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A Review of Synthesis Methods and Applications of Zinc Oxide Nanostructures

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مراجعة لطرق تصنيع وتطبيقات هياكل أوكسيد الزنك النانوية

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ABSTRACT

In this review, the methods of synthesis and applications of zinc oxide nanoparticles (ZnO NPs) were presented for the period from 2002 to 2024. Zinc oxide (ZnO) has a high economic value because of its inexpensive cost, natural availability, environmental friendliness, simple manufacturing process, and so on. ZnO has developed novel laser and optoelectronic device approaches that will increase the density of data storage and the speed of optical communication recording. Because of the changes in mechanical, chemical, and optical properties with decreasing size, that is generally assumed to arise from quantum confinement effects who is scale-dependent, there is a lot of research going on with ZnO, particularly in the area of nanotechnology. Low defect density ZnO nanostructures might be useful. Because their stress may be successfully regulated via flexible relaxation on free-side surfaces rather than plastic relaxation, nanostructures are more likely to generate faultless structures than epilayers.

***Keywords**: Nanostructures; Zinc Oxide, Synthesis; Characterization and Application*

INTRODUCTION

Zinc oxide nanostructure is considered one of the important semiconductor materials used in various important industries. The results of research show that as-prepared Zn/O nanorods with sizes ranging from (10:60) nanometers and lengths ranging from one to three meters are produced by using thermal decomposition on the precursor [1]. The report in 2003, One-dimensional single crystal Two-step condensation considered a unique process used depending on ZnO nanorods grown on sub/strata in a water-based solution at an alluringly low temperature of 90C° [2]. ZnO nano-rods with a diameter of approximately 45-nm may be successfully produced, allowing for large-scale manufacturing at a low cost and possible use in optoelectronic nanodevices as shown in [2, Fig.1] and figure 2 the images from transmission electron microscope (TEM) and scanning electron microscope (SEM).

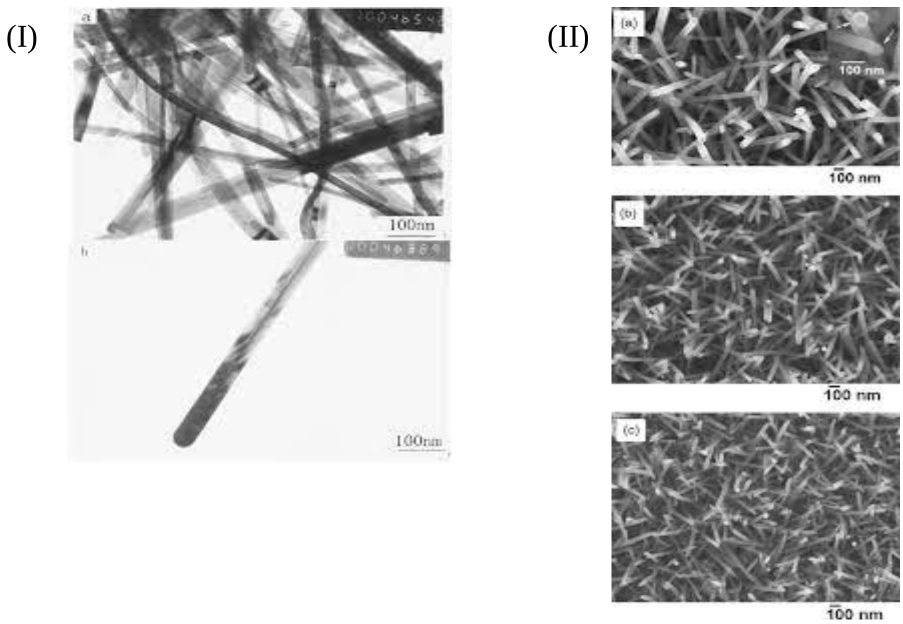

Figure 1. (I) TEM image of the ZnO nanorods [1]. (II) SEM image of ZnO nanorods .

ZnO nano- combs, nano-rings, nano- helixes, nano- springs, nano-belts, nanowires, and nanocages were created under particular growth conditions using a solid-vapor phase thermal sublimation process. The nanostructures have the ability to be useful in sensors, transducers, optoelectronics, and biomedical sciences [3].

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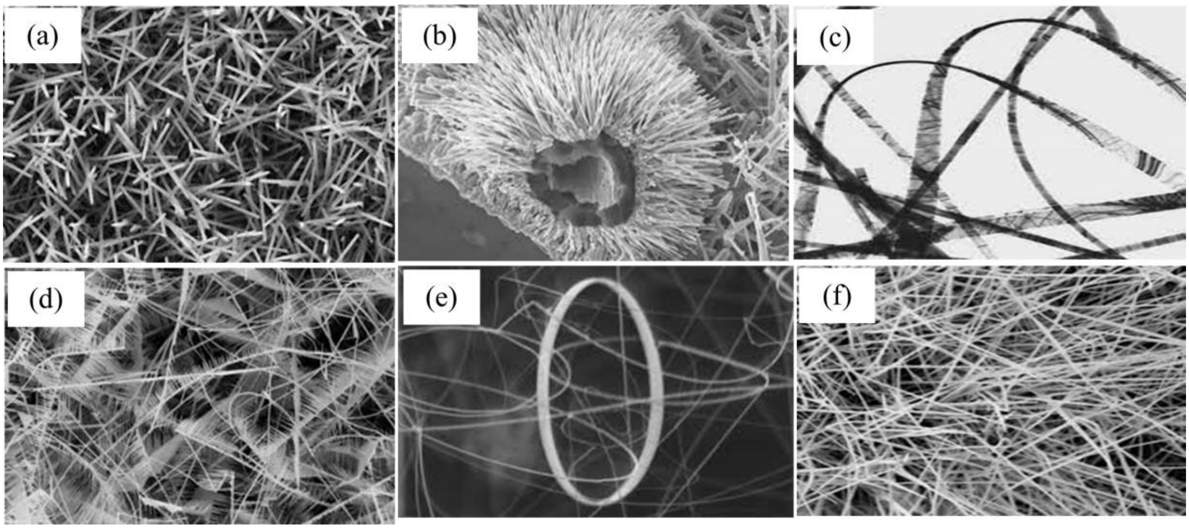

