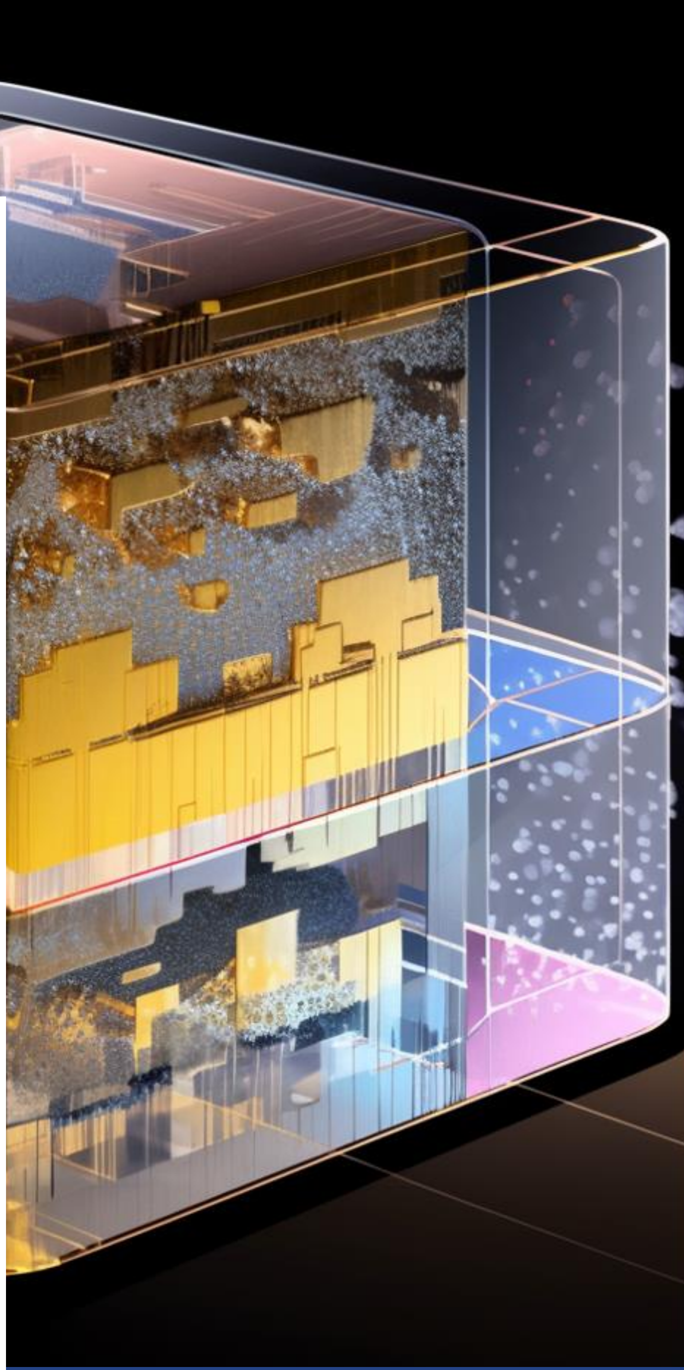
In-depth Report on the SSB Industry

Industrialisation: Challenges and Solutions



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ADER-DES Consulting Team

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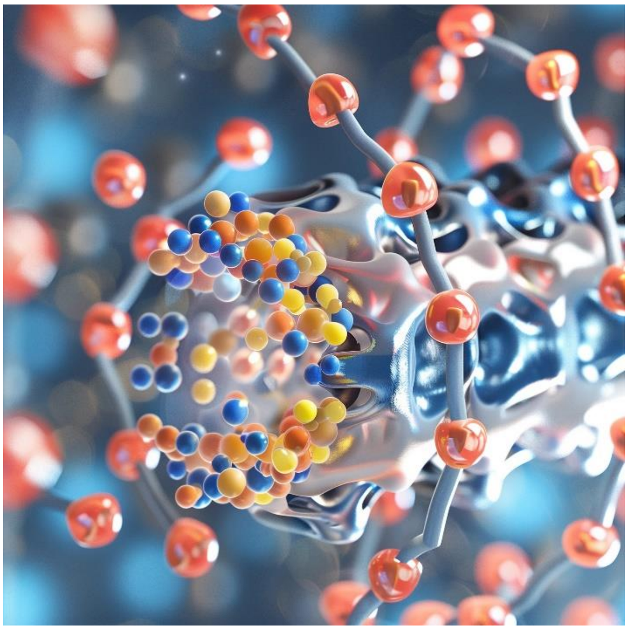
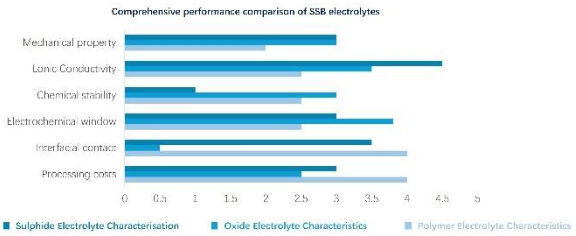
TECHNICAL DIFFICULTIES AND SOLUTION IDEAS

Solid state electrolyte development faces three major scientific problems. Solid-state electrolyte ion transport mechanism, lithium metal anode lithium dendrite growth mechanism, multi-field coupling system runaway failure mechanism for the development of solid-state batteries facing the core scientific issues, to solve these problems is to create a new type of solid-state electrolyte materials, optimise the physical and chemical properties of solid-state batteries, to promote the development of solid-state batteries must go through.



1.1 The comprehensive performance of solid-state battery electrolytes is challenging to balance.

From the perspective of material properties, regardless of polymer, oxide or sulfide, its comprehensive performance as a solid-state electrolyte is limited. For instance, polymer electrolytes are straightforward to process and have a low production difficulty, yet their ionic conductivity is not high, which affects the charging and discharging performance. Oxide and sulfide electrolytes have higher conductivity, safety and mechanical strength, but their manufacturing difficulty is more complex and their cost is higher.



Solution Idea

