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GREEN SYNTHESIS OF ZnO NANOMATERIALS FOR GAS SENSOR APPLICATIONS

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ABSTRACT:

Zinc oxide (ZnO) nanomaterials have gained immense popularity in gas sensing due to their high sensitivity, chemical stability, and low cost. However, conventional chemical synthesis methods often involve toxic reagents and energy-intensive processes, raising environmental concerns. . Green synthesis aligns with the principles of green chemistry, aiming to minimize the environmental and health hazards associated with conventional synthesis techniques and minimize environmental impact. Green synthesis techniques have emerged as a sustainable alternative, utilizing plant extracts, microbes, and biopolymers to produce ZnO nanostructures under mild and eco-friendly conditions. Green-synthesized ZnO has shown promising results in detecting various gases like Ammonia (NH_3), Ethanol, NO_2, H_2S, LPG etc This paper explores green synthesis methods for ZnO and their effect on gas sensing properties, highlighting performance enhancements, advantages and limitations.

KEYWORDS: *Gas sensor, Green synthesis, sensitivity, chemical stability, environmental impact.*

INTRODUCTION

Green synthesis refers to the biological or eco-friendly production of nanoparticles using naturally derived resources. Green synthesis is cost-effective, and sustainable method for preparing nanomaterials, especially metal oxide nanoparticles (MONPs), using biological agents and natural resources instead of hazardous chemicals or high-energy methods. It aligns with the principles of green chemistry, aiming to minimize the environmental and health hazards associated with conventional synthesis techniques and minimize environmental impact. Green synthesis of metal oxide nanomaterials refers to the use of biological entities (like plants, microbes, algae, or biopolymers) and natural extracts to synthesize metal oxides at the nanoscale in a non-toxic, energy-efficient, and environmentally safe manner. Typical agents used in green synthesis include Plant extracts (rich in flavonoids, phenolics, alkaloids), Microorganisms (bacteria, fungi, algae), Biopolymers (chitosan, starch, cellulose), Biowaste (fruit peels, agricultural residue). The biological molecules in these agents act as reducing, capping, and stabilizing agents during nanoparticle formation. Green-Synthesized Metal Oxides like ZnO, TiO_2, Fe_3O_4, CuO, MnO_2 have wide applications in the field of Gas sensors, antibacterial coatings, Photocatalysis, solar cells, MRI contrast agents, magnetic separations, Electrochemical sensors, catalysis, Supercapacitors, water purification.

Green Synthesis Routes for Metal Oxide Nanoparticles

Plant Extract-Mediated Synthesis method uses leaves, fruits, peels, flowers, etc. e.g. Green tea extract used to synthesize TiO_2 nanoparticles. Phytochemicals act as reducing and stabilizing agents. This method is common for synthesis of ZnO, TiO_2, Fe_2O_3, CuO, etc. In Microbial Synthesis method bacteria, fungi, yeast, or algae are used. Microorganisms secrete enzymes and metabolites that reduce metal ions. This method have more control on shape and size, but slower than plant-based methods. Biopolymer-Assisted Synthesis method uses biodegradable polymers like chitosan, cellulose, or starch. Acts as a template, fuel, or stabilizer in oxide formation. Waste-Derived Green Synthesis utilizes agricultural waste, food waste, or biomass. This promotes circular economy and sustainability. Banana peel extract used for green synthesis of MnO_2 nanoparticles. In Green Sol-Gel Method, Sol-gel process modified using eco-friendly solvents or plant-based reducing agents. Green Combustion Method uses biomass-derived fuels (like glycine, urea, glucose) for combustion to form metal oxides. Marine or freshwater algae act as reducing and stabilizing agents due to high bioactivity in Algae-Mediated Synthesis. Specific enzymes catalyze the reduction of metal ions under mild conditions in Enzyme-Mediated Synthesis. Microwave-Assisted Green Synthesis combines plant extracts with microwave heating to accelerate reactions. Hydrothermal/Green Autoclave Synthesis uses green agents under controlled temperature and pressure in a sealed vessel.

The key Components of Green Synthesis methods are Metal precursors (Metal salts) which are the Sources of metal ions, Biological reducing agents like Plant extracts, bacteria, fungi, algae which reduces metal ions to metal oxides, Natural compounds are used as biological reducing agents to control size and to prevent agglomeration, Energy sources such as mild heating, microwave, or solar radiation are used to Initiate or accelerate reactions. Following steps are included in general Procedure for Green Synthesis . 1. Preparation of extract from plant or biological source. 2. Mixing of extract with metal salt solution. 3. Stirring/heating under mild conditions. 4. Formation of nanoparticles (precipitation, color change). 5. Filtration, drying, and calcination to obtain metal oxide nanoparticles. For Characterization of synthesized nanomaterials the techniques used are XRD, SEM/TEM, FTIR, UV, TGA etc.