Figure 2. Illustrates (a) SEM image ZnO Nanorods. (b) SEM image ZnO Nanowires. (c) TEM image ZnO nanobelts. (d) SEM image ZnO like nanocombs. (e) TEM image ZnO nanorings. (f) SEM image ZnO Nanobelts.

zinc oxide nanorods were synthesized at an average size of 50 x250 nm, and they were processed hydrothermally while cetyltrimethylammonium bromide (CTAB) was present. Zinc oxide nanorods were produced after five hours at 120 °C, with $ZnCl_2$ and KOH expected to be the starting materials. According to an analysis, while the PL spectra did not generally differ, the zinc supply and reaction temperature impacted the end products' morphologies and absorption characteristics [4].

A novel sort of flower-like ZnO was created on a big scale in a reasonably clean ethanol environment using a very easy solvothermal process [5]. The nanoflowers are made up of several hexagonal-structured ZnO nanosheets that are very thin and homogeneous, with a thickness of around 6 nm, as shown in [5, Fig.3].

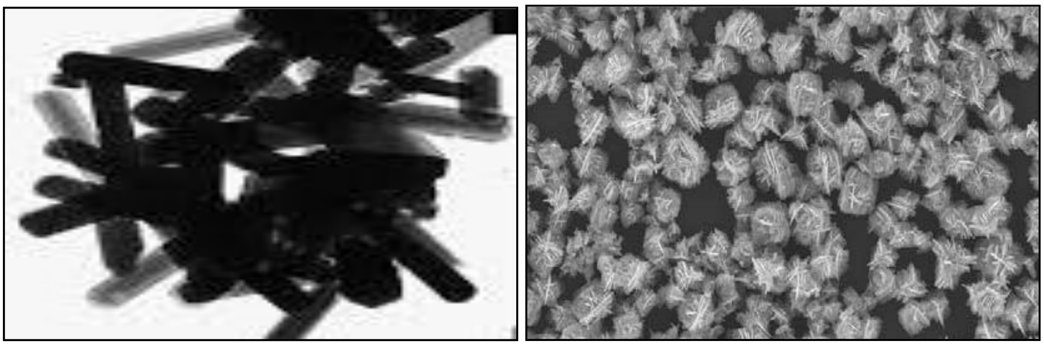

Figure 3. Illustrates (a) TEM image ZnO nanorods [4]. (b) SEM image ZnO nanoflowers.

metal-organic chemical vapor deposition was utilized to create Zinc oxide thin films coated on fused quartz [6]. The band gap of as-grown zinc oxide blue increased from (3.13 - 4.06 eV) therefore, decrease processes that occur on the growth temperature from (500 °C- 200 °C). In samples deposited at low

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temperatures (less than 450 °C), amorphous and crystalline phases were discovered. ZnO nanoparticles was produced in ethanolic solution using a sol-gel technique [7]. XRD analysis demonstrates that the nanoparticles have the hexagonal wurtzite structure and the particle size is increased after annealing. Due to quantum confinement effects, the absorption peak of the annealed nanoparticles is blue shifted compared with bulk material. The yellow and green emissions were observed in the visible region for the as-prepared and annealed samples, respectively as shown in [7, Fig.4]

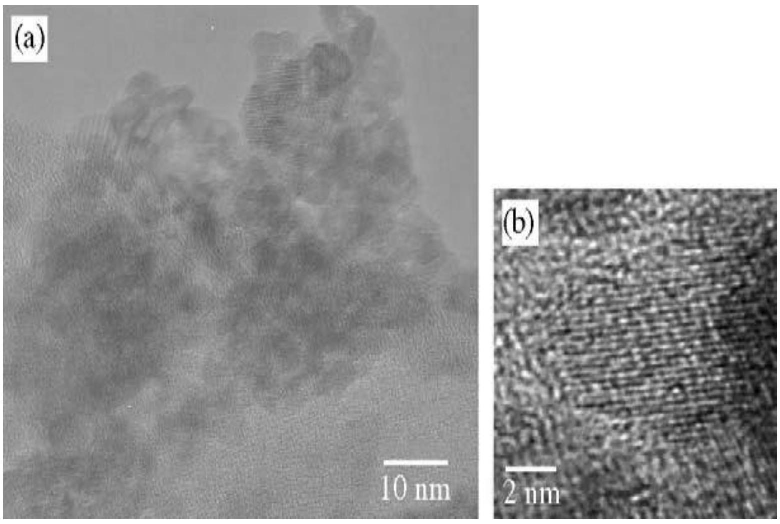

Figure (4, a, b): Show the TEM image of nanocrystalline ZnO NPs .

