Design and Synthesis of a Novel MIL-101(Fe)/GQDs/PPy Nanocomposite for High-Performance Hybrid Energy Storage Applications

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The global demand for energy increases by 4% annually, which shows the need to develop improved energy storage technologies. Traditional energy storage devices, such as batteries and supercapacitors, have limitations: batteries have high energy density but slow charge-discharge rates and limited lifespans, while supercapacitors offer rapid charge-discharge and high-power density but have low energy density. In addition, both devices rely on toxic materials that have contributed to environmental pollution. To overcome these limitations, we aim to develop a highly efficient hybrid energy storage device: "Ultra-Supercapacitor", which combines the advantages of both devices. The core innovation is a novel MIL-101(Fe)/GQDs/PPy nanocomposite electrode material synthesized using a novel and eco-friendly approach combining chemical solvothermal and Pulsed Laser Ablation in Liquid (PLAL) to ensure high purity and uniformity of the final composite. Several material characterizations—including XRD, SEM, TEM, UV-Vis, BET, and Raman spectroscopy—confirmed the successful synthesis of the composite. Electrochemical performance tests such as CV, GCD, and EIS indicated superior results in specific capacitance, energy, and power density. Our device achieved an enhancement of efficiency by over 170% compared to commercial supercapacitors. Moreover, the final device has two additional features: a gel electrolyte to enhance stability and reduce leakage and self-recharging capability. The device was tested in a real-life application by powering an LED continuously for 1 hour, showing high potential to be used in applications like renewable energy systems and portable and medical devices. Our research makes a significant contribution to the advancement of sustainable energy storage solutions.

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