Multiscale and Multiphysics Characterization of Advanced Materials Systems

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Research Overview

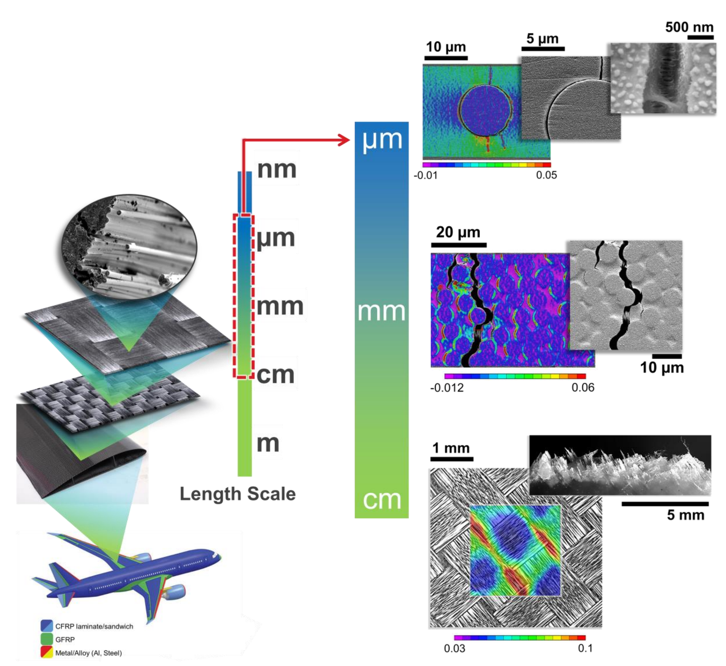
We are broadly interested in understanding **process-structure-property-performance** relations in advanced materials systems. We use a variety of different measurement techniques to explore the origins of temperature-dependent and rate-sensitive response of advanced materials and structures at multiple length and time scales.

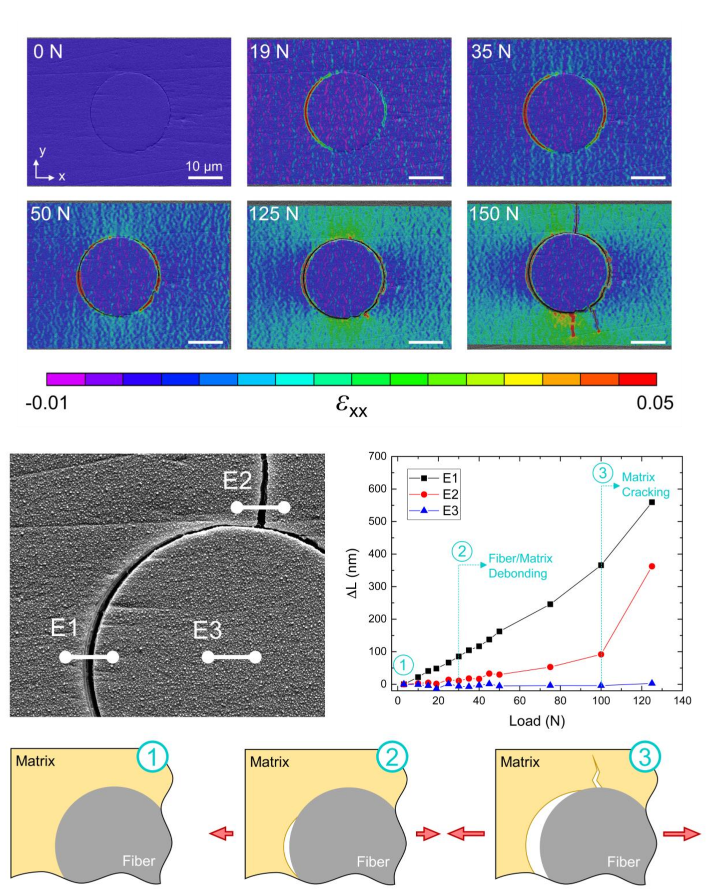
The current research interests of the group include but are not limited to:

