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Tunable Magnetic and Electrochemical Behavior in Spinel Ferrite-CNT Nanocomposites for Energy and Environmental Applications

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The integration of energy storage and environmental remediation within a single material system offers a promising pathway toward sustainable device architectures. In this work, cobalt-engineered copper ferrite nanostructures were hybridized with multi-walled carbon nanotubes (MWCNTs) to develop a multifunctional platform exhibiting coupled electrochemical and photocatalytic functionalities. The composites were synthesized via a co-precipitation route followed by controlled ultrasonication with varying CNT content (5-15 wt%). Structural analysis confirmed the formation of a stable cubic spinel phase, with crystallite size reduced from 16.87 nm to 14.89 nm upon CNT incorporation, indicating inhibited grain growth. Electron microscopy revealed uniform dispersion of ferrite nanoparticles (~14-17 nm) along the CNT framework, promoting enhanced interfacial connectivity. Magnetic measurements indicated a reduction in saturation magnetization from 31.87 to 26.01 emu g-1, reflecting increased non-magnetic contribution and soft magnetic characteristics. Electrochemical evaluation demonstrated a significant enhancement in capacitive behaviour, with the optimized composite delivering a specific capacitance of 437.4 F g-1 at 10 mV s-1, compared to 161.7 F g-1 for pristine ferrite. This improvement is attributed to synergistic contributions from pseudocapacitance and electric double-layer effects enabled by the conductive CNT network. Photocatalytic studies further revealed efficient degradation of methylene blue, achieving 91.3% removal within 90 min and a rate constant of 0.024 min-1, alongside reduced electrical energy demand (EEO ⊠ 9.04 kWh m-3 order-1). The enhanced performance arises from improved charge separation and rapid electron transport. These findings establish ferrite-CNT nanohybrids as viable candidates for integrated systems such as supercapacitors and wastewater treatment technologies.

Keywords: Pseudocapacitive energy storage; Photocatalytic degradation; Interfacial charge transport

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