Advantages of Green Synthesis Methods

Green Synthesis Methods are environmentally friendly which avoids toxic chemicals and solvents, reducing environmental pollution. Green Synthesis Methods are simple which Involves fewer steps, often with one-pot synthesis under ambient conditions.Green Synthesis Methods shows biocompatibility. This method produces nanoparticles safe for biomedical and environmental applications. This is a cost-effective method which utilizes easily available natural materials like plants, waste biomass, and microbes. They uses renewable resources , sustainable sources like plant extracts, agricultural waste, and microorganisms promotes waste valorization by using bio-waste as precursors. Energy Efficiency of Green Synthesis Methods is high. These methods require lower temperatures and less energy than traditional chemical/physical methods. Natural capping agents enhance stability and dispersion. Green Synthesis Methods often yields nanoparticles with high surface area, porosity, and reactive functional groups.

Limitations of Green Synthesis Methods

Green Synthesis Methods have lack of Size/Shape Control. Difficult to precisely control particle morphology and size distribution. Inconsistency in natural extracts leads to non-uniform nanoparticle properties which shows batch variability. Hard to scale up from lab to industrial levels while maintaining quality. In Green Synthesis Methods slow reaction rates is issue as biogenic reactions are slower compared to chemical synthesis. Biological residues may remain on the nanoparticle surface, requiring extra purification shows purity concerns. As biologically synthesized materials may degrade faster or agglomerate over time so there is a storage instability. Seasonal or regional dependency of plant/microbial sources give rise to limited availability of some biogenic agents.

Comparative overview between Green Synthesis methods and Conventional Methods

Aspect	Green Synthesis methods	Conventional Methods
Raw Materials	Plant extracts, microbes, biopolymers, biomass	Chemical precursors, surfactants, toxic reagents
Reducing/Capping Agents	Natural compounds	Synthetic chemicals
Environmental Impact	Low	High
Toxicity	Minimal	Often toxic
Energy Requirement	Low to moderate	High
Reaction Speed	Moderate to slow	Fast
Cost	Low	Moderate to high
Control (Size/Shape)	Moderate	High
Scalability	Limited	Well established
Application Suitability	Biomedical, eco-products	Industrial, precision materials

Effect of Green Synthesis on Gas Sensing Properties of ZnO

Green synthesis techniques significantly influence the physicochemical properties of ZnO, thereby enhancing its gas sensing performance. Surface area and porosity changes due to bio-templating which provides more adsorption sites gives higher sensitivity. Obtained particles of different morphology such as Nanoflowers, rods, spheres etc enhances surface–gas interaction. Mild synthesis changes Oxygen vacancies boosted charge carrier density giving better response. Surface functional groups improve selectivity and reactivity. Crystallinity is moderate but tunable via calcinations. Changes are observed in Operating temperature, Stability and reproducibility. Green-synthesized ZnO has shown promising results in detecting various gases like Ammonia (NH_3), Ethanol, NO_2, H_2S, LPG etc

Synthesis of nano ZnO was done using two different processes i.e., biological (green synthesis) and chemical synthesis for LPG sensing. They observed that the green synthesis route, to fabricate sensor devices is more advantageous as it is cost-effective, eco-friendly and simple. It was experimentally concluded that the biosynthesized ZnO exhibits similar properties of chemical synthesis of ZnO including the sensing responses towards LPG. [1]. Highly stable, eco-friendly ZnO nanoparticles synthesized by an easy and cost-effective plant (Aloe barbadensis miller gel as crystal growth modifier) mediated synthesis route. LPG sensing properties were systematically investigated. This method offers a really simple, non-toxic, low cost, environment-friendly route for the synthesis of zinc oxide nanoparticles. [2] , ZnO NPs are successfully prepared through green synthesis method using sugarcane stem extract. They conclude that the green synthesis route, to fabricate sensor devices is encouraging as it is simple, cost-effective and eco-friendly. Green synthesized ZnO sensor would be a potential candidate for LPG sensors. [3] , A sustainable environmentally friendly method was used to synthesize zinc oxide nanoparticles (ZnO NPs) by employing natural plant extracts, specifically utilizing green tea powder commonly known as Camellia sinensis. This method opens paths for the utilization of bio-derived materials in advanced sensing applications. This sensor exhibited notable selectivity and sensitivity to Ammonia-NH3, Acetone-C3H6O, Formaldehyde-HCHO, and Benzene-C6H6. [4] , The ZnO NPs obtained from Nelumbo nucifera (lotus) leaf extract-mediated solution combustion synthesis at a much lower initiation temperature. The selectivity and sensitivity of the fabricated device in CO gas detection was found to be more prominent than the other reducing gases (hydrogen sulphide, H2S and ammonia, NH3) and methanol vapours tested. [5] , ZnO nanoparticles (NPs) were synthesized by using a novel green synthesis method. ZnO nanoparticles were successfully synthesized by green synthesis method using Zinc nitrate hexahydrate and wheat grass pieces. CH4 sensing was observed. Green-synthesized ZnO NPs have gained a lot of interest because of their intrinsic qualities such as efficiency, ecofriendliness, and less expensive. [6] , ZnO NPs were produced from a zinc acetate precursor with dye extract of Ixora Coccinea (IC) leaves as a capping agent. the gas sensing properties of ZnO films, prepared by doctor blade method, were used to detect ethanol vapour. [7], A sensor has been developed for trace-level detection of Ammonia (NH3) gas using low-cost eco-friendly green synthesis process. The results showed the optimal sensing characteristics of the sensor for NH3 that exhibited an ultrafast response and recovery time with long term stability. [8] , Zinc oxide nanoparticles (ZnO NPs) have been prepared using a natural tea-assisted auto-combustion method. ZnO NPs showed good sensor response to different gases. ZnO NPs show outstanding sensor response to ethanol gas compared to the other test gases.[9], A. indica plant proteins over chemical methods in the morphology of zinc oxide nanoparticles (ZnO NPs) prepared by a co-precipitation method, and ethanol sensing performance.To sum up, the addition of A. indica dye extracts to ZnO thin films significantly increased the sensing, response, and recovery times of the ethanol-based gas sensor.[10]

