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REVIEW ARTICLE

Structure, Synthesis and Applications of ZnO Nanoparticles: A Review

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Abstract: Nanotechnology deals with the creation and utilization of materials at a nanoscale. Nanoparticles, in general, possess enormous surface area per unit volume and have explicit characteristics. Zinc oxide (ZnO) - based nanomaterials have been recognized to be of countless uses for numerous important requests from the beginning of nanoscience as a result of the great quantity of zinc element and the comparatively simple adaptation of its oxide to nanostructures. Currently, ZnO as nanoparticles, nanowires, nanofibers in addition to other classy nanostructures occurs amongst the innovator nanomaterials utilized in solar cell systems, fuel cells, water purification and biomedical fields. ZnO nanoparticles had been a research target for many investigations because of their vast band-gap and extraordinary exciton binding energy. The performance of ZnO nanoparticles is completely different from those of corresponding bulk materials, through enhancing the properties and using lesser amount of materials, which leads to price reduction. The main purpose behind this review article is to give a deep view on structure, synthesis and applications of ZnO nanoparticles prepared through various approaches to give the reader a comprehensive understanding.

Keywords: ZnO, Nanoparticles, Structure, Synthesis, Applications.

Introduction

In recent years, among metal oxide NPs, a lot of research focused on zinc oxide, because it has strange chemical, optical, magnetical and mechanical characteristics that are clearly unlike those of corresponding bulk materials [1]. Currently, nanotechnology is available in different scientific fields. Also, different techniques have been utilized for the operation of nanoparticles (NPs) in nano-scale range. NPs are an extensive type of materials comprising particulate materials which possess at least one dimension below 100 nm [2].

ZnO has distinctive chemical and physical properties; for instance, higher photostability, higher chemical stability, naturality, paramagnetism, a wide range of radiation absorption and higher electrochemical coupling coefficient [3]. Due to famous performance of ZnO nanostructured material in photonics, optics and electronics, it acquired great attention. The lack of a center of symmetry in wurtzite

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structure, joined with great electro-mechanical coupling, strong pyroelectric and piezoelectric properties are reasons behind using ZnO in piezoelectric detectors and mechanical actuators. Moreover, zinc oxide possesses a broad energy gap (3.370 eV), which is typical for a compound semiconductor, sufficient for different types of applications; for instance, in power generators, solar cells, ultraviolet (UV) lasers [4], gas detectors [5], photo catalysts,field emission devices, capacitors [6, 7]. It can also be utilized for clear UV resistance coating, electro-photography, photo-printing, electrochemical and electromechanical nano-devices, anti-bacterial agents, sun blockers, anti-hemorrhoids, cosmetic wound healing [8], eczema and excoriation from human medicine [9]. Zinc oxide powder is broadly utilized as an additive in many products and materials involving ceramics [10], rubber, cement, lubricants, glass, paints, adhesives, ointments, plastics, pigments, sealants, food, ferrites, batteries and fire retardants [8]. ZnO-based coating can be utilized as a protecting layer against moisture in woody samples [11].

ZnO nanoparticles can be classified depending on physical and chemical properties; for instance, crystal structure, shape, surface area, size and other properties changing with size reduction. This has given rise to the improvement of methods to prepare mixtures [12], as well as mechanic and chemical procedures [13, 14], procedure of precipitation [15, 16], surfactant precipitation [17], sol-gel [18], hydrothermal and solvothermal procedures [19], technique of microwave [20], emulsion [21], technique of microemulsion [22], CVD (chemical vapor deposition) [23], MBE (molecular beam epitaxy) [24], spray method [25], laser ablation [26], among others.

To our best knowledge, there is only a few review articles regarding ZnO NPs, such as Ref. [27] and Ref. [28]. Thus, due to the importance of ZnO NPs and their potential applications, this review article is originally designed to give a comprehensive understanding of the structure and the main approaches of synthesizing ZnO NPs, which are not fully covered by previous review. Further detail has been given to chemical and physical properties. The mechanical, electro-chemical, electrical and photoluminescence properties are among the properties that took more explanation during this investigation.

Zinc Oxide Structure

Zinc oxide nanoparticles are categorized among the materials that have potential applications in many areas of nanotechnology [29, 30]. ZnO possesses one-, two- and three-dimensional structures. 1D structure involves tubes, needles, ribbons, nanorods helixes, belts, combs, wires, rings and springs [12]. Two-dimensional structure involves nanoplates and nanosheets that can give us zinc oxide. However, three-dimensional structure of zinc oxide includes snowflakes, coniferous, urchin-like flowers and dandelions. Zinc oxide gives greatly different particles among materials [27]. Also, zinc oxide in different shapes and structures can be seen in Fig. 1.

Crystal Structure

Crystallization of zinc oxide exists in two types: cubic zinc-blende and hexagonal wurtzite structure. The structure of wurtzite is stable and common in ambient situations. At ambient temperature and pressure, zinc oxide is crystal in the wurtzite structure type B4, as displayed in Fig. 2. It is a hexagonal lattice, going to the P63mc space group and can be characterized *via* two connecting lattices O^{2-} and Zn^{2+}; each Zn ion is bounded *via* a tetrahedral of O^{2-} ions or *vice versa*. The coordination of this tetrahedral provides an increase to polar symmetry on the hexagonal axis [10]. This polarity is superior to a few properties of zinc oxide, involving (piezoelectricity and spontaneous polarizations). However, it is a hide factor from crystal growth, defect generation and etching. The ultimate face terminations of wurtzite zinc oxide are the polar (Zn) terminated (0001) and (O) terminated (000.1) faces [c-axis oriented], as well as the nonpolar (11.2) (a-axis) and (10.1) faces. This can commonly hold an equal number of atoms of Zn and O. On the other hand, polar faces are identified to possess different physical and chemical properties and the (O) terminated face possesses a slightly changed electronic structure compared to the other three faces of O [35].

