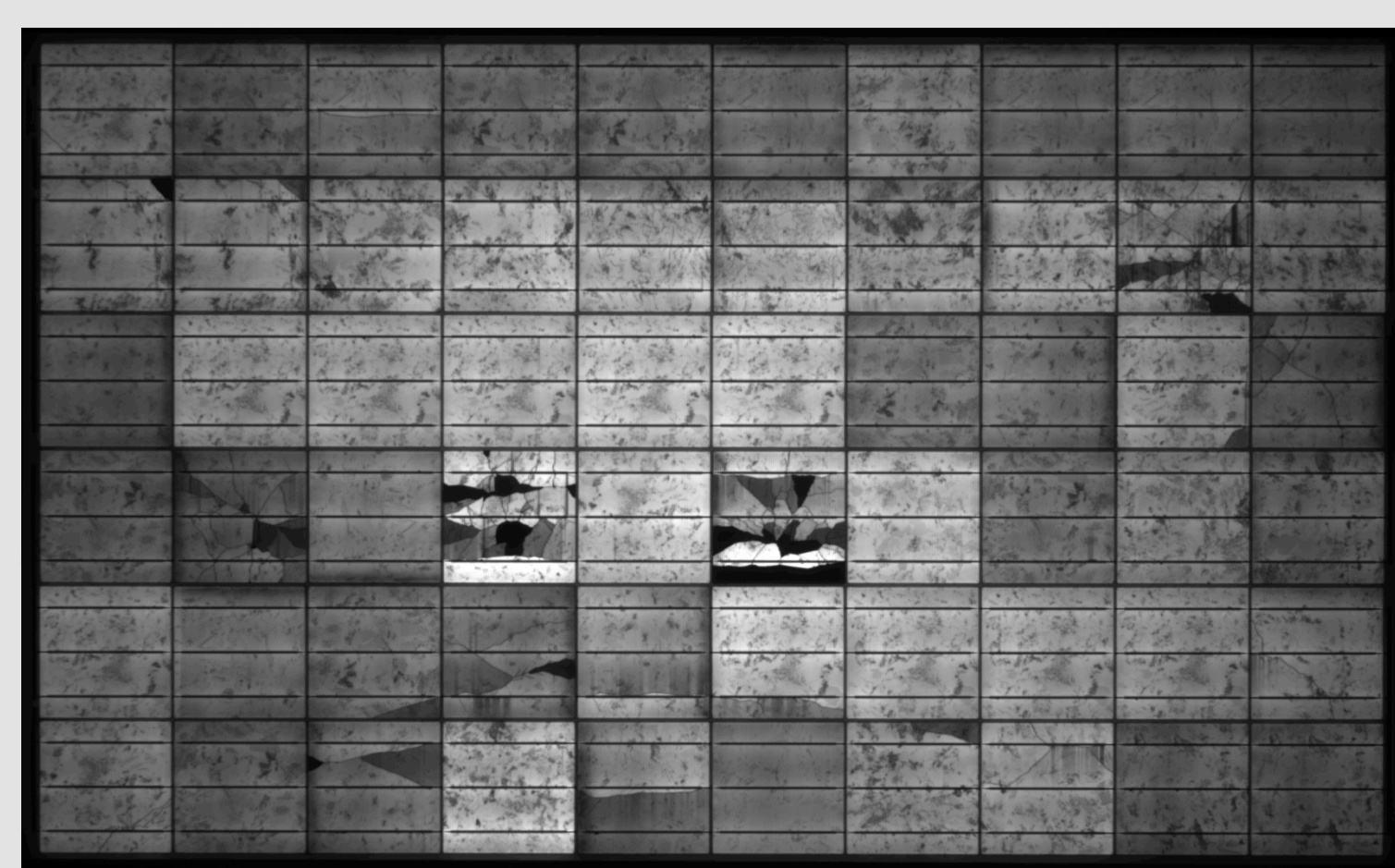


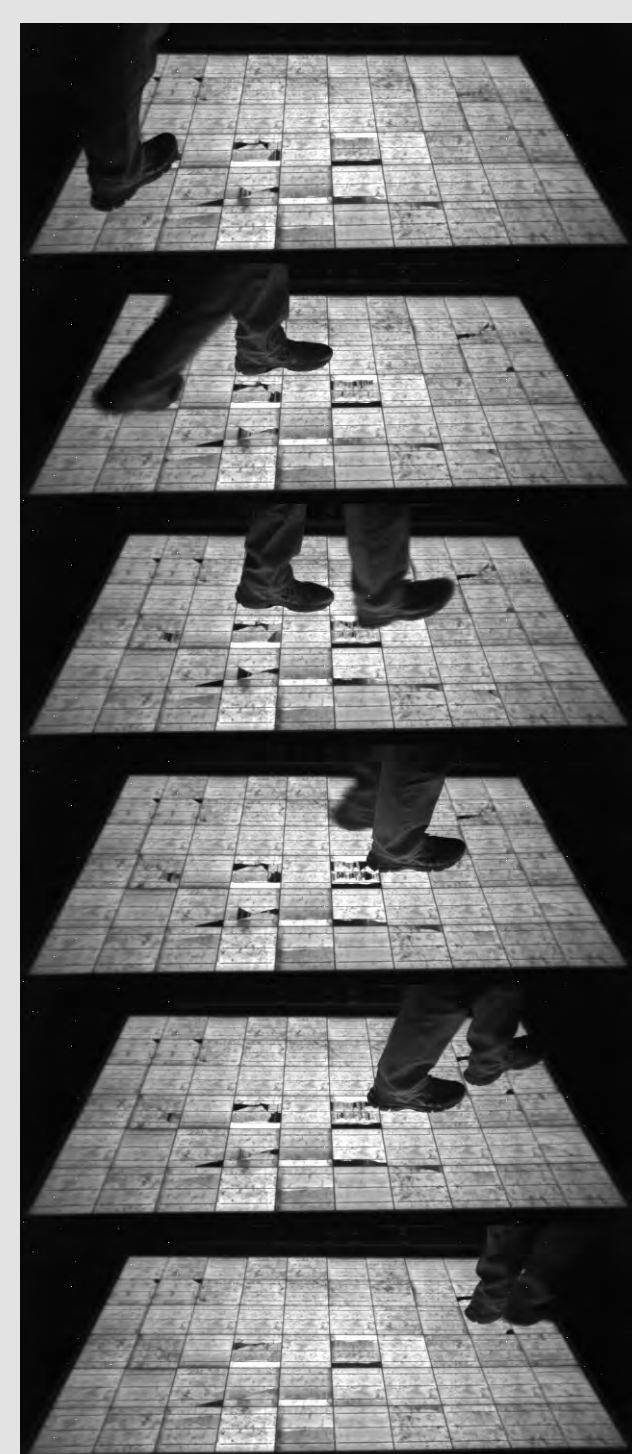
NREL Testing, Measurement, and Characterization

Steve Johnston, Tim Silverman, Bill