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NATIONAL RENEWABLE ENERGY LABORATORY

"The Durability of Polymeric Encapsulation Materials for Concentrating Photovoltaic Systems"

David C. Miller[1], Matt Muller[1], Michael D. Kempe[1], Kenji Araki[2], Cheryl E. Kennedy[1], and Sarah R. Kurtz[1]*

1. National Renewable Energy Laboratory (NREL), 1617 Cole Blvd., Golden, CO, USA 80401
2. Daido Steel Co., Ltd. 2-30 Daido-cho, Minami, Nagoya 457-8545, Japan
* David.Miller@nrel.gov

The 7th International Conference on Concentrating Photovoltaic Systems (CPV-7)

(Las Vegas)

2011/04/04 (Monday)

6:00-6:15 pm

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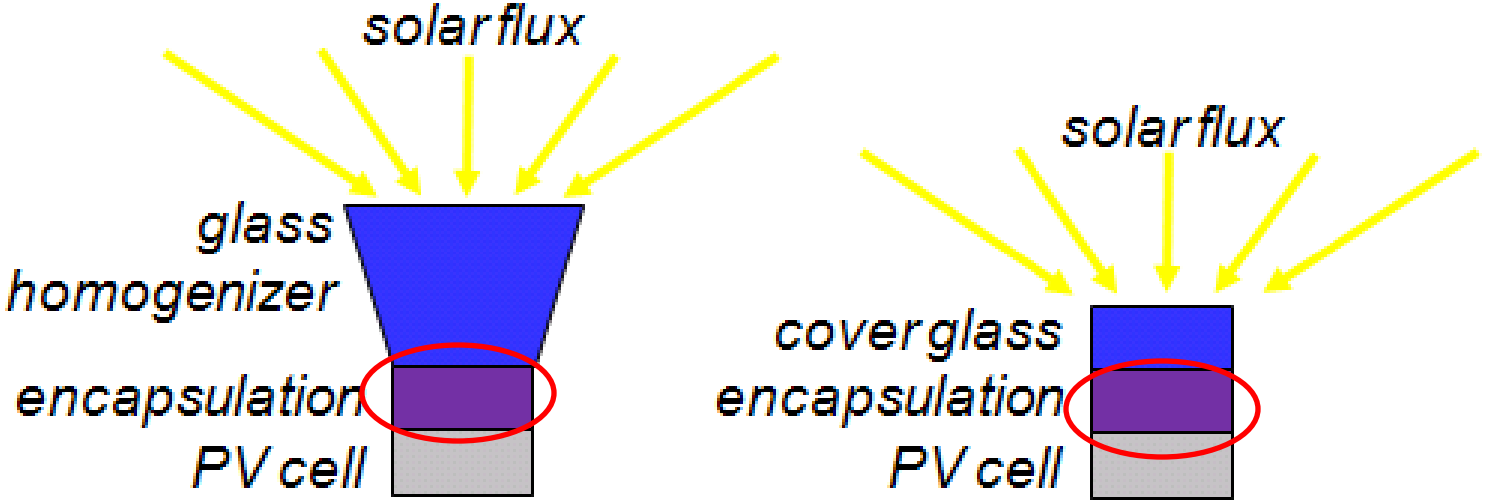
Motivation for the NREL Field Study



cross-sectional schematic of the components near the cell in CPV systems (not to scale)

