Accelerated UV Photothermal Degradation of Polymer Encapsulants used in Low Concentration PV (LCPV)

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Design for LCPV Module Reliability

polymeric components

• **UV stability of polymers under concentration**
  » Accelerated UV conditioning (close to concentration factor)
  » UV Spectral matching
  » Temperature management

• **Dielectric stability of polymers**
  » LCPV module designs involve grounded metal for thermal management
    - Accelerated testing requires knowledge of E-field based polymer degradation

• **Thermal stability of polymers**
  » LCPV can be required to operate at higher temperatures (~120°C) for cogeneration / thermal storage
    - Accelerated testing can be achieved with high temperature ovens and/or running actual system under stagnation conditions
  » LCPV can be required to cycle between wider temperature ranges and at higher frequency than flat plate solar modules
    - Accelerated via rapid thermal cycling with higher temperature extremes
Accelerated UV conditioning

- **UV0834**
  - UVA Enhanced Metal Halide Lamp 600W medium pressure
  - Can achieve 150-200mW/cm² UV flux (~30-40 suns of UV)
    - Measured between 320nm – 390nm using a UV flux meter
  - Use of low-Fe glass screen to achieve better spectrum matching
Solar spectrum from reflector (silvered mirror) was obtained directly at receiver exposure plane using a calibrated spectrophotometer/fiber optic receptor with a 5% aperture.

- Measurements taken at/near solar noon at 37.39° Latitude during peak of summer

In this accelerated testing, the goal was to match UV spectrum of indoor light source with the light beam from reflected surface (NOT just to AM1.5D)

- UVB is considerably attenuated by the mirror and, in effect, has a closer spectral match to the metal halide light source than AM1.5D
- Still a bit more UVB (~300nm) in glass filtered metal halide light source than experienced in field conditions...
Sample Construction

- Encapsulant and superstrate match product construction
- Backside glass is necessary to quantify optical transmission loss
- Degradation mechanisms will be different than what is typically observed in glass/glass or glass/cell/backsheet type constructions due to front surface breathability
Experimental Overview

• Looked at a library of commercially available polymeric encapsulants
  » EVA, non-EVA alternatives

• Placed identical samples on chiller plates vs. no chiller plates at locations under lamp where UV flux was similar
  » Provided comparison of degradation rates at two temperature values (55°C vs. 90°C)

• Carried out exposure for over 4,700hrs approaching many years of simulated UV degradation in the field for LCPV application
  » UV flux was measured at each sample location in order to plot degradation as a function of total UV dose
    - As a result, every sample has been accelerated to a slightly different extent
Transmission Loss Curves
EVA “hot” (90°C) vs. “cold” (55°C)

- Total UV Dose for the EVA samples, specifically, is over 7,500kWh/m² (160mW/cm² flux)
  » One year in Arizona on a single-axis tracker ~100kWh/m² of UV at 1-sun illumination
- Loss of UV absorbers happens within the 1st 1000hrs of exposure
  » typical for most samples tested which have UV absorbers/stabilizers
- Rate of transmission loss is severely retarded by effect of photobleaching.
  » If this were a glass/glass sample, the level of EVA browning would have occurred in less than 1000hrs
- Difference in degradation between two temperature extremes is significant
Summary of encapsulant degradation via solar/EQE weighted optical transmission loss

• Equivalent years is simply a calculation of equivalent UV dose at 14X in Tucson, AZ
  » If exponential photon energy weighting is used ($\beta=0.07$), this would add an acceleration factor of 2 to equivalent years shown
      \[ E(\lambda) \sim I(\lambda)\lambda e^{-0.07\lambda} \]
  • Significant difference in degradation rates between “hot” and “cold” samples for most encapsulants tested
“hot” vs. “cold” UV degradation

- All but two of the polymeric encapsulants tested showed significantly enhanced degradation at higher temperatures
- Most extreme set of samples is shown

<table>
<thead>
<tr>
<th>Total UV Dose (kWh/m²)</th>
<th>Eq. Years</th>
<th>&quot;hot&quot; transmission loss</th>
<th>&quot;cold&quot; transmission loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encap A</td>
<td>7065</td>
<td>7yrs</td>
<td>-11%</td>
</tr>
<tr>
<td>Encap B</td>
<td>7065</td>
<td>7yrs</td>
<td>-9%</td>
</tr>
<tr>
<td>Encap C</td>
<td>5652</td>
<td>5.7yrs</td>
<td>(+)1%</td>
</tr>
<tr>
<td>Encap D</td>
<td>5080</td>
<td>5yrs</td>
<td>-60%</td>
</tr>
<tr>
<td>EVA</td>
<td>7536</td>
<td>7.5yrs</td>
<td>-7.50%</td>
</tr>
</tbody>
</table>
Conclusions

• It is a challenge to accelerate UV stresses for polymers used in LCPV applications
  » Spectral matching, temperature management, etc.

• If operating for significant periods over 90°C, only one encapsulant tested is viable for >10X concentration

• If temperatures are managed at no greater than 60°C for majority of field operated life, then several other encapsulant options can be chosen