SAND2020-10053C

DuraMAT Fielded Module Study

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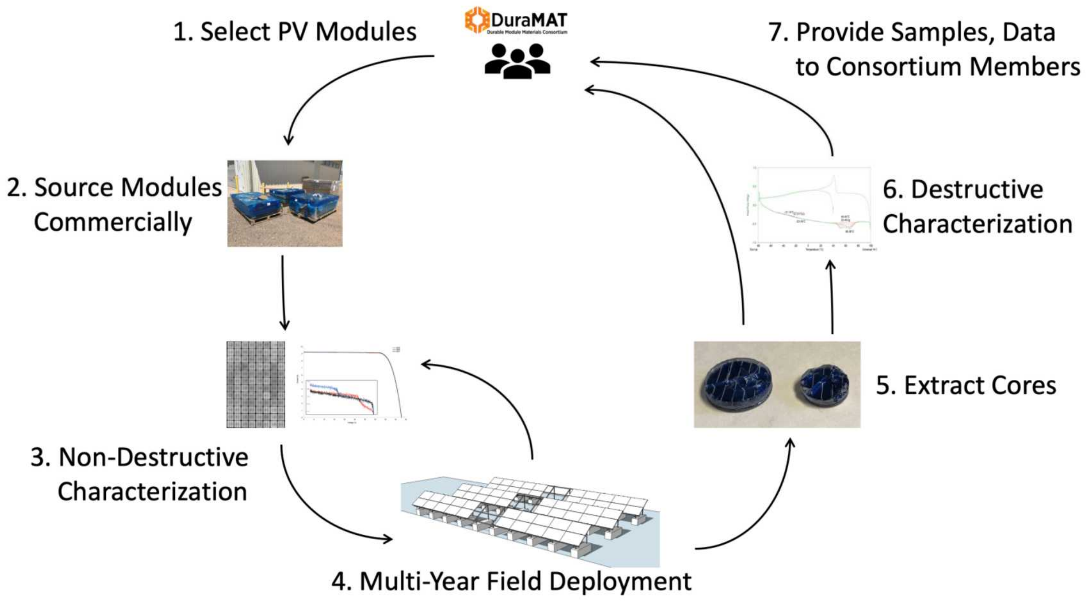
Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Project Overview

Characterize material degradation from natural aging in commercially relevant PV modules.

- Acquire commercially available PV modules from independent vendors
- Deploy alongside existing operational systems for extended timeframe (upwards of 10 years)
- Remove single modules of each type at a fixed interval for destructive characterization to track changes in packaging materials
- Utilize breadth of modules to develop and validate new field forensics methods



Manufacturer	Model	Cell Type
Canadian Solar	CS6K-300MS Quintech	Mono-Si
Hanwa Q-Cells	Q.Peak-G4.1 300	Mono-Si
Jinko	JKM270PP-60	Multi-Si
LG	LG320N1K-A5	Mono (N)
Mission Solar	MSE300SQ5T	Mono PERC
Panasonic	VBHN330SA17 HIT	HIT N-type

Status:

- Seven systems are operational
- Original six systems have accumulated one year of exposure
- Detailed materials characterization is in process
- Cores have been provided to SLAC and LBNL

Characterization Methods

Traditional non-destructive

- Indoor light IV (flash test)
    - YoY STC parameters
    - Series and shunt resistance
    - Fill-factor
- Outdoor light IV (2-axis tracker)
    - the above, plus
    - Temperature coefficients
    - Diode factor
    - Spectral response
    - Surface reflectivity/AOI
- Electroluminescence
- Infrared thermography (MWIR, LWIR)
- Visual

ND Field Forensics

- FTIR
    - Backsheet identification
- UV Fluorescence
    - Encapsulant degradation
    - Oxidation, diffusion
- Reflection Spectroscopy
    - Backsheet Yellowing
- Gloss
- *Field Raman*
- *Near IR spectroscopy*

Other methods, as available

Laboratory destructive

- Raman Spectroscopy
    - Chemical identification
    - Polymeric structure - Degree of cross-linking
- Differential Scanning Calorimetry
    - Endothermic/Exothermic transitions
    - Glass transition temperature
    - Melting and freezing points
    - Heat of fusion
- FTIR
- TGA
- X-ray Fluorescence
- SAXS/WAXS (SLAC)
- Coatings Characterization
- SEM – inorganics, EDS, WDS

