ADVANCING LITHIUM-ION BATTERIES RECYCLING: A MATERIAL SCIENCE REVIEW

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ABSTRACT

ADVANCING LITHIUM-ION BATTERIES RECYCLING: A MATERIAL SCIENCE REVIEW

Lithium-ion batteries (LIBs) are essential for modern energy storage due to their high energy density, advanced operating voltage, and long cycle life. Their growing use in portable electronics and electric vehicles, along with falling costs, has driven global lithium demand, raising concerns about resource depletion and environmental sustainability. Traditional recycling methods like pyrometallurgy and hydrometallurgy, though effective, involve high energy consumption and chemical waste. Electrochemical extraction presents a greener alternative, operating at room temperature with reduced waste and improved energy efficiency. However, complexities in setup and scalability limit its adoption. This review examines factors influencing LIB recycling efficiency, focusing on separation membrane materials and their role in enhancing electrochemical processes. Key topics include increasing lithium-ion concentration, improving membrane mechanical and ionic properties, and selecting environmentally compatible materials. By integrating recent advances in material science, this study addresses current gaps in recycling methods, promoting sustainability and innovation. It is shown that Garnet-type LLZO stands out due to its superior mechanical robustness, wide electrochemical window and have porous structure. However, its high interfacial resistance with Li requires surface modification as it hinders the Li-ion conductivity The findings aim to support the development of efficient, scalable, and eco-friendly LIB recycling processes, reducing mining reliance and supporting a circular economy. Future research directions are suggested to refine methodologies and expand practical applications for sustainable energy storage.

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