Synthesis, Characterization and Applications of ZnO nanoparticles: MiniReview

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Abstract:

Zinc oxide, with its unique physical and chemical properties, such as high chemical stability, high electrochemical coupling coefficient, broad range of radiation absorption and high photostability, is a multifunctional material.This review articles presents the important synthesis methods of ZnO.Further, to improve properties of ZnO various modification techniques are described.The modification with organic (carboxylic acid, silanes) and inroganic (metal oxides) compounds, and polymer matrices were mainly described. Finally , this review article presents the applications of ZnO in various fields : rubber, pharmaceutical, cosmetics, textile, electronic and electrotechnology, photocatalysis were introduced.

Keywords : ZnO nanoparticles ; Synthesis; Modification; application

Abbreviations:

SEM- Scannig electron microscopy

XRD- X-ray diffraction

DMSO- Dimethyl Sulfoxide

APTS- Aminopropyltriethoxysilane

VTES- Vinyltriethoxysilicane

FED- Field emission display

OLED- Organic light emitting diode

I. INTRODUCTION

Zinc oxide, with its relevant physical and chemical properties, such as high chemical stability, high electrochemical coupling coefficient, broad range of radiation absorption and high photostability, is a multifunctional material [1]. zinc oxide is a semiconductor in group II-VI, whose covalence is on the boundary between ionic and covalent semiconductors. A broad energy band (3.37 eV), high bond energy (60 meV) and high thermal and mechanical stability at room temperature.ZnO too have piezo- and pyroelectric properties .ZnO Properties make it attractive for potential use in electronics, optoelectronics and laser technology[2],it can be used as a sensor, converter, energy generator and photocatalyst in hydrogen production [3]. Because of its hardness, rigidity and piezoelectric constant it is an important material in the ceramics industry, while its low toxicity, biocompatibility and biodegradability make it amaterial of interest for biomedicine and in pro-ecological systems [4]. It can be easily etched in all acids and alkalis. Due to this reason it can be used in the fabrication of small size devices e.g.transparent electrodes, window materials for displays and solar cells

Discovery of polymers has given a new dimension to the present era. Polymers are known so far as a class of heat sensitive, flexible, electrically insulating amorphous materials.Polymers are generally known for their insulating property because of covalent bond present in saturated carbon compounds.

Polymers, which consist of large molecules linked together in repeated fashion to form long chains, have naturally existed for a long time.They almost provide low costlarge-area scalability. In most applications however, polymeric materials are multicomponent systems.The integration of fillers such as minerals, ceramics, metals or even air, can generate an infinite variety of new materials with unique physical properties and possibly reduced production cost.

Typically, when the filler in these multicomponent systems, which represents a minor constituent, has at least one dimension below 100 nm, the resulting material is termed, polymer nanocomposite.

In this paper, the methods of synthesis, modification and application of zinc oxide will be discussed. The zinc oxide occurs in a very rich variety of structures and offers a wide range of properties. The variety of methods for ZnO production, such as vapour deposition, precipitation in water solution, hydrothermal synthesis, the sol-gel process, precipitation from

ISSN: 2229-6913 (Print), ISSN: 2320-0332 (Online) -, Web Presence: http://ijoes.vidyapublications.com

microemulsions and mechanochemical processes, makes it possible to obtain products with particles differing in shape, size and spatial structure.

II. METHODS OF SYNTHESIS OF ZINC OXIDE (ZnO)

ZnO nanoparticles were synthesized by different methods. It is confirmed that the various applications of ZnO nanoparticles depend upon the control of both physical and chemical properties such as size, size dispersity, shape, surface state, crystal structure, organization onto a support, and dispensability[5]. This has led to the development of different techniques for synthesizing ZnO that are given below:

Method	Precrusor	Synthesis conditions	Properties
Precipitation method	$(Zn(NO_3)_2.6H_2O)$, KOH	calcination: 2h, 500 °C; aging: 240 h, 320 °C	wurtize structure; particles diameter: 50 nm; application: as a gas sensor
Hydrothermal method	$Zn(CH_3COO)_2..2H_2O$ NaOH	reaction: 10–48 h, 100-200 °C	hexagonal (wurtize) structure, size of microcrystallites: 100 nm–20 μm
Sol-gel method	$Zn(CH_3COO)_2$, oxalic-acid $(C_2H_2O_4)$, ethanol	reaction: 50 °C, 60 min; dried of gel: 80 °C, 20 h; calcined: under flowing air for 4 h at 65^0C	hexagonal wurtize structure; uniform, spherically shaped of particle
Microwave method	zinc acetylacetonatealkoxyethanols	reaction: 15 h, 140 °C; drying: 60	size of the particles of the final product lay in the range 40–

