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Synthesis of Pure and Mg Doped Zno Nanoparticles for Photocatalytic Degradation of Organic Dye

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Abstract
ZnO nanoparticles, both pure and doped with magnesium, are of great interest because of their distinct optical, thermal, and structural characteristics. Precipitation was used to create ZnO and Mg doped ZnO nanoparticles with varying doping concentrations. Additionally, the impact of Mg doping on the nanoparticles shape, optical characteristics, and crystal structure was examined. In this work, we describe the effective synthesis of pure and Mg-doped ZnO nanoparticles using the precipitation method, with diameters ranging from 60 to 90 nm. Using a scanning electron microscope (SEM), the surface morphology of the produced material was examined. Powder X-ray diffraction (XRD) was used to study the structure and phases of Mg-ZnO, while UV-Vis spectrophotometers were used to determine the optical characteristics.

Keywords: ZnO, Nanoparticles, Precipitation, PL spectra, XRD

1. Introduction

The creation of multifunctional and size-dependent materials is gaining momentum as nanotechnology advances and complex nanosystems are created. Potential building blocks for nanoscale electronics, optoelectronics, pharmaceuticals, and solar cells have been introduced by recent advances in nanoscience and nanotechnology[1]. As the material dimension approaches nano-order, the surface/volume ratio rises. When it comes to energy storage density, nanoparticles' high surface/volume ratio has important ramifications[2]. Due to their exceptional performance and prospective applications in a variety of industries, nanomaterials particularly metal oxides have drawn a lot of attention in recent years[1,3,4].

ZnO has the most varied and prevalent nanostructure configurations among these oxides. One of the best metal oxides for use at the nanoscale is zinc oxide (ZnO). ZnO is a well-known n-type II–VI semiconductor with a broad direct band-gap of roughly 3.37 eV and a significant exciton binding energy of 60 meV[2,5,6]. It often has a hexagonal or wurtzite structure. ZnO has become a wonder material for material scientists due to its many uses, and the amount of ZnO used in various applications is growing. ZnO production is constantly growing, and scientists are challenged to find an efficient way to prepare

ZnO with superior characteristics[7], a restricted size range, and lower operating costs while operating at room temperature. In the meantime, doping ZnO nanostructures with certain elements provides an efficient way to improve and regulate their electrical and optical characteristics, which is essential for their practical use[8,9]. Studies have been conducted on ZnO doped with appropriate elements, such as Li, Mg, Al, Mn, and Cr[2,10–16].

The band-gap of ZnO can be modified to realize light-emitting devices working in a larger wavelength area by doping it with Mg, which has a wider band-gap (7.3 eV)[2]. ZnO is a significant material because it is available in a wide variety of nanostructures. Doping ZnO with a metal could alter its characteristics; doping with Group II elements (Cd, Mg) could alter the band gap value and boost the intensity of UV luminescence[14]. Numerous techniques, including precipitation, microemulsion, ultrasonic radiation precipitation, microwave irradiation, mechanical milling, solution combustion, microwave-assisted solvothermal, and sol–gel processes, are documented in the literature for the synthesis of ZnO[16].

For the fabrication of nano-ZnO, several physical techniques have been developed, including chemical vapor deposition, vapor phase transparent procedure, pulse laser deposition, and vapor transparent deposition[2]. The creation of nanostructured ZnO powders with spherical, rod-like, flower-like, and sheet-like forms has been documented by several researchers to date[17]. There have only been a few studies on the chemical production of porous ZnO using an oxalate intermediate. Thus, it could be beneficial to look into the precipitation process of creating ZnO and Mg doped ZnO nanopowders[18]. In this work, we describe the production and characterisation of ZnO and Mg doped ZnO nanoparticles using the precipitation method.

2. Synthesis of ZnO and Mg-ZnO nanoparticles

To prepare ZnO nanoparticles, 100 mL of 0.2 M NaOH was added drop-wise into a solution containing 100 mL of 0.1 M Zinc sulphate solution under constant stirring[19]. About 10 mg of CTAB was added as capping agent which inhibits anomalous growth of magnesium hydroxide crystals during the course of precipitation[20,21]. Then the resulting solution was kept at room temperature for three hours under constant stirring. The so obtained white precipitate was centrifuged, washed several times with distilled water and then with alcohol and dried at 80ºC in an oven for 5 hours[22].

NaOH was added to a mixture of 0.1 M zinc sulphate and magnesium sulphate solution 0.015, 0.020, and 0.025 M in order to create Mg doped ZnO with varying concentrations of Mg (0.015, 0.020, and 0.025 M) [4]. The process was then repeated. To create magnesium-doped ZnO nanoparticles, the resulting samples were calcinated in air at 400 degrees Celsius for two hours[23].