- Multiscale characterization of composites and other heterogeneous materials
- *In situ* and *operando* characterization of materials for energy applications
- Design, fabrication, and characterization of functionally graded structures

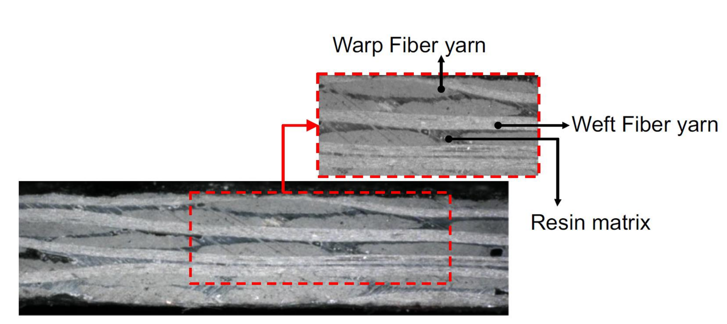
Multiscale Characterizations

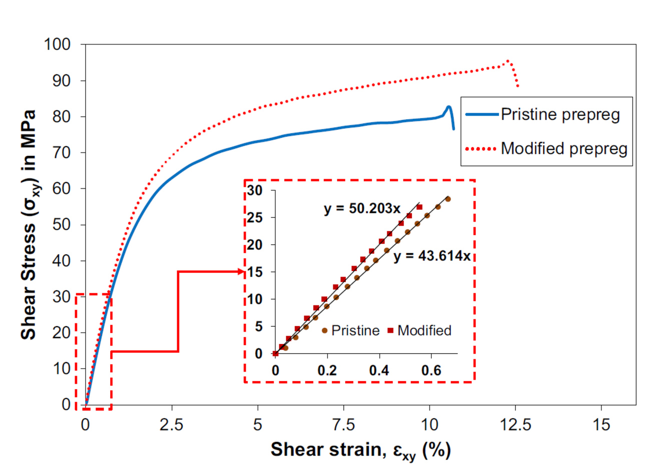
Bridging between various length scales is the key to explore the origin of load-bearing and failure mechanisms in fiber-reinforced composites and other highly heterogeneous materials. Development of hybrid experimental/computational techniques is a major part of our research, allowing for such multiscale characterizations.





Microscale characterization
Top: Full-field strain distribution in the vicinity of a single glass fiber embedded in an epoxy resin
Bottom: Measurement of local deformation response with nanometric resolution





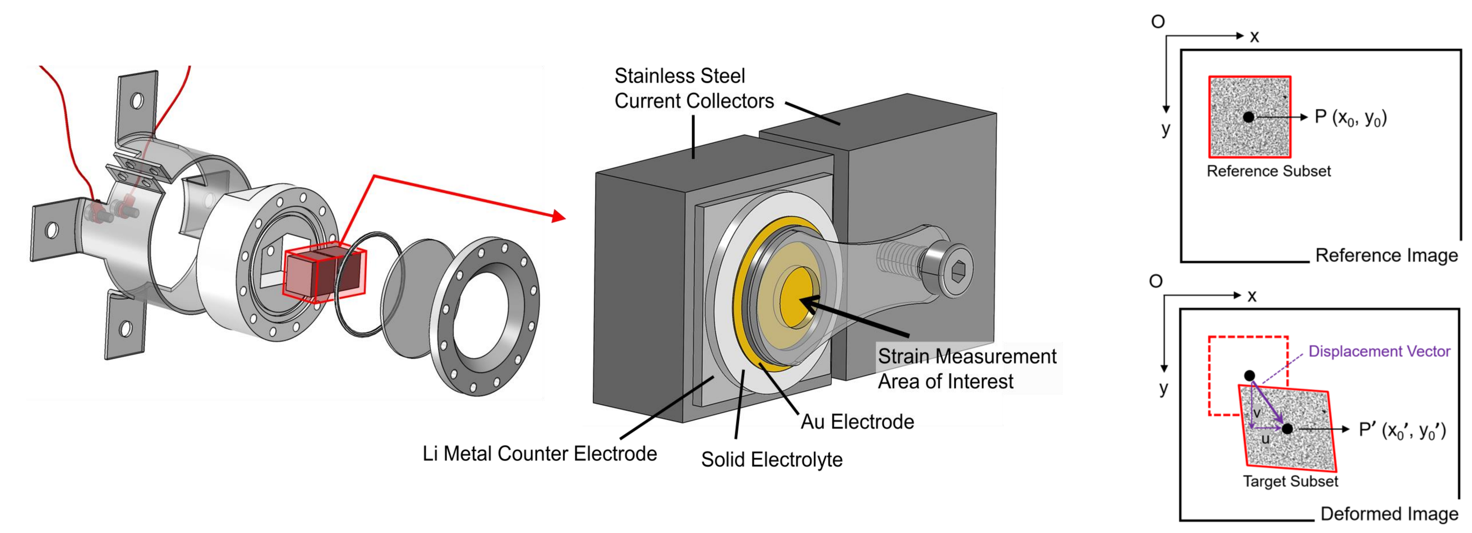
Meso and Macroscale characterization
Top: Microscopic view of the Warp yarn, weft yarn, and resin Matrix
Bottom: In-plane shear stress–strain curve for pristine and silica nanoparticle reinforced laminates

