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Green Synthesis and Characterization of ZnO Nanoparticles by Using Cow Dung Extract for Gas Sensing Applications

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***Abstract*— Green synthesis has emerged as an environmentally friendly, economical, and sustainable approach for the preparation of metal oxide nanoparticles using natural reducing, capping, and stabilizing agents. In the present study, zinc oxide (ZnO) nanoparticles were synthesized using cow dung extract, an abundant agricultural waste containing proteins, enzymes, chlorophyll, and other bioactive compounds. Ethanol and methanol were used as extraction solvents to obtain the bioactive constituents responsible for the formation and stabilization of ZnO nanoparticles. UV–Visible spectroscopic analysis of the extracts exhibited characteristic absorption bands in the 300–730 nm region, indicating the presence of chlorophyll and other chromophoric compounds. The synthesized ZnO nanoparticles were characterized by UV–Visible spectroscopy and Fourier Transform Infrared (FTIR) spectroscopy. FTIR analysis confirmed the presence of hydroxyl, carbonyl, and methyl functional groups associated with the biomolecules, indicating their interaction with the ZnO nanoparticle surface. The bio-mediated synthesis resulted in nanoscale ZnO particles with surface functionalization and defect-related active sites that are favorable for gas-sensing applications. The synthesized ZnO nanoparticles exhibited enhanced sensitivity and selectivity toward the target gases, along with rapid response and recovery characteristics, which can be attributed to efficient gas adsorption–desorption and charge-transfer processes at the nanoparticle surface. The presence of bio-derived functional groups may further contribute to the modification of surface electronic properties and sensing performance. The use of cow dung extract provides a renewable and low-cost route for ZnO nanoparticle synthesis while reducing the dependence on hazardous chemical reagents and energy-intensive processing. Overall, the study demonstrates the potential of cow dung-mediated green synthesis for producing functionalized ZnO nanoparticles with promising gas-sensing properties for environmental monitoring and related applications.**

***Keywords*—Green synthesis, Zinc oxide nanoparticles, Cow dung extract, Gas sensing, Bio-functionalization, Agricultural waste, FTIR, UV–Visible spectroscopy.**

I. INTRODUCTION

Nanotechnology has emerged as a rapidly developing field of science and engineering due to the distinctive physicochemical properties exhibited by materials at the nanoscale [1].

Nanoparticles possess a high surface-to-volume ratio, small particle size, and unique optical, electrical, mechanical, and catalytic properties that differ significantly from those of their bulk counterparts [2]. These characteristics have led to their widespread application in diverse areas, including medicine, environmental remediation, agriculture, food technology, energy, catalysis, and sensing [3].

Among various nanomaterials, metal oxide nanoparticles have attracted considerable attention because of their multifunctional properties and wide range of technological applications [4]. Zinc oxide (ZnO) is one of the most extensively investigated metal oxide semiconductors owing to its wide direct band gap, high exciton binding energy, good chemical and thermal stability, and favorable electrical and optical properties [5]. ZnO nanoparticles have been employed in photocatalysis, ultraviolet (UV) shielding, biomedical applications, optoelectronic devices, agricultural technologies, and chemical sensing [6]. In particular, their large specific surface area and surface-dependent electrical conductivity make them promising materials for detecting toxic and volatile gases [7].

Conventional approaches for the synthesis of metal oxide nanoparticles generally involve physical and chemical methods. Although these techniques can provide good control over particle size and morphology, they may require high temperatures, considerable energy input, expensive equipment, and toxic or hazardous chemical reagents [8]. Furthermore, the generation of undesirable chemical by-products during synthesis can create environmental and health-related concerns [9]. These limitations have encouraged the development of green synthesis methods that utilize biological resources as alternatives to conventional chemical reducing and stabilizing agents [10].

Green synthesis is considered a relatively simple, economical, and environmentally benign approach for the preparation of nanoparticles. Plant extracts, microorganisms, algae, proteins, enzymes, and agricultural wastes have been investigated as biological resources for nanoparticle synthesis [11].