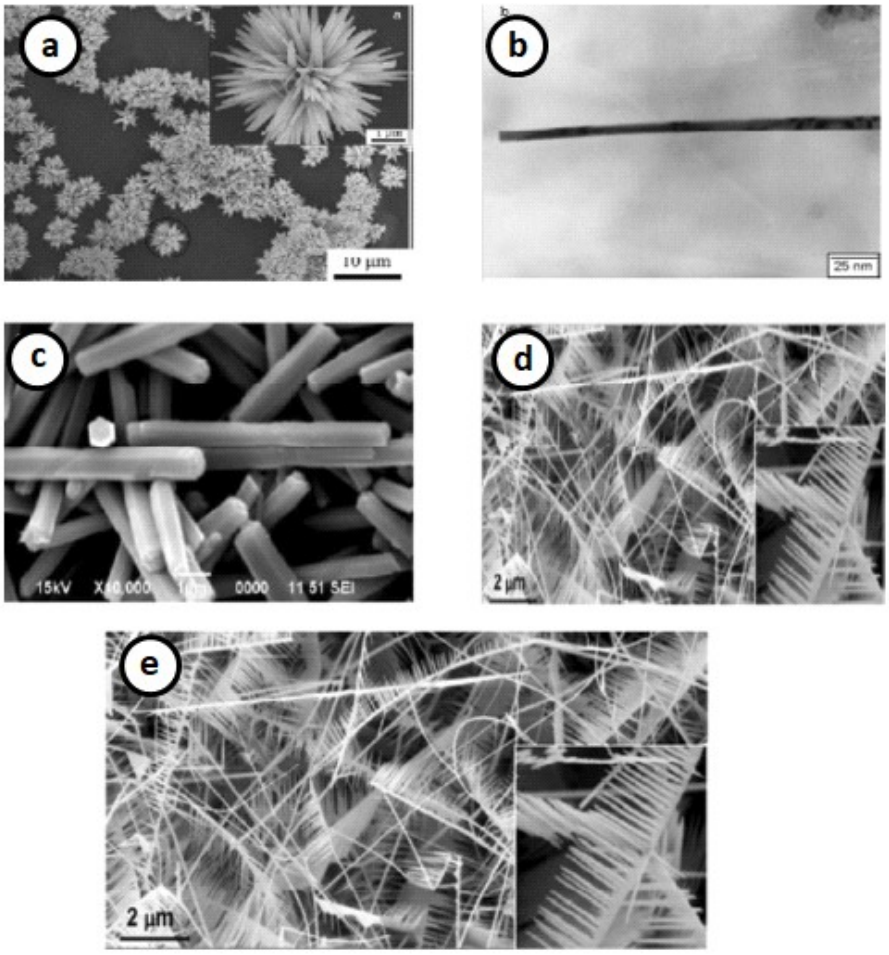

FIG. 1. Different structures and shapes of zinc oxide, (a) flower [31], (b) wire [32], (c, d) rod & mushroom [33], (e) comb [34].

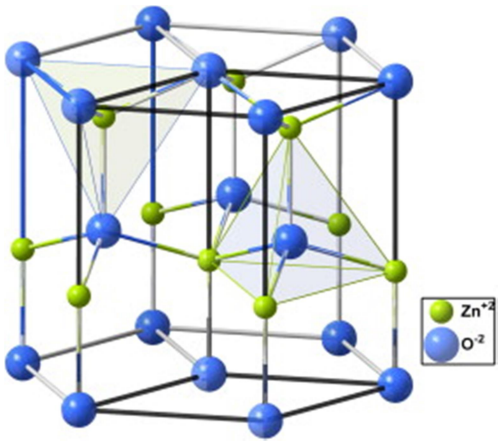

FIG. 2. Crystal structure of zinc oxide NPs [10].

Preparation Methods of ZnO NPs

Preparation of nanoparticles simply requires a low-cost and high-yield process. The approaches to preparing zinc NPs can be detached into solid phase, liquid phase and gas phase procedures. The solid phase methods involve mechanical milling and mechanochemical processes. The liquid phase methods involve exploding wire, laser ablation, decomposition process and solution reduction. However, the gas phase methods include laser ablation, exploding wire, gas evaporation and spark discharging [36], as well as chemical bath deposition (CBD) [37], green preparation [7] and wet chemical approach [38].

Mechanochemistry

Mechanochemistry is a field that deals with thermal or ultra-fast chemical reactions between solids or between solids and surrounding gaseous or liquid molecules under mechanical forces. Mechanochemistry includes the composition of mechanical and chemical incidence at molecule scale and involves mechanical breaking and chemical display of srainning of mechanics in solids. Mechanochemical preparation is different from ball milling. A classic ball milling procedure under inert atmosphere effects in a reasonable drop of particle powder size yields eventually the creation of nano-size grains in micro-size particles. The mechanochemical treatment includes the beginning of a displacement solid state reaction throughout the ball milling procedure in which nano-scale size particles drop to near 5 nm in size fixed through big particle production phase [39]. Synthesis by mechanochemical processing was predicted by Ao *et al.* [13]. They prepared zinc oxide in a standard size crystallite of 21 nanometers. Milling procedure took six hrs, manufacturing $ZnCO_3$ through the zinc oxide precursor. However, calcination of the precursor at 600 °C created zinc oxide in the form of hexagonal structure. Investigations displayed that the size of the ZnO crystallites changed by the change of milling time and temperature of calcination. Increasing the milling time (from 2 to 6 h) reduces the crystalline size (from 25 to 21.5 nm), which may show the presence of a (critical moment). Temporarily, a rise in the temperature of calcination from 400- 800 °C initiated a growth in the size of the crystalline (from 18 to 35 nm) [13]. The advantages of this mechanochemical approach are: finer particle size, higher purity of production, faster reactivity speed and different micro-reaction mechanism [40].

Sol-Gel Approach

The sol-gel preparation procedure of NPs was changed to the formation of inorganic composition along chemical reaction of a given solution. The importance of utilizing sol-gel technique is that this method produces best thermal stability ratio, best solution resistance, higher mechanical stability and the probability to the transform simulation.

Sol-gel and calcination method was used for the synthesis of zinc oxide NPs by Darroudi *et al.*[41]. ZnO NPs formed after characterization of that crystal structure including particle size and morphology. The results revealed that good procedure situation for the preparation of ZnO NPs was predictable at 60 minutes of ultra-sonication time and pH 10. The crystal size of the created ZnO NPs was 45.350 nm, with high morphology homogeneity. The particle size of ZnO NPs is about 50 nm with a ZnO content of 87.31 percent [42]. The main advantages accompanying the sol-gel approach include lower dispensation temperatures, extraordinary levels of purity, control of dopant concentrations and the aptitude to manufacture multicomponent compositions in dissimilar product forms [43].

Hydrothermal Approach

The hydrothermal technique doesn't require using (organic solvents) or supplementary processes of grinding and calcination; so, it's an easy and environmentally friendly method. This method requires an autoclave place when the substrate combination is heated gradually to a temperature between 100 and 300 °C and left for more days. Consequently, after cooling, (crystal nuclei) are created, with an increase in size. This method has a lot of advantages; it can be applied at low temperatures and size and shape of the crystals depend on the structure of the mixture and the temperature of the process as well as on pressure. Moezzi and coworkers [42] have manufactured ZnO nanotubes synthesized by hydrothermal approach utilizing $Zn(NO_3)_2$ as a precursor. However, the outer diameter and length of the ZnO nanotubes were about 200nm and 2.4μm, respectively [44]. Advantages of the hydrothermal method over other types of nanoparticle preparation methods include the ability to create crystalline phases which are not stable at the melting point. Also, materials which have a high vapor pressure near their melting points can be grown by using the hydrothermal method [45].

