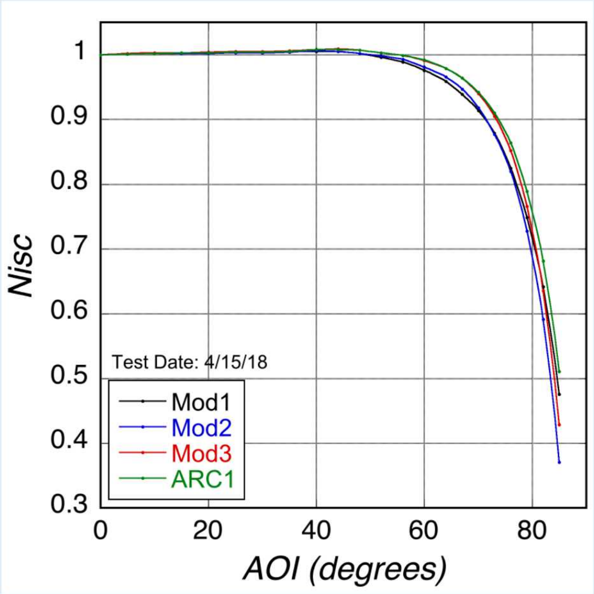
Problems can occur when:

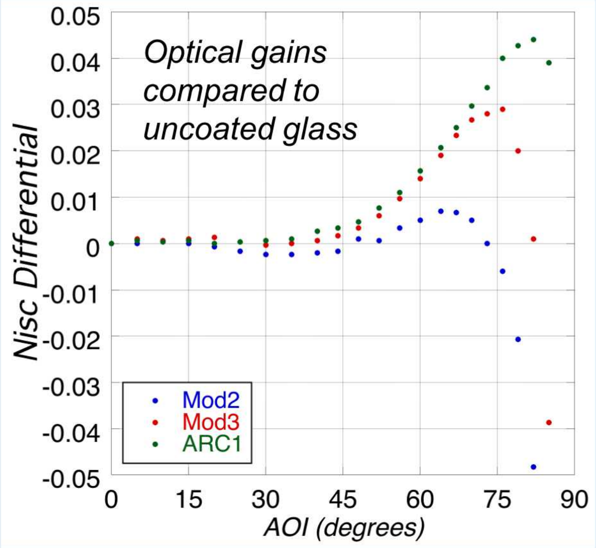
- Material requirements are not met
- Interactions with other materials or the evironment are not anticipated or understood



Top sheets

- **Materials:**
  - Low iron glass (<120ppm Fe)
  - Polymers (ETFE or Ultra Barrier Film - Higher cost)
- **Functional Requirements:**
  - High solar transmittance (e.g., 3.2mm: >91%
    - Reflection losses
  - Environmental barrier (keeps moisture out)
  - Strength
  - Safety - Glass is typically tempered

