DuraMAT
Durable Module Materials Consortium

Discover, Develop, and De-Risk module materials, architectures, accelerated testing protocols, data analytics, and financial models to reduce the LCOE of solar energy

High-Throughput Optical Mapping for Accelerated Stress Testing of PV Module Materials

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DuraMAT Capabilities

1. Data Management & Analytics, DuraMAT Data Hub
2. Predictive Simulation
3. Advanced Characterization & Forensics
4. Module Testing: Module Prototyping and Combined-Accelerated Stress Testing (C-AST)
5. Field Deployment
6. Techno-Economic Analysis

Capability Goals

•Demonstrate **rapid batch specimen measurement capability**, e.g., allowing measurement time to be reduced from 6 minutes/specimen to 5 seconds/specimen.

•Demonstrate **specimen mapping measurement capability**, allowing the spatial dependence of material degradation to be assessed within the same specimen.

Approach

•**Transmittance** (-hemispherical and -direct) and **reflectance** (-hemispherical) **channels** will be added to the NREL CCD array spectrometer for thick specimens.

•Measurement capability will be **benchmarked against existing specimens**, examined in a round-robin study using conventional spectrophotometer instruments.

•Data acquisition and storage will be **integrated into** the DuraMAT **DataHub** network along with data visualization tool, facilitating sharing of information.

Outcomes and Impact

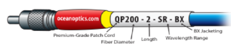
•The measurement tool may be applied for other materials (encapsulants, backsheets, optical coatings) and accelerated test methods in the DuraMAT network.
•The study here will provide guidance towards the design and application of larger and/or outdoor-use intended instruments.

Motivation

•Traditional spectrophotometers require a long measurement time (~ 6 minutes) because macroscopic components must be physically actuated for measurement.
•Traditional spectrophotometers are limited to measurement of single spots (~ 1cm^2).
•Traditional spectrophotometers require physical reconfiguration (with associated setup delay) for measurements of separate characteristics.

Key Components

DH-2000-BAL
(deuterium and halogen light source)
•Output from 215 to 2500 nm.



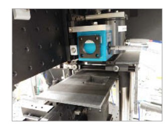
Optical Fibers
(solarization resistant and UV durable)
•Practical operating range: 200 nm – 1100 nm.

FOIS-1 Integrating Sphere
(transmittance measurements)
•38.1 mm diameter with 9.5 mm port.

ISP-50-8-R-GT integrating sphere
(reflectance measurements)
•50 mm diameter with 8.0 mm port.

EPP2000-UVN-SR spectrometer
(all optical measurements)
•25um slit width for 0.43 nm resolution.

IMS300PP
(long travel linear stage, stepper motor)
•300 mm travel in 1.25 μm minimum increment.



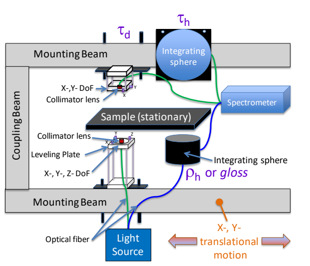
Custom masks
•Greatly improve measurement quality.
(see below)

Project Timeline

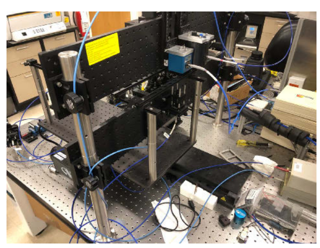
- **Project begins** (Q1-2020): Design & build 3 tests channels. Integrate acquisition system and spatial mapping.
- **Benchmark PVQAT TG5 samples** (Q4-2021): Compare transmittance coupons (spot measurement) to quantify instrument repeatability & reproducibility
- **Develop data pipeline & visualization capability** (Q1-2021): Share data through DuraMatHub, including data visualization tool.
- **Compare weathered specimens** (Q3-2021): including encapsulant coupons (PVQAT TG5) and MiMos (e.g., C-AST).
- **Present results** (Q4-2021): for weathered MiMo specimens.

Optical Mapping instrument (In Development)

•The Optical Mapping instrument has been added to the Combi tester at NREL to leverage the existing control, analysis, and data storage software.