Montgomery et al. Experimental Mechanics, 2019

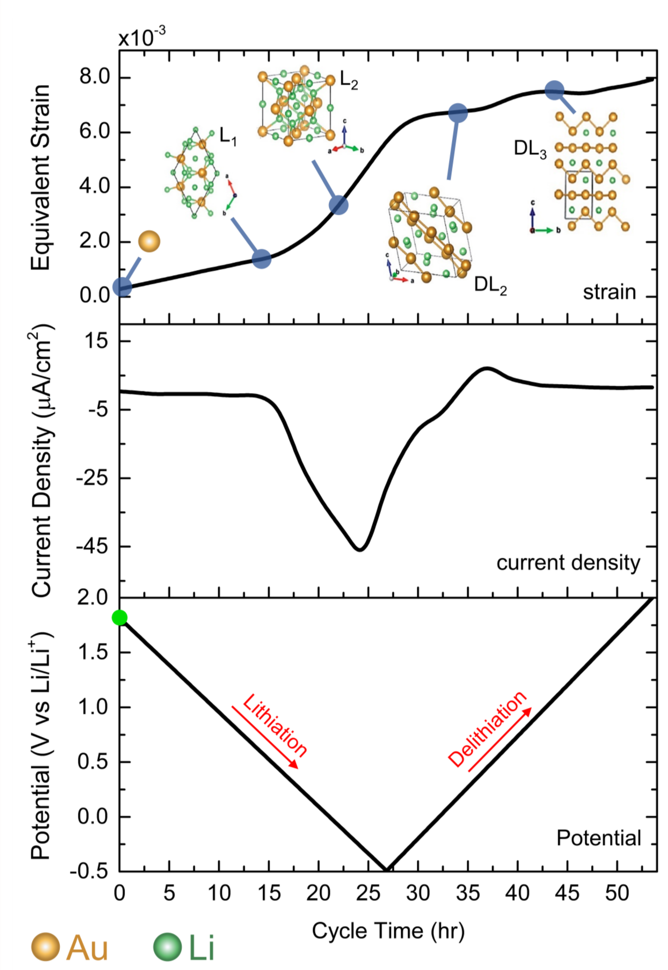
Tessema et al. Journal of Dynamic Behavior of Materials, 2018

Chemo-Mechanics of Solid Batteries

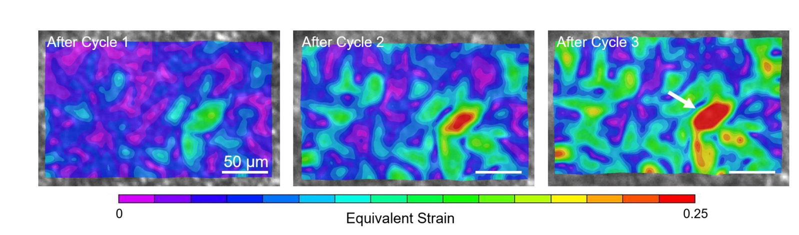
Custom battery cell for measurement of chemo-mechanical strains in solid-state batteries. Digital Image Correlation (DIC) is used for measuring chemo-mechanical strains in these batteries.