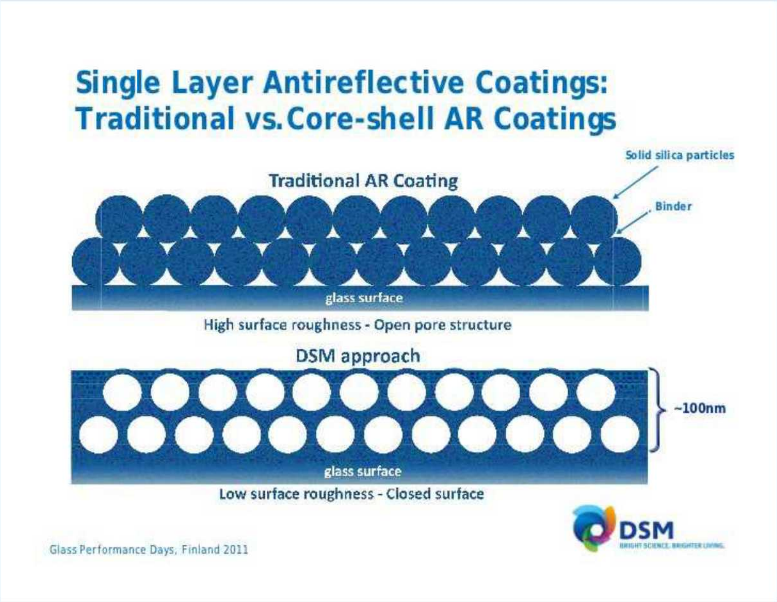


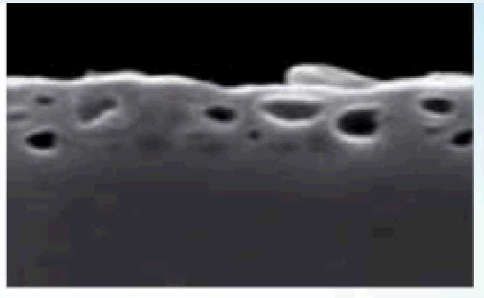


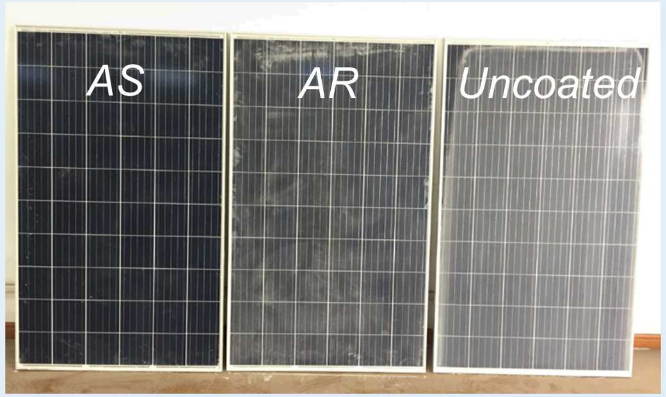
King and Robinson, 2019 PVSC

Top Sheet Coatings

- **Anti-reflection coatings**
  - Materials:
    - Sol-gel nano-porous particles
    - DSM's KhepriCoat uses hollow core polymer particles with a silica shell
  - Functional Requirements:
    - ~3% increase in STC flash rating (normal incidence)
    - 3.5% – 5% increase in energy from fielded systems (diffuse and off-angle incident light)
- **Anti-soiling coatings**
  - Materials:
    - Metal-oxide nanoparticles with polymer binder
  - Functional Requirements:
    - Resist soil accumulation
    - Hydrophobic – relies on water droplet formation, droplets carry away particles
    - Hydrophilic – enhances water sheeting



