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

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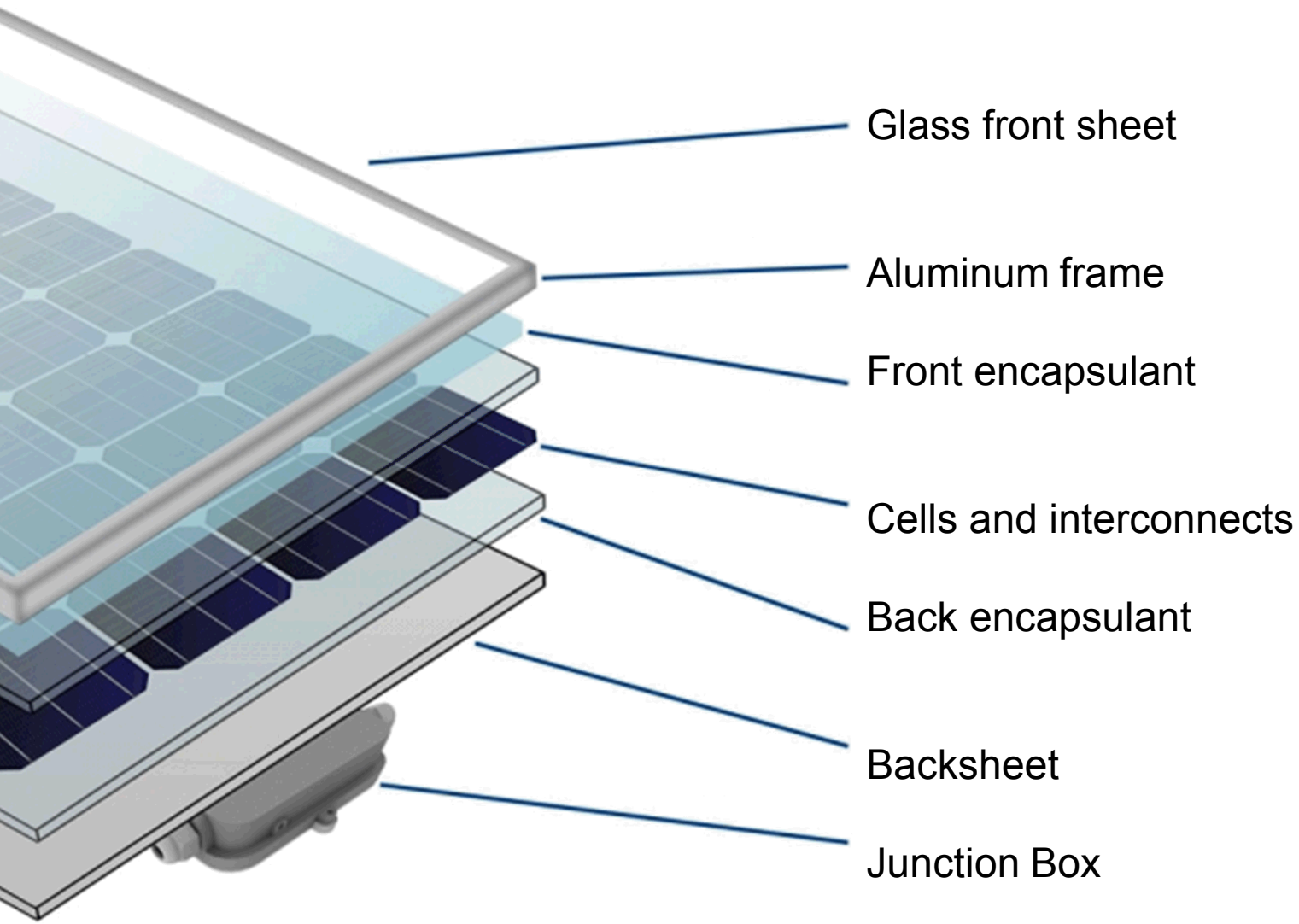
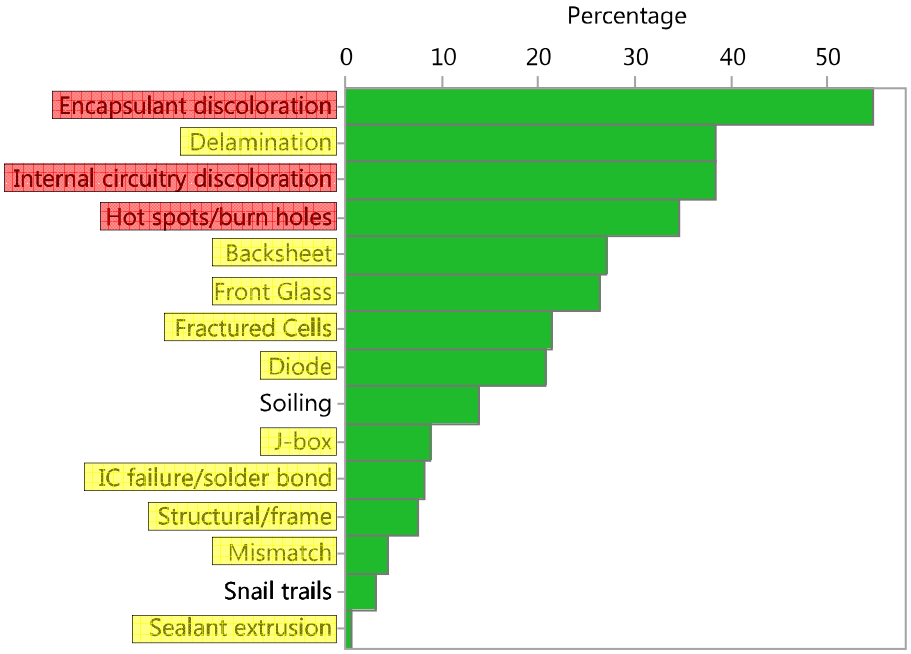
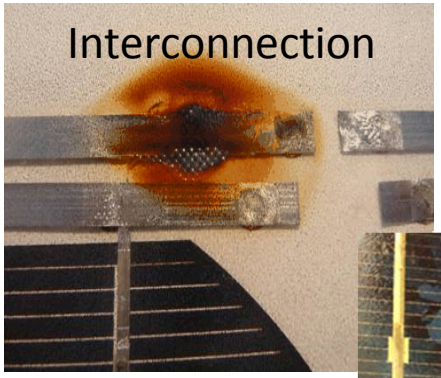
PV modules