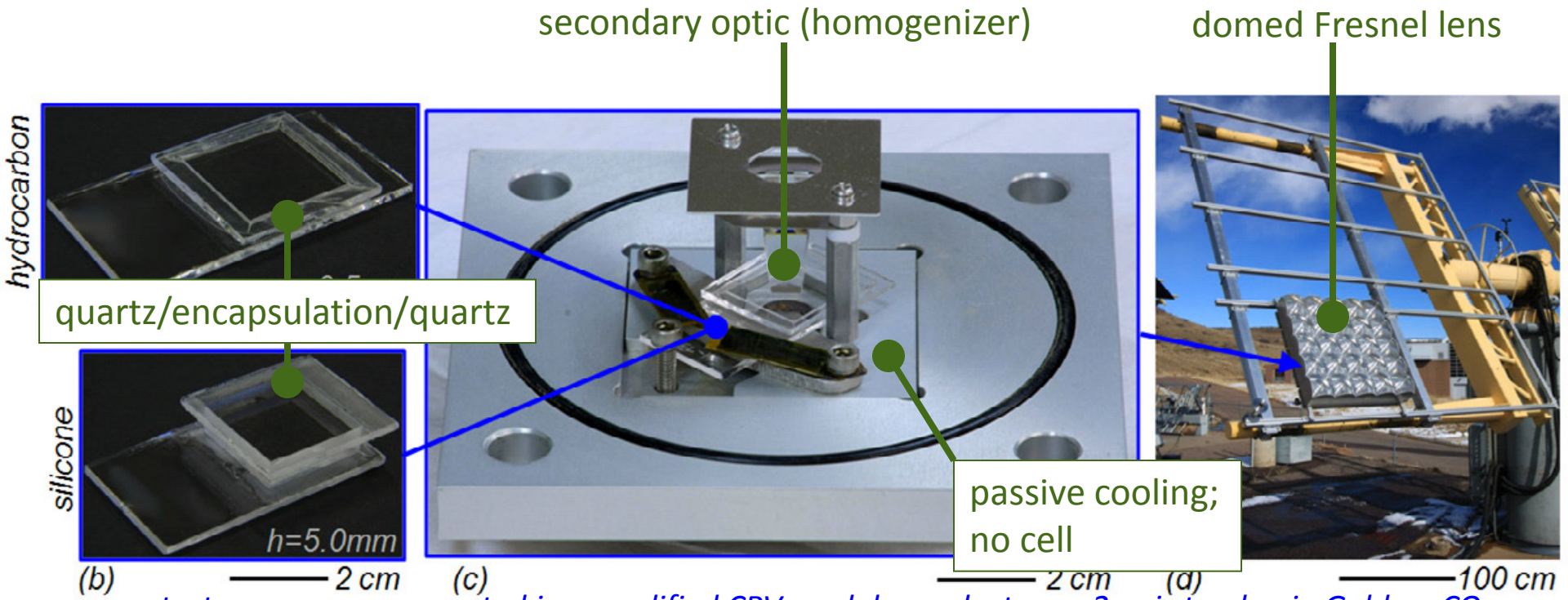
corrosion prevention, optical coupling : CPV systems typically use encapsulation to adhere optical component(s) or cover glass to the cell

encapsulation durability (25 year field deployment) is unknown:

- identify field failure modes
- gain insight related to failure mechanisms
- distinguish between material types
- identify materials for future study (HALT & qualification tests)

Details of the Experiment (Specimens & Apparatus)

	MATERIAL	ON-TEST	IN QUEUE
hydrocarbons (representative types)	EVA	6	2
	ionomer	2	0
	polyolefin	1	1
	PVB	2	0
	TPU	1	2
silicones (representative grades)	PDMS	11	5
	PPMS	2	1
	TOTAL	25	11



test coupons are mounted in a modified CPV module product on a 2-axis tracker in Golden, CO

Details of the Experiment (Measurands & Schedule)

"Continuous" measurements:

ambient conditions (irradiance, temperature, wind…)

fixture temperature (via thermocouple)

Periodic measurements:

→ transmittance ($T[\lambda]$, hemispherical & direct)

mass

appearance (photograph)

⇒ from $T[\lambda]$, calculate: yellowness index (D65 source,1964 10° observer), haze, $\lambda_{cut\text{-}on}$ …

→ fluorescence & RAMAN spectroscopy

Final measurements:

FTIR, NMR

TGA, DSC (polymer physics)

Test schedule:

0, 1, 2, 4, 6, 12, 18, 24, 30, 36 … months

The Field Conditions (Irradiance & Ambient Temperature)