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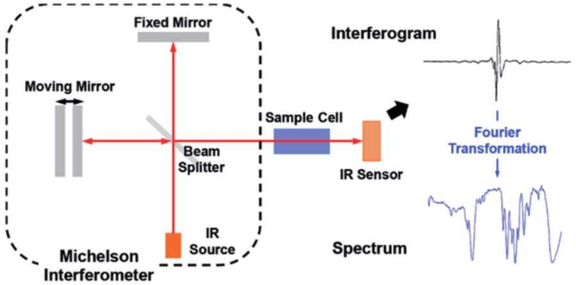
Classification of Back-sheet Materials using FTIR

Motivation/Background

- Fourier-Transform Infrared Spectroscopy: uses Michelson Interferometer to vary wavelengths of light; each spectra is unique to the material investigated
- Handheld device makes FTIR a fast spectroscopy technique
- Many methods considered including machine learning; Pearson correlation provided best results



Basic FTIR set-up and theory: split beam hits sample cell, produces interferogram, computer FT to spectrum (Lee et al. 2013)

Research questions/project goals

- Identify back-sheet materials using FTIR
  - Label peaks with bond locations in molecules based on well documented papers and FTIR chemistry tables
  - Degradation: label new bond locations and peak location/intensity shifts

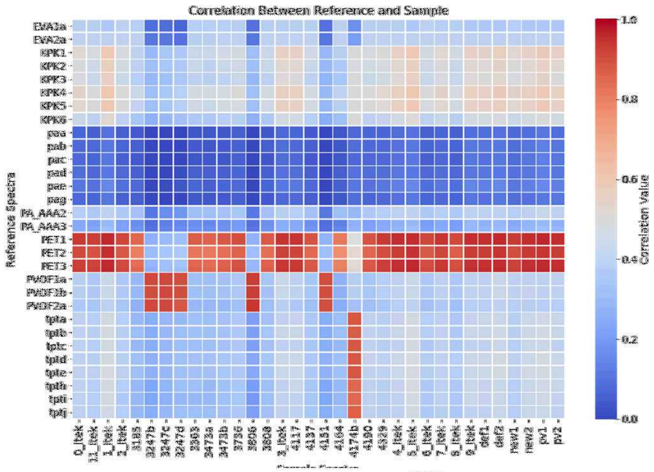
Methods

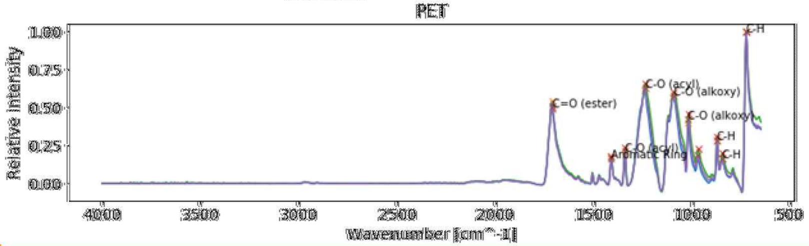
Identify
- Baseline subtract using Asymmetric Least Squares Smoothing
- Identify unknown back-sheets using correlation values with known reference sheets

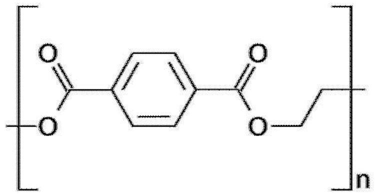
Label
- Define wavenumber ranges for each bond type
- Label known materials with specific bond locations
- Make conjectures about unknown samples

Output
- Spreadsheet of classified back-sheets
- Conjectures made about unknown back-sheets
- Degradation behaviors

