UV Degradation Study of Encapsulate Backsheet System for PV Modules Using Metal Halide Lamp

Shuying Yang, Kent Whitfield, Eugene Rhee, SunEdison Belmont, CA

Alelie Funcell, Cherif Kedir RETC, Fremont, CA

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Shuying Yang: syang3@sunedison.com
Kent Whitfield: kwhitfield@sunedison.com
Eugene Rhee: erhee@sunedison.com
Alelie Funcell: alelief@retc-ca.com
Cherif Kedir: cherif@retc-ca.com

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This presentation contains no confidential information.

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Abstract

- The majority of PV module manufacturer's offer a 25 year warranty for their products and some of them are even in the stage of extending their warranty for longer terms. The reliability and durability of the solar modules are highly dependent on the UV stability of the encapsulation system and the protecting backsheet system. Among the environmental factors of temperature, humidity and UV irradiation, it is UV irradiation that is arguably the most difficult stress to accelerate. The commonly used fluorescent UV lamp and Xenon Arc light source typically provide up to about three times natural sunlight irradiance (with irradiation acceleration higher depending on lamp duty cycle). This study considered UV acceleration up to ~ 30X natural sun exposure via a metal halide lamp.
- Activation energy was calculated for different EVA encapsulations (UV transparent version and the traditional fast cure UV stable version) in combination with commercial PET type solar backsheets, using yellowness index as a characterization for UV degradation. The activation energies were found to be about 0.12 to 0.15 ev.
- This low level of activation energy means that the system is easily degraded by UV stress and increasing temperature does not provide significant acceleration. The potential error caused by this large value of irradiance acceleration is discussed as it bears on the finding of low activation energy.
- Validation based upon similarly constructed EVA/Backsheet samples subjected to one-year EMMAQUA exposure (~ 4 to 5X Natural sun concentration in Arizona) is underway and results will be discussed at a future time.

Summary

- Commercial UV transparent and normal Fast Cure EVAs and PET-only backsheet systems were evaluated

- UV aging was performed using Metal Halide Super-UV (SUV) Tester
  - ~30X UV
  - Capable of achieving various yellowness-index values for EVA/backsheet systems in a relatively short time period (~2 weeks)
  - High acceleration may introduce artificial results:
    - The actual degradation effect to be verified by ~5X natural sun testing result (underway)

- Activation energies of the three EVA/PET backsheets systems were obtained
  - 0.12 to 0.15ev
  - For this low level of activation energy, the acceleration factor by increasing testing temperature from 45°C to 90°C is only **1.9X**

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Background/Objective

- Typical Location Annual UV Dosage
  - Florida: 78 KWH/m^2 (280 MJ/m^2)
  - Arizona: 93 KWH/m^2 (334 MJ/m^2)
- 25 Year Typical Location Total UV Dosage
  - Florida: 1944 KWH/m^2 (7000 MJ/m^2)
  - Arizona: 2319 KWH/m^2 (8350 MJ/m^2)
- IEC61215 UV Precon Dosage
  - Precon: 15 KWH/m^2
- UL746C UV Testing Condition
  - 0.35 w/m^2 @ 340nm for 1000 hours
  - Equivalent to ~ 34 KWH/m^2
- IEC **82/747/NP:** Polymeric materials for photovoltaic (PV) modules – Part 2: Frontsheets and backsheets
  - 0.35 w/m^2 @ 340nm for 1000 hours
- In Summary, compared to 25 years UV total dosage, all typical UV tests are low-dose
  - Need to develop an efficient accelerated UV simulation. How much can we accelerate?
- Objective of this Study: Run UV aging at 3 different temperatures (50, 70 and 90°C), and calculate the activation energy for UV aging, using Yellowness Index as the parameter for aging result.

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Sample Field Failure Due to UV Exposure

- ~1.5 Years US Installation Backsheet/EVA Yellowing Picture

Sample Preparation

- Raw Materials
  - Glass: 180mm*180mm*3.2mm, AGC Solite solar glass
  - EVAs: Commercial UV Transparent EVA (UVT EVA) and Normal Fast Cure EVA (FC EVA): 0.5mm thick
  - Backsheet: Commercial single layer PET type
  - Stackup:
    - Sample 1: Glass/FC EVA/FC EVA/PET backsheet
    - Sample 2: Glass/UVT EVA/UVT EVA/PET backsheet
    - Sample 3: Glass/UVT EVA/FC EVA/Backsheet

