In-depth Report

Solid State Battery Industry ——
Industry Overview

6.5.26

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Currently, traditional liquid lithium batteries have an energy density close to the theoretical limit of 350Wh/kg. However, they still pose safety hazards such as battery thermal runaway. The rapid expansion of the new energy vehicle market has created an urgent need for power batteries with high energy density and safety, which has driven the development of solid-state batteries. The development of solid-state batteries can be divided into several stages, including semi-solid state, quasi-solid state, all-solid state, and others. Currently, due to constraints such as immature material and preparation technology and high production costs, the industrialization of all-solid-state batteries will require more time.

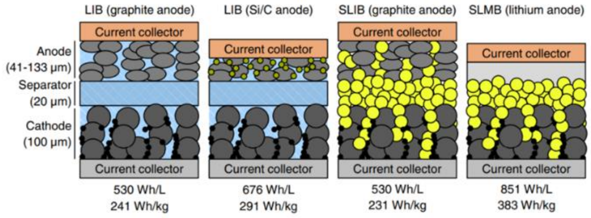
In the following, we will introduce the concept, advantages, technical routes, and other basic content of solid-state batteries. We will also analyze the current industrialization difficulties and provide solution ideas.

Then, we will analyze the manufacturing process and industrial status of solid-state batteries, and sort out the industrial chain of solid-state batteries and related companies in detail. We hope this content inspires your understanding of the solid-state battery industry.

1

THE CONCEPT OF SOLID STATE BATTERIES

Solid-state batteries are a new type of battery that use a solid-state electrolyte instead of the liquid electrolyte found in traditional lithium-ion batteries. These batteries are composed of four key elements: a positive electrode, a negative electrode, an electrolyte, and a diaphragm. By replacing the liquid electrolyte with a solid-state one, solid-state batteries offer several advantages over traditional lithium-ion batteries.



A comparison of the design of solid state batteries and lithium battery cells.

The solid-state battery operates similarly to the traditional liquid lithium battery. In the liquid lithium battery, the positive and negative poles are located at opposite ends, with the liquid electrolyte in between. This same process occurs in the solid-state battery. The battery charges and discharges as lithium ions move between the positive and negative electrodes. The working principle of solid-state batteries is as follows: during charging, lithium ions are de-embedded from the active material lattice at the positive electrode, migrate through the solid electrolyte to the negative electrode, and combine with composite lithium atoms in the negative electrode material through alloying or embedding. The electron migration occurs through the external circuit to the negative electrode. The discharge process is the opposite of the charging process.

Using a solid-state electrolyte instead of a liquid one is expected to increase the specific capacity of both positive and negative electrode materials. Additionally, it can completely solve battery safety issues, making it a fundamental way to achieve high energy density, safety, and long cycle life in all-solid-state lithium batteries. Therefore, solid-state batteries represent the future of lithium-ion battery upgrades.

2

ADVANTAGES OF SOLID STATE BATTERIES

Solid-state batteries offer significant advantages in terms of high energy density and safety, making them the next generation of high-performance lithium batteries. Based on the performance comparison, solid-state batteries are theoretically superior to liquid batteries in various indicators, including ionic conductivity, energy density, high voltage resistance, high temperature resistance, and cycle life. Solid-state batteries offer high energy density and safety characteristics that traditional liquid lithium batteries cannot match, making them the ideal battery for electric vehicles. The advantages of solid-state batteries are mainly reflected in:

2.1 High level of security

Liquid lithium batteries are prone to thermal runaway, which can be caused by overcharging, impact, short circuits, water, and other factors. Liquid lithium batteries are prone to thermal runaway, which can be caused by overcharging, impact, short circuits, water, and other factors. Liquid lithium batteries are prone to thermal runaway, which can be caused by overcharging, impact, short circuits, water, and other factors. These conditions increase the risk of thermal runaway. When the solid electrolyte interface (SEI) film on the surface of the negative electrode begins to decompose at 90°C, the embedded lithium carbonate is directly exposed to the electrolyte. This reaction generates a large amount of flammable gas, which can melt the diaphragm and cause an internal short circuit. If the temperature rises to 200°C, the electrolyte will decompose by vaporization, leading to a violent combustion and explosion of the battery.

