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SYNTHESIS AND CHARACTERIZATION OF Zn-DOPED NiO NANOMATERIALS FOR ENHANCED VOC SENSING APPLICATIONS

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ABSTRACT
Metal oxide nanomaterials are promising candidates for volatile organic compound (VOC) sensing due to their high surface area, tunable band gap, and chemical stability[1,2]. In this study, NiO and Zn-doped NiO nanoparticles were synthesized via a sol–gel method and systematically characterized[3]. UV–Vis spectroscopy confirmed strong absorption in the UV region with band gap tuning attributed to Zn incorporation[4]. while SEM revealed porous surface morphology favorable for gas adsorption[5]. Doping introduced lattice modifications and oxygen vacancies, improving charge transfer and surface activity[6,7]. The results demonstrate that Zn-doped NiO nanomaterials exhibit enhanced optical properties and sensing potential, highlighting their suitability for next-generation VOC detection devices[8].

Keywords: NiO nanoparticles, Zn doping, Sol–gel synthesis, VOC sensing, Band gap tuning, Metal oxide nanomaterials.

I. INTRODUCTION

Volatile organic compounds (VOCs) are hazardous pollutants that pose serious risks to the environment and human health[9]. Conventional detection methods often lack sensitivity and selectivity, creating a demand for advanced sensing materials[10]. Metal oxide semiconductors have emerged as promising candidates due to their high surface-to-volume ratio, chemical stability, and tunable electronic properties[11]. Among them, nickel oxide (NiO), a p-type semiconductor with a wide band gap, has attracted attention for gas-sensing applications[13]. However, its performance is limited by slow response and moderate sensitivity[14]. Doping with suitable metal ions offers an effective strategy to tailor its structural and electronic properties, thereby enhancing sensing efficiency[15]. Zinc (Zn) doping, in particular, can induce lattice distortion, oxygen vacancies, and band gap modification, all of which improve charge transfer and surface reactivity[16].

This study reports the sol–gel synthesis of pure and Zn-doped NiO nanoparticles, with structural, morphological, and optical characterization. The influence of Zn incorporation on band gap tuning and surface activity is analyzed to establish its role in improving the sensing performance of NiO nanomaterials for VOC detection.

II. EXPERIMENTAL SETUP AND METHODOLOGY

2.1 Synthesis of NiO and Zn–NiO Nanoparticles:

NiO and Zn-doped NiO nanoparticles were synthesized using the sol–gel method[17,18]. Nickel nitrate hexahydrate was used as the precursor, while zinc nitrate was added in controlled molar ratios to achieve doping[19]. Citric acid acted as a chelating agent, and ammonia solution was used to adjust the pH. The resulting sol was stirred, allowed to gel, aged at room temperature, dried at 100 °C, and finally calcined at 500 °C to obtain fine nanopowders[20].

Figure 1 Flow chart of NiO and Zn–NiO nanoparticles

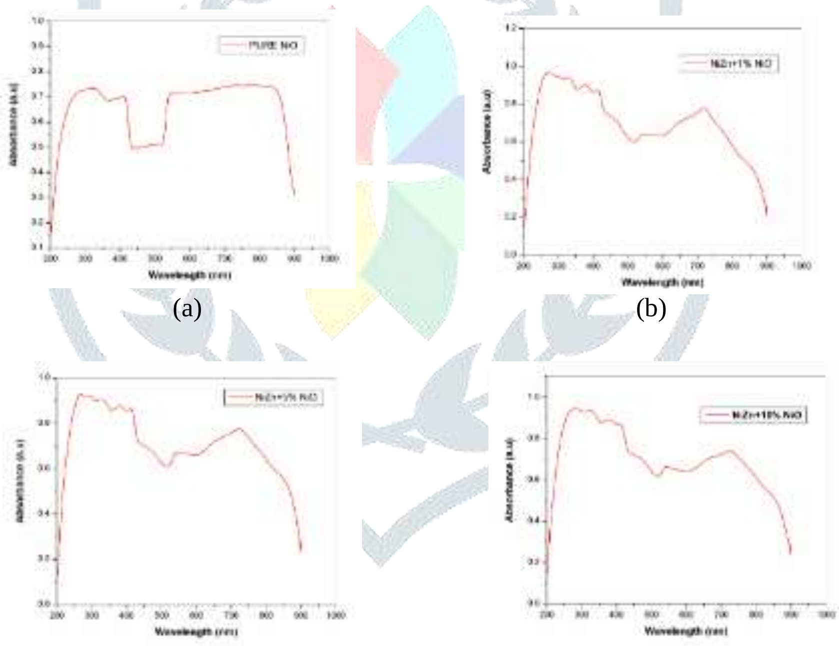
2.2 Characterization Techniques:

