

A Sol-Gel Approach for the Fabrication of Zinc Oxide Nanoparticles and Their Nanocomposite with Urea Formaldehyde (UF)

Hemantkumar N. Kohale^{1,2}, Sudhanshu Kharkate^{2*}, Rakesh Naktode², Mangesh Thakare²

Abstract

In the performed work, zinc oxide nanoparticles were synthesized via the sol-gel method using zinc sulphate as the precursor material. Urea-formaldehyde (UF) resin was employed as a polymer matrix to encapsulate the produced ZnO through an acid-catalyzed polymerization process. This encapsulation aimed to improve the dispersion stability and surface reactivity of ZnO within the polymeric medium. The synthesized materials were subjected to comprehensive characterization using Fourier Transform Infrared Spectroscopy (FT-IR), X-ray Diffraction (XRD), Scanning Electron Microscopy (SEM), and Energy Dispersive X-ray Analysis (EDX). FT-IR spectra exhibited characteristic metal-oxygen stretching vibrations confirming the formation of ZnO bonds, while additional bands corresponding to functional groups in the UF resin indicated successful encapsulation. The XRD pattern showed sharp and well-defined peaks, signifying the highly crystalline nature of ZnO nanoparticles. SEM micrographs revealed that the particles possessed predominantly spherical morphology with uniform size distribution, suggesting controlled nucleation during synthesis. EDX analysis provided the elemental composition and verified the presence of zinc and oxygen as major constituents. Furthermore, the ZnO-UF nanocomposite demonstrated enhanced structural integrity, which could contribute to improved mechanical strength, thermal stability, and potential antimicrobial properties. Overall, the combined spectroscopic and microscopic analyses validated the successful synthesis and encapsulation of ZnO nanoparticles within the UF matrix. Additionally, the incorporation of ZnO nanoparticles into the UF resin matrix offers significant potential for diverse industrial and environmental applications. The encapsulation process not only prevents agglomeration but also enhances the durability and surface activity of the nanoparticles.

Keywords: Nanoparticle, sol-gel, urea-formaldehyde, resin, metal oxides

INTRODUCTION

Nanotechnology, which emerged in the 20th century, is a novel field of study that has found numerous uses in science and engineering due to its ability to produce materials with extremely small sizes (1-100 nm) and a wide variety of crystal shapes, such as spherical nanoparticles, nano-rods, nano-ribbons, and nano-plates.[1]. Today it has been proved that metal oxide nanomaterial are widely used as decontaminant to remove heavy metal ions and dyes [2]. There are so many metals oxide including Fe₃O₄[3], MnO₂[4], TiO₂[5], MgO [6], CdO[7] and ZnO[8] provide high surface area and specific affinity. Metal oxide possesses low solubility, thermal stability, high surface area, minimal environmental impact makes them to be used as excellent adsorbent to remove heavy metal

*Author for Correspondence

Sudhanshu Kharkate
E-mail: kharkatesudha@gmail.com

¹ Department of Chemistry, R.T.M. Nagpur University, Nagpur, India

² Department of Chemistry, D.R.B. Sindhu Mahavidyalaya, Panchpaoli, Nagpur, India

Received Date: September 18, 2025

Accepted Date: October 13, 2025

Published Date: October 20, 2025

Citation: Hemantkumar N. Kohale, Sudhanshu Kharkate, Rakesh Naktode, Mangesh Thakare. A Sol-Gel Approach for the Fabrication of Zinc Oxide Nanoparticles and Their Nanocomposite with Urea Formaldehyde (UF). International Journal of Crystalline Materials. 2025; 2(2): 21–27p.

ions and dyes [9]. In current work based on the taking the references of the synthesis of ZnO taking consideration of its wide applications in medicinal and industrial applications [10]. Lot of chemical methods were used to prepared ZnO nanoparticles like sol-gel method, chemical precipitation, thermal decomposition, chemical vapor decomposition [11-18]. From the existing methods, the sol-gel approach stands out for its simplicity and its ability to adjust particle size and shape while monitoring reaction parameters.

