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 (~120C) 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

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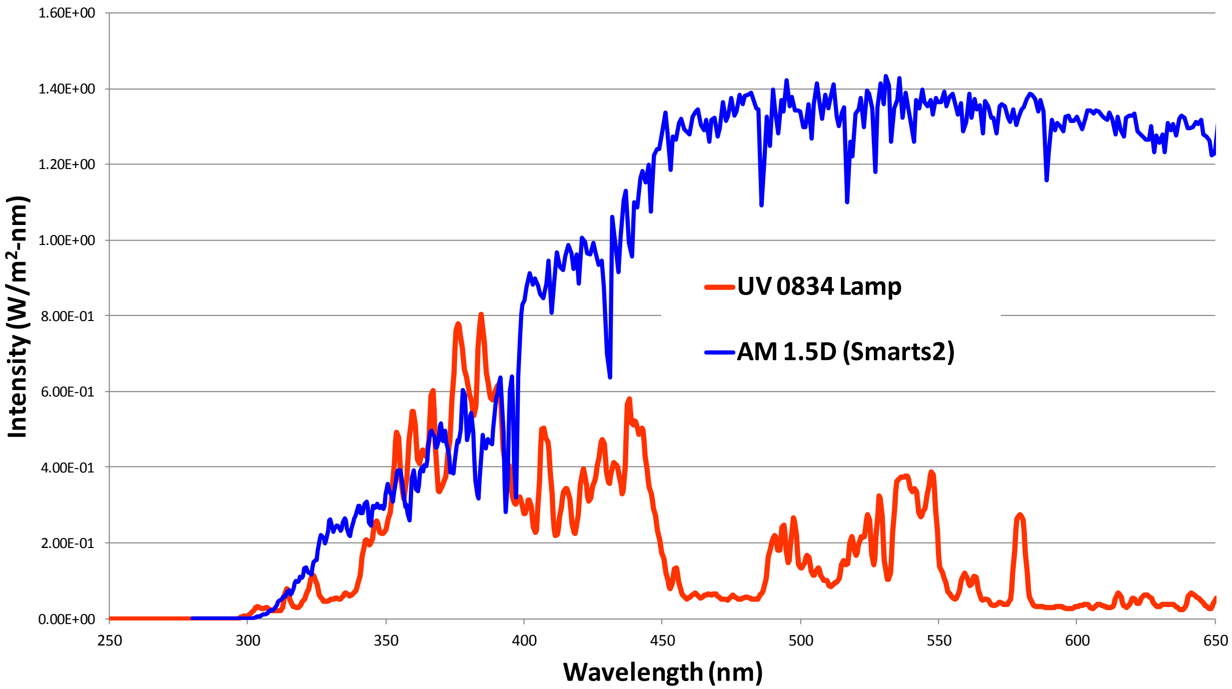
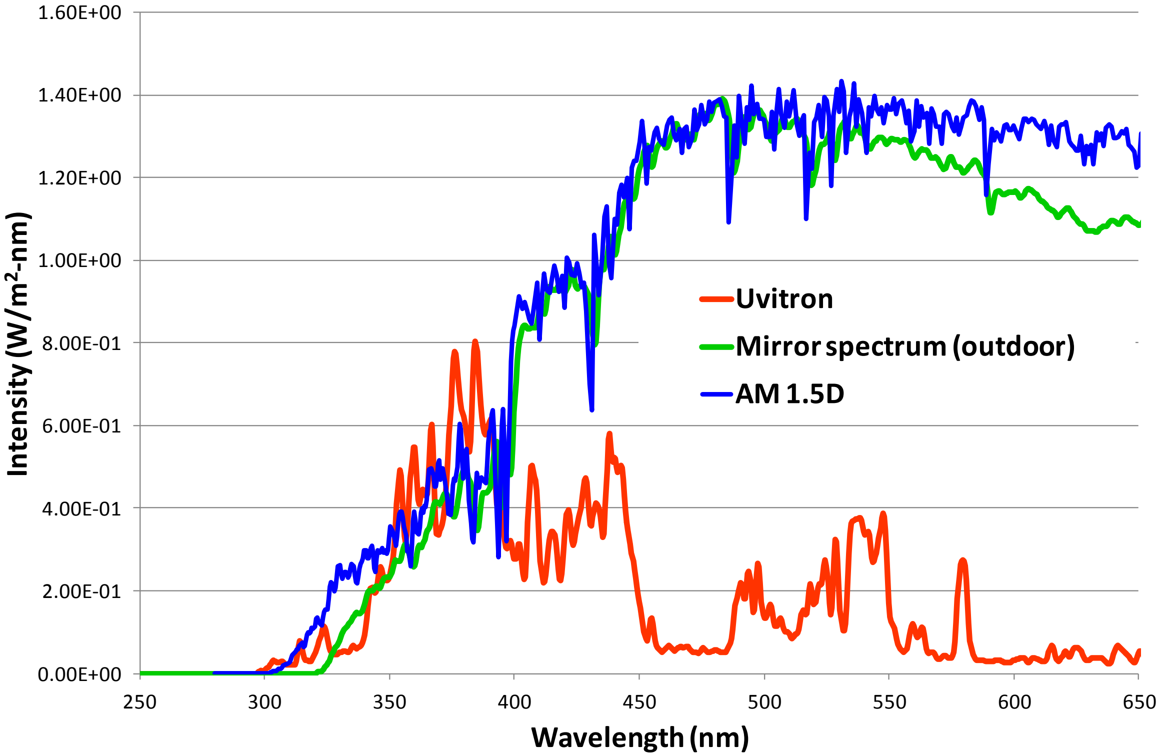
Accelerated UV conditioning