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Such biological materials contain a variety of functional biomolecules, including proteins, enzymes, phenolic compounds, flavonoids, polysaccharides, organic acids, and other metabolites, which can participate in nanoparticle nucleation, growth, capping, and stabilization [12]. The use of these biomolecules can modify the surface characteristics of nanoparticles and may influence their morphology, stability, and functional properties [13]. Consequently, green synthesis has gained importance as a sustainable strategy for the development of nanomaterials for applications in catalysis, antimicrobial systems, wastewater treatment, biosensing, agriculture, and environmental monitoring [14].

ZnO nanoparticles are particularly attractive for gas-sensing applications because gas adsorption on their surface can alter the concentration of charge carriers and consequently produce measurable changes in electrical resistance or conductivity [15]. The sensing performance of ZnO depends strongly on particle size, surface morphology, defect concentration, operating temperature, and the nature of the target gas [16]. Surface oxygen species and defects, particularly oxygen vacancies, can play an important role in the adsorption and desorption of gas molecules and in the associated charge-transfer processes [17]. Therefore, controlling the surface properties and defect structure of ZnO nanoparticles is essential for improving their gas-sensing response, selectivity, and response–recovery characteristics.

In recent years, agricultural and agro-industrial wastes have attracted increasing interest as sustainable and inexpensive resources for nanoparticle synthesis [18]. The conversion of agricultural waste into value-added nanomaterials provides an additional environmental benefit by reducing waste accumulation while minimizing the use of synthetic chemical reagents. Cow dung is an abundant biomass resource containing organic matter, proteins, enzymes, minerals, microorganisms, and other bioactive constituents [19]. Traditionally, cow dung has been used as an organic fertilizer, soil conditioner, and component of sustainable agricultural practices [20]. Its diverse chemical composition makes cow dung extract a potential biological medium for the synthesis and stabilization of metal and metal oxide nanoparticles [21].

The use of cow dung extract for ZnO nanoparticle synthesis therefore provides a promising route for combining waste valorization with green nanomaterial production. Biomolecules present in the extract can interact with zinc precursor species and the growing ZnO particles, potentially influencing nucleation, particle growth, surface functionalization, and stability [22].

The properties of the resulting nanoparticles can also be affected by synthesis parameters such as precursor concentration, extract concentration, pH, reaction temperature, reaction time, and calcination conditions [23]. Appropriate control of these parameters is important for obtaining ZnO nanoparticles with desirable crystalline, morphological, optical, and surface characteristics.

In the present study, ZnO nanoparticles were synthesized using cow dung extract through a green synthesis route. Ethanol and methanol extracts were investigated to obtain bioactive constituents capable of participating in the formation and stabilization of ZnO nanoparticles. The synthesized nanoparticles were characterized using UV–Visible spectroscopy, Fourier Transform Infrared (FTIR) spectroscopy, Scanning Electron Microscopy (SEM), Energy Dispersive X-ray Spectroscopy (EDS), and X-ray Diffraction (XRD) to investigate their optical, functional, morphological, elemental, and crystalline properties. Furthermore, the gas-sensing performance of the synthesized ZnO nanoparticles was evaluated toward ethanol, acetaldehyde, and carbon monoxide (CO) under different operating temperatures and gas concentrations.

The study aims to demonstrate the potential of cow dung, an abundant agricultural waste resource, as a sustainable biological precursor for the preparation of functional ZnO nanomaterials. The developed approach combines waste utilization with green nanoparticle synthesis and may provide a cost-effective route for producing ZnO-based sensing materials for environmental monitoring and industrial safety applications. The findings further highlight the potential of bio-mediated synthesis as an alternative approach for developing functional semiconductor nanomaterials with application-specific properties.

II. EXPERIMENTAL DETAILS

2.1. Preparation Of Cow Dung Extracts

Fresh cow dung was used as a biological source for the green synthesis of zinc oxide (ZnO) nanoparticles. Briefly, 10 g of fresh cow dung was accurately weighed and mixed with 100 mL of distilled water in a clean glass beaker. The mixture was stirred thoroughly to ensure uniform dispersion of the organic constituents and was subsequently heated to boiling for 30 min to facilitate the extraction of soluble bioactive compounds such as proteins, enzymes, organic compounds, and other biomolecules.

