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An Outlook on the Current State of Future Energy Storage Technologies

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INTRODUCTION

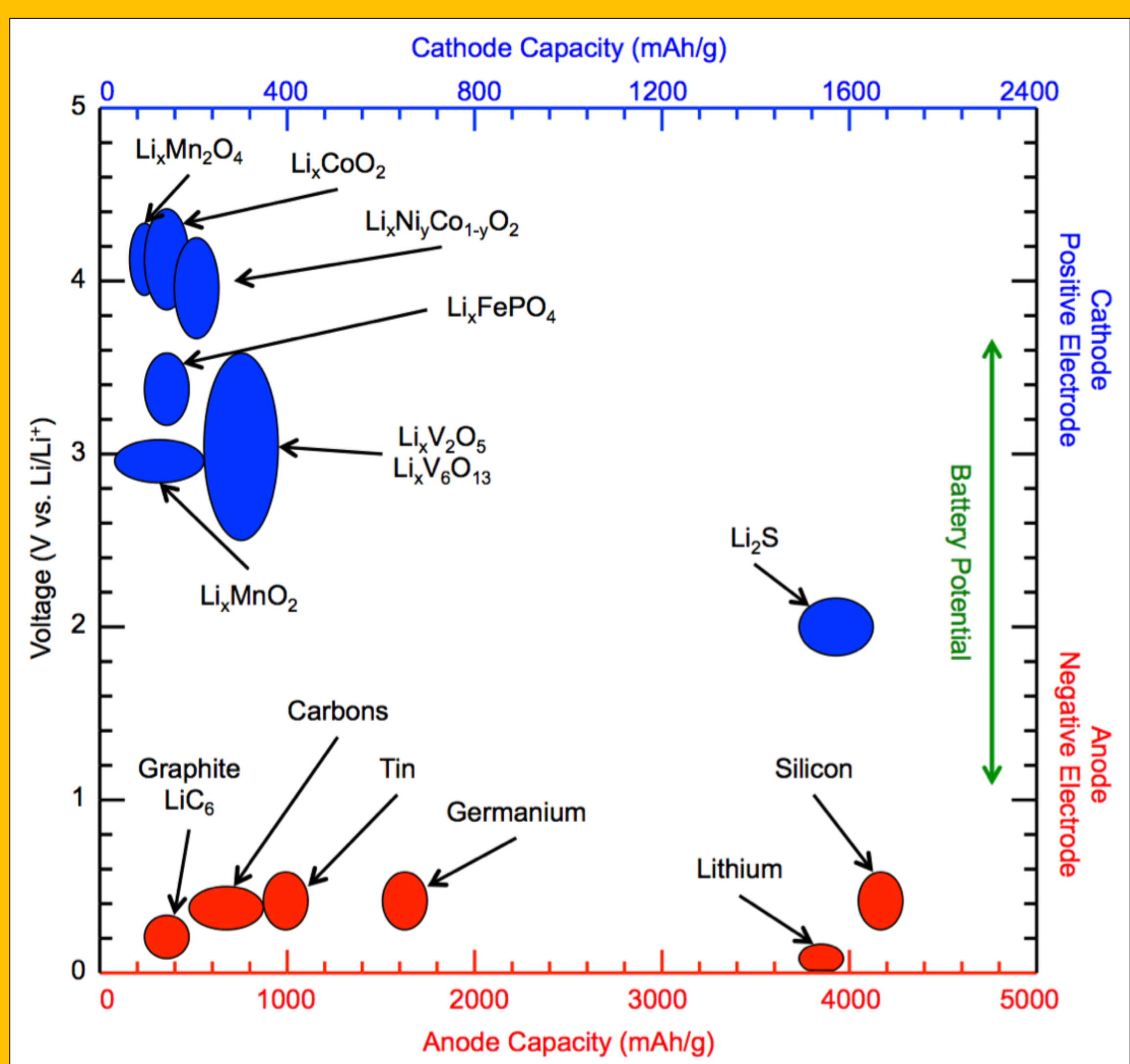
Most battery energy storage research aims to:

- Increase energy density and/or power density
- Improve safety

Increasing the energy storage capacity of the battery electrodes will increase energy density. There are two ways to increase a cell's energy capacity:

1. Use *more* electrode active material
2. Use *new* high capacity electrode active material

Increasing *anode* capacity increases the available discharge energy of the battery. **Lithium metal** or **silicon** as battery anodes could increase battery anode capacity tenfold. However, **lithium metal is volatile and potentially very dangerous** and **silicon anodes tend to have very short lives**. These issues must be overcome in order to realize the potential of next generation high capacity anode materials.