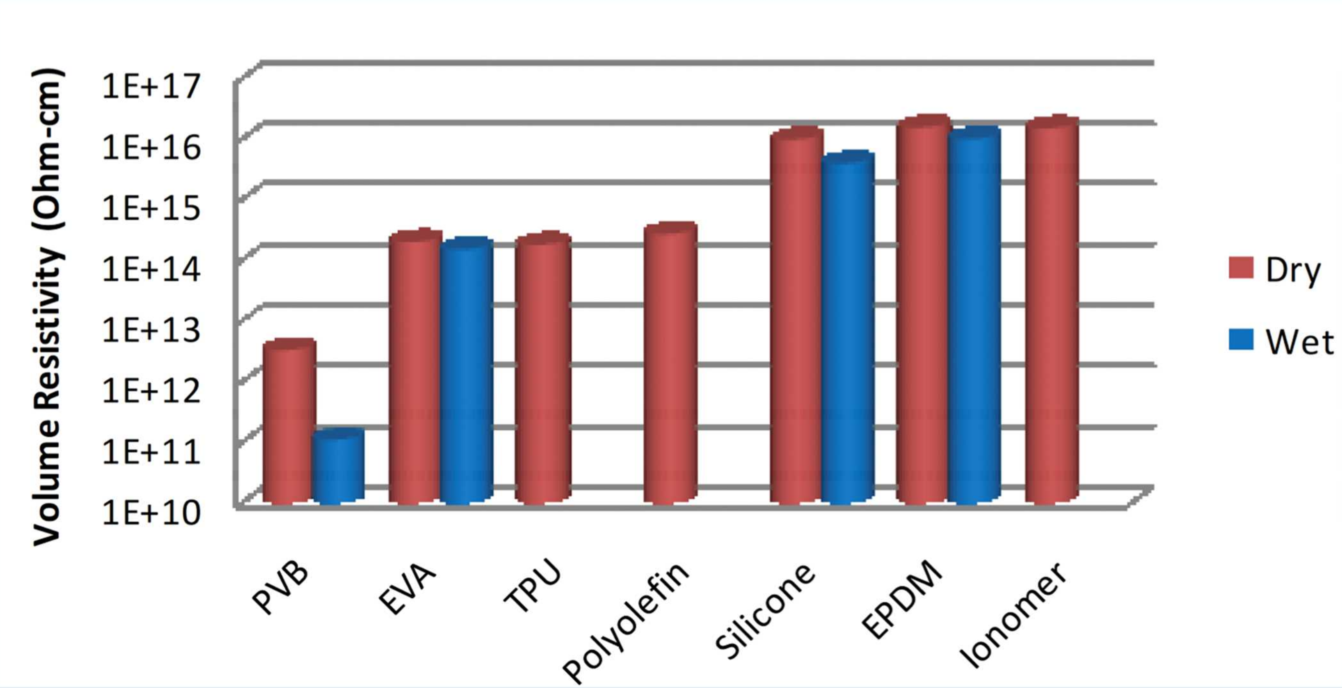

SEM cross-section of KhepriCoat



DSM Study in Gobi Desert

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**
  - Broad class of ethylene copolymers
- **Silicones**
  - Many options have been researched including curing and non-curing
- **Ionomers**
  - Reduce time/temperature of lamination step



From Wenchao Li et al, 2014

Encapsulant Additive Compounds

- **UV-stabilizers & absorbers –** absorb UV and dissipate as heat
- **Radical scavengers –** antioxidants that remove peroxy, alkoxy, hydroxyl, and alkyl radicals
- **Crosslinking agents –** curing agents that help to form covalent bonds between polymer molecules
- **Adhesion promoters –** coupling agents (typically organosilanes) that help dissimilar materials to bond (e.g. glass, PV cells, encapsulants, backsheets).

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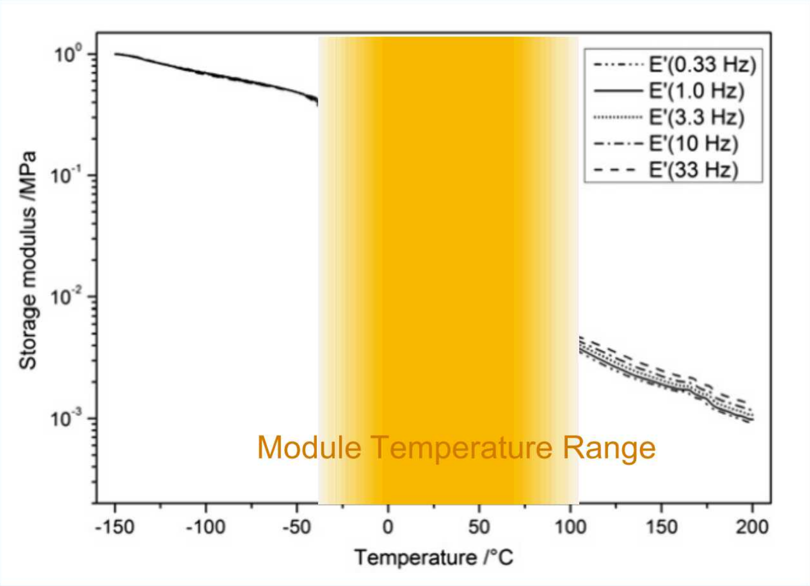
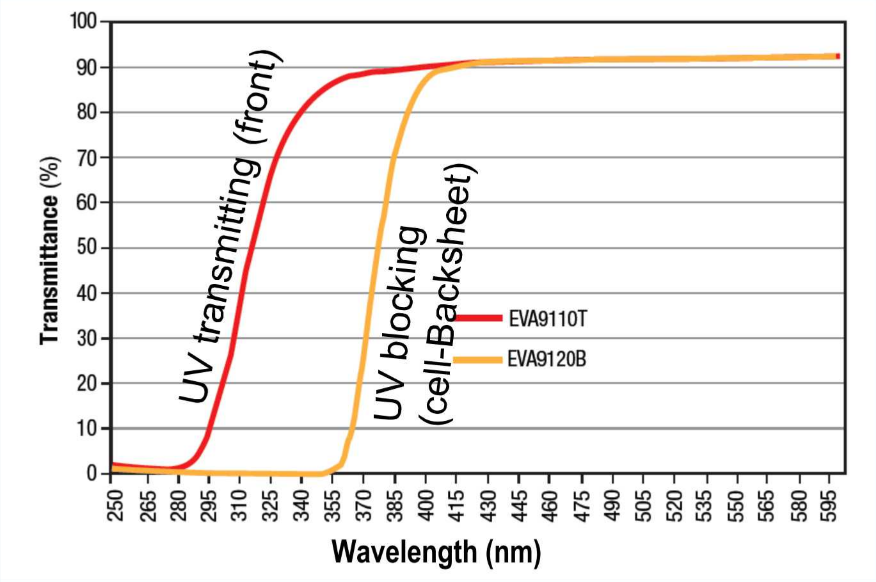
Encapsulant Requirements

