© September 2024 | IJIRT | Volume 11 Issue 4 | ISSN: 2349-6002

Synthesis Characterization and Chemical Properties of Pure and Doped ZnO Nanoparticles and Its Applications

RENUKA THAKUR[1], DR. S. K. UDAIPURE[2], DR. ARUN SIKARWAR[3]
[1]*Research Scholar, Govt Narmada College, Narmadapuram*
[2]*Supervisor, Professor, and Head, (Department of Chemistry) Govt Narmada College, Narmadapuram*
[3]*Co – Supervisor, Professor, and Head, (Department of Chemistry) Govt. Homescience P. G. College Narmadapuram Govt. Narmada College, Narmadapuram*

Abstract— Nanoparticles are extremely fine particles of matter ranging from 1 to 100 nanometres. ZnO is taken as one of the thir most formed nano-structured materials. Zinc oxide nanoparticles have diameters in the range of 1-100 nanometres. ZnO nanoparticles bear a great surface-area-to-size ratio. The most appealing and attractive element in research field is preparation of nanoparticles with specialized properties. Because of unique properties of metal-oxides of nanoparticles achieve great consideration in research areas. The XRD analysis results exposed that the synthesized nanoparticles have a hexagonal wurtzite structure.

Index Terms- Nanoparticles, Synthesis, Chemical Properties, XRD

I. INTRODUCTION

Nanomaterials are particles, either crystalline or amorphous, that have sizes ranging from 1-100 nm (nanometer). These materials can be categorized into nanostructured materials and nanophase or nanoparticle materials. Nanostructured materials refer to condensed bulk substances composed of grains with sizes within the nanometer scale, while nanophase or nanoparticle materials are typically dispersive particles. To differentiate nanomaterials from their bulk counterparts, it is crucial to highlight the distinctive properties of nanomaterials and their potential influence on scientific and technological advancements. Nanomaterials have garnered noteworthy attention for their applications in wastewater treatment. They have been so effectively used to target and remove various toxins, including heavy metals (Tang et al., 2014), organic pollutants (Yan et al., 2015), inorganic anions (Liu et al., 2014).

Zinc oxide is an inorganic compound with the formula ZnO. It is found in the form of mineral zincite in the earth's crust. Zinc Oxide (ZnO) is a undertaking candidate for potential role in different fields in this era. at the time was on bulk samples, including subjects such as growth, doping, deep center, band structure, etc. ZnO is insoluble in both ethanol and water but dissolves in dilute mineral acids. It is a fine powder, white and slightly yellow. ZnO with high purity is used in the pharmaceutical, food, and cosmetics industries.As ZnO presents intermediate properties between acid and basic oxide. It is relatively inexpensive, presents low toxicity, and is very effective in protecting against UV rays. ZnO has a 3.37 eV band gap at ambient temperature, corresponding to close ultra-violet region. Because of this large band gap energy, pure ZnO is colorless and transparent. An interesting property of ZnO is that even without introducing impurities, it appears naturally conductive when it is missing oxygen atoms. Sunscreens enclosing metal-oxide NPs appear translucent on the skin and provide exceptional protection against sunburn caused by UV radiation. Megan J. *et al* (2010) Doping is a method which is widely used for the modification of nanoparticles to improve their electrical, optical, and biological activities. It's been used from some previous studies that doping may increases the antimicrobial effect. K. Rekha, *et al.* (2010). Mn doping in ZnO nanoparticles by the sol-gel method allows for controlled modifications of structural, optical properties. The existence of Mn can improve the photocatalytic properties of ZnO nanoparticles, making them more effective for environmental remediation applications such as the degradation of pollutants. Gültekin, Z. et al., (2023) Cobalt doping in ZnO nanoparticles via the sol-gel method significantly enhances their photocatalytic, structural, optical, magnetic, and antibacterial properties, making them highly versatile for various advanced applications. The sol-gel method provides a controlled and cost-effective approach to synthesizing these doped nanoparticles with tailored properties for specific needs. K. Chehhat, *et al.*, (2023). El Ghoul, et al., (2015). Michele Karoline Lima, *et al.*, (2014). Singh, N.K. *et al.*, (2019). Silver doping in ZnO nanoparticles synthesized by the sol-gel method leads to enhanced structural, optical, photocatalytic, antibacterial, and electrical properties, broadening the scope of ZnO applications in various fields. Chauhan, R.*et al*., (2012).

II. MATERIAL AND METHODS

Zinc Acetate Dihydrate-$Zn(CH_3COO)_2.2H_2O$ ≥99% purity,Zinc Nitrate, $Mn(CH_3COO)_2.2H_2O$, $Co(CH_3COO)_2.4H_2O$, $AgNO_3$ sodium hydroxide solution - (NaOH) ≥98% ('Sigma Aldrich'), Ethyl alcohol (C_2H_5OH) and deionized water.