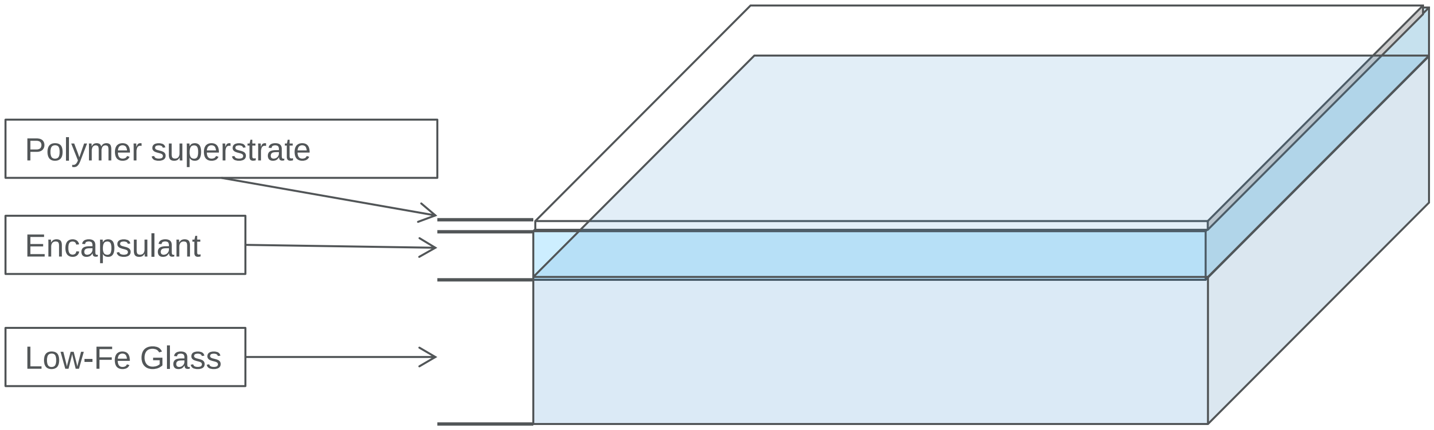
- **UV0834**
  - » UVA Enhanced Metal Halide Lamp 600W medium pressure
  - » Can achieve 150-200mW/cm^2 UV flux (~30-40 suns of UV)
    - \- Measured between 320nm – 390nm using a UV flux meter
  - » Use of low-Fe glass screen to achieve better spectrum matching