ISSN: 2229-6913 (Print), ISSN: 2320-0332 (Online) -, Web Presence: http://ijoes.vidyapublications.com

			200 nm
Emulsion method	$Zn(C_{17}H_{33}COO)_2$, NaOH, decane, water, ethanol	reaction: 2h, room temperature or 90 °C	particles morphology: irregular particles aggregates (2–10 μm); needle-shaped (L: 200–600 nm, T: 90–150 nm)

Table no. 1 Synthesis methods of ZnO

Precipitation Method

Precipitation is a widely used to synthesize zinc oxide, since it makes it possible to obtain a product with repeatable properties. The method involves fast and spontaneous reduction of a solution of zinc salt using a reducing agent, to limit the growth of particles with specified dimensions, followed by precipitation of a precursor of ZnO from the solution. At the next stage this precursor undergoes thermal treatment, followed by milling to remove impurities. It is very difficult to break down the agglomerates that form, so the calcined powders have a high level of agglomeration of particles. The process of precipitation is controlled by parameters such as pH, temperature and time of precipitation ZnO nanoparticles were synthesized by direct precipitation method using zinc nitrate and KOH as precursors. In this work, the aqueous solution (0.2 M) of zinc nitrate ($Zn(NO_3)_2.6H_2O$) and the solution (0.4 M) of KOH were prepared with deionized water, respectively. The KOH solution was slowly added into zinc nitrate solution at room temperature under vigorous stirring, which resulted in the formation of a white suspension. The white product was centrifuged at 5000 rpm for 20 min and washed three times with distilled water, and washed with absolute alcohol at last. The obtained product was calcined at 500 °C in air atmosphere for 3 hr. The size of the produced ZnO powder was approximately 20–40 nm.[6] A controlled precipitation method was also used by Hong et al., the process of precipitating zinc oxide was carried out using zinc acetate ($Zn(CH_3COO)_2 \cdot H_2O$) and ammonium carbonate $(NH_4)_2CO_3$[7].

Hydrothermal Method

Hydrothermal technique is a another method with low process temperature and very easy to control the particle size. The hydrothermal process have several advantage over other growth processes such as use of simple equipment, catalyst-free growth, low cost, large area uniform production, environmental friendliness and less hazardous. The low reaction temperatures make this method an attractive one for microelectronics and plastic electronics[8]. This method has also been successfully employed to prepare nanoscaleZnO and other luminescent materials. The particle properties such as morphology and size can be controlled via the hydrothermal process by adjusting the reaction temperature, time and concentration of precursors.

In order to synthesize the ZnO nanoparticles, solutions of $Zn(CH_3COO)_{2.}2H_2O$ (0.1 M) was prepared in 50ml methanol under stirring. After this 25ml solution of NaOH (varying from 0.2 M to 0.5 M) prepared in methanol was added under continuous stirring in order to get the pH value of reactants between 8 and 11. These solutions was transferred into teflon lined sealed stainless steel autoclaves and maintained at various temperature in the range of 100 – 200 ^{0}C for 6 and 12 h under autogenous pressure. It was then allowed to cool naturally to room temperature. After the reaction was complete, the resulting white solid products were washed with methanol, filtered and then dried in air in a laboratory oven at 60 ^{0}C.[9]

Sol-gel Method

The sol-gel process, involves the evolution of inorganic networks through the formation of a colloidal suspension (sol) and gelation of the sol to form a network in a continuous liquid phase (gel).

Sol-gel method used for preparation of zinc oxide nanoparticles (ZnO-NPs) starts with 12.6g of zinc acetate dihydrate was added to 400 ml of double distilled water with continuous stirring to dissolve zinc acetate completely. Then the solution was heated to 50°C and 600 ml of absolute alcohol was added slowly with stirring. After this, 6ml of H_2O_2 (% 47) was added dropwise to the vessel and mixed it using a magnetic stirrer to get an almost clear solution. This solution was incubated for 24 hours and the solution was dried at 80℃ for several hours to obtainwhite nano zinc oxide. Nano zinc oxide was washed several times with double distilled water to remove the byproducts. After washing, the ZnO nanoparticles were dried at 80℃ in hot air oven. Complete conversion of zinc oxide will occur during the drying process.[10]

Microwave Method

Microwaves method make it possible to heat the solutions from which the synthesis products are obtained, while avoiding loss of energy on heating the entire vessel. Many chemical syntheses proceed with greater speed and yield when microwaves are used than in the case of traditional methods.

