MAX PLANCK INSTITUTE
FOR SUSTAINABLE MATERIALS

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# Understanding the short circuit in solid-state batteries

Max Planck team explains dendrite propagation, paving the way for safer and longer-lasting next-generation batteries. They publish their findings in the journal Nature.

**At a glance:**

- **Topic:** The commercialization of solid-state batteries which come with a higher energy-storage capacity, longer lifetime and safety than the widely used lithium-ion batteries, is till now prevented by short circuits happening during charging.
- **Challenge:** During charging, dendrites form at the electrodes and penetrate the solid electrolyte, leading to short circuits.
- **Research question**: How can soft lithium metal used for the electrodes fracture the stiff ceramic electrolyte?
- **Approach**: Sample preparation and material's characterization under cryogenic temperatures and vacuum conditions, supported by micromechanical fracture modelling.
- **Results**: Lithium-metal electrodes generate hydrostatic stress that leads to tensile stress in the solid electrolyte and causes fracture.

Smartphones, electric vehicles and many portable devices rely on batteries. Their energy storage capacity, lifetime and safety will strongly shape the future of electrification. Among the most promising next-generation technologies are solid-state batteries. These batteries would allow smartphones to run for several days instead of requiring daily charging and electric vehicles with third as high driving range as today's options.

Unlike today's widely used lithium-ion batteries, which use a liquid electrolyte between two solid electrodes, solid-state batteries employ a solid electrolyte. This design can increase energy density, improve safety and extend battery lifetime. However, one major challenge still limits their commercial use. During charging, microscopic intrusions known as dendrites, form. These tiny tree-like structures grow from the anode, penetrate the solid electrolyte and cause short circuits inside the battery.

An interdisciplinary team at the Max Planck Institute for Sustainable Materials (MPI-SusMat) has now uncovered how dendrites induce fracture, leading to short circuits. They published their results in the journal Nature.

**What causes dendrite-induced cracking in solid-state batteries?**

Dendrite formation in solid-state batteries is a counterintuitive phenomenon. "Although the electrodes and the forming dendrites consist of lithium metal, which is soft like a gummy bear, the dendrites are able to penetrate the ceramic electrolyte and lead to a short circuit," says Dr. Yuwei Zhang, first author of the new publication and head of the group "Chemo-Mechanics of Battery Materials" at MPI-SusMat. "How can soft dendrites fracture the stiff solid ceramic? There are two hypotheses: either internal stress is built up inside the dendrites and induces mechanical fracture of the solid electrolyte. Or, electrons leak along the grain boundaries of the solid electrolyte promoting the formation of lithium nuclei that interconnect later."

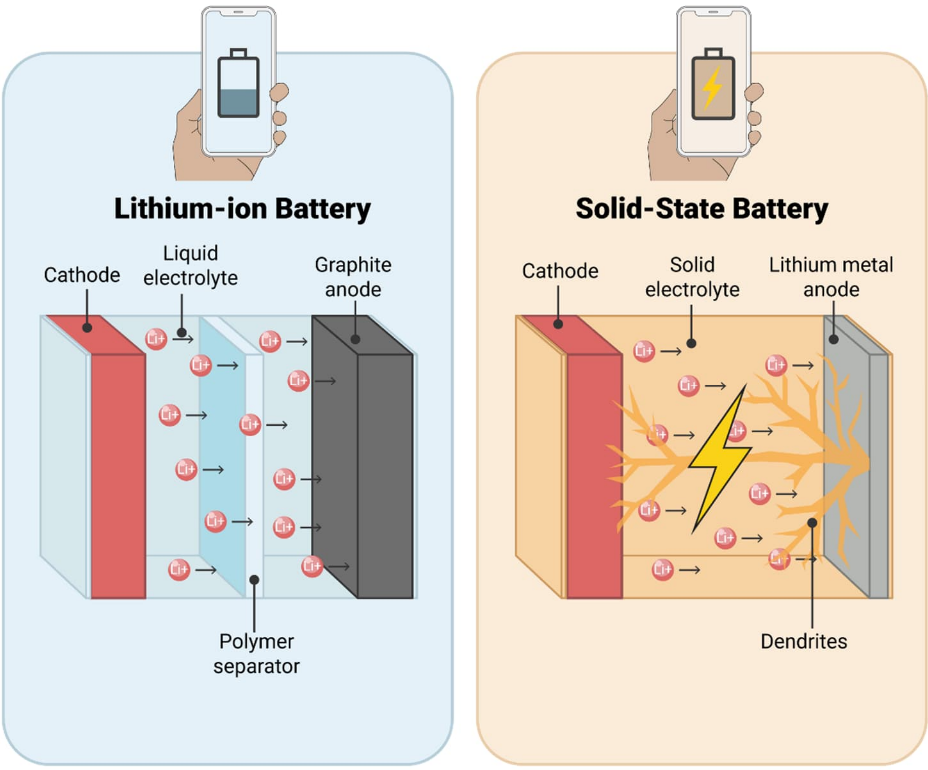
To prove either hypothesis, the researchers used a complex setup of sample preparation and material's characterization techniques, characterized entirely under vacuum and cryogenic temperatures to exclude any influence from oxygen, water or from the electron beam of the microscopes.

The Max Planck team analysed the stress state and plastic activity of lithium dendrites confined within the cracks and was able to show that no lithium was enriched ahead of the dendrite tip. "The soft lithium metal is able to penetrate the stiff ceramic electrolyte, like a continuous waterjet that penetrates a rock. We calculated that hydrostatic stress in the dendrite leads to brittle fracture of the solid electrolyte in the end", says Zhang. Additional phase field simulations and electron backscatter diffraction measurements backed up their findings.

**Possible ways to prevent or delay dendrite-induced cracking**

After uncovering how dendrite-induced cracking occurs, the researchers are now exploring strategies to prevent it. Possible approaches include increasing the toughness of the solid electrolyte to delay crack formation, introducing microscopic voids that redirect dendrite growth and deflect cracks, or applying protective coatings to the lithium electrodes to suppress dendrite formation.

These findings highlight how crucial a fundamental understanding of materials behaviour is for turning promising technologies into practical, real-world applications.




Inside of a lithium-ion battery compared to a solid-state battery. The widely use of solid-state batteries is till now prevented due to the formation of dendrites while charging. Copyright: P. Mehta: Max-Planck-Institut für Nachhaltige Materialien GmbH

**Original publication:**

Y. Zhang, S. Motahari, E.V. Woods, S. Zaefferer, P. Schweizer, Z. Zhang, Y. Liu, B. Gault, F. Roters, D. Raabe, C. Scheu, Y. Joshi, S. Zhang, C. Liu, G. Dehm: Mechanically driven Li dendrite penetration in garnet solid electrolyte. In: Nature 652 (2026) 912. DOI: 10.1038/s41586-026-10415-9



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