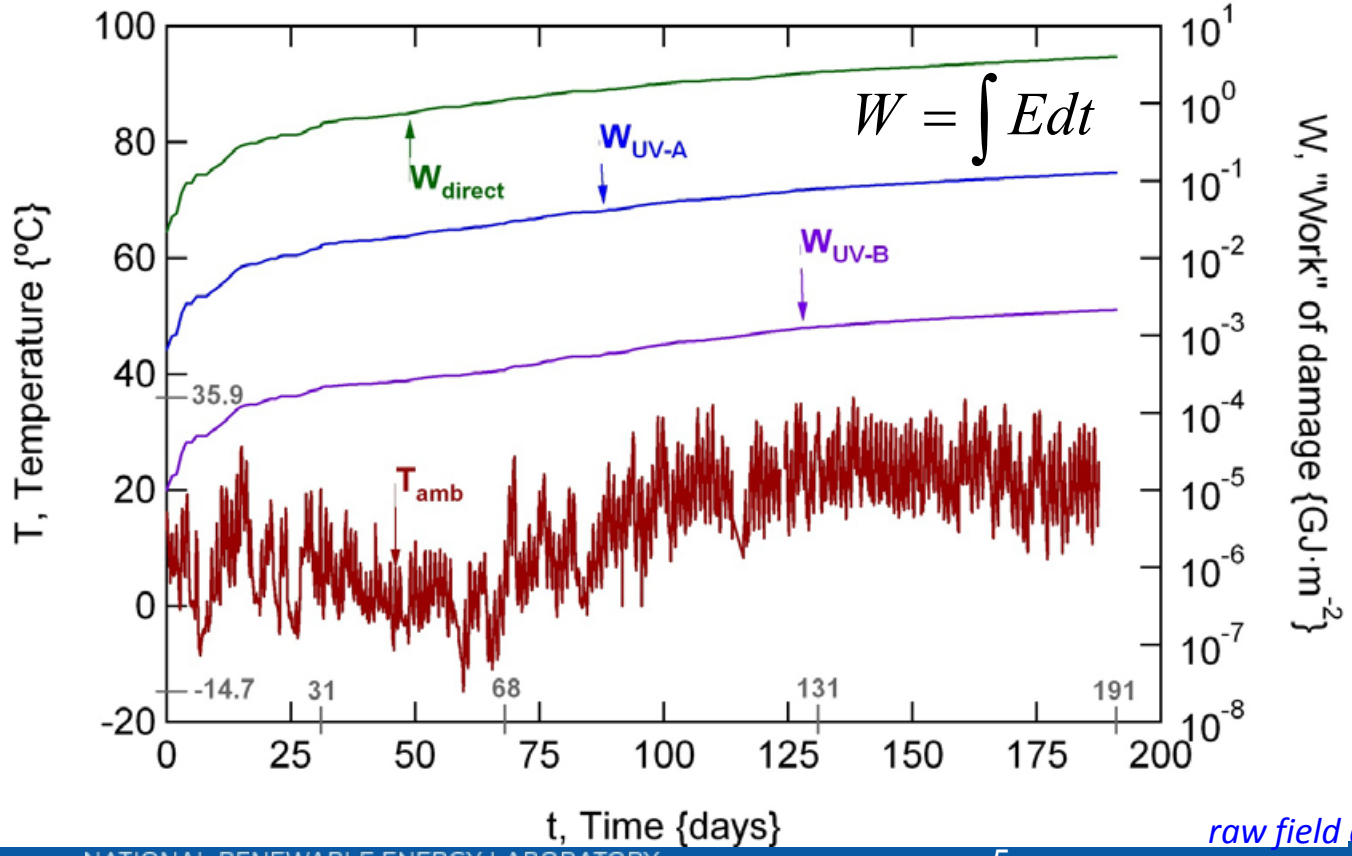
Golden, CO: Steppe climate, elevation 1.79 km, 39.740 °N latitude

W: Seasonal effects (winter cloudiness and latitude-related) observed during first 68 days

$$\frac{W_{UV-A,\,summer}}{W_{UV-A,\,winter}} = 2.3 \qquad \frac{W_{UV-B,\,summer}}{W_{UV-B,\,winter}} = 4.3$$

W: Consider seasonal, optical design, and material's action spectrum

*D.C. Miller, M.D. Kempe, C.E. Kennedy, S.R. Kurtz, Optical Engineering, **50** (1), 2010, 013003.*



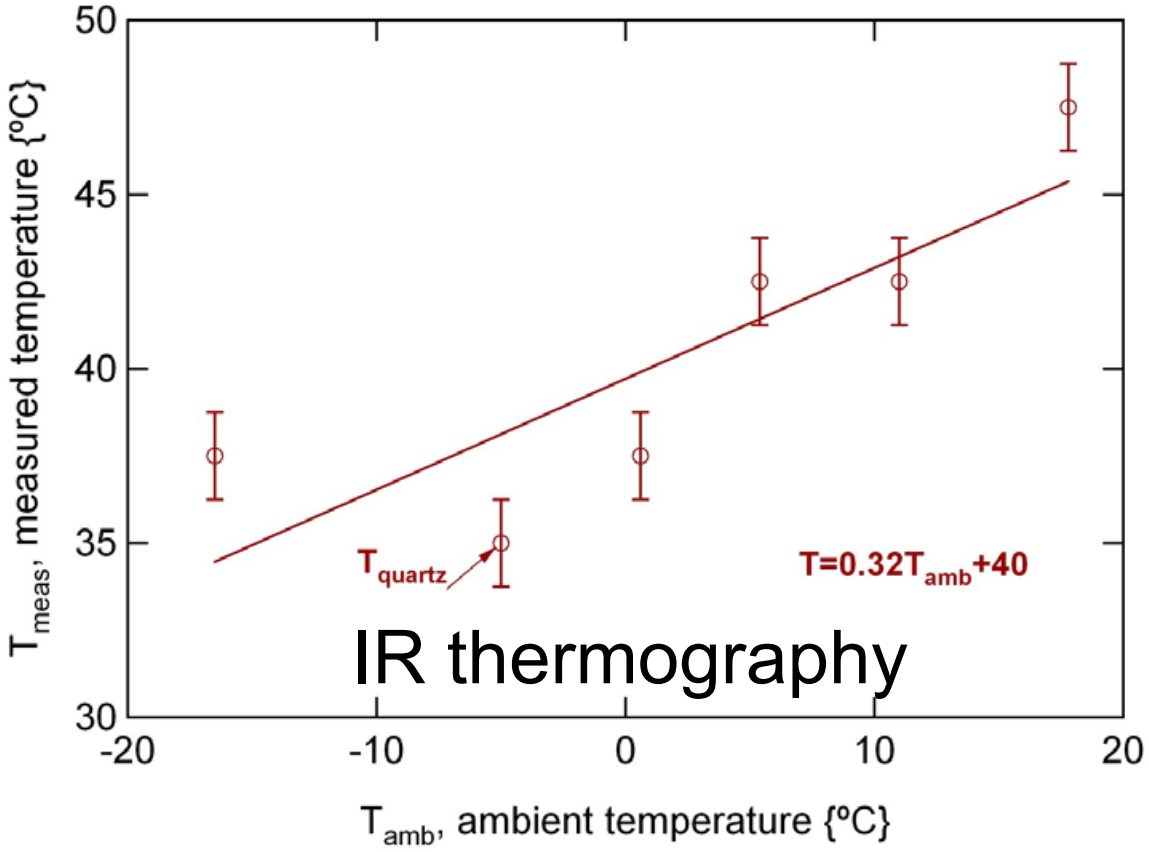
T: Ambient shown. Module's back and inside monitored too.

