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Dumbbell-shaped nanorod assembly of a NiO/CuO composite for high-performance redox-active battery-type supercapacitor electrodes†

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Engineering nano-/microstructured electrode architectures with enhanced redox properties plays a pivotal role in boosting the electrochemical performance of battery-type hybrid supercapacitors. Herein, we report the synthesis of a dumbbell-shaped NiO/CuO nanorod composite *via* a one-step hydrothermal approach and comprehensive characterization techniques were employed to gain in-depth insights into the physicochemical properties of the composite. The unique nanorod-assembled dumbbell-like morphology, coupled with the synergistic interaction between the NiO and CuO phases, imparts a high surface area of 120.5 $m^2\ g^{-1}$ and enhanced charge transport kinetics compared to pristine NiO. Electrochemical analysis reveals the battery-type characteristics of the NiO/CuO electrode, which exhibits a remarkable specific capacity of 1005.2 C g^{-1}—nearly twice that of pristine NiO (498 C g^{-1})—along with exceptional cycling stability, retaining 98% of its initial capacity over 5000 cycles. These findings highlight the structural and compositional merits of the NiO/CuO composite, positioning it as a promising redox-active electrode for next-generation hybrid supercapacitors.

1. Introduction

The demand for sustainable and efficient energy storage systems has increased dramatically due to the depletion of fossil fuels, growing environmental concerns, and rapid economic growth.[1–3] Lithium-ion batteries (LIBs) and supercapacitors (SCs) are two of the many energy storage technologies that have attracted a lot of interest.[4,5] While LIBs deliver high energy density, they are limited by low power output, slow charge/discharge rates, and finite cycling stability.[5] In contrast, supercapacitors offer outstanding power density and long cycle life but suffer from inherently low energy density.[6,7] These limitations have fueled the development of hybrid supercapacitors (HSCs)—devices that integrate battery-type and capacitor-type electrodes to simultaneously achieve high energy and power densities.

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In a typical HSC configuration, the battery-type electrode contributes to high energy storage through faradaic redox reactions, while the capacitor-type electrode ensures rapid charge–discharge behavior through non-faradaic processes.[5,8] Activated carbon and graphene, both carbon-based materials, are frequently utilized for capacitor-type electrodes, whereas transition metal compounds are generally employed for battery-type electrodes.[8–10]

Nickel oxide (NiO) stands out as a noteworthy candidate for battery-type supercapacitors, attributed to its impressive theoretical specific capacitance of 2573 F g^{-1} at 0.5 V and specific capacity of 1286 F g^{-1}.[11] In addition to these properties, NiO offers excellent chemical and thermal stability and is environmentally friendly, cost-effective, readily available, and easy to synthesize, making it a strong candidate for supercapacitor applications.[3,11] Despite these advantages, the potential of NiO for supercapacitor applications remains underexplored. However, its inherently poor electrical conductivity significantly limits its performance in HSCs.[11–13] Improving its conductivity is key to unlocking its full potential in energy storage devices.

To address the challenge of low electrical conductivity in NiO as a battery-type electrode material, various methods have been explored. These approaches include directly growing NiO on conductive substrates,[3] creating bimetallic materials,[14] employing atomic doping,[15] and synthesizing composites with highly conductive materials like graphene

