J Mater Sci: Mater Electron (2026) 37:887

Efficient fabrication of Cd-doped NiO nanostructures as high-performance electrode materials for supercapacitors

C. Kathiravan[1], K. Balachandran[2,*], J. Venkatesan[3], and A. Mani[3]

[1] *Department of Chemistry, Muthayammal Engineering College, Rasipuram, Namakkal, India*
[2] *Department of Chemistry, Vivekanandha College of Engineering for Women, Tiruchengode, Namakkal, India*
[3] *Department of Physics, Muthayammal Engineering College, Rasipuram, Namakkal, India*

Received: 22 March 2026
Accepted: 14 April 2026

© The Author(s), under exclusive licence to Springer Science+Business Media, LLC, part of Springer Nature, 2026

ABSTRACT

Pure and cadmium-doped NiO nanostructured porous materials, including various concentrations, were successfully synthesized via a solvothermal approach consuming citric acid as a hydrolysis-regulating substance and evaluated for supercapacitor applications. Powder X-ray diffraction was employed to examine the phase composition of nanomaterials. The typical crystallite size of the oxide samples ranged from 21 to 9 nm. Fourier transform infrared spectroscopy established the presence of M–O bonding. Morphological investigations revealed a mesoporous, flake-like building in the prepared materials. Energy-dispersive X-ray spectroscopy was used to find out the oxidation states and elemental composition, respectively. Electrochemical performance was analyzed in an aqueous electrolyte using cyclic voltammetry, galvanostatic charge–discharge, and electrochemical impedance spectroscopy. Among the four electrodes, Cd–nickel-oxide ($X = 10\%$) exhibited the maximum surface redox activity and brought a superior specific capacitance of 832 F g^{-1} at a current density of 1 A g^{-1}.

1 Introduction

Nanotechnology encompasses a wide range of scientific fields, such as microfabrication, molecular engineering, materials science, organic chemistry, molecular biology, and semiconductor physics, largely because of its extremely small scale [1]. Research and applications in this area are equally varied, spanning from advancements in predictable device physics to entirely new strategies based on molecular self-assembly, the development of innovative nanoscale materials, and the precise manipulation of matter at the atomic level. At the same time, nanotechnology raises challenges similar to those associated with other emerging technologies, such as concerns about the environmental effects and toxicity of nanomaterials, their influence on the global economy, and speculation about extreme or catastrophic outcomes. These issues have prompted discussions among governments and advocacy groups

Address correspondence to E-mail: balanano06@gmail.com

https://doi.org/10.1007/s10854-026-17303-y
Published online: 22 April 2026

regarding the need for specialized regulations for nanotechnology. Among nanomaterials, transition metal oxide nanoparticles have gained increasing importance for supercapacitor applications [2]. Owing to their nanoscale dimensions, nanoparticles exhibit properties that differ knowingly from those of bulk materials. In particular, nickel-oxide nanoparticles with uniform size and good diffusion are highly wanted for use in ceramic, magnetic, electrochromic, and heterogeneous catalytic systems [3]. Various synthesis methods have been reported for producing nickel-oxide nanoparticles, including sol–gel processes [4], surfactant-assisted methods [5], thermal decomposition [6], polymer-matrix-assisted synthesis [6], and spray pyrolysis [7]. However, several of these approaches face difficulties in achieving uniform particle size and effective dispersion. Electrochemical capacitance has gained significant attention due to its outstanding features, such as high-power density, long-lasting and sustainable energy storage capability, excellent reversibility, prolonged operational life, and minimal maintenance requirements. Supercapacitors also offer higher energy storage capacity than conventional capacitors and are considerably safer compared to batteries [8].

Supercapacitors are usually divided into two types based on their charge storage mechanisms. One category is pseudo-capacitors, which store charge through fast Faradaic redox reactions. Materials commonly used in pseudo-capacitors include conducting polymers, metal oxides, and metal hydroxides. The other category is electrical double-layer capacitors (EDLCs), which store energy through the electrostatic adsorption of ions at the electrode–electrolyte interface. EDLCs are typically composed of carbon-based materials such as graphene, carbon nanotubes, and activated carbon.

As reported in [9, 10], transition metal oxides (TMOs) including TiO_2, V_2O_5, Fe_3O_4, CuO, SnO_2, Bi_2O_3, nickel-oxide, MnO, ZnO, and Co_3O_4, have attracted considerable interest due to their low cost, environmental compatibility, and comparable electrochemical performance. Among these materials, nickel-oxide stands out as promising electrode materials for pseudo-capacitors because of its high theoretical capacitance (2584 F g^{-1} within a 0.6 V potential window), strong electrochemical activity, abundant redox reactions, eco-friendly nature, affordability, and excellent stability [11]. Owing to these advantages, nickel-oxide has been widely explored for various applications, including lithium-ion batteries, gas sensors, catalysis, and water treatment adsorption processes [12]. The key properties of nanoparticles, such as particle size, structure, distribution, and morphology, are strongly influenced by the synthesis method employed. Various synthesis techniques, including electrochemical routes, hydrothermal reactions, and precipitation methods, have been widely developed for the production of nanoparticles (NPs). Among these, the sol-gel method was selected for this study due to its easiness, low cost, and ease of comparison with other fabrication approaches. This technique allows nanoparticle formation at relatively low temperatures while offering effective control over particle size and composition.

The foremost objective of this work is to examine nickel-oxide nanoparticles doped with Cd^{2+} ions at a concentration of 0.02 M%. With the quick expansion of the electric vehicle industry in recent years, supercapacitors have gained considerable attention [13]. To achieve enhanced pseudocapacitive performance, it is essential to design electroactive materials with optimized structures and geometries that maximize surface area utilization and incorporate well-defined porous networks [14]. Previous studies have demonstrated that employing nanostructured electrode materials with diverse nickel-oxide morphologies—such as nanoparticles, nanoflowers, nanosheets, and nanowires—significantly increases the accessible superficial area of the electrodes [15]. Recent progress in nanoscience and nanotechnology has further enabled the development of nanostructured electroactive materials with improved surface properties, thereby advancing their application in high-performance supercapacitors.

A number of methods, including homogeneous precipitation [16], hydrothermal [17], and microwave-assisted homogeneous precipitation [18], can be used to create α and β nickel hydroxides, or diverse phases of α and β nickel hydroxide samples in the presence of cinnamic acid (pH stays comparatively low for the duration of the process). Among these, a simple hydrothermal method is beneficial for producing nickel-oxide nanoflakes because it requires less equipment, minimal external energy consumption, and cheap precursors. Here, we used a simple hydrothermal method to create undoped and Cd^{2+}-doped diverse phases of α- and β-nickel