

PAPER

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Concluding remarks: Solid electrolyte interphases in next-gen batteries

Ying Shirley Meng  *

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Concluding remarks for the *Faraday Discussions* meeting on Solid electrolyte interphases in next-gen batteries.

Fellow scientists, colleagues, ladies and gentlemen. As we gather here for the *Faraday Discussions* meeting, I am reminded of Michael Faraday's pragmatic answer to those questioning the utility of a new experimental fact: "Endeavour to make it useful". Today, I want to discuss our ongoing efforts to do exactly that, focusing on advanced metrology, interfacial engineering, and the standardization necessary to push solid-state and sodium batteries to the terawatt-hour scale.

We know that the solid electrolyte interphase, or SEI, and the cathode electrolyte interphase (CEI) are responsible for the critical 0.1% efficiency loss in electrochemical systems. In our laboratory, we discovered that electrodeposited lithium metal can only be accurately imaged with cryogenic electron microscopy. While commercial lithium metal can be cut at room temperature using a xenon ion source, cryogenic temperatures remain necessary to prevent surface and grain boundary contaminations. The live video analysis demonstrates rapid contamination at room temperature, whereas cryogenic conditions show no contamination after 15 seconds of exposure. Furthermore, complete airtight sample transfer is critical; with less than 5 seconds of air exposure, lithium metal particles develop a nearly 40-nanometer thick layer of lithium compounds consisting of lithium oxides and carbonates. However, cryo-EM is not a silver bullet. Cryogenic temperatures improve the electron beam tolerance of both lithium and sodium SEIs, but delicate beam dose control remains strictly necessary. We observed that sodium carbonate is significantly more susceptible to electron beam damage than its lithium counterpart, demanding even more precise control during the metrology development.

This understanding of sodium metal and its SEI is vital because sodium-ion batteries will be the next terawatt-hour scalable energy storage technology. Through careful control of sodium metal deposition and stripping, we have demonstrated sodium metal full cells that achieve a 99.91% average coulombic

efficiency. Operating at a 2C rate, these cells exhibit over 91% capacity retention over 300 cycles.

Transitioning to all-solid-state batteries, we gain distinct physical advantages over liquid cells, including a transference number of one in inorganic solid state electrolytes, the elimination of cross-talk between anode and cathode, and the ability to utilize all-dry processing. However, in these solid state battery architectures, we must treat the physical “void” as one of the most critical components in the entire battery. Effective interfacial engineering, such as applying nanometer thick coatings, is essential to manage these boundaries. We must also rethink our anode architecture entirely. We have developed 99.9% micro-silicon anodes enabled by sulfide solid electrolytes. By eliminating carbon additives in silicon anode, we prevent continuous SEI growth and trap accumulation while retaining a robust electron pathway directly through the micro-silicon. These carbon-free, high-loading silicon anodes operate effectively across a wide temperature range—from negative 20 to 80 degrees Celsius—and perform remarkably well at high current densities.

To move these technologies from the laboratory to commercial pouch cells, we have to deeply understand mechanical pressure effect on cell performance. While our cells show stable cycling at 5 MPa, increasing the stack pressure to 25 MPa induces plating short-circuits, and 75 MPa causes immediate mechanically-induced shorts. Our engineering goal is to reduce required stack pressures from 100 MPa down to 5 MPa or even lower, preferably below 1 MPa. We are also pushing the boundaries with anode-free all-solid-state designs. For sodium-ion anode-free systems, we require an anodically stable, borohydride-based solid electrolyte and a dense aluminum pellet current collector to prevent sodium trapping. We recently discovered that a metastable ortho-NBH structure— $\text{Na}_3(\text{B}_{12}\text{H}_{12})(\text{BH}_4)$ —can be stabilized by rapid cooling, which improves its conductivity by a million times over its precursors.

Yet, the major bottleneck facing all solid-state battery research is the lack of standardized cell fixtures and assembly procedures across different laboratories. To establish credibility and eliminate systematic errors, eight different research groups are currently participating in a new round robin study to validate standard operating procedures and optimize testing protocols. If we are to scale this technology globally, we must master dry processing at scale, dramatically reduce operating pressures to the 1 to 2 MPa range, and wait for the price of precursors like lithium sulfide to inevitably drop. I leave you with another profound thought from Michael Faraday: “Nothing is too wonderful to be true if it is consistent with the laws of nature”. I look forward to our discussion and debate.

Conflicts of interest

There are no conflicts to declare.

Data availability

There is no additional data associated with this article.