Adapted from Landi et al. 2009, ©RSC Publishing, DOI: 10.1039/b904116h

CHALLENGES

LITHIUM METAL

- Compromised safety
  - Formation of dendrites
  - Increased risk for thermal runaway event

SILICON

- Compromised life
  - Extreme volumetric changes
  - Charged silicon reactivity

APPROACHES

LITHIUM METAL

SOLID-STATE BATTERIES

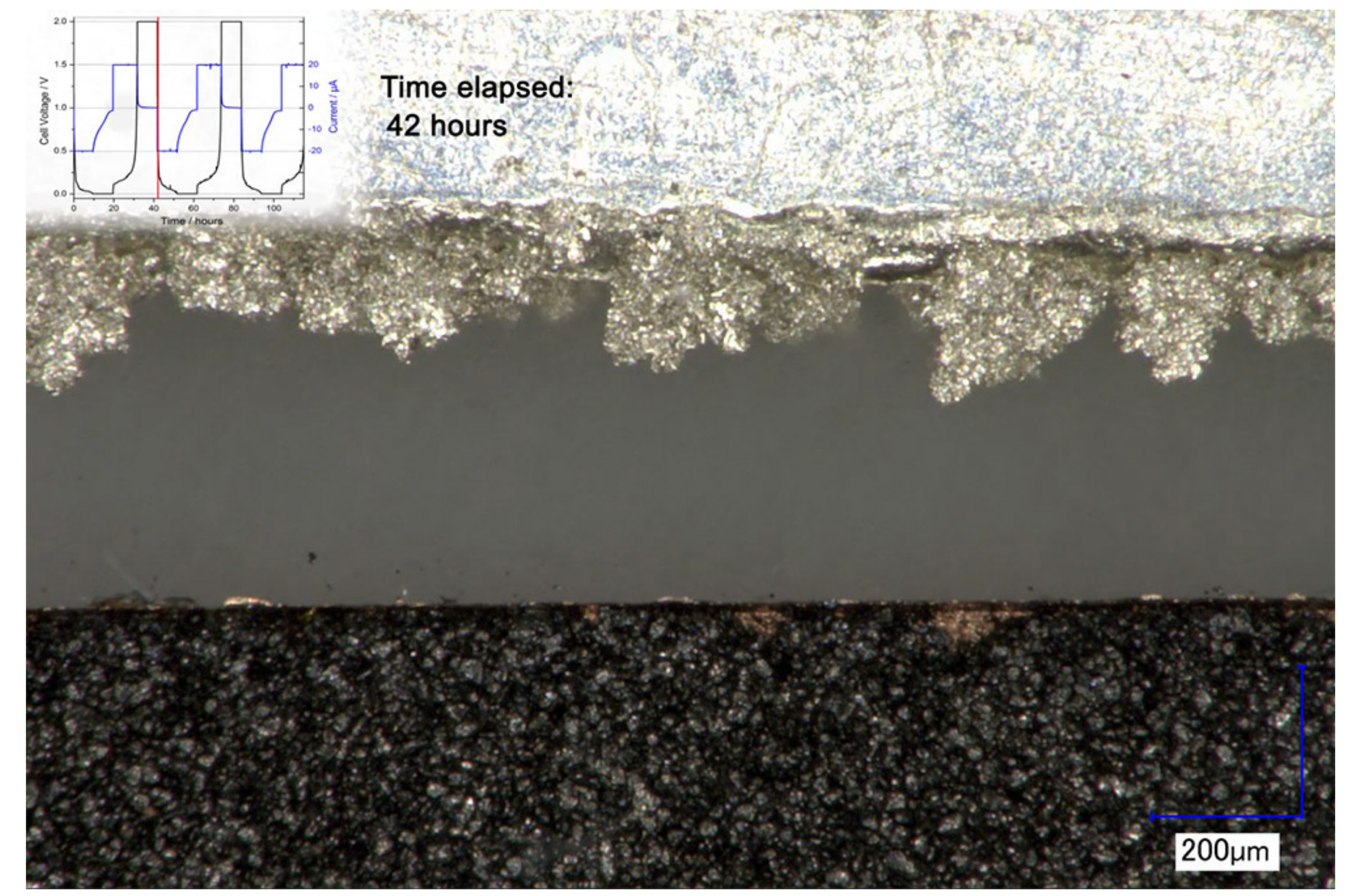
Replacing the liquid electrolyte with a solid can improve the safety of lithium metal anode cells by:

- Physically suppressing dendrite growth
- Providing superior mechanical, electrochemical, and thermal stability

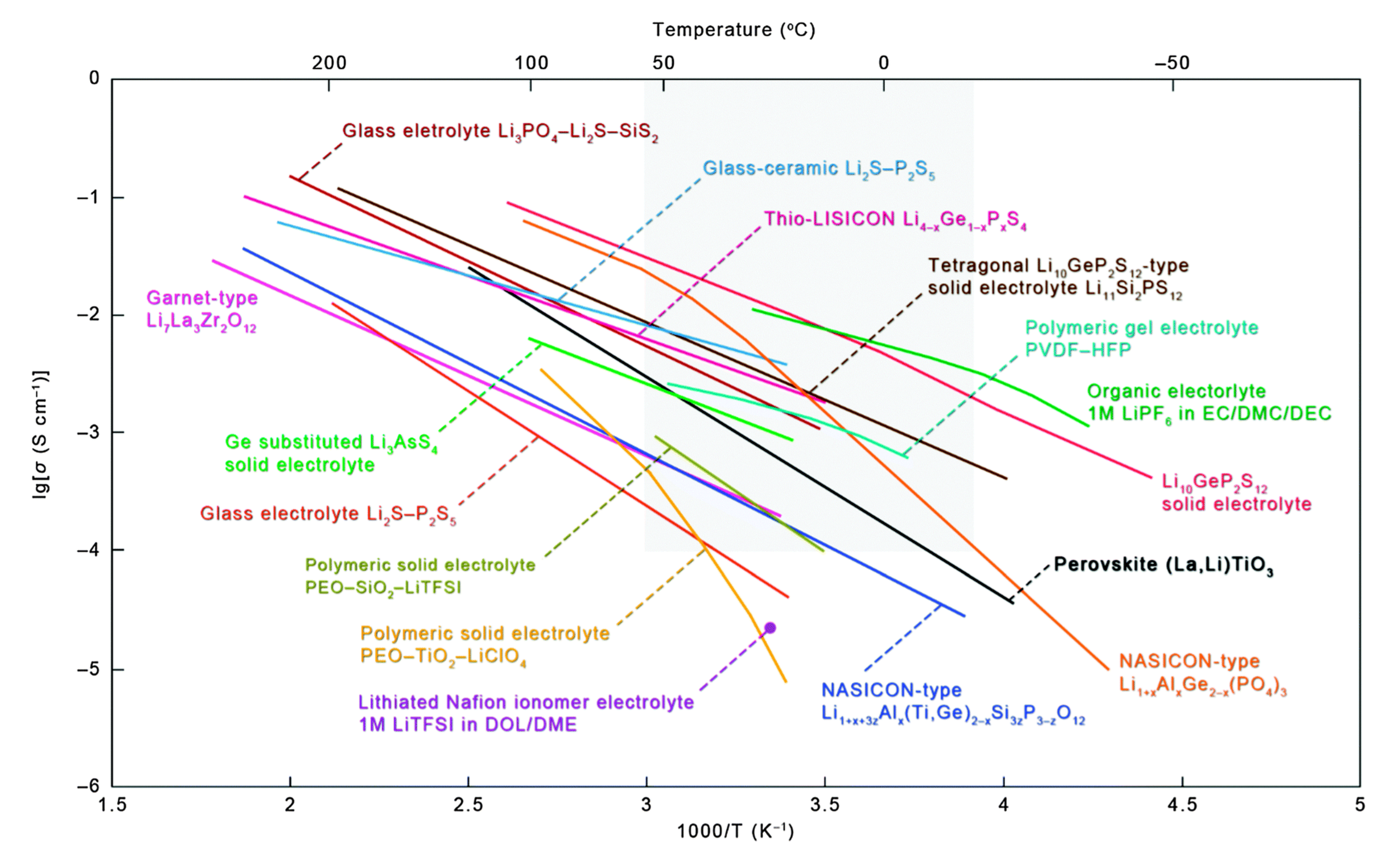
Complications

The physical limitations of solid electrolytes make them inherently less conductive than their liquid counterparts due to the slowed ion diffusion through a solid medium.

- Liquid electrolyte ion conductivity at room temperature is typically on the order of 10^{-1} S cm^{-1}, while the most conductive solid electrolytes have reported conductivities on the order of 10^{-3} S cm^{-1}.
- Ion conductivity of solid electrolytes is thermally dependent and increases with temperature, meaning they are not well suited for low temperature applications.
- High interfacial resistance at the electrode-electrolyte interface is due to poor adhesion of the two solid surfaces and the poor penetration of the electrolyte into the porous electrode structure. Introducing liquid electrolyte at the interface can help to overcome this but defeats the purpose of using a solid electrolyte for improving battery safety.



