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Green Synthesis of Nd_2O_3 /Cr_2O_3 Binary Oxide Nanocomposite Using Vitex negundo Leaf Extract and Investigation of its Electrochemical Potential

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ABSTRACT

Chemical synthesis of metal oxide nanocomposites uses toxic chemicals and high energy, which harms the environment and limits their use for clean energy storage. There is a need for a low-cost, eco-friendly method to produce efficient electrode materials for supercapacitors. Current study has employed single-step, economical, and begin mean to synthesize metal oxide nanoparticles via leaves extract of *Vitex negundo* plant. Synthesized binary oxides were subjected to various characterization tools to evaluate their potential for storage devices. Optical analysis revealed that the synthesized nanomaterial possessed narrow bandgap 3eV than the pristine Nd_2O_3 5eV therefore inherits strong applicability in the electronic industry. FE-SEM showed porous, irregularly shaped particles with slight agglomeration, having sizes within the nano range. The average crystallite size was computed as 3.86 nm. The electrochemical studies were carried out using a three-electrode system immersed in 0.2 M KOH. The electrode slurry was prepared by dispersing the active material in ethanol with Nafion binder (5 mg/15 mL) and drop-cast via a micropipette onto FTO. Cyclic voltammetry at 100 mV/s in the 0- 1.5 V window showed pseudocapacitive behavior. The value of specific capacitance was calculated as 25 F g^{-1}. The synthesized material possessed stability up to 600 sec. Studies demonstrate potential application of phytofunctionalized Nd_2O_3/Cr_2O_3 nanocomposite as electrode material for supercapacitors.

Introduction

Due to overpopulation, energy demand is rising; this ultimately increases the consumption of fossil fuels. Electrochemical energy storage devices have been evolved because of being friendly, clean, sustainable, and efficient (Yang et al., 2016). Due to fast propagation, high power density, fast charging capacity, and long-term stability of supercapacitors, batteries and conventional capacitors are deemed suitable electrochemical energy storage devices. In today's world, supercapacitors are considered an important candidate in the field of portable power, energy storage, and transportation. There are two categories of capacitors: electrical double-layer capacitors, where charge storage is accomplished via increased surface area of active electrode material; nanomaterials possess high surface area due to their small nanoscale size. The second category is pseudocapacitors, which store charge via redox reactions, such as different metal oxides (iron oxide, chromium oxide, zinc oxide, zirconium oxides, etc.) that are conducting (Farisabadi et al., 2020; Meena et al., 2024).

Nanomaterials can be synthesized by various routes; conventional synthesis methods, including hydrothermal, sol–gel, precipitation, and combustion techniques, may involve substantial chemical consumption, energy requirements, and additional processing steps. Although these approaches have enabled the preparation of materials with controlled structural properties, increasing environmental concerns have encouraged researchers to explore alternative synthesis strategies. Plant-mediated synthesis has emerged as an interesting approach because naturally occurring plant constituents can participate in metal-ion complexation, nucleation, and stabilization during nanoparticle formation. This approach provides an opportunity to reduce

dependence on certain synthetic additives while developing nanostructured materials for electrochemical applications (Meena et al., 2024).

Plant extracts contain several classes of phytochemicals, including phenolic compounds, flavonoids, alkaloids, terpenoids, and other oxygen-containing biomolecules. Depending on their chemical composition, these compounds may interact with metal ions and influence the formation, growth, and stabilization of nanoparticles. Their functional groups can participate in complexation and surface adsorption, potentially affecting particle size, aggregation, and morphology. Nevertheless, the precise contribution of individual phytochemicals depends on the plant species, extraction conditions, precursor chemistry, and reaction environment. Therefore, plant-mediated synthesis should not automatically be considered a fully established mechanistic process; rather, its chemical pathways and reproducibility require further investigation. In addition, the environmental advantages of photosynthesis should be assessed alongside the energy required for subsequent drying and calcination processes (Meena et al., 2024).

At the nanoscale, metal oxides have a large surface area, high plasma absorption, high magnetic properties, high surface energies, excellent mechanical strength, high optical properties, quantum confinement, low melting points, and a high kink number, making them attractive candidates for pseudocapacitive electrode applications (Dissanayake & Kularatna-Abeywardana, 2024; Gaikwad et al., 2024; Kumar et al., 2018). Within the broader family of metal oxides, chromium oxide (Cr_2O_3) has been investigated as a potential electrode material because of its electrochemical response and chemical stability. Literature on plant-mediated synthesis of Cr_2O_3 exists, but literature on its supercapacitive applications is absent (Koohpeyma, H., & Mosleh-Shirazi, S. 2025; Cheah et al. 2025; Khalid, A., & Yaseen, G. 2026).