Liquid Phase Approach

PLD (Pulsed laser deposition) is an amazing synthesis approach because of its capability to create NPs in a small size and a low impurity level. There are 3 famous steps to participate in the laser ablation preparation approach and create NPs in a target sunk in liquid. Yoshitak explains that the morphological phase in controlling zinc oxide crystals was aware of the simple water solution approach. Zinc oxide nanotubes were produced at (50 °C) with a

length of 50 μm and a width of around 100 nm [46].

Liquid-phase synthesis methods have several advantages over other gas-phase and solid-phase synthesis methods. Liquid phase synthesis is the most common synthesis method for preparing nanoparticles (NPs) and nanostructured materials together with gas-phase synthesis. Also, size and shape control of NPs obtained could be achieved at low temperatures within a short time ranging from minutes to hours [47].

Precipitation Control

A general way to obtain ZnO is controlled precipitation, given the fact that it makes it possible to obtain results with repeated properties. This procedure includes quick and natural reduction of $ZnCl_2$ solution utilizing a reducing agent, to stop the increase of particle size with the definite dimensions, through deposition of a precursor of zinc oxide in the solution. This precursor is then under the effect of thermal treatment, through milling for removal of impurities. It is too difficult for breaking collective form; consequently, the powders calcined have a higher scale of particle collection. The deposition procedure is prohibited *via* parameters like temperature, pH and deposition time. ZnO is deposited in water solutions of $ZnCl_2$, $ZnSO_4$ and $ZnC_4H_6O_4$, where the reagent concentration controlling factors are the ratio of adding of the substrates and the reaction temperature. Zinc oxide NPs with the average size of 30 nm were found by using William-Hal approach by Sadraei *et al.* [48].

Precipitation method relies upon the precipitation of nanometer-sized particles within an incessant fluid solvent. An inorganic metal salt, such as chloride, nitride … and so on, is dissolved in water. Metal cations exist in the form of metal hydrate species. The hydrolyzed species condense and are then washed, filtered, dried and calcined in order to obtain the final product [49].

Vapor Transport Approach

The famous approach to manufacture zinc oxide NPs is the vapor transport procedure. It is able to be clamped into a catalytic (free vapor-solid VS) procedure and a (catalyst-assisted vapor liquid solid VLS) procedure depending upon the variation in the creation mechanisms of the nanostructures. The vapor-solid procedure can generally generate a large scale of nano-structures, such as nanorods, nanowires, nanobelts, among others. In a usual vapor-solid procedure, composite zinc oxide nanostructures like nanobelts and nanohelixes were prepared by Kong *et al.* [50], establishing through synthesized NPs a belt pattern in lengths grater than hundreds of micrometer, thicknesses from 5 to 20 nm and widths from 10 to 60 nm [50]. In some processes like this, the vapor of zinc, oxygen or oxygen vapor are volatile and interact with each other, creating zinc oxide NPs. There are many ways to generate zinc and O vapor. Zinc oxide decomposition is a direct and easy approach; however, it is confined to higher temperatures [51]. From the vapor-solid procedure, the NP structure is created via contracting directly in the phase vapor. While different NP structures can be grown, this way prominently gives fewer control in the geometrical shape, arrangement and specific position of zinc oxide nanostructures. The geometrical nanobelt parameters are found to be T519 nm and W528 nm. Table 1 summarizes the different ways of zinc oxide nanostructure creation.

The vapor transport method has full advantages represented in impulsively accumulating pure one-dimensional single crystals directed by developing along the lowermost energy direction, favored orientation and least energy surface, leading to creation of low index crystallographic planes of NPs [52].

Physical Properties of Zinc Oxide Nanostructures

Zinc oxide NPs have different physical properties. It should be noted that since the dimensions of semiconductor materials are continuously reduced to a nanometer or even smaller size, several physical properties fall under the effects of changes called (quantum size effects). For instance, quantum confinement rises the energy band gap of quasi, one-dimensional (Q1D) zinc oxide, which was accepted via optical radiation [34]. It can be stated that quantum confinement is the alteration of electronic and optical characteristics once the material tested is of an adequately tiny size; characteristically 10 nm or less. The band gap rises as the dimensions of the nanostructure decrease. Explicitly, the consequence is that electrons and holes are pressed into a dimension

that is close to a critical quantum measurement, named the exciton Bohr radius [53].

Acceptance of primary physical properties is critical to the intelligible design of useful devices' properties. Investigation of specific zinc oxide NPs is required to examine their potential application as building blocks for nano-scale view devices. This review article is going to summarize the previous research on the physical properties of zinc oxide NPs, involving magnetic properties, electrical properties, mechanical properties and properties of photoluminescence [54].

TABLE 1. Summary of ZnO NP preparation approaches.

Technique	Precursors	Synthesis conditions	Properties and uses	Ref.
Mechanochemical 1 process 2 process	$ZnCl_2$, Na_2C0_3, NaCl	calcination: 2 h, 600 °C 400-800 °C	hexagonal structure particle diameter 21-25 nm hexagonal structure	[13] [14]
Precipitation process	$Zn(N0_3)_2$, NaOH ZnO powder, NH_4HC0_3	synthesis: 2 h; drying: 2h, 100 °C reaction.r-Z h, 25 °C; drying: 80 °C; calcination:1 h, 350 °C	particles of spherical size of around 40 nm hexagonal wurtize structure; flower-like and rod-like shapes (D: 15-25 nm, BET: 50- 70 m^2/g)	[15] [16]
Precipitation in the presence of surfactants	$Zn(N0_3)_2$, NaOH, SDS, TEA (trieth- anolamine)	precipitation: 50-55 min, 101 °C	wurtize structure, rod-like shape (L: 3.6 mm, D: 400 500 run) nut-like shape and rice-like shape, size: 1.2-1.5 µm	[17]
Sol - gel	$Zn(CH_3COO)_2$, oxalic acid, ethanol and methanol	reaction temperature: 60 °C; drying: 24 h, 80 °C; calcination: 500 °C	zincite structure; aggregate particles: ~100 nm; rod-like shape; particles L: ~500 nm, D: ~100 run; BET: 53 m2/g	[18]
Solvothennal hydrothermal and microwave techniques	$Zn(CH_3COO)_2$, $Zn(NO_3)_2$, LiOH, KOH, NH_4OH $ZnCl_2$, NaOH	reaction: 10-48 h, 120-250 °C reaction: 5-10 h, 100-220 °C in teflon- lined autoclave	hexagonal (wurtize) structure, size of micro- crystallite: 100 nm - 20 µm particle morphology: bullet-like (100 - 200 nm), rod-like (100 - 200 nm), sheet (50 - 200 nm), polyhedron (200 - 400 nm), crushed stone-like (50-200 nm)	[19] [20]
Emulsion	$Zn(CH_3COO)_2$, heptane, Span- 80, NH_4OH	reaction: 1 h; aging: 2.5 h; drying: in rotary evaporator; calcination: 2 h, 700 - 1000 °C	hexagonal structure; spherical shape; particle diameter: 0.05-0.15 µm	[21]
Microemulsion	$Zn(NO_3)_2$, NaOH, heptane, hexanol, Triton X-100, PEG400	reaction: 15 h, 140 °C; drying: 60 °C	hexagonal (wurtize) structure; particle morphology: needle-likr (L: 150-200 nm, D: ~55 nm), nanocolumns (L: 80-100 nm, D: 50-80 nm), spherical (~45 nm)	[22]

