IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 12, May 2026
Impact Factor: 8.2

Eco-Friendly Synthesis and Electrochemical Characterization of Cobalt Oxide (CoO) Nanoparticles Using Pilea microphylla Extract

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Abstract: *Cobalt oxide (CoO) nanoparticles were successfully synthesized using Pilea microphylla extract via a green synthesis approach. X-Ray Diffraction (XRD) confirmed their crystalline structure, while Field Emission Scanning Electron Microscopy (FESEM) revealed platelet-like morphology. Electrochemical studies demonstrated their pseudocapacitive behavior, with a maximum specific capacitance of 377 F/g at 5 mV/s. Galvanostatic charge-discharge (GCD) analysis showed an energy density of 87 Wh/kg, and electrochemical impedance spectroscopy (EIS) confirmed a low internal resistance of 5.3 Ω, indicating excellent charge transport. These results highlight the potential of green-synthesized CoO nanoparticles for supercapacitor applications.*

Keywords: Cobalt Oxide Nanoparticles, Green Synthesis, Pilea Microphylla, Supercapacitors, Electrochemical Characterization

I. INTRODUCTION

Nanoparticles have become a focal point in recent scientific research due to their wide-ranging applications in biology, chemistry, and physics. However, nanoparticles produced through conventional physical and chemical methods often involve toxic reducing agents such as sodium borohydride and hydrazine hydrate, posing risks to human health and the environment [1, 2]. While it was observed in the nineteenth century that biological organisms could reduce metal precursors, the precise mechanisms remain unclear. Biological methods have gained popularity because they can effectively synthesize nanoparticles using natural reducing, capping, and stabilizing agents, thus eliminating harmful chemicals and minimizing energy usage [3]. The practice of green synthesis, guided by "green chemistry" principles, has become increasingly common for producing nanoparticles [3]. This approach aims to reduce or eliminate harmful substances during chemical design, production, and application [4, 5]. It is recognized not only as an environmentally friendly approach but also as a way to mitigate health risks associated with toxic substances [6]. Various biological resources, including plants, bacteria, yeast, fungi, algae, and viruses, are utilized in green synthesis to create nanoparticles [7,8,9,10]. Recently, plant extracts containing phytochemicals have gained attention as a sustainable option for nanoparticle synthesis [11]. The creeping herb Pilea microphylla, also known as the artillery plant, thrives in humid environments [12]. This plant contains bioactive phytochemicals, including six phenolic compounds:

1. Quercetin-3-O-rutinoside
2. 3-O-Caffeoylquinic Acid
3. Luteolin-7-O-Glucoside
4. Apigenin-7-O-Rutinoside

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5. Apigenin-7-O-β-d-glucopyranoside
6. Quercetin. These compounds act as capping agents in the synthesis of nanoparticles [13, 14].

In our recent study, we synthesized cobalt nanoparticles using Pilea microphylla extract and characterized these particles through techniques such as XRD and FESEM to determine their size and morphology. Furthermore, to assess their energy storage potential, we conducted cyclic voltammetry (CV), galvanostatic charge-discharge (GCD), and electrochemical impedance spectroscopy (EIS) measurements. The results demonstrate the feasibility of green-synthesized CoO nanoparticles as a potential electrode material for supercapacitor applications.

II. MATERIALS & METHOD

All the chemicals utilized in this synthesis are non-toxic. Pilea microphylla was collected from a rural area, and the entire herb was thoroughly washed with distilled water to remove sand particles. About 80 g of the herb was ground into a paste using a mortar and pestle. This paste was then mixed with 100 ml of distilled water and heated on a mantle for 15 to 20 minutes. The extract was allowed to cool and was filtered using filter paper. For the preparation of a 0.5 M solution, 14.55 g of cobalt nitrate [Co(NO3)2.6H2O] was dissolved in 100 ml of diluted water. Both the 100 ml plant extract and the 100 ml metal solution were combined, resulting in a 200 ml mixture, which was then placed on a magnetic stirrer for 1 to 2 hours. During stirring, 1 to 3 drops of NaOH solution were added to the mixture. Following this, the mixture was transferred to test tubes and centrifuged for 30 to 45 minutes. The resulting semi-fluid deposit was collected in a crucible and then calcined in a muffle furnace at a temperature of 300 to 400°C. Schematic representation of green synthesis of cobalt-derived material using plant extract, followed by thermal treatment to obtain the final powdered product. As shown in Fig. 1.