Recently, researchers have shown great interest in the exploration of rare metal oxides because they possess high magnetic, optical, and electrical properties. The scientific community has recently developed an approach to forming combinations of transition metal oxides with rare metal oxides that enhance the magnetic, electronic, optical, morphological, and electrochemical properties (Kubra et al., 2020). Neodymium oxide (Nd_2O_3), in particular, represents an interesting material for exploring alternative oxide-based electrode systems. Recent work by Amate et al. (2025) investigated the effect of precursor concentration on the structural and electrochemical properties of sol–gel-synthesized Nd_2O_3. Their study demonstrated that variations in precursor concentration influenced crystallinity, morphology, and electrochemical performance. The optimized sample exhibited an areal capacitance of 20 F cm^{-2} and retained 86.3% of its capacitance after 12,000 cycles. The authors also reported a substantial diffusion-controlled contribution to the charge-storage response. These findings provide evidence of the potential of Nd_2O_3 in electrochemical energy storage and emphasize the importance of synthesis conditions in determining its functional properties. Nevertheless, further investigation is required to understand its behaviour when combined with other electroactive metal oxides and prepared through alternative synthesis routes (Amate et al., 2025). Kubra et al. (2020) have reported the hydrothermal synthesis of neodymium oxide/manganese oxide nanocomposite and investigated its supercapacitive properties. The results showed that the neodymium content within the composite enhances the stability and coulombic efficiency, which indicates that neodymium oxide is an excellent candidate for formulating nanocomposites. Green synthesis of $Nd_2Sn_2O_7$ was achieved using date palm extract and investigated as a potential energy storage material (Zinatloo-Ajabshir et al., 2020). Progress is being made in plant-mediated synthesis of Nd_2O_3 and is widely being explored for its anticancer, antimicrobial, and photocatalytic abilities (Nashita, A., & Anantharaman, R., 2026; Rajeswari, S. et al., 2025; Velmurugan, S. et al., 2025).

The combination of two metal oxides into a binary nanocomposite provides an opportunity to modify the structural and electrochemical characteristics of individual components. Depending on their composition and interfacial interactions, binary oxide systems may offer a greater diversity of electroactive sites, altered electronic properties, and improved accessibility of electrolyte ions. Such modifications can potentially influence charge-transfer processes and electrochemical response. However, the formation of a binary composite does not necessarily guarantee enhanced performance. Any proposed synergistic effect must be supported by structural characterization and comparative electrochemical measurements of the individual oxides and their combined system. In particular, establishing the phase composition, interfacial characteristics, and contribution of each oxide is essential for understanding the actual charge-storage behaviour of a binary nanocomposite.

Considering the electrochemical potential of Cr_2O_3 and the emerging application of Nd_2O_3 in supercapacitor research, their combination presents an interesting direction for the development of alternative metal oxide electrode materials. Despite the progress achieved in investigating individual chromium and neodymium oxides, their plant-mediated combination and associated electrochemical characteristics remain comparatively underexplored in the literature. Furthermore, the 0.2 M KOH electrolyte used in the current investigation is different from the 1–6 M KOH used for electrochemical analysis in some published studies. Here, the development of plant-mediated Nd_2O_3/Cr_2O_3 binary oxide nanocomposites represents an interesting research direction at the intersection of green nanotechnology and electrochemical energy storage. Establishing their phase composition,

interfacial properties, charge-storage mechanisms, electrochemical durability, and environmental advantages will be essential for determining their suitability as sustainable supercapacitor electrode materials.

Current research has placed strong emphasis on the green route of synthesis where phytochemicals behave as both stabilizing and reducing agents, and no additional agent is required. This plant-based synthesis is greener in a way as it is cheap high surface energies, temperature. The selected metals have ease of availability, are economical, and have potential applications in various domains. Apart from all, the current study has employed one of the most sustainable approaches to fabricate clean and stable electrodes to be used in energy storage devices. The synthesized material was investigated for its optical properties using absorbance data obtained from a UV-Vis Spectrophotometer (UV-Visible); different functional groups were identified via Fourier Transform Infrared (FTIR), while morphological and crystallographic studies were carried out via Field Emission Electron Microscopy (FE-SEM) and powder X-ray Diffraction (XRD). The electrochemical analysis was done by Cyclic Voltammetry (CV), Linear Sweep Voltammetry (LSV), and Chronoamperometry

Materials and Methods

Reagents

High-analytical-grade precursors Chromium (III) nitrate nonahydrate and Neodymium (III) nitrate nonahydrate were obtained from UNI. Chem and Sigma-Aldrich. Deionized water was used throughout the experiment. All apparatus was washed with distilled water and sterilized before experiments. The chemicals used for the fabrication of the working electrode were ethanol, Nafion binder, and potassium hydroxide (KOH). For green synthesis, fresh and healthy leaves were collected in September from Hajira, an area of Azad Kashmir, Pakistan.

Green Synthesis of Nd_2O_3/ Cr_2O_3 nanocomposite

Leaves of the selected plant were brought to Fatima Jinnah Women University, where they were washed with distilled water to remove adhering dust. Leaves were spread on a sheet in the greenhouse for drying in shade. The dried leaves were crushed with a pestle and mortar and passed through a sieve to remove large granules. 2.5 g of weighed powdered leaves were subjected to boiling at 100 ˚C for one hour ten, then left to cool down. The obtained mixture was filtered twice, and the obtained filtrate was refrigerated at 4 ˚C.

