

Eco-Friendly Synthesis of Zinc Cobaltite Using Piper nigrum Extract: Structural, Morphological and Electrochemical Properties for Energy Storage

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Abstract

Green synthesis strategies provide sustainable pathways for advanced energy materials by minimizing hazardous reagents and energy-intensive processes. In this work, zinc cobaltite (ZnCo_2O_4 , ZCO) nanoparticles were synthesized using Piper nigrum (black pepper) extract as a natural reducing and stabilizing agent. XRD analysis confirmed the polycrystalline spinel phase, with greater crystallite sizes in ZCO @ pure compared to ZCO@300 and ZCO@500. Upon incorporation of black pepper extract. Electrochemical behavior was systematically evaluated using the Dunn plot method, where $\log(i)$ versus $\log(v)$ analysis provides mechanistic insight into charge storage. The slope values revealed distinct regimes: ZCO@500 exhibited a slope of ≈ 0.50 , indicating diffusion-controlled dominance; ZCO@300 showed ≈ 0.58 , consistent with a mixed mechanism leaning toward diffusion; and ZCO@300 with extract displayed ≈ 0.33 , reflecting strong diffusion control. Among all samples, ZCO@500 demonstrated the highest specific capacitance, underscoring its suitability for high-performance supercapacitors. These findings highlight the dual role of Piper nigrum extract in tailoring crystallite size and optimizing electrochemical kinetics, establishing a green and scalable synthesis route for next-generation energy storage materials.

Keywords

Zinc Cobaltite, piper nigrum extract, green synthesis, electrochemical properties, supercapacitors, structural characterization.