ZnO nanocrystals were synthesized from microwave irradiation, by using Zn (II) acetate and triethanol amin (TEA) as primary materials and water solvents. According to the findings, ZnO nanoparticles were made of a hexagonal wurtzite phase with exceptionally high crystallinity [8]. The measured particle size ranged from 35 to 45 nm. A group of researchers they tried to regulate the growth temperature and precursor concentration so that stable OH-free zinc oxide (ZnO) nanoparticles could be produced using a hydrothermal approach [9]. The findings showed that the nanoparticles had a hexagonal wurtzite structure and that there is a connected relationship between the particle size and temperature rise and decrease with precursor concentration. An optical characterization process was used to analyze the band gaps and optical constants of crystalline and non-crystalline ZnO thin films generated by spray pyrolysis onto glass substrates at varied deposition periods [10]. The study found that the film structure varied from non-crystalline to crystalline as the deposition time increased. The direct optical band is unaffected by film thickness; however, it does change the index of refraction, dielectric constants, extinction coefficient, and Urbach energy gap of the films. Zn/O nanowires were created on conductive glass substrates using a solvothermal technique for dye-sensitized solar cells (DSCs) in 2008 [11]. They also demonstrated that the divaricate Zn/O nanowire DSCs had twice functions at 4.27 mA/cm2 and 1.51%, respectively, evaluate the bare Zn/O nanowire's energy conversion efficiency and short-circuit current density. Hexagonal Zn/O micro and nanorods were fabricated using the hydrothermal solution approach in 2008[12].

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At 95Co, Zn/O rod products have a higher aspect ratio than those grown at 60°C. The results showed that temperature increase, total precursor concentration, and deposition time all had an effect on the morphology and ordering of Zn/O nanorods. When compared between volume ratio and morphology of zinc oxide nanorods, demonstrate the most responsiveness to bath temperature. So, by reducing the reactants or raising the temperature from 60Co to 95Co, it may decrease the size of Zn/O microrods to nano-rods as shown in [11,12, Fig.5]

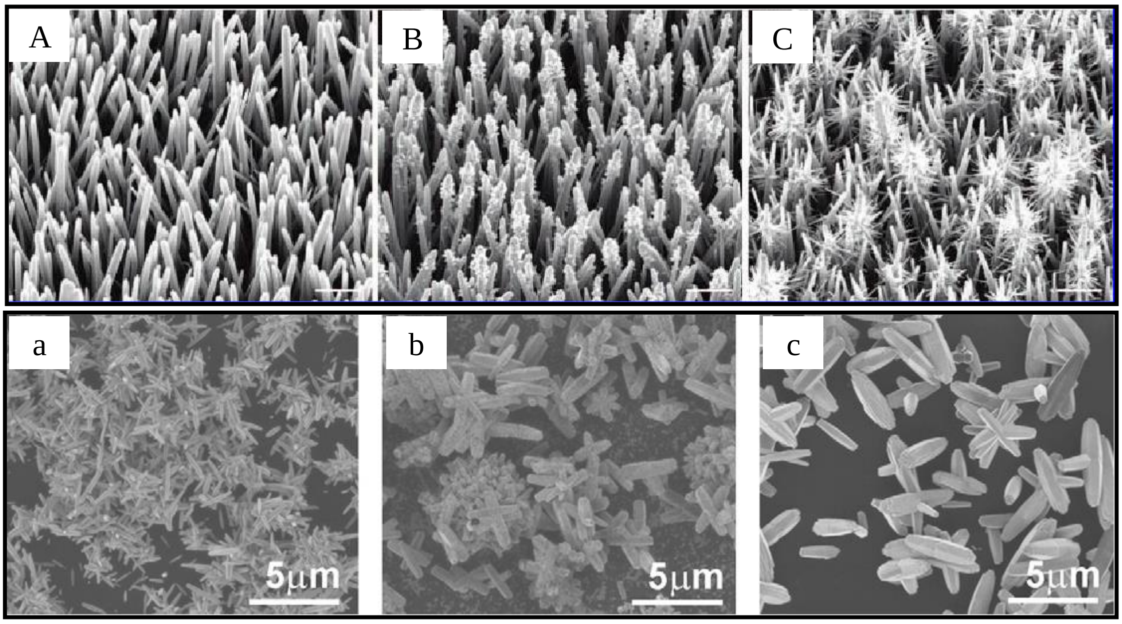

Figure 5. Upper part shows the SEM images of the zinc oxide nanowires before and after recoating. The lower part of the SEM images shows the zinc oxide nanorods under the influence of different temperatures, 95^o, 75^o, and 60^o , respectively.

Zn/O nanorods were produced under particular growth condition. The combination with favored ratio 1:25, Zinc Acetate and Sodium Hydroxide pellets has been produced by hydrothermally oxidizing zinc metal for a whole day at 120 degrees Celsius in 2008 [13]. Zn/O nanorods with sizes ranging from 50 to 150nm were produced. A homogeneous phase technique was used to create Zn/O nanoparticles from sodium hydroxide and zinc chloride at high temperatures in 1, 2-ethanediol or water in 2008 [14]. Smaller nanoparticles are produced by the reaction in 1, 2-ethanediol at 150 C^o than by the reaction in water at 90 C^o. The nanoparticles in together cases, the Nanoparticales appear to be a very narrow size range and spherical were used as UV absorbers.