Sample results





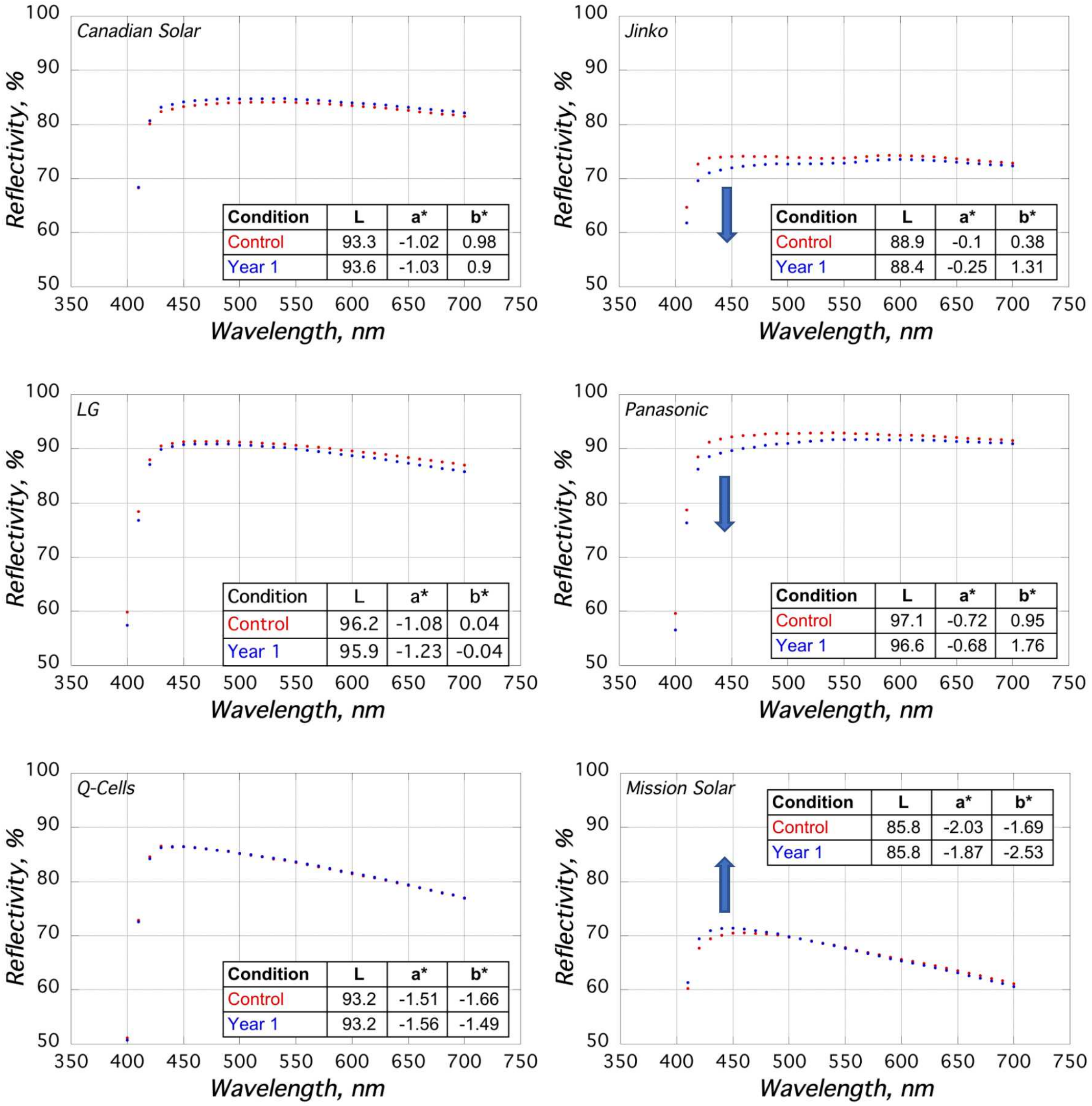


Polyethylene terephthalate (PET) molec... (top), ... of PET

Challenges & next steps

- Peak location for the same bond shifts based on structure of entire molecule
  - Difficult to definitively define which peak is which bond
- Some materials (KPK, TPT) are trademarked and layered materials
  - Unsure of exact molecule structure makes labeling bonds difficult
  - Probing different layers of back-sheet gives different spectra
- Very old back-sheets have poor SNR coupled with degradation

Non-Destructive Laboratory Characterization



Backsheet Reflectivity and Yellowing

- La*b* color space determined from reflection spectroscopy
- L = 0 (black) – 100 (white)
- b*; blue (-) to yellow (+), 0 = neutral gray
- a*; green (-) to red (+), 0 = neutral gray
- Canadian Solar, LG modules and Q-Cells showed little to no change in backsheet color after one year
- Jinko and Panasonic showed a shift toward yellow
- Mission showed a slight shift toward blue

Electrical Performance

- 1-2% decrease in power measured for all modules except Panasonic (flat YoY)

Manufacturer	Rating, W	Initial	Year 1	% change
Canadian Solar	300	300 ± 2	295 ± 1	-1.8
Hanwa Q-Cells	300	302 ± 1	295 ± 1	-2.2
Jinko	270	273 ± 1	268 ± 1	-1.9
LG	320	319 ± 1	316 ± 1	-0.9
Mission Solar	300	292 ± 1	289 ± 1	-1.0
Panasonic	330	330 ± 0	330 ± 1	+0.2

Upcoming Work

- Destructive characterization of Year 1 samples
    - Backsheet inner layer, front and rear encapsulant
    - Raman, DSC, TGA, FTIR
    - SEM analysis of Anti-Reflective Coatings (ARCs)

- Further refinement of FTIR classification method
    - Add more ”knowns” to database
    - Perform classification on Year 1 samples
    - Investigate automated detection of shifted/new peaks due to degradation

- Year 2 Characterization (Winter 2021)