To synthesis pure ZnO nanoparticles involves a well-defined and controlled process to achieve nanoparticles with precise characteristics. A suitable precursor compound, such as zinc acetate or zinc nitrate, is initially dissolved in a solvent. This solution is subjected to a controlled temperature and reaction time, which are key factors in the determination of size, morphology, and composition of the resulting nanoparticles. Typically, a base, such as sodium hydroxide or ammonium hydroxide, is added to initiate the precipitation of ZnO nanoparticles from the precursor solution. The reaction mixture is then carefully stirred and maintained under specific environmental conditions to facilitate the formation and nucleation of ZnO nanoparticles. Finally, the synthesized nanoparticles are separated, washed, and dried to get the pure ZnO nanomaterial.The preparation of pure ZnO nanoparticles is accomplished using a well stated and controlled process to achieve nanoparticles with precise characteristics.

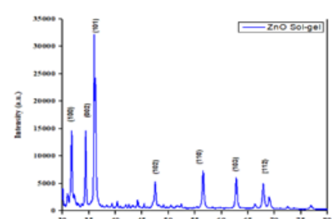
Once the desired particle size and morphology are achieved, the synthesized ZnO nanoparticles are precipitated from the reaction mixture. This is typically achieved by centrifugation or filtration to separate the solid nanoparticles from the solution. To remove any residual impurities or unreacted reagents, the separated nanoparticles are washed multiple times with a suitable solvent, followed by drying to get the pure ZnO nanomaterial.

These reactions illustrate the conversion of the primary compounds into ZnO nanoparticles through controlled precipitation and subsequent conversion of zinc hydroxide intermediates for different use cases. The synthesis of pure ZnO nanoparticles involves a meticulously designed process with careful selection of precursor compounds, precise control of reaction parameters, and the understanding of chemical reactions leading to the formation of ZnO nanoparticles with tailored properties..The synthesis of pure ZnO nanoparticles is a meticulously controlled process, involving precise quantities of reagents, temperature, pH, time, and controlled environmental conditions. This synthesis method is crucial for achieving nanoparticles with tailored characteristics for various applications in nanomaterials science. David Levy *et al*., (2015); Hench, Larry L. *et al*., (1990); Sakka, *et al*., (2005).

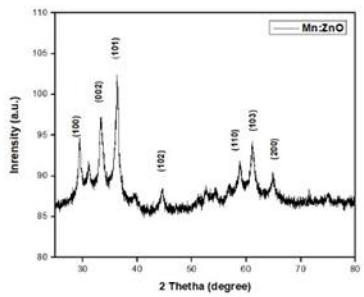
III. CHARACTERIZATION

The pure zinc oxide nanoparticle & doped zinc oxide nanoparticles have been synthesized and characterized using XRD.

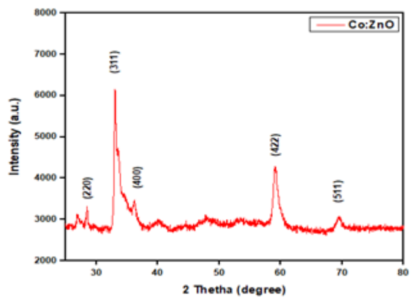
X-ray diffraction is the significant technology for material characterization. The XRD data could be used for calculating a substantial amount of information. The appropriate technique for all samples for all samples e.g. materials, including bulk, thin film, and powder. By means of such technologies, one may receive information on the crystalline nature of a material, the type of the phase present, lattice parameter, and particle dimension. D. Liu et al., (1995).



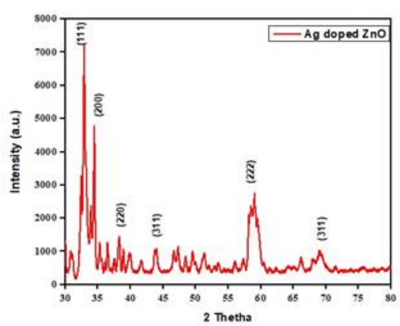
(a)



(b)



(c)



(d)

Figure: a) pure ZnO nanoparticles, b) Mn doped ZnO nanoparticles, c)Co doped ZnO nanoparticles, d) Ag doped ZnO nanoparticles