The structural properties were analyzed using X-ray diffraction (XRD), while surface morphology was examined by scanning electron microscopy (SEM)[21]. Functional groups and bonding were confirmed using Fourier-transform infrared spectroscopy (FTIR), and optical properties were studied by UV–Vis spectroscopy[22].

III. RESULTS AND DISCUSSIONS

3.1. UV-Vis Spectroscopy:

In pure NiO (Figure 2.a), the absorption edge appears near 350–380 nm, consistent with the reported band gap of NiO (~3.4–3.6 eV)[23].The spectrum shows strong absorption in the UV region, but weak in the visible region, limiting photocatalytic efficiency under visible light. No significant red shift is observed, confirming the wide band gap nature of pure NiO[24].



(a) (b)

(c) (d)

Figure.2 UV -Visible spectroscopy (a) Pure NIO, (b) Zn 1% doped NiO,
(c) Zn 5% doped NiO and (d) Zn 10% doped NiO

In Zn 1% doped NiO (Figure 2.b)**,** the absorption intensity increases compared to pure NiO. A slight red shift of the absorption edge is observed, suggesting band gap narrowing due to Zn incorporation.Zn^{2+} doping introduces lattice strain and oxygen vacancies, which enhance light harvesting and charge transfer.

In Zn 5% doped NiO (Figure 2.c)**,** the enhancement in absorption across both UV and visible regions. The absorption edge shifts slightly more toward longer wavelengths compared to 1% Zn-doped NiO. This indicates stronger band gap reduction, increasing the potential for visible-light-driven applications. Higher Zn doping introduces more defect states, which may act as active sites for charge separation.

In Zn 10% doped NiO (Figure 2.d), shows broad absorption with significant intensity in the visible region. A more pronounced red shift confirms further band gap narrowing. However, excessive doping can also lead to lattice disorder and possible recombination centers, which may reduce efficiency at higher concentrations despite better absorption.

Therefore, pure NiO has limited visible absorption due to its wide band gap. Progressive Zn doping (1%, 5%, 10%) enhances absorption and shifts the band edge toward the visible spectrum. This trend indicates effective band gap engineering by Zn, improving optical and photocatalytic properties.

3.2. SEM Analysis:

The SEM of Zn-doped NiO nanoparticles (Figure 3) reveals an irregular, agglomerated morphology with plate-like and fragmented structures. The particles appear to be distributed in clusters, which is typical of sol–gel-derived oxides due to drying and calcination processes. The surface is rough and porous, providing a high surface area that is advantageous for gas adsorption and sensing applications.

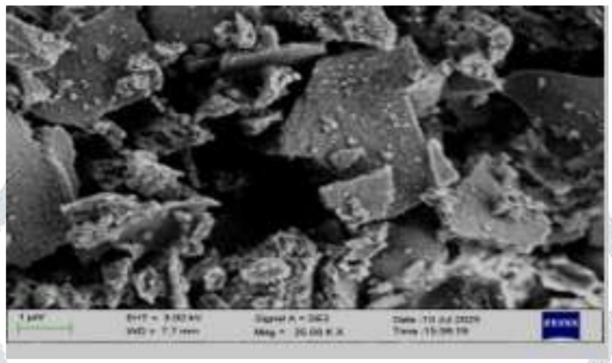


Figure.3 SEM of Zn-doped NiO nanoparticles

The nanoscale features observed confirm successful synthesis, while Zn incorporation is expected to further influence surface reactivity and defect density.

IV. CONCLUSION

Zn-doped NiO nanoparticles were successfully synthesized by the sol–gel method and systematically characterized. UV–Vis analysis confirmed band gap tuning with Zn incorporation, enhancing light absorption toward the visible region. SEM revealed porous, agglomerated nanostructures, favorable for surface activity. The combined structural and optical modifications introduced by Zn doping improve the potential of NiO for photocatalysis and VOC sensing. These results demonstrate that Zn–NiO nanomaterials are promising candidates for next-generation environmental remediation and sensing applications.

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