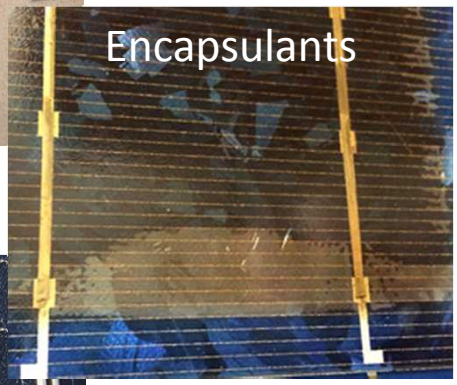

Glass front sheet
Aluminum frame
Front encapsulant
Cells and interconnects
Back encapsulant
Backsheet
Junction Box

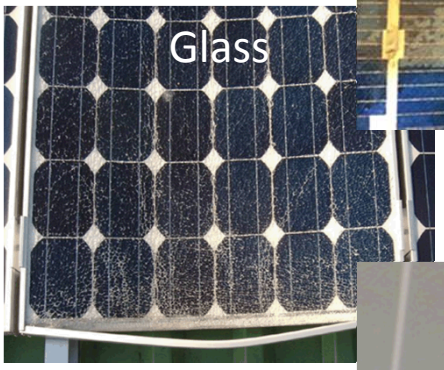
Thermo-mechanical-electrical failure mechanisms

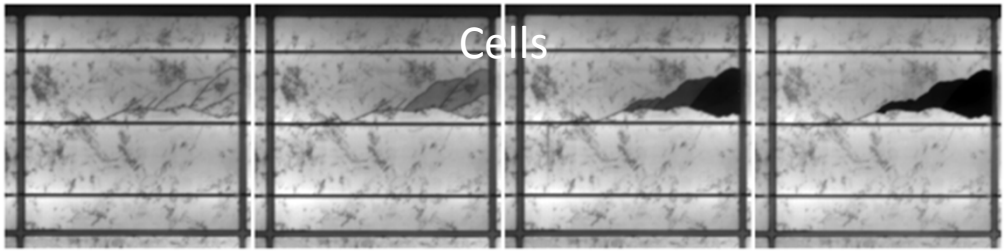


PV failures and degradation modes reported in literature









Module design questions to be answered by modeling

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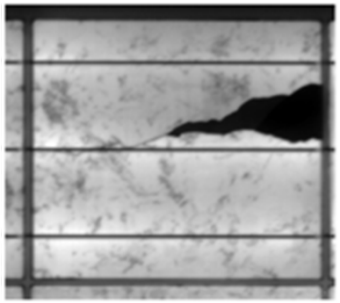
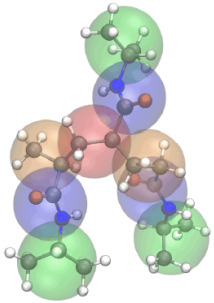
What is the driving force for delamination between layers?