Mechanical Properties of ZnO NPs

After the traditional elasticity theory, the bending coefficient was determined. Determination of the mechanical properties of the specific NPs is moderately difficult, since the classic measurement approach for bulk substances does not directly apply. Based on the resonant excitation caused by the electric field, according to Bai *et al.* [51], the bending coefficient of zinc oxide nanobelts is characterized by TEM. By this way, distinctive holder sample TEM was performed to apply an oscillating electric field between the zinc oxide nanobelt and a static electrode. This field of electricity led the nanobelt vibration and increased resonance oscillation due to heavy frequency tuning. Based on the conventional elasticity theory, bending modulus was calculated. Zinc oxide nanobelt proves to be a capable material as nanocantilever and nanoresonator. Its size is decreased and its sensitivity improvement differs from that of (conventional cantilever) invented by micro-technology displayed in Fig. 3 [51]. Hughes *et al.* [55] stated the influence of the zinc oxide nanobelt to chosen position and length. This indicates the possibility of applying it as a very atomic force microscope (AFM) cantilever [55].

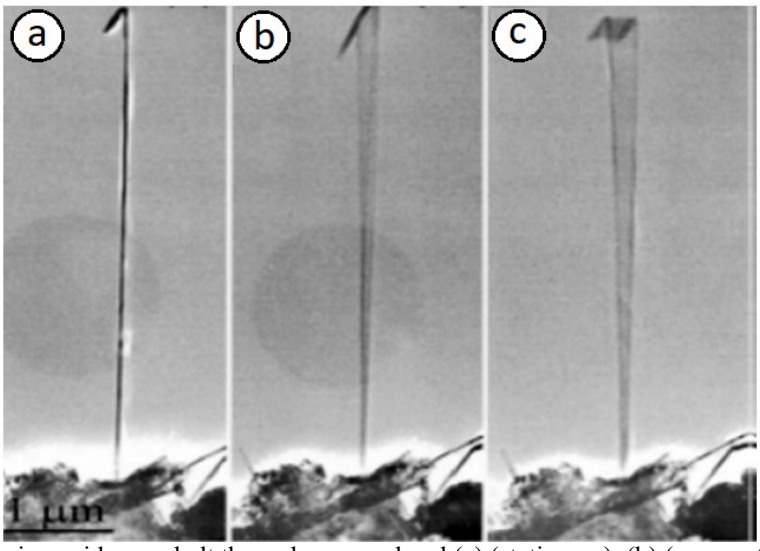

FIG. 3. A particular zinc oxide nanobelt through a curved end (a) (stationary), (b) (resonant) at (731 kHz) from the parallel plane to the looking direction and (c) (resonant) at (474 kHz) from the perpendicular plane to the looking direction [51].

Electrical Properties

The important revision of electrical properties of zinc oxide NPs is difficult to increase their applications in nano-technology. Measurement of electrical transfer has been carried out on specific nanowires and nanorods [38, 56]. Private zinc oxide nanowire was arranged as a field effect transistor through several techniques. Isopropanol alcohol was first synthesized to install a nanowire suspension system and then deposited on SiO_2 / Si material. Lithography photo has been used to characterize (contact electrode range) and (degenerately doped Si substrate) worked as a (back gate electrode). Due to population defects like (oxygen vacancy) and (zinc interstitials), zinc oxide nanowires described clearly the behavior of n-type semiconductors.

It is established that the electrical properties of zinc oxide depend on the ratio of doping ions, as found by Chu and Li [57], when they worked on the improvement of electrical properties of doped zinc oxide via electrochemical deposition. Following this, just pure zinc oxide displays the behavior of a resistive switch, indicating that defects in zinc oxide are importantly responsible for determining the behavior of a resistive switch. From Fig. 4a for pure zinc oxide, it is clear that a rapid fall of leak of current demonstrates that it has a higher resistance and is non-volatile, while according to Fig. 4b and Fig. 4c, In^{3+} and Al^{3+} are dopings to zinc oxide, which correspondingly do not display the behavior of a resistive switch. By (Al^{3+}) doping, conductivity rose and In^{3+}displayed a rectifying behavior as a current reduction upon growing voltage [57].

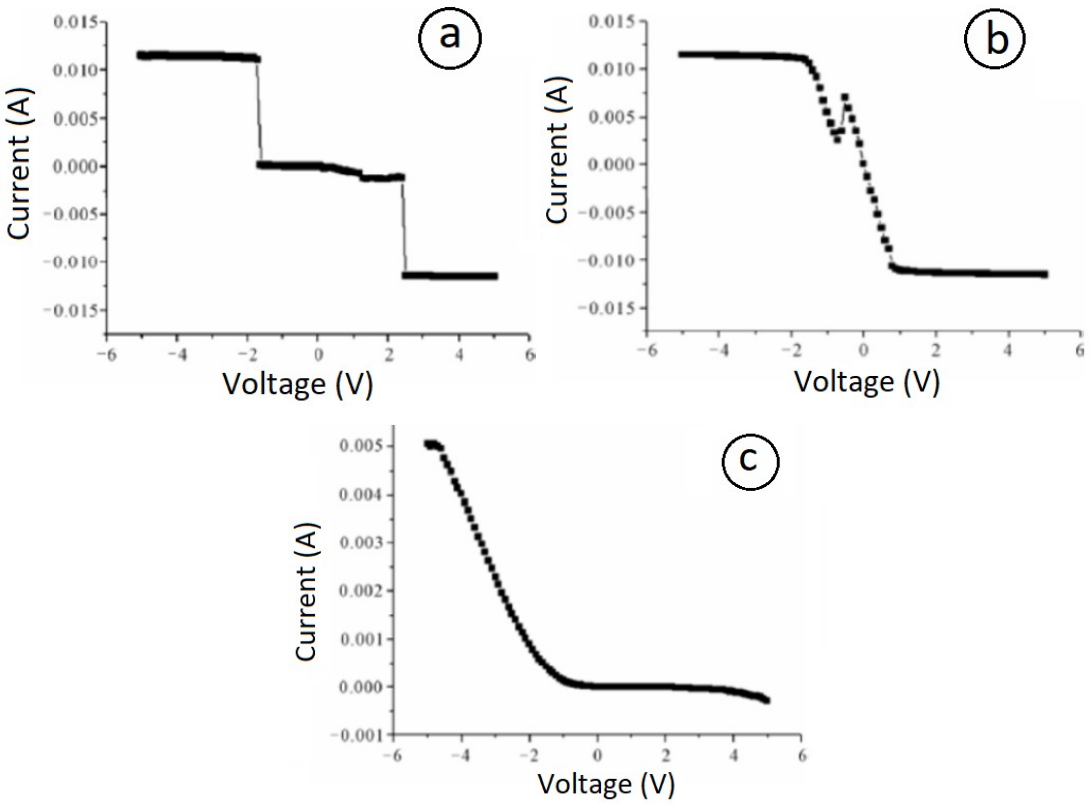

FIG. 4. I-V characteristics of (a) pure zinc oxide, (b) indium (In^{3+})-doped zinc oxide and (c) aluminum (Al^{3+})-doped zinc oxide created on the (FTO/ZnO/Pt) structure [57].