Marion, Chris Deline, Peter Hacke

1. Module-scale EL imaging (c-Si)



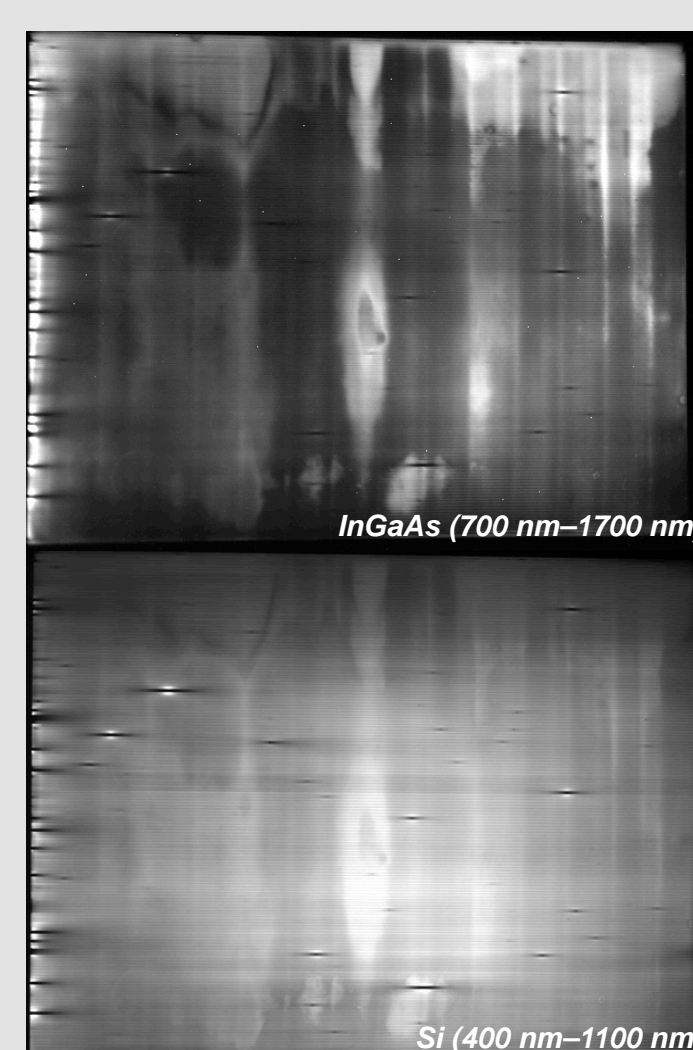
Detect broken cells with electroluminescence (EL) imaging



