NREL
NATIONAL RENEWABLE ENERGY LABORATORY

SLAC NATIONAL ACCELERATOR LABORATORY

Sandia National Laboratories

Exceptional service in the national interest

Thermal-mechanical-electrical model for PV module-level mechanical failure mechanisms

James Y. Hartley† (SNL), Scott A. Roberts (SNL), Nick Bosco (NREL), Laura Schelhas (SLAC)

†Thermal Sciences and Engineering Department
Sandia National Laboratories, Albuquerque, NM

May 22, 2017
DuraMat Workshop, SLAC, Stanford, CA

U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration | U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

Sandia National Laboratories is a multi mission laboratory managed and operated by National Technology and 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

NREL is a national laboratory of the U.S. Department of Energy Office of Energy Efficiency & Renewable Energy Operated by the Alliance for Sustainable Energy, LLC.

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. DE-AC02-76SF00515.

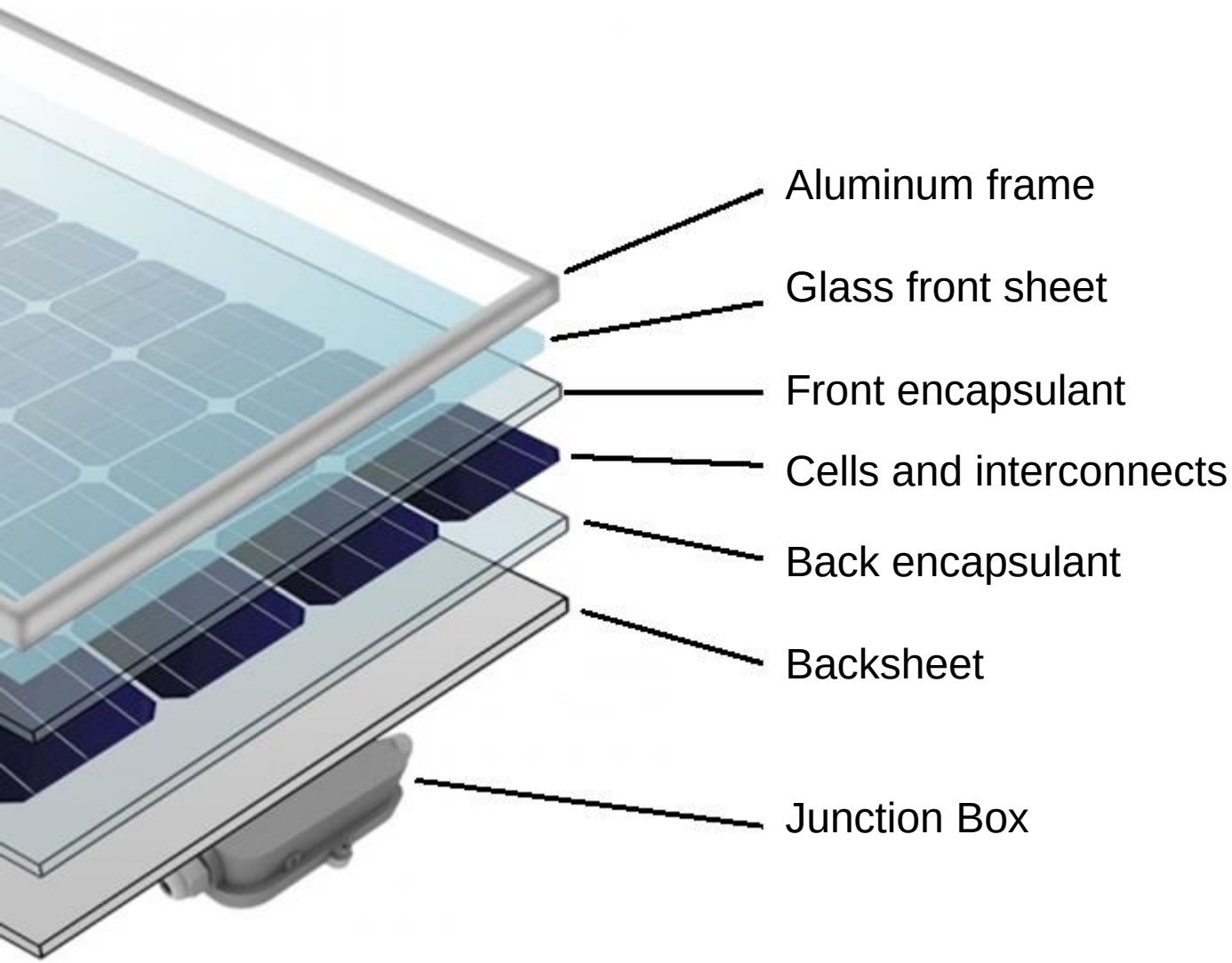
Overview

- PV modules and degradation mechanisms
- Design questions to be answered with modeling
  - Benefits of a module-level model; existing capabilities; previous efforts
- Model validation capabilities
- Capability development plan

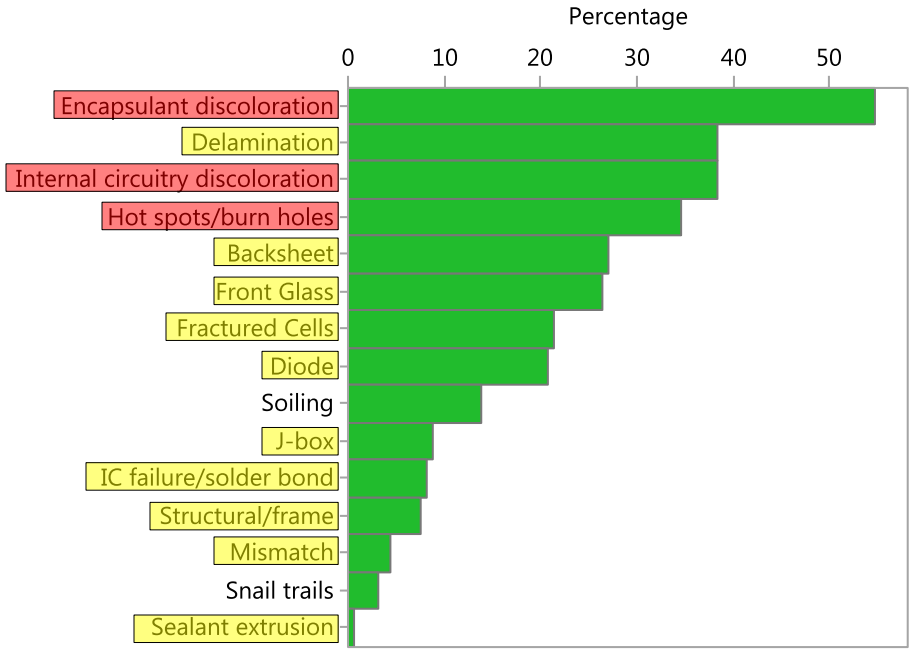
DuraMAT Capability Area 2: Predictive Simulation

"This capability will be a suite of modeling and simulation tools, model workflows, and a community of experts who work in concert with experiments and data analytics… to help interpret and enrich existing test/experimental data, design durability-testing experiments, and help create design rules for Materials Discovery"

