

REVIEW OF ZINC OXIDE (ZNO) NANOPARTICLES APPLICATIONS AND PROPERTIES

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Abstract—The nanoparticles have continuously been analyzed and applied in many industrial applications for the decade. Nanomaterials have been an essential research in applied science and engineering. Zinc oxide (ZnO) nanoparticles have received a remarkable consideration due to their extra ordinary UV filtering properties, photochemical antifungal, high catalytic and antibacterial activities. Zinc Oxide (ZnO) is a provocative material for applications in electronics, photonics, acoustics and sensing. Zinc Oxide nanoparticle is a unique material that exhibits itself as semiconductor and piezo-electric material. In this paper, a modern review of Zinc Oxide nanostructure, its unique characteristics at nanoscale level and the properties is presented through an analytical process. The behavior of Zinc Oxide at nanoscale is explored and its industrial application as a semiconductor, nanowire and other area of material science is presented. Finally, this review is concluded with many future scope and enhancement.

Keywords— Zinc Oxide (ZnO), Nanotechnology, Nanoparticles, Semiconductor Properties.

I. INTRODUCTION

Recent researches in the area of modern nanotechnology, particularly the efficiency to prepare highly ordered small nanoparticles of any scope, size and shape, have directed to the advancement of a recent technology[1]. With the technological arrival of field of nanotechnology, wide categories of nanoparticles with unique characteristics are being fabricated and applied for a wide range of industrial applications[1]. Nanosized particles of semiconductor materials have achieved great interest in recent years due to their desirable properties and applications in different areas such as electronic industries, textile industries, photo catalysts, sensors, photoelectron devices, pharmaceutical, cosmetic industries, highly functional and effective devices as shown in figure 1. These nonmaterial's have unusual thermal, structural and electronic properties, which are of important scientific interests in the fundamental and applied research fields [2, 3]. Zinc oxide (ZnO) is usually a semiconductor having wide band gap with an energy gap of 3.37 eV at normal room temperature. It has been used reasonably for its catalytic, electrical, optoelectronic, and photochemical properties [2,3]. Due to their high catalytic activity and vast surface area, ZnO nanostructures have a great benefit to be applied in a catalytic reaction process [3]. Since Zinc Oxide presents different physical and chemical properties which depends on the morphology of nanostructures, not only various synthesis methods but also the physical and chemical properties of synthesized zinc oxide are to be investigated in terms of its morphology [4]. Zinc Oxide (ZnO) is analyzed to be a technologically remarkable material having a broad field of applications like semiconductor, gas sensor, piezoelectric

sensor, electro luminescent material, magnetic material and actuator, ingredients of cosmetics [4].

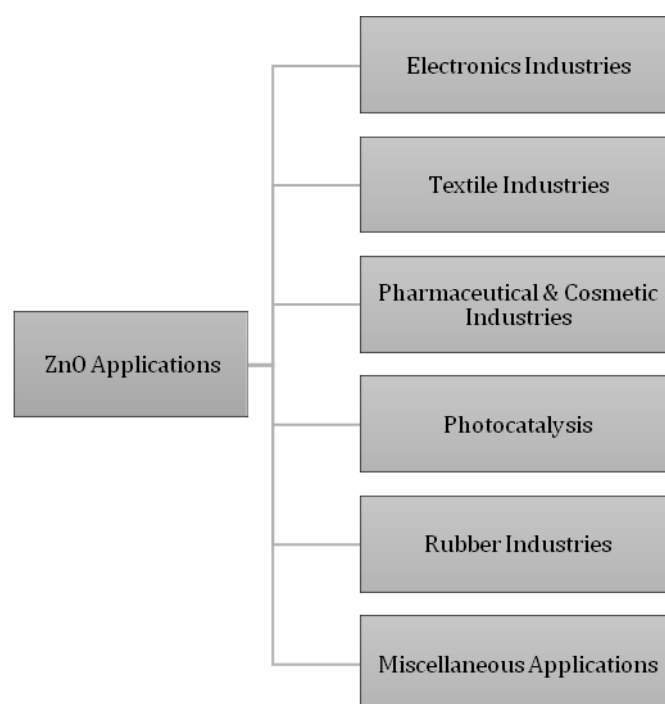


Figure 1: Industrial Applications of Zinc Oxide (ZnO)