Considering all of the foregoing, it is clear that ZnO has several potential applications owing to its unique features, such as its binding energy, high refractive index, antibacterial capabilities, and UV-protection. Products include food, solar cells, rubber, cosmetics, and medicine.[19]. A review of the relevant literature reveals that ZnO outperforms bulk size in terms of performance.[20]. Nanoparticles of zinc oxide (ZnO) are biocompatible with human cells and contain the essential mineral zinc.[21].

The US FDA (Food and Drug Administration) has just approved ZnO as a safe material.[22]. Nanoparticles made from zinc sulfate using an NH_4OH solvent have a spherical form, but those synthesized with sodium hydroxide have a wire-like appearance. As the size of zinc oxide nanoparticles decreases, they become more effective antibacterial agents. [23]. Zinc oxide is an excellent material for sensors and transducers since it is both biocompatible and generally safe to use. Metal oxide nanostructures have attractive biocompatible, non-toxic, and catalytic nano-morphological functional characteristics. [24].

In recent year zinc oxide has promoted itself as interesting metal-oxide material because of its unique physical and chemical properties such as high chemical and mechanical stability broad range of radiation absorption, high catalytic activity, electrochemical coupling coefficients, and nontoxic nature. Zinc oxide can occur in two-dimension structure. such as nano pellets, nanosheet/ nanoplates [25]. The mentioned properties and applications make ZnO nanoparticles as area of interest as per as nano chemistry of transition metal oxide is concerned.

J. N. Hansidawani et.al.,(2015) discuss the synthesis of ZnO nanostructure using zinc sulphate dihydrate as precursor by sol-gel method it concludes that ZnO nanoparticles is successfully synthesized by sol-gel method. It obtained nano-rod like structure and particle nanosized range 81.28nm to 84.98nm [26]. S. Jurablue et al., (2015) discuss about the synthesis of ZnO nanoparticles and study its structural and optical properties [27]. The characterisation and fabrication of ZnO NPs using the sol-gel technique are covered in the 2015 study by Riyadh M Alwan et., al. [28].

MATERIALS AND METHODS

Chemicals and Reagents

Zinc Sulphate Dihydrate (Merk), Absolute alcohol (47%) sd fine chemicals, hydrogen peroxide.

Synthesis of ZnO Nanoparticle

All analytical grade chemicals were used as received without further purification. Approximately 15 grams of zinc sulfate dihydrate were dissolved in 300 milliliters of double-distilled water with constant stirring to ensure total dissolution. The solution was further heated to 50°C , and 300 ml of absolute alcohol was added gradually while stirring. After 6 ml of H_2O_2 (47%) was incrementally added to the mixing vessel and stirred with a magnetic stirrer, a nearly clear solution was obtained. The solution was then dried at 80°C after being incubated for 24 hours. After waiting for a few hours, white nano-ZnO was produced. Zinc Oxide was rinsed with distilled water many times to eliminate any byproducts. The ZnO NPs were then dried in a hot air oven at 80°C , ensuring that the entire conversion of zinc oxide would take place during this procedure.

Preparation of ZnO-UF Resin

To create a ZnO-UF nanocomposite with a white colour, we combined formaldehyde and urea in a standard molar ratio of 2:1 (w/w) in a 250 ml round-bottom flask and stirred magnetically until the

mixture was uniformly mixed at 60°C. We then added 100 mg of ZnO and 0.5 ml of concentrated H₂SO₄ while continuously stirring. After 12 hours at 100 °C, the ZnO-UF nano-composite had dried in an oven. [29].

CHARACTERIZATION

The FT-IR spectra of the ZnO and ZnO-UF materials were acquired in the 400 to 4000 cm⁻¹ range using a Bruker Alpha Spectrometer. A Benchtop X-ray Diffractometer was used to measure the powder X-ray diffraction (XRD) pattern.

The XRD data was obtained using a 2θ value ranging from 10 to 80 degrees in a Bragg-Brentano geometry with a flat holder.

FT-IR Spectra

The FT-IR spectra of the synthesized ZnO and ZnO-UF nanocomposite were recorded to identify the functional groups and confirm the formation of metal–oxygen bonds. In the spectrum of pure ZnO, a strong absorption band appeared around 430–450 cm⁻¹, which is characteristic of Zn–O stretching vibrations, confirming the formation of zinc oxide nanoparticles. The ZnO-UF nanocomposite spectrum exhibited additional peaks around 3343 cm⁻¹ and 1633 cm⁻¹ corresponding to N–H and C=O stretching vibrations, respectively, arising from the urea-formaldehyde matrix.