Madhuri *et al.* [58] measured the electrical properties of zinc oxide and films of rGO-ZnO measured by Madhuri *et al.* are shown in Fig. 5a. Contacts are created by utilizing an Ag paste on the films composed under (SiO_2 300 nm/Si) substrates. Currents are determined in light and dark situations by external UV illumination at ƛ = 365 nm. (I-V) curves of zinc oxide are rectifying (Schottky) in nature, causing metal and semiconductor contacts as shown in Fig. 5b. At -1 V bias, the current in the on state is approximately 7 times higher than in the off state. Fig. 5c displays I-V curves acquired on (rGO-ZnO hybrid films). The curves are a little nonlinear and rGO contact with zinc oxide takes place near Schottky junctions aiding effective charge transport. Dark current of rGO-ZnO is closely 50 times higher than that of zinc oxide. The rising amount of current in the off state is caused by less film resistivity, while the existence of zinc oxide is obviously demonstrated in UV-On situation. In the two cases, we observed a linear increase in current with the voltage [58].

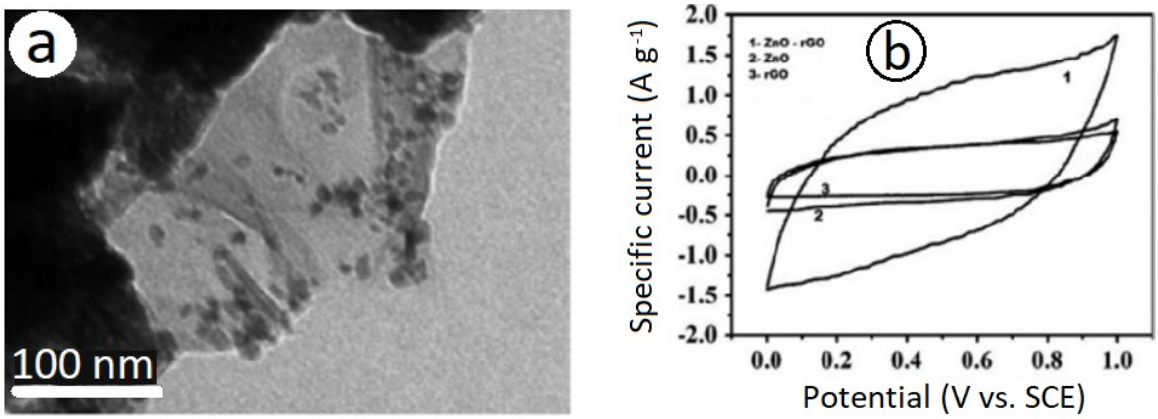

FIG. 5. (a) Circuit graphic for 2-probe measurement, (b) I-V characteristic curves of films manufactured of zinc oxide nanoparticles and (rGO-ZnO) nanoparticles on silicon dioxide by (UV illumination) [58].

Electrochemical Properties of ZnO NPs

The electrochemical properties of ZnO NP substances were studied *via* galvanic static and cyclic voltammetry (CV). Measurement of dynamic electrochemical potential is concerned with measuring the potential along the work electrode and the reference electrode *via* the current measured along the work electrode and the counter electrode. Specific capacitance was determined [59, 60] as:

$$C_s = \frac{Q}{\triangle V \times m} = \frac{I \times t}{\triangle V \times m} \quad (1)$$

where C_s: specific capacitance of the electrode, I: current through the discharge process, t: time discharge, $\triangle V$: potential window and m: mass of active electrode substance.

Raja *et al.* [61] synthesised ZnO/rGO compound by chemical wet preparation as displayed in Fig. 6a. CV curve indicates a high integral area of (positive synergetic effects) in a particular capacitance as displayed in Fig. 6b. Specific capacitance is about 280 F/g which is greater than that of the pure zinc oxide and (rGO) under a current density of (1 A/g) [61].

Babu *et al.* [63] perceived from electrochemical experiments that the zinc oxide/graphene nano-compound produces an elementary charge capacity of (420 mAh g^{-1}) and that the nano-compound displays a clearly enhanced cycling stability associated to simple zinc oxide causing buffer, conduction and confinement effects [63]. As in Fig. 7, Song *et al.* [62] synthesized ZnO/graphene compound utilizing *in-situ* hydrothermal preparation, with a capacitance of (300 mAh g^{-1}) after twenty-five cycles. However, the capacitance of pure zinc oxide decreased to (101 mAh g^{-1}) after the same cycles. Combination of graphene improved the cyclic stability of pure zinc oxide [62].

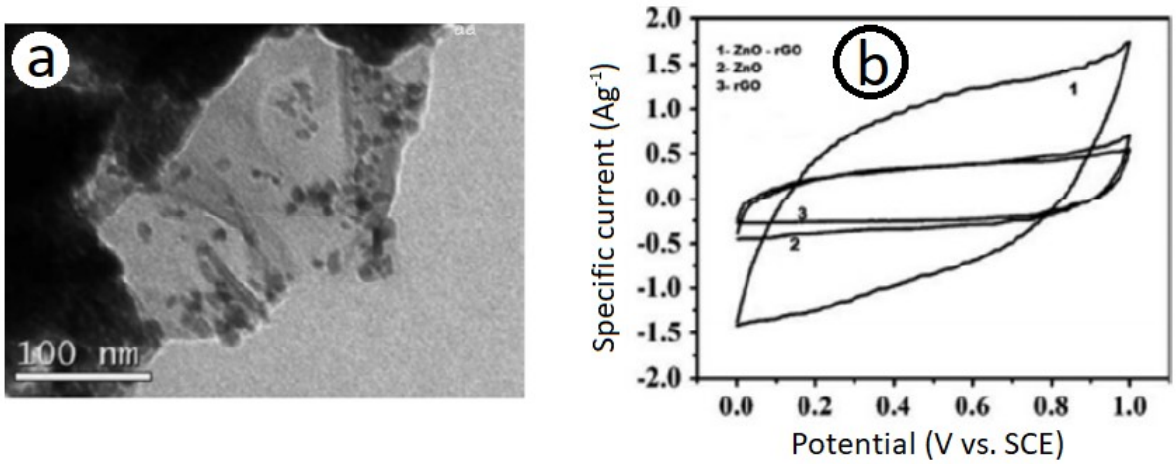

FIG. 6. (a) (ZnO/rGO) compound TEM image and (b) CV characteristics for (zinc oxide), (rGO) and (ZnO/rGO) compound as electrodes from (0.1M Na_2SO_4 electrolyte) at a sweep ratio of (5mV/s) [61].

