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Green Synthesis and Characterization of Zinc Oxide Nanoparticles Using *Adhatoda* Leaf Extract

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Abstract

Zinc oxide nanoparticles (ZnO NPs) have attracted significant interest in recent years due to their wide range of applications, particularly in food fortification, biomedical, and environmental fields. In the present study, ZnO nanoparticles were synthesized using an eco-friendly green synthesis method employing *Adhatoda vasica* leaf extract. This method is simple, non-toxic, and environmentally sustainable. The synthesized nanoparticles were characterized using X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), Ultraviolet–Visible (UV–Vis) spectroscopy, and Scanning Electron Microscopy (SEM). XRD analysis was used to determine the crystalline structure and particle size, FTIR analysis to identify functional groups, UV–Vis spectroscopy to calculate the optical band gap, and SEM to study surface morphology. The results confirmed the successful formation of hexagonal ZnO nanoparticles with an average particle size of 30.94 nm. These biosynthesized ZnO nanoparticles show strong potential for applications such as antimicrobial agents, biosensors, and water treatment.

Key Words: ZnO NPs, X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), Ultraviolet–Visible (UV–Vis) spectroscopy, and Scanning Electron Microscopy (SEM).

1. Introduction

Nanoparticles, owing to their unique physicochemical properties, have revolutionized several scientific fields, including medicine, energy, and environmental science. Among various metal oxide nanoparticles, zinc oxide nanoparticles (ZnO NPs) have emerged as promising materials due to their excellent optical, electrical, and antimicrobial properties. Conventional synthesis methods of ZnO NPs often involve hazardous chemicals and high energy consumption, making them environmentally unfriendly.

In recent years, green synthesis approaches have gained considerable attention as sustainable alternatives. Plant extracts are widely used in green synthesis due to the presence of phytochemicals that act as reducing and stabilizing agents. *Adhatoda vasica*, a medicinal plant rich in alkaloids, flavonoids, and phenolic compounds, is well known for its biological activity. The bioactive compounds present in *Adhatoda* leaf extract facilitate the reduction of metal ions and stabilization of nanoparticles.

In this study, ZnO nanoparticles were synthesized using *Adhatoda* leaf extract through a green co-precipitation method. The synthesized nanoparticles were systematically characterized to evaluate their structural, optical, and morphological properties, highlighting their potential biomedical and environmental applications.

2. Experimental Procedure

2.1 Materials

Zinc sulfate, fresh *Adhatoda* leaves, distilled water, ethanol, and sodium hydroxide were used for the synthesis of zinc oxide nanoparticles. All chemicals were of analytical grade and used without further purification.

2.2 Preparation of *Adhatoda* Leaf Extract

Fresh *Adhatoda* leaves were collected from Badapalli Village, Krishnagiri District. The leaves were thoroughly washed with deionized water to remove dust and impurities. Exactly 10 g of cleaned leaves were finely cut and crushed using a mortar and pestle. The crushed leaves were boiled in 50 mL of deionized water at 50 °C for 1 h 30 min with continuous stirring. The resulting extract was filtered using Whatman filter paper to obtain a clear leaf extract, which was stored for further use.

Fig 2.1 Adhatoda (Adhatoda vasica)

2.3 Synthesis of Zinc Oxide Nanoparticles

A solution of zinc sulfate was prepared by dissolving 20 g of zinc sulfate in 80 mL of distilled water and stirring for 1 h. Subsequently, 30 mL of *Adhatoda* leaf extract was added to the zinc sulfate solution and stirred magnetically for 2 h at room temperature. Then, 5 mL of sodium hydroxide solution was added slowly to the mixture. The solution was kept undisturbed at room temperature for 24 h, resulting in the formation of a precipitate. The precipitate was collected and washed repeatedly with deionized water to remove impurities. The obtained material was calcined at 180 °C using a microwave oven. Finally, the dried product was ground into a fine powder, yielding zinc oxide nanoparticles.

3. Results and Discussion

3.1 XRD Analysis of Zinc Oxide Nanoparticles

The crystalline structure of the synthesized ZnO nanoparticles was analyzed using X-ray diffraction (XRD). The XRD pattern showed prominent diffraction peaks in the 2θ range of 20°–80°. The observed peaks at 33.13°, 47.07°, 56.35°, 57.18°, and 74.86° correspond to the (002), (102), (110), (110), and (220) planes, respectively. These peaks confirm the hexagonal wurtzite structure of ZnO nanoparticles, which matches the standard JCPDS file no. 05-0566.