raw field data for irradiance and temperature

The Field Conditions (Specimen Temperature)

- Specimen temperature proportional to optical (IR) absorptance (thermal management "system": conduction to the frame.)
- ~40°C temperature rise observed. T_{max} 70-80°C in summer.

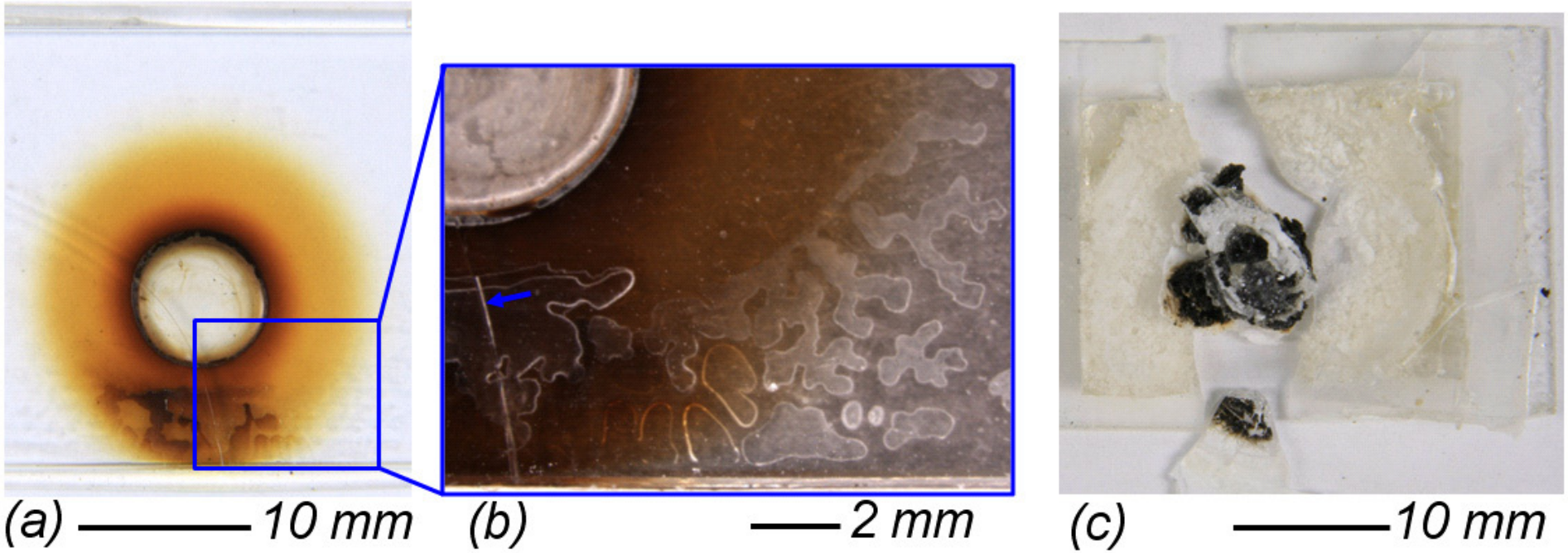
Audience: does this compare to temperatures within your CPV module?



specimen and lens temperature, determined using optical thermography (inset)

Results of Discovery Experiments
(The Homogenizer)

EVA: without homogenizer, rapid discoloration ⇒ combustion (smoke)



optical images of EVA in (a) & (b), and PDMS in (c).
inset shows: voided center, char, cracked coverglass, discoloration, delamination

silicone: without homogenizer ⇒ combustion

- Likely motivated by local hot spots (10^1 to $10^3 \cdot C_g$)

D.C. Miller, S.R. Kurtz, Solar Energy Materials and Solar Cells, 2011.