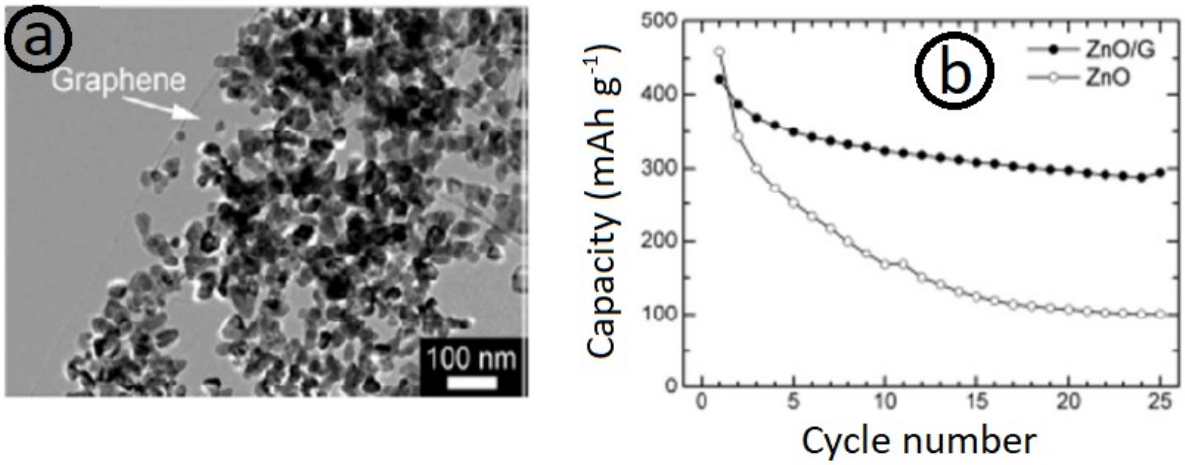

FIG. 7. (a) (ZnO/G) TEM image and (b) differences of (cycling stability) along (zinc oxide) and (ZnO/G) at (50mA g-1) [62].

Luo and co-workers [64] synthesized ZnO-SnO_2 compound *via* the (electro-spinning) method and displayed enriched cyclic production at 700 °C owing to small-size particles of zinc oxide and stannic oxide as shown in Fig. 8. Through a flexible capacity of (560 mAh g^{-1}) after (100 cycles) while the compound was heated at 800 °C to 900 °C, the capacity decreased after (100 cycles) [64]. Guler *et al.* [65] prepared ZnO-MWCNTs having a capacity of 527 mAh $g^{-1}$by larger cyclic stability up to 100 cycles, as displayed in Fig. 9. This best stability is attributed to zinc oxide NP adhesion over CNT through having higher electrical conductivity, best relaxation stress and best flexibility [65].

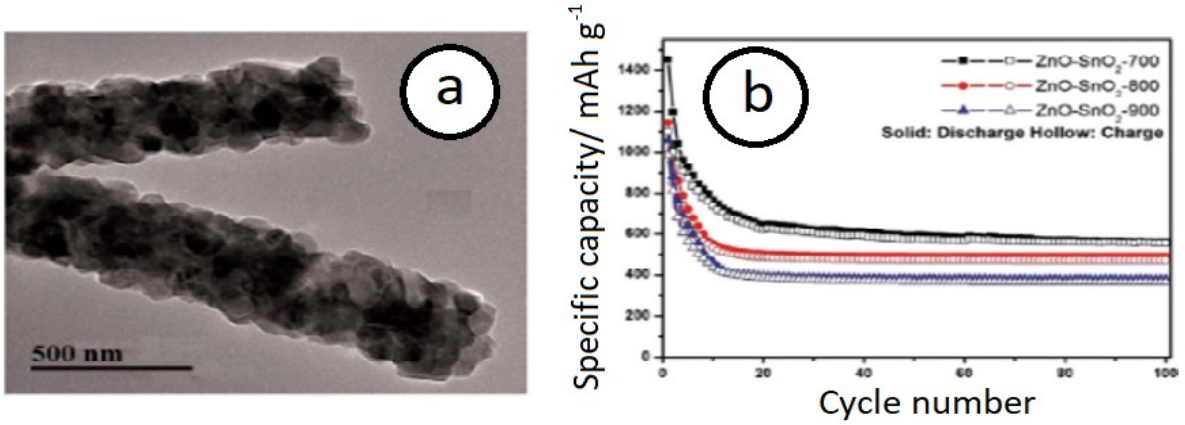

FIG. 8. (a) (ZnO–SnO_2) compound nano-fiber TEM image and (b) (cycling performance) and (Coulombic efficiencies) [64].

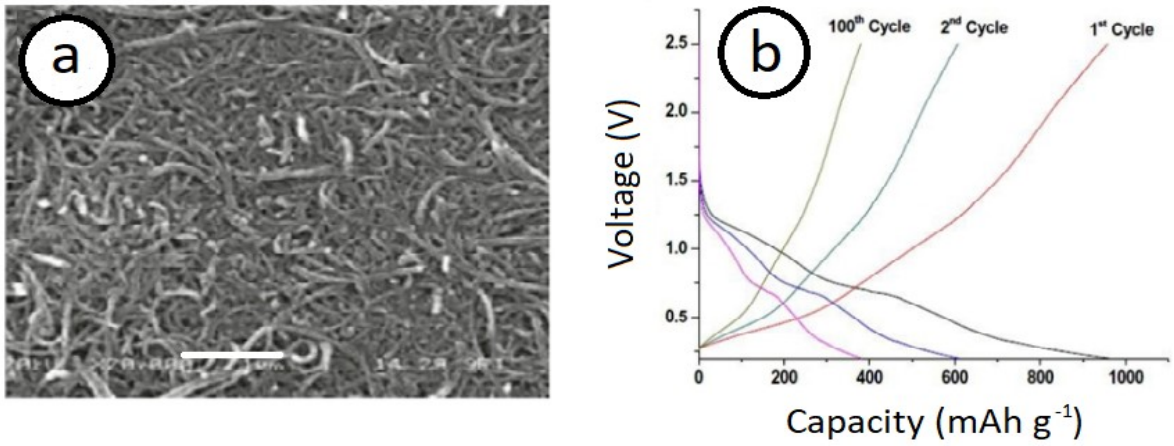

FIG. 9. (a) (SEM) and (HRTEM) images for the oxidized films from (99.99 %) of (high-purity oxygen) and Ar (99.999 %) at a rate of (a) (1:4) and (b) curves of galvanostatic charge/discharge of the oxidized films below (a) (1:4) (oxygen & argon) gas pressures [65].

Photoluminescence Properties of ZnO NPs

Photoluminescence properties of zinc oxide and nano-substance were considered by Rauwel *et al.* [66]. Zinc oxide givess the photoluminescence emission from the UV and visible ranges depending upon preparation shape, routes, deep level, size and surface defects. Once zinc oxide NPs are pooled between carbon nano-substances, surface defects are converted.

