Polyacrylic Acid-Based Gel Polymer Electrolyte Coated Ni/NiO Foam Anode for Enhanced Lithium-Ion Battery Performance

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Lithium-ion batteries (LIBs) are among the most widely used energy storage technologies, powering portable electronics, electric vehicles, and renewable energy systems due to their high energy density, long cycle life, and reliable performance. However, their further development is often hindered by challenges such as structural degradation of electrode materials, limited ion transport in conventional two-dimensional architectures, and unstable electrode–electrolyte interfaces, all of which contribute to capacity fading and reduced cycling stability [1].

Lithium-ion batteries with traditional flat, two-dimensional architectures face inherent limitations in achieving high energy output per unit area and in utilizing internal volume efficiently. The planar configuration of these electrodes restricts the loading of active material and extends the pathways for both lithium-ion and electron transport. Consequently, such structural constraints negatively impact electrochemical performance, leading to slower charge–discharge rates and reduced overall energy storage capacity.

A promising strategy to address the limitations of conventional battery designs is the development of three-dimensional (3D) electrode architectures. These advanced structures provide a larger surface area, enable greater loading of active materials, and reduce the diffusion paths for both ions and electrons. As a result, they facilitate faster electrochemical processes and significantly improve energy storage capability. Incorporating 3D frameworks into LIBs holds great potential for building compact, high-performance systems that meet the demands of modern, energy-intensive technologies [2].

Nickel foams are highly promising 3D electrode architectures for lithium-ion batteries due to their dual role as conductive current collectors and mechanically stable frameworks. Their porous, interconnected structure offers large surface area, uniform active material distribution, and efficient electron transport, while the open-cell design improves electrolyte infiltration and ion diffusion. With excellent chemical stability, catalytic activity, and mechanical resilience, Ni foams support high mass loading without structural failure, resulting in enhanced capacity, faster charge/discharge rates, and improved cycling stability, making them ideal candidates for advanced LIB anodes.

Ni/NiO foam is a promising anode material for lithium-ion batteries due to its high surface area, conductivity, and porous 3D framework, but its practical performance is limited by severe volume fluctuations during lithiation/delithiation and unstable electrode–electrolyte interfaces, which lead to capacity fading and poor cycling stability. To overcome these challenges, a polyacrylic acid (PAA)-based gel polymer electrolyte (GPE) coating can be employed, providing a flexible and adhesive layer that buffers mechanical stress, improves interfacial contact, and enhances electrode wettability. The gel structure of PAA accommodates liquid electrolyte, offering efficient lithium-ion conduction while simultaneously stabilizing the solid–electrolyte interphase and suppressing side reactions. As a result, the incorporation of PAA-based GPE with Ni/NiO foam electrodes significantly improves reversible capacity, rate capability, and long-term cycling performance, making this hybrid system a promising candidate for next-generation lithium-ion batteries.

In this work, a Ni/NiO foam-based anode was coated with polyacrylic acid (PAA) to address the challenges of volume expansion and unstable electrode–electrolyte interfaces. The PAA-based gel polymer electrolyte not only enhanced mechanical stability and ionic conductivity but also improved interfacial contact, resulting in higher reversible capacity, superior rate performance, and prolonged cycling stability. This strategy demonstrates the effectiveness of polymer-assisted interface engineering for advancing Ni/NiO foam electrodes in next-generation lithium-ion batteries.

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