The methodology of Velmurugan, S. et al. (2025) was followed with some modifications. 5 mM solutions of the respective salts were formulated with precursors, viz. Cr $(NO_3)_3.9H_2O$ and $(NO_3)_3.9H_2O$ in 100 mL of deionized water. For the synthesis of the nanocomposite, a 1:1 ratio was maintained. The solutions were subjected to constant stirring and heating for an hour. After complete dissolution, both solutions were mixed together and homogenized. 10 mL of plant extract was added to the mixture; it was heated and stirred for an hour. The mixture was left to attain room temperature; the development of precipitates was clearly visible at the bottom of the flask. This solution was incubated for 24 hours at room temperature in a dark cabinet. The obtained precipitates were centrifuged to remove the unwanted water content. The precipitates were dried in a pre-heated oven and calcined at 500˚C for two hours in a furnace. Green-toned powder of Nanoparticles (NPs) was obtained.

Characterization of Nd_2O_3/ Cr_2O_3

The obtained powder was scrutinized via different techniques i.e. UV-Vis Spectrophotometer (1602, Biomedical, services, Spain) within 200-800 nm wavelength range at Fatima Jinnah Women University Pakistan, FESEM (SEMSS-550 Superscan, Shimadzu, Japan) at various magnifications at Institute of Space and Technology, Pakistan, Fourier Transformer Infra-Red (8400, Shimadzu, Japan) within 4000-400 cm^{-1} range at Fatima Jinnah Women University Pakistan.

Fabrication of working electrode and electrochemical studies

The sustainable electrode was fabricated by preparing a slurry of Nd_2O_3/ Cr_2O_3 nanocomposite in ethanol. The electrode slurry was prepared by dispersing 5 mg of green-synthesized nanocomposite powder in 1 mL ethanol. The suspension was sonicated for 30 min using a bath sonicator to obtain homogeneous dispersion. For drop casting, 10 µL of slurry was taken using a micropipette (Eppendorf P10, 2-20 µL range) and drop-cast onto pre-cleaned FTO.FTO glass substrates (1×1 cm^2) were cleaned sequentially by sonicating in acetone, ethanol, and deionized water for 10 min each and dried at 60 °C. For drop casting, 10 µL of slurry was taken using a micropipette (Eppendorf P10, 2-20 µL range) and drop-cast onto pre-cleaned FTO. The mass loading was calculated as m = 5 mg/mL × 0.01 mL = 0.05 mg. The mass loading was calculated as m = 5 mg/mL × 0.01 mL = 0.05 mg. Then 10 µL of Nafion (5 wt%) was added as a binder to improve adhesion on FTO and sonicated for an additional 10 min. The final concentration of the slurry was 5 mg/mL. The fabricated electrode was dried with a hot gun under vacuum to form a uniform Nafion-bonded film.

The synthesized electrode was subjected to different electrochemical tests in a three-electrode system: reference electrode (saturated calomel electrode), reference electrode (platinum wire), and the working electrode immersed in 0.2 M KOH. The techniques used for electrochemical characterization were Cyclic Voltammetry (CV), Linear Sweep Voltammetry (LSV), and Chronoamperometry (CA.

