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Synthesis and characterization of ZnO Nanoparticles and its application by Sol-Gel Method

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Abstract:

Zinc oxide plays an important role in the current industry due to its special characteristics such as anti-corrosion, anti-bacteria, low electron conductivity and excellent heat resistance. The synthesis of Zno NPs by the sol-gel method has recently gained widespread use to synthesize and characterize zinc oxide nanoparticles. Sol-gel method is the simplest method and has the ability to control the particle size and morphology through systematic monitoring of reaction parameters. ZnO nanoparticles were synthesized via sol-gel method using Zinc acetate dehydrate ($Zn(CH_3COO)_2.2H_2O$) as a precursor and ethanol (CH_2COOH) were used as a solvent, Sodium hydroxide (NaOH) and distilled water were used as a medium. ZnO nanoparticles were characterized by using XRD, EDX, FESEM, and nano-particles analyser. The result of EDX characterization shows that the ZnO nanoparticles have good purity with (Zinc content of- 55.38% and; Oxygen content of- 44.62%). XRD result spectrum displays mainly oxygen and zinc peaks, which indicate the crystallinity in nature as exhibited. FESEM micrographs show that synthesized ZnO have a rod-like structure. The obtained ZnO nanoparticles are homogenous and consistent in size which corresponds to the XRD result that exhibits good crystalline. ZnO nanoparticles were successfully synthesized by the sol-gel method in the nano size range between 81.28 nm to 84.98 nm.

Key Words: -Zno Nanoparticles, XRD, EDX, FESEM, Ability to control particle size, result to give good crystallinity

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Introduction

A. Background information on ZnO nanoparticles

Zinc Oxide nanoparticle is a metal oxide and is an inorganic mixture belonging to group II-IV. The chemical and physical characteristics of ZnO nanoparticles can be transformed by changing the morphology with the use of several materials. The energy band of the ZnO nanoparticle is 3.37 eV and the energy of bonding is 60 meV (Ravichandran et al. 2020). The low toxicity and high UV-absorption feature make it easily usable in the field of bio-medical. ZnO is generally known as having good resistance to various microbes. As a result, it is hugely used for different purposes like the delivery of genes and drugs, biological sensing, nanomedicine, and biological labeling.

B. Motivation for the study

For making synthesis and characterization of such nanoparticles the compound name comes out as Zinc Oxide. This compound is the material of wide gap semiconductor very well satisfying the mentioned needed elements. Besides possessing many versatile resources, ZnO has also been used in its polycrystalline for hundreds of years in a huge range (Roy et al. 2021). The present study related to the synthesis and characterization of ZnO nanoparticles and its utilization by the method of sol-gel is the main focus. At present ZnO become one of the most considered elements having interesting characteristics for sensing applications in the synthesis of nano range.

C. Objectives of the study

In this study of synthesis and characterization of ZnO nanoparticles and their utilization by the method of sol-gel, the main objectives are

- To analyze the application of ZnO by the sol-gel method

- To identify the charismatic of ZnO nanoparticles
- To investigate the crystalline nature of ZnO

II. Synthesis of ZnO Nanoparticles

A. Materials and methods

The synthesis of ZnO nanoparticles can be expressed by two methods. Every method has some advantages in the techniques while accepting limitations from the others. The first method is the 'Bottom Up' process and the second one is the 'Top Down' process. In the Bottom Up method, the main regulating parameters are chemical composition, morphology, size of the particle, and colloidal aggregation (Sadiq et al. 2021). On the other hand in the process of Top Down, there are huge objects which are converted by giving smaller characteristics such as nanoimprint, mechanical polishing, film deposition and growth etc. The main cause of changes in various thermal, mechanical and other characteristics is due to an increase in the ratio of surface to volume.

B. Synthesis process

The synthesis process of ZnO nanoparticles is done on the basis of three strategies that are Liquid-phase synthesis, Vapour-phase synthesis, and Gas-phase synthesis. In the Liquid-phase synthesis process, some techniques like template synthesis, microwave synthesis, micro-emulsions, processing of sol-gel and solve-thermal synthesis are used. In the process of vapor synthesis flame spray pyrolysis, flame synthesis, and chemical vapor synthesis procedures are used (Thi et al. 2020). Saturation is accomplished by vaporizing elements into a culture gas, then the cooling process is done by the method of Ion Sputtering, Spark Discharge creation, and Condensation of Inert gas.