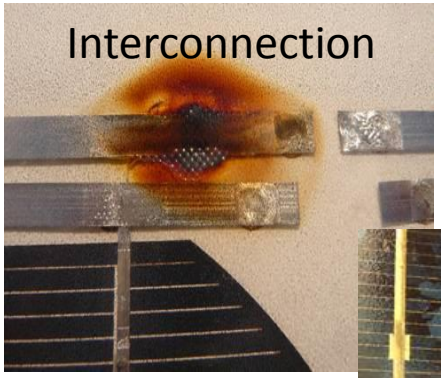
PV modules

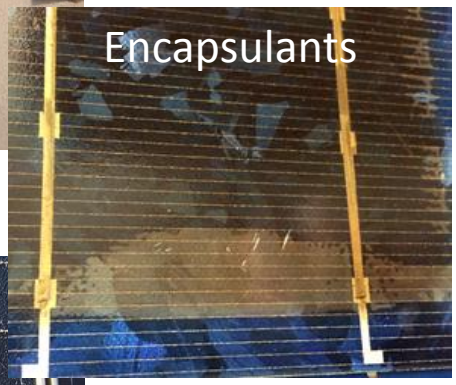

Aluminum frame
Glass front sheet
Front encapsulant
Cells and interconnects
Back encapsulant
Backsheet
Junction Box

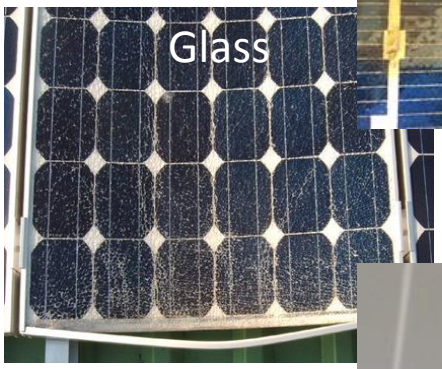
Thermo-mechanical-electrical failure mechanisms

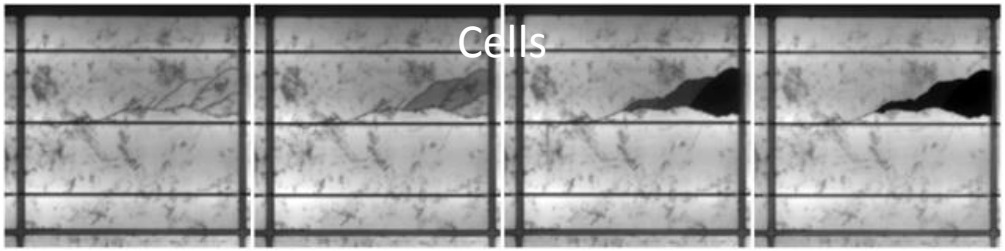


PV failures and degradation modes reported in literature







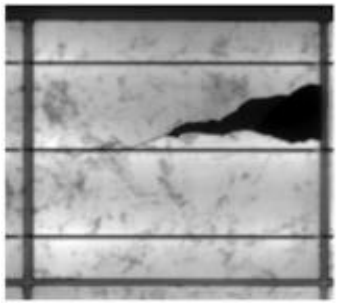


Overview

- PV modules and degradation mechanisms
- **Design questions to be answered with modeling**
  - **Benefits of a module-level model; existing capabilities; previous efforts**
- Model validation capabilities
- Capability development plan

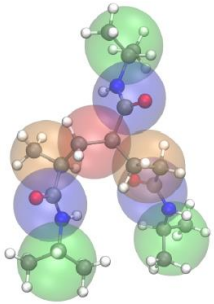
Module design questions to be answered by modeling

What is the driving force for delamination between layers?



What environments are most damaging?

What would the ideal material properties of an encapsulant be to avoid cell cracking and delamination?



Are we *really* capturing a lifetime of exposure in accelerated tests?

Thermal-mechanical-electrical module-level model capability

Sandia National Laboratories

Module CAD

FEM Mesh

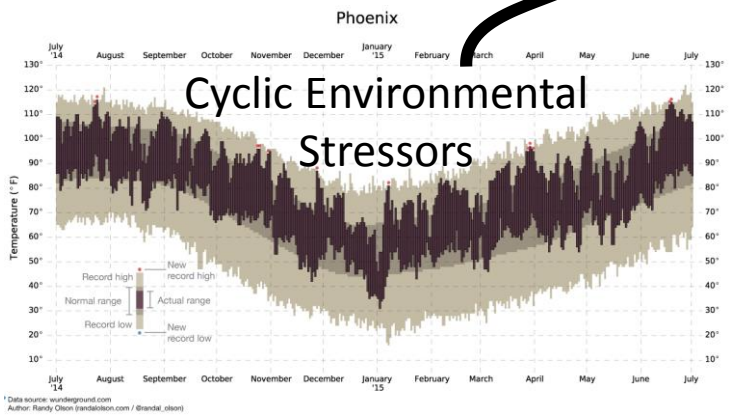
Coupled effects at the full module level