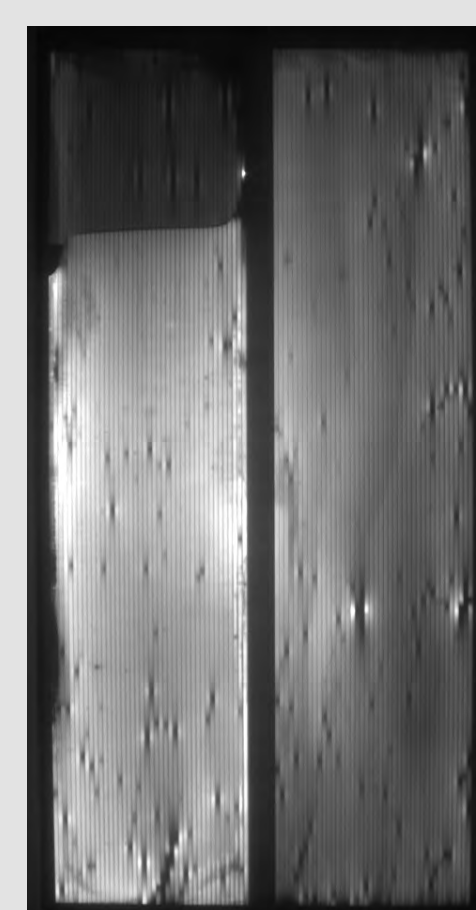
High-rate EL imaging during mechanical stress

• Contact: steve.johnston@nrel.gov, timothy.silverman@nrel.gov

2. Module-scale EL imaging (monolithic thin-film)



Characterize nonuniformity in different wavelength ranges using EL imaging



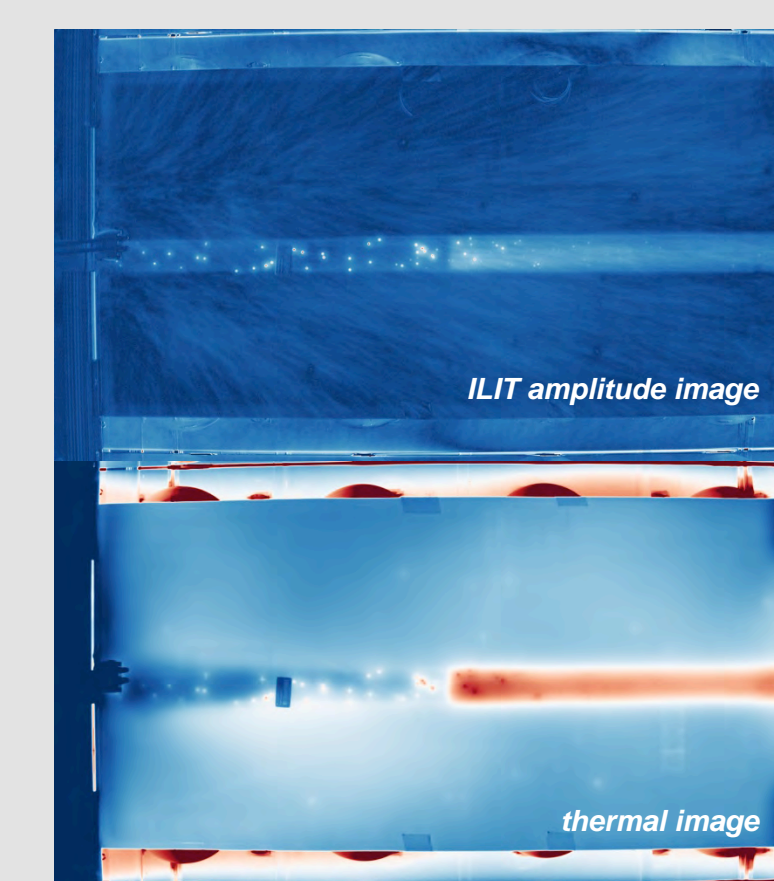
EL images can show cracks and defects in the module.