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C. Characterization techniques

Nanoparticles of ZnO have been produced by the use of wet chemical techniques and are also characterized by XRD, TEM, SEM, Absorption of UV- vis, SAED and spectroscopy of photoluminescence. The studies on XRD and SEM established the microstructure for the arranged nanoparticles of ZnO (Ameen et al. 2021). On the other hand, the SAED structure is made up of bright rings with preferential direction for nanocrystals in place of random direction. From the UV-visual spectrum, the estimated approx size of the ZnO nanoparticle is found to be 2.2 nanometers.

III. Characterization of ZnO Nanoparticles

A. Structural characterization

1. Scanning electron microscopy (SEM)

SEM gives morphological inspection with direct observation. This technique is based on electron microscopy over different advantages in size analysis. SEM gives limited data about the distribution of size. For the characterization of SEM, the solutions of nanoparticles should be transformed into dry powder (Chaudhary et al. 2019). After that, it is attached with a holder which is coated with conductive metal like gold. Then the sample is focused with electron beams. As a result, the nanoparticles must be capable of resisting a vacuum. The resulting size is comparable with outcomes acquired by dynamic scattering of light.

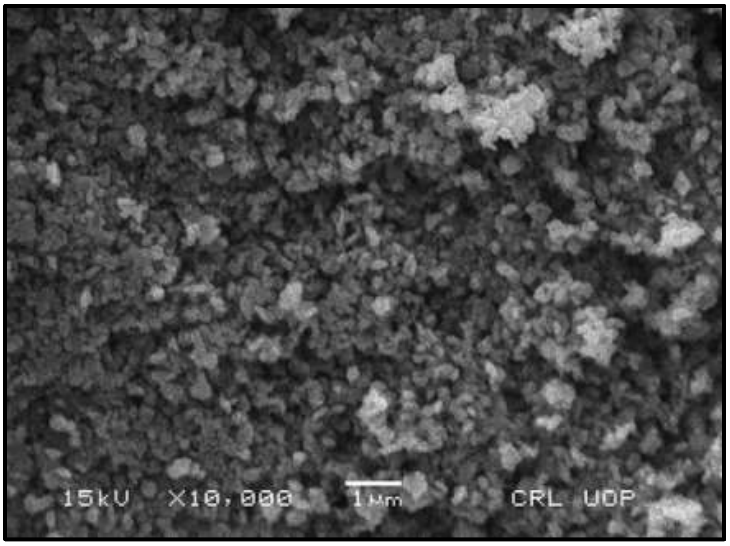

Figure 2: SEM analysis of ZnO nanoparticles

(Source: Chaudhary et al. 2019)

2. X-ray diffraction (XRD)

Nanoparticles of ZnO were successfully synthesized by a common process using tetramethylammonium hydroxide and zinc acetate. The characteristics of ZnO nanoparticles were synthesized by diffraction of X-Ray inspection (XRD). The result of XRD disclosed a structure for the nanoparticles of ZnO which is hexagonal (Pillai et al. 2020). For the inspection of X-Ray diffraction Williamson-Hall (W-H) and Size-Strain Plot (SSP), techniques are inclined to analyze the result of crystallite shape on the peak of ZnO particles.

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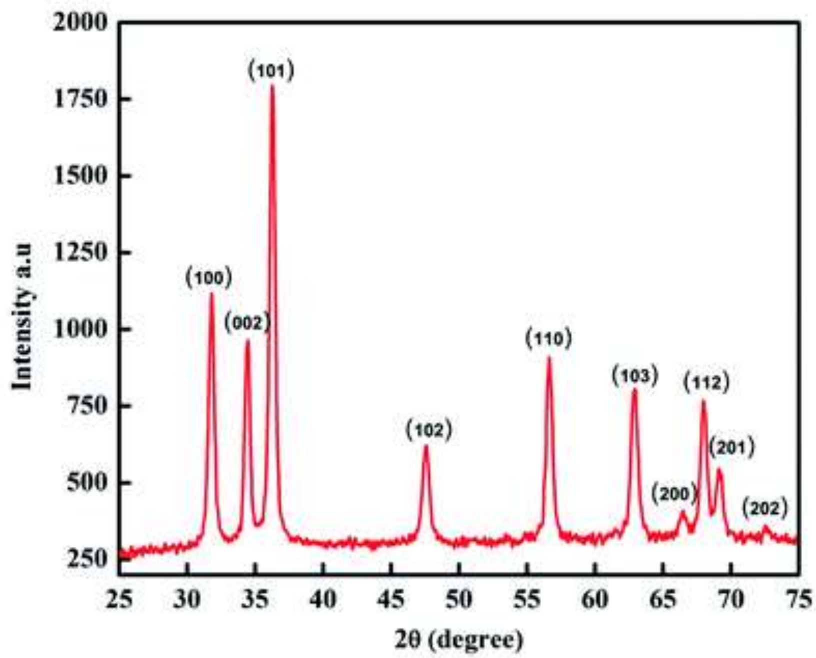

Figure 1: XRD pattern of ZnO nanoparticles

(Source: Pillai et al. 2020)

3. Transmission electron microscopy (TEM)

The Transmission electron microscopy (TEM) characteristics of ZnO particles prove that the nanoparticles are hexagonal in size with a variation of slight in thickness and it gives support to the observation of scanning electron microscopy (Jayachandran et al. 2021). The mean size of the particle by histogram was found to be 50-200 nanometers. These results disclose that maximum ZnO nanoparticles are hexagonal in size with a mean particle size of 100 nanometers.