Zinc oxide permits the organization of photoluminescence properties to create as white light. Furthermore, the efficient transfer of energy in zinc oxide to the carbon nanotubes makes it suitable not just for energy gathering applications, but also as photo-detectors, biosensors and thermal imaging at low temperatures. Furthermore, it was shown that zinc oxide NP embodiment from (metal oxide matrix) creates changes in the (PL) response causing the inactivation of (surface defects) [66]. Different colors emitted by zinc oxide include: red, orange, green and blue [67].

Applications of ZnO NPs

ZnO has different chemical and physical properties. It can be used in numerous fields. Zinc oxide is important in a wide range of applications, from medicine to agriculture, from paints to chemicals and from tires to ceramics. Fig. 10 displays the universal consumption of ZnO *via* area [27].

Medicinal Applications

Zinc oxide NPs have certain properties that make them appropriate for applications associated with the central nervous system (CNS) and possibly wit the improvement procedures of disease treatment over (mediating neuronal excitability) or (even the release of neurotransmitters). Several types of research have shown that zinc oxide influenced unalike tissues, cells or functions, as well as neural tissue engineering and biocompatibility [68].

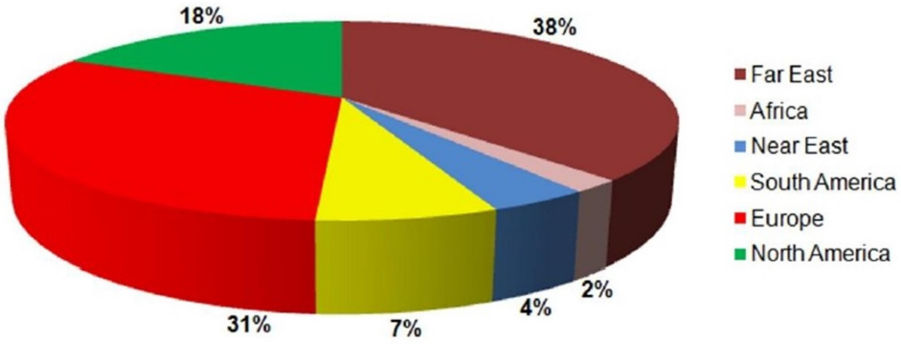

FIG. 10. Universal consumption of ZnO [27].

Agricultural Applications

ZnO NPs have potential to enhance the growth of food crops. Seeds fixed by various ZnO NP concentrations improved seed propagation, seed strength and plant growth. ZnO NPs showed to be active in growing roots stems and seeds [69]. Importance of zinc oxide NPs in biotechnology area was investigated by Paul and Ban [70]. They observed the effect of chemically prepared ZnO NPs on the biological system. Zinc oxide is also used at different concentrations from (*Streptococcus pneumonia, Bacillus subtitles, E.Coli and Pseudomonas aeruginosa*). A quick rise of enzymatic activity was found through high concentrations of zinc oxide [70]. A summary of ZnO uses in different fields is shown in Fig. 11 [27].

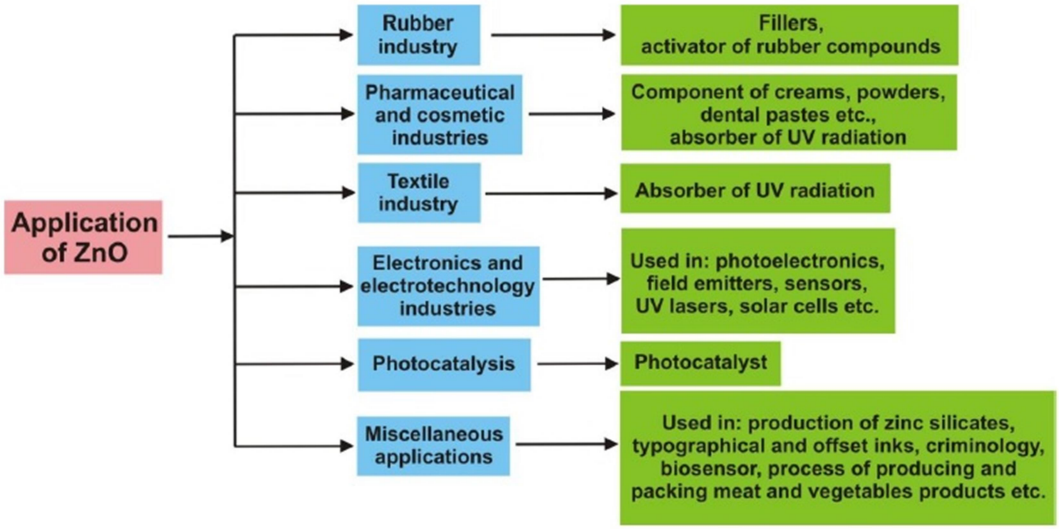

FIG. 11. Chart showing zinc oxide applications stated in the manuscript [27].

Summary

ZnO is a useful, most functional and single material with some distinguished properties; therefore, zinc oxide proposes unbelievable potential to future applications, such as electronic, magnetoelectronic and optoelectronic devices. The authors believe that this review article intensively focused on ZnO NPs from preparation, structure and application points of view. According to the assessment of studies presented here, ZnO NPs can be formed by numerous approaches. These can be alienated into metallurgical and chemical approaches. In metallurgical procedures, ZnO NPs are acquired by the burning of a suitable zinc ore, through a straight or unintended procedure.

This study indicated that zinc oxide NPs constitute building blocks in a massive range of devices and a plenty of applications. This investigation suggested that continuous effort is required to attain large arrays of structural programs for constructing recoverable architectures. Thus, attention to ZnO NPs will remain to develop and this will cause the growth of novel potentials for their request.

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References

[1] Kumar, H. and Rani, R., International Letters of Chemistry, Physics and Astronomy, 14 (2013) 26.

[2] Khan, I., Saeed, K. and Khan, I., Arabian Journal of Chemistry, 12 (7) (2019) 908.

[3] Parihar, V., Raja, M. and Paulose, R., Reviews on Advanced Materials Science, 53 (2) (2018) 119.

[4] Wang, D. et al., Nano-Structures & Nano-Objects, 10 (2017) 1.

[5] Tomchenko, A.A. et al., Sensors and Actuators B: Chemical, 93 (1-3) (2003) 126.

[6] Marci, G. et al., The Journal of Physical Chemistry B, 105 (5) (2001) 1033.

[7] Singh, S. et al., Nano-Structures & Nano-Objects, 11 (2017) 1.

[8] Serpone, N., Dondi, D. and Albini, A., Inorganica Chimica Acta, 360 (3) (2007) 794.

[9] Ozgur, U., Hofstetter, D. and Morkoc, H., Proceedings of the IEEE, 98 (7) (2010) 1255.