Compared to liquid lithium batteries, solid-state batteries have five major safety features.

- The solid-state electrolyte has high mechanical strength, which inhibits the growth of lithium dendrites and reduces the risk of short circuits.
- Solid-state batteries are less prone to combustion or explosion.
- There are no sustained interfacial side reactions.
- There is no risk of electrolyte leakage or drying out.
- High-temperature life is unaffected or even improved.

2.2 High energy density

The energy density of traditional liquid batteries is nearing the theoretical limit of 350Wh/kg. Solid-state batteries, on the other hand, have a broader electrochemical window, can withstand higher voltages (above 5V), and offer a wider range of materials to choose from. The overall specific capacity of a battery follows the barrel effect, which is limited to the lower of the positive and negative electrodes because the energy density of a battery is equal to the operating voltage multiplied by the specific capacity. Currently, the graphite negative electrode has a specific capacity of 372mA-h/g, while the silicon and lithium negative electrodes have theoretical specific capacities of 4200mA-h/g and 3860mA-h/g, respectively. These values are significantly higher than that of the positive electrode in current solid-state batteries. Therefore, improving the performance of lithium-ion batteries is mainly limited by the positive material. The all-solid electrolyte is compatible with both high specific capacity anode materials and conventional anode material systems. It can also be paired with high specific capacity anode materials to achieve an energy density of 500Wh/kg or higher.

2.3 Wide temperature range operation

Conventional liquid batteries have a limited operating temperature range. At low temperatures, their performance decreases due to increased electrolyte viscosity, decreased conductivity, increased impedance at the electrolyte/electrode interface and charge transfer, and decreased lithium ion migration rate. In addition, liquid batteries are limited by the low flash point of the electrolyte and the low melting temperature of the diaphragm at high temperatures, which poses a risk of combustion.

Solid electrolyte batteries, on the other hand, do not have the problem of electrolyte solidification at low temperatures. Additionally, they are safe at high temperatures and have a greater operating temperature range of up to -40°C to 150°C, which is significantly better than liquid batteries.

2.4 Small volume

Conventional liquid batteries typically require a diaphragm and electrolyte, which account for almost 40% of the volume and 25% of the mass of the battery. In contrast, solid-state batteries use a solid electrolyte instead of the diaphragm and electrolyte of liquid batteries. This allows for a shorter distance between the positive and negative electrodes, reducing the battery's thickness to just a few to a dozen micrometers. As a result, solid-state batteries can be much smaller while still providing the same amount of power.

3

SOLID STATE BATTERY DEVELOPMENT PATH

The development path of solid-state batteries can be divided into three phases: semi-solid-state (5-10wt%), quasi-solid-state (0-5wt%), and all-solid-state (0wt%), as the liquid electrolyte content gradually declines. Semi-solid-state and quasi-solid-state use mixed solid-liquid electrolytes.

Currently, all-solid-state batteries are mainly in the research, development, and trial production stage worldwide. Currently, the industrialization of all-solid-state batteries is limited by material technology, immature preparation technology, and high production costs. The industry consensus is that large-scale industrialization of all-solid-state batteries is at least five years away.

Semi-solid-state batteries may serve as a viable transitional technology solution before all-solid-state batteries are commercially available. Semi-solid-state batteries utilize a solid-liquid hybrid electrolyte with an electrolyte content of 5-10%. By increasing the coating of the solid-state electrolyte, the battery operates on the same electrochemical principle as liquid lithium batteries. This allows for easy integration with existing battery manufacturing processes and reduces production difficulty compared to solid-state batteries.