Detect damage due to partial shade using EL imaging

• Contact: steve.johnston@nrel.gov, timothy.silverman@nrel.gov

3. Module-scale thermal imaging



Identify and quantify shunts using illuminated lock-in thermography (ILIT)

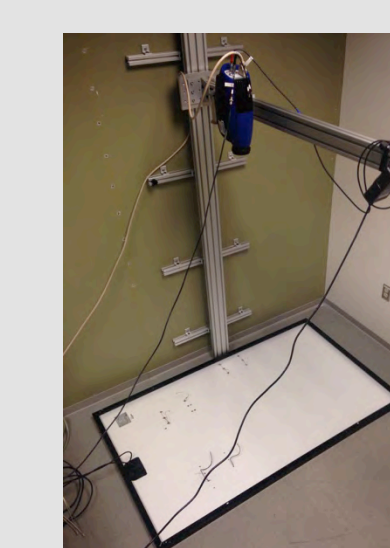
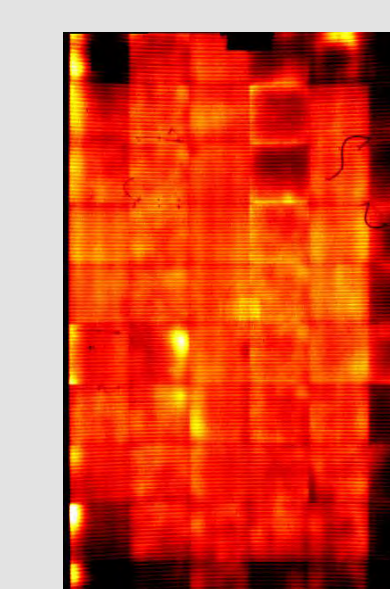
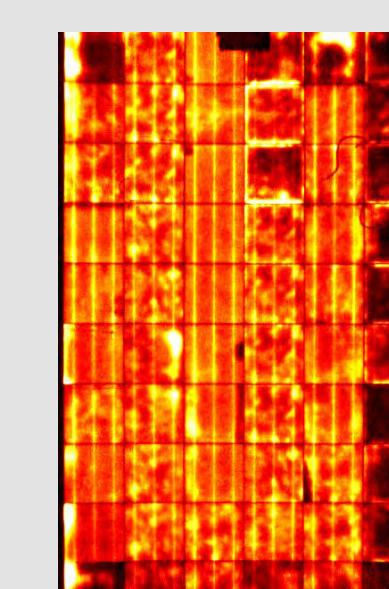


Image through glass or backsheet of Si modules. (Better spatial resolution with backside imaging and lock-in)