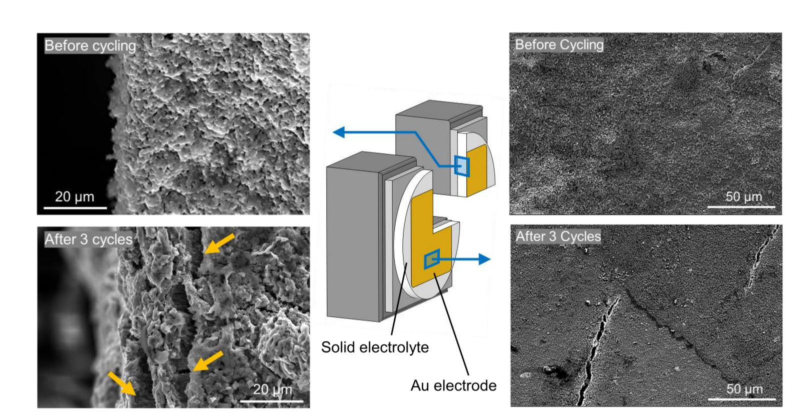
Strain Measurement in Au Electrodes



Measurement of electrochemical and mechanical responses

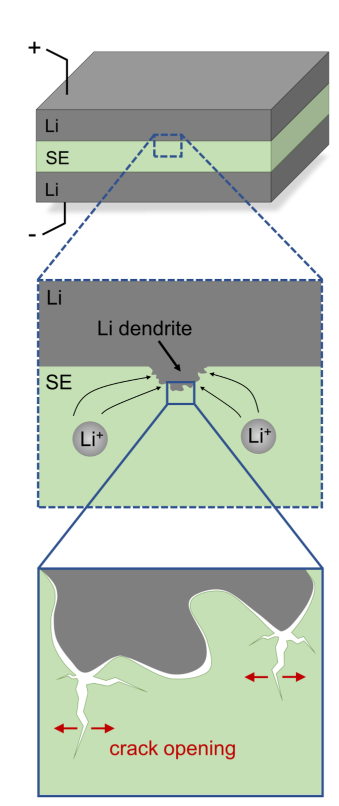


Irreversible increase of chemo-mechanical strains in Au working electrode leads to mechanical instability

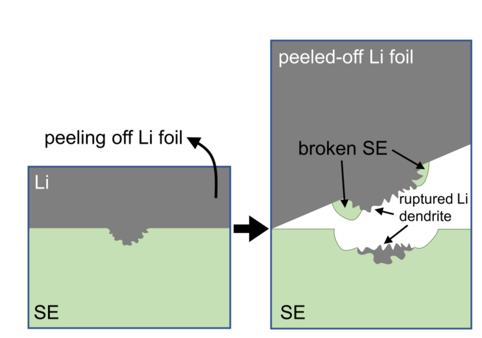


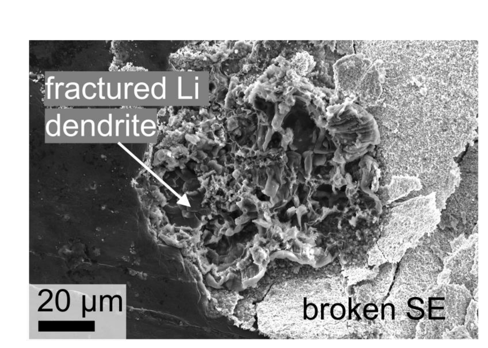
Mechanical Instability in solid electrolyte (*left*) and Au electrode (*right*)

