High Energy and High Safety Rechargeable Batteries

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Keywords: Rechargeable batteries, Li ion battery, Solid-state battery, Aqueous Zn ion battery

The growing demand for safe, high-performance energy storage systems has accelerated research into next-generation battery technologies. Among these, solid-state lithium-ion batteries (SSLBs) and aqueous zinc-ion batteries (AZIBs) have emerged as promising candidates due to their complementary strengths. SSLBs offer high energy density and improved safety by replacing flammable liquid electrolytes with solid-state materials, making them ideal for compact, long-lasting applications. In contrast, AZIBs provide a cost-effective and environmentally friendly solution, utilizing water-based electrolytes and abundant zinc resources to deliver reliable performance with enhanced safety and sustainability.

While lithium-ion batteries (LIBs) have dominated the secondary battery market, their dependence on scarce elements like lithium and cobalt, along with safety risks from flammable organic electrolytes, limits their scalability for grid-level storage. AZIBs address these concerns with zinc's natural abundance (75 ppm in Earth's crust), high theoretical capacity ($819\ mAh\ g^{-1}$), and low redox potential ($-0.763\ V$ vs. SHE). Aqueous electrolytes further contribute to safety and high ionic conductivity ($\sim 1\ S\ cm^{-1}$).

Typical ZIBs consist of zinc metal anodes, (in)organic cathodes, neutral or mildly acidic aqueous electrolytes, and separators. However, challenges such as cathode limitations, electrolyte instability, separator inefficiency, and zinc anode issues—including corrosion, hydrogen evolution, and dendrite formation—hinder their commercial viability.

This work investigates the design principles, electrochemical behavior, and material innovations of both SSLBs and AZIBs. Through advanced characterization and modeling, key challenges such as interfacial stability, ion transport, and electrode compatibility are addressed, offering strategic insights for the development of safer, high-performance energy storage systems.