- Low light absorption and a refractive index that minimizes interface reflections
- High thermal conductivity to reduce operating temperature
- Protect cells and metallization from water
- Protect cells from mechanical stresses
- Maintain electrical insulation
- Provide adhesion between layers of the laminate



(W Stark, et al., 2011)

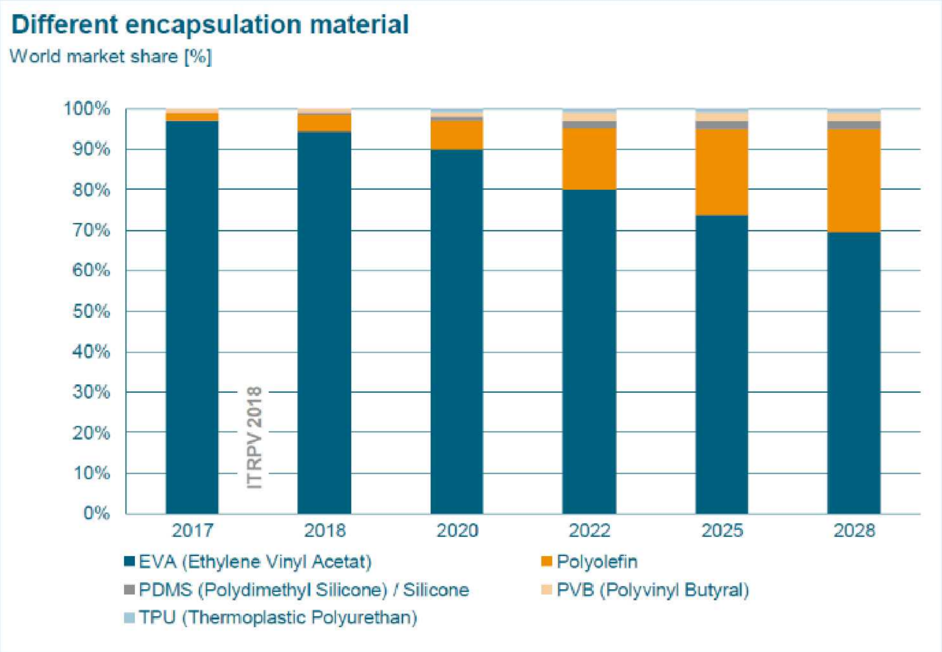


(3M EVA Tech. Data, 2013)

Encapsulant Properties

- Volume resistivity
- Moisture volume transmission rate (MVTR)
- Light transmission (%)
- UV cutoff wavelength
- Thermal conductivity
- Young's modulus
- Glass transition temperature
- Curing class (slow, fast, ultra-fast, etc.)

EVA vs. Polyolefin



ITRPV, 9th ed. 2018

- Polyolefin encapsulants have increased their market share, targeting particular drawbacks of traditional EVA
- Higher volume resistivity and lower WVTR protect cells against potential induced degradation (PID)
- Lower T_g protects cells from mechanical stress to lower operating temperatures

	ENGAGE™ PV POE-based Film	EVA-based Film
Volume Resistivity, ohm-cm @ 23°C (73.4°F)(2)	≥2.64E+16	1.32E+14
Leakage Current, picoamp @ 23°C (73.4°F)	19	3,795
Dielectric Strength, kV/cm	601	444
Water Vapor Transmission Rate (WVTR), g/m2-day @ 38°C (100°F)(3)	3.3	34
Thermal Conductivity, W/m-K	0.291	0.246
Optical Transmission, %(4)	>92%	93
Refractive Index(2)	1.475	1.455
Glass Transition Temperature (Tg), °C (°F)	-45 (-49)	-35 (-31)