3D Thermal, Mechanical, Electrical Model

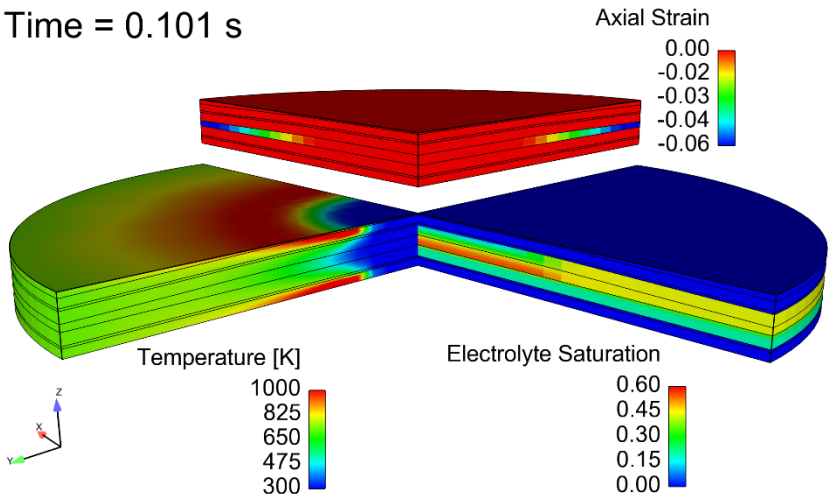
Stress Generation Analysis

Failure prediction

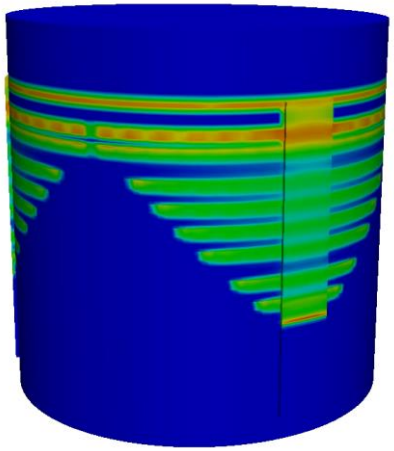
Cyclic Environmental Stressors

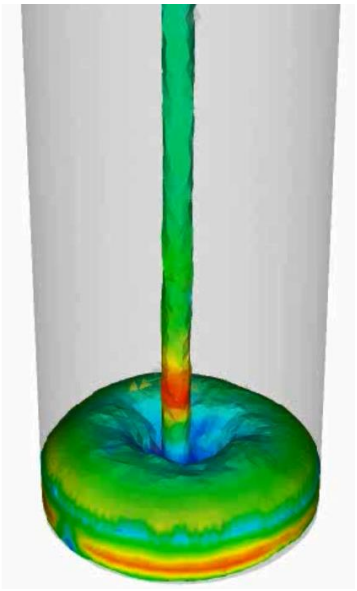


3D thermal-mechanical-electrical modeling capabilities

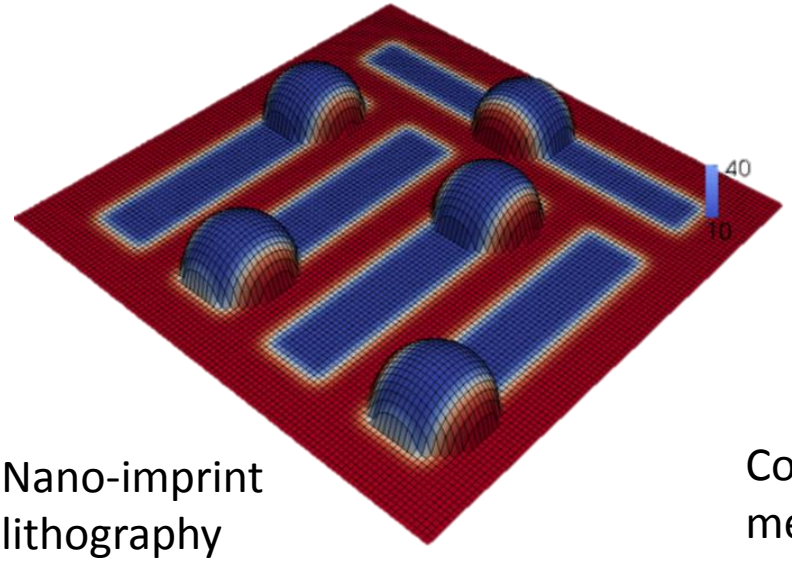


Molten salt batteries

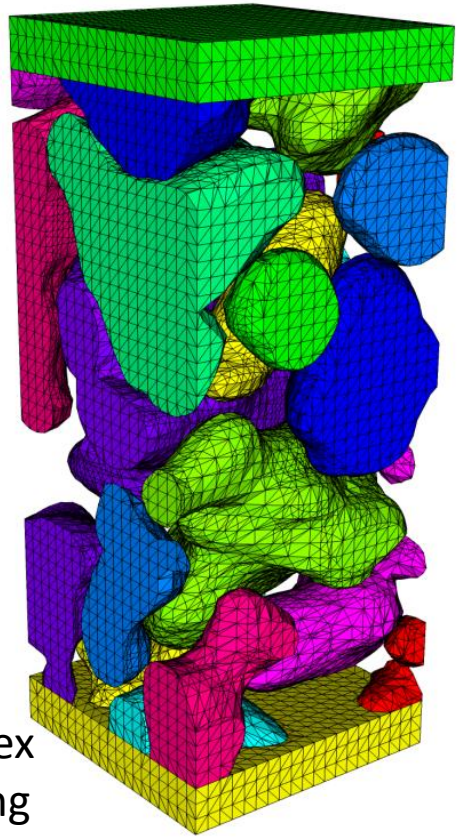