Schneider *et al.* [11] obtained Zinc oxide by using this method. Zinc oxide was obtained by heating, using microwaves, zinc acetylacetonate and a zinc oxime complex in various alkoxyethanols (methoxy-, ethoxy- and butoxyethanol). Schneider et al., showed that the morphology and aggregation of ZnO particles depends strongly on the precursor used. The size of the particles of the final product lay in the range 40–200 nm, depending on which precursor and alcohol were used. With an increase in the concentration and chain length of the alcohol, the particle size increased.

Emulsion Method

Emulsion is firstto dividethem into two large groups based on the nature of the external phase. The two groups are usually called oil-in-water (O/W) and water-in-oil (W/O) emulsions.

Vorobyova *et al.* used emulsion systems in their work. Zinc oxide was precipitated in an interphase reaction of zinc oleate (dissolved in decane) with sodium hydroxide (dissolved in ethanol or water). The process as a whole involved in the reaction

$$Zn(C_7H_{33}COO)_2 + 2\ NaOH \Longrightarrow ZnO + H_2O + 2C_{17}H_{33}COONa$$

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The conditions of the process (temperature, substrates and ratio of two-phase components) affect the size of the particles and the location of their phases.Vorobyova*et al*.obtained zinc oxide with different particle shapes and with diameters in the range: 2–10 μm, 90–600 nm, 100–230 nm and 150 nm respectively, depending on the process conditions.[12]

III. METHODS OF MODIFICATION OF ZINC OXIDE

Modification is also often carried out with aim to improve Zinc oxide performance properties, such as high or low (depending on application) photocatalytic activity. Synthesis of ZnO particles with a precipitation method in alcohol solution is the most commonly used and low-cost route. But ZnO particles aggregate easily in solution due to van der Waals forces and surface effects.So some modifications had done by the scientists ,Figure.1 presents a schematic that includes all the method of modification

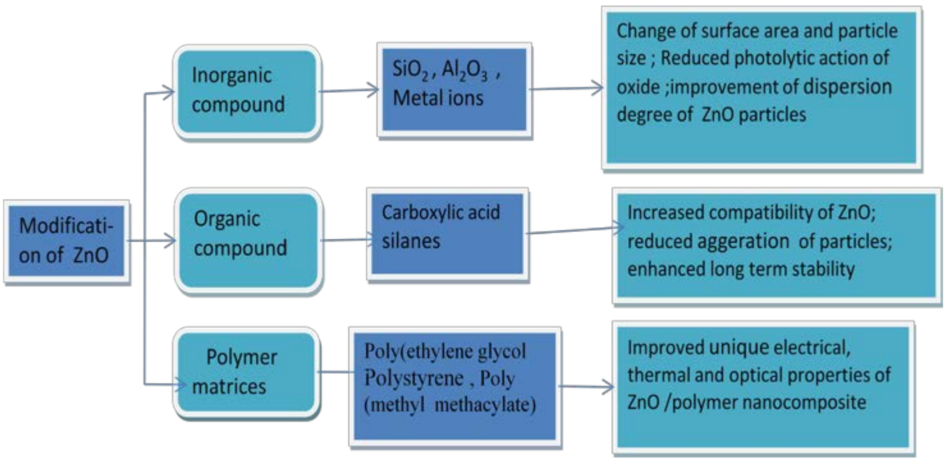

Figure.1 Schematic diagram of the most popular modifying methods of ZnO[13]

Modification of zinc oxide using silica and trimethylsiloxane (TMS)

Cao *et al*. performed modification of zinc oxide using silica and trimethylsiloxane (TMS). The finest particles of ZnO were produced by calcination of the precursor zinc carbonate hydroxide (ZCH). ZCH was obtained in a process of precipitation from substrates such as zinc sulfate heptahydrate ($ZnSO_4 \cdot 7H_2O$), ammonium solution (NH_4OH) and ammonium bicarbonate (NH_4HCO_3). The surface of the ZCH was then successively modified by an in situ method using TEOS and hexamethyldisilazane (HMDS) in water. The ZCHobtained in this way was calcined, to obtain ultrafine particles of ZnO. Modification of the ZnO particles made possible a solution to the problem of their agglomeration. The highly transparent modified zinc oxide surface was found to provide excellent protection against UV radiation, which represents a significant advantage of the use of these modifying agents.[14]