Due to the magnificent properties such as high thermal conductivity, high refractive index, binding energy, UV protection and antibacterial capabilities of Zinc Oxide, it is widely applied in various products and materials, including medicine, cosmetics, solar cells, rubber and concrete, foods. Due to the antimicrobial and antitumor activities, Zinc Oxide (ZnO) among nano-sized metal oxides has been extensively applied. ZnO is basically included in some cosmetic lotions as it is also known to maintain UV blocking and absorbing capabilities [5]. ZnO can also be used as the astringent for wounds healing, anti-hemorrhoids, eczema and excoriation in the human medicine [5]. ZnO nanoparticles have recently fascinated consideration owing to its unique features. There are potentially numerous promising applications of ZnO nanoparticles in veterinary sciences due to their wound healing, antibacterial, antineoplastic and antigenic properties. The Zinc Oxide (ZnO) has unique properties, which is summarized in the table 1 below.

Table 1: Properties of ZnO

Basic ZnO Properties		
1.	Appearance	White Solid
2.	Odor	Odorless
3.	Molecular Weight	81.38 g/mol
4.	Crystal Structure	Wurtzite
5.	Coordination Geometry	Tetrahedral
6.	Lattice Constant	$a = 3.25 \text{ \AA}$, $c = 5.2 \text{ \AA}$
7.	Band Gap	3.3 eV
8.	Solubility in Water	0.0004% (17.8°C)
9.	Refractive Index (μ_D)	2.0041
10.	Density	5.606 g/cm ³
11.	Melting Point	1975°C
12.	Flash Point	1436 °C

Recently, many researches and experimental analysis have improved the efficiency of Zinc Oxide (ZnO) materials by producing nano-structures where each nano dimension is reduced to compose nanowires, thin films and other structures for plenty of applications including intracellular pathogens and brain tumors due to its small nano size [5]. This review compacts with the promising applications of ZnO nanoparticles in veterinary sciences. There are numerous conditions in animals where ZnO nanoparticles may play role and the potential uses of ZnO nanoparticles as feed additive and food preservative have also been described. Finally, the challenges in terms of the potential toxic effects of ZnO nanoparticles have also been discussed.

II. ZINC OXIDE NANOSTRUCTURE

Generally, Zinc oxide crystallizes in two main forms, hexagonal wurtzite and cubic zinc blende as shown in the figure 2 (a) and 2 (b) respectively. The wurtzite structure is most stable at environmental conditions and thus it is most common. By growing ZnO on substrates with cubic lattice structure, the zinc blende form can be stabilized [4, 5].

In both structures, the zinc and oxide centers are tetrahedral, which is the most characteristic structural geometry for zinc (Zn). ZnO converts into the rock-salt theme at considerably high pressures. In hexagonal and zinc blende polymorphs, there is no inversion symmetry, it means reflection of the crystals relative to any point do not alter it into itself. Also, other lattice symmetric properties consequence in piezoelectricity of the zinc blende ZnO and hexagonal, and pyro-electric properties of hexagonal ZnO.

