Types of Encapsulant Materials and Physical Differences Between Them

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This presentation does not contain any proprietary or confidential information.
Purposes of Polymer Materials in PV

Helps Protect Cell Materials From Environmental Stress
  – Must Provide Good Adhesion.
  – Resistant to Heat, Humidity, UV Radiation, and Thermal Cycling.

Electrical Isolation
Control, reduce, or eliminate moisture ingress.

Optically Couples Glass to Cells
  – High Photon Transmission.

Cost Must Be Balanced With Performance.
Outline

Encapsulant Chemistry
Optical Transmission
Electrical insulation
Moisture ingress
Encapsulant Materials Structures

- Ionomer
- Thermoplastic Polyurethane (TPU)
- Polyvinyl Butyral (PVB)
- Ethylene Vinyl Acetate (EVA)
- Polydimethyl Silicone (PDMS)
Early PV Modules Used PDMS

EVA Film Composition

- **Ethylene Vinyl Acetate (EVA, 96% to 98%)**
- **Hinder Amine Light Stabilizer (HALS, 0.1% to 0.2%)**
  Decomposes Peroxide Radicals
- **Decomposes Peroxide**
  (1% to 2%)
  Cross-Linker
- **Benzoltriazole (0.2% to 0.35%)**
  UV Absorber
- **Trialkoxy Silane (0.2% to 1%)**
  Adhesion Promoter
- **Phenolic Phosphonite (0.1% to 0.2%)**
  Peroxide Decomposer/
  Radical Scavenger

The PDMS Samples Did Not Degrade

Exposure of encapsulant materials to 42 UV suns at 80°C to 95°C. Samples between 3.18mm low Fe non-Ce glass.

EVA Has Good Optical Transmittance

<table>
<thead>
<tr>
<th>Encapsulant</th>
<th>Transmission to Cells through 3.18 mm glass and 0.45 mm Encapsulant</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Momentive RTV615</td>
<td>94.5 ± 0.3</td>
<td>PDMS, Addition Cure</td>
</tr>
<tr>
<td>Dow Corning Sylgard 184</td>
<td>94.4 ± 0.3</td>
<td>PDMS, Addition Cure</td>
</tr>
<tr>
<td>Dow Corning 527</td>
<td>94.4 ± 0.3</td>
<td>PDMS, Addition Cure</td>
</tr>
<tr>
<td>Polyvinyl Butyral</td>
<td>93.9 ± 0.4</td>
<td></td>
</tr>
<tr>
<td>EVA</td>
<td>93.9 ± 0.4</td>
<td></td>
</tr>
<tr>
<td>NREL Experimental</td>
<td>93.4 ± 0.4</td>
<td>Poly-α-olefin</td>
</tr>
<tr>
<td>Thermoplastic Polyurethane</td>
<td>93.3 ± 0.3</td>
<td></td>
</tr>
<tr>
<td>Thermoplastic Ionomer #1</td>
<td>92.3 ± 0.4</td>
<td>Copolymer of Ethylene and Methacrylic acid</td>
</tr>
<tr>
<td>Dow Corning 700</td>
<td>91.7 ± 0.3</td>
<td>PDMS, Acetic Acid Condensation Cure</td>
</tr>
<tr>
<td>Thermoplastic Ionomer #2</td>
<td>88.4 ± 0.4</td>
<td>Copolymer of Ethylene and Methacrylic acid</td>
</tr>
</tbody>
</table>

Solar photon-weighted average optical density determined from transmittance measurements through polymer samples of various thickness (1.5 to 5.5 mm) between two pieces of 3.18 mm thick Ce doped low Fe glass.
Electrical Conductivity Varies Greatly

Polymer Resistivity

Resistivity measured at 22°C using alternating polarity DC current a +/- 700V. “Wet” samples were soaked in water at 40°C.
PVB, 1000 Times more Conductive than EVA

Figure 2. Bulk Electrical Conductivity of PVB and EVA

Leakage Current Correlates With Performance loss

Figure 8. Power Output Reductions Versus Accumulated Unit Charge Transfer for α-Si Cells

Backsheets Protect Against Electrical Shock

Framed Silicon Wafer Module

- Glass
- EVA
- PET
- PVF

Cells - Al Frame

Polyethylene Terephthalate (PET)

Poly Vinyl Floride (PVF)

PET provides Electrical insulation.

PVF provides UV stability
Time Constant for Water Ingress

\[ C(t) = C_o \left(1 - e^{-\frac{WVTR_{B,Sat} t}{CSat,EVA l_{EVA}}} \right) \]

\[
\tau_{1/2} = 0.693 \frac{CSat,EVA l_{EVA}}{WVTR_{B,Sat}} = 0.693 \frac{\text{Amount of water EVA can hold}}{\text{Rate of moisture ingress}}
\]

\[ l_{EVA} = 18 \text{ mil, } T=27 \, ^\circ\text{C, } C_{Sat,EVA}=0.0022 \, \text{g/cm}^3 \]

\[
\begin{array}{c|c|c|c|c}
\text{PVF} & \text{ETFE} & \text{PVF/PET} & \text{PET} & \text{PCTFE} \\
\hline
0.0741 & 0.223 & 0.457 & 1.78 & 6.87 (day)
\end{array}
\]

For \( \tau_{1/2}=20 \text{ years need } 10^{-4} \, \text{g/m}^2/\text{day} \)

Even a Glass/Glass Module Will Let in Moisture

Finite element analysis using meteorological data from Miami Florida 2001

Dissolved Water (g/cm³)

Distance X from edge (cm)

X=0

X=20

H₂O

Glass

EVA

Glass

H₂O

Increasing Months

Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Edge Seals Can Keep Moisture Out

Schematic of module edge

H₂O → Glass → Seal → Encapsulant → Glass

Schematic of Test sample

H₂O → Glass (3.18 mm) → Butyl Rubber (0.3 mm) → Ca (100 nm) → Glass (3.18 mm)

PIB test sample after 3500 h at 85°C and 85% RH

50 mm → 50 mm
Conclusions

Packaging materials are formulated to:

- Resist to Heat, Humidity, UV Radiation, and Thermal Cycling.
- Provide Good Adhesion.
- Optically Couples Glass to Cells
- Electrically isolate components
- Control, reduce, or eliminate moisture ingress.

Choices made by Balancing cost With Performance.