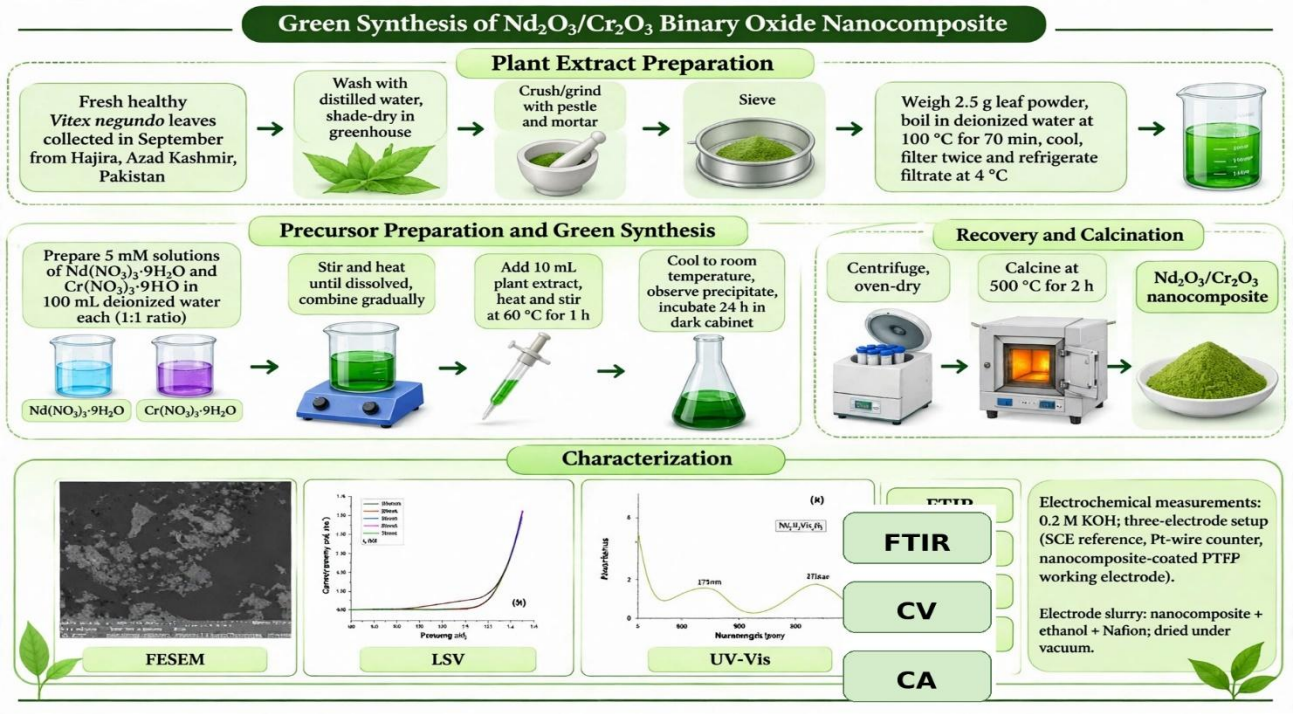


Figure 1. Schematic illustration of the plant-mediated green synthesis, starting from preparation of plant extract to synthesis and characterization of Nd_2O_3/Cr_2O_3 binary oxide nanocomposite.

Results and Discussion

Absorbance and bandgap

The optical response of the synthesized Nd_2O_3/Cr_2O_3 nanocomposite was examined using UV–visible spectroscopy over the ultraviolet–visible wavelength region. As illustrated in Figure 2 (a), two distinct absorption features are observed at approximately 271 and 370 nm. These absorption bands may be associated with electronic transitions within the oxide-based nanostructure and the combined optical contributions of the constituent metal oxides. The presence of multiple peaks portrays the fact that the nanocomposite retains two distinctive crystalline phases, which are further revealed via the XRD study (Narasimharao and Ali 2019). The peak at 271 nm is associated with Nd_2O_3 NPs, and 370 nm is associated with Cr_2O_3 NPs (Sharba 2018; Ahmad et al., 2018). The bandgap value is obtained as 3.0 eV, which is smaller than pristine neodymium oxide, which is reported in the literature as 5 eV. The decrease in band gap value is due to compositing, which results in alterations within electronic levels. The direct bandgap was calculated via the Tauc plot

$$\alpha = A(h\upsilon - Eg)/h\upsilon$$

Where α represents the absorption coefficient, h represents Planck's constant, υ represents vibrational frequency, and Eg represents bandgap energy.

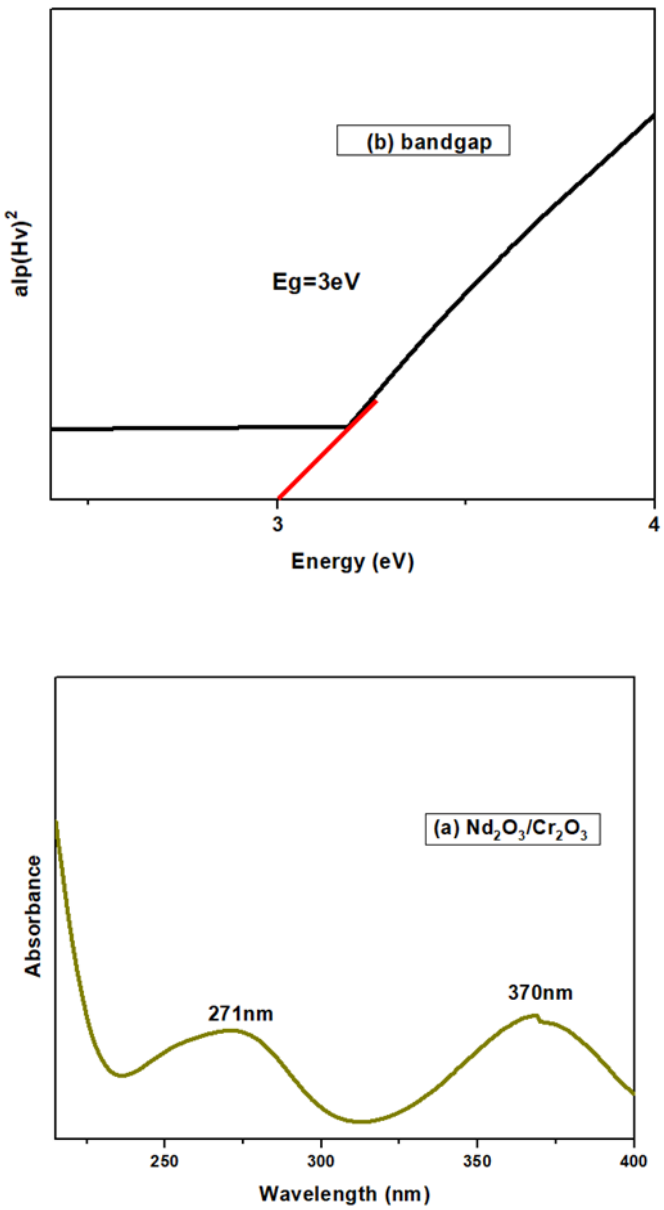


Figure 2. (a) UV of Nd_2O_3/ Cr_2O_3 NPs (b) band gap of Nd_2O_3/Cr_2O_3 NPs

FTIR

The FTIR spectrum of the synthesized nanocomposite is presented in Figure 4. The spectrum contains several absorption features across the measured range of 4000–400 cm^{-1}, indicating the presence of different chemical bonding environments on the material's surface. A broad absorption feature in the higher-wavenumber region, approximately around 3300–3400 cm^{-1}, may be attributed to O–H stretching vibrations. These vibrations can arise from surface hydroxyl groups and/or adsorbed moisture. Such surface hydroxyl groups are commonly observed in metal oxide nanomaterials and may influence their interaction with the aqueous electrolyte during electrochemical testing.

