Synthesis of Zinc Oxide Nanoparticles by Sol-gel method to Study its Structural Optical Properties and Morphology

Sonam Ghulam Hussain¹, Muhammad Junaid¹*, Noor Ul Ain¹, Raheela Jabeen², Waheed Qamar khan³, Nasir Abbas¹
¹Institutes of Physics, The Islamia University of Bahawalpur 63100 Bahawalpur Pakistan
²Institute of advance Material, Bahauddin Zakariya University Multan 60000, Multan Pakistan

Received: 5 Jan 2022 Published: 24 June 2022

Abstract:
Zinc oxide nanoparticles can be classified as a multipurpose material, along with their distinctive features and applications in optoelectronic devices. This research looks at the morphological, structural, and optical features of zinc oxide (ZnO) nanoparticles. The sol-gel procedure has been used to form zinc oxide nanoparticles with zinc nitrate [Zn (NO₃)₂.4H₂O] and sodium hydroxide [NaOH] as precursors. The main objective is to synthesize zinc oxide (ZnO) nanoparticles by using the sol-gel approach because that is easy to implement and offers the capacity to adjust particle size and morphology by systematically monitoring reaction conditions. X-ray diffraction phenomenon, Scanning Electron Microscopy, and Ultraviolet-vis spectroscopy characterization techniques were used to determine the structural, morphological, and optical features of produced zinc oxide nanoparticles. According to the XRD examination, the produced nanoparticles are in a highly crystalline phase nature. The high crystallinity of ZnO is observed in all diffraction peaks, implying that Zinc oxide nanoparticles were synthesized properly using the sol-gel process. The UV-vis spectroscopy produced an absorption spectrum at 370nm due to ZnO nanoparticles. The Scanning Electron Microscopy (SEM) measurements reveal the surface structure and grains size of zinc oxide (ZnO) nanoparticles at a different resolution.

Keywords: Nanoparticles, Zinc oxide, XRD, UV, SEM, Sol-gel.

DOI Number: https://doi.org/10.52700/jn.v2i2.51

© 2022 The authors. Published by The Women University Multan. This is an open access article under the Creative Commons Attributions-NonCommercial 4.0.

Introduction:
ZnO is a white powder that is hydrophobic. As it is the most adaptable element, it is utilized as an ingredient in a wide range of products. Zinc oxide is a chemical component that occurs naturally in the minerals Zincates, but the majority of zinc oxide is manufactured synthetically. Zinc oxide is a notable n-type semiconductor metal oxide with a large energy gap and an excitation binding energy of 60 meV at ambient temperature. This shows improved radioactive maintenance performance for initiating spontaneous emission and a low threshold voltage for laser emission operation. ZnO nanoparticles are a good and efficient absorber as they have binding energy in the UV region. Since ZnO has a wide bandgap, it is captivating for the generation of ultraviolet (UV)
optoelectronics such as diode lasers, light-emitting diodes, and field emission displays. It has gotten a lot of attention due to its inexpensive cost and simple technique.

ZnO has been widely used as a host material among nanoscale metal oxides due to its remarkable thermal and chemical durability, high efficiency, and nontoxicity. ZnO is effective because of its vast surface area and high catalytic activity. Zinc oxide has a variety of chemical and physical properties depending on the shape of nanoarrangements. Furthermore, the nano-ethical regime's diversity has made this material a candidate in the realm of nanotechnology, opening up numerous possibilities for elevated devices based on nanotechnology. Zinc oxide nanoparticles are important in a variety of applications, including gas devices, biodevices, chemical sensors, superconductors, optoelectronic devices, varistors, cosmetics, photocatalysts, diodes, field emitters, and piezoelectric devices as well as solar energy conversion. Because of confinement effects, ZnO nanocrystals have some superior optical properties. ZnO nanoparticles are good sunscreen agents because of their excellent UV (ultraviolet) spectrum response and visible light transparency. It can not only block UV rays but also remove sulfur dioxide and hydrogen sulfide. This is a major benefit because it allows chemical factories to protect the environment by removing and preventing poisonous gas from being discharged into the atmosphere. The preparation method determines the shape of zinc oxide nanoparticles. Some of the methods used to make ZnO nanoparticles include co-precipitation, Solvothermal, spray pyrolysis, electrochemical deposition, hydrothermal, hydrolysis, and sol-gel methods. The sol-gel process used to make ZnO nanoparticles were chosen in this study because it is the simplest, uses the least energy and can be carried out in a stable environment.