After heating, the suspension was allowed to cool naturally to room temperature. The cooled mixture was initially filtered through a clean muslin cloth to remove coarse particulate matter and undigested residues.

The resulting filtrate was transferred into centrifuge tubes and centrifuged at 10,000 rpm for 15 min to remove fine suspended impurities. After centrifugation, the sediment was discarded, and the clear supernatant was carefully collected.

The collected supernatant was further filtered through Whatman No. 1 filter paper to obtain a relatively clear cow dung extract containing soluble bioactive constituents. The prepared extract was stored at 4 °C until further use in the synthesis of ZnO nanoparticles. The biomolecules present in the extract were expected to interact with the zinc precursor and the developing ZnO particles, thereby facilitating nucleation, growth, surface functionalization, and stabilization of the synthesized nanoparticles.

2.2 Green Synthesis of ZnO Nanoparticles Using Cow Dung Extract

ZnO nanoparticles were synthesized using a green-mediated precipitation method in which cow dung extract was employed as a natural bioactive and stabilizing medium. Initially, 90 mL of 0.02 M zinc nitrate hexahydrate [$Zn(NO_3)_2 \cdot 6H_2O$] solution was prepared in deionized water under continuous magnetic stirring. The precursor solution was maintained at 30 ± 2 °C for approximately 10 min to ensure complete dissolution and to establish a uniform reaction medium.

The prepared cow dung extract was subsequently added dropwise to the zinc nitrate solution under continuous magnetic stirring. Controlled addition of the extract facilitated interaction between the zinc precursor and the bioactive constituents present in the extract, promoting controlled nucleation and growth of the ZnO precursor. The proteins, enzymes, phenolic compounds, and other organic constituents present in the extract may have contributed to complexation, surface capping, and stabilization of the developing nanoparticles.

The reaction mixture was continuously stirred for 30–60 min and subsequently aged at room temperature for 2 h to facilitate further particle growth and precipitation. The formation of a creamy-white precipitate indicated the formation of the Zn-containing precursor/precipitated product. The precipitate was separated by centrifugation at 8000–10,000 rpm for 10 min, and the resulting supernatant was discarded. The collected precipitate was washed several times with deionized water followed by ethanol to remove unreacted precursor, soluble impurities, and loosely bound organic constituents.

After each washing cycle, the precipitate was recovered by centrifugation.

The purified precipitate was dried in a hot-air oven at 60–80 °C overnight to remove residual moisture. The dried material was subsequently calcined in a muffle furnace at 300–500 °C for 2–3 h to promote the formation and crystallization of ZnO. After calcination, the product was gently ground using a clean mortar and pestle to obtain a fine ZnO nanoparticles. The synthesized material was stored in airtight containers until further characterization by UV–Visible spectroscopy, Fourier Transform Infrared (FTIR) spectroscopy, X-ray Diffraction (XRD), Scanning Electron Microscopy (SEM), Energy Dispersive X-ray Spectroscopy (EDS), and gas-sensing measurements.

III. CHARACTERIZATION

3.1. UV–Visible Analysis

The UV–Visible absorption spectrum of the synthesized ZnO nanoparticles was recorded over the wavelength range of 200–800 nm to investigate their optical properties and confirm nanoparticle formation. The spectrum exhibited strong absorption in the ultraviolet (UV) region, with a characteristic absorption peak observed around 360–380 nm. This absorption peak is attributed to the intrinsic band-gap absorption of ZnO nanoparticles and corresponds to the electronic transition from the valence band to the conduction band, confirming the successful formation of ZnO nanoparticles.

The broad absorption behavior observed in the UV region is indicative of the nanoscale nature of the synthesized particles and their high surface activity. The gradual decrease in absorbance toward the visible region suggests that the synthesized ZnO nanoparticles exhibit relatively good optical transparency in the visible range. The slight shift in the absorption peak may be associated with variations in particle size, morphology, and surface interactions arising from the presence of biomolecules during the green synthesis process.