The average crystallite size was calculated using the Debye–Scherrer equation:

$$D = K\lambda / \beta\cos\theta$$

here D is the crystallite size (nm),

K is the shape factor (0.9),

λ is the X-ray wavelength (1.5406 Å),

β is the full width at half maximum (FWHM), and

θ is the Bragg angle.

The calculated average particle size was found to be 30.94 nm, confirming the nanoscale nature of the synthesized ZnO particles.

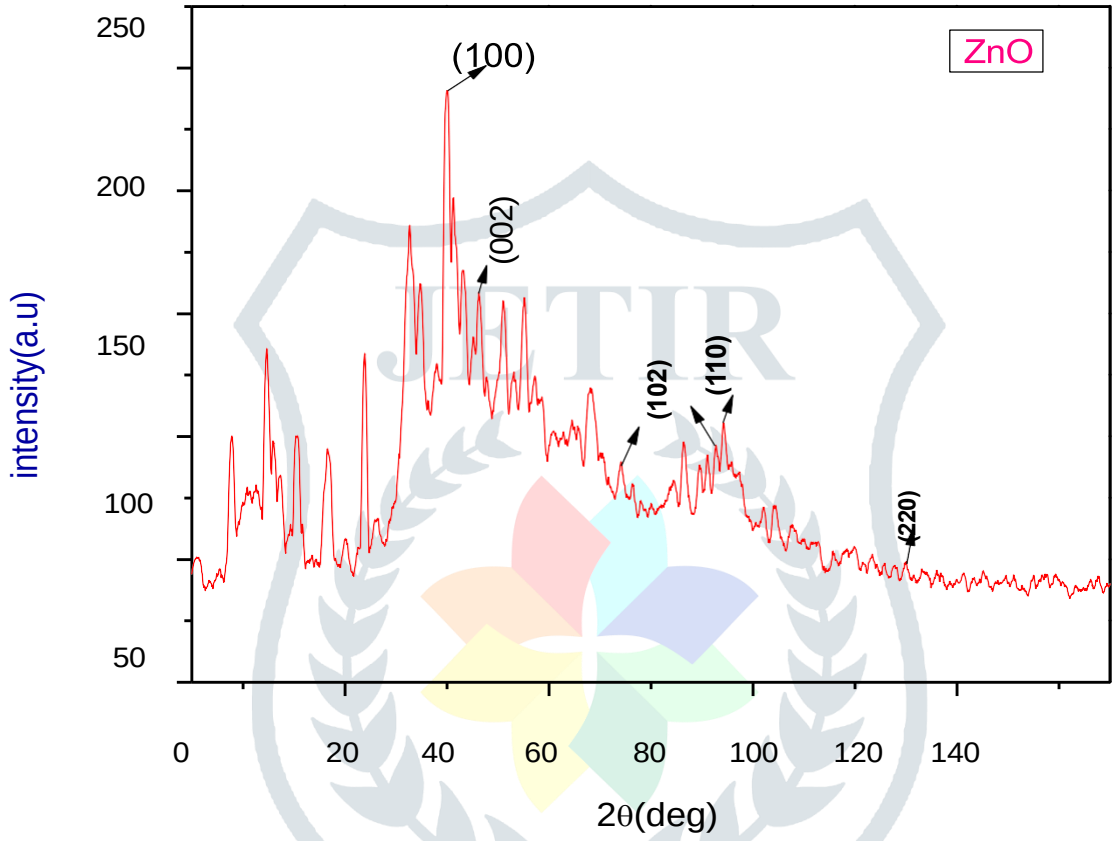

Fig 3.1 X-Ray Diffraction of zinc oxide nanoparticles

Tabulation: 1 To Determine the Size of the Zinc Oxide Nps by Using XRD Analysis

S.NO	2Θ	Θ	COSΘ	FWHM	$\beta=\Pi/180^0$(FWHM)	D=Kλ/βCOSΘ
1	33.13	16.5679	0.9584	0.1468	2.56084	56.4949
2	47.07	23.5368	0.9168	0.2669	4.6559	32.4828
3	56.35	28.1751	0.8815	0.5858	10.2189	15.3923
4	57.18	28.5913	0.8780	0.8272	14.4300	10.9432
5	74.86	37.4326	0.7940	0.2539	4.4291	39.4239
						30.94 nm