Their advantages include enhanced safety, higher energy density, greater flexibility, longer cycle life, wider operating temperature range, and resistance to extrusion and vibration. Compared to traditional liquid lithium batteries, semi-solid batteries offer significant performance improvements. As a result, semi-solid batteries have emerged as a transitional technology for the shift from liquid batteries to all-solid-state batteries.

In 2023, several companies are developing capacity for semi-solid batteries. Mass production of these batteries is imminent and will soon enter the commercialization stage.

4

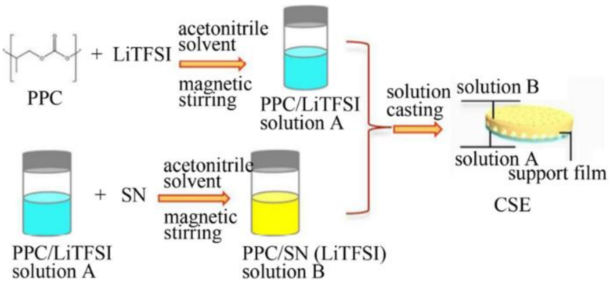
THREE MAIN TECHNOLOGY PATHS FOR SOLID-STATE BATTERIES.

The classification of solid-state electrolytes also identifies three main technology routes. Polymer, oxide, and sulfide electrolytes are the three main types.

Ideal solid-state electrolyte materials should have high ionic conductivity, chemical and electrochemical stability of lithium metal, good inhibition of lithium dendrites, low manufacturing cost, and should not require the use of rare metals. However, the current three major technology routes have their own advantages and disadvantages, and none can meet all of the above requirements simultaneously. There is still a certain degree of difficulty in achieving technological breakthroughs. Overall, sulfide electrolytes have the most development potential in all-solid-state batteries.

Polymer electrolytes：

They are easy to process, more compatible with existing electrolyte production equipment and processes, and have good mechanical properties. However, they also have some disadvantages.
(1) The ionic conductivity is too low, requiring a high temperature of 60℃ for normal charging and discharging.
(2) The chemical stability is poor, making it unsuitable for high-voltage cathode materials and prone to fire at high temperatures.
(3) The electrochemical window is narrow, and if the potential difference is too large (>4V), the electrolyte is easily electrolyzed, which limits the polymer's performance.



Schematic diagram of the manufacture of a sandwich type solid polymer electrolyte

Oxide electrolyte:

Its advantages include better electrical conductivity and stability, higher ionic conductivity than polymers, thermal stability up to 1000°C, and better mechanical and electrochemical stability. However, it has some disadvantages.
(1) Compared to sulfide, oxide has lower ionic conductivity, which can cause performance limitations such as capacity and multiplicity in the process of enhancing the performance of oxide solid-state batteries.
(2) The hardness of oxide results in a rigid interface contact problem for solid-state batteries. Even with simple cold pressure at room temperature, the battery's porosity is very high, which may prevent the battery from functioning properly.

Sulfide electrolyte：

Sulfide electrolyte has the highest ionic conductivity, good mechanical properties, and a wide electrochemical stabilization window (above 5V), making it an excellent choice for all-solid-state batteries. However, it does have some shortcomings:
(1) The interface is unstable and can easily react with positive and negative materials, resulting in high impedance and increased internal resistance.
(2) The preparation process for sulfide solid-state batteries is relatively complex, and sulfide can react with water and oxygen in the air to produce hydrogen sulfide and highly toxic gases.

Polymer electrolyte has undergone rapid development and has mature technology. It was the first to promote commercialization and has achieved small-scale mass production. However, it has some shortcomings such as low conductivity and a lower upper limit of performance. On the other hand, oxide electrolyte has more balanced performance in all aspects and is progressing faster. The conductivity of sulfide electrolytes is higher, making them the best choice for electric vehicles due to their superior performance and commercialization potential. However, research in this area is challenging, as maintaining high stability remains an unresolved issue. Technical breakthroughs in solid-state electrolytes are crucial to accelerate the industrialization process.

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