The obtained UV–Visible absorption results are consistent with previously reported studies on ZnO nanoparticles and further support the successful synthesis of ZnO nanoparticles via the green synthesis method. The strong UV absorption exhibited by ZnO nanoparticles highlights their potential for applications in photocatalysis, UV-blocking materials, sensors, and antimicrobial systems.

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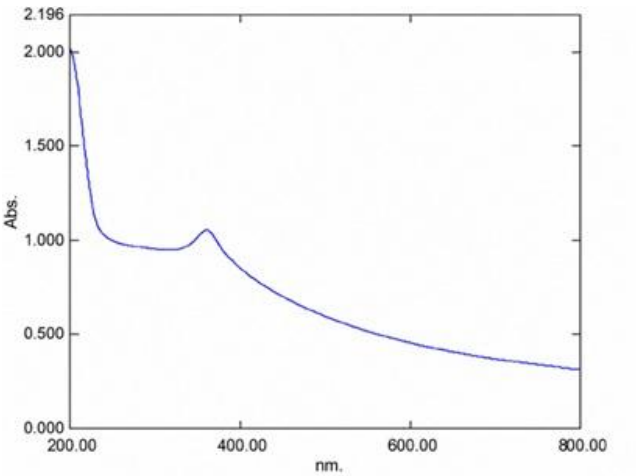

Fig 1. UV–visible absorption spectrum showing absorbance as a function of wavelength from 200 to 800 nm.

3.2. SEM Analysis

The SEM micrographs (A–D) confirm the successful synthesis of ZnO nanoparticles, which exhibit predominantly quasi-spherical to irregular morphologies at the nanoscale. The particles show varying degrees of agglomeration, which is commonly observed in ZnO nanoparticles due to their high surface energy and strong interparticle interactions. The morphological variations observed among the micrographs may be attributed to differences in nucleation, particle growth, and crystallization during the synthesis process.

In micrograph (A), highly agglomerated ZnO nanoparticles form cauliflower-like clusters, indicating strong interparticle interactions and high surface energy. Micrograph (B) shows relatively more uniformly distributed nanoparticles with reduced agglomeration, suggesting comparatively improved nucleation and controlled particle growth. In micrograph (C), agglomerated nanoparticles coexist with larger irregular or flake-like structures, which may be associated with partial grain growth and secondary aggregation during the synthesis or subsequent calcination process. Micrograph (D) reveals larger faceted or plate-like crystalline ZnO particles embedded within densely packed nanoparticle aggregates, indicating enhanced crystallization and the formation of a rough and porous surface morphology.

Overall, the SEM analysis demonstrates that the synthesized ZnO nanoparticles possess a nanostructured and porous morphology with a relatively high surface area. These morphological characteristics are advantageous for surface-dependent applications, particularly gas sensing, photocatalysis, and other related applications.

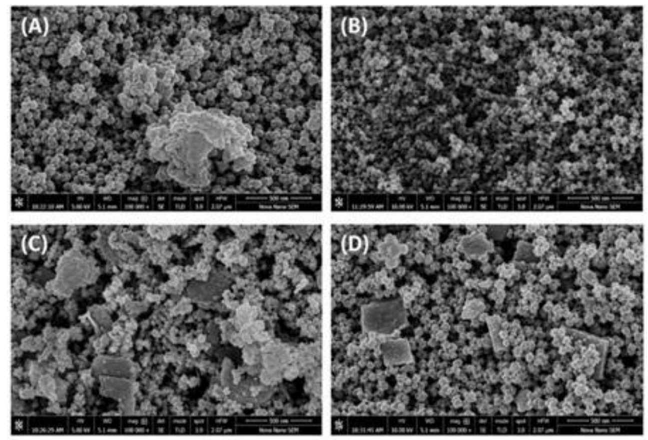

Fig 2. SEM images of synthesized ZnO nanoparticles at different magnifications showing nanosized spherical and agglomerated surface morphology.