Strain Measurement in Solid Electrolytes

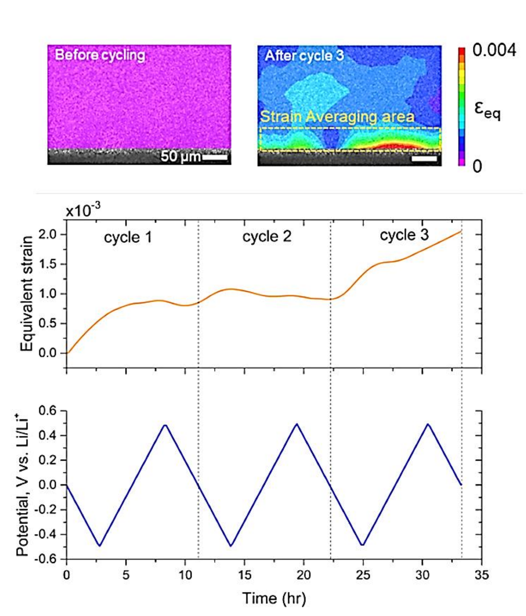


Li deposition at the SE-electrode interface leads to microcrack formation in the solid electrolyte.





Evidence of Li deposition in solid electrolyte in a Li/LAGP/Li cell

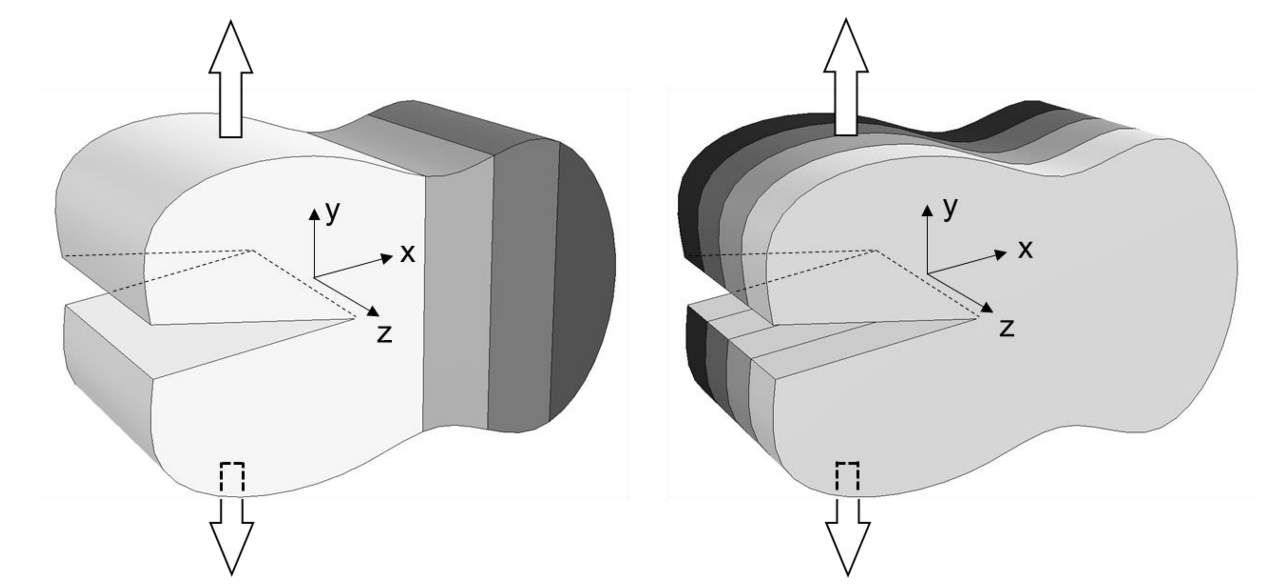


In situ strain measurement facilitated by DIC enables the observation and characterization of Li deposition in solid state batteries.

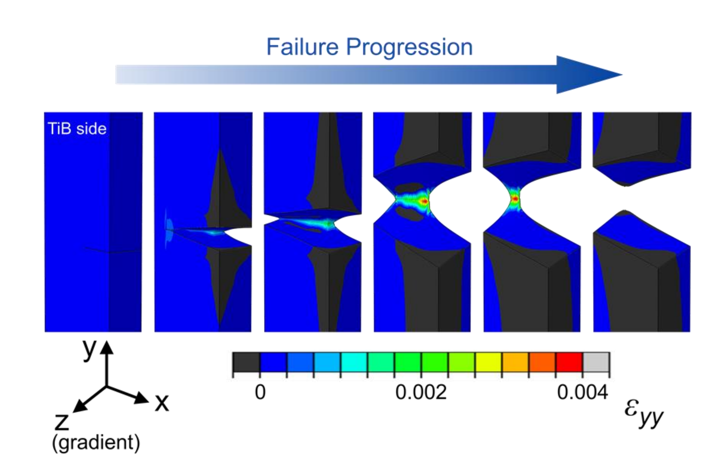
Contour maps showing the evolution of chemo-mechanical strain in the vicinity of Li/LAGP interface