3. Results and Discussion

An X-ray diffractometer (PHILIPS1710) with Cu Kα radiation (λ = 0.154 nM) was used to record the diffraction patterns for the produced pure and Mg-ZnO nanoparticles[2]. The produced nanoparticles' surface shape and elemental analysis were examined using a scanning electron microscope (SEM) equipped with an energy dispersive X-ray spectroscopy (EDAX). The optical characteristics were measured using a UV-VIS-NIR spectrophotometer[14].

3.1 **XRD Analysis**

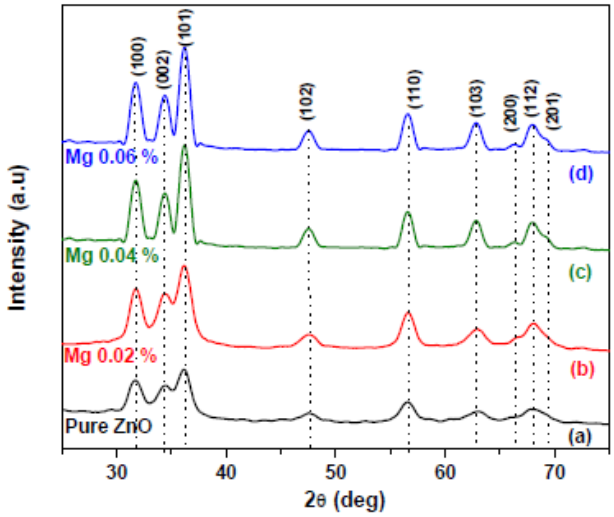

Figure 1 XRD patterns of pure and Mg doped ZnO nanoparticles

The XRD pattern of MgO and Mg-doped ZnO with varying Mg concentrations annealed at 4000ºC for two hours is displayed in Fig. 1[2]. A typical XRD spectrum of ZnO nanoparticles made using the precipitation process is shown in Fig. 1. According to the data base in JCPDS card (No-780-0075), seven major diffraction peaks were observed at 31.7, 34.6, 36.2, 47.6, 56.5, 62.9, and 68.0[2]. These can be attributed to the diffractions from (100), (002), (101), (102), (110), (103), and (112) planes, respectively. The lattice parameters are a = 0.3253 nm and space group P63mc[2]. This demonstrated that the resulting nanoparticles had a hexagonal shape and were pure ZnO.

3.2 FESEM Analysis

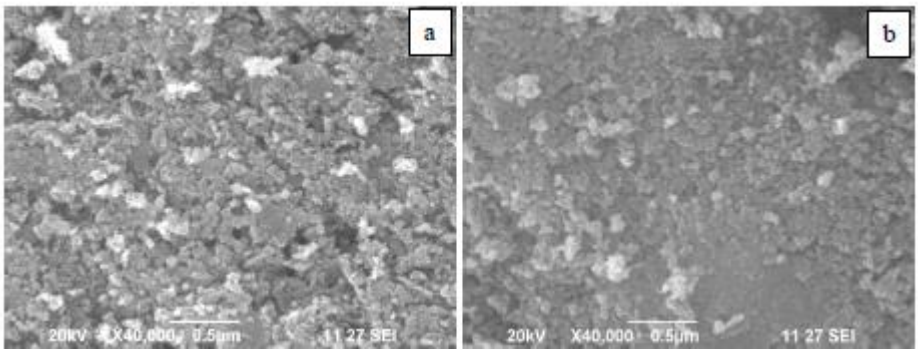

Figure 2 Surface morphology of (a) Pure ZnO, (b) Mg doped ZnO **nanoparticles**

FESEM was used to examine the nanoparticles' surface morphological characteristics. The scanning electron microscopy pattern of ZnO nanoparticles is shown in Fig. 2(a), while the SEM pattern of Mg-doped ZnO with varying concentrations of Mg (0.15, 0.20, and 0.25 M) is shown in Fig. 2(b)[24]. The resulting ZnO nanoparticle has a granular, widely distributed form. Dopant inclusion can occasionally affect ZnO's surface characteristics. The type and quantity of dopant, in particular, can have a significant

impact on the surface characteristics[2]. The Mg-doped ZnO nanoparticles are inhomogeneous and have shapes resembling flakes[16]. The flaws brought forth by magnesium doping could be the cause of this. Particle size increases when the dopant concentration rises from 0.015 to 0.025 M due to particle agglomeration[25].

3.3 Elemental Analysis pure and Mg doped ZnO nanoparticles

The elemental analysis of pure and Mg doped samples is displayed in Figure 3. The existence of Zn and O without any impurity element is evident from the peaks of O appearing at 0.5 keV, Zn appearing at 1, 8.4, and 9.6 keV, and Mg appearing at 1.8 and 3.0 keV, respectively[2,14,16]. The peak also shows that Mg, Zn, and O elements are present in the Mg doped ZnO catalysts.