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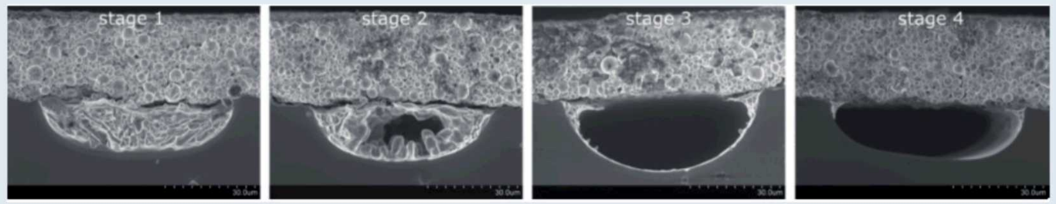
PV Cell and Metallization

- Materials: Ag, Al, Ni/Cu
- Methods:
  - **Screen Printing:** Ag printing, Contact anneal at 740-800 °C – Most common (Less precision and cheaper)
    - Positional accuracy is limited due to screen stretching
    - Highest optical, transmission, and recombination losses
  - **Lithography:** Application of photoresist, evaporation of metal seed layer, plating to thicken fingers, FGA at 400 °C – Precise but expensive
  - **Laser grooving:** Ni plating + NiSi formation, Cu plating + Ad dip, FGA at 400 °C
    - Precise but expensive (longer process times)
    - Environmental concerns from metal bath waste
- PERC cell metallization requires creating a local BSF
  - Deep AL-BSF minimizes recombination

- Functional Requirements:
  - Low resistance contacts with cell
  - Low cost materials and fast process
  - High aspect ratio (line height to width)



Good contact | Void | Shallow BSF

(Balaji et al., 2019)

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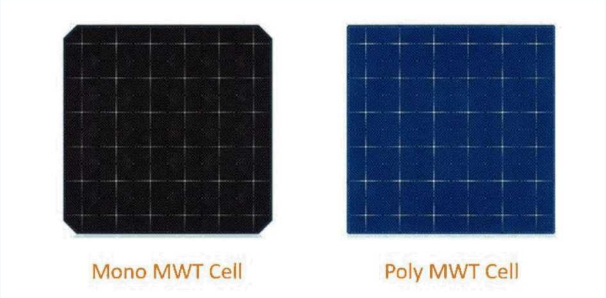
PV Cell to Cell Interconnection

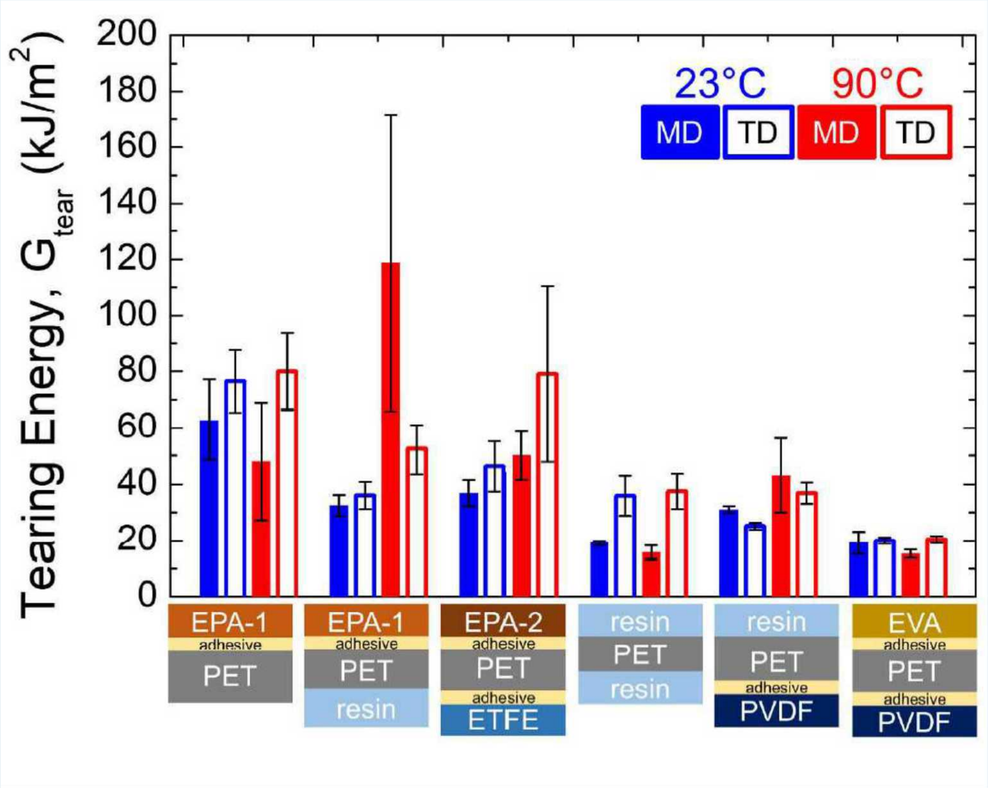
- **Soldered Busbars**
  - Trend toward higher # BBs, reducing Ag and cell finger area
  - Process control is important (bad solder bonds = common failure mode)
- **Multiwire (SmartWire)**
  - Wires coated with low melting temp alloy, connection made during lamination. Bus bars on the front and back are not needed.
  - Reduces Ag, cell cracks, stress on wafer (low temp processing)
- **Shingling**
  - Optimal area utilization, Low ohmic losses (up to 10% power gain)
  - Low processing temperatures, Lower operating temperatures
  - Improved aesthetics, Rounded cell corners are an issue
  - Cell fingers and aspect ratio should be optimized to maintain good FF.
- **Metal Wrap Through (MWT)**
  - Holes drilled in cells, filled with metal to bring front contacts to back.
  - Backsheet with conductive circuit pattern attached with ECA and then laminated.