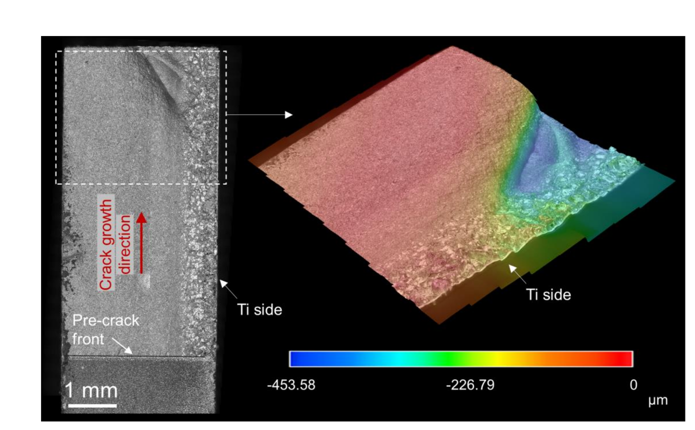
Functionally Graded Structures

Functionally graded materials (FGMs) are non-homogeneous composites with discrete or continuous variation of material composition over a definable geometrical length. Our work aims to characterize the load bearing and fracture resistance of FGMs. Our goal is to identify material/property gradation functions that lead to optimal thermo-mechanical and fracture properties.

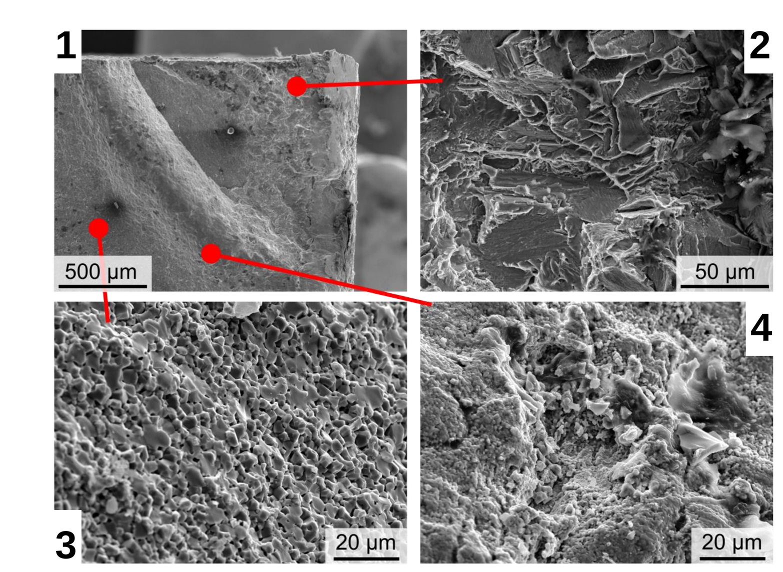


Schematic representation of cracked through-gradient (***left***) and transversely-graded (***right***) plates under far-field tensile load.





Top: FE simulation snapshots showing the distribution of opening strain during failure progression in a Ti-TiB graded structure. ***Bottom:*** Post-mortem 3D profilometry of the fracture surface.



Post-mortem fracture surface of a Ti-TiB FGM showing a variety of different surface morphologies corresponding to different layer compositions:

1: Plastically deformed local region at the Ti side
2: A high magnification view of the Ti quasi-cleavage fracture surface
3: Brittle fracture surface of 45TiB-55Ti layer
4: Brittle-to-semi ductile fracture transition area developed in the 15TiB-85Ti layer.

Koohbor et al. Composite Structures, 2019

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