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SYNTHESIS AND CHARACTERIZATION OF Ag-DOPED ZnO NANOPARTICLES FOR PHOTOCATALYTIC ACTIVITY

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ABSTRACT
Silver-doped ZnO (Ag–ZnO) nanoparticles were synthesized via the sol–gel method using polyvinylpyrrolidone (PVP) as a stabilizer to achieve uniform nanoscale morphology[1]. Ag incorporation enhanced photocatalytic activity under visible light by promoting electron–hole separation and extending light absorption[2]. Structural, morphological, and optical properties were confirmed through XRD, UV–Vis, and FTIR analyses[3]. Photocatalytic performance was evaluated using methylene orange (MO) dye under visible irradiation, where Ag–ZnO achieved over 90% degradation within 90 minutes, surpassing pure ZnO[4]. The improved efficiency arises from the synergistic effects of Ag doping and PVP capping, demonstrating the potential of Ag–ZnO nanomaterials for efficient photocatalytic wastewater treatment[5].

Keywords: Ag–ZnO nanoparticles, Sol–gel method, Polyvinylpyrrolidone (PVP), Photocatalysis, Visible light degradation, Methylene orange (MO), Environmental remediation.

I. INTRODUCTION

Industrial dyes are major pollutants in aquatic systems due to their toxicity, persistence, and resistance to conventional treatments[6]. Methyl orange (MO), a widely used azo dye, is particularly hazardous and difficult to degrade[7]. Semiconductor photocatalysis offers a sustainable alternative, with ZnO widely studied for its photosensitivity, stability, and strong oxidation ability[8]. However, its wide band gap (~3.3 eV) restricts absorption to the UV region, limiting efficiency under visible light[9].

Doping ZnO with silver (Ag) extends absorption into the visible range and suppresses electron–hole recombination[10], while polyvinylpyrrolidone (PVP) as a capping agent improves nanoparticle stability and dispersion[11]. In this study, Ag–ZnO nanoparticles were synthesized via a sol–gel route, characterized by XRD, SEM, and UV–Vis, and evaluated for MO degradation under UV and visible light[12]. The work demonstrates the role of Ag doping and PVP stabilization in enhancing ZnO photocatalytic activity for environmental remediation[13].

II. EXPERIMENTAL SETUP AND METHODOLOGY:

2.1 Materials:
Zinc acetate dihydrate [$Zn(CH_3COO)_2 \cdot 2H_2O$], silver nitrate ($AgNO_3$), polyvinylpyrrolidone (PVP), ethanol, distilled water, and NaOH (or ammonia solution) were used as precursors[14,15]. A magnetic stirrer with hot plate, standard glassware, oven, and muffle furnace were employed in synthesis[16].

2.2 Synthesis of Ag–ZnO Nanoparticles:
Ag–ZnO nanoparticles were synthesized via the sol–gel method. Zinc acetate dihydrate (0.1 mol) was dissolved in ethanol (50 mL) and mixed with 0.5 g PVP as a stabilizer. A silver nitrate solution (2 mol%) was prepared separately and added dropwise to the Zn–PVP

solution under vigorous stirring. The pH was adjusted to 9–10 using NaOH while heating at 60–70 °C until gelation occurred. The gel was aged for 12–24 hrs. at room temperature, dried at 80–100 °C, and calcined at 400–500 °C for 2 hrs. to obtain Ag–ZnO nanopowder[17-19].

2.3 Photocatalytic Activity:

Photocatalytic performance was tested using methyl orange (MO, 10–20 mg/L) as a model dye. A fixed amount of catalyst (0.05 g) was dispersed in the dye solution and kept in dark for 30 min to establish adsorption–desorption equilibrium. The suspension was then irradiated with visible light, and aliquots were collected at regular intervals. Dye degradation was monitored by measuring absorbance at ~464 nm using UV–Vis spectroscopy[20-22].

III. RESULTS AND DISCUSSIONS:

3.1. XRD Analysis:

The XRD patterns of pure ZnO and Ag–doped ZnO (Figure 1) show sharp diffraction peaks corresponding to the hexagonal wurtzite structure of ZnO (JCPDS 36-1451)[23]. The observed reflections at (100), (002), (101), (102), (110), (103), (112), and (201) confirm high crystallinity and phase purity[24]. No additional peaks for metallic silver or silver oxides were detected, indicating successful incorporation of Ag ions into the ZnO lattice[25].

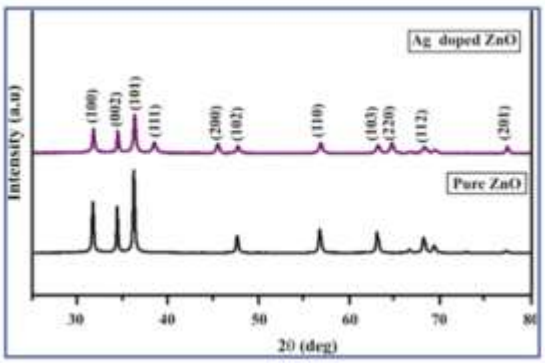

Figure 1. XRD patterns of pure ZnO and Ag–doped ZnO

Compared to pure ZnO, Ag–ZnO exhibits slight peak broadening and intensity variation, suggesting reduced crystallite size and lattice distortion due to doping. These structural modifications, along with defect formation and oxygen vacancies, are beneficial for enhancing photocatalytic performance by improving charge carrier separation and light absorption.