3.3. EDS Analysis

Energy-dispersive X-ray spectroscopy (EDS) analysis was performed to determine the elemental composition and assess the purity of the synthesized ZnO nanoparticles. The EDS spectrum exhibited prominent peaks corresponding to zinc (Zn) and oxygen (O), confirming the formation of zinc oxide nanoparticles. The characteristic Zn peaks observed at approximately 8.6 and 9.5 keV are attributed to zinc, while the peak near 0.5 keV corresponds to oxygen.

The absence of significant additional elemental peaks indicates that the synthesized ZnO nanoparticles are relatively free from detectable impurities or contaminants. Quantitative EDS analysis revealed that the synthesized material contained approximately 80.36 wt.% Zn and 19.64 wt.% O, corresponding to atomic percentages of 66.46% and 33.54%, respectively. The observed elemental composition confirms the predominant presence of Zn and O in the synthesized material and supports the successful formation of ZnO nanoparticles.

The higher weight percentage of zinc compared with oxygen is consistent with the elemental composition detected by EDS, although slight deviations from the theoretical stoichiometric composition of ZnO may arise from factors such as surface adsorption, oxygen vacancies, instrumental limitations, and the presence of organic residues associated with the green synthesis process. Overall, the EDS results confirm the successful green synthesis of ZnO nanoparticles and provide evidence of their elemental composition and relative purity, supporting their suitability for further applications.

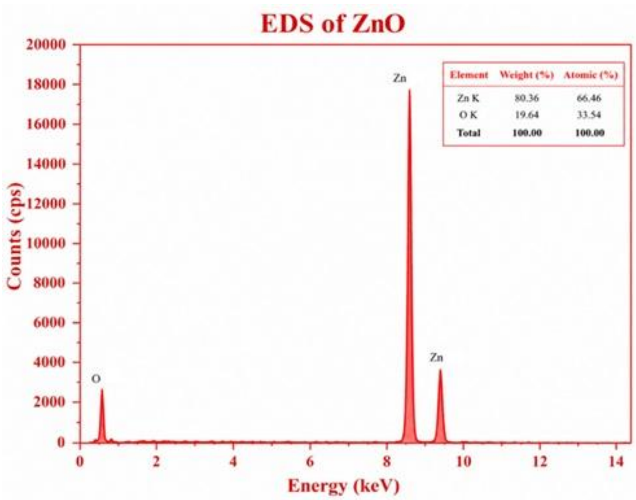

Fig 3. Energy Dispersive X-ray Spectroscopy (EDS) Spectrum of Green Synthesized ZnO Nanoparticles.

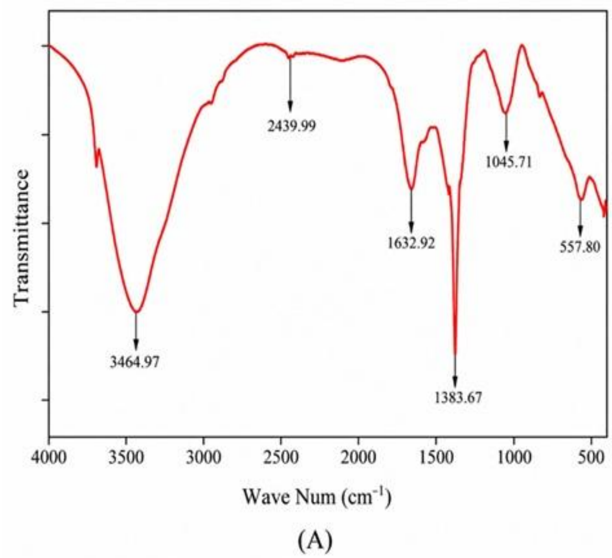

Fig 4. FTIR spectrum of green synthesized ZnO nanoparticles

3.4. FT-IR Analysis

The FT-IR spectrum of the synthesized ZnO nanoparticles was recorded over the wavelength range of 4000–400 cm^{-1} to identify the functional groups associated with nanoparticle formation and stabilization. A broad absorption band observed at 3464.97 cm^{-1} can be attributed to the O–H stretching vibrations of hydroxyl groups, which may arise from surface-bound hydroxyl groups and adsorbed water molecules. The absorption band at 2439.99 cm^{-1} may be associated with atmospheric CO_2 and/or weakly adsorbed organic species. The band observed at 1632.92 cm^{-1} can be assigned primarily to the H–O–H bending vibration of adsorbed water, with possible contributions from carbonyl- or amide-containing biomolecules.