- **Functional Requirements**:
  - Low resistance contacts between cells
  - Low cost materials and fast process
  - Minimize shading losses
  - Reliability to stresses



Backsheet Requirements

- Electrical Isolation
  - Safety from electrical shock
  - Protect cells and metallization from corrosion
- Reflects light for enhanced performance
  - A pseudo-square cell can experience about 2% improvement by using a white vs black backsheet.
- Backsheets do not appreciably keep moisture out
  - Typical backsheets allow equilibration with a timescale of days, not years
  - Diurnal thermal cycling can move moisture in and out of the package



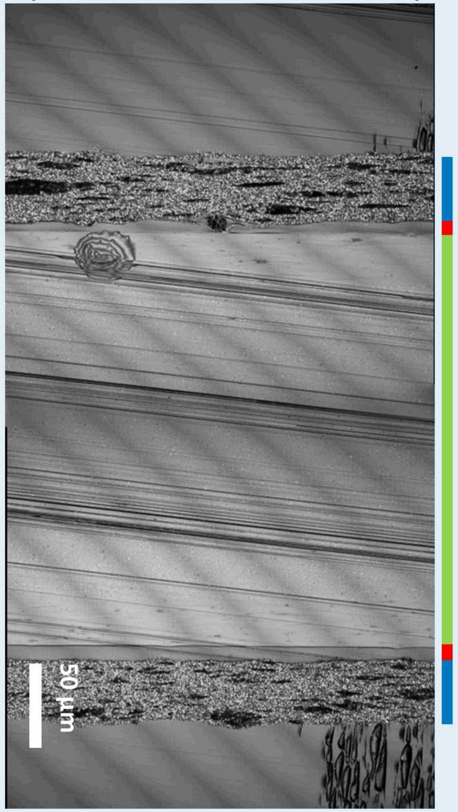
(PK Yuen, et al., 2019)

- Additive compounds:
  - Similar to encapsulant materials, need stabilizers and adhesion promoters
  - Flame retardants
  - Pigments

Typical Backsheet Materials

- Generally a multi-layer structure bound together by adhesives or co-extruded
- Materials:
  - **PET** (polyethylene terephthalate)
  - **TPT** (Tedlar-PET-Tedlar where Tedlar is a polyvinyl fluoride)
  - **PVDF** (polyvinylidene difluoride)
  - **Polyamide**

Tedlar/PET/Tedlar
(TPT, **most common**)