Composite electrolytes offer a unique combination of the advantages of multiple materials.

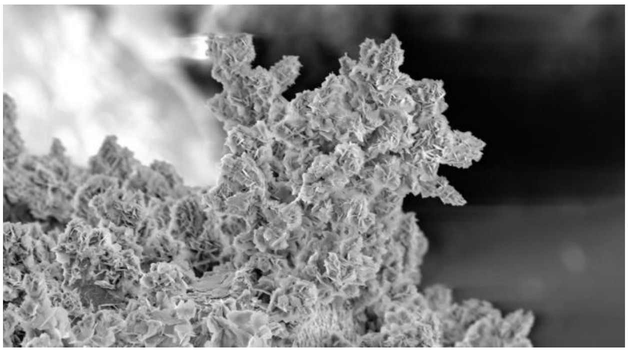
The concept of composites is based on the idea of combining different materials to take advantage of their respective strengths. Polymer/polymer composite electrolyte materials can be prepared more strongly, with enhanced mechanical strength and ionic conductivity. Polymer/inorganic (oxide/sulfide) composite electrolyte materials combine the characteristics of polymer and oxide/sulfide, offering a combination of multiple advantages, including high strength and better flexibility, conductivity and ease of preparation. Consequently, composite solid-state electrolytes represent a significant development opportunity for solid-state battery electrolytes, offering a potential solution to overcome current performance limitations.

The main challenge currently facing all-solid-state batteries is the slower charging and discharging rate and the faster capacity decay.

Ionic conductivity is the key to improving the charging and discharging speed of all-solid-state batteries. The ion transport performance in solid-state electrolytes is jointly determined by the ion transport process in the bulk phase and surface interface. Compared with liquid electrolytes, solid-state electrolytes have strong inter-ion interaction forces, higher ion transport energy barriers, and lower ionic conductivities.

The development of a high mechanical strength solid state electrolyte that can completely inhibit the growth of lithium dendrites and achieve uniform deposition of lithium metal remains a challenge.