The absorption band at 1383.67 cm^{-1} may be attributed to C–N stretching and/or O–H bending vibrations, while the band at 1045.71 cm^{-1} can be associated with C–O stretching vibrations of alcohols and other oxygen-containing organic compounds derived from the biological materials used during the green synthesis process. The characteristic absorption band observed at 557.80 cm^{-1} is attributed to the Zn–O stretching vibration, providing evidence for the formation of ZnO nanoparticles.

Overall, the FT-IR results indicate the presence of hydroxyl and other oxygen- and nitrogen-containing functional groups associated with biomolecules on the nanoparticle surface. These biomolecules may contribute to the formation, capping, and stabilization of the ZnO nanoparticles during the green synthesis process. The characteristic Zn–O vibration further supports the successful synthesis of ZnO nanoparticles.

3.5. XRD Analysis

X-ray diffraction (XRD) analysis was performed to investigate the crystalline nature, phase purity, and structural properties of the synthesized ZnO nanoparticles. The XRD pattern exhibited distinct diffraction peaks at 2θ values of approximately 31.17°, 34.51°, 36.31°, 47.53°, 56.67°, 63.07°, 68.09°, and 69.11°. These diffraction peaks can be indexed to the crystallographic planes (100), (002), (101), (102), (110), (103), (112), and (201), respectively, which are characteristic of the hexagonal wurtzite crystal structure of ZnO.

The obtained diffraction pattern was in good agreement with the standard JCPDS data for ZnO (JCPDS Card No. 36-1451), confirming the formation of crystalline ZnO nanoparticles with no detectable secondary or impurity phases. Among the observed reflections, the intense diffraction peak at approximately 36.31°, corresponding to the (101) plane, indicates the preferential orientation and high crystallinity of the synthesized ZnO nanoparticles.

The sharp and well-defined diffraction peaks indicate good crystallinity, while the observed peak broadening is characteristic of the nanocrystalline nature of the synthesized material. The absence of additional unidentified diffraction peaks further supports the phase purity of the synthesized ZnO nanoparticles. The nanoscale crystallite size may be attributed to the restricted growth of ZnO crystallites during the green synthesis process.

Overall, the XRD results confirm the successful synthesis of crystalline ZnO nanoparticles with a hexagonal wurtzite structure and good phase purity.

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The structural characteristics of the synthesized ZnO nanoparticles make them promising materials for potential applications in photocatalysis, sensing, antimicrobial activity, and environmental remediation.

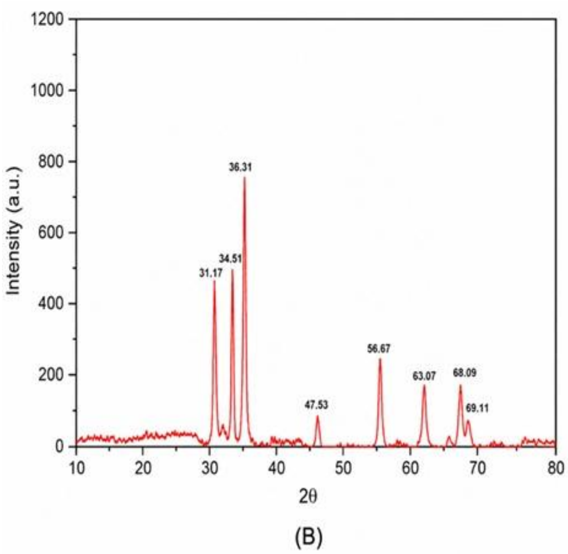

Fig 5. X-ray Diffraction (XRD) Pattern of Green Synthesized ZnO Nanoparticles

IV. GAS SENSING RESULTS

The gas-sensing performance of the synthesized ZnO nanoparticles was evaluated toward ethanol, acetaldehyde, and carbon monoxide (CO) at different gas concentrations and operating temperatures. The sensor exhibited typical n-type semiconducting behavior, characterized by a decrease in electrical resistance upon exposure to the target gases, followed by recovery after removal of the gas. This reversible response indicates the effective interaction between the target gas molecules and the ZnO nanoparticle surface, demonstrating good sensing reversibility and stability.