ZnO

Figure 1 shows two peaks in the infrared spectrum, which are used to identify the presence of specific functional groups in compounds. The first peak at 1736 cm⁻¹ wave number was describe H-O-H bending and, on the O-H stretching of hydroxyl group. wavenumber 448cm⁻¹ is for ZnO bond. This region exhibits absorption bands arising from interatomic vibrations due to the stretching of Zn-O bonds within the ZnO nanoparticles.

ZnO-UF

Shifting of band at higher wavelength gives information of composites formation. The peaks for M-O shifts at 537cm⁻¹. Carbonyl group peaks shifted to 1633cm⁻¹. N-H Peaks gets shifted to 3343cm⁻¹ shown in Figure.No.2.

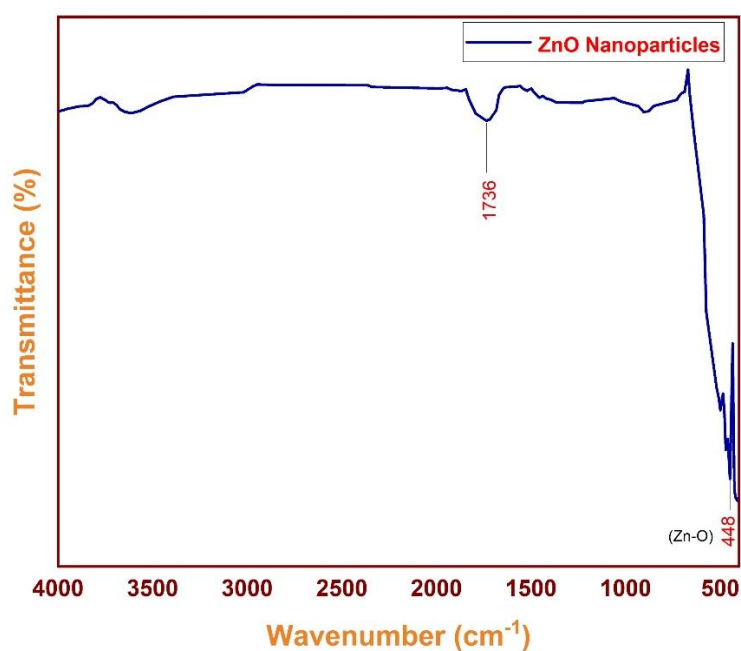


Figure 1. FT-IR spectra of ZnO.

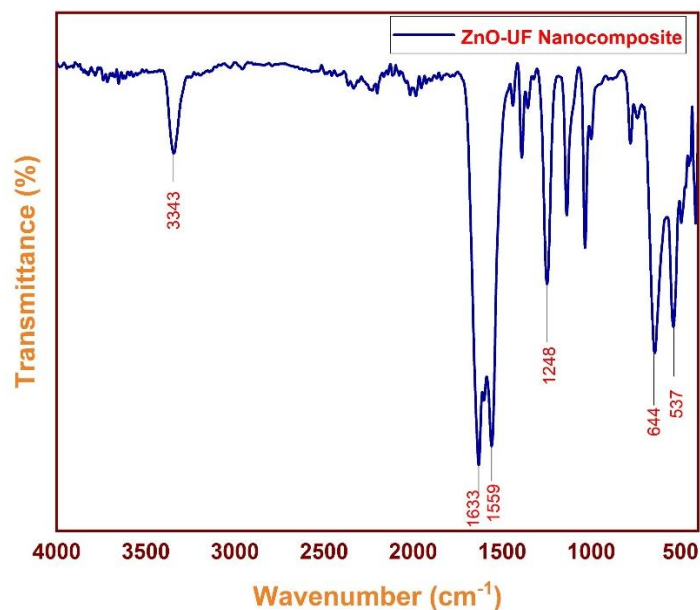


Figure 2. FT-IR spectra of ZnO-UF.