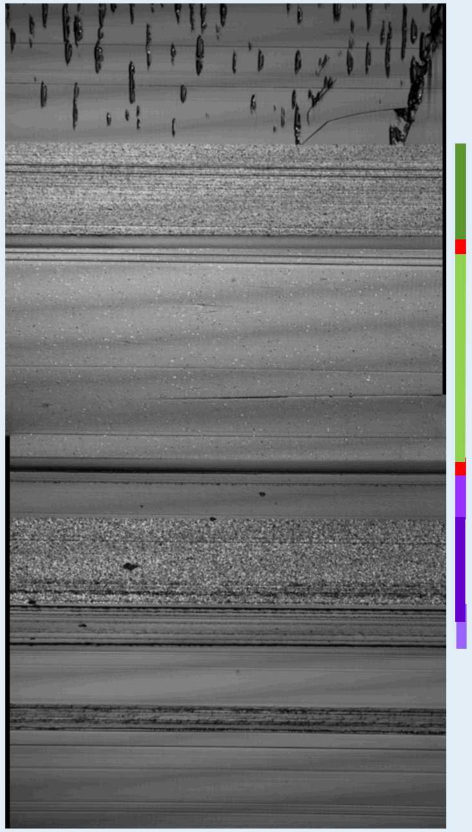


Tedlar
Adhesive
Tie layer

PET

Adhesive
Tie Layer
Tedlar

PET/PET/"E" (PPE)



Pigmented PET outer Layer
Adhesive Tie layer

Clear PET Inner Layer

Adhesive Tie Layer
Inner Low VA-EVA
Pigmented Low VA-EVA
Outer Low VA-EVA

From Mike Kempe, 2019 DuraMAT Workshop

Junction Box, Cabling, and Connectors

Functional Requirements:

- Bring electricity from the module while keeping moisture and dirt out.
- Electrical isolation, Comparative tracking index (CTI)
- UL-94 flammability rating, UV protected.
- Housing for bypass diodes or power electronics
  - Must withstand temperatures near 100°C (in bypass condition) RTI=relative temperature index
- Durability and abrasion resistance (wind)
- Easy and quick installation and service
- Adhesives must be reliable and durable.

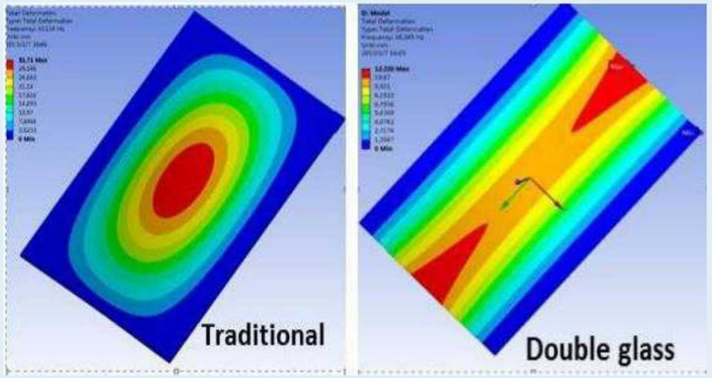
Materials and Design

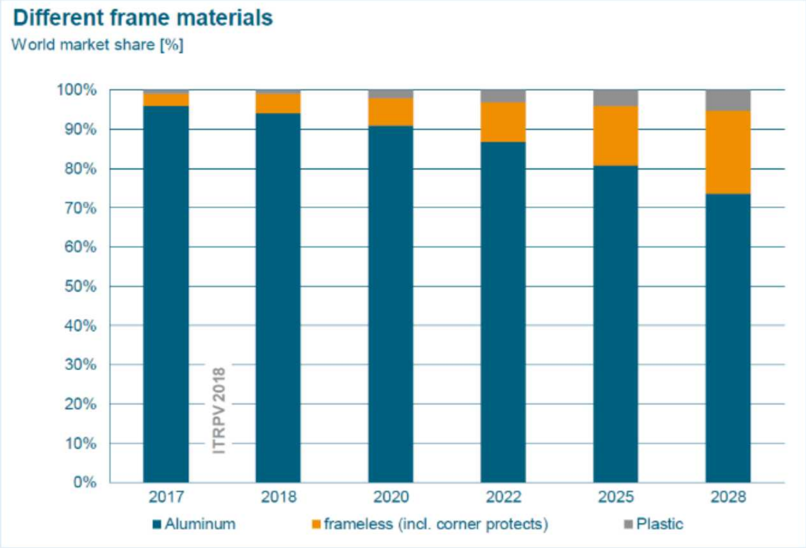
- Polyphenylene (PPO) – RTI ~100 °C
- Polyamide 66 resin w/glass filler (Dupont's Zytel) RTI ~130 °C, CTI ~250V
- Single → multiple
- Potted in polymer resin