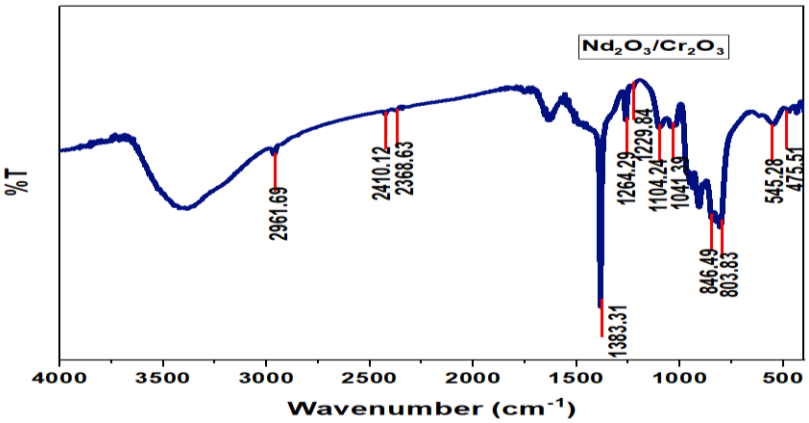


Figure 3. FTIR of Nd_2O_3/ Cr_2O_3 NPs

Weak bands at 2961 cm^{-1} are attributed to the C-H bond, while these two minor vibrations at 2410 cm^{-1} and 2368 cm^{-1} are due to the OH bond of water. Medium bends at 11042 cm^{-1} are ascribed to alkyl halides (C- H wag), while the bend at 11041 cm^{-1} is associated with the presence of the O-H group. The bands in the 1600–1000 cm^{-1} region are due to bending or stretching vibrations of oxygen-containing functional groups, such as C–O and C=O. They may indicate that some plant-derived species contributed to the formation and surface stabilization of the NPs or remained adsorbed on the surface of the material after formation. Plant extracts contain diverse phytochemicals that can interact with metal precursors and influence nucleation, growth, and surface chemistry during nanoparticle formation (Matinise, 2025). The lower-wavenumber region, particularly below approximately 800 cm^{-1}, is important for identifying metal–oxygen vibrations. Absorption bands in this region may be associated with Nd–O and Cr–O bonding in the oxide structure. Absorption bands at 846 cm^{-1}, 803 cm^{-1}, 545 cm^{-1}, and 475 cm^{-1} are associated with the presence of Nd-O and Cr-O bonds in the synthesized nanomaterial (Palermo et al., 2019; Narasimharao and Ali, 2020).

XRD

The XRD pattern Figure 4 shows formation of mixed hexagonal Nd_2O_3(JCPDS 41-1089 / 74-1147) and rhombohedral Cr_2O_3 (JCPDS 38-1479). The broad peak at 2θ ≈ 31° corresponds to the (101) plane of Nd_2O_3, the peak at ≈50° to overlapping (110) Nd_2O_3 and (024) Cr_2O_3, and the peak at ≈65° to (214) Cr_2O_3 . (Dhamale et al. 2016; Ramesh et al. 2012). Broadening indicates a nanocrystalline nature. The average crystallite size was calculated by the Debye-Scherrer equation and was found to be 3.86 nm, indicating the formation of ultra-small nanocrystallites. The broad nature and low intensity confirm that the synthesized material is mostly amorphous, with nanocrystalline domains embedded in an amorphous matrix, typical for low-temperature (500°C) green synthesis using Vitex negundo extract.

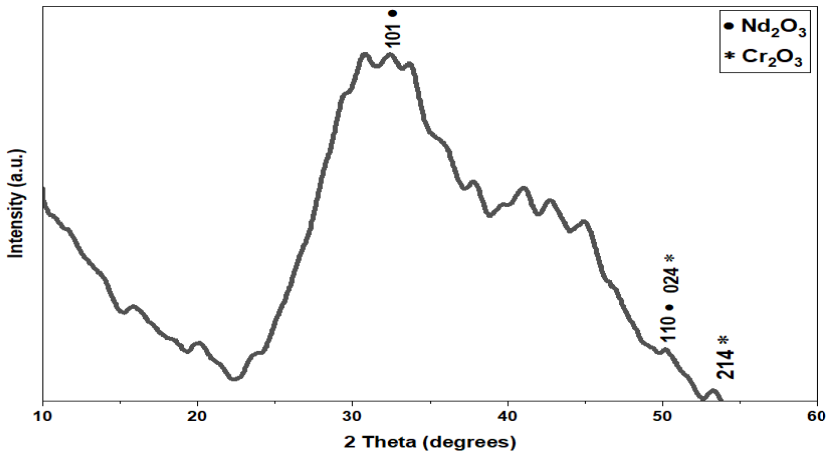


Figure 4. XRD of Nd_2O_3/Cr_2O_3 NPs

FESEM

The surface morphology of the synthesized material was investigated using field-emission scanning electron microscopy, as shown in Figure 5. The micrographs recorded at different magnifications reveal a non-uniform surface consisting of irregularly shaped particles and aggregated structures. Some regions exhibit relatively large plate-like or flake-like features, while other areas appear to contain smaller particles distributed over or clustered around these structures. This distinct morphology is attributed due to two distinct phases possessed by the synthesized nanomaterial. The variation in particle dimensions and the formation of aggregates suggest that the prepared material has a heterogeneous surface morphology.

