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Non-Destructive Imaging of Moisture Ingress in Double Glass Encapsulant Laminates

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Capability Goals

- Determine conditions and mechanisms for module failure
- Identify degradation characteristics: corrosion, cracking,
- Imaging module through backsheet, quantify water content
- The capability helps qualify materials , and module designs for improved performance
- **Advanced Characterization & Forensics, Module Testing, Field Deployment**

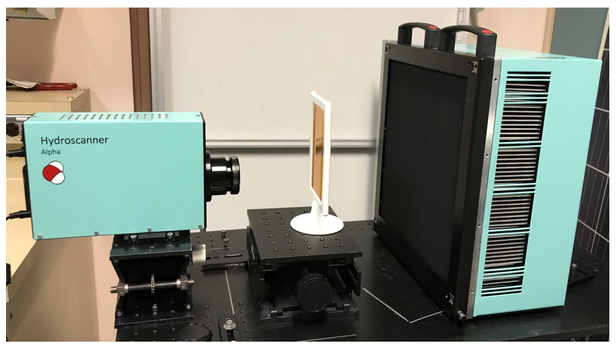
Accomplishments

- Infrared imaging of module backside up to cell metallization
- Screening tool for assessing module damage
- Impact: improved characterization and understanding of photovoltaic module failures
- Collaboration between SCP SYS, LLNL and Sunrun Inc.

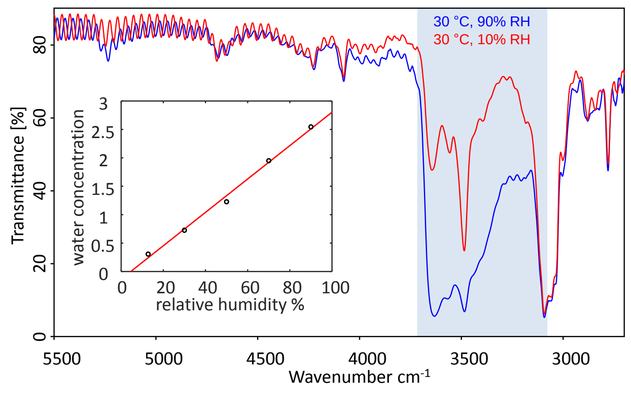
Outcomes and Impact

- Develop qualification procedures for: encapsulant, back sheet, edge seal, front sheet
- Investigate field failure modes in bifacial modules
- Partnering with interested users
- Expand protocol for any water related accelerated testing: damp heat, humidity freeze, potential induced degradation

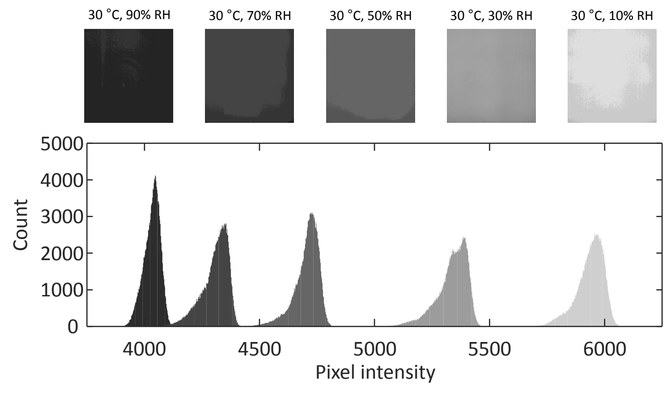
Capability Development: quantitative imaging of water in polymers, 100 ppm concentration resolution



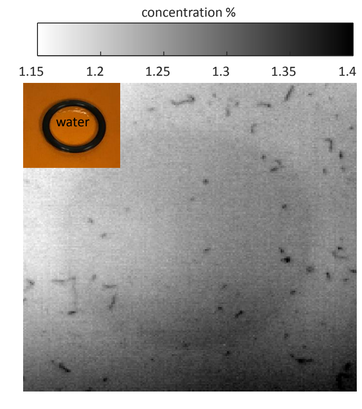
Hydroscanner instrumentation. Development of a novel infrared imaging technique to determine water content in polymers. Applicability in testing photovoltaic module packaging materials and imaging through white backsheet for indicators of degradation: corrosion, cracking and delamination.