Research indicates that a high shear modulus inorganic solid-state electrolyte is unable to fully prevent lithium dendrites from forming in the solid-state electrolyte. Lithium dendrites remain a significant obstacle to the practical application of all-solid-state batteries. If the shear modulus of the oxide solid-state electrolyte is more than ten times that of lithium metal (in excess of 50 GPa), the growth of lithium dendrites may still result in a short circuit in solid-state batteries.



Lithium Battery Diodes

1.2 The main reason for battery failure is reduced stability at the solid-state interface contact.

The solid-state battery interface is a solid-solid contact, which can result in reduced conductivity due to high contact resistance at the electrode-electrolyte interface. The elevated impedance results in an increased overpotential, which in turn leads to a reduction in capacity and a decline in energy density. The higher impedance at the interface can be attributed to the following factors:

1) **The interface problem between the solid-state electrolyte and the negative electrode;**

2) **The interface problem between the solid-state electrolyte and the composite positive electrode;**

3) **The microscopic interfacial problem between the cathode active substance inside the composite positive electrode and the solid-state electrolyte.**

Solution Idea

The objective is to engineer and modify the interface in order to achieve improvement through both material and process dimensions.

In terms of material dimensions, we recommend selecting a Li metal negative electrode and a clad composite positive electrode. For the negative electrode, we have found that adopting a Li alloy with a smaller volume change can help alleviate the problem of negative electrode expansion. For the macroscopic interface problem, a solid electrolyte with higher stability is selected to reduce the occurrence of side reactions between the interfaces. At the microscopic interface of the composite positive electrode, the interfacial stress can be reduced by means of surface cladding (coating), which improves the efficiency of ion and electron transfer. Process Dimension: Macroscopic Interface Issues

One solution is to increase the pressure during the preparation process to eliminate pores and enhance interfacial contact. Another option is in-situ solidification, whereby liquid is injected into the solid-state battery. Once the encapsulation is complete, the liquid is allowed to solidify by means of heating, thus enhancing the interfacial contact between the solid-state electrolyte and the electrode.

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ECONOMIC CHALLENGES AND POTENTIAL SOLUTIONS

The supply chain for raw materials used in solid-state batteries and battery manufacturing equipment is not yet fully developed. Some of the raw materials for solid-state batteries have not yet been mass-produced, and the overall industrial chain is still imperfect, which increases the cost of battery manufacturing. Furthermore, the lack of specific equipment, such as sintering, vacuum, drying room, specific atmosphere and other links, increases the cost of manufacturing solid-state batteries.

The cost of solid-state battery electrode materials is a significant factor to consider.

Oxide cathode materials are mainly made of inorganic materials such as alumina and titanium oxide; sulphide cathode materials are made of sulphur, sulphide and polymers; and polymer cathodes are made of various polymer compounds such as polycarbonate and cellulose. The high cost of germanium, as in the case of the LGPS-type sulfide electrolyte, which has impressive performance, has hindered mass production. Furthermore, the electrode materials required for solid-state batteries are all new, high-tech materials that require both technological advances to reduce the difficulty of production and time for the market to digest the high price, in order to make them widely used. Currently, there are only a few examples of solid-state batteries being sold commercially. The cost of semi-solid-state batteries is approximately 1.7-2.2 RMB/Wh, which is significantly higher than the average price of square ternary batteries and lithium iron batteries, which is 0.73 RMB/Wh. As of 3 April 2024, the average price of square ternary batteries and lithium iron batteries has dropped to 0.465 RMB/Wh and 0.3 RMB/Wh, respectively. The average price of liquid lithium batteries has

continued to decline, with solid-state batteries also experiencing cost reduction.
The average price of liquid lithium batteries continues to decline, while solid-state batteries still face significant challenges in terms of cost reduction.

Solution Idea

The first step is to semi-solidify the material, which will reduce costs. Semi-solid state batteries are more mature than other types of batteries, and they are closer to liquid lithium-ion batteries. Semi-solid state battery industrialisation will bring corresponding benefits, including a reduction in raw material costs, optimised processes, and lower production costs.

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