Steady-state



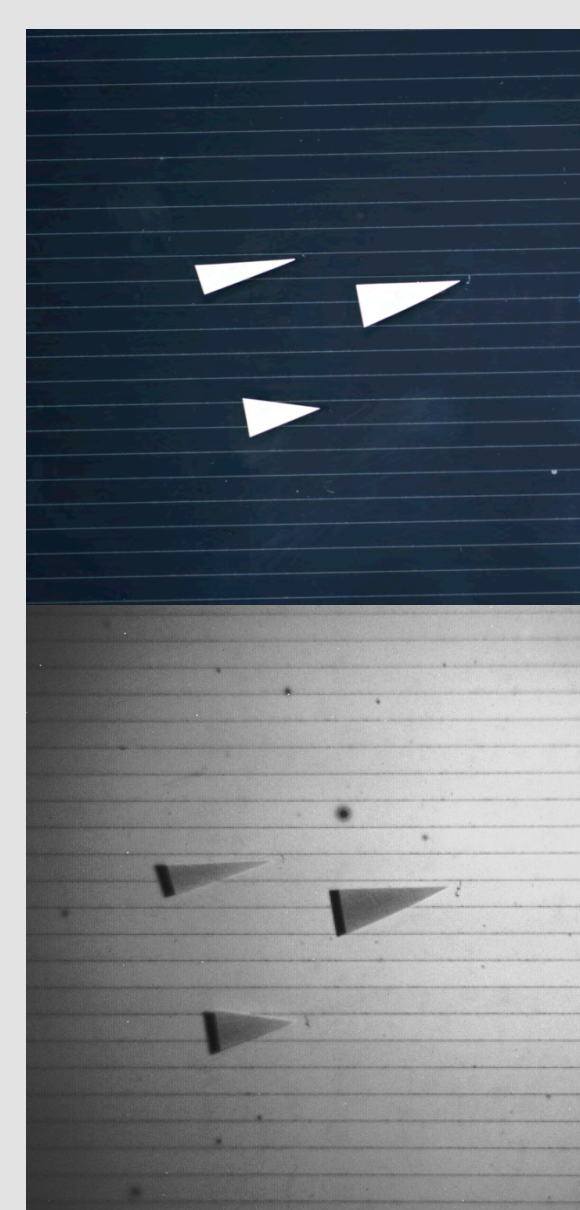
Dark lock-in thermography

• Contact: steve.johnston@nrel.gov, timothy.silverman@nrel.gov

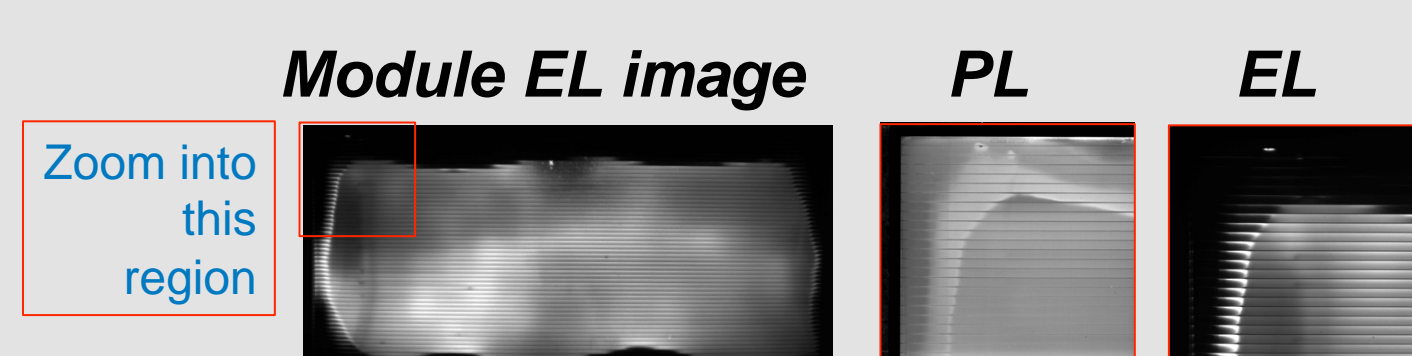
4. Module-scale PL imaging



Indoor PL to detect partial-shade damage in CIGS



Outdoor PL imaging of c-Si in full sunlight



PL shows response from device, while EL shows that series resistance is high.