Water uptake in polyimide films. Comparison of transmission spectra after equilibration at 90% and 10% relative humidity. Lower transmission in the 3500 cm^{-1} band is due to increased water content and excitation of hydroxyl vibrational modes. Inset: absolute water content in the polymer film is determined by Karl Fischer titration and is used for spectroscopic and imaging calibration

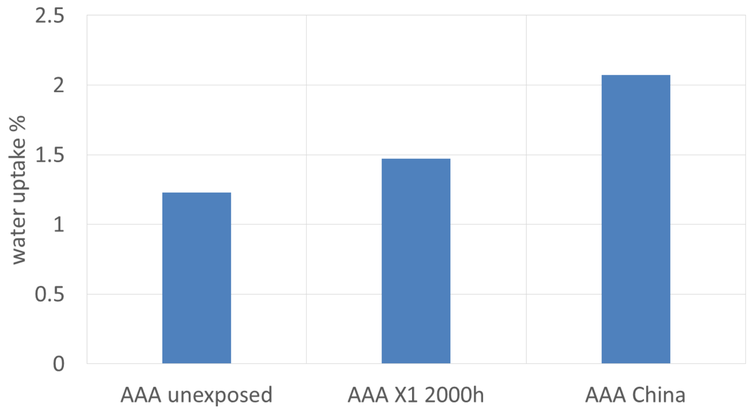


Quantitative imaging. Upper panel: transmission bandpass images of a polyimide film equilibrated at 10, 30, 50, 70 and 90% relative humidity and 30 °C, showing an increase in intensity with lower water content. Lower panel: pixel intensity histogram of the same images. Imaging can be correlated with the independently measured absolute water content with linear or higher order interpolation.



Concentration resolution. A test sample is prepared by selective exposure to water (inset). As water diffuses out, images are taken at different times to determine the minimum concentration difference that can be resolved (0.01%, 100 ppm, 10 nm water thickness equivalent).

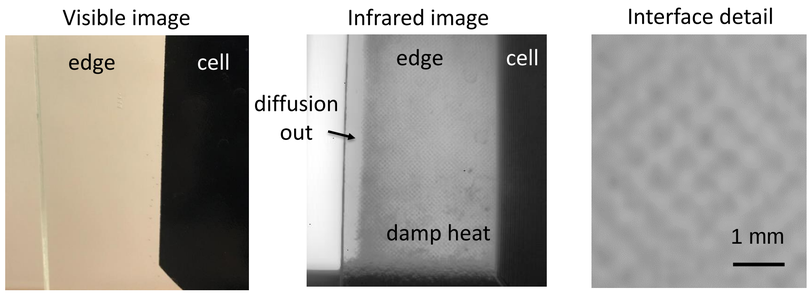
Water content as an indicator of aging



AAA: polyamide based backsheet
X1 2000 h: accelerated testing with temperature (85 C), humidity (85 % RH), UV (x1 Sun), time 2000 hours
AAA China: field deployed backsheet of failed modules deployed in China (tropical climate)

- Moisture content measured after immersion in water at 80 °C for 24 hours
- Aged and field deployed samples hold more water compared to unexposed samples