In recent studies, pure and (Mn, Co, Ag) doped-Zinc oxide NPs are prepared via the Sol-gel method. The pure and doped Zinc oxide NPs were characterized by XRD.. The 'XRD patterns' of Ag-doped Zinc oxide nanoparticles prepared via the sol-gel method are shown. The sharp and intense peaks indicate that the samples are highly crystalline and it has polycrystalline structure. The 'XRD pattern' of undoped & Ag-doped zinc-oxide nano-structured particles recorded in range of 20^0- 80^0, with a scanning step size of $0.02^{0.}$ it is found that all the major diffraction peaks can be perfectly indexed with the hexagonal wurtzite structure of ZnO (Lattice: Primitive, space group: P63mc (186); a = 3.2539 Å, c = 5. 2098 Å). In this pattern some peaks have low intensity. The data obtained agree with the joint committee on powdered standards (JCPDS) card for ZnO (JCPDS card no: 01-080-0075). The peaks were detected at 2θ values are 31.70, 36.21, 47.47, 56.51, 68.61 corresponding to the following lattice (hkl) plane: (100), (101), (102), (110), (201) respectively.The silver doped samples indicate some additional peaks of diffraction associated with the FCC phase of metallic silver (JCPDS reference no. -3\ITC\RG, 01-087-0597). The appearance of silver peaks in the diffraction pattern indicates the formation of crystalline silver clusters in the nanoparticles lupan, *et al.* (2010) . For Cobalt doped ZnO the 'XRD' peaks planes are (220), (311), (400), (422), (511) planes. The average size of pure ZnO is 25.77nm, 40.32nm, 22.42nm, 19.32nm, 24.13 nm. The values of a, b for cobalt-doped Zinc oxide NPs values are close to JCPDS car no.- 01-89-7094. The average particle dimension is '*manganese-doped ZnO'* is 23.34 nm, 20.45 nm, 23.31 nm, 13.99 nm,23.36 nm. The usual crystalline size of Manganese doped nanoparticle is decreased due to doping. The decrease of crystal size subsequently increases the band gap. The diffraction peaks at 2θ (degree) of 31.16, 36.3, 47.2, 56.73, 68.61 are respectively indexed to (211), (220), (320), (331), (422) planes of manganese doped ZnO. Its average particle size is pure ZnO is 25.77 nm, 40.33 nm, 23.29 nm, and 22.41 that causes the red-shift of the absorption band_(elangovan *et al*., (2015**).** The diffraction peaks at 2θ (degree) of 31.70, 36.21, 47.47, 56.51, and 68.61 are respectively indexed to (100), (101), (102), (110), (201) planes of ZnO.

Chemical properties

The chemical properties of Zinc oxide (mineral zincite)is usually based on a definite amount of manganese and other elements which is of yellow to red color. The crystalline zinc oxide is thermochromic, transforming from white to yellow when heated and reverting to white when cooled. This colour shift occurs by a very slight loss of oxygen at higher temperatures, resulting in non-stoichiometric ZnO.

$$ZnO + 2HCl \longrightarrow ZnCl_2 + H_2O$$

Bases further dissolve the solid to produce soluble zincates:

$$ZnO + 2NaOH + H_2O \longrightarrow Na_2(Zn(OH)_4)$$

It combines with hydrogen sulfide to produce the sulfide. This reaction is employed commercially in eliminating H_2S utilizing ZnO powder. (For example: deodorant)

$$ZnO + H_2S \longrightarrow ZnS + H_2O$$

When ointments (creams, lotions) containing ZnO along with water are melted and placed under UV light, they form hydrogen peroxide. (Porter 1991).

Applications

The applications of this study are based on certain points:
Development of synthesized nanomaterials has immense advantages because morphologically, nano-materials exhibit extraordinary properties. The optical emphasis on pure and doped Zinc-oxide NPs using the UV-visible spectrum is determined by the Tauc plot. The impact regarding UV-rays have a considerable impact on our daily lives & environment. The formation of efficient UV protecting agents having enormous significance to the community. Zn-oxide are most efficient UV protecting agent. The study of reduction of photo-activity as a result of outer layer alteration and doping. Zinc-oxide nanoparticles after doping could be a convincing photo-catalyst regarding water & ecological decontamination.

CONCLUSION

The XRD analysis results exposed that the synthesized nanoparticles have a *hexagonal wurtzite structure*. The studies suggest the size of the crystal of ZnO varies when Manganese is introduced. The average crystalline size is 20.33nm. The inclusion of Mn^{2+} is evidenced by the shrinkage of the atomic arrangement of prepared nanoparticles. The structural studies of Cobalt-doped ZnO nanoparticles shows the crystal-size varies in contrast with pure Zn-oxide as a result of *doping*. The approximate grain size is lying in the range of 22.49nm- 25.77nm. The Ag peaks appear in XRD form clearly directed, if the silver clusters are formed in doped ZnO nanoparticles.

ACKNOWLEDGEMENT

First and foremost, praises and thanks to the God, the Almighty, for his showers of blessings throughout my research work to complete the successfully.

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