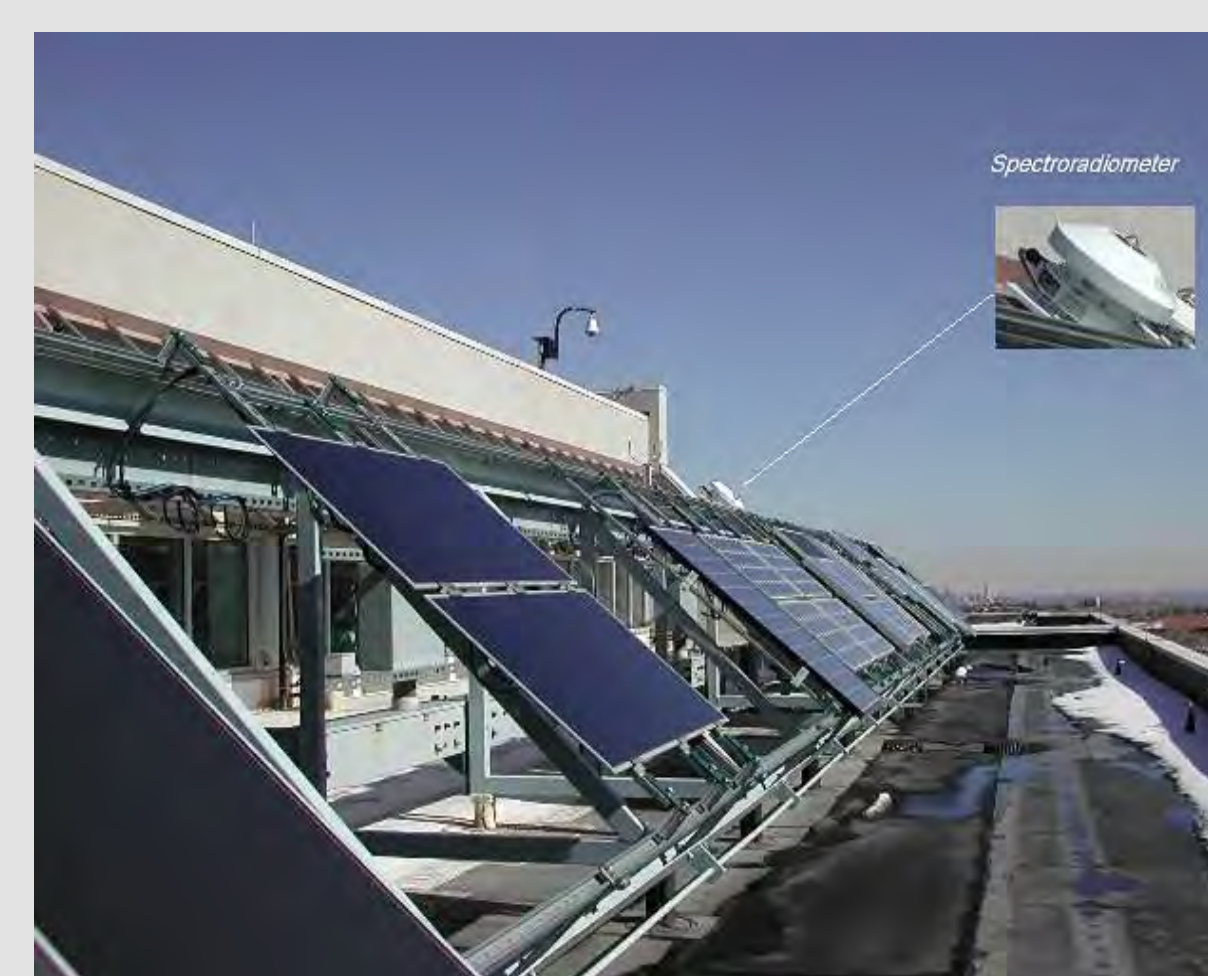
• Contact: steve.johnston@nrel.gov, timothy.silverman@nrel.gov

5. Performance and Energy Rating Testbed (PERT)

- ISO 17025 accredited outdoor PV performance measurements
- Can resolve performance differences as small as 0.5% between side-by-side PV modules
- 15-minute I-V curves, peak-power tracking, and PV module temperature data measured with Raydec Multi-Tracer

- Irradiance measured with Kipp & Zonen CMP-22 pyranometers
- 45 PV module capacity
- PV module powers to 350 W
- Test durations from days to years

• Contact: bill.marion@nrel.gov



6. Testing of coupons and modules

Multiple environmental chambers may be used for damp heat, humidity freeze, thermal cycling, etc.; with capabilities for in-situ evaluation by dark I-V methods for modules

Multiple Xe and UV-A-based weathering chambers are also available. A salt fog chamber is available for corrosion testing.

Optical and electrical characterization Light IV, Dark IV, FTIR, mass spectroscopy, and Ramen spectroscopy are available for analyses of degradation mechanisms. Various spectrophotometers, reflectometers, and a gloss meter exist for analyzing optical properties of materials.