A Zn/O nanotube was synthesized in 2008 [15] utilizing transport vapor-phase depended on Zn/O and graphite powder mixation in air. Investigation results pointed to uniform diameter of around 60 nm and a wall thickness of about 10-nm with a wurtzite crystal structure for Zn/O nanotubes. Zn/O was synthesized using a solvothermal process and starting components of Zn $(NO_3)_2.6H_2O$ and NaOH, a new hexangular tube structure of Zn/O in 2009 [16]. The local wall thickness of a tube ranges from (100-nm to 150-nm). Zn/O rods may form tubes due to strain between the surface and the inner surface. The wurtzite phase of the Zn/O tub emit a green emission centered at 549.8 nm, a broad blue emission at about 448.5 nm, and emits a weak violet emission at about (399.9-nm). hexangular pillars Zn/O nano-rods (tubes, tablets, and tube-structured needles) were manufactured under simply changing solvents among, alcohol, and olefin, utilizing Zn $(NO_3)2$.$6H_2O$ and NaOH as primary substances by using hydro- and solve-thermal methods because an oxygen-rich environment might affect the near-band-edge structure, the violet peak is not visible in samples produced in 2009 [17]. In 2009, one-dimensional ZnO nanorod arrays on single- and poly-crystalline Zn substrates was created. Surface oxidation was executed in a solvent collection of water and 1-propanol, with ammonia employed to achieve the desired pH [18]. This method of producing ZnO NRs allows them to be employed directly in piezoelectric antenna arrays, UV lasers, and field emission devices. Using the concept of chemical potential.

The researchers group developed and manufactured novel mineralizers that prevented and stopped certain impurities from being absorbed into ZnO crystals in 2009[19]. The novel mineralizers synthetize a ZnO crystal with a special electrical property of enhanced carrier concentration in the case of the highest carrier concentration. At 10K temperature, the good quality of the ZnO crystal was formed, loss of visible emission bands in the PL range was acute. Zinc oxide nano: materials were synthesized with a mean particle size of (20-30nm) using a hydrothermal reaction of zinc acetate and oxalic acid in 2009 [20]. The results showed that the fabricated materials are crystalline in nature, and the optical characteristics of ZnO nanoparticles were examined using absorption and photoluminescence spectra. Photoluminescence spectra indicate the high crystallization and purity of ZnO nanoparticles.

Zinc oxide nanoparticles were prepared in 2009 by reacting zinc metal with ethanol at 200°C in a straightforward manner [21]. The nano-particles have diameters ranging from 50 to 200 nanometer, with a mean size of 100 nm. The complex reaction includes the dissociation of the alcohol's C-O bond that happens facilely on the surface of zinc metal. Nano-Rods resulted from ethylenediamine addition to the re-action, with the amine acting as a shape control agent. This simple, reproducible, and low-cost technique should pave the way for large scale synthesis of Zn/O Nano-Structures for a variety of nanotechnology applications in the future. The researchers group reports the simple and economical hydrothermal synthesis of several ZnO nanostructures on the Si substrate with controlled synthesis in 2009 [22]. By adjusting hydrothermal growth parameters, such as the seed layer, solution concentration, reaction temperature, and surfactant, the shape progression of the ZnO nanostructures was closely observed. The shape of the ZnO nanostructures has a critical role in determining the optical characteristics and crystal quality, as demonstrated by X-ray diffraction and photoluminescence experiments. This method has a significant deal of potential for nanoscale applications due to its ease of synthesis and convenience in tuning shape and optical characteristics.

Zn/O nanorods were prepared using a template-free aqueous solution-based simple chemical rout. (A 0.5M zinc nitrate solution was added dropwise to a 1M NaOH solution at room temperature for 15 minutes. 3 hours were spent stirring) in 2009 [23]. The nanorods created emit light at 421 nm (violet). This emission is induced by electron recombination at a hole in the valance band and the Zn interstitial, and it is supported by a few weaker defect states created by many

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oxygen vacancies. As a result, it contributes to our understanding of ZnO nanostructures and might be utilized to investigate possible applications in optoelectronic devices, nano-photonics, lasing, and luminescence. Zn/O nanocrystals were prepared using the Solvothermal technique at 80C^o in 2009 [24]. The zinc source was zinc acetate dihydrate. The sizes of the produced Zn/O nanoparticles prepared in ethylene glycol are 68.1±7 nm. The diameter and length of the Zn/O nanorod were 8.2 ± 2nm and 54.3 ± 11nm, respectively.

In 2010, Zn/O nanorods were prepared, hexagonal shaped zinc oxide was obtained at low operating temperatures, utilizing metallic zinc foil and de-ionized water with a few drops of ethanol. Zn/O nanorods have a size of 50-60 nm with 1 micrometer in length. The grown generated products have hexagonal crystallinity in wurtzite and are pure Zn/O [25]. In 2010 Zn/O nanorods with diameters of 80 nm-1200µm and lengths of several micrometers on various substrates were prepared used chemical bath deposition to create uniformly distributed [26]. The size of the ZnO nanorods on the various substrates may be varied by adjusting the growth conditions. The ZnO nanorods' morphology changed from rods to wire or pie. These types of structures are useful in laser and solar cell applications due to research on the growth properties of ZnO on various substrates.