The observed aggregation may result from interactions between neighbouring particles during nucleation, drying, and subsequent calcination. In addition, the high surface energy associated with nanoscale particles can promote agglomeration. Plant-derived compounds may influence particle growth and surface stabilization during synthesis; however, the FESEM images alone cannot establish the precise role of individual phytochemicals. The morphology observed here is therefore discussed in relation to the overall plant-mediated preparation process rather than attributed to a specific biomolecule.

The irregular and aggregated surface may provide multiple exposed regions for contact with the electrolyte. Such surface features can potentially influence electrolyte penetration and the accessibility of electrochemically active sites. But they should not be used alone to claim a high surface area or improved ion-diffusion kinetics. Nanomaterials showed an average diameter of about 98.8 nm. On higher magnification slightly agglomeration and distinctly shaped NPs were observed. This slight agglomeration is because of the production of a large quantity of heat during the annealing process during the synthesis of NPs. (Srihasam et al., 2020).

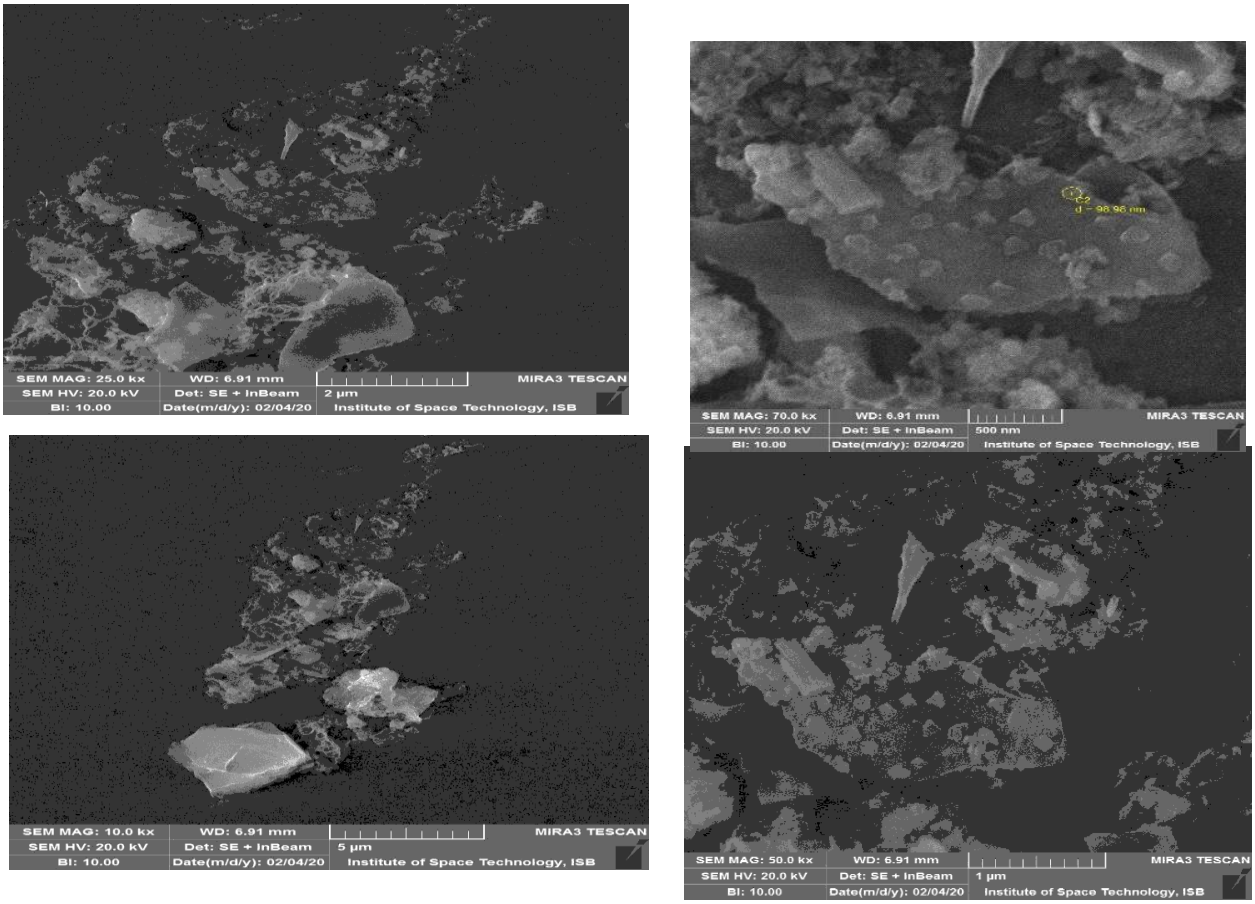


Figure 5. FESEM micrographs of Nd_2O_3/Cr_2O_3 NPs

Electrochemical Investigations

The electrochemical investigations of the synthesized nanomaterial were done by employing the cyclic voltammetry technique, which is one of the essential tools to scrutinize the capacitive behavior of nanomaterials. Redox processes play an essential role