[10] Sabir, S., Arshad, M. and Chaudhari, S.K., The Scientific World Journal, 2014 (2014) 1.

[11] Makarona, E. et al., Nano-Structures & Nano-Objects, 10 (2017) 57.

[12] Frade, T., Jorge, M.M. and Gomes, A., Materials Letters, 82 (2012) 13.

[13] Ao, W. et al., Powder Technology, 168 (3) (2006) 148.

[14] Stanković, A. et al., Journal of Materials Science, 46 (11) (2011) 3716.

[15] Lanje, A.S. et al., Advanced Powder Technology, 24 (1) (2013) 331.

[16] Khoshhesab, Z.M., Sarfaraz, M. and Houshyar, Z., Synthesis and Reactivity in Inorganic, Metal-Organic and Nano-Metal Chemistry, 42 (10) (2012) 1363.

[17] Li, P. et al., Journal of Solid State Chemistry, 178 (3) (2005) 855.

[18] Mahato, T. et al., Journal of Hazardous Materials, 165 (1-3) (2009) 928.

[19] Dem'Yanets, L., Li, L. and Uvarova, T., Journal of Materials Science, 41 (5) (2006) 1439.

[20] Chen, D., Jiao, X. and Cheng, G., Solid State Communications, 113 (6) (1999) 363.

[21] Lu, C.-H. and Yeh, C.-H., Materials Letters, 33 (3-4) (1997) 129.

[22] Li, X. et al., Journal of Colloid and Interface Science, 333 (2) (2009) 465.

[23] Park, J.-H. et al., Applied Physics Letters, 89 (12) (2006) 121108.

[24] Fons, P. et al., Physical Review Letters, 96 (4) (2006) 045504.

[25] Joseph, B. et al., Materials Chemistry and Physics, 58 (1) (1999) 71.

[26] Chen, J. et al., Applied Physics Letters, 87 (17) (2005) 173119.

[27] Kołodziejczak-Radzimska, A. and Jesionowski, T., Materials, 7 (4) (2014) 2833.

[28] Sirelkhatim, A. et al., Nano-Micro Letters, 7 (3) (2015) 219.

[29] Hahn, Y.-B., Korean Journal of Chemical Engineering, 28 (9) (2011) 1797.

[30] Ding, Y., Zhang, F. and Wang, Z.L., Nano-Research, 6 (4) (2013) 253.

[31] Xie, Q. et al., Solid State Communications, 136 (5) (2005) 304.

[32] Chen, W. et al., Applied Surface Science, 253 (16) (2007) 6749.

[33] Haq, I.U. and Azad, A.-M., Sensors, 12 (6) (2012) 8259.

[34] Wang, Z.L., Kong, X. and Zuo, J.-M., Physical Review Letters, 91 (18) (2003) 185502.

[35] Dulub, O., Boatner, L.A. and Diebold, U., Surface Science, 519 (3) (2002) 201.

[36] Kabbara, H. et al., Nano-Structures & Nano-Objects, 10 (2017) 22.

[37] Manthina, V. and Agrios, A.G., Nano-Structures & Nano-Objects, 7 (2016) 1.

[38] Gayen, R. and Paul, R., Thin Solid Films, 605 (2016) 248.

[39] Ghorbani, H.R., Oriental Journal of Chemistry, 30 (4) (2014) 1941.

[40] Chen, D. et al., High-energy Ball Milling, Mechanochemical Processing of Nanopowders (2010) 149.

[41] Darroudi, M. et al., Ceramics International, 39 (8) (2013) 9195.

[42] Moezzi, A., McDonagh, A.M. and Cortie, M.B., Chemical Engineering Journal, 185 (2012) 1.

[43] Fan, J., Boettcher, S.W. and Stucky, G.D., Chemistry of Materials, 18 (26) (2006) 6391.

[44] Salahuddin, N.A., El-Kemary, M. and Ibrahim, E.M., International Journal of Scientific and Research Publications, 5 (9) (2015) 1.

[45] Madathil, A.N.P., Vanaja, K. and Jayaraj, M., Proc. in Nanophotonic Materials IV, 66390J (2007). International Society for Optics and Photonics.

[46] Masuda, Y., Kinoshita, N. and Koumoto, K., ISRN Nanotechnology, 2012 (2012) 1.

[47] Sinkó, K., Szabó, G. and Zrínyi, M., Journal of Nanoscience and Nanotechnology, 11 (5) (2011) 4127.

[48] Sadraei, R., Research & Reviews: Journal of Chemistry, 2319 (2016) 9849.

[49] Rodrıguez-Paéz, J. et al., Journal of the European Ceramic Society, 21 (7) (2001) 925.

[50] Kong, X.Y. and Wang, Z.L., Nano-letters, 3 (12) (2003) 1625.

[51] Bai, X. et al., Applied Physics Letters, 82 (26) (2003) 4806.

[52] Kuo, T.-J. et al., Chemistry of Materials, 19 (21) (2007) 5143.

[53] Roduner, E., Chemical Society Reviews, 35 (7) (2006) 583.

[54] Kukreja, L., Barik, S. and Misra, P., Journal of Crystal Growth, 268 (3-4) (2004) 531.

[55] Hughes, W.L. and Wang, Z.L., Applied Physics Letters, 82 (17) (2003) 2886.

[56] Kita, K., Kyuno, K. and Toriumi, A., Applied Physics Letters, 85 (1) (2004) 52.

[57] Chu, D. and Li, S., New Journal of Glass and Ceramics, 2 (01) (2012) 13.

[58] Madhuri, K.P., Bramhaiah, K. and John, N.S., In: AIP Conference Proceedings, (2016), AIP Publishing.

[59] Yong-gang, W. and Xiao-gang, Z., Electrochimica Acta, 49 (12) (2004) 1957.

[60] Gamby, J. et al., Journal of Power Sources, 101 (1) (2001) 109.

[61] Raja, M. et al., Fullerenes, Nanotubes and Carbon Nanostructures, 23 (8) (2015) 691.

[62] Song, W.-T. et al., Int. J. Electrochem. Sci., 7 (3) (2012) 2164.

[63] Babu, K.S. and Narayanan, V., Chemical Science Transactions, 2 (S1) (2013) S33.

[64] Luo, L. et al., Ceramics International, 42 (9) (2016) 10826.

[65] Guler, M.O. et al., Microelectronic Engineering, 118 (2014) 54.

[66] Rauwel, P. et al., Journal of Nanomaterials, 2016 (2016) 19.

[67] El Hichou, A. et al., Journal of Luminescence, 113 (3-4) (2005) 183.

[68] Osmond, M.J. and Mccall, M.J., Nanotoxicology, 4 (1) (2010) 15.

[69] Prasad, T. et al., Journal of Plant Nutrition, 35 (6) (2012) 905.

[70] Paul, S. and Ban, D.K., International Journal of Advances in Chemical Engineering and Biological Sciences (IJACEBS), 1 (1) (2014) 1.