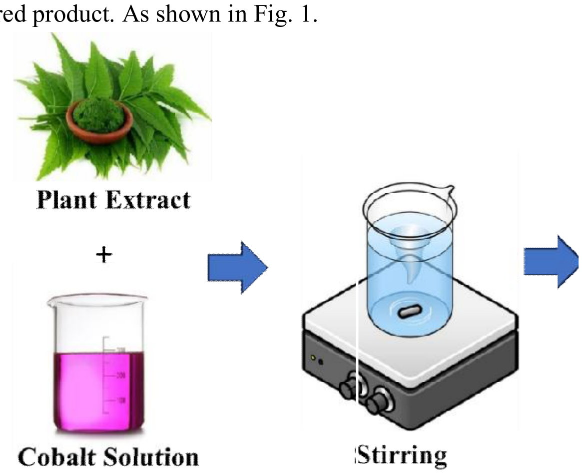

Fig. 1 Schematic representation of green synthesis of cobalt-derived material using plant extract, followed by thermal treatment to obtain the final powdered product.

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III. RESULTS AND DISCUSSION

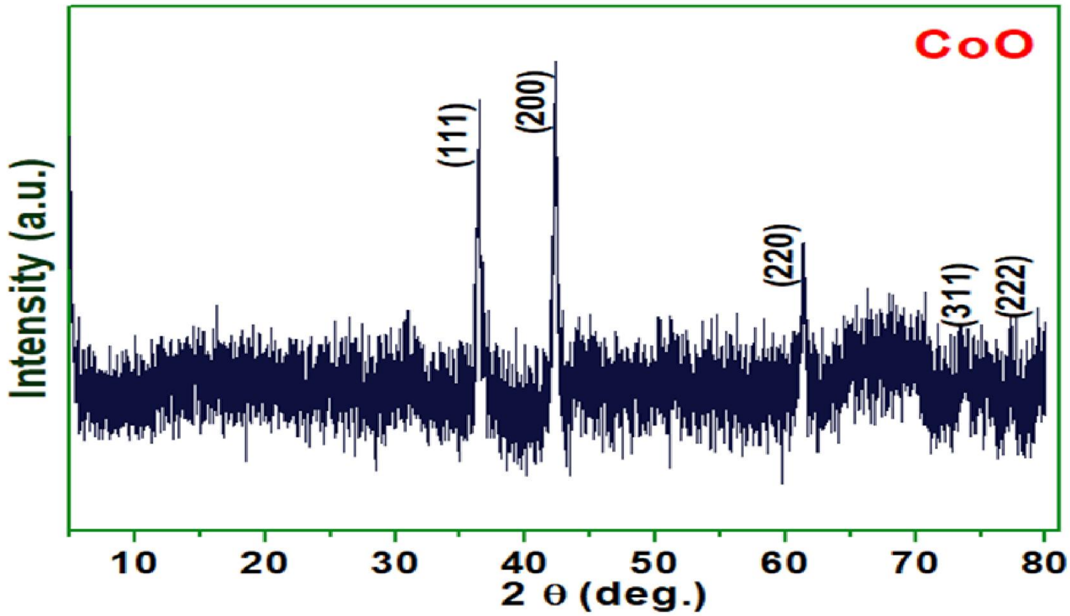
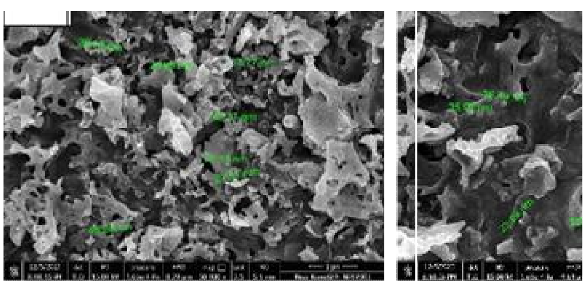


Fig. 2: XRD plot of sample CoO.

Fig. 2 presents the XRD analysis used to examine the crystalline structure of the synthesized CoO sample. The diffraction peaks observed at angles 2θ = 36.39°, 44.57°, 61.39°, 73.44°, and 77.30° correspond to the diffraction planes (111), (200), (220), (311), and (222), indicating the face-centered cubic (fcc) phase structure of the CoO sample, as referenced by JCPDS: #78-0431 [16]. An XRD scan of moderate intensity was conducted to determine the crystallite size (d) of the CoO sample, which averaged 38.45 nm.



a) b) c)

Fig. 3 (a-c): FE-SEM images of sample CoO

Fig. 3 (a-c) displays the FE-SEM images of the CoO sample at varying magnifications between 1 μm and 400 nm. The FE-SEM images reveal platelets with numerous broken edges, which may be attributed to the selective oxidation of Co(OH)2 along specific crystallographic axes. Similar observations in FE-SEM images have been previously reported by Pralong et al. [16].