Results of Discovery Experiments

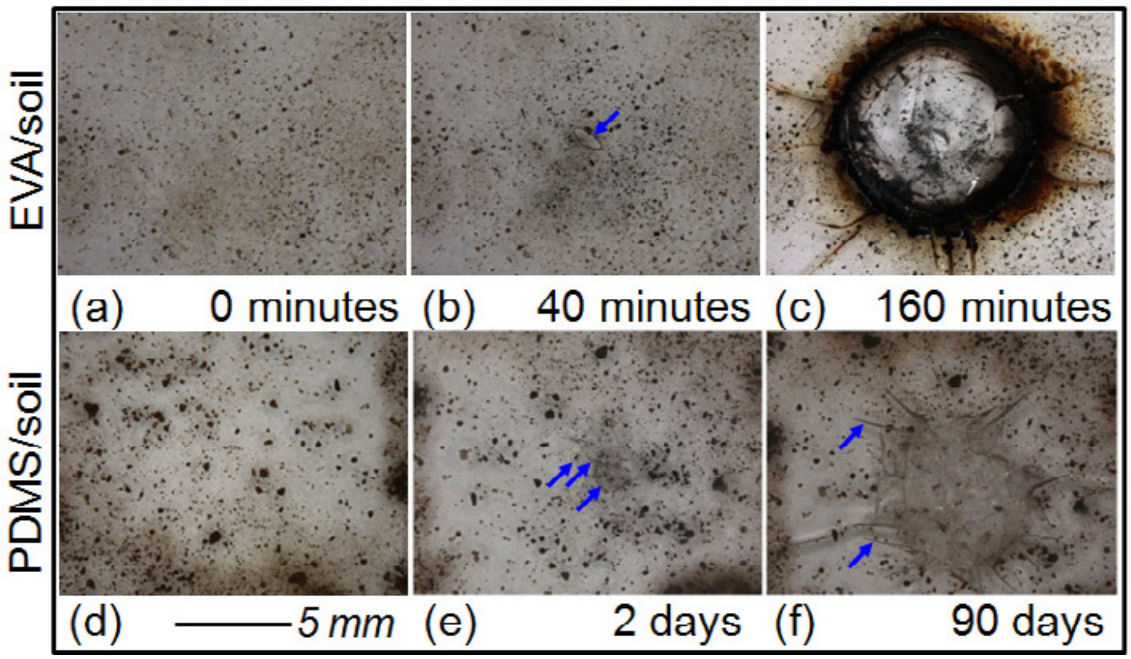
The Effect of Contamination)

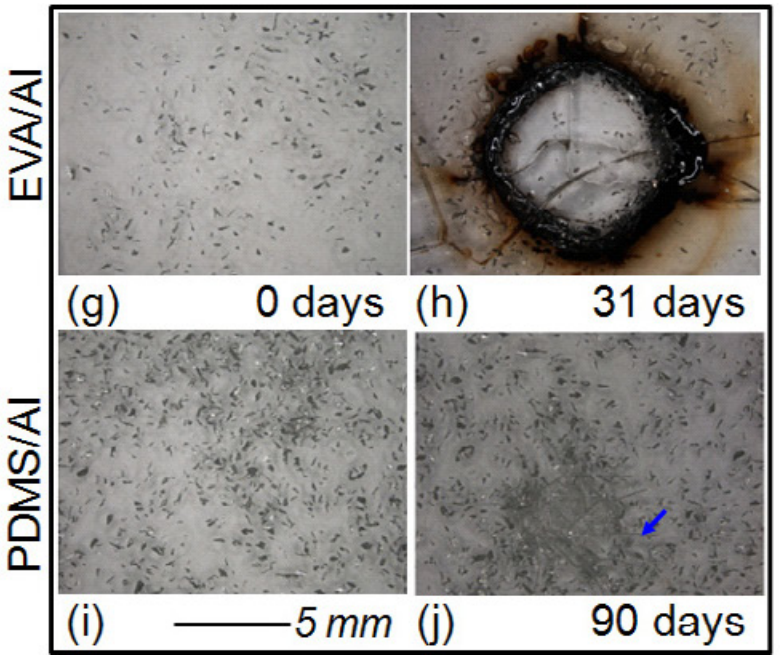
- Intentionally introduce soil, Al, PE, or bubbles into EVA or silicone

EVA: soil, Al, PE motivated localized discoloration ⇒ combustion

silicone: soil, Al ⇒ localized cracking. (no primer present)

- elapsed time: minutes – days/weeks
- bubbles: no failure @C_g=500, despite measured $T[\lambda]$ reduction