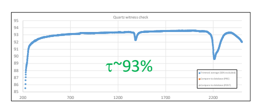
Schematic of the OM instrument, the capabilities for transmittance (τ, green interconnections) and reflectance (ρ, blue) are shown.



Photograph of the OM instrument on the Combi tester.

General Operation (Traditional Spectrophotometer)

•The procedure used for conventional spectrophotometer measurements (e.g., as in IEC 62788-1-4) can be applied here to minimize measurement noise and verify proper instrument operation.
•NREL's usual procedure requires (i.e., for ρ): working reference sample, calibrated reference, and a light trap.



Representative transmittance spectra for silica

baseline (at 100% and 0%) → silica working reference → measure specimens → silica working reference → analyze & publish

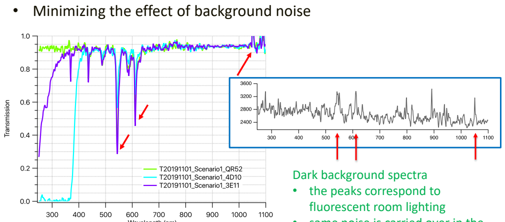
baseline:
-τ: use air and opaque mask
-ρ: use Spectralon and light trap

silica working reference:
-Verify baseline and proper operation
-silica: will not solarize or degrade
-silica: broad spectral bandwidth
-τ~93% (most wavelengths)
-ρ~8% (most wavelengths)
-if *fail*: rebaseline or troubleshoot

silica working reference:
-Verify continued operation

Initial Measurements & Shortcomings

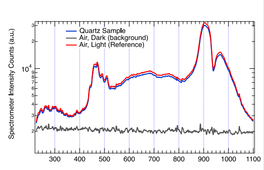
- Minimizing the effect of background noise



Initial Transmission measurement of Unaged Encapsulant Coupons

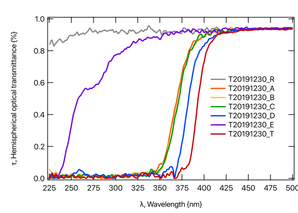
Dark background spectra
- the peaks correspond to fluorescent room lighting
- same noise is carried over in the transmission spectra (left)

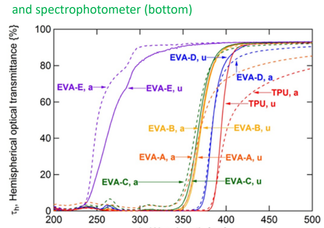
Steps taken
- ❑ Increased halogen lamp intensity
- ❑ Applied baseline procedure
- ❑ Shielding stray light
  - ❑ Table reflection minimization
  - ❑ Local blocking around light source
  - ❑ Modified sample holder



Raw spectrometer counts after the noise minimizing steps, showing much reduced noise contribution in both the light reference and dark background spectra

Early Benchmark of Unaged Encapsulant Coupons





Hemispherical optical transmittance measurement data obtained by Combi Optical Mapping instrument (top) and spectrophotometer (bottom)

Compare spectrophotometer & Optical Mapping instrument
- Developed early prototype Igor Pro loader and procedure for data analysis
- Preliminary benchmark results of unaged encapsulant coupons showed comparable results for spectrophotometer and combi optical mapper instruments.

[Spectrophotometer Data] [Combi Optical Mapper]	Quartz	MATERIAL A	MATERIAL B	MATERIAL C	MATERIAL D	MATERIAL E	MATERIAL T
λ_{cUV} {nm}	N/A	357.7	359.3	355.0	376.0	244.3	388.0
	N/A	353.0	355.00	355.00	371.0	241.0	383.0
τ mapping representative weighted {%} (300 nm $\leq\lambda\leq$1100 nm)	93.22	91.51	91.64	91.46	90.71	93.28	90.28
	93.29	92.43	92.60	92.58	91.95	94.13	91.27
YI (D65 spectrum, 10° observer)	0.14	0.59	0.46	0.44	1.14	0.37	1.11
	0.10	0.74	0.74	0.74	1.20	0.25	1.25

Future Work
- ❑ (Year 1) Measure and compare hemispherical transmittance of IEC 62788-1-4 round-robin samples.
- ❑ (Year 2) Example the reflectance of weathered backsheet materials on MiMo samples.

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