CONCLUSION

Green synthesis provides a sustainable pathway for producing ZnO nanomaterials with enhanced gas sensing properties. The natural reducing agents not only reduce environmental impact but also confer beneficial surface characteristics such as high porosity, oxygen vacancies, and bio-functionalized surfaces—critical for high-performance gas sensors. Despite current limitations in reproducibility and scale-up, ongoing research continues to unlock the full potential of green ZnO in environmental monitoring, healthcare, and industrial safety. Green synthesis as a promising route for sustainable sensor development. Green synthesis route, to fabricate sensor devices is more advantageous as it is cost-effective, eco-friendly and simple.

REFERENCES

[1] Nanostructured ZnO gas sensors obtained by green method and combustion technique Goutham , Sukhpreet Kaur , Kishor Kumar Sadasivuni , Jayanta umar Bal, Naradala Jayarambabu , Devarai Santhosh Kumar , Kalagadda Venkateswara Rao ,Materials Science in Semiconductor Processing, Volume 57, January 2017, Pages 110-11,

[2] Green Synthesized Zinc Oxide Nanoparticles and Evaluation of their Use in Nanoelectronics Gas Sensing Result and Performance Dayanand B Jadhav and Rajendra D Kokate, J Biosens Bioelectron, Volume 14:3, 2023

[3] Green synthesis of ZnO nanoparticals using sugarcane juice for LPG gas sensing applications, Avadhut V. Kardile M. H. Moulavi , Ramakant P. Joshi , Pandit N. Shelke ,Ravindra U. Mene, Journal of the Maharaja Sayajirao University of Baroda ISSN: 0025-0422

[4] Camellia sinensis-mediated green synthesis of ZnO nanoparticles: An eco-friendly approach for high-performance gas sensing, Umadevi, Godavarti , Krishna, Kurugundla Gopi, Sensors and Actuators: A. Physical, Volume 374, id.115479

[5] Green and low-cost synthesis of zinc oxide nanoparticles and their application in transistor-based carbon monoxide sensing, Ashwath Narayana, Sachin A. Bhat, Almas Fathima, S. V. Lokesh, Sandeep G. Surya and C. V. Yelamagga, RSC Adv., 2020, 10, 13532–13542

[6] Study of Electrical, Structural and Gas Sensing Properties of ZnO Nanoparticles Synthesized By Green Synthesis Method, Archana A. Chaudhari, Umesh. J. Tupe, Arun V. Patil, Chandrakant. G. Dighavkar, March 2022 IJSDR | Volume 7 Issue 3

[7] Green Synthesis of Zinc Oxide Nanoparticles Using Ixora Coccinea Leaf Extract for Ethanol Vapour Sensing, Leela Pradhan Joshi, Bal Vikram Khatri, Sumana Gyawali, Shiromani Gajurel, and Dinesh Kumar Chaudhary*, Journal of Physical Science, Vol. 32(2), 15–26, 2021

[8] Ultrafast, trace-level detection of NH3 gas at room temperature using hexagonal-shaped ZnO nanoparticles grown by novel green synthesis technique, Anshika Nagar , Avshish Kumar , Utkarsh Tyagi , Hrishikesh Dhasmana , M.A. Majeed Khan , Samina Husain , Abhishek Verma , V.K. Jain Physica B: Condensed MatterVolume 626, 1 February 2022, 413595

[9] Investigation of physicochemical properties of ZnO nanoparticles for gas sensor applications, S. Ananthi , M. Kavitha , E. Ranjith Kumar , T. Prakash , R. Vandamar Poonguzhali , B. Ranjithkumar , A. Balamurugan , Ch. Srinivas , D.L. Sastry ,Inorganic Chemistry Communications,Volume 146, December 2022, 11015

[10] Study on the Synthesis of ZnO Nanoparticles Using Azadirachta indica Extracts for the Fabrication of a Gas Sensor, Tirtha Raj Acharya , ,Pradeep Lamichhane,Rizwan Wahab 3,Dinesh Kumar Chaudhary,Bhanu Shrestha,Leela Pradhan Joshi,Nagendra Kumar Kaushik , and Eun Ha Choi , Molecules 2021, 26(24), 7685