**Experimental method:**

All of the compounds were available commercially and didn't need to be purified further. Zinc Oxide nanoparticles were prepared using the technique called sol-gel synthesis with zinc nitrate as a precursor, NaOH, and distilled water was utilized as a medium. 2.06 g of zinc nitrate [Zn(NO3)2.4H2O] were dissolved in 10 mL distilled water. Take 100ml distilled water in which 39.56g sodium hydroxide [NaOH] is added and stir it for 15 minutes. This prepared mixture was then added dropwise to the [Zn (NO3)2.4H2O] solution that was made previously. Furthermore, agitate the mixture with a magnetic stirrer at room temperature until white precipitates collect at the bottom of the solution. The precipitates were dried for 1 hour at 100⁰C temperature on a hot plate. Sintering the final sample at 250⁰C to 300⁰C temperature for further purification by which
we obtained an approximate amount of ZnO nanoparticles. Different characterization techniques were used to verify ZnO nanoparticles.

**Result and discussion:**

**Structural study:**

X-ray powder differentiation (XRD) is a high-speed analytical method used to categorize substances in a crystal lattice phase. This unit can deliver information about cell dimensions [12][13]. The spectrum of X-Ray Diffraction for generated ZnO nanoparticles is shown in Fig1, which confirms the wurtzite hexagonal formation. ZnO nanoparticles have values for the unit cell a=b=3.2420Å and c=5.1760Å. Nine distinct peaks developed having 2θ values with crystal planes 31.83⁰(100), 34.50⁰(002), 36.32⁰(101), 47.66⁰(102), 56.71⁰(110), 62.77⁰(103), 67.96⁰(112), 69.03⁰(004), and 72.54⁰(202). There are no additional impurities' diffraction peaks, indicating that the compounds are all ZnO nanoparticles.

![ZnO](image)

**Fig. 1:** X-ray diffraction’s pattern of ZnO nanoparticles.

The high crystallinity of ZnO is observed in all diffraction peaks, implying that Zinc oxide nanoparticles were synthesized properly using the sol-gel process [14]. The Debye-Scherrer equation was used to determine the particle size of the zinc oxide nanoparticles for the (101) peak intensity.

\[
D = \frac{0.89\lambda}{\beta \cos \theta} \tag{1}
\]
The average particle size of obtained ZnO nanoparticle at the highest peak intensity (101) is discovered to be almost 33nm, reveals by using Debye-Scherrer’s equation.

**Morphological analysis:**
A scanning electron microscope is used to conclude some milligrams amounts of particle size, shape, and texture [17]. The surface morphology of zinc oxide nanoparticles was investigated using a JSM-JEOL 6390 Scanning Electron Microscope at 500nm and 200nm are shown in Figures 2, 3 respectively. SEM image shows that there are cleared grains at a lower magnification of specimen with grain size is less than 100nm.

![Fig. 2: SEM analysis of ZnO NPs at lower magnifications](http://jn.wum.edu.pk)

The SEM images of the sample in figure3 reveal the morphology of ZnO NPs having an unsymmetrical and spherical shape with cleared grains at different magnifications. The fact that the agglomeration had occurred was stated clearly.
Fig. 3: SEM analysis of ZnO NPs at lower magnifications

**Optical analysis:**

The UV absorption spectrum is frequently used to determine the optical properties of nano-scale particles [17]. The highest absorption peak for zinc oxide (ZnO) nanoparticles generated by using the sol-gel technique appears at around 370 nm, which is attributed to ZnO nanoparticles. Furthermore, the absorbance band gap is between 200 and 400 nm. The intensity of the absorption peak in the UV–visible spectrum is related to the granular size of nanoparticles.
The following formula was used to calculate the energy bandgap (Eg) of Zinc oxide nanoparticles.

$$E_g = \frac{hc}{\lambda}$$  \hspace{1cm} (2)

$$E_g = 4.13567 \times 10^{-15} \times 3 \times 10^8 / 370 \times 10^{-9}$$

$$E_g = 3.3 \text{ eV}$$

The energy band-gap of Zinc Oxide nanoparticles is derived by interpreting the curve which is approximately 3.3 eV. The fact that ZnO has a large acute absorption band implies that the nanoparticle distribution is mono dispersed.