• See also posters by David Miller, Michael Kempe

7. Testing of coupons and modules

Mechanical properties Static loading, pull testers, ice ball testing, and other tools are available for examining adhesion, creep, and other mechanical properties.

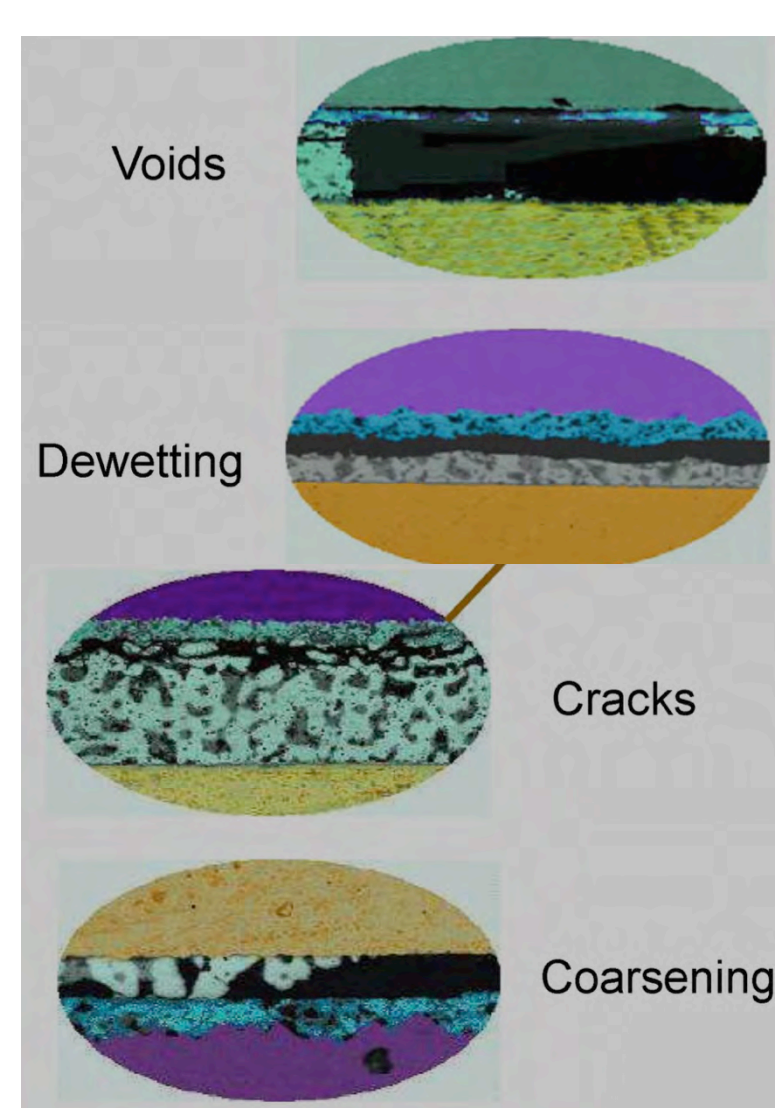
Wear and durability TABER, falling sand, and brush testing equipment are capabilities for testing wear and durability of surfaces and coatings.

Surface science A goniometer is a capability available for measuring contact angles.

Non-destructive analysis tools including acoustic microscopy and X-ray tomography are available

Metallography including polishing (sanding, FIB), microscopy, X-ray for study of metallization, adhesion, interfaces, etc.

• See also capabilities by Nick Bosco, David Miller Steve Johnston, Michael Kempe and Mowafak Al-Jassim



8. Module-integrated electronics testing

Roof-top and field test beds OTF facility has extensive system monitoring for ambient temperature, module temperature, device heat sink temperature, humidity, AC & DC current, monitoring RMS power, etc.

Chamber testing Application of high temperature stress, humidity freeze, damp heat, etc. Powered and unpowered tests.

Power analyzers Yokogawa WT 500

DC power supplies for sourcing and DC loading of devices

LabVIEW software for driving testing

NREL Energy Systems Integration Facility (ESIF) for larger scale testing (grid simulators, regenerative loading, multi-channel power analyzers)

Failure Analysis Multiple analysis, imaging, and microscopy tools available

• See also poster by Steve Johnston