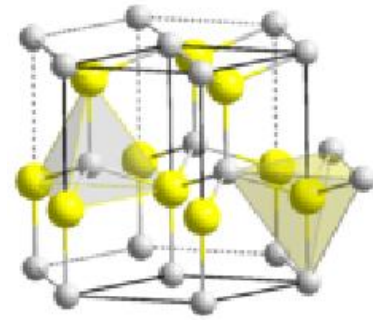


Figure 2 (a): ZnO Wurtzite Structure

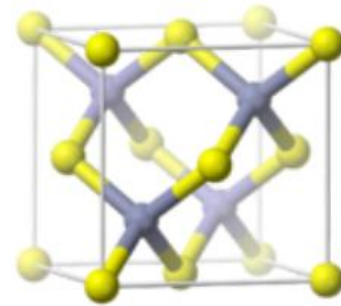


Figure 2 (b): ZnO Zinc blende Unit Cell

The hexagonal structure of zinc oxide (ZnO) has a point group 6 mm in Hermann-Mauguin notation or C_{6v} in Schoenflies notation and the reported space group is generally P6₃mc or C_{6v}4. The lattice constants of ZnO solid structure are $a = 3.25 \text{ \AA}$ and $c = 5.2 \text{ \AA}$, its ratio $c/a \sim 1.60$ is near to the perfect ideal score for hexagonal cell $c/a = 1.633$. The molecular bonding of zinc oxide (ZnO) is completely ionic ($\text{Zn}^{2+}-\text{O}^{2-}$) with the consisting corresponding radius of around 0.074 nm for Zn^{2+} and 0.140 nm for O^{2-} . This belongs to the underlying fabrication of wurtzite structure rather than zinc blende structure as much as the strong piezoelectricity of zinc oxide (ZnO) [5]. By reason that the polar Zn-O molecular bonds, the zinc and oxygen planes are usually electrically charged. For maintaining electrical neutrality, those planes are rebuilt at atomic level in most correlated materials, however it does not occur in zinc oxide (ZnO) and its surface is atomically flat, firm and exhibit no reconstruction. This type of abnormality of ZnO is not completely defined yet.

III. LITERATURE REVIEW

In this section, some realistic analysis, techniques and methods with reference to Zinc Oxide (ZnO) nonmaterial's are reviewed.

A. Zinc Oxide (ZnO) for Nanowire Applications

The zinc oxide (ZnO) nanowires are most commonly synthesized by the approaches like metal-organic chemical vapor deposition, pulsed laser deposition and chemical vapor transport [7]. These procedures can generate high-quality, single crystalline nanowires with lengths of several microns. However, these processes require elevated temperatures of

around 450 to 900°C and often encounter other limitations in terms of substrate choice, sample uniformity and low product yield. In parallel, the solution approaches are affecting because of the low growth temperatures, which is below 350 °C, potential for scaling up and straight forward procedures of producing high-density nanowires [7]. In review focuses on the synthesis and fabrication of ZnO nanowires from the zinc salts solution. This review concentrates on two methods: the hydrolysis of zinc nitrate [Zn(NO₃)₂·6H₂O] in water with the addition of hexa methylenetetramine and the decomposition of the zinc acetate [Zn(CH₃-CO₂)₂] in trioctylamine. The characteristic of the produced nanowires is characterized by the scanning electron microscopy, photo luminescence and transmission electron microscopy. The outline dependence of the products on pH value, solvent and other different additives is reviewed to clarify possible growth mechanisms. The nanowires grown using zinc (Zn) acetate in trioctylamine is doped with transition metals (cobalt, iron, manganese and copper) with an insistence on cobalt-doped nanowires. Also, this survey discusses a method of producing vertical nanowire arrays from substrates coated with zinc oxide (ZnO). Dissolution for a thin layer of zinc (Zn) acetate on the surface, which forms the textured seeds.

We review two strategic techniques for growing zinc oxide (ZnO) nanowires from zinc (Zn) salts in anhydrous and organic solvents. The nanowire arrays with diameters in the nanoscale regime can be grown in an anhydrous solution of zinc nitrate and hexamethylenetetramine. By the combining of poly (ethylenimine), the lengths of the nanowires are increased to 25 μm. Additionally, these arrays of nanowires were fabricated vertically by nucleating the nanowires from oriented zinc oxide (ZnO) nanocrystals. ZnO nanowire arrays are constructed by decomposing zinc acetate in trioctylamine. With the combining of a metal salt to this solution, the ZnO nanowires can be doped with the range of transition metals. Particularly, ZnO nanowires are homogeneously doped with cobalt and it shows a marked deviation from paramagnetic behavior. Finally, by highlighting the usage of these solution-grown nanowire arrays in the dye-sensitized solar cells. The nanowire cells showed an improvement on the charge collection efficiency over conventional nanoparticle cells.

B. Zinc Oxide (ZnO) Nano Structure as Field Effect Transistor

The Zinc Oxide (ZnO) nanostructures nanowire-based field-effect transistors (FETs) are the basic element for nano-electronics applications [8]. Also, The ZnO nanowires FETs are the fundamental building blocks for many nanoscale electronic devices. Early studies of zinc oxide (ZnO) nanowire FETs have focused only on their device performance, and photo detection[9, 10]. Recently, there are so many studies on the role of geometric properties surface states, and passivation on the transport properties of ZnO nanowire FETs, particularly on the effect of nanowire size and surface roughness associated with the presence of surface trap states at the interfaces. The interface roughness plays a prominent role in the electronic transport for transistors. Meanwhile, the qualities of nanostructures used of nanoscale devices strongly depend on their shape and size. The influence of nanowire size and surface roughness associated with the presence of surface trap densities at zinc oxide (ZnO) nanowire interface is presented.

