Solid State Batteries - A Novel Approach

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Abstract- We are all aware of the importance of batteries in our daily lives. **The battery powers our everyday devices such as home appliances, remote controls, toys, etc. Portable electronic devices like cell phones and laptops are battery powered making them wireless. They are also a power source in medical devices and Electric Vehicles. However, many people are unaware that batteries also play a crucial role in the future energy systems of our society. The importance of energy storage in electrical grids originates from the intermittent energy output of renewable energy sources such as wind and solar. In recent years' solid-state batteries have emerged as a leading research focus, due to their distinct advantages over conventional batteries. Solid-state batteries, having solid electrolytes, offer higher energy and power density, enhanced safety features, and longer lifespan. This makes them ideal in fulfilling demand for energy storage in electric vehicles, and smart grid applications. This paper will focus on explaining different types of Solid State Batteries. Furthermore, the advantages of SSBs are discussed. Finally, the research challenges and future potential associated with Solid State Batteries are discussed.**

I INTRODUCTION

Solid State Batteries harness more stable solid electrolytes to replace the volatile and flammable liquid
electrolytes in traditional Lithium-ion batteries. The rapid development of LIB technology and the continuous expansion of the market have put great pressure on battery safety, and broad attention from the public can be expected once a battery-related accident occurs. Battery-related accidents, especially in emerging applications such as EVs and energy storage, have been increasing in recent years. Moreover, the scale of such accidents increases significantly with the increase in battery capacity. Researchers and engineers have proposed numerous methods to handle the safety issues of LIBs from the perspectives of intrinsic, passive, and active safety; among these methods, the development of solid-state batteries (SSBs) has great potential for covering all three types of safety strategies. Europe, Japan, the United States, and the Republic of Korea have launched national projects to support the research and development (R&D) of SSBs, including Battery 2030+ in Europe, RISING3 and Solid-EV in Japan, Battery500 in the United States, and K-Battery 2030 in the Republic of Korea. Different types of SSBs, such as sulfide-, oxide-, thin-film-, and polymer-based batteries, are being developed at the same time. It is very important to strengthen both the fundamental scientific research and the applied research related to the safety of SSBs to facilitate the maturity of SSB technology and eventually establish a market.

II. TYPES OF SSBs

Solid State Batteries are classified into various categories based on the solid electrolyte material used:

1. **Polymer Solid Electrolyte:**

Polymer electrolytes are widely used in electrochemical devices. They have a high molecular weight membrane and are easier to process. The properties of polymer electrolytes include transparency, lightweight, highly flexible, increased ionic conductivity, wide range in the electrochemical window, and low fabrication cost. Polymer electrolytes are further classified into gel polymer and all solid-state polymer electrolytes. A gel-based polymer consisting of a polymer matrix typically in the form of a gel holds a liquid electrolyte; this unique combination provides stability and superior conductivity. It has an enhanced safety profile, and is less corrosive, reducing the risk of leakage of damage. Solid polymer electrolyte also known as solvent-free polymer electrolyte is a pure solid electrolyte without liquid components it's key functionality lies in the coordination of inorganic salt within a polymer matrix. It has low conductivity at room temperature and is more suitable for working in high temperatures.

2. **Oxide Solid Electrolyte:**
Oxide solid electrolytes can be subdivided into crystal state and glass state (amorphous). Crystalline electrolytes, also known as conductive ceramics, include perovskite-type, Na Super Ionic Conductors type, Li Super Ionic Conductors type, and garnet type. Perovskite type has high electrochemical oxidation voltage but is resistant to heat flow which serves as a drawback. These electrolytes have high strength, high hardness, and high chemical stability and they are also stable in the air.

3. **Sulphide Solid Electrolyte:**
Similar to oxide inorganic electrolyte but has a larger ionic radius and stronger polarization than oxide electrolyte hence it can increase lattice volume and expand the size of lithium-ion channels. In addition, it has an increased concentration of carriers and exhibits greater ionic conductivity. Its key characteristics include easy operation, resistance to thermal conductivity, highly flexible and can withstand a sufficient range of stress and strain, and highly conductive. Limitations of Sulphide electrolytes include poor compatibility, sensitivity to moisture, and can easily form oxides and peroxides.

III. ADVANTAGES OF SSBs

1. **Safety:**
The most important incentive for implementing solid-state batteries is their improved safety relative to conventional Lithium-ion batteries. The liquid electrolytes are flammable and if damaged can lead to them catching fire and can even explode. Solid electrolyte provides a solution to this since it is not flammable. Moreover, it can reduce the dendrite growth of Lithium ions to a certain degree.

2. **Durability:**
Electrolyte decomposition and electrode side reaction are the main factors affecting battery life. The presence of solid electrolytes can reduce the tendency to decompose the electrolyte through an electrochemical process. Besides, solid electrolytes can improve battery life by inhibiting side reactions on electrodes. This results in a longer lifetime of the batteries which is highly desirable for several applications including automotive.