in charge storage mechanisms in supercapacitors (Joshi & Sutrave 2018). CV is an advantageous technique as it is brisk, simple, sensitive, and cheap in comparison to other techniques. Areas that fall under the applicability of cyclic voltammetry are paint, medical, environment, energy, engineering, food, battery, forensic, corrosion, catalysis, fuel cell, polymers, and material sciences. (Chooto 2019).

Figure 6 (a) presents the CV response of the Nd_2O_3/Cr_2O_3 electrode over the investigated potential range. The recorded voltammograms show a gradual increase in current density as the potential moves towards the positive region. The curves do not exhibit clearly separated, sharp anodic and cathodic redox peaks. Instead, the response is characterized by a relatively smooth current profile with a more pronounced increase at higher applied potentials.

The absence of well-defined redox peaks suggests that no strongly resolved redox couple is evident within the investigated potential window. The observed current may therefore include a substantial contribution from interfacial charging, together with possible weak or overlapping faradaic processes at the oxide–electrolyte interface. In metal oxide electrodes, charge storage can involve both electrostatic accumulation of ions at the electrode surface and faradaic reactions associated with changes in the oxidation state of electrochemically active species. Chromium oxide has previously been investigated as a pseudocapacitive electrode material, with its electrochemical response reported to include both electric-double-layer and faradaic contributions (Shafi et al., 2021).

Due to the stepwise oxidation of Cr^{+3} to Cr^{+6} an increasing trend of oxidation peak potentials is observed, while the reduction behavior occurs at 0.8 V- 1.2 V vs SCE when the potential is swept back. The Faradaic processes taking place at the positive side of the window depict the redox coupling of Cr^{+3}/Cr^{+6} this vividly signifies that the synthesized nanomaterial has inherent pseudocapacitive behavior (Ullah et al., 2015). Apart from all this, the potential window portrayed there shows the absence of non-faradaic processes, while the presence of faradaic processes signifies that the nanocomposite possesses pseudocapacitive properties. Then, enhanced electrochemical behavior is attributed to increased charge accumulation ability and the high accessibility of ions via nano Nd_2O_3 (Ullah et al., 2015).

The theoretical value of Specific Capacitance was computed via the following equation from the integrated area under the CV curve.

$$Cs = \frac{A}{2mk(\triangle V)}$$

Where A represents the integrated area under the curve computed via OriginPro 8.1, Cs represents the value of specific capacitance, $\triangle V$ represents the CV window, k represent the selected scan rate and represent the mass of active material on electrode (0.5 mg), the value was calculated as 25 F g^{-1}.

The morphology of the nanocomposite was responsible for forming the open three-dimensional structure of the bimetallic oxide, which facilitated the contact of the composite with the electrolyte; this reduced the impedance and enhanced diffusion of ions. As a consequence, synergistic effect is created this accelerates the surface reaction (Yan et al., 2013). This combination of different oxides makes the electrode a high-performance electrochemical electrode. The CV voltammogram depicts the reversible nature of redox reactions occurring within the electrode.

The LSV studies depict that, upon increasing the scan rate, an increase in current value is found at both the positive and negative potentials when applied to observe the behavior of the nanomaterial. LSV investigations were carried out at different scan rates of 100 mV/s, 80 mV/s, 50 mV/s, 25 mV/s, and 10 mV/s at positive potential (1.0 V) and negative potential (-1.0 V) in 0.2 M KOH. The LSV curves depicted that there exists a positive correlation between the scan rate and current density. By increasing scan rates, the rise in current is seen; this increase in current density is attributed to an increase in the number of active sites, enhanced redox potential, fast transportation of ions, and reduced resistivity (Ferreira et al., 2013).

The chronoamperometry technique was employed to study the stability of the nanocomposite at a fixed potential of 1.5 V in 0.2 M KOH electrolyte. It is a time-dependent electrochemical technique where a step potential was applied at the electrode in the electrolyte, and the current at the electrode was recorded as a function of time (Franklin et al., 2016). The initial current response may be associated with rapid charging of the electrode–electrolyte interface and the availability of accessible surface sites at the beginning of polarization. (Ferreira et al., 2013). As the experiment proceeds, the current decreases, which may reflect the gradual establishment of an interfacial equilibrium and changes in the concentration gradients of electroactive species near the electrode surface. The subsequent slower decay indicates that the current response becomes less pronounced with time under the applied constant-potential condition.