UV Spectral 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 37.39º 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



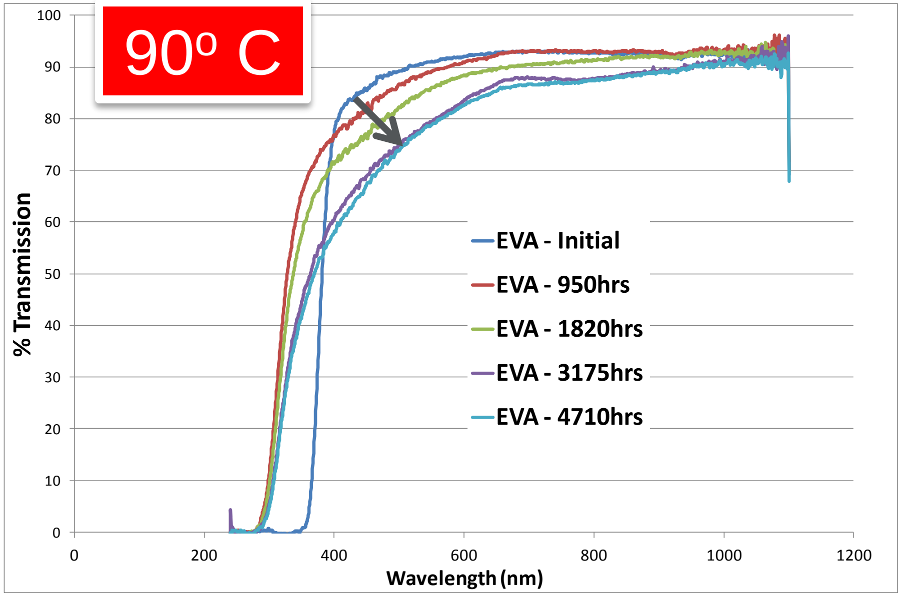
- Encapsulant and superstrate match product construction
- Backside glass is necessary to quantify optical transmission loss
- Degradation mechanisms will be different than what is typically observed in glass/glass or glass/cell/backsheet type constructions due to front surface breathability

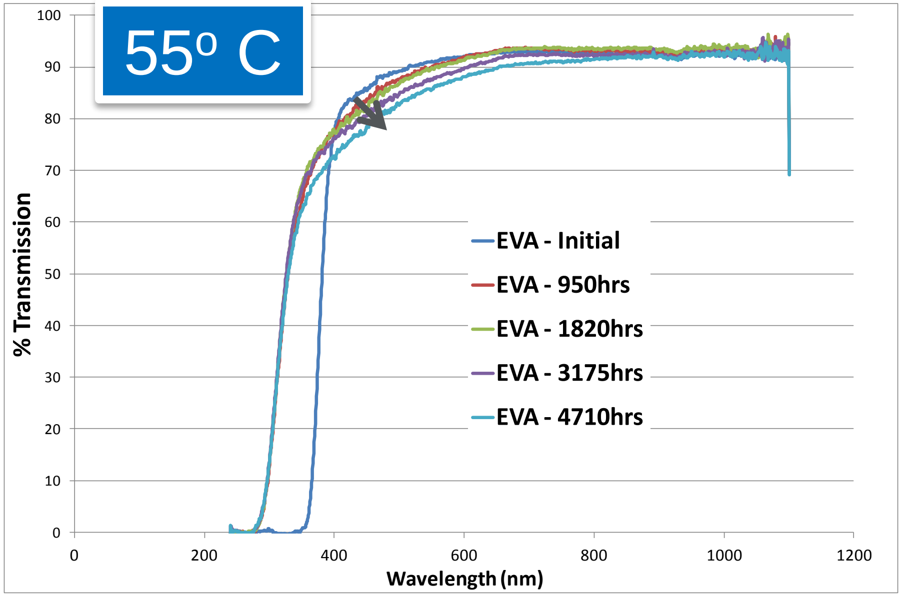
Experimental Overview

- **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^oC vs. 90^oC)
- **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" (90C) vs. "cold" (55C)