Frame and Adhesives

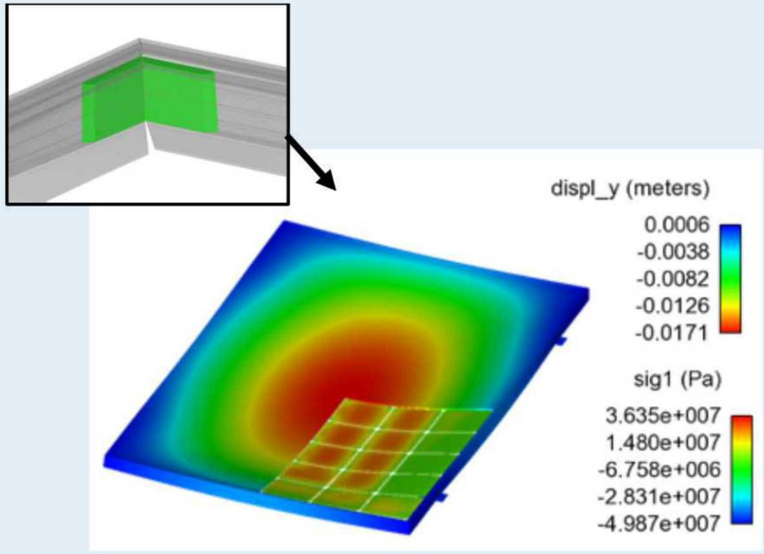
Frame Functions

- Structural support and strength
    - If module is frameless this support is still necessary and must be achieved from racking
- Attachment points for mounting
- Protection during shipping, handling, and installation
- Module is attached to frame with adhesives or tape
    - Adhesive properties and placement influences stress on module and cells





Sandia Module Mechanical Model

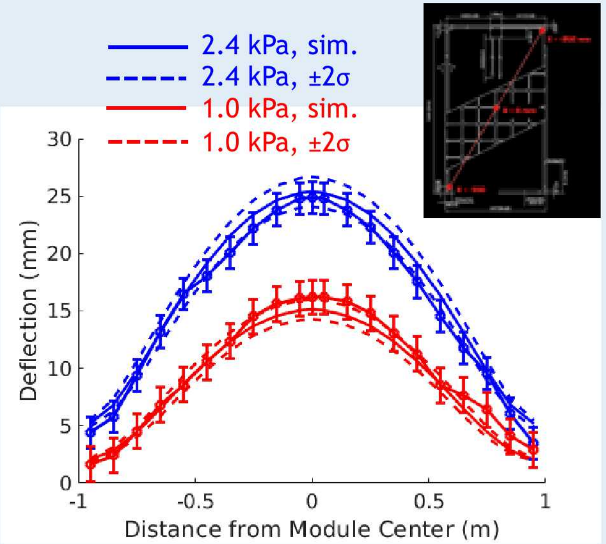


(J. Hartley, DuraMAT, 2019)

Deflection Sensitivity

1.0 kPa		2.4 kPa	
Parameter	|R|	Parameter	|R|
Edge tape modulus	0.630	Glass modulus	0.561
Glass modulus	0.532	Edge tape modulus	0.553
Edge tape Poisson's	0.336	Edge tape Poisson's	0.361
Glass thickness	0.286	Glass thickness	0.321
Encap. thickness	0.132	Encap. thickness	0.111

Parameters highly correlated to module deflection



Predicted deflection vs. load with parametric uncertainty

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Summary and Conclusions

- PV modules are comprised of **many components**, each with their own set of requirements.
- Less attention is paid to **material interactions at interfaces** between different materials
  - Thinner, lighter materials → stress transfer to cell → cell cracking
  - Interaction of cell AR coating with encapsulant →Adhesion degradation → delamination
  - UV degradation of EVA → acetic acid → corrosion
- Developing new and innovative materials for PV requires a **careful and complete systems analysis of possible interactions**.

Thank you