What material properties most affect stress generation?

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



Can we tailor the materials to their target environments?

Thermal-mechanical-electrical module-level model capability

Module CAD

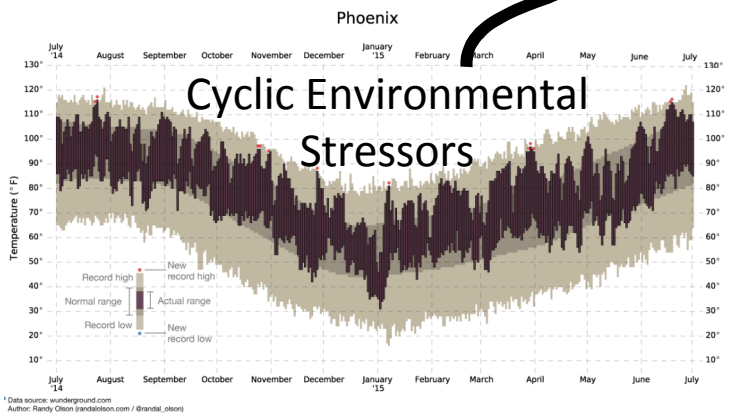
FEM Mesh

3D Thermal, Mechanical, Electrical Model

Stress Generation Analysis

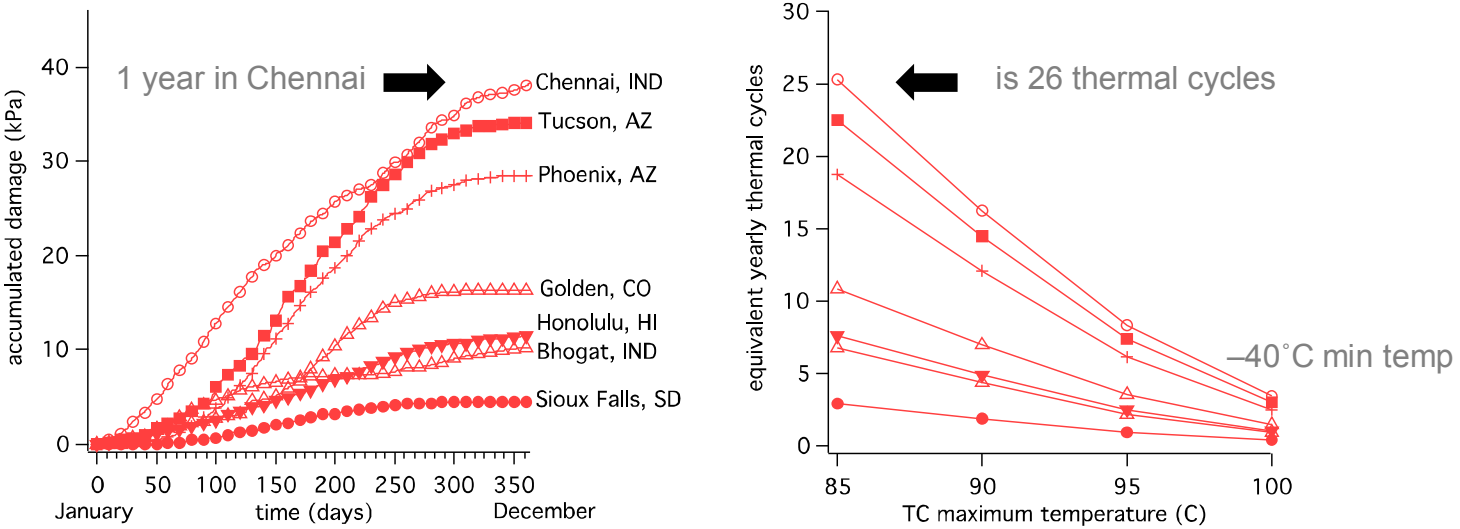
Failure prediction

Cyclic Environmental Stressors



Previous modeling efforts at NREL

- 2D model of a flat plate PV module to simulate the accumulation of solder thermal fatigue damage through outdoor deployment.