B. Optical characterization

1. UV-Vis spectroscopy

UV-visual spectroscopy was directed to confirm the biogenic synthesis of ZnO particles. For this crucial inspection, the component was dissolved into water. The range of wavelengths of UV-visible lies between 200 nm to 800 nm (Ahmad et al. 2021). The top peak was confirmed at 356 nm with the presence of nanoparticles of ZnO in the admixture. This investigation was executed for the extract of the plant and the outcome showed different peaks at several wavelengths that range from 200n to 500 nm. This extract is found along with protein, Starch and molecules of antioxidants. These molecules are responsible for the minimization of zinc metal salt to create ZnO particles.

2. Photoluminescence spectroscopy

Photoluminescent ZnO particles are an increasing class of nanoparticles with the feature of unique optical properties. This is an advantage of being eco-friendly and non-toxic. Zinc oxide has photoluminescence radiation in the ultraviolet and visible regions. It depends on the synthesis routes, deep level, surface defects, size, and shape. When conjugated with the nanomaterials of carbon compounds, the transformation of surface defects in zinc oxides permits the tuning of those photoluminescence characteristics to produce (Ma et al. 2019). However, sufficient transfer of energy from ZnO to carbon nanostructure turns them into suitable elements not only in harvesting energy but also in low-temperature thermal imaging, biosensors, and photodetectors.

C. Other characterization techniques

1. Fourier transforms infrared spectroscopy (FTIR)

FTIR is always termed as one of the most powerful tools in the determination of organic compounds. Fourier transform infrared spectroscopy is a technique of characterization that is used to determine the functional groups which are present in the element. The FTIR series of photo-fabricated zinc nanoparticles in the wavenumber lies in the range of 500-4400 cm-1 (Fakhari et al. 2019). The characteristics absorption is used for the recognition of chemical structures along with chemical composition. Among the methods, Layered Double Hydroxides (LDH) is a fast technique.

2. Raman spectroscopy

Zinc Oxide is a semiconductor with a hexagonal structure. It is an important spectroscopy due to the remarkable admixture of its structural, electronic, optical, and morphological properties. ZnO has a direct band gap of 3.37 eV and notable exciton energy of 60meV including proper thermal solidity. ZnO Raman spectroscopy makes it possible to determine the quality of high crystal along with the limitations such as zinc excess, surface impurities, and oxygen vacancies (Korepanov et al. 2019). Raman spectra reveal a peak commonly detected for big ZnO crystals and this process also authorizes the recognition of large monocrystals.

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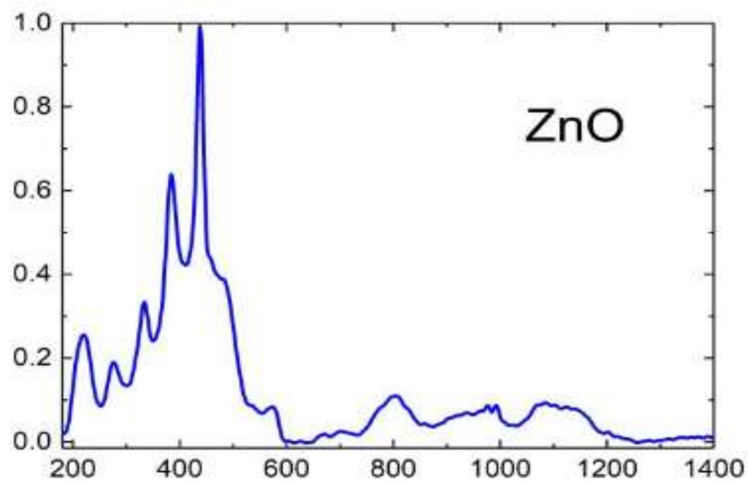

Figure 3: Raman shift

(Source: Korepanov et al. 2019)

IV. Applications of ZnO Nanoparticles

A. Antimicrobial activity

The antimicrobial activity of ZnO nanoparticles has obtained remarkable interest all over the world especially in the application of nanotechnology to synthesize elements in the region of nanometers. Several microorganisms are alive in the range from 100 nm-10 mm. ZnO particles reveal many antibacterial characteristics as a cause of expanding particular surface area. Nanoparticles of ZnO are an organic element that accesses photo-oxidizing and photocatalysis influences biological and chemical species (Lallo da Silva et al. 2019). Significant emphasis was specified on bacteriostatic and bactericidal techniques with the aim of creating Reactive Oxygen Species (ROS) along with hydrogen peroxide (H2O2). It is considered a main factor for different techniques along with the damage to the cell wall, increase in the permeability of membrane and assimilation of toxic Z ions.