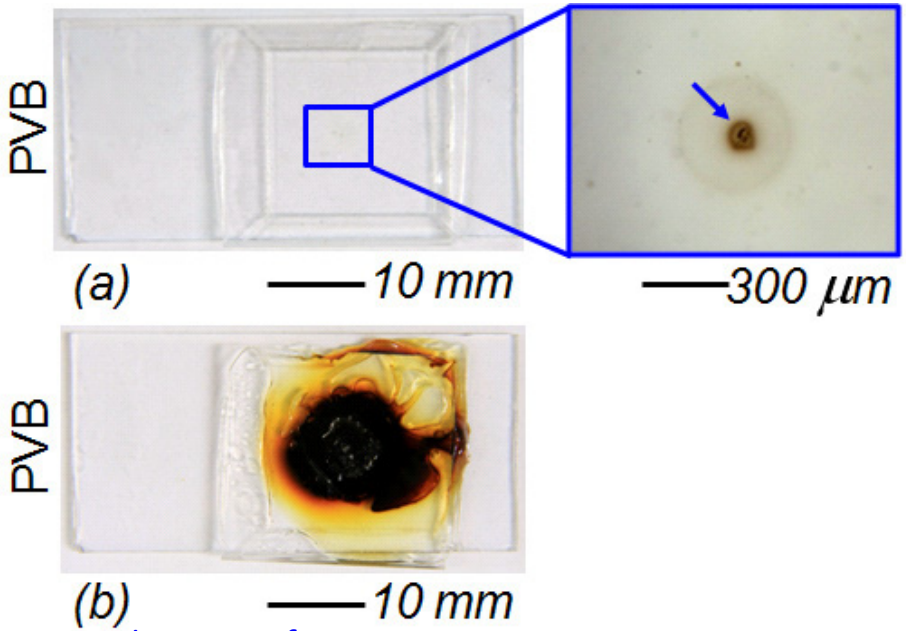


time sequence: optical images of test specimens

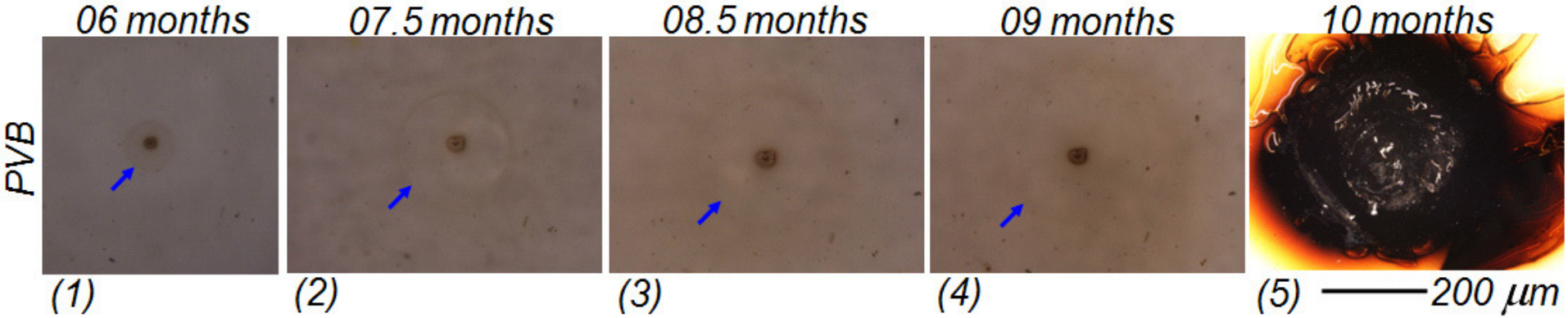
Results of the Formal Experiment
(Hydrocarbon Specimens)

- PVB was the first material to demonstrate thermal runaway mediated failure

- The radius of the affected region was seen to slowly grow during the cold winter months