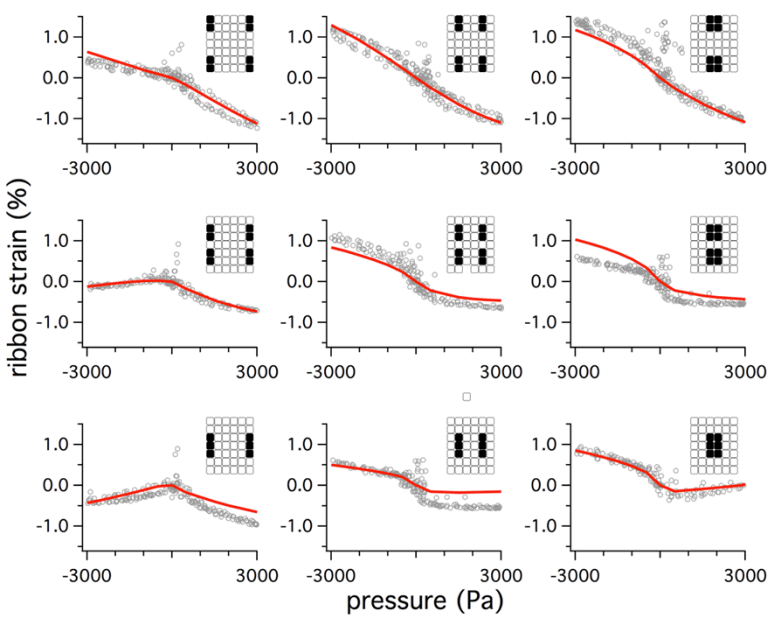


- Results elucidated:
  - how the damage rate differs in different climatic zones
  - the equivalency between outdoor deployment and accelerated thermal cycling
  - how module materials effect solder fatigue and its accelerated testing

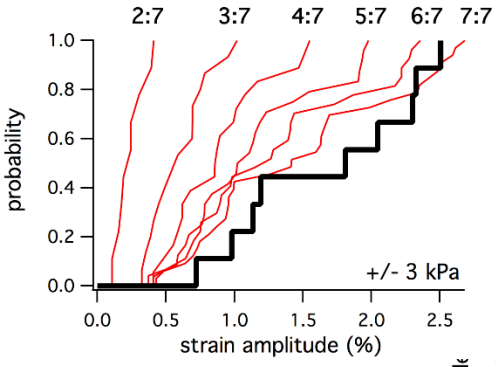
Previous modeling efforts at NREL

- 3D model of a flat plate PV module to simulate the mechanical fatigue of interconnect ribbon.

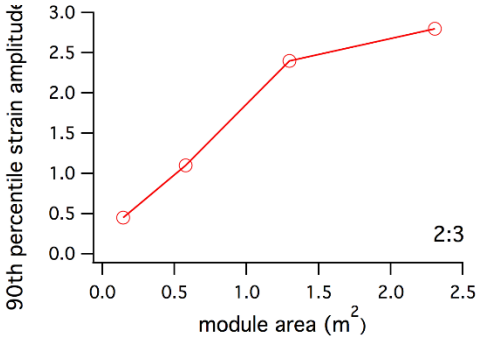
ribbon strain response to mechanical loading



