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# Glass for batteries

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## Abstract

The lithium-ion battery (LIB) has been the dominant technology in the rechargeable energy storage market for more than twenty years. However, to meet the increasing need for electric vehicles and portable electronics as well as stationary electricity and grid-scale energy storage, there is an emerging demand for alternative battery technologies.

The transition to clean energy requires the introduction of energy storage devices with excellent electrochemical properties that respect economic, environmental, and social aspects. Analysis of issues associated with liquid electrolytes led scientists in the past to consider solid-state electrolytes, which made it possible to apply a metal lithium anode and design all-solid-state batteries (ASSB) (Figure 1, (BUBULINCA 2023)).

The typical battery architectures for the conventional lithium-ion and solid-state batteries are represented Figure 2 (JANEK 2016).

Conventional lithium-ion batteries (LIB, Figure 2.b.) contain a porous anode (negative electrode typically made of graphite, grey circles) and a porous cathode (positive electrode typically made of a layered transition metal oxide, violet circles) as ‘active’ storage components, coated on thin copper (negative electrode) and aluminum (positive electrode) foils, serving as current collectors. A thin separator (grey band, about 10  $\mu\text{m}$  thick) is placed between the much thicker electrodes (each about 100  $\mu\text{m}$  thick). A liquid electrolyte infiltrates the porous electrode and separator assembly, providing fast ion transfer between the electrodes and preventing electronic short-circuiting.

In a lithium ion solid-state battery with a conventional anode (LI-SSB, Figure 2.c.), the liquid electrolyte in the electrodes is completely replaced by solid electrolyte (dark orange circles) in the electrodes and the electrolyte-filled separator is replaced by another or the same solid electrolyte (orange circles). Only with a lithium-metal anode (light yellow) that has a theoretical energy density of 3,700  $\text{mA g}^{-1}$ , can a significant gain in energy density be achieved. Changes in energy density are estimated based on the density increase from liquid to solid, considering the high specific capacity of lithium metal (LiM-SSB, Figure 2.a.) and complete replacement of the graphite and anode electrolyte.

The price of lithium and its resource increasing day by day, there is an emerging need to develop alternative technologies. Sodium ion batteries SIBs are an alternative choice to

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LIBs. They share similar operating principle as LIBs, they are based on cheaper and abundant raw materials, the electrolytes are water-based and the copper collectors at the anode can be replaced with aluminum collectors. So All-solid-state sodium batteries (ASSSBs) using nonflammable solid-state electrolytes (SEs) and earth-abundant sodium metal are also attracting worldwide research attention. (CHI 2022)

All-solid-state sodium and lithium batteries (respectively ASSSBs and ASSLBs) are promising candidates and could provide high power density with good safety and cycle durability, making them a potential next-generation battery technology. As a result, the identification and optimization of suitable cathode materials and solid electrolytes (SSEs) are essential for developing the practical application of ASSBs.

After years of development, SSEs can be divided into three categories: inorganic solid electrolytes (ISEs), polymer solid electrolytes (PSEs) and composite solid electrolytes (CSEs). Among them, ISEs can be divided into amorphous glass, glass-ceramic and polycrystalline ceramic. Glass is an amorphous super-cooled liquid, whereas glass-ceramics are partially crystallized glasses, consisting of a mixture of a crystalline phase and an amorphous glass phase (SAKAMOTO 2010). The percentage of crystalline phase present can vary across a wide range, typically in the range of 10–90%. The main advantages of glass-ceramic materials are their dense, non-porous microstructure, and good mechanical, electrical and thermal properties. Glass-ceramic SSEs have become one of the hot research directions for SSEs due to their excellent ionic conductivity, electrochemical properties and better compatibility with electrodes. Apart from the obvious advantages of eliminating the liquid electrolyte and associated problems, such as dendrite growth and liquid leakage, the use of solid electrolyte also provides the benefit of removing the need for a separator (e.g., porous polymer membrane), which in turn reduces the cost and fabrication complexity. The use of a solid electrolyte is not without its challenges. At present, the major challenge is the development of materials with high ionic conductivity at room temperature and improved chemical and electrochemical stabilities. (LIN 2023) (VIALLET 2019)

The energy density of batteries will depend upon the capacity of cathode materials. Many researchers developed various cathode materials for SIBs. It is particularly important to develop cathode materials with sufficiently large interstitial spaces within their crystallographic structures to host ions ( $\text{Li}^+$  or  $\text{Na}^+$ ) and achieve satisfactory electrochemical performances of SIBs. Researchers have developed new class glass and glass-ceramic materials that have improved electrochemical performance and cycle life for use in the development of ASSIBs. As a result of the controlled crystallization and evolution of variable proportions of crystalline and glassy phases, glass-ceramics cathodes can significantly outperform conventional crystalline cathodes in terms of superior mechanical properties, good formability, strong electrochemical stability, high ionic and electronic conductivity, and chemical resistance to volumetric changes upon dissolution of alkali metal cations. These properties make them promising candidates for use as cathode materials in next-generation. (GANDI 2022)

The aim of this presentation is to give an overview of glassy and glass-ceramic solid electrolytes and active materials (anode and cathode) for lithium and sodium technologies.

After a description of an ASSB and the requirement, in terms of solid electrolyte and processing, we will present the synthesis and characterization of glass and glass ceramic materials and will provide a review of ionic conductors and describe the current state of research and development of All-solid-state batteries.

The challenges and opportunities associated with these glass and glass-ceramic systems, and All-Solid-State batteries, will be discussed.

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**Keywords:** glass, glass ceramic, all solid state batteries, Li ion batteries, Na ion batteries, solid electrolytes