Unraveling Dendrite Formation in Solid-State Batteries

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Solid-state batteries are promising next-generation energy storage devices because they can offer higher energy density and improved safety compared with conventional lithium-ion batteries. However, their widespread deployment is limited by the formation of lithium dendrites—metallic structures that grow within the battery and can cause catastrophic short circuits and failure. Understanding how dendrites form is therefore essential for developing reliable solid-state battery technologies.

To investigate dendrite formation, measurements combined with high-field nuclear magnetic resonance (NMR), magnetic resonance imaging (MRI), and electron paramagnetic resonance (EPR) spectroscopy at the National High Magnetic Field Laboratory (NMHFL) enabled non-destructive observation of lithium transport and microstructure evolution inside operating batteries. ^{7}Li MRI images revealed that dendrites can originate through two distinct mechanisms: direct lithium metal plating and lithium-ion reduction within the solid electrolyte.

This work provides new insight into the fundamental failure mechanisms of solid-state batteries by establishing that multiple dendrite formation pathways can coexist and evolve differently during battery operation. The findings provide a framework for designing electrolytes and interfaces that suppress dendrite growth, accelerating the development of safer, longer-lasting batteries for electric vehicles, portable electronics, and large-scale renewable energy storage.

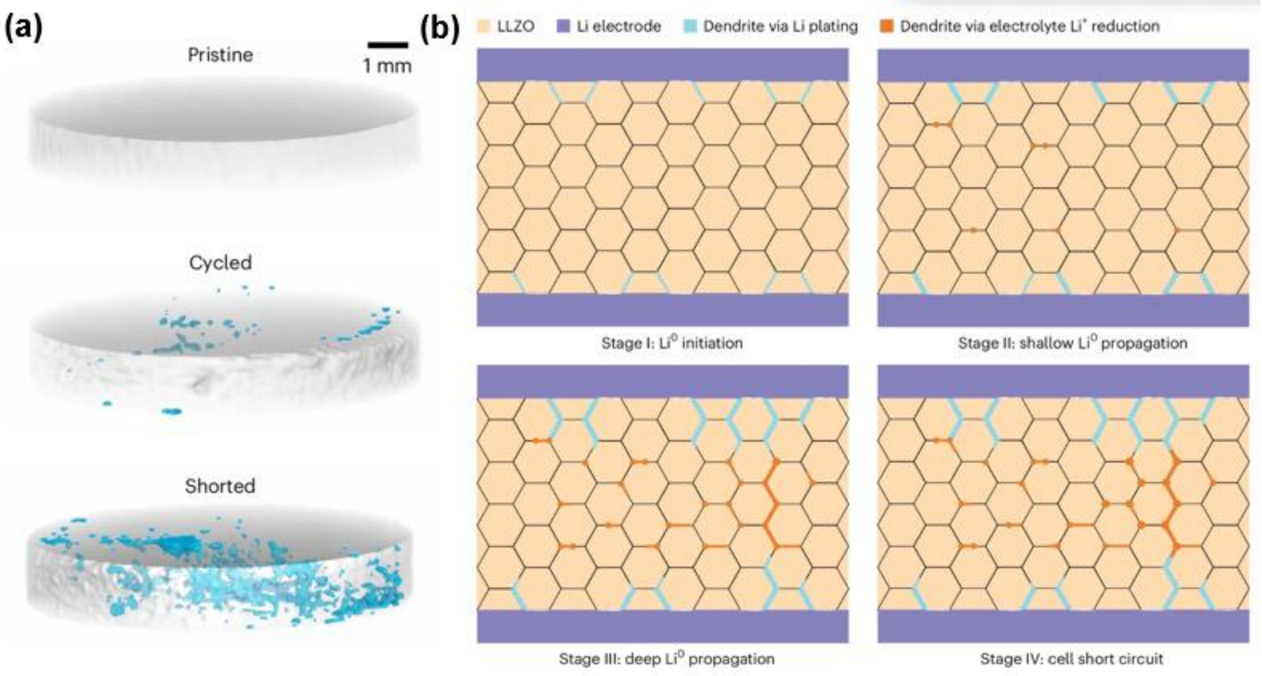

Figure 1 (a) Volume-rendered 3D ^{7}Li MRI images of pristine, cycled, and shorted $Li_7La_3Zr_2O_{12}$ (LLZO) pellets. Blue regions show metallic lithium growing inside a transparent solid-electrolyte pellet. (b) Schematic illustrating Li dendrite formation mechanisms and propagation processes in Li/LLZO/Li.

Facilities and instrumentation used: 21.1 T 19.6 T and 11.75 T NMR spectrometers (NMR Facility) and 240 GHz continuous-wave heterodyne EPR spectrometer (EMR facility)

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