3. **Higher Power and Energy Density:**
Power density is a measurement of how fast batteries can provide stored energy. Solid electrolytes have a higher potential to increase power density. With the continuous development of new materials, a large number of solid electrolytes with high ionic conductivity are being discovered. They give solid-state batteries a big breakthrough in power density and make the solid-state battery reach a high power density comparable to lithium-ion batteries. Also to keep up with demanding energy storage applications, lighter and smaller batteries with higher energy densities are required. SSBs have great potential in delivering high energy density as well.

4. **Faster Charging Time:**
Faster charging times are highly desirable to EV consumers. The charging rate of current lithium-ion automotive batteries is fundamentally limited by the cell chemistry as well as the engineering required to protect the battery from exposure to high

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temperatures. SSEs have close to unity lithium-ion transference numbers and, in theory, negligible concentration polarization, and higher thermal conductivity compared to liquid electrolytes. These properties should allow SSEs to transport lithium ions efficiently with adequate dissipation of heat and therefore may be a route to faster charging automotive battery systems.

5. **Larger Electrochemical Window:**
The chemical window refers to the potential difference between oxidation and reduction reactions. Both electrodes must be inert to electrolytes. This means that the oxidation potential needs to be higher than the lithium-ion embedding potential in the cathode, and the reduction potential must be lower than the lithium metal potential in the anode. Generally, solid electrolytes can withstand higher electrochemical windows which are around 4-5 V. Therefore, solid electrolytes are more compatible with more electrode materials.

IV. RESEARCH CHALLENGES

Solid-state batteries still have multiple challenges to overcome. The main challenge is to overcome dendrite formation. These tree-like structures grow on the Li-metal anode, promote degradation, and ultimately grow to the opposite electrode resulting in a short circuit. Another major challenge in solid-state batteries is contact loss, solids have a definite shape and when voids are present in the structure, the solid cannot flow into the void as easily as liquids, which results in contact loss. Additionally, during battery operation electrode particles expand or shrink during cycling and can lose contact with the electrolyte. Besides contact loss, interphase formation is one of the main challenges. Interphases are formed at the active material/electrolyte interface, which, in battery literature, is often referred to as the solid electrolyte interphase or SEI. In this interphase layer, Li-ion diffusion is often sluggish which limits the performance of the battery.

V. DEVELOPMENT AND FUTURE POTENTIAL

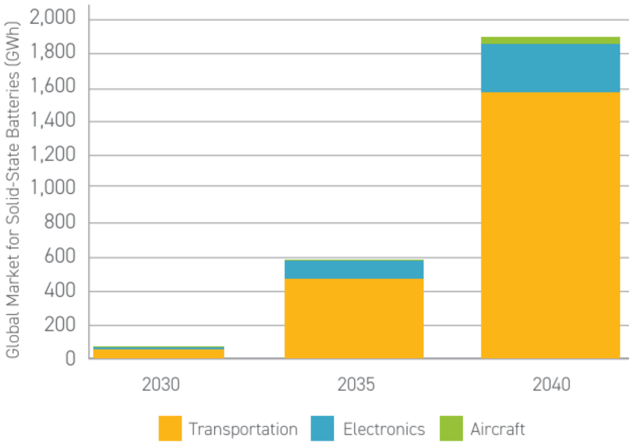
The development and future potential of SSBs is as follows:

Wave 1 in the 2020s: Consumer electronics, healthcare, and wearables: Small healthcare products and niche electronics are already available and smaller applications in consumer electronics and wearables have hit the mass market around 2022 (e.g. Ilika). Barriers to entry are low as the size of batteries required are very small. Consumer products are replaced frequently, so do not require a long lifecycle. One of the most promising technologies for use in extremely hot and cold temperature environments. Its ability to charge relatively quickly is also important for viable consumer products.

Wave 2 in the 2030s: **Electric Vehicles:** In this period, the safety issue of flammability in lithium-ion batteries will be addressed. Increased energy density of SSBs will deliver significant improvements in EV range and the issue of range anxiety will be addressed. Commercial SSBs are already available in EVs (e.g. Blue Solutions) but need to operate at above room temperature. This period would be too early to compare the performance, safety, and cost of SSB EVs with current EV models with liquid electrolytes.

Wave 3 in the 2040s: **Aircraft and Aviation:** This period will witness a leap forward in performance leading to large-scale roll-out across the aviation industry. Aircraft are heavy and aviation requires substantial amounts of energy. SSBs will likely be introduced initially for smaller/narrow-body aircraft, helicopters, and hybrid technologies, initially in the 2030s but with a wider roll-out in the 2040s. SSBs could be used in new concepts such as vertical take-off and landing for applications in urban transport. Initial application to commercial aviation is unlikely for 20+ years given long manufacturing lead times in aerospace.

Global annual SSB GWh demand by application to 2040



Source: The Faraday Institution / various web sources

VI. CONCLUSION

1. SSBs have the potential to significantly improve safety, thereby reducing the need for additional safety measures.
2. With advanced cell design SSBs are a feasible technological route to achieve both high power and energy density and high safety.
3. In the future, all solid-state batteries will break through technology and production bottlenecks. With the continuous improvement of battery material performance, solid-state batteries will improve further in terms of energy density and safety. Eventually, solid-state batteries will be industrialized and become one of the essential energy storage tools for future development.

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