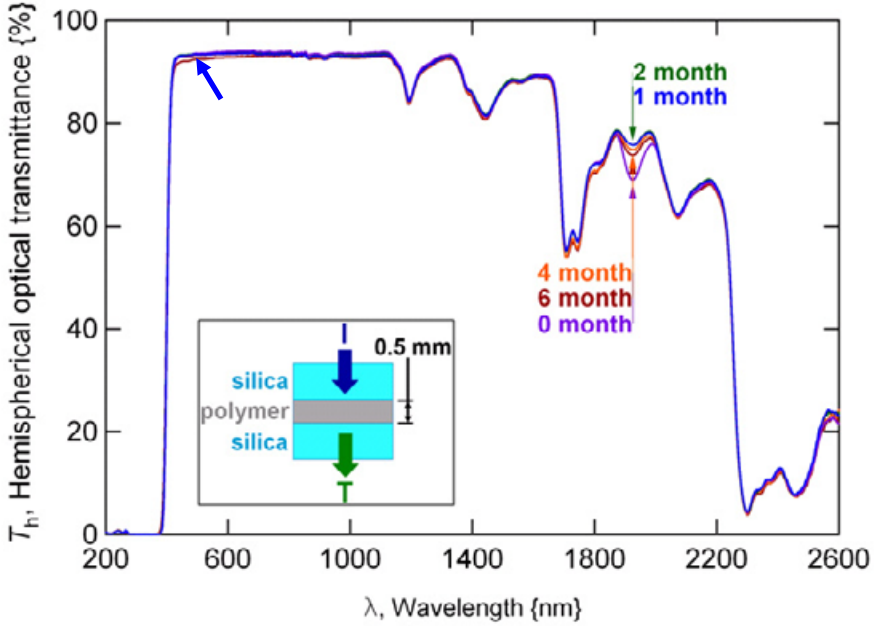


optical images of test specimen at: (a) 6 months and (b) 10 months



time sequence: optical images of test specimen

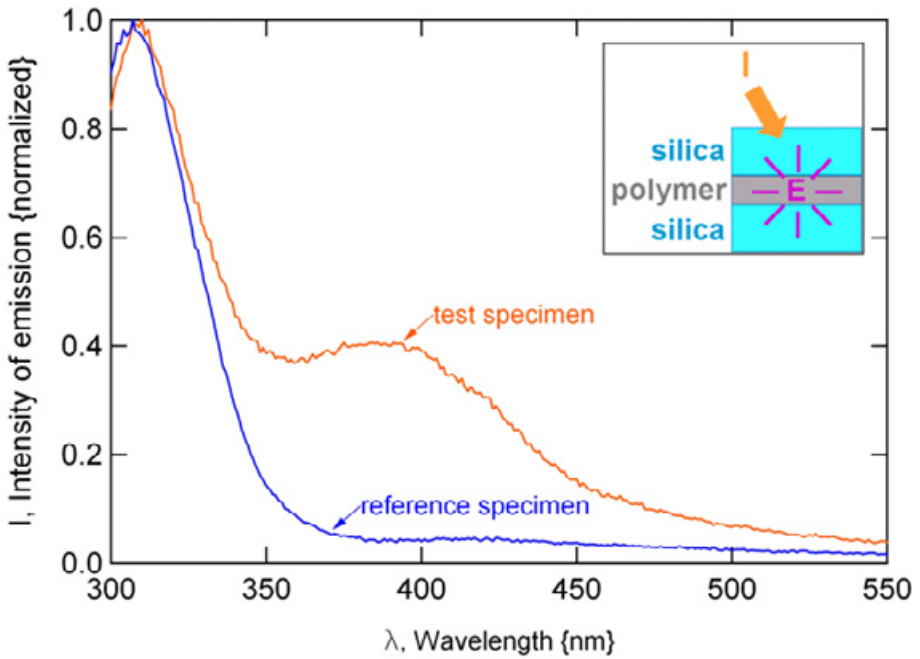
Results of the Formal Experiment
(Hydrocarbon Specimens)



time sequence: transmittance of the PVB specimen

- Transmittance & YI not significantly affected, despite impending failure
- A characteristic with predictive capability is preferred!!!

- Optical & Raman spectroscopy clearly indicate fluorescence
- These techniques may help understand the degradation mechanism (*e.g.*, chromophores)



optical fluorescence spectrum of PVB, for λ_I= 280 nm

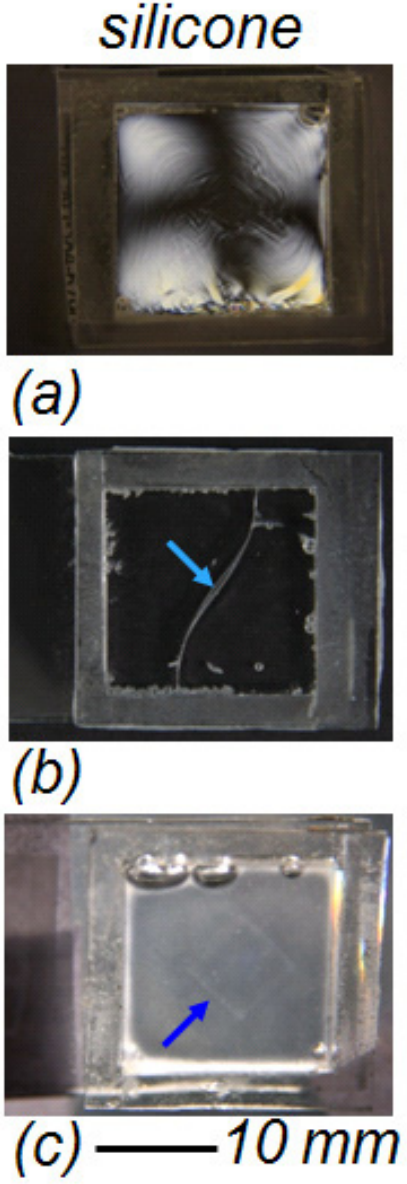
Results of the Formal Experiment
(Silicone Specimens)

- Observations of silicone specimens include: (a) densification, (b) cracking, and (c) haze formation

No mass loss with time for the (5) **densified** specimens ⇒ likely occurred during molding

