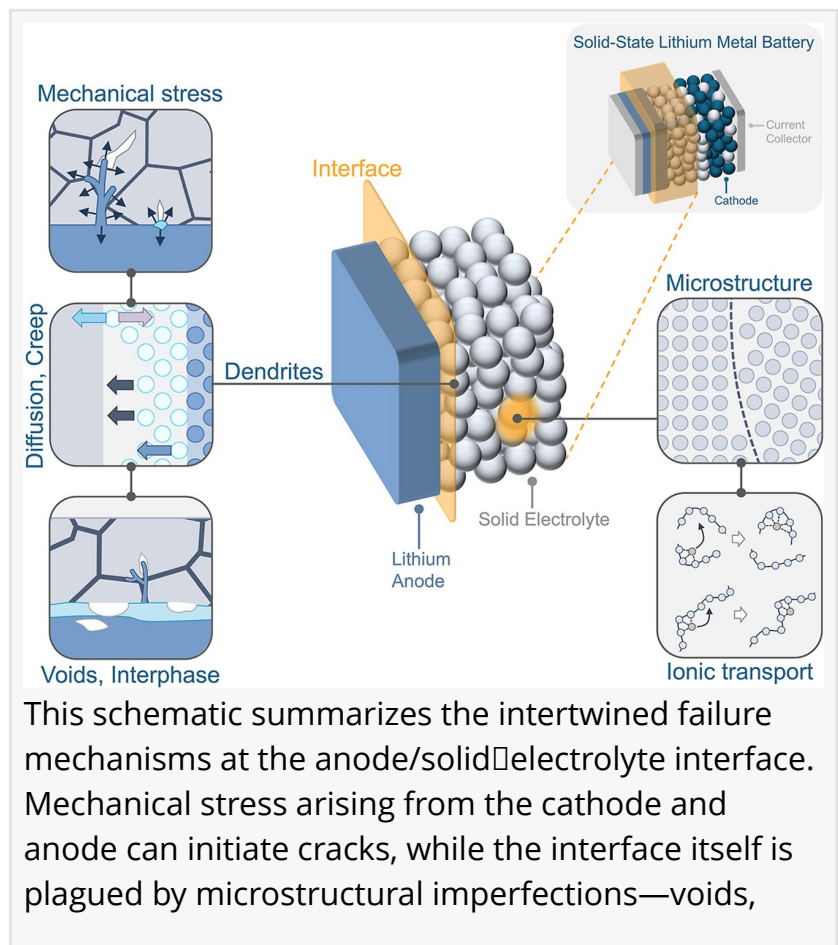


A microscopic view of dendrites: Why solid-state batteries still fall short

GA, UNITED STATES, September 11, 2026 /EINPresswire.com/ -- All-solid-state lithium metal [batteries](#) have long been hailed as the future of energy storage—offering higher energy density, faster charging and improved safety over conventional lithium-ion batteries. Yet after years of research, these batteries still fall short of commercial expectations. The primary obstacle? Dendrites—microscopic lithium filaments that grow inside the battery during charging, eventually causing short circuits and failure. A comprehensive new review brings together the latest microscopic evidence to decode exactly how and why dendrites form, identifying low lithium self-diffusion and interfacial defects as the critical drivers behind this persistent problem.



Lithium metal anodes offer a theoretical energy density nearly double that of conventional graphite anodes—454 Wh kg⁻¹ compared to 314 Wh kg⁻¹ at the cell level when paired with lithium nickel cobalt aluminum oxide cathode. But dendrite formation has sabotaged this promise for decades. Inorganic solid electrolytes such as garnet-type LLZO and sulfide-based solid electrolytes often fail at current densities below 1 mA cm⁻², far below the 4–10 mA cm⁻² achievable with liquid electrolytes. Polymer solid electrolytes, while more flexible, suffer from ionic conductivities several orders of magnitude lower. The core challenge lies at the interface where the solid electrolyte meets the lithium anode—a region plagued by voids, grain boundaries, cracks and chemical instabilities. Based on these challenges, there is an urgent need for an in-depth investigation into the microscopic origins of dendrite formation across all types of solid electrolytes.

Now, researchers from Forschungszentrum Jülich in Germany, RWTH Aachen University and Stanford University have published a comprehensive review in the journal *eScience* that synthesizes the current understanding of dendrite formation at the solid electrolyte/lithium metal anode interface. Available online since 7 May 2026, the review examines inorganic, polymer and hybrid solid electrolytes, establishing critical correlations between key parameters and the processes that govern dendrite growth.

The review reveals that dendrite formation is rarely the result of a single failure mode but rather a cascade of interconnected degradation processes. At the atomic level, lithium-ion transport in inorganic solid electrolytes relies on ion hopping through crystal lattices, with grain boundaries often acting as bottlenecks—ionic conductivity at grain boundaries can be three orders of magnitude lower than through the bulk material. These same grain boundaries, particularly when enriched with impurities, become preferential nucleation sites for lithium filaments.

The researchers identify lithium self-diffusion—the movement of lithium atoms within the metal anode itself—as a critical factor. With a self-diffusion coefficient around $10^{-11} \text{ cm}^2 \text{ s}^{-1}$, lithium atoms simply cannot replenish the interface fast enough during stripping at low stack pressure, leading to void formation. These voids then concentrate current density, accelerating dendrite growth in subsequent plating cycles. To overcome the issue of low self-diffusion, high stack pressure is often used to promote lithium creep and avoid void formation. However, lithium creep into the solid electrolyte during storage or long-term operation under high stack pressure can also be detrimental. For polymer solid electrolytes, the review highlights how segmental motion of polymer chains governs ion transport, and how dynamic crosslinked polymers with reversible bonds can potentially self-heal interfacial defects.

The review also examines how electronic conductivity in solid electrolytes—often arising from defects or decomposition—creates internal electron pathways that allow lithium to plate inside the solid electrolyte, not just at the interface. This internal plating can generate mechanical stress sufficient to fracture even ceramic solid electrolytes with fracture toughness in the $\text{MPa m}^{0.5}$ range.

The authors said that the biggest takeaway from their review is just how interconnected these failure mechanisms really are. “You can’t solve dendrites by fixing just one thing—the voids, the grain boundaries, the electronic conductivity, the slow self-diffusion—they all feed into each other,” they explained. “What we’re learning is that the lithium metal anode isn’t just a passive source of ions; its own slow atomic movement is actually one of the main reasons voids form and dendrites take off.” They emphasized that understanding these microscopic origins is the only way to design better interfaces and, ultimately, batteries that can survive commercial cycling conditions.

These insights point toward several practical strategies for improving solid-state battery performance. For inorganic solid electrolytes, controlling grain boundary chemistry and reducing electronic conductivity are essential—but so is managing stack pressure, since too little pressure

causes contact loss while too much promote lithium creep into the solid electrolyte to form short-circuit. For polymer systems, the review points to dynamic, self-healing polymer networks as a promising avenue; these materials can reorganize and repair microcracks and interfacial voids under operating conditions, circumventing the mechanical brittleness that plagues ceramics. Hybrid solid electrolytes that combine polymers with ceramic fillers offer a middle path, but the filler fraction must be carefully optimized—too much filler increases tortuosity and hinders ion transport. Ultimately, the review makes clear that commercializing solid-state batteries will require not just better materials, but a deeper, microscopic understanding of how those materials behave—and fail—under real-world cycling conditions.

References

DOI

[10.1016/j.esci.2026.100589](https://doi.org/10.1016/j.esci.2026.100589)

Original Source URL

<https://doi.org/10.1016/j.esci.2026.100589>

Funding information

The work was supported by the U.S.–German Cooperation on Energy Storage project (LISI-2, grant No. 13XP0509A) and the HIPSTER project of the Ministry of Culture and Science of North Rhine-Westphalia.

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