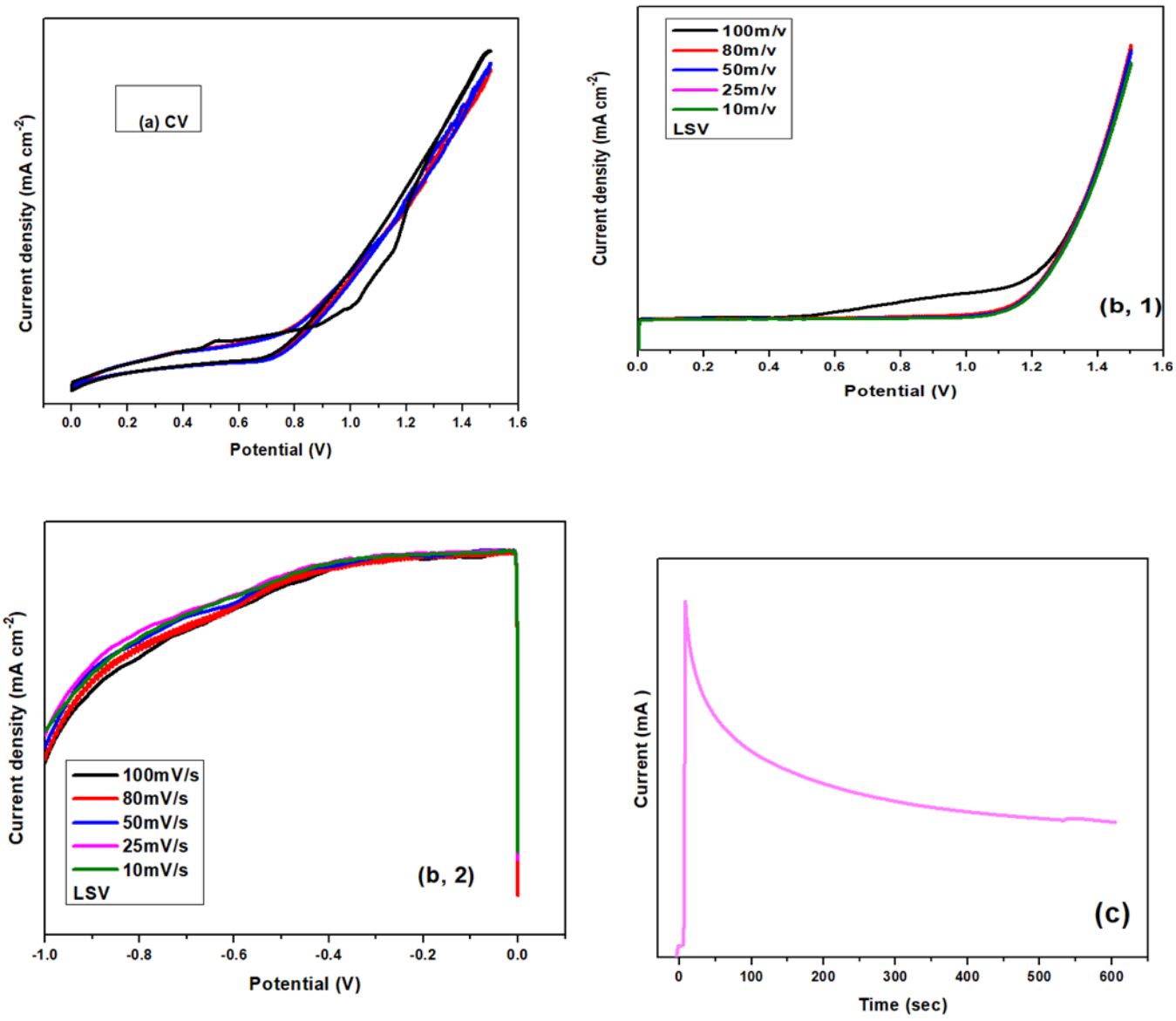


Figure 6. (a) CV of Nd_2O_3/ Cr_2O_3 at 100mV/s (b 1,2) LSV of Nd_2O_3/ Cr_2O_3 at different scan rates 100mV/s, 80mV/s, 50mV/s, 25mV/s, and 10mV/s (c) CA of Nd_2O_3/ Cr_2O_3 till 600 seconds

Conclusion

The synthesized material was found to be stable and durable for up to 600 seconds. CV profile depicts that the synthesized material possessed a pseudocapacitive response. The combination of these two metal oxides was novel and type result showed that the synthesized material morphological features which was responsible for free ion movement. The bandgap value was found to be lower, viz 3.0 eV, in comparison to the reported values. Taken together, the results support the successful preparation of an Nd_2O_3/Cr_2O_3-based material through a plant-mediated route and demonstrate its optical, structural, morphological, and preliminary electrochemical characteristics. Electrochemical testing in 0.2 M KOH with FTO working electrode (0.05 mg loading via 10 µL micropipette from 5 mg/mL slurry) specific capacitance of 25 F g^{-1} at 100 mV/s. The Nafion-bound dropcast method gave stable and reproducible electrodes. This work demonstrates that green-synthesized Nd_2O_3/Cr_2O_3 can be a promising, sustainable electrode material for next-generation supercapacitors and low-cost energy storage devices. Further electrochemical studies, particularly galvanostatic charge–discharge, electrochemical impedance spectroscopy, and cycling measurements, would be necessary to establish its charge-storage capacity, internal resistance, rate capability, and long-term stability.

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