**Conclusion:**

The sol-gel process was used to successfully synthesize zinc oxide nanoparticles. The average size of zinc oxide generated by sol-gel has been determined using XRD characterization and Scherrer's equation. According to the XRD examination, the size range of the generated ZnO powder was
approximately 30-40nm. XRD measurements clearly show the creation of extremely pure Zinc oxide NPs. The SEM analysis reveals that the morphology of ZnO NPs has unsymmetrical nature and agglomeration with cleared grains at different magnifications. The UV-Vis spectroscopy indicates the maximum absorption at 370nm. The energy band gap of a derived nanoparticle is near 3.3eV.

References:

Moezzi, A. M. McDonagh, and M. B. Cortie, “Zinc oxide particles: Synthesis, properties, and applications,” Chemical Engineering Journal. 2012, doi: 10.1016/jcej.2012.01.076.

H. Mirzaei and M. Darroudi, “Zinc oxide nanoparticles: Biological synthesis and biomedical applications,” Ceramics International. 2017, doi: 10.1016/jceramint.2016.10.051.

M. Hambidge, “Zinc and Health: Current Status and Future Directions Human Zinc Deficiency,” J. Nutr., 2000.

A. Kolodzieczak-Radzimska and T. Jesionowski, “Zinc oxide-from synthesis to application: A review,” Materials. 2014, doi: 10.3390/ma7042833.

V. A. Coleman and C. Jagadish, “Basic Properties and Applications of ZnO,” in Zinc Oxide Bulk, Thin Films and Nanoarrangements, 2006.

Z. Fan and J. G. Lu, “Zinc oxide nanoarrangements: Synthesis and properties,” J. Nanosci. Nanotechnol., 2005, doi: 10.1166/jnn.2005.182.

A. Janotti and C. G. Van De Walle, “Fundamentals of zinc oxide as a semiconductor,” Reports Prog. Phys., 2009, doi: 10.1088/0034-4885/72/12/126501.

Z. L. Wang, “Zinc oxide nanoarrangements: Growth, properties, and applications,” J. Phys. Condens. Matter, 2004, doi: 10.1088/0953-8984/16/25/R01.

J. Wu, J. Cao, W. Q. Han, A. Janotti, and H. C. Kim, “Functional Metal Oxide Nanoarrangements,” Springer Ser. Mater. Sci., 2012, doi: 10.1007/978-1-4419-9931-3.

Srivastava, V., Gusain, D., & Sharma, Y. C. (2013). Synthesis, characterization, and application of zinc oxide nanoparticles (n-ZnO). Ceramics International, 39(8), 9803-9808.

Shi, L. E., Li, Z. H., Zheng, W., Zhao, Y. F., Jin, Y. F., & Tang, Z. X. (2014). Synthesis, antibacterial activity, antibacterial mechanism and food applications of ZnO nanoparticles: a review. Food Additives & Contaminants: Part A, 31(2), 173-186.
A. Clearfield, J. H. Reibenspies, and N. Bhuvanesh, Principles and Applications of Powder Diffraction. 2009.

M. Eckert, “Max von Laue and the discovery of X-ray diffraction in 1912,” Annalen der Physik. 2012, doi: 10.1002/andp.201200724.

B. Fultz, J. M. Howe, B. Fultz, and J. M. Howe, “Diffraction and the X-Ray Powder Diffractometer,” in Transmission Electron Microscopy and Diffractometry of Materials, 2002.

J. Lodge and J. P. Lodge, “X-Ray Powder Diffraction,” in Methods of Air Sampling and Analysis, 2018.

A. Becheri, M. Dürr, P. Lo Nostro, and P. Baglioni, “Synthesis and characterization of zinc oxide nanoparticles: Application to textiles as UV-absorbers,” J. Nanoparticle Res., 2008, doi: 10.1007/s11051-007-9318-3.

Hasnidawani, J. N., Azlina, H. N., Norita, H., Bonnia, N. N., Ratim, S., & Ali, E. S. (2016). Synthesis of ZnO nanostructures using sol-gel method. Procedia Chemistry, 19, 211-216.

Omri, K., Najeh, I., Dhaahri, R., El Ghoul, J., & El Mir, L. (2014). Effects of temperature on the optical and electrical properties of ZnO nanoparticles synthesized by sol-gel method. Microelectronic Engineering, 128, 53-58.

Gimenez, A. J., Yáñez-Limón, J. M., & Seminario, J. M. (2011). ZnO– paper-based photoconductive UV sensor. The Journal of Physical Chemistry C, 115(1), 282-287.