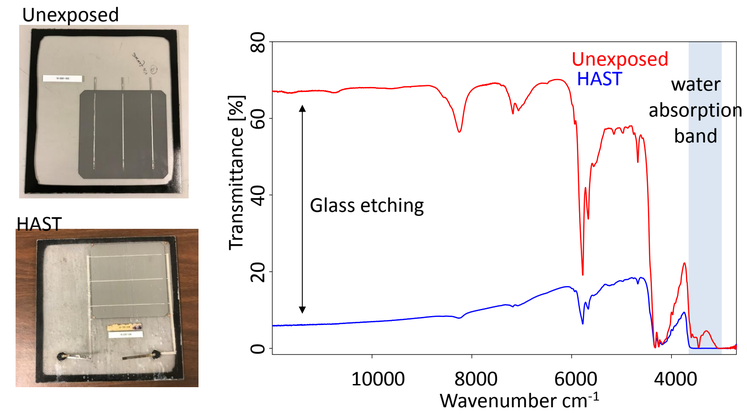
Water ingress imaging in encapsulants



Sample: One cell mini-module fabricated with Solite double glass, ethylene vinyl acetate encapsulant, interdigitated back contact cell (SunPower)
Accelerated testing: damp heat for 12 hours
Infrared imaging: bandpass at water absorption band

- Infrared images show regions of high water content that can't be observed in visible images
- Distribution of water in the encapsulant is not uniform and it accumulates at glass EVA interfaces in regions of weak bonding
- Image resolution: 100 µm

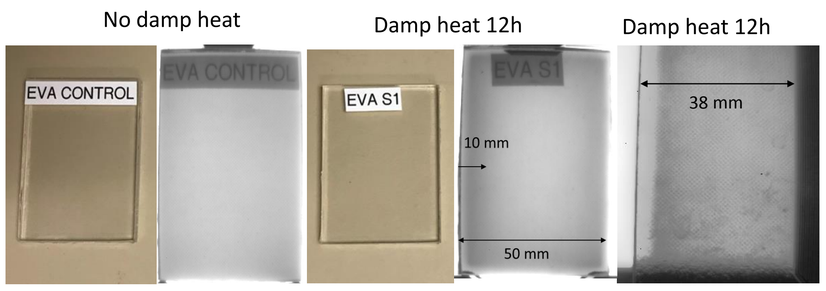
Testing of edge seal failure



Sample: One cell mini-module fabricated with Solite glass, ethylene vinyl acetate encapsulant, architectural glass, and edge seal
Accelerated testing: HAST (highly accelerated stress testing, 120 °C, 10 psi pressure, 100% relative humidity) for 500 hours
Spectroscopic testing through clear sections of the mini-module

- Accelerated testing is very aggressive, glass etching interferes with the measurement
- No transmission in the water absorption band indicates high water content compared to unexposed sample
- Imaging may help identify weak points in edge seal perimeter (e.g. corners)

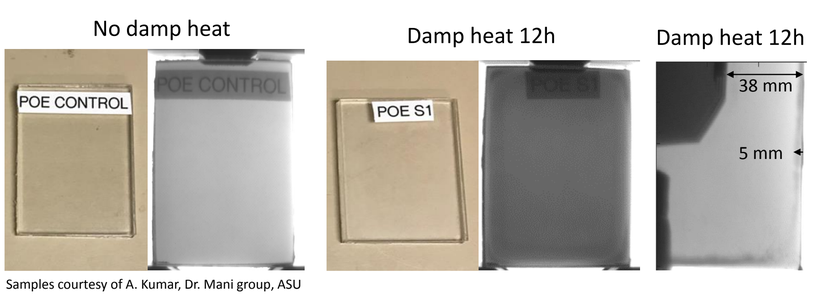
Water ingress in ethylene vinyl acetate (EVA)



Lamination: 15 min, 150 °C
Lamination: 20 min, 145 °C

Moisture ingress rate changes significantly with processing parameters for EVA

Water ingress in polyolefin



Samples courtesy of A. Kumar, Dr. Mani group, ASU

Lamination: 15 min, 145 °C
Lamination: 20 min, 165 °C

Moisture ingress rate changes significantly with processing parameters for polyolefin

Summary

- **Hydroscanner: novel investigation tool for module construction quality**
- **Quantitative imaging of water content with 50 ppm concertation resolution, 100 um spatial resolution**
- **Capability to image through white backsheet to probe back cell metallization**
- **Use case to evaluate adhesion of encapsulant for EVA and polyolefin in double glass laminates**

Capability summary: quantitative imaging water content in packaging materials can be used to evaluate reliability of photovoltaic modules