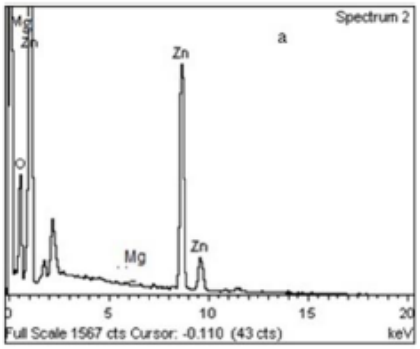

Figure 3 EDX of (a) pure and (b) Mg doped ZnO nanoparticles

3.4 UV-Vis spectroscopy studies

The UV-Vis spectra of ZnO and Mg doped ZnO nanoparticles produced by the precipitation process are displayed in Fig. 4. ZnO has an absorption peak at 361 nm, while Mg-doped ZnO nanoparticles with varying Mg concentrations (0.015, 0.020, and 0.025 M) exhibit absorption peaks at 363, 368, and 371 nm, respectively[26]. The doping of Mg into ZnO is responsible for the slight shift in the absorption band. ZnO's band gap was determined to be 3.41 eV, whereas Mg-doped ZnO at various Mg concentrations (0.015, 0.020, and 0.025 M) was found to be 3.39, 3.36, and 3.34 eV nm, respectively[2,27,28]. The optical absorption edge marginally shifts towards the longer wavelength region when the Mg concentration increases from 0.015 to 0.025 M, which could be explained by the rise in particle size[2].

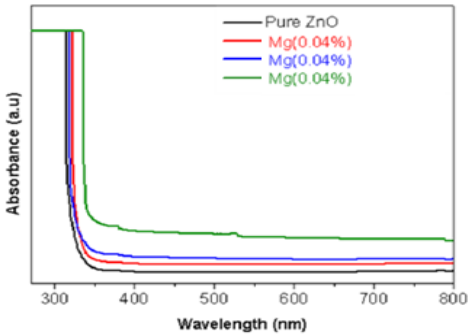

Figure 4 UV-Vis spectrum of (a) pure ZnO and (b) Mg doped ZnO nanoparticles

4. MB dye Degradation of pure and Mg doped ZnO nanoparticles

Figure 5 (a to b) shows the MB dye degradation of Mg (0.02%, 0.04%, and 0.06%) doped with ZnO NPs at different time periods[2]. According to the figure, the MB (663 nm) peak gradually drops when the concentrations of Mg doped with ZnO NPs (0.02%, 0.04%, and 0.06%) increase[29]. The materials' high surface areas and surface oxygen vacancies may be responsible for the increased photocatalytic activity attained for Mg (0.04%) doped ZnO NPs[2].

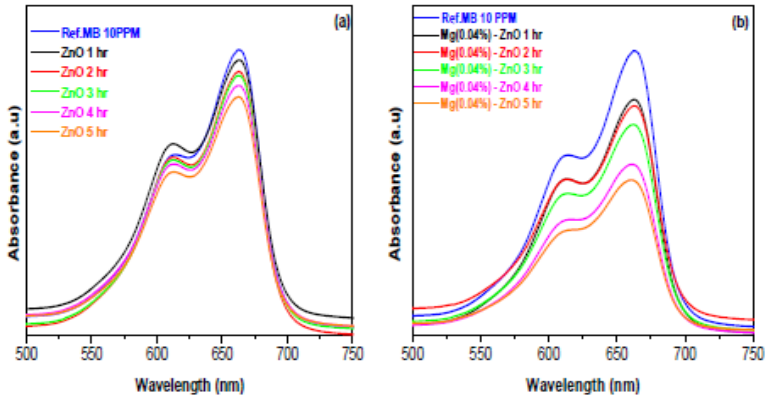

Figure 5 Mb Dye Degradation of (a) ZnO and (b) Bi:Zno Nanoparticles

According to Figure 5(b), the presence of Mg (0.04%) doped ZnO NPs with MB dye solution was to breakdown the dye at 5 hours, with degradation efficiencies of 83% and 92%, respectively[2]. The outcome demonstrates that dye decolorization is high, which is caused by the inclusion of Mg content with ZnO NPs to enhance photogenerated electron and hole recombination[2]. These findings allow us to conclude that the increased surface area of magnesium doped with ZnO NPs has significantly aided in the breakdown of organic compounds and dyes[16].

5. Conclusion

The current study used a straightforward precipitation process to create ZnO and Mg doped ZnO nanoparticles with varying dopant concentrations. The size of the Mg-doped ZnO nanoparticles is between 60 and 90 nm. Agglomeration occurs when the concentration of magnesium rises, and the absorption edge slightly moves toward the longer wavelength region, which may be explained by the narrowing of the band gap. The chemical dye was effectively degraded by both pure and Mg doped ZnO photocatalysts, with degradation efficiency measured as 83% and 92%, respectively.

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Conflicts of interest/Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Consent for publication

This manuscript has not been published previously and it is not under consideration for publication elsewhere, its publication is approved by all authors and if accepted, it will not be published elsewhere

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