XRD – Rays Diffraction Studies

ZnO

In X-ray diffraction studies shows that product ZnO is crystalline. The appears of sharp peaks shows crystalline nature of ZnO. X-Ray Diffraction (XRD) patterns of ZnO nanoparticles synthesized at 500°C which are in accordance with the JCPDS Card No.36-1451. It confirms the crystalline nature and hexagonal phase (wurtzite structure) of ZnO with Lattice Constants $a=b=3.249\text{\AA}$ and $c=5.206\text{\AA}$. The reflections observed in Figure No.3 at 18.25° , 26.70° , 30.02° , 35.22° , 45.02° , 55.22° , 65.02° , 73.02° , 74.05° , can be indexed to [100], [002], [101], [111], [102], [110], [103], [201],[202] planes of ZnO.

The crystalline size is calculated by using Debye Scherer formula is $D = k \lambda / \beta \cos \theta$
Where,

D = crystalline size (nm)

$K = 0.9$ (Scherrer constant)

$\lambda = 0.15406\text{nm}$ (wavelength of x-ray source)

β = FWHM (radians)

θ = peak position in radians

The crystalline size of ZnO found to be 60 nm.

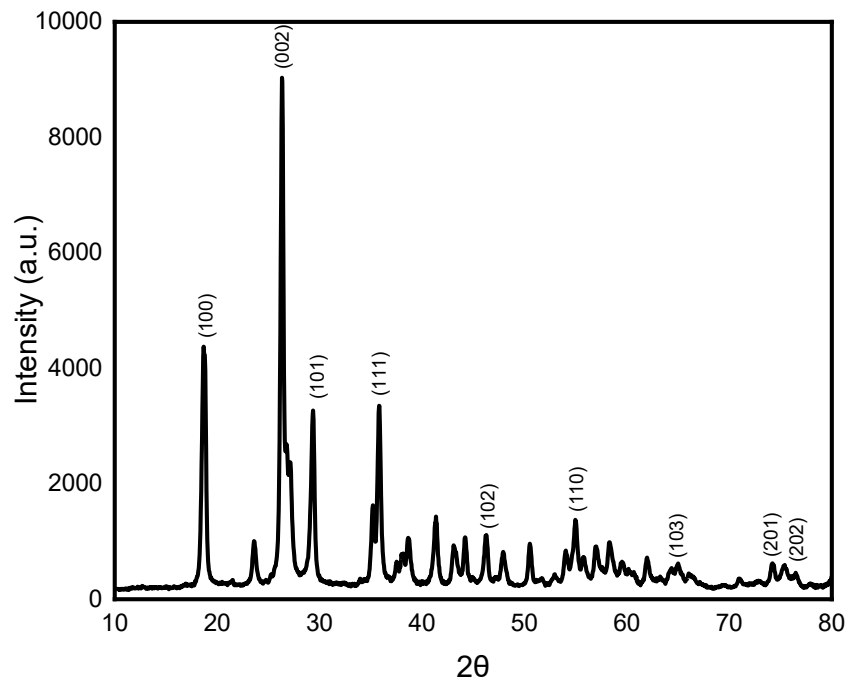


Figure 3. XRD of ZnO.