3.2 FTIR Analysis of Zinc Oxide Nanoparticles

FTIR analysis was carried out to identify the functional groups involved in the synthesis and stabilization of ZnO nanoparticles. The FTIR spectrum exhibited characteristic absorption peaks at 3209.49, 1631.5, 1403.00, 1110.93, and 615.50 cm^{-1}. The broad peak at 3209.49 cm^{-1} corresponds to O–H stretching vibrations of carboxylic groups. The peak at 1631.5 cm^{-1} is attributed to C=O stretching of amide groups. The absorption at 1403.00 cm^{-1} indicates C–H stretching of alkanes, while the peak at 1110.93 cm^{-1} corresponds to C–O stretching vibrations of ether groups. The peak observed at 615.50 cm^{-1} is associated with Zn–O stretching vibrations, confirming the formation of ZnO nanoparticles.

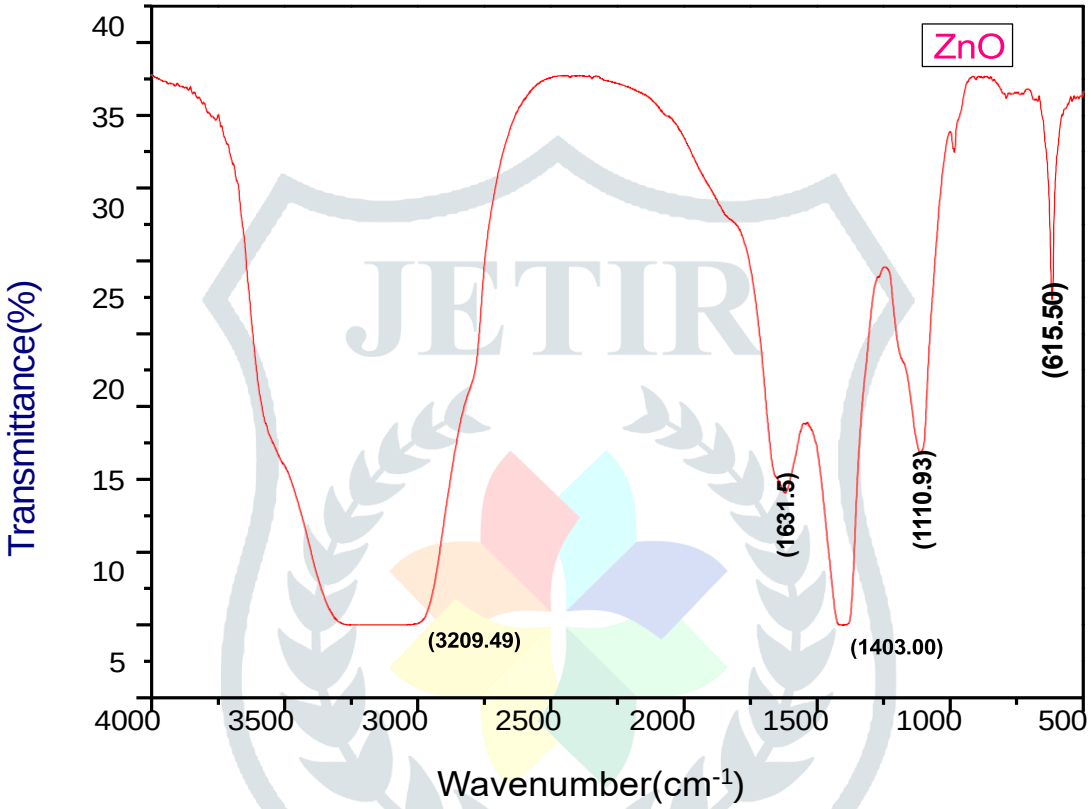

Fig. 3.2 FTIR Spectrum of Zinc Oxide nanoparticles

Tabulation: 2 To Determine the Functional Group of Zinc Oxide NPs By Using FTIR Analysis

