Defect-Modulated $NiCo_2O_4$@rGO Nanostructures with Enhanced Redox Activity for Energy Storage Applications

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Abstract

Interface-engineered $NiCo_2O_4$@rGO nanocomposites were synthesized via an ultrasonication-assisted assembly strategy to achieve uniformly anchored quasi-spherical $NiCo_2O_4$ nanostructures on conductive reduced graphene oxide (rGO) sheets. An optimized 1.5:1 molar composition exhibited the smallest crystallite size and highest microstrain, originating from accelerated nucleation and enhanced cation disorder within the spinel lattice. Incorporation of rGO significantly modified the structural and electronic landscape, inducing compressive interfacial strain, moderated defect density, and efficient charge redistribution across the oxide–graphene interface. Spectroscopic analyses (FTIR, Raman, and UV–Vis) confirm strong π–d coupling, defect-assisted electronic transitions, and interfacial hybridization, leading to enhanced sub-bandgap absorption. Vacuum-level-referenced XPS reveals pronounced negative core-level shifts (0.1–0.3 eV) and a 0.17 eV upward Fermi-level shift, evidencing robust electron transfer from rGO to $NiCo_2O_4$ driven by work-function mismatch. BET analysis demonstrates a hierarchical micro–mesoporous architecture that improves ion accessibility and suppresses particle agglomeration. Electrochemical evaluation shows outstanding pseudocapacitive performance, delivering a high specific capacitance of 1059 F g^{-1} at 1 A g^{-1}, along with excellent rate capability, reduced charge-transfer resistance, and long-term cycling stability. The synergistic integration of defect-rich $NiCo_2O_4$ redox centers with the highly conductive rGO network establishes a strong structure-property-performance relationship, positioning $NiCo_2O_4$@rGO as a promising electrode material for next-generation energy storage devices.

References

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Figure

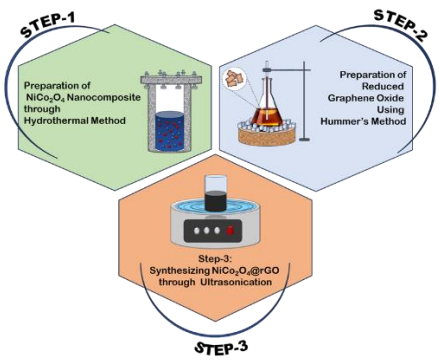

Figure 1: Schematic illustration of the synthesis and interfacial structure of $NiCo_2O_4$@rGO nanocomposite.