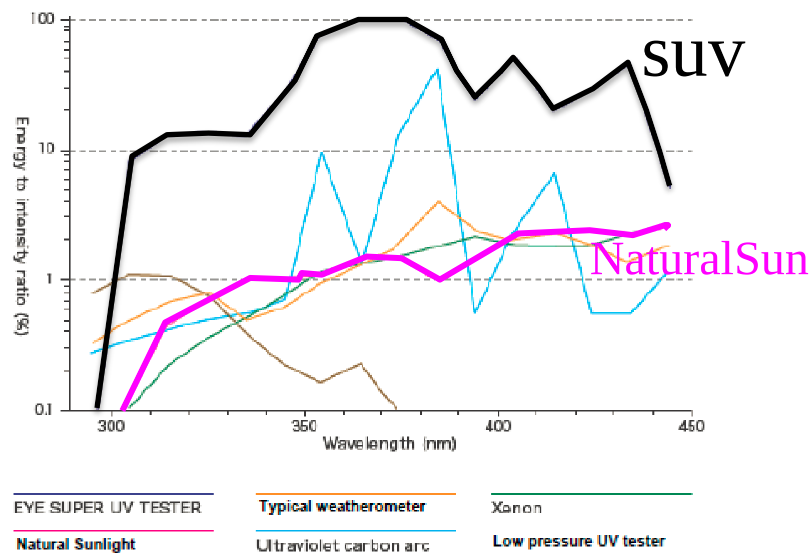
- Lamination Condition
  - 140°C/4min Vacuum/5min Press/90KPa
  - Gel Content: >80%

UV Source: EYE Super UV Tester SUV-W161

- UV Tester @ RETC
  - Iwasaki Electric Corp., Ltd.
    - Lamp: Metal Halide Type
    - ~30X natural sun UV intensity when set to 1500 W/m^2

- UV Aging Setting
  - T: 50°, 70°, 90 °C
  - RH: 50%
  - Intensity: 1500 W/m^2
  - Water spray: 8 minutes every 112 minutes
  - Total Duration:
    - Samples were aged @ 70°C/5 day to reach the target Yellowness Index
    - Then new groups of samples were exposed to 50°C and 90°C for varying duration to reach the same yellowness index for activation energy calculation

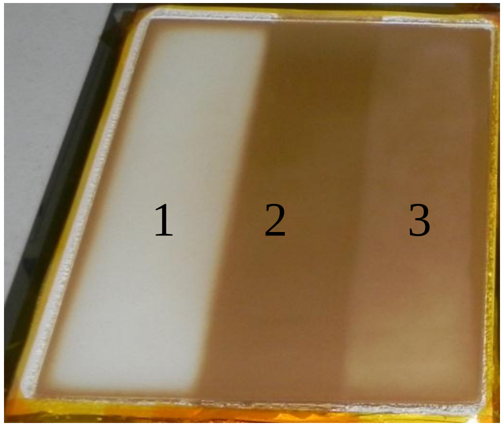
Ratio of energy to intensity by wavelength for different testers



Pictures of Aged Samples

- Fresh Sample

70°C for 120hrs (180kWh/m^2)



- 90°C for 96hrs (144kWh/m^2)

50°C for 240hrs (360kWh/m^2)

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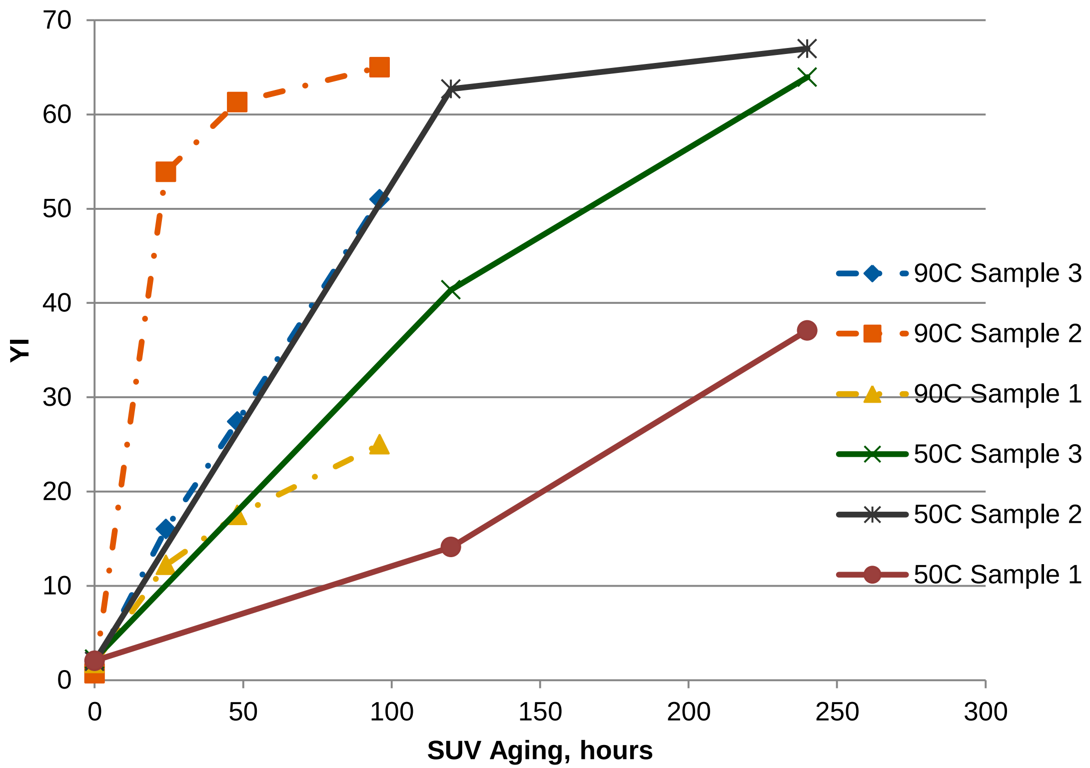
Yellowness Index of the Samples