FREQUENCY(Cm^{-1})	FUNCTIONAL GROUP	BOND
3209.49	Carboxylic	O-H Stretch
1631.5	Amides	C=O Stretch
1403.00	Alkanes	C-H Stretch
1110.93	Ether	C-H Stretch
615.50	Alkanes	C-H Bend

3.3 UV-Visible Absorption Spectroscopy Analysis

UV-Visible spectroscopy absorption peak confirmed the synthesis of ZnO NPs. The ZnO nanoparticles prepared using the extract obtained from the leaf of Adathoda were subjected to recorded UV- Visible spectroscopy as shown in bellow Fig (5.3). UV- absorption peak was obtained at 304.47nm, which indicates the presence of zinc nanoparticles.

The following equation was used to calculate the band gap of the ZnO NPs.

$$Eg=hc\backslash \lambda.....eV$$

Where,

Eg is a band gap of the material.

h is represents the Planck constant (6.625×10^{-34}S).

C is the velocity of light (3×10^{8} m/s).

λ is the wavelength at 304.47 nm

UV-Visible absorption, the band gap energy of the calculated value was 4.079 ev [5]. This belongs to semiconductor materials.

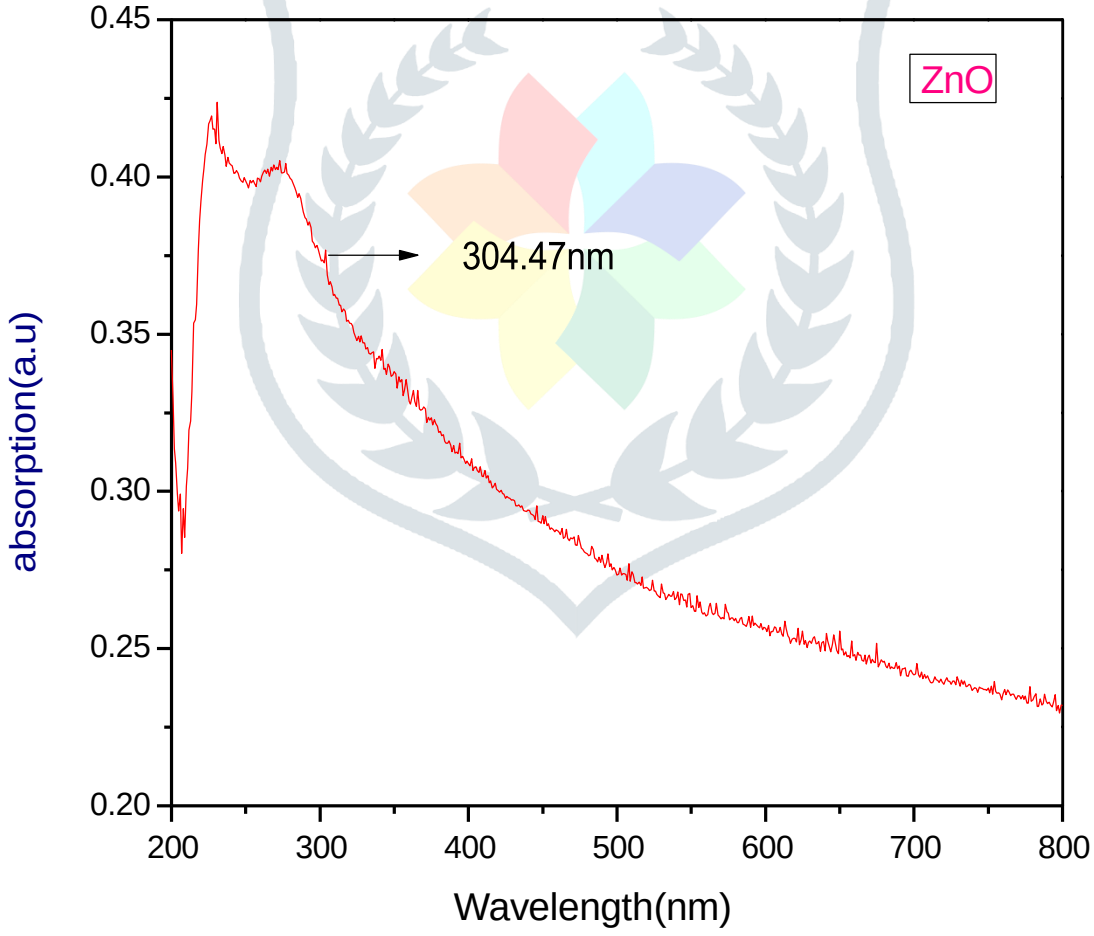

Fig 3.3 UV-Visible spectrum of Zinc Oxide nanoparticles

3.4 Scanning Electron Microscopy Analysis