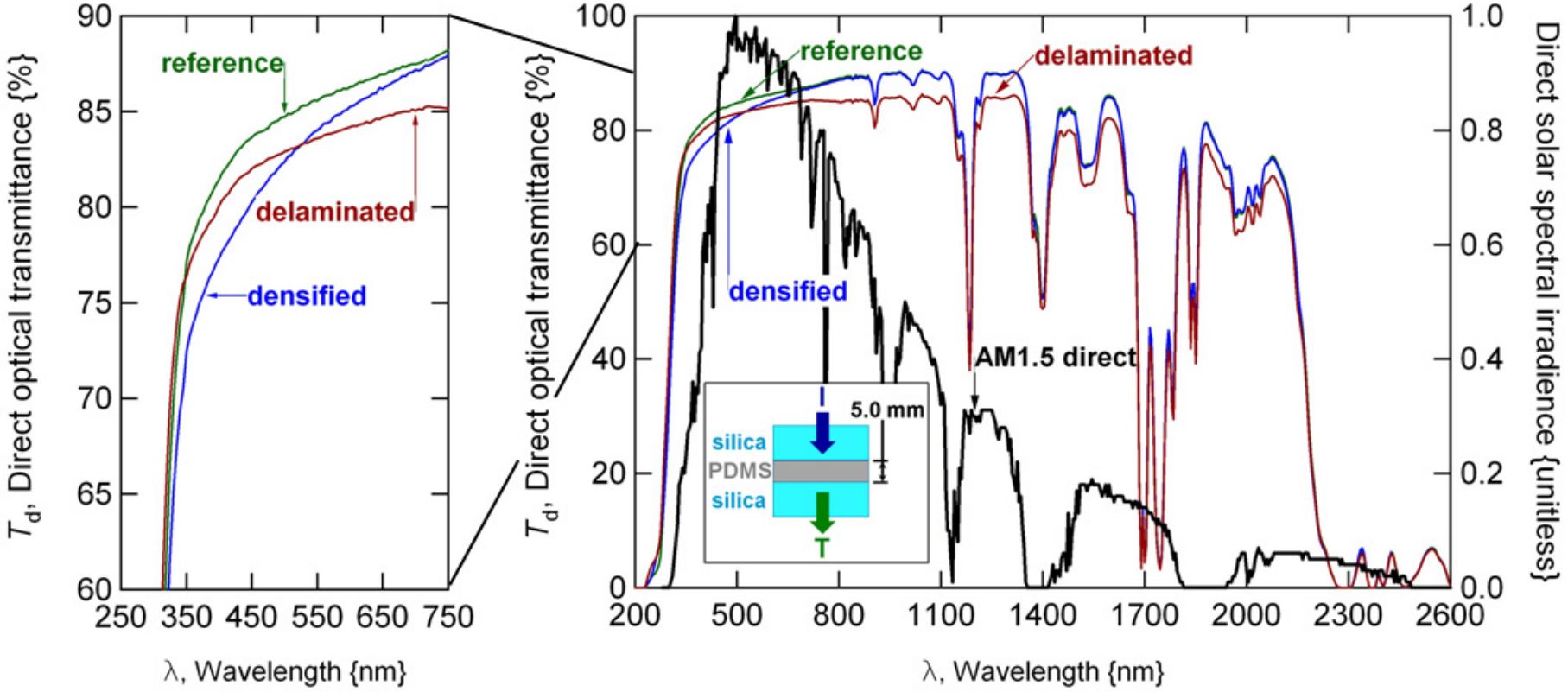
Crack advancement occurred during cold weather periods only ⇒ likely motivated by CTE misfit

Haze formation is attributed to one material's unique formulation



optical images of silicone specimens, including those obtained using (a) cross-polarization or (c) back-lighting

Results of the Formal Experiment
(Densified Silicone Specimens)



- Densification is not delamination
- Densification does scatter direct light

Problematic for CPV?

- Current limited condition (blue light) • Optical attenuation (less power)

⇒May not be significant in thin bond layers

Summary & Conclusions

Field study of the durability of polymeric encapsulation materials for CPV

Discovery experiments:

- Quickly confirmed the importance of an optical homogenizer
- Al, soil, polymeric contamination ⇒ *T* runaway & combustion of EVA
- Al, soil contamination ⇒ cracking of silicone

Formal experiment:

- 17 of 25 specimens not discussed today!
- 3 of 25 specimens "failed".

PVB: localized discoloration ⇒ thermal runaway ⇒ combustion

Fluorescence & Raman spectroscopy may provide prediction & diagnosis

Silicone: densification, cracking, haze-formation

Densification affects the direct transmittance

✋I am looking for your feedback about CPV module temperature conditions and observed failure modes

Acknowledgements

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Paper: "The Durability of Polymeric Encapsulation Materials for Concentrating Photovoltaic Systems", *in preparation*.