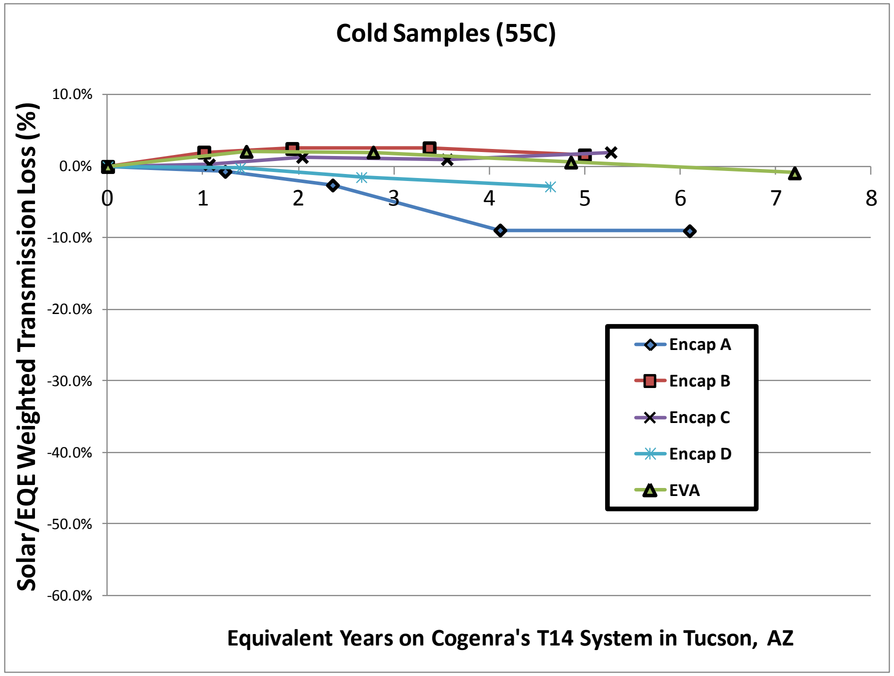


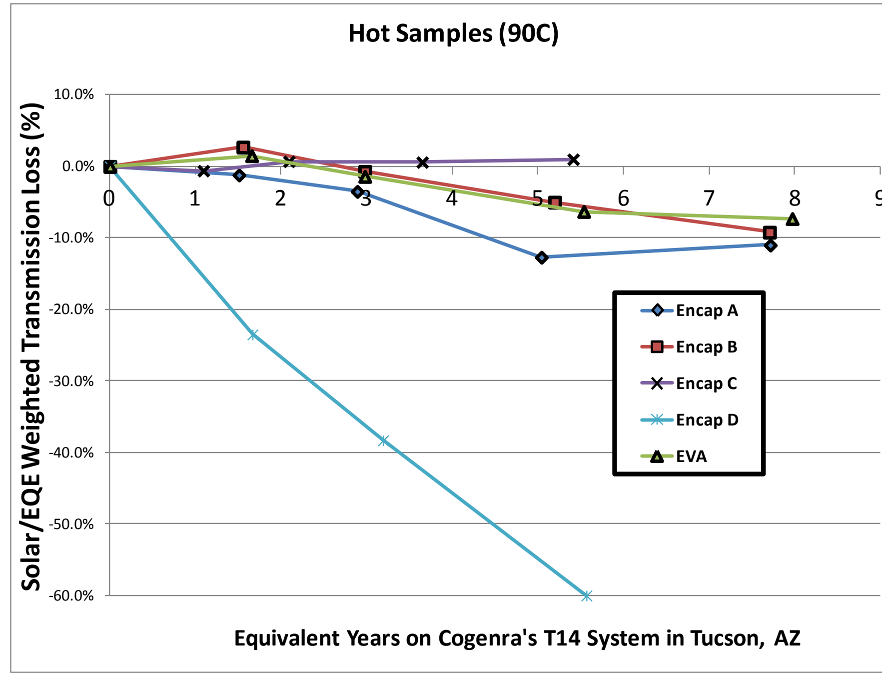


- Total UV Dose for the EVA samples, specifically, is over 7,500kWh/m^2 (160mW/cm^2 flux)
  - One year in Arizona on a single-axis tracker ~100kWh/m^2 of UV at 1-sun illumination
- Loss of UV absorbers happens within the 1st 1000hrs of exposure
  - typical for most samples tested which have UV absorbers/stabilizers
- 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

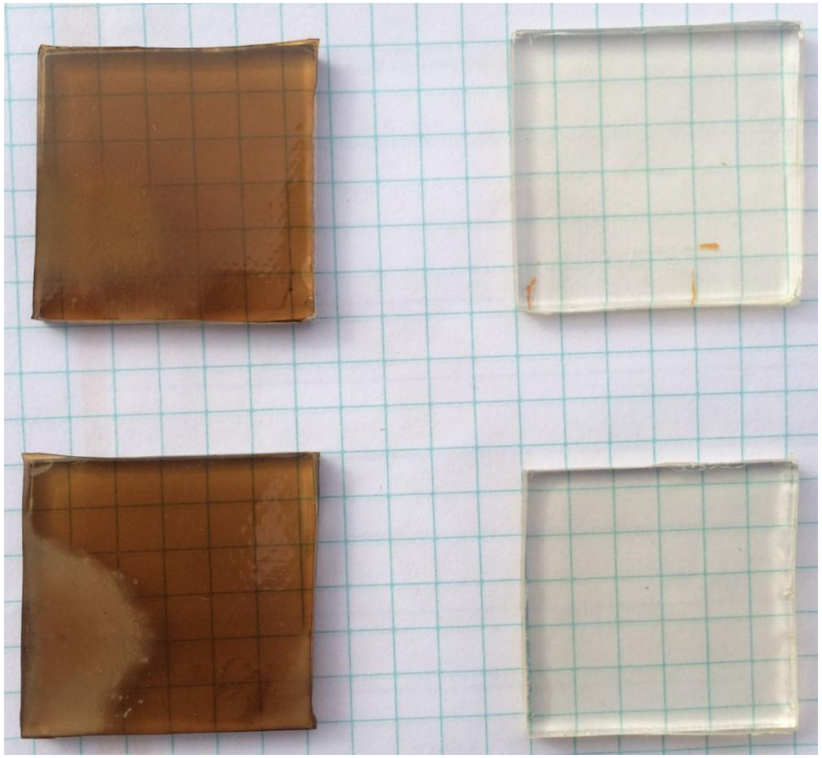
via solar/EQE weighted optical transmission loss





- Equivalent years is simply a calculation of equivalent UV dose at 14X in Tucson, AZ
  - » If exponential photon energy weighting is used (β=0.07), this would add an acceleration factor of 2 to equivalent years shown
    - Kempe, M.D. IEEE PV Specialists Conference 2008, “Accelerated UV Test Methods for Encapsulants of PV Modules” $E(\lambda) \sim I(\lambda)\lambda e^{-B\lambda}$
- Significant difference in degradation rates between “hot” and “cold” samples for most encapsulants tested

“hot” vs. “cold” UV degradation



	Total UV Dose (kWh/m2)	Eq. Years	"hot" transmission loss	"cold" transmission loss
Encap A	7065	7yrs	**-11%**	**-9%**
Encap B	7065	7yrs	**-9%**	**(+)1.6%**
Encap C	5652	5.7yrs	**(+)1%**	**(+)2%**
Encap D	5080	5yrs	**-60%**	**-3%**
EVA	7536	7.5yrs	**-7.50%**	**-1%**

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

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^{o}C, only one encapsulant tested is viable for >10X concentration
- If temperatures are managed at no greater than 60^{o}C for majority of field operated life, then several other encapsulant options can be chosen