The interface roughness of zinc oxide (ZnO) FET does an important role in the electronic transport, also the electronic capabilities of ZnO nanowire FETs strongly depend on their size and shape. An analysis on the tunable electrical properties of ZnO nanowire FETs calculated and found efficient. The FETs made from surface-tailored ZnO nanowire exhibit two different types of operation modes, which are distinguished as depletion and enhancement modes in terms of the polarity of the threshold voltage. The zinc oxide (ZnO) nanowires FET shows excellent properties, such as good transparency to visible light, excellent uniformity, and high mobility compared with traditional amorphous/polycrystalline silicon devices. The stability of the threshold voltage of ZnO nanowires FETs with different temperatures is one of the most critical problems remaining to be resolved for ZnO FETs. The temperature dependency of the device stability of pristine ZnO nanowire FETs temperature range from 323 to 363 K without any treatment is reported.

C. Zinc Oxide Nanostructure as Nanorods Devices

The Zinc Oxide (ZnO) nanorods devices based containing heterojunction diodes and light emitting diodes (LED) have recently been actively investigated by many researches [8, 9]. The electroluminescence in the ultra violet visible range from ZnO nanorods grown on different substrates has been reported. The hetero junction diodes fabricated from n-ZnO nanorods grown on p-Si substrates reported around 387 nm ultra violet emissions, related to the ZnO near-band gap recombination, and around 535 nm greenish emission related to interface defects. These defects and shortcomings are the defect-free heterojunction interface which is highly preferable for the high and stable injection of carriers and exciton emission of the light emitting diodes (LED) [10].The feasibility of hole injection from highly doped p-type silicon (Si) wafer into a single zinc oxide (ZnO) nanowire has been successfully fabricated.

D. Zinc Oxide nanostructure as Photo Diodes

The Zinc Oxide (ZnO) nanostructures are synthesized and fabricated as photo diodes also. There are increasingly plenty of scientific and industrial applications of photo diodes at nanoscale [11, 12]. The experimental analysis of Zinc Oxide (ZnO) reported that the nanostructures of ZnO heterojunction photodiodes consisting of p-Si and n-ZnO nanowire core and shell structures. The conformal coating made by an n-type ZnO layer that encircled a p-type silicon (Si) nanowire is applied in many photo diode applications. These photodiodes present enhanced ultra violet (UV) and visible responsivities compared to other planar thin film photodiodes [13, 14].

IV. PERFORMANCE MEASURE

The undertaking evaluation of Zinc Oxide (ZnO), the parameter ‘figure of merit’ (zT) is used when ZnO nanostructure is applied as field effect transistor and photo diode. It qualifies the performance of its nanostructure, in the FET and photo diode applications. It is expressed as the temperature T times z as shown in the equation (1):

$$z = \frac{\sigma \cdot S^2}{k} \dots \dots \dots (1)$$

Where, σ = electric conductivity,
 S = Seebeck Coefficient,
 k = Thermal conductivity.

Zinc Oxide (ZnO) nanostructures are perfect photo electric diode have present high Seebeck value and electric conductivity [6]. This property allows it to convert waste heat flow into the electrical energy or inversely, electrical energy into cooling power.

V. CONCLUSION AND FUTURE RESEARCH

In this review, the theoretical, experimental, exploratory and comprehensive analysis of Zinc Oxide (ZnO) nanostructures is presented. Basic qualities of ZnO are outlined and its unprecedented characterizations are explored based on the analytical methods and previous experiments. The nanostructured and experimental investigations of ZnO are reviewed as well. The properties of ZnO at nanoscale, applications in industries, combination into various other nanomaterials, and electrochemical deposition and optimization are analyzed. There will be several further future analysis of Zinc Oxide (ZnO) nano-structures when it is combined with other nano-materials and alloys. The properties and characterization of ZnO will be applied to many industrial applications.

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