Among the tested gases, ethanol exhibited the highest sensing response, followed by acetaldehyde and CO, indicating the comparatively higher sensitivity of the synthesized ZnO nanoparticles toward ethanol vapor. The sensor response increased with increasing gas concentration and operating temperature, with the maximum response observed at an operating temperature of 400 °C. The highest responses were obtained at concentrations of 250 ppm for ethanol, 250 ppm for acetaldehyde, and 1000 ppm for CO, suggesting enhanced surface reactions and improved charge-transfer processes at elevated operating temperatures.

The comparatively lower response toward CO may be attributed to the different surface reaction kinetics and interaction mechanisms of CO with the ZnO sensing material. Nevertheless, the synthesized ZnO nanoparticles demonstrated a pronounced response toward the tested volatile organic compounds, particularly ethanol and acetaldehyde. Overall, the results indicate that the synthesized ZnO nanoparticles possess concentration-dependent gas-sensing characteristics, good response and recovery behavior, and promising sensitivity toward ethanol and acetaldehyde. These properties highlight their potential for applications in semiconductor-based gas sensors and environmental monitoring.

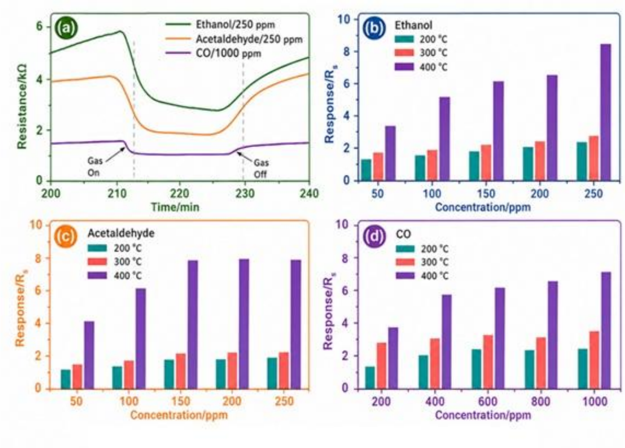

Fig 6. Gas-Sensing Performance of the Sensor toward Ethanol, Acetaldehyde, and CO at Different Operating Temperatures.

V. CONCLUSION

In the present study, ZnO nanoparticles were successfully synthesized through an eco-friendly green synthesis approach and systematically characterized using UV–Visible spectroscopy, SEM, EDS, FT-IR, and XRD techniques. The UV–Visible analysis confirmed the optical characteristics of the synthesized nanoparticles, while SEM revealed a nanostructured morphology with varying degrees of agglomeration. EDS analysis confirmed Zn and O as the major constituent elements, and FT-IR analysis indicated the involvement of biomolecules in the formation, capping, and stabilization of the nanoparticles. XRD analysis confirmed the formation of a crystalline hexagonal wurtzite ZnO phase with good phase purity and nanocrystalline characteristics.

The synthesized ZnO nanoparticles demonstrated promising gas-sensing performance toward ethanol, acetaldehyde, and carbon monoxide.

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The sensing response was dependent on both gas concentration and operating temperature, with the highest response observed toward ethanol at an operating temperature of 400 °C. The sensor exhibited typical n-type semiconducting behavior, together with good reversibility and concentration-dependent sensing characteristics. The enhanced response toward ethanol and acetaldehyde suggests that the synthesized ZnO nanoparticles are particularly promising for the detection of volatile organic compounds.

Overall, the results demonstrate that green synthesis provides a simple and environmentally friendly route for producing ZnO nanoparticles with favorable structural and gas-sensing properties. The combination of nanoscale morphology, good crystallinity, and active surface sites contributes to their sensing performance. Therefore, the synthesized ZnO nanoparticles have significant potential as low-cost and environmentally sustainable sensing materials for gas detection and environmental monitoring applications.

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