Constitutive modeling: non-Newtonian, visco-plastic, elasto-plastic



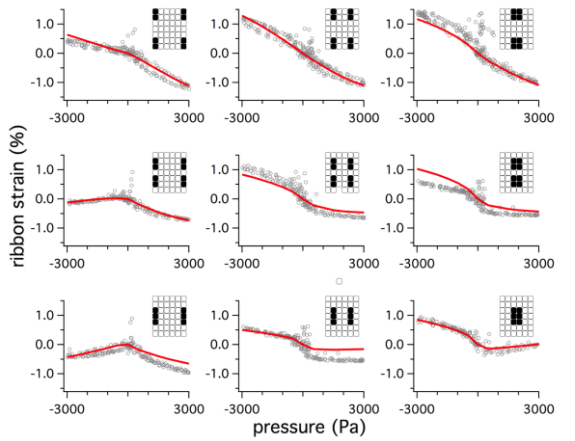
Nano-imprint lithography



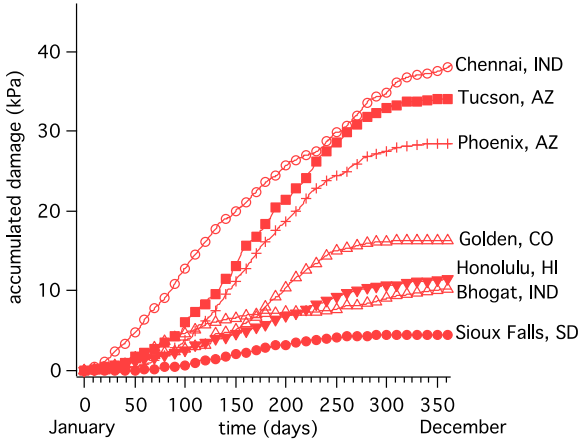
Complex meshing

Previous modeling efforts at NREL

- 3D model of a flat plate PV module to simulate interconnect ribbon strain for module level loading
- 2D model of a flat plate PV module to simulate accumulation of solder thermal fatigue damage through outdoor deployment