- 70°C/120hrs YI Result: Used to set YI target for subsequent 50°C and 90°C aging

Testing T	YI
Sample 3	56.4
Sample 2	64.8
Sample 1	25.2

- 50°C, 90°C, See right plot



Activation Energy Calculation

- Time to Failure, assume Arrhenius Relationship

$$TTF = A\exp\left(\frac{Ea}{RT}\right)$$

  - Take log on both side:
  - $$\ln(TTF) = \ln(A) + \frac{Ea}{RT}$$
  - Then by plotting ln(TTF) vs 1/T (Kelvin), we are going to get the slope as Ea/R, where R is the gas constant (8.314 J/mol).
    - Ea= Slope*8.314 J/mol

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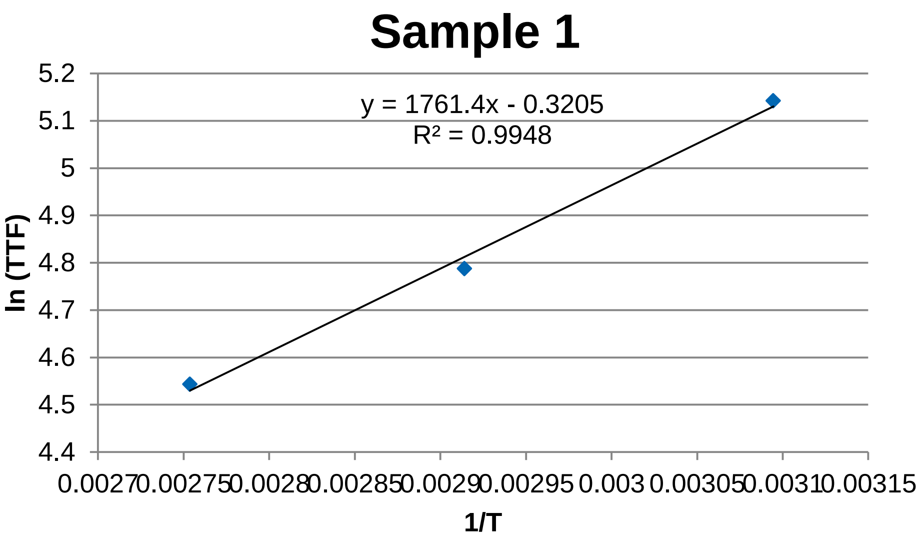
Activation Energy for System 1

- Time to Failure (TTF):

T, C	Time to failure, hrs
50	171
70	120
90	94

- Plotting ln(TTF) vs 1/T:
  - Slope=1761.4
  - Ea=14644 J/mol=0.15eV



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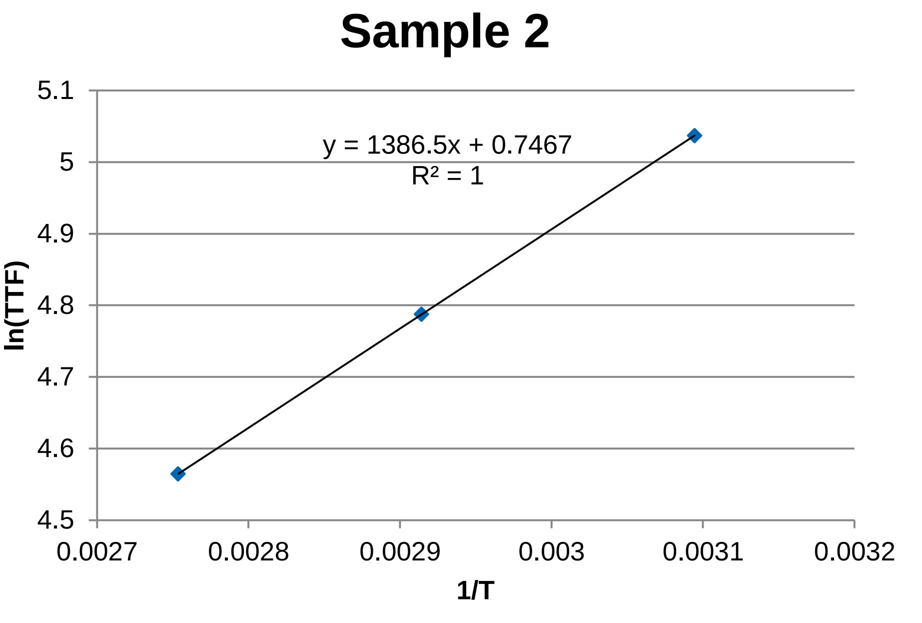
Activation Energy for System 2