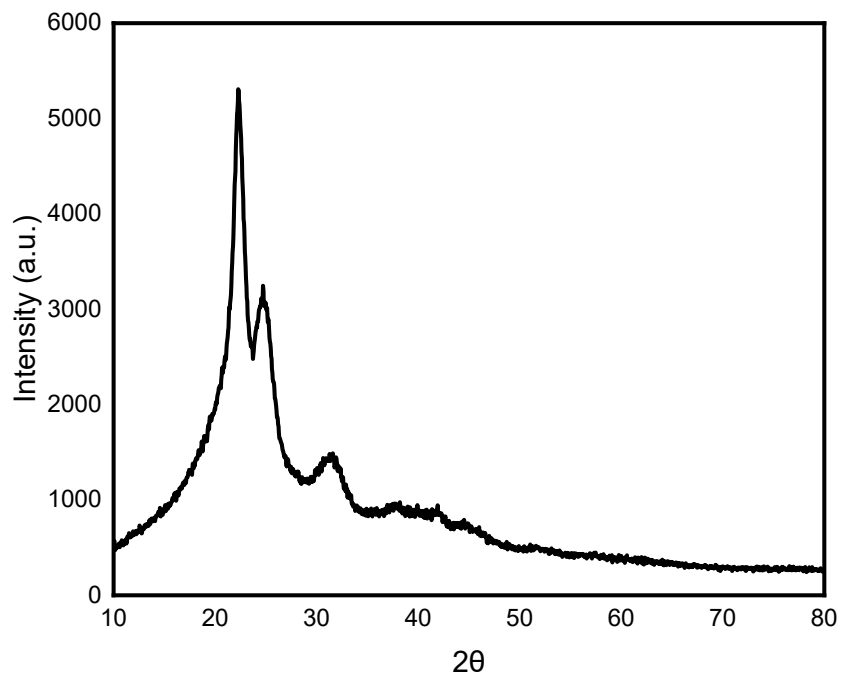


Figure 4. XRD of ZnO-UF.

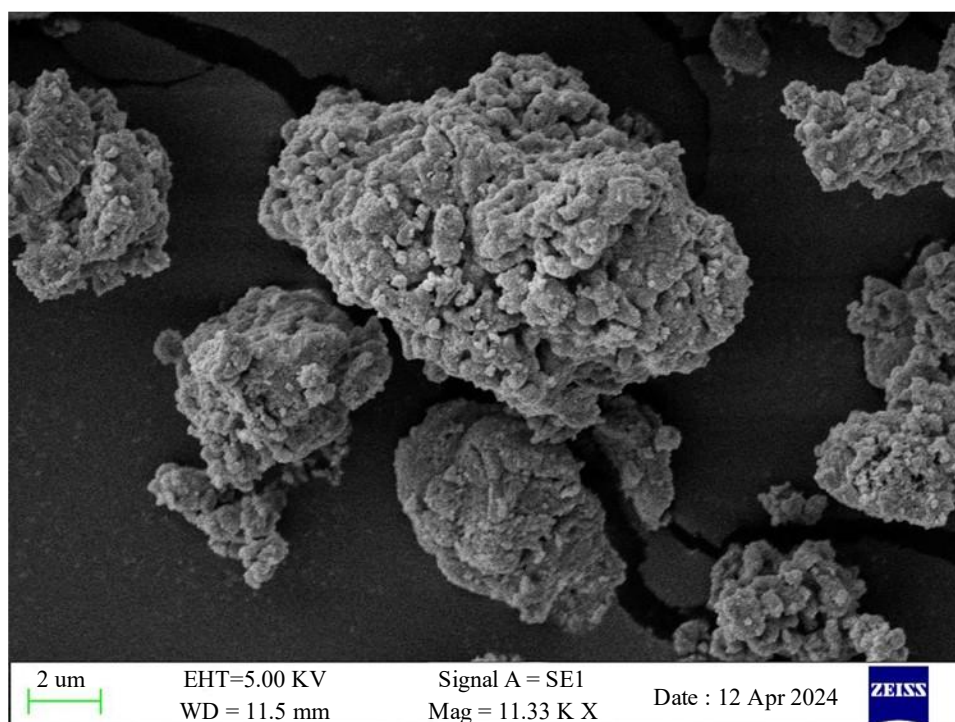


Figure 5. SEM of ZnO.

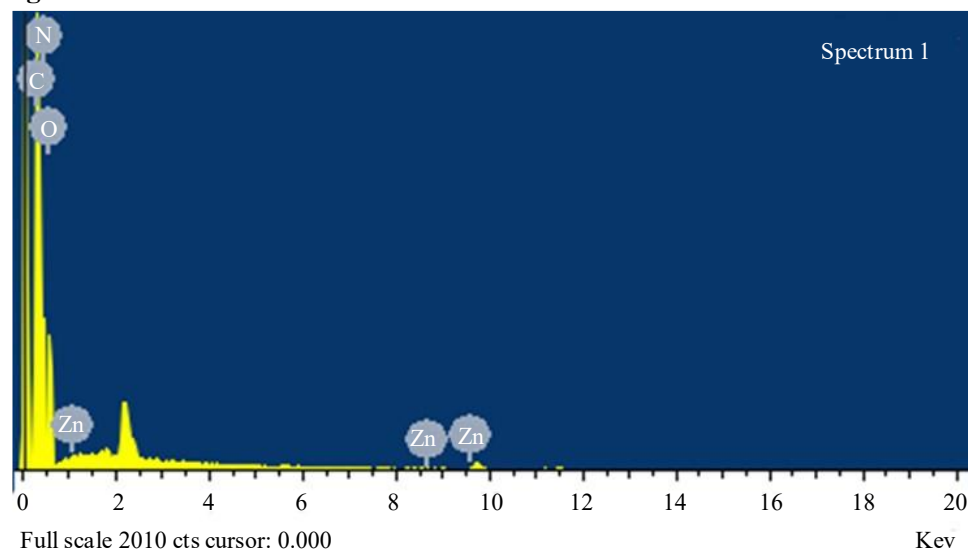


Figure 6. EDX of ZnO-UFS.

ZnO-UF

The XRD spectra of ZnO-UF reveal individual nanometer layers suspended in a urea formaldehyde polymer matrix, exhibiting well-ordered encapsulation of the metal oxide in the urea formaldehyde. The "d" spacing between the layers is markedly increased owing to the formation of the composite Figure 4.

SEM & EDX

In SEM analysis of ZnO show in Figure No.5 that the particles are spherical, uniform in nano size with diameter range from 40 nm to 100 nm. From gaussian graph shows that developments of pores in ZnO-UF nanocomposite due to encapsulation of ZnO. SEM is coupled with an EDX detector, whereby X-rays serve as a signal to generate chemical information. The elemental composition and

stoichiometric ratio of ZnO nanoparticles were validated by EDX analysis shown in the Figure Number 6.

EDX performed with SEM from the measurements of percentage composition of elements synthesis of ZnO and ZnO-UF was confirmed.

CONCLUSION

The sol gel process is used to manufacture nanosized ZnO. Confirmation of ZnO and its nanocomposite ZnO-UF fabrication is consistent with results obtained from FTIR, XRD, SEM, and EDX. The size of the final metal oxide ZnO is precisely the same in both XRD and SEM. Analysing all of the characterization findings validated the fabrication of ZnO NPs and ZnO-UF nanocomposites. This research also demonstrates the relevance of UF and offers up new possibilities for using UF as a suitable stabilizer to build nanocomposite.

REFERENCES

1. Patel M., Mishra S., Verma R., Shikha D., *Discover Materials.*, 2(1) (2022) 1-11.
2. Prapti P. Warbhe, Rakesh M. Naktode, Mamta R. Lanjewar *Int J Sci Res Sci and Technol*, vol.11(3) 2024.
3. Feng, L., Cao, M., Ma, X., Zhu, Y., Hu, C.: Superparamagnetic high-surface-area Fe₃O₄ nanoparticles as adsorbents for arsenic removal. *J. Hazard. Mater.* Vol. 217-218, (2012) 439–446.
4. Gupta K., Bhattacharya S., Chattopadhyay D., Mukhopadhyay A., Biswas H., Dutta J., Ray N.R., Ghosh U.C.: Ceria associated manganese oxide nanoparticles: synthesis, characterization and arsenic (V) sorption behaviour. *Chem. Eng. J.* 172(1), 219–229 (2011)
5. Luo, T., Cui, J., Hu, S., Huang, Y., Jing, C.: Arsenic removal and recovery from copper smelting wastewater using TiO₂ *Environ. Sci. Technol.* 44(23), 9094–9098 (2010).
6. Gao, C., Zhang, W., Li, H., Lang, L., Xu, Z.: Controllable fabrication of mesoporous MgO with various morphologies and their absorption performance for toxic pollutants in Water, *Cryst. Growth Des* 8(10), 3785–3790 (2008).
7. Tadjarodi, A., Imani, M., Kerdari, H.: Adsorption kinetics, thermodynamic studies, and high performance of CdO cauliflower-like nanostructure on the removal of Congo red from aqueous solution. *J. Nanostruct. Chem.* 3(1), 51 (2013).
8. Singh S., Barick K., Bahadur D.: Fe₃O₄ embedded ZnO nanocomposites for the removal of toxic metal ions, organic dyes and bacterial pathogens. *J. Mater. Chem. A* 1(10) 3325–3333 (2013).
9. Hamidreza Sadegh, Gomaa A. M. Ali Vinod Kumar Gupta, Abdel Salam Hamdy Makhlof, RaminShahryari-ghoshekandi, MallikarjunaN. Nadagouda, Mika Sillanpää & Elzbieta Megiel. *J. Nanostruct. Chem.* 7,1-4 (2017).
10. Sauvik Raha and Md. Ahmaruzzaman *Nanoscale Adv.*, 2022, 4, 1868-1925.
11. Ranvir S. P., Preparation of modified ZnO nanoparticles by sol -gel process and their characterization, *Master of Technology*, 2009, Thapar university, Punjab.
12. Haung X. H, Guo R. Q. and WuL. B.; Mesoporous ZnO nanosheets for lithium-ion batteries, *Materials Letters*, Volume 122, 2014, 82-85.
13. Hua Li, Jain C.D. and HuiR.D.; Synthesis and Characterization of chitosan ZnO nanoparticles composite membranes, *carbohydrate research*, Vol.345(8)2010 994-998.
14. Boudiba A., Zhang C. and Lahem M.; Highly sensitive and rapid NO₂ gas sensors based on ZnO nanostructures and the morphology effect on their sensing performances, *14th international meeting on chemical sensor (IMCS) 2012*.
15. Kolekar T.V., Yadav H.M. and Bandgar S.S.; Synthesis by sol- gel method and characterization of ZnO nanoparticles, *Indian streams research Journal*, 1(1) 2011 1-4.
16. Khorsand A. Z., Razali R., Majid W. H.; Synthesis and characterization of narrow size distribution of zinc oxide nanoparticles, *international journal of nanomedicine*. 6(2011)1399-1403.
17. Surya P.G., synthesis and characterization of zinc oxide nanoparticles by sol-gel process, *Master of science in physics*, National institute of technology Rourkela, Orissa, India, (2012) 1-36.

18. Sreetama D. and Bichitra N. G.; Characterization of ZnO nanoparticles grown in presence of Folic acid template, *Journal of nanobiotechnology* 10(29) 2012 29-34.
19. Klingshirn C, ZnO: Material, Physics and Application. *Chem Phy Chem* 8(6) 2007 782-803.
20. Radyum I., Putri R. I., and Siswanto S., Effect of PH variation on particle size and purity of Nano zinc oxide synthesized by sol-gel method; *International Journal of Engineering and Technology*, 12(6) 2012 5-9.
21. Emamifar A., Kadivar M., and Zad S.S. Evaluation of nanocomposite packaging containing Ag and ZnO on shelf life of fresh orange juice innovative-food science and Emerging Technology 11(4) 2010 742-748.
22. Sawai J. Qualitative evaluation of antimicrobial activities of metallic oxide powders (ZnO, MgO and CaO) by conductimetric assay. *J.Microbial methods* 54(2) 2003 177-182.
23. Mishra S. Use of nanotechnology and Nanoscience in food packing., *Int J Advance science Tech Res.* 1 (2014) 394-406.
24. H.A. Wahab, A.A. Salama, et al Optical, structural and morphological studies of ZnO nano-rod thin film using sol-gel., 3 (2013) 46-51
25. Agnieszka Kołodziejczak-Radzimska and Teofil Jesionowski (2014) “Zinc Oxide—From Synthesis to Application: A Review” materials 2833-2881.
26. J.N.Hasnidawani,H.N.Azlina H. Norita,N.N.Bonnia,S.Ratim and E.S. Alif., *Procedia chemistry* 19(2016) 211-216.
27. S. Jurablue et al., *Journal of Science Volume* 26(3) 2015,281-285.
28. Riyadh M . Alwan et.al., *Nanoscience and Nanotechnology*.5(1) 2015,1-6.
29. Neeta Pandey, S.K,Shukla, N.B.Singh *Adv.Mater.Lett.* 6(2) 2015 172-178.