Cell-to-cell ribbon strain vs. position in module



Damage rate vs. Geographical Location

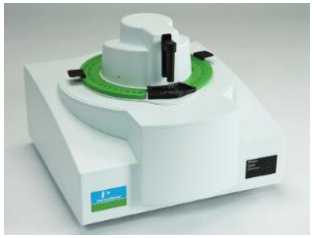
- Results have elucidated:
  - Equivalency between mechanical test conditions and a 30 year exposure
  - What climate conditions drive fatigue damage rate

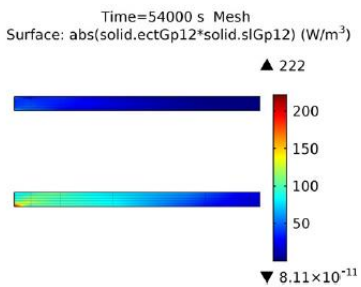
With existing modeling capabilities, much more is possible!

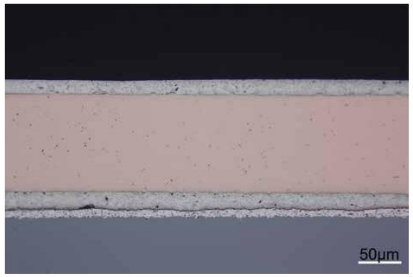
Overview

- PV modules and degradation mechanisms
- Design questions to be answered with modeling
  - Benefits of a module-level model; existing capabilities; previous efforts
- **Model validation capabilities**
- Capability development plan

Thermal-Mechanical validation capabilities



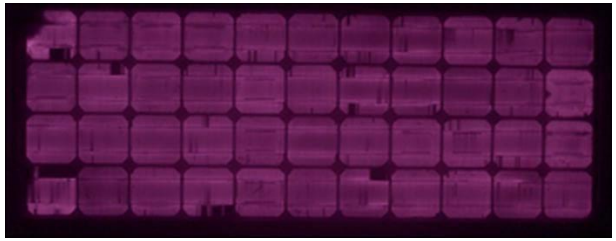




Component scale validation

Materials characterization

3D Thermal, Mechanical, Electrical Model



Module-level test data

Sandia National Laboratories

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Thermal-mechanical validation capabilities