- Time to Failure (TTF):

T, C	Time to failure, hrs
50	154
70	120
90	96

- Plotting ln)TTF) vs 1/T:
  - Slope: 1386.5
  - Ea=11527 J/mol=0.12eV



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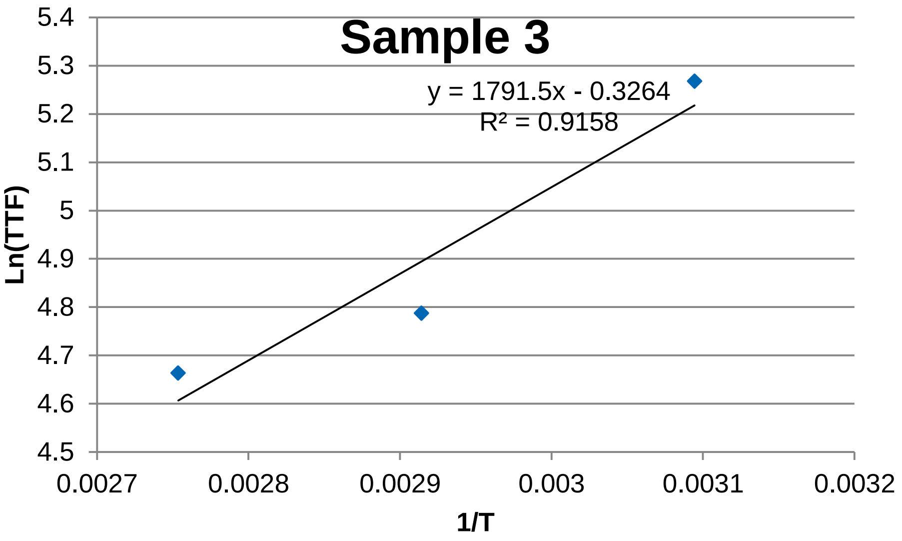
Activation Energy for System 3

- Time to Failure (TTF):

T, C	Time to failure, hrs
50	194
70	120
90	106

- Plotting ln (TTF) vs 1/T:
  - Slope: 1791.5
  - Ea=14895 J/mol=0.15eV



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Acceleration Factor at Elevated Testing Temp

- Assume 45°C is the normal module operating temperature
- The degradation rate is proportional to exp(-Ea/RT)
- Then we can calculate the acceleration factor at elevated T:
  - Acceleration Factor=exp(-Ea/RT)/exp(-Ea/R*(45+273.15))
  - Plugging in 11527 J/mol for Ea from the Sample 2 system, the calculated acceleration factors are tabulated below:

T, C	T, K	exp(-Ea/RT)	Acceleration Factor
45	318.15	0.012803877	
60	333.15	0.015579661	1.2
80	353.15	0.019720556	1.5
100	373.15	0.024339276	1.9

Conclusion

- The activation energy of the different EVA/backsheet system were obtained
  - Glass/UV Transparent EVA/UV Transparent EVA/PET backsheet: 0.12eV;
  - Glass/UV Transparent EVA/FastCureEVA/PET: 0.15eV;
  - Glass/FastCureEVA/FastCureEVA/PET: 0.15eV.

- This extremely low level of activation energy means:
  - These EVA/PET backsheet systems may be easily degraded by UV
  - These EVA/PET backsheet systems' aging are difficult to accelerate by elevating temperature:
    - **Testing at 100°C only gets 1.9X acceleration factor**
    - **This implies that you can not just simply do UV aging at elevated temperature to achieve the acceleration effect, you have to run UV testing at increased duration to achieve aging effect.**

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Conclusion Cont'd

- Former activation study showed that one has to increase UV dosage to achieve UV aging effect
  - Option 1: by increase testing duration with low UV intensity setting
  - Option 2: by increase UV intensity setting with shorter duration
  - Option 3: by slightly increase both UV intensity and duration
- Super UV technology here takes option 2
  - 1500W/m^2 setting for UV range
- Equivalent to ~30X Sun UV. One can easily get relative UV resistance result on the encapsulant/backsheet system choice within one to two weeks.