The surface morphology of the synthesized ZnO nanoparticles was examined using scanning electron microscopy (SEM). The SEM images revealed irregular and flat particles with uneven distribution. The nanoparticles exhibited a predominantly hexagonal morphology, with some degree of agglomeration. These observations confirm the successful synthesis of ZnO nanoparticles using the green synthesis approach.

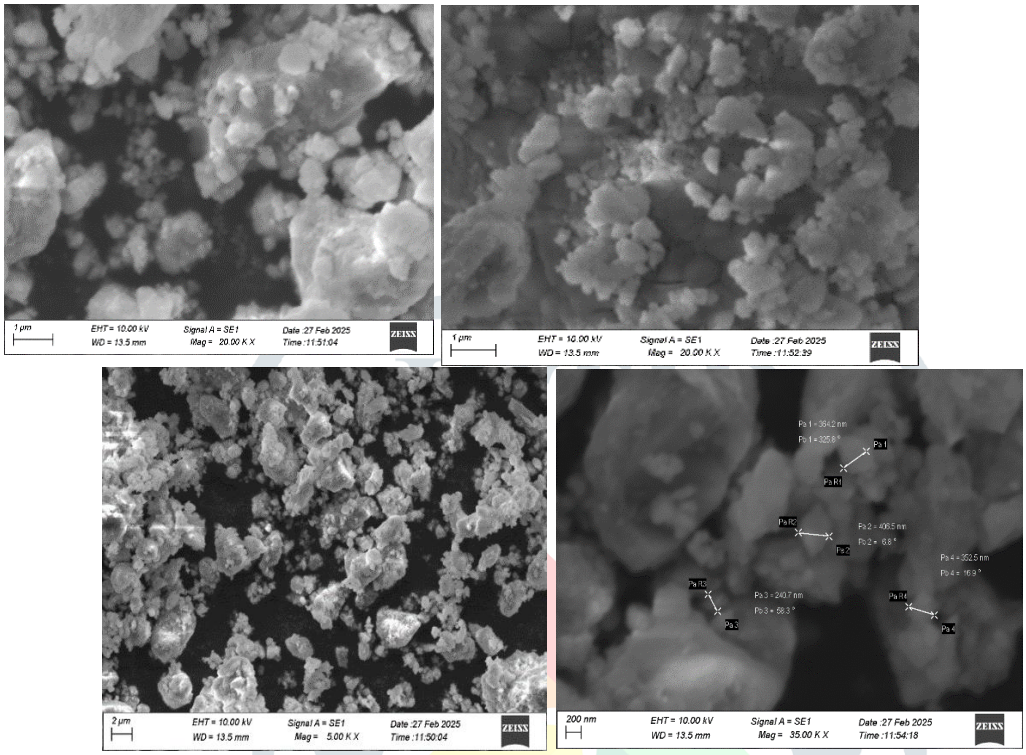

Fig 3.4 SEM images of Zinc Oxide Nanoparticles

4. Conclusion

Zinc oxide nanoparticles were successfully synthesized via a green co-precipitation method using zinc sulfate and *Adhatoda* leaf extract as a reducing and stabilizing agent. The synthesized nanoparticles were characterized using XRD, FTIR, UV–Vis spectroscopy, and SEM. XRD analysis confirmed the hexagonal crystalline structure with an average particle size of 30.94 nm. UV–Vis analysis revealed an absorption peak at 304 nm and a band gap energy of 4.07 eV. FTIR analysis identified various functional groups responsible for nanoparticle stabilization, while SEM analysis confirmed the morphology of the ZnO nanoparticles. This eco-friendly and cost-effective synthesis method offers promising potential for biomedical and environmental applications. Future studies may focus on evaluating the biological activities and application-specific performance of these biosynthesized ZnO nanoparticles.

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