In 2010, ZnO nanostructures were prepared by thermally evaporating Zn and ZnO precursors in a tube heater to synthesize nanowires, nanospheres, nanorods, tubules, and tetrapod. (Using a mixture of graphite powders and high purity ZnO in a tube furnace). When compared to theoretical and experimental data, the results showed a (High) blue-shift in all morphologies. This blue-shift in (High) is caused by defects and internal strains caused by various growth directions. This research might be very useful in understanding the diverse morphologies of ZnO and their associated growth [27]. In 2010, hexagonal wurtzite rod-like ZnO micro-nanostructures were prepared used a solvothermal supported heat action method to make. The prepared material exhibit stability and better photocatalytic activity in the degradation of organic dyes [28]. Zn/O-NPs were created depended on solvothermal technique at a decreased temperature of 150C^o for 18 hours. As a result of its special structure in 2011, TEA (Triethanolamine) was conception as a polymerization agent to control the development of the Zn/O NPs. The experimental results demonstrate that the Zn/O NPs was produced in a hexagonal form with a crystalline range of 33.0±2.0nm. In the UV-VIS region, a strong absorption peak at 370 nm was observed, which translates to a 3.3 eV optical band gap for Zn/O NPs. The Zn/O powder was largely homogenous, and the Zn/O NPs moderate particle size was 48 7 nm, according to the particle size curve. The results support the Zn/O NPs' high quality, making them appropriate for medicinal applications [29]. Zn/O nanostructures were synthesized via microwave-assisted solvothermal synthesis in 2011[30].The beginning materials where zinc synthesize dihydrate and sodium carbonate, solvents were ethylene glycol (EG), diethylene glycol (DEG), and demineralized water, and the surface stabilizing agent was polyethylene glycol (PEG). The shape of the obtained powders varies depending on the time duration of the microwave assisted reaction and, in particular, the solvent used. Prepared particles are classified as needle-like structures, platelet structures, urchin-like structures, and other forms based on their morphology, demonstrating the great potential of this synthesis process. The size of prepared particles ranges from hundreds of nanometers to micrometers**.** Zinc oxide nanorods were created in 2011 [31] by using a Solvothermal technique. Zinc oxide

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nanorods' shape can be readily altered by adjusting the [OH^-] to [Zn^{+2}] ratio. Two varieties of alkylamine molecules, hexadecyl amine and ethylenediamine, were also used to study surfactant effects. Zinc oxide nanorods in both their surfactant-free and surfactant-filled forms were identical. It was possible to effectively reduce the intensity of green emission brought on by oxygen or other flaws by applying surfactants.

ZnO nanoparticles were synthesis of capped with hexadecylamine (HAD) in a variety of solvents including acetone, ethanol, and water in 2011[32]. Under identical conditions, the formation of rods and spheres in ethanol is smaller than that in acetone. The use of water as a solvent result in star-shaped ZnO nanoparticles with very crystalline. Under microwave irradiation, the solvent effects were shown to stimulate the interaction of Zn/O nano/particles growth with HDA, with both kinetic and thermodynamic parameters evaluated. The researchers group used a spray pyrolysis technique with a water solution of zinc acetate at various concentrations ranging from (5 to 25 wt. %) to create zinc oxide nanoparticles in 2011 [33]. Precursor solutions were dissolved at different atomizing pressures and temperatures (800, 100, and 1200 ^oC). All prepared nano powders generated with (5% - 20% wt.) zinc acetate at (1000 ^oC and 1200 ^oC) demonstrated hexagonal wurtzite phase with no impurities. It was exposed that decreasing the atomizing pressure of the precursor solution and the reaction temperature from (1200 to 1000 ^oC) reduced the size of the crystallites (17.1 nm to 10 nm**).**

Zinc acetate sol- gel dip coating is used to form nanocrystalline zinc oxide thin films onto two different substrates: aluminum foil and glass. The zinc oxide films are annealed at three different temperatures (100, 300, and 500C^o) in 2011[34]. The surface of the film is decorated with ganglia-like patterns. Ion doping has not discernible effect on crystal structure. As the Ni content increases, the moderate crystallite size falls. The adding of (1 to 15% wt. %) to the initial solution changes the morphology of the films. Zn/O nano/particles was synthesized by sol-gel method using Zinc acetate Zn-(CH_3COO) $_{2.}2H_2O$ and Triton X-100 as starting materials in 2011 [35]. The average particle size for ZnO nanoparticles calcined at 673K was determined to be 10 nm. ZnO has tremendous promise for more applications in the future in many fields, including electrical, optoelectronic, and magnetoelectronic devices. Thus, the ZnO nanoparticles that were produced might be used for photocatalysis, gas sensing, biomedical devices, and solar screens. Solvothermal process of nanometric Zn/O mixing with stearic acid oxide, as well as the oxide in the layered nanocomposite Zn/O was used to synthesis and study three types of 1D Zn/O nano-structures in 2012 [36]. The processes are carried out at 180C^o in a 1: 1 (ethanol / water) ratio. The precursor and reaction time both had an effect on the formation of morphologically homogenous phases resembling ZnO nanowires, nanorods, and nanoneedles. ZnO nanorods was synthesis in 2012 under specific conditions, such as 200 °C for around 8 hours, can be approved for the facilitation of CTAB orientation, especially when it is prepared from zinc acetate by a hydrothermal process assisted by N-cetyl-N, N, N-trimethyl ammonium bromide (CTAB) [37]. ZnO nanoparticles was fabricated using a solvothermal technique at 500 ^0C in 2012 [38]. To begin, prepare 0.1 M zinc acetate stock solutions in 50 ml methanol continuously stirring with a magnetic stirrer. Under continuous stirring, added 25ml of methanol-prepared NaOH (0.2 M) solution to the stock solution. These solutions were placed in sealed, Teflon-