Modification of Zinc oxide using Silica

Modification with the use of silica was also performed by Xia and Tang.By a method of controlled precipitation, clusters of zinc oxide were obtained on the surface of silica modified using triethanolamine $N(CH_2CH_2OH)_3$(TEOH) and containing silanol (≡Si-OH) and siloxane (≡Si-O-Si≡) groups. Molecules of TEOH are adsorbed by the silica, and the siloxane and silanol networks are broken as a result of the changes occurring in the SiO_2. The Zn2+ ions, in reaction with triethanolamine, produce clusters of ZnO on the silica surface. According to the theory of maturing and aggregation, the final clusters are susceptible to rapid collision with other clusters of zinc oxide, leading to an appropriate concentration of the compound. An important role in the proposed modification technique is played by TEOH, which enables complex structures to be obtained.[15]

Modification of Zinc Oxide using Inorganic Compound

Modification of ZnO using an inorganic compound, namely Al_2O_3, was carried out by Yuan et al.Nanometric zinc oxide coated with Al_2O_3, with diameter 50–80 nm, was obtained by calcination of basic zinc carbonate (BZC) with simultaneous modification with a precipitate of $Al(OH)_3$ at 400–600 °C. The coating obtained was highly uniform, and had a thickness of 5 nm. The pH at the isoelectric point for ZnOnanoparticles with an Al_2O_3 layer moved from around 10 to a value of 6, which may improve the dispersion of ZnO particles.[16]

Modification of zinc oxide using poly(ethylene glycol)

Modification of zinc oxide using poly(ethylene glycol) and octadecyltrimethoxysilane, performed by Pyskło*et al*[17].In order to improve its dispersion in rubber mixtures. The modification used zinc oxide synthesized by a hydrothermal method.. The modification was carried out in the following way: in a solution containing 5% by Silane relative to the mass of ZnO used, a ZnOnanopowder was dispersed. The resulting system was then mixed using an ultrasound disintegrator ,in the case of silane the system was first mixed with a magnetic mixer, with simultaneous heating. The resulting precipitate was filtered and dried at a temperature of 80 °C for 48 h.

Modification of Zinc oxide using Modified Sol gel Method

Modified sol-gel method is used for the synthesis of ZnOnano- particles using zinc acetate dihydrate, ethylene diaminedihydrochloride and NaOH as precursors and poly(vinyl pyrrolidone) as surfactant to control the morphology and shape of synthesized ZnO nanoparticles. Poly(vinyl pyrrolidone) are used as capping agent and distilled water as solvent, using magnetic stirrer. The synthesized ZnOnano particles are dried in oven at 100 °C for 2 h and then calcinated at 500 °C in muffle furnace for 2 h. [18]

Modification of Zinc oxide using Graphene oxide

Graphene oxide is a two-dimensional material with intriguing properties such as large surface-to-volume ratio, robust optical transparency, and electronic transport capabilities.[19]Microscopic characterization has revealed that graphene oxide has a layered structure in which carbon atoms twist to form tetrahedrons, which creates wrinkles and grooves on the surface.Chemically functionalized groups on the π-conjugated planes of graphene oxide allow easy anchoring of covalently bonded micrometer and nanometer particles onto grapheneoxide.Diverse applications for graphene oxide in biological sensors, photocatalysis, and nanocomposites have been explored.The modification of graphene oxide effectively prevented the aggregation of ZnO particles and resulted in strong stability in the ambient environment.Firstly , zinc oxide particles are synthesized using simple method .After this Graphene oxide synthesized using Hummer method with Graphite powder as precursor .Then in last ZnO and grapheme oxide composites are fabricated .The prepared ZnO (0.50 g) was dissolved in 10 mL DMSO and ultrasonicated for 1 hour. APTS (10 mL) was added to the solution and sonicated for 2 hours to complete the reaction. The amino-functionalized ZnO was separated from the solution via centrifugation, washed with absolute ethanol, and dried in an oven. ZnO-APTS particles (0.10 g) and graphene oxide powder were dissolved in dimethylformamide (DMF). The solution was mixed and sonicated for 2 hours to obtain uniform dispersion. Finally, ZnO/graphene oxide composites were recovered via centrifugation and washed three times with alcohol, and dried in an oