OPEN ACCESS

NEWS & BUZZ

Journal homepage: www.the-innovation.org/energy-use

INNOVATION PRESS

Energy Use

Energy Use 1 (2026):100037

Contents lists available at INNOVATION PRESS

A Ductile Gatekeeper in Solid-State Batteries

Kai Shi,[1] Hassan Raza,[1] and Xiaoliang Yu[1,*]

[1]Department of Mechanical Engineering and Research Institute for Smart Energy, The Hong Kong Polytechnic University, Hong Kong SAR, China

*Correspondence: xiaoliang.yu@polyu.edu.hk

Received: January 17, 2026; Accepted: March 3, 2026; Published Online: March 25, 2026; https://doi.org/10.59717/ipj.energy-use.2026.100037

Citation: Shi K., Raza H. and Yu X. (2026). A Ductile Gatekeeper in Solid-State Batteries. *Energy Use* **2**:100037.

Solid-state lithium metal batteries (SLMBs) promise enhanced safety and high energy density, but suffer from poor cycling stability due to brittle fracture of the solid electrolyte interphase under practical conditions of large current rates and high lithium deposition capacities. Now, a ductile interphase effectively mitigates this issue, thereby advancing high-energy SLMBs toward real-world applications.

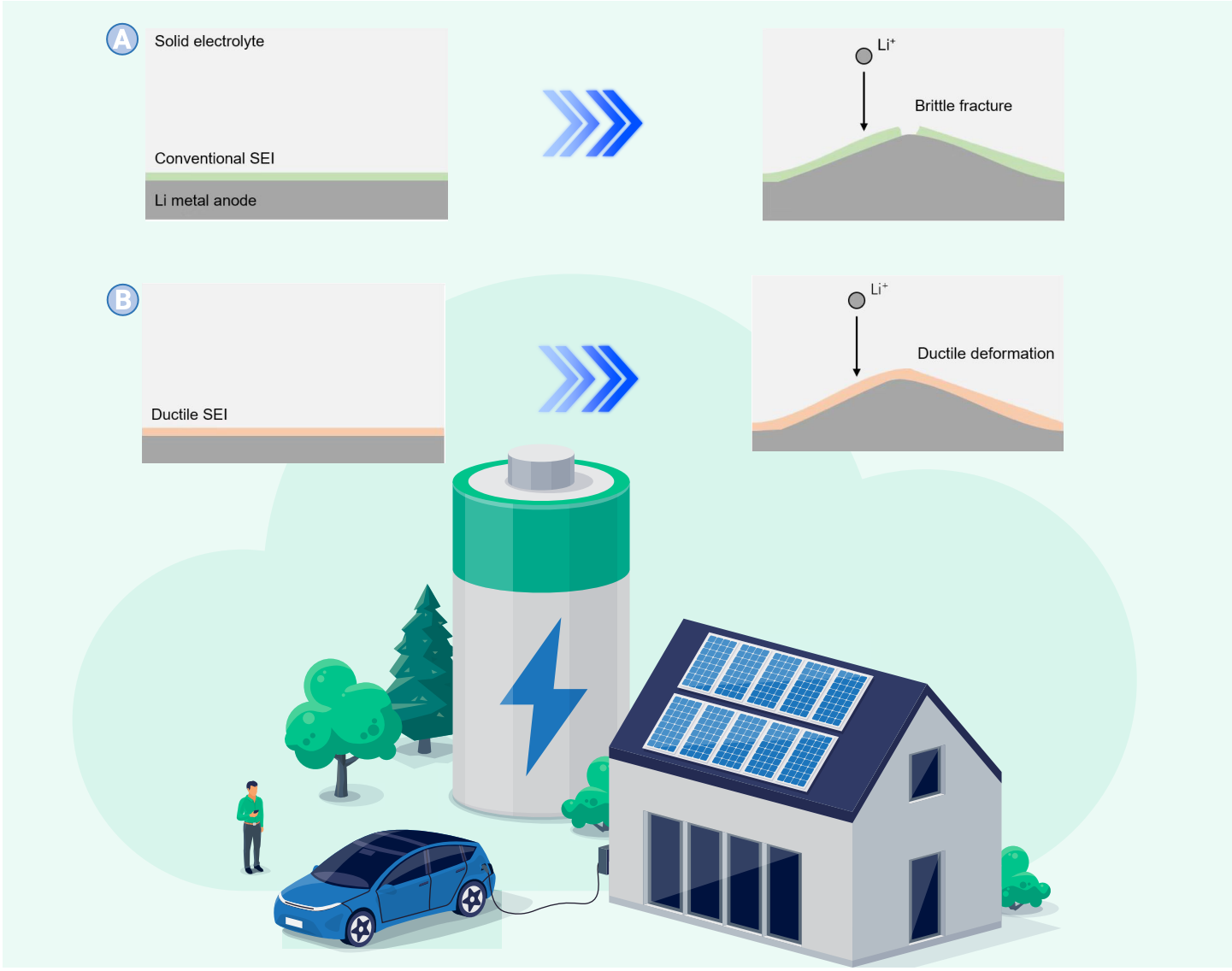

Figure 1. Comparison of ductile SEI with conventional SEI during cycling. (A) conventional SEI is prone to brittle fracture due to large volume fluctuations during lithium plating/stripping. (B) a ductile SEI can maintain its structural integrity through ductile deformation without cracking.

The ongoing transition to sustainable and renewable energy, coupled with the rise of electric vehicles, drones, and emerging AI-driven devices such as robots, demands advanced batteries that offer high energy, high power, and enhanced safety. Solid-state lithium metal batteries (SLMBs) are widely considered a promising candidate due to the use of a lithium metal anode, which provides high specific capacity and low electrochemical potential, along with a thermally stable solid-state electrolyte.[1] Among different types of solid-state electrolytes, organic–inorganic composite electrolytes present a superior comprehensive performance in terms of interface affinity with electrodes, ionic conductivity, and cost-effectiveness.[2] The composite systems can offer an optimal balance of properties by integrating the advantages of both inorganic and polymer electrolytes while mitigating their individual shortcomings. Nevertheless, SLMBs with state-of-the-art composite electrolytes still struggle to meet the practical requirements of fast-charging, high capacity, and long-term cycling stability. The root cause lies in the fragility of the solid electrolyte interphase (SEI), which is prone to mechanical failure due to the large volume changes during fast and uneven lithium plating/stripping. Writing in *Nature*, Mi et al. reported the development of a ductile SEI that maintains structural integrity and supports fast lithium-ion transport at the interface during long cycling under harsh conditions.[3]

The SEI acts as a gatekeeper between the lithium-metal anode and the solid-state electrolytes, allowing lithium-ions to pass while blocking electrons. It is spontaneously formed between the metal anode and electrolytes during electrochemical cycling, and is typically composed of thermodynamically stable constituents such as lithium fluoride (LiF), lithium nitride (Li_3N), lithium sulfide (Li_2S).[4] However, those inorganic materials have the inherent brittleness, tend to brittle fracture during repeated lithium deposition/stripping (Figure 1A). The fracture of the SEI not only hinders lithium-ion transport but also promotes the growth of lithium dendrites and the accumulation of dead lithium, thereby accelerating battery failure. The fracture of the SEI not only hinders lithium-ion transport but also promotes the growth of lithium dendrites and the accumulation of dead lithium, thereby accelerating battery failure. This cascade begins when localized cracking exposes fresh lithium metal to the electrolyte, creating preferential nucleation sites for subsequent lithium deposition. As lithium preferentially accumulates in these cracked regions, the non-uniform plating amplifies localized current densities and mechanical stresses, further propagating dendrites through a self-reinforcing cycle. The ductile interphase design effectively interrupts this sequence by maintaining a conformal and defect-free contact layer, thereby suppressing both the initiation sites and the propagation pathways for dendrite growth.[5]