distribution of ribbon strain for module aspect ratio…

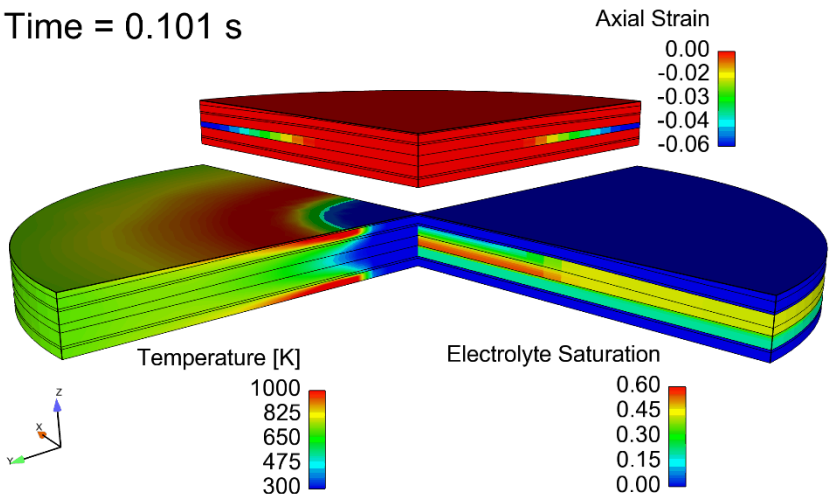


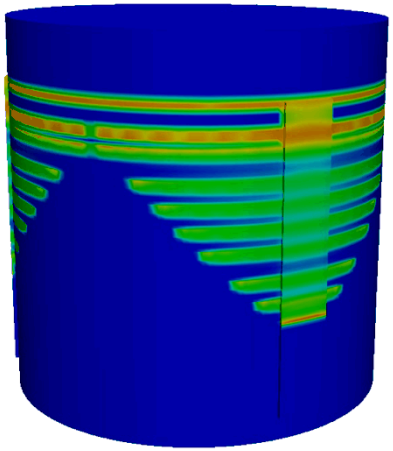
and module area



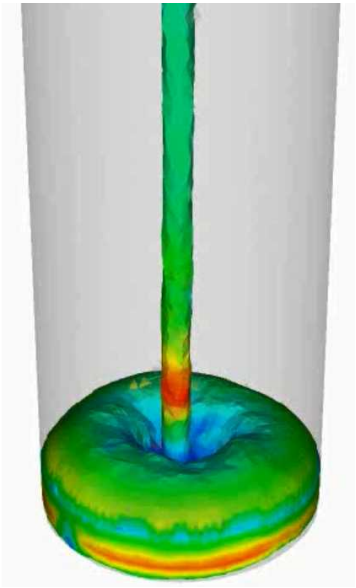
- Results:
  - accurately simulated ribbon strain through module thermal and mechanical loading
  - elucidated how module characteristics effect the distribution of ribbon fatigue
  - predicted failure through thermal and mechanical cyclic loading