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lined stainless-steel autoclaves and autogenously heated under pressure at 50 °C for six hours. After that, allow it to cool naturally to room temperature. The particle size of the Zn/O produced is calculated to be (11nm) with energy gap is (3.39 eV).

Zn/O nanoparticles were synthesized by precipitation technique by sodium hydroxide and zinc nitrate as precursors in 2012 [39]. The statistical average size was 2.2 nm for the created Zn//O nanoparticles as a peak absorbance wavelength. At room temperature, the released Zn/O nanoparticles display a strong band (λexc=320 nm) associated with an oxygen vacancy-induced wide green emission band and excitonic emission close to the band gap. These Zn/O nanoparticles can be applied in many different industrial fields, such as an active medium for lasers, sensors, and luminous materials for fluorescent tubes.

Zinc oxide nanostructured particles were prepared using a pyrosol method in 2012 [40] with poly-crystalline structures ranging in size from 5.7 to 21.8 nm from a diluted solution of $Zn(NO_3)_2•6H_2O$ at final concentrations of (0.1, 0.05, and 0.025 M). The temperatures used for synthesis were (400, 500, 600, and 700 ^{0}C). The synthesis process is strongly linked to the increase in grain size with decreasing solution concentration. zinc oxide nanorods was created using a thermal decomposition process in 2012 [41]. Zinc chloride ($ZnCl_2$) was utilized as a precursor in 1:2 molar ratios with sodium hydroxide (NaOH) for the wet chemical process of creating zinc oxide nanoparticles. Its use in solar cells should be expanded. The results show that the prepared zinc oxide Nanorods have consistent diameters of 100-200 nm and lengths of around 1μm.

ZnO nanoparticles were manufactured by micro emulsion method in 2012 [42] at room temperature from $ZnSO_4.7H_2O$ crystallizes in the orthorhombic structure and $N_2H_4.H_2O$ PVP work as a stabilizer for these Zn NPs. Surfactant and PVP polymer molecules bind to the surface of nano-particles, making a protective coating that prevents more reactions. Zn NPs are oxidized to Zn/ONPs at 100C^o in the air oxygen condition. Zn/O nanoparticles have a rod form and an average size of 10.0:12.0nm. Peaks for Zn-O stretching do exist. At 214 nm, there is a blue shift in absorption band. The allowed direct band-gap energy of Zn/ONPs is shown to be larger than that of their bulk materials. The DSC method is used for thermal research, which supports the creation of ZnO nanoparticles. zinc oxide nanostructures were created used water and methanol as solvents in 2013 [43] by solvothermal technique from zinc acetate dihydrate. In the case of ZnO nanostructures synthesized with water solvents, hexagonal shaped nanocrystals are developed at a pH of 8 while platelet shaped nanostructures progress at a pH of 12. The modification of hexagonal shaped nanorods in ZnO nanostructures synthesized with methanol solvents grows at pH values of 8 and 9. The above results indicate that the solvents and pH of the $Zn(CH_3COO)_2.2H_2O$ solution may have a highly scientific role in the external structure of ZnO nanostructures in hydrothermal synthesis. The researchers group employed pulsed laser deposition in 2013 [44] to produce a zinc oxide thin film using a KrF laser. The films were deposited onto sapphire substrates at 400 0C, with oxygen pressures of 0.3 and 0.4 mbar and target-substrate distances of 30- and 40-mm. Oxygen stoichiometry has been discovered to be correlated with high photoluminescence quality in films. nanosized ZnO particles were synthesized in aqueous solution using zinc-nitrate as a zinc source and urea as a precipitating agent in 2013 [45]. The obtained Zn/O powder ranged in size from 30 to 50 nm.

The particles have a spherical shape. The band gap of synthetic Zn/ONPs was smaller than that of bulk Zn/O. Thus, the direct precipitating method of production of ZnO nanoparticles is easy, rapid, and environmentally friendly.

Sol-Gel process was used to synthesize ZnO quantum dots in 2014 [46] using sodium hydroxide, methanol, and zinc acetate dehydrate. The fabricated sample was annealed at (500 °C) for 1h. The results indicated that the ZnO nanoparticles exhibit strong crystallinity and an average crystallite size of fourteen nanometer at reaction value of 9. The ZnO QDs produced were effectively employed in dye-sensitized solar cells. The researcher's group were used a sonicated sol-gel dip-coating methods to deposit zinc oxide thin films onto glass substrates at different deposition speeds in 2014 [47]. The current experiment investigates the influence of deposition speed on crystallization behavior as well as the optical and electrical characteristics of the resultant films. The results demonstrated that the thin films were preferentially orientated along the crystal's (002) c-axis direction. The optical band gap energy (Eg) was calculated to be 3.276-3.289 eV, and it increased when compressive stress along the c-axis decreased. The preferred c-axis (002) orientation was shown to have a considerable influence on the energy band gap of the produced ZnO films.