3.2. FTIR Analysis:

FTIR spectra of pure ZnO and Ag–ZnO nanoparticles (Figure 2) show characteristic Zn–O stretching vibrations in the 500–600 cm^{-1} region, confirming ZnO formation. Broad absorption bands around 3400 cm^{-1} correspond to O–H stretching, indicating surface hydroxyl groups and adsorbed water. Peaks near 1600 cm^{-1} are attributed to O–H bending vibrations, while weak bands around 1380–1400 cm^{-1} and 1100–1200 cm^{-1} arise from residual carbonates and C–O bonds.

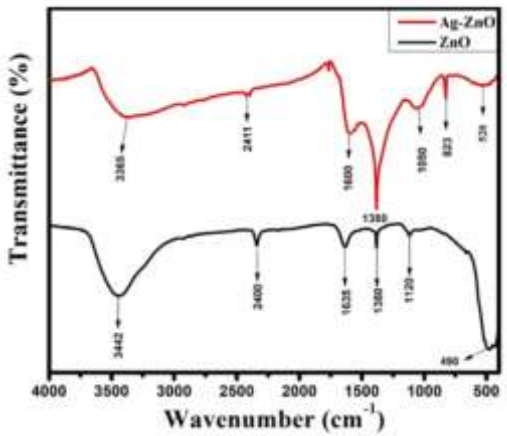

Figure.2 FTIR spectra of pure ZnO and Ag–ZnO nanoparticles

Compared with pure ZnO, Ag–ZnO exhibits slight band shifts and enhanced O–H related peaks, suggesting Ag incorporation and increased surface hydroxylation, which promote photocatalytic activity through the generation of reactive hydroxyl species.

3.3. UV–Vis Analysis:

The UV–Vis spectra of ZnO, Ag, and Ag–ZnO nanoparticles (Figure 3) reveal strong absorption in the UV region. Pure ZnO shows an absorption edge around 380 nm, corresponding to its wide band gap (~3.3 eV). Ag–ZnO exhibits a slight red shift with enhanced absorption in the visible region, indicating band gap narrowing due to Ag incorporation. The additional absorption feature arises from the surface plasmon resonance (SPR) of Ag nanoparticles, which improves light harvesting.

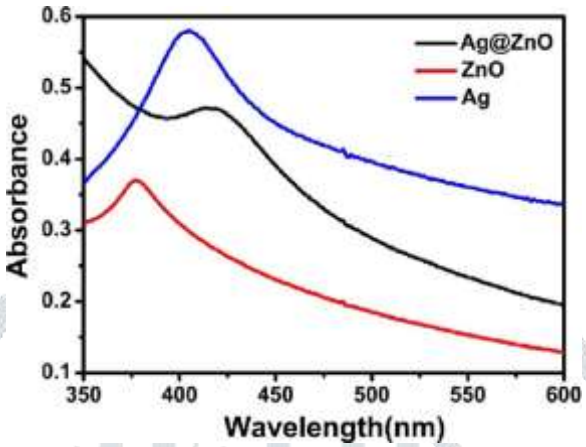

Figure.3 UV–Vis absorption spectra

These optical modifications demonstrate that Ag doping extends the photocatalytic response of ZnO into the visible spectrum and enhances charge carrier utilization, leading to improved photocatalytic performance.

IV. CONCLUSION

Ag–ZnO nanoparticles were successfully synthesized via the sol–gel method using PVP as a stabilizer. XRD confirmed the hexagonal wurtzite ZnO structure with slight lattice distortion upon Ag doping. FTIR verified Zn–O bonding and revealed increased surface hydroxyl groups in Ag–ZnO, favorable for photocatalysis. UV–Vis spectra showed band gap narrowing and visible-light absorption due to Ag incorporation and plasmonic effects.

The photocatalytic tests demonstrated that Ag–ZnO exhibited significantly higher degradation efficiency of methyl orange compared to pure ZnO. The enhancement is attributed to improved light absorption, reduced electron–hole recombination, and the stabilizing role of PVP. These results highlight Ag–ZnO as a promising photocatalyst for wastewater treatment and environmental remediation.

V. FUTURE SCOPE

Further optimization of Ag doping concentration and calcination conditions can enhance the photocatalytic efficiency of Ag–ZnO nanoparticles. Extending this work to other organic dyes and real industrial wastewater will provide broader validation of their practical applicability. In addition, coupling Ag–ZnO with other semiconductors or carbon-based materials (e.g., graphene, g-C_3N_4) could improve visible-light utilization and stability. Scaling up the synthesis for pilot-scale treatment systems will be an important step toward real-world environmental remediation applications.

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