3D thermal-mechanical-electrical modeling capabilities

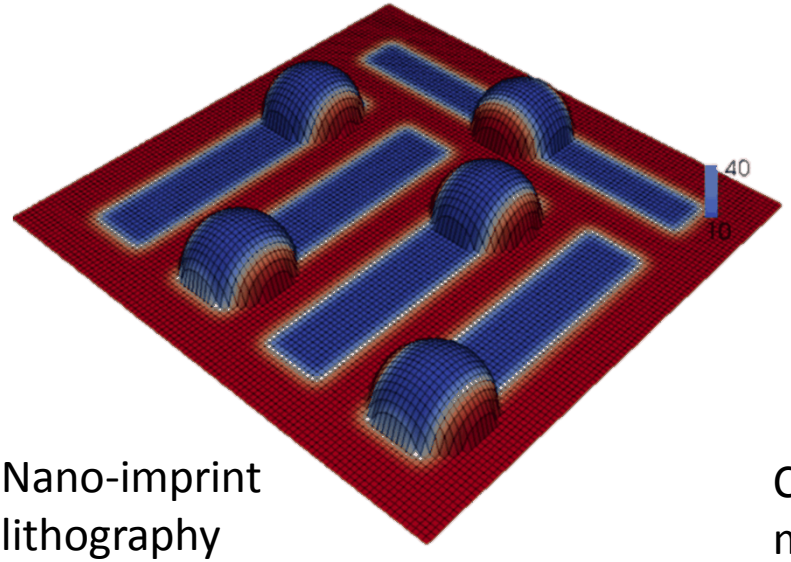




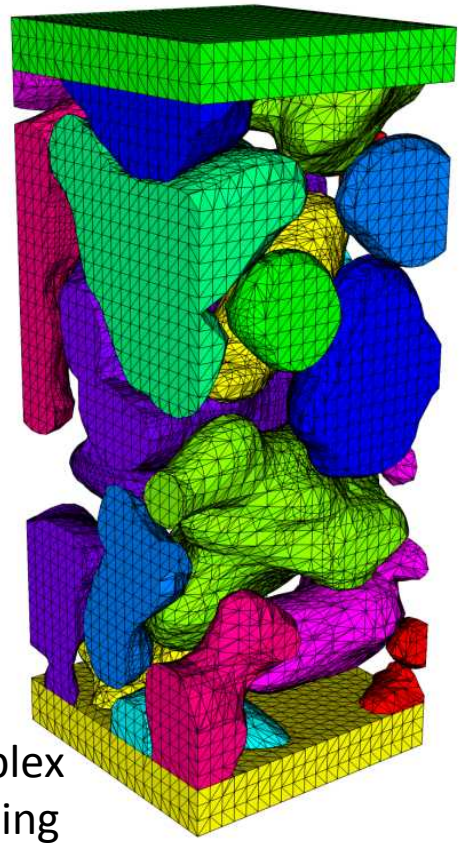
Molten salt batteries



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



Nano-imprint lithography



Complex meshing

Component-scale thermal-mechanical validation

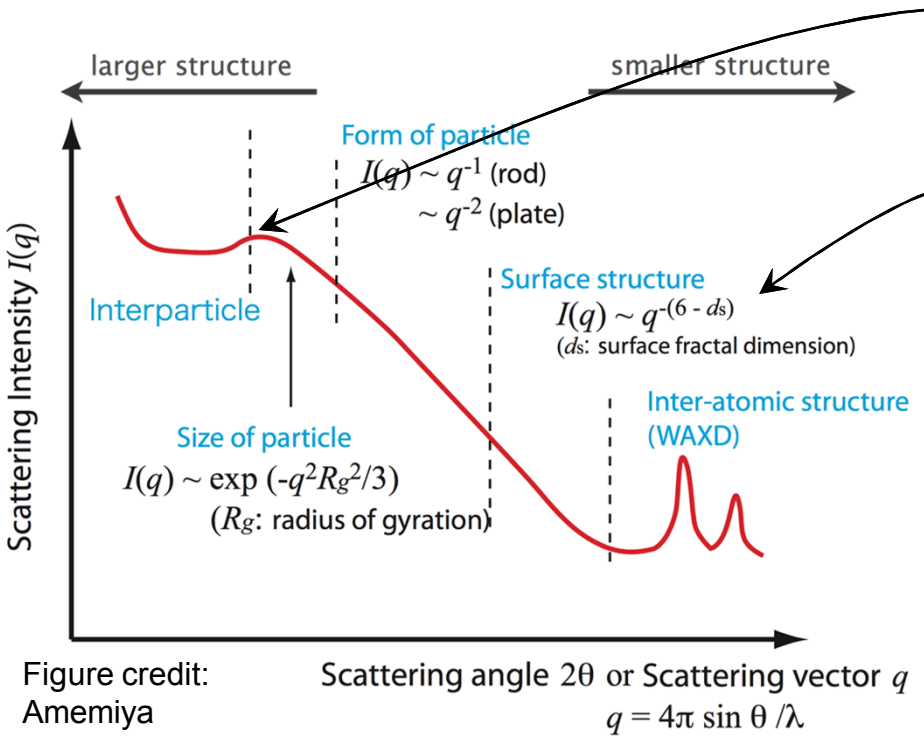
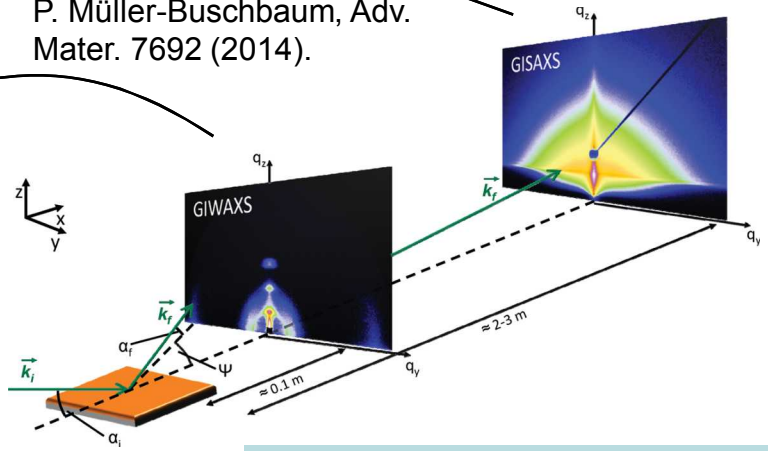


Figure credit: Amemiya

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



Structural Analysis across manly length scales

Operando Structural & Microstructural analysis

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

Capability development plan

- Scope problem
  - Define the problem (nominal geometry, materials, environment)
  - Scope the simulation (how big will this have to be? Where can we simplify?)
- 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
  - Validate against real-world module data

Conclusions

- Summary
  - Goal: Develop 3D thermal-mechanical-electrical module-scale computational model
  - Experience:
    - PV modules and materials, 2D modeling
    - 3D thermal-mechanical-electrical modeling of thin materials
    - Operando structural and microstructural analysis

- Questions?

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