In 2014, a simple wet-chemical process for producing ZnO nanoparticles at room temperature. The analysis indicated the existence of defect states. The hexagonal crystal unit cell of the nanoparticles was observed. The nanoparticles are round and single crystalline [48]. The researchers group investigated the synergic antibacterial effective to zinc oxide nanoparticles incorporating anti-bacterial antibiotics against human pathogenic bacteria in 2015 [49]. The wet method was used to create zinc oxide nanoparticles (with zinc sulphate and sodium hydroxide as precursors), and the nanoparticles were then loaded with ofloxacin, norfloxacin, and cephalexin. Using an agar diffusion assay and a biofilm inhibition assay, anti-bacterial activity against Pseudomonas aeruginosa, Staphylococcus aureus, and Escherichia coli was investigated. Zinc oxide nanoparticles produced by wet technique produced nanoaggregates with sizes ranging from 52 to 75 nm. The anti-bacterial activity of nanoparticles conjugated with corresponding antibiotics was enhanced, and the anti-bacterial activity of nano drug conjugation against all bacterial infections tested showed a rise of inhibition-zone and inhibition of biofilm forming in a dosage dependent manner.

Thin-film transistors were synthesis using ZnO films applied via ultrasonic spray pyrolysis at 250 °C. It appears that when the structure takes on a polycrystalline structure, the ZnO layer may act like a semi-metal. The ZnO TFTs displayed the effects of a poor metal-semiconductor interface, which led to high contact resistance. Because of the smaller gate dielectric, the consequences of high leakage current are not fully appreciated in the transfer characteristics [50].

The researchers group used a vapor solid method in 2014 to generate a pure ZnO nanowire (NWs) with an appropriate vertical structure and grown-up it on a Substrate. Without the usage of external element catalytic agents, these nanostructures were produced. Given the existence of an additional interface layer, we depended on ambient pressure rather than furnace pressure. The analysis indicates adequate environmental control in the presence of supersaturated zinc oxide vapor, the results indicate that the ZnO Nanowires have uniform distribution, and a single crystal hexagonal structure. The forbidden diffraction band of ZnO is shown by the peak at 383 nm [51]. A hydrothermal method was

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used to create ZnO nanoparticles with a wurtzite form and a diameter of 12.1 nm. This technique is simple, low-cost, and environmentally benign, producing high crystalline particles with (high purity) in controllable shape. Because of the quantum confinement, the blue and energy gap shift, indicating that the manufactured ZnO Nanoparticles in Nanoscale with low defect [52]. ZnO NPs were synthesized in 2016, it's can be used as agents to stop the growth of dangerous microorganisms in food because of their strong antibacterial activity. However, the reported high toxicity of ZnO NPs in numerous prior toxicity studies limits their usage as food additives. The findings demonstrated that, under both neutral and acidic conditions, silica coating effectively prevents ZnO NPs from dissociating from zinc ions, therefore lowering their toxicity. However, ZnO NPs' intended antibacterial action against S. aureus and E. coli was unaffected by the silica covering [53].

ZnO nanoparticles were prepared coupled with GA (gallic acid) by a surface modification in 2017[54], these multifunctional ZnO@GA nanoparticles exhibit strong multifunctional antioxidant and antibacterial effect, indicating that they might be beneficial as a new antimicrobial action against Methicillin-resistant Staphylococcus aureus (MRSA). prepared Zn/ONPs (Zn/ONPs) in 2018 [55]. ZnO NPs have also exhibit successfully developed for diabetes therapy. Furthermore, ZnO NPs have excellent brilliant properties, they are making it one of the essential nominees for bio-imaging. We discuss the synthesis and current advances of Zn/ONPs in biological domains, which will assist in their future research progress

Zn/ONPs were prepared in 2019 [56] using a simple and repeatable method involving heat decomposition of a zinc: based metal organic framework, and utilized it at a constant dose (0.01 g/ml) against Gram-negative bacteria Escherichia Coli utilizing the agar diffusion technique. Based on zone inhibition, ZnO NPs with smaller sizes had stronger antibacterial activity in the existence of a coat agent and at a higher temperature. Particle size, concentration, shape, and surface changes all have an impact on antibacterial activity. The effective variables on antibacterial activity in this study can include NO^{3-} (produced by TEA) and Zn^{+2} (produced by a zinc cluster) ions, as well as metallic Zn. in 2020**,** Zn/ONPs were **c**reated from cassava starch or Aloe-vera. The zinc oxide nanoparticles were evaluated as copper adsorbents in wastewater, and it was revealed that at little (Cu^{+2}) ion concentrations ~ 40 mg/L, both approaches had the equal removal efficiency, but when the concentration of absorbate increases > 80 mg/L, the zinc oxide nanoparticles synthetic via Aloe vera have a greater removal efficiency. The generated zinc oxide nanoparticles can be utilized in wastewater as effective and environmentally friendly metal trace absorbers [57]. The researchers group prepared green ZnO-NPs in 2021. At 200 ppm, it inhibited both types of bacteria, gram-positive and gram-negative bacteria such as (*Candida albicans*, a type of unicellular fungus, Bacillus *subtilis* and *Staphylococcus aureus*), (*Pseudomonas aeruginosa and Escherichia coli*) respectively, and the inhibition-zones measured at approximately 12.330±0.90, 29.30±0.30, 19.30±0.30, 11.7±0.3, 11.7±0.3, and 22.3±0.3 mm, respectively. With inhibition zones ranging from 11.7±0.3 to 14.60±0.6mm, the minimum inhibitory concentration (MIC) for E. coli, B. subtilis, and Candida albicans was 50ppm, whereas the MIC for S. aureus and P. aeruginosa was 200 ppm. Moreover, with percentages of 100%, biosynthesized Zn/ONPs show considerable mortality for Culex pipiens when

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compared to zinc acetate (44.3±3.30%) at the same concentration after 24 h at 200 ppm [58].