DOI: 10.48175/IJARSCT-35913

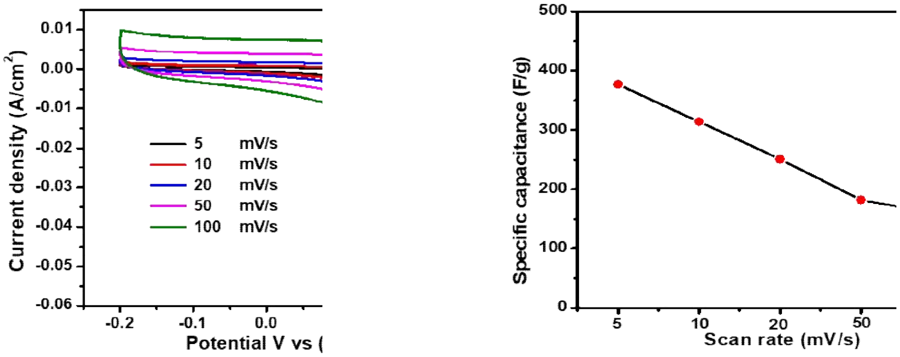


Fig. 4: (a) CV curves at scan rates ranging from 5 to 100 mV/s with a functional window of 0.4, **(b)** Specific capacitance against various scan rate.

Cyclic voltammetry was performed at scan rates ranging from 5 to 100 mV/s within a functional window of 0.4 V. Fig. 4(a) presents the CV curves, which exhibit characteristic redox peaks, indicating the pseudocapacitive nature of the CoO nanoparticles. Additionally, Fig. 4(b) illustrates the variation of specific capacitance with different scan rates. The observed decline in specific capacitance at higher scan rates is attributed to the limited diffusion of electrolyte ions into the electrode material. This trend is consistent with the typical behavior of pseudocapacitive materials, where slower scan rates allow for deeper ion penetration and higher charge storage.

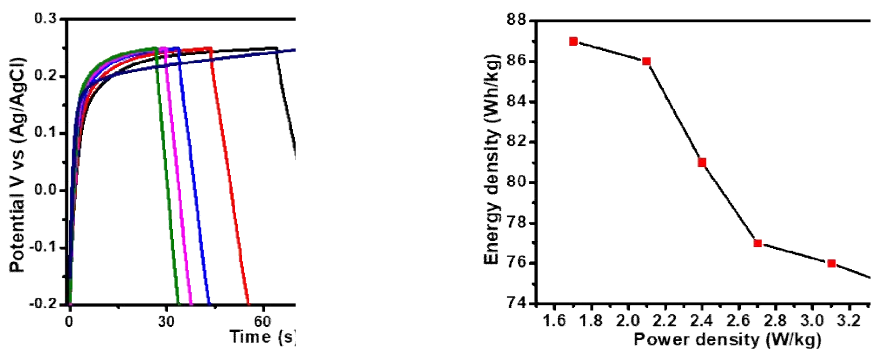


Fig. 5: (a) GCD curves by applying different current density ranging from 5 to 10 mA/cm2., **(b)** Ragone plot of energy density in Wh/kg vs power density in W/kg at various current density from 5 to 10 mA/cm2 respectively.

The charge-discharge characteristics of the CoO thin film were examined at different current densities ranging from 5 to 10 mA/cm². The GCD curves, depicted in Fig. 5(a), display a nearly symmetric profile, suggesting high reversibility and excellent capacitive behavior. Furthermore, the energy and power density values were extracted and plotted in a Ragone plot (Fig. 5(b)), highlighting the energy storage potential of CoO. The energy density varied between 87 Wh/kg at 5 mA/cm² and 75 Wh/kg at 10 mA/cm², while the power density ranged from 1.7 kW/kg to 3.4 kW/kg,

IV. CONCLUSION

CoO nanoparticles were successfully synthesized using Pilea microphylla extract via a green synthesis approach. XRD analysis confirmed their fcc phase structure, and FESEM revealed platelet-like morphology. Electrochemical studies demonstrated their high specific capacitance (377 F/g), excellent energy density (87 Wh/kg), and low internal resistance (5.3 Ω), making them a promising electrode material for supercapacitors.

These findings highlight the potential of green-synthesized CoO nanoparticles in energy storage applications, supporting further exploration of eco-friendly materials for sustainable electrochemical devices

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