Lithium metal dendrite growth (EL-CELL, 2017)



Ion conductivity comparison of various lithium ion battery electrolytes. (Zhao et al., 2015)

SILICON

NANOSTRUCTURING

Silicon can expand up to 400% during lithiation. The extreme and cyclic volumetric changes can cause the material to fracture and separate from the current collector. Nanostructuring the anode substrate to accommodate material expansion can improve cycle life, enhance ion conductivity, and potentially improve ultra-fast charging capability.

Complications

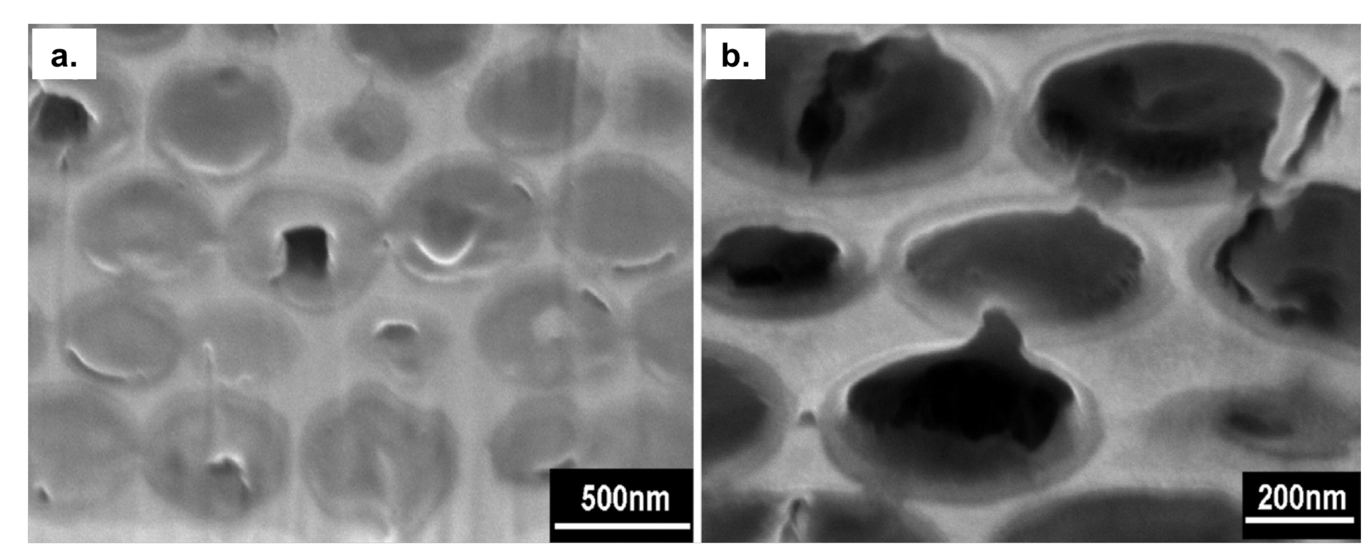
- The cost to manufacture nanostructured electrodes makes them infeasible for commercial use.
- Nanostructuring does not address the issue of SEI layer destabilization. SEI material will continue to accumulate with each cycle, increase cell resistance, and negatively affect battery capacity.
- Connectivity and stability of the nanostructure is fragile creating disconnection issues

ADDITIVES

Charged silicon anions are highly reactive with the electrode binders and electrolyte solvents. This redox activity reduces the free electrolyte solvents, breaks the binder-surface interactions, and contaminates interfacial surfaces with various impurity phases. Certain additives have been shown to significantly increase cycle life and capacity of silicon anode batteries.

Complications

- Does not address volumetric expansion.



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OUTLOOK

LITHIUM METAL

Solid electrolytes for solid-state lithium metal batteries are a promising solution for increasing battery capacity while enhancing battery safety, but the general challenges in using a solid electrolyte must be resolved. Solid-state lithium ion batteries are continually improving but will not be commercially available for years.

SILICON

Some battery manufacturers have already begun to add small quantities of silicon into their battery anodes to improve battery energy density. As discussed, there are still some major challenges to overcome before we can successfully incorporate large quantities of silicon into the anode material. However, it is likely that we will see more Si,C composite anodes in the next decade.

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