The researchers group identified actinomycetes species from the soil's rhizosphere and biologically manufactured ZnO nanoparticles in 2022 [59]. ZnO has a hexagonal structure and is usually white. Gram-positive bacteria named Actinomycetes are normally found in soil, but because of their powdery size, they resemble fungi. Actinomycete called *Streptomyces* was oriented to produce zinc oxide nanoparticles (ZnO NPs). In this review, pointed out that manufactured nanoparticles were employed against pathogenic bacteria in antibacterial and anti-biofilm applications with an 88% biofilm destruction capacity and a 92% hydrophobicity index, the biofilm inhibition BIC of 200 g/mL to biosynthesized ZnO NPs on multidrug resistant (K. pneumoniae) was discovered.

In 2022, ZnO nanoparticles were prepared developing green methods for producing. ZnONPs were tested for antibacterial efficacy using gel agar good diffusion and broth dilution tests against pathogenic bacterial strains of *Bacillus cereus* MTCC 430, *Staphylococcus aureus* 26923, Salmonella enterica, and *Klebsiella pneumonia*, all of which were isolated from beef. With a MIC value of 100 g/mL, the biosynthesized ZnONPs demonstrated strong antibacterial efficacy against all test isolates. According to the findings, the nanoparticles' antibacterial efficiency against the specific bacteria was as follows: (*S. aureus*) > (*B. cereus*) > (*K. pneumonia*) > (*S. enterica*) [60].

ZnO-NPs were preparation in 2023, they found that the prepared (ZnO-NPs) have gotten appreciable importance in the agriculture and food chain as the method used in750 killing or inactivation of microorganisms. The specific activity of ZnO-NPs includes killing bacteria and is known to enhance the quality of foods that directly affect the fabric of human lives [61]. In 2023, Zn/ONPs were synthesized using plant extract from sodium hydroxide and zinc nitrate and also the same with calcination of nanoparticles [62]. In this research, Myrtus communisuextract was combined with three-different molarities of alkaline (0. 50 M, 1 M, and 2 M) to synthesize Zn/ONPs from the same precursor, by using Zn/O with 1M NaOH calcined at 800 C^{o}, DE MAX of approximately 99 % MB is obtained.

Zn/ONPs were synthesized in 2024,[63] the solution combustion method was used to generate Zn/ONPs. UV-vis spectroscopy, FTIR and XRD, SEM, and EDX were used to measure their properties. The produced zinc oxide nanoparticles were found to have a lethal effect on MCF-7 (breast) mammalian cancer cell lines, with an estimated IC50 value of 3. Features include EDX. The produced zinc oxide nanoparticles were found to have a lethal effect on MCF-7 (breast) mammalian cancer cell lines, with determined IC50 values of 3. The following characteristics apply: 66 μgmL^{-1}. M for LN-18 (Glioblastoma–Brain), 23, and HER2 negative. It is equivalent to 14 μgmL^{-1} for A-549 (Lung) and 94 for all other cell lines. For SHSY-5Y (Neuroblastoma-Bone) human cell lines, the cytotoxicity was consistently 33 µg/L. Nonetheless, LN-18 glioma of the brain was linked to the majority of cell loss.

Zn/O NPs were prepared in 2024 by co-precipitation of zinc acetate with Ampelocissus martini rhizome extract (AM). Four conformations of Zn/ONPs were obtained by conjoined precipitation of sodium hydroxide, zinc acetate dihydrate, and AM: ZnO NPs-01, ZnO NPs-02, Zn/ONPs-03, and Zn/ONPs-04. Antibacterial activity was tested by the disc/-diffusion method together with minimal inhibitory concentration (MIC) and minimal bactericidal concentration (MBC). Zn/ONPs-04 showed the highest inhibition significantly in DPPH and ABTS assays and was active against *E. coli* and *S. aureus* with MICs of 10 mg/mL and 05mg/mL, respectively [64].

CONCLUSION

This review highlights the diverse methods used for synthesizing zinc oxide (ZnO) nanostructures, reflecting their versatile applications across various industrial, biological, and medical fields. While advancements in ZnO synthesis have enabled better control over size, morphology, and purity, the choice of method significantly influences the material's characteristics. As nanotechnology evolves, the optimization of ZnO for specific applications such as sensors, optoelectronics, and antibacterial agents becomes increasingly crucial. Moreover, the ecological and cost benefits of ZnO, coupled with its compatibility with other nanomaterials, pave the way for further exploration in nanodevice fabrication and sustainable industrial applications. Continued research is expected to unlock additional potential for ZnO, particularly in emerging fields like energy harvesting and environmental remediation.

Conflict of interests.

There is no conflict of interests.

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