To address this challenge, Mi et al. proposed a new interphase design with high ductile deformation ability, capable of accommodating substantial volume changes during cycling without cracking (Figure 1B). To identify suitable components, the authors screened a series of oxides, fluorides, nitrides, and sulfides based on Pugh's criterion, which uses the ratio of bulk modulus to shear modulus (B/G) to evaluate the ductility and brittleness of solid-state materials. The Ag_2S and AgF phases emerge as exceptional candidates, showing a ductility index approximately 3 to 10 times higher than that of conventional SEI components such as LiF and Li_2S. These ductile phases are formed *in situ* through stepwise reactions of Li metal, LiF and Li_2S with $AgNO_3$ in a tailored composite electrolyte. New interphases also create favorable LiF–Ag_2S and Li_2S–Ag_2S interfacial pathways with lower lithium-ion diffusion energy barrier compared with bulk LiF and the LiF–Li_2S interface, thereby realizing both high mechanical stability and ionic conductivity within a single integrated structure. This mechanical compliance not only accommodates volume expansion but also mitigates dendrite propagation by relaxing local stress concentrations, thereby preserving interfacial integrity over extended cycling.

The ductile interphase leads to dramatic improvements in performance at the cell level. A Li||Li symmetrical cell with this interphase presented impressive cycling stability for over 4500 hours at an ultrahigh current density of 15 mA cm^{-2} and areal capacity of 15 mAh cm^{-2}. Even at a low temperature of −30 °C, the Li||Li symmetrical cell achieved a 7000-hour stable cycling at a current density of 5 mA cm^{-2} with an areal capacity of 5 mAh cm^{-2}. In full-cell paired with a high-loading (22.9 mg cm^{-2}) nickel-rich cathode, the cell with a low negative/positive capacity (N/P) ratio of 2.43 delivered a capacity retention rate of 90% after 150 cycles, further demonstrating the effectiveness of the ductile SEI towards practical SLMBs.

It should be noted, however, that the successful operation of full cells with high-loading cathodes was achieved by introducing a small amount of liquid electrolyte, which may compromise the battery safety. This also indicates that the cathode/solid-state electrolyte interface remains a critical limiting factor for the practical application of SLMBs. The practicality of the ductile interphase requires further validation in high-energy-density Ah-level pouch cells. Moreover, the construction of the ductile phase relies on sliver compounds, which could lead to increased costs. There is a need to explore cost-effective, highly ductile alternatives for large-scale applications.

REFERENCES

1. Kalnaus S., Dudney N. J., Westover A. S., et al. (2023). Solid-state batteries: The critical role of mechanics. *Science* **381**:eabg5998. DOI:10.1126/science.abg5998
2. Li S., Zhang S.-Q., Shen L., et al. (2020). Progress and Perspective of Ceramic/Polymer Composite Solid Electrolytes for Lithium Batteries. *Advanced Science* **7**:1903088. DOI:10.1002/advs.201903088
3. Mi J., Yang J., Chen L., et al. (2025). A ductile solid electrolyte interphase for solid-state batteries. *Nature* **647**:86–92. DOI:10.1038/s41586-025-09675-8
4. Zhang W., Koverga V., Liu S., et al. (2024). Single-phase local-high-concentration solid polymer electrolytes for lithium-metal batteries. *Nature Energy* **9**:386–400. DOI:10.1038/s41560-023-01443-0
5. Wan H., Zhang B., Liu S., et al. (2024). Interface Design for High-Performance All-Solid-State Lithium Batteries. *Advanced Energy Materials* **14**:2303046. DOI:10.1002/aenm.202303046

FUNDING AND ACKNOWLEDGMENTS

The authors gratefully acknowledge financial support from the Natural Science Foundation of Guangdong (No. 2025A1515011149), the Young Collaborative Research Grant of the Hong Kong Research Grant Council (C1002–23Y), and Innovation and Technology Fund (ITS-322–23FP).

DECLARATION OF INTERESTS

The authors declare no competing interests.