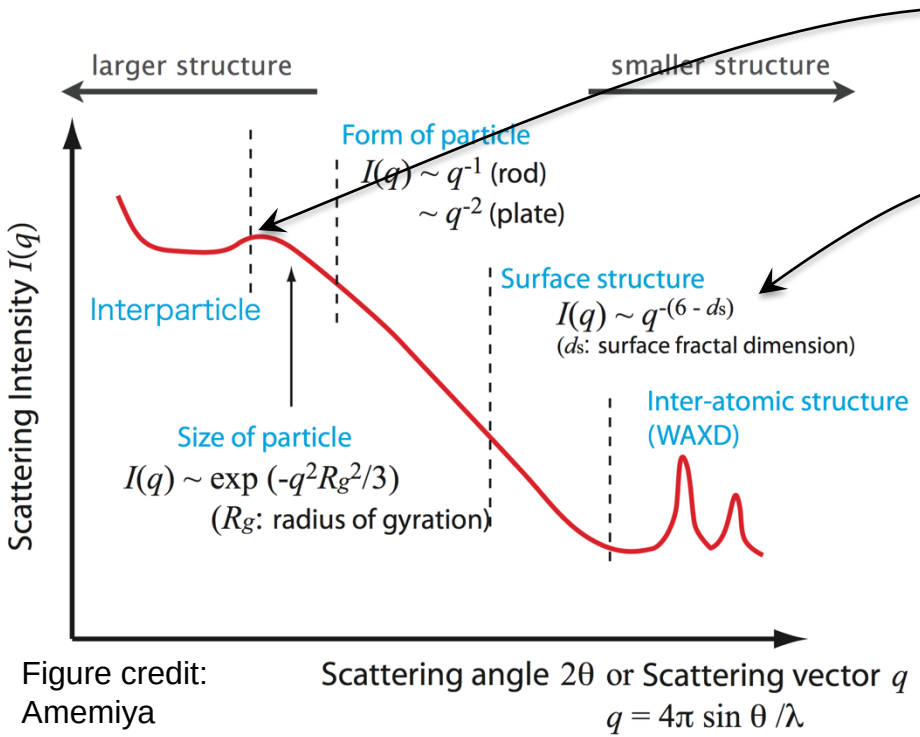
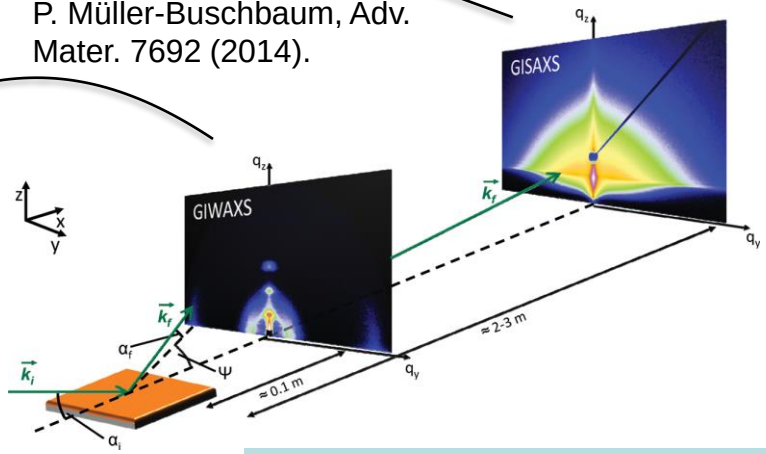


Figure credit: Amemiya

P. Müller-Buschbaum, Adv. Mater. 7692 (2014).



Structural Analysis across many length scales

Operando Structural & Microstructural analysis

- Understand the effects of aging & thermal cycling
- Applied stressors:
  - Atmosphere
  - Humidity
  - Temperature
  - Light
  - Electric field bias
  - Mechanical loading

Overview

- PV modules and degradation mechanisms
- Design questions to be answered with modeling
  - Benefits of a module-level model; existing capabilities; previous efforts
- Model validation capabilities
- **Capability development plan**

Capability development plan

- Scope problem
  - Define the problem (nominal geometry and materials, types of stressors to include)
  - Scope the simulation (single model or coupled workflow? What are key degradation mechanisms to target?)
  - Identify property needs
- Build constitutive models
- Component-level modeling
  - Build model capability for critical components
  - Validate component-level models
- Module-level modeling
  - Combine component concepts into module-scale model workflow
  - Validate against real-world module data

Working with Sandia and DuraMAT

- Capability Area goal is "[a suite of modeling and simulation tools and a community of experts, available to DuraMAT partners and industry/academia teams]"
  - Sandia will stand up and maintain the simulation code and capability
  - Intermediate results to be published and disseminated to the community of practice
  - Intent is for all Sandia modeling expertise to be available to the DuraMAT network

- Collaboration opportunities exist:
  - DuraMAT Solicitation of Letters of Interest
  - Sandia-specific avenues
    - Cooperative Research and Development Agreement (CRADA)
    - Strategic Partnership Programs (SPP); Work For Others (WFO)

Questions?

James Y. Hartley
jkyuan@sandia.gov
(505) 284-8267

Scott A. Roberts
sarober@sandia.gov
(505) 844-7957

Nick Bosco, Ph.D.
nick.Bosco@nrel.gov
(303) 384-6337

Laura Schelhas, Ph.D.
schelhas@slac.stanford.edu
(231) 730-0581