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Material	Size (nm)	Bacterial species	Antibacterial mechanism
ZnO nanoparticles	30	E. Coli	Destroy the integrity of membrane
Ag- ZnO composite	65	S. Aureus	ROS and the discharge of Ag ion and Zn ion
Ge - ZnO nanoparticles	20	P. aeruginosa	Caused death of bacterial cell
ZnO nanoparticles	Less than 80	V. cholera	Damage of DNA and creation of Ros

Table 1: Antibacterial effects of ZnO nanoparticles in several bacterial species

(Source: Lallo da Silva et al. 2019)

B. Photocatalytic activity

A superficial green route has been engaged for the combination of ZnO and silver-doped ZnO as a reducing agent. The nanoparticles which are doped in arsenic were characterized as examined for photocatalytic degradation and antimicrobial activity (Uribe-López et al. 2021). This outcome indicates that nanoparticles of ZnO have shown the activity of antimicrobial against various human pathogenic bacteria like Salmonella typhi, MRSA, E-coli and others. Nanoparticles that are doped in silver (Ag) have shown comparatively better removal of methyl orange and congo red under the spectrum of visible light.

C. Sensor applications

Having interesting properties at present, nanoparticles of ZnO are termed as good material for highly sensitive and selective gas elements. Therefore nanoparticles of ZnO are widely used for gas sensors for the identification of several harmful and toxic gasses. Gas-sensing features like a tone of response, stability, and limit of detection are also engaged with it. Basically, there are two functions of a gas sensor like a transducer function and a receptor function (Shetti et al. 2019). The transducer function turns the chemical signals into electrical and the receptor function consists of the identification of the chemical substances. The gas-sensing characteristics of ZnO are influenced by its crystal defects. The sensing performance of this gas has been found greatly to be reliant on the size of the nanoparticles.

D. Other potential applications

There are huge applications of nanoparticles of ZnO in biomedical fields as a cause of low cost and low toxic elements. The application of ZnO particles are in the field of biomedical areas such as anti-inflammatory activities, antioxidant, antidiabetic, and anticancer along with drug delivery and bio-imaging. The movement of mitochondria electrons is also connected with the creation of ROS. Nanoparticles of zinc are present in cancer cells based on a large intracellular discharge of zinc ions that can cause the death of cancer cells (Mohd Yusof et al. 2019). Nanoparticles of ZnO with a size of 100 nm are termed to be approximately biocompatible that supports their biomedical implementation and differs a strong property to promote biomedical research.

V. Conclusion

A. Summary of the study

ZnO nanoparticles have been composed for the use of chemical synthesis techniques and were characterized by SEM, TEM, UV-vis absorption, XRD, SEAD, and Photoluminescence spectroscopy. The analysis of SEM and XRD accessed the nanostructures for the synthesis of ZnO nanoparticles. SAED structure includes uniform rings that are bright indicating the preferential direction for nanoparticle intakes of continuous direction. The synthesis nanoparticles of ZnO are in the size of 2.2nm for peak absorbance wavelength. This article can be used in several industrial applications such as fluorescent tubes, luminescent elements, gas sensors and others.

B. Implications and significance of the study

ZnO nanoparticles are used in a huge number of industrial and medical fields. This is to promote contribution in the biomedicine field which is also engaged with their capability to keep the structural unification. However, nanoparticles of zinc oxide have luminescent characteristics and have transformed them into bioimaging. In this study, the synthesis and present advances of ZnO particles are summarized which will be helpful for expediting future research works.

C. Future research directions

Nanoparticles of Zno are enlisted as one type of safe element by the FDA. This study is focused on the synthesis and characterization of ZnO nanoparticles and their application by the sol-gel method. However some crucial issues such as the limitation of ZnO nanoparticle toxicity towards biological fields are still a disputed issue in the current study. Also the lack of information on randomized research with the exploration of the therapeutic role in curing many diseases is

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observed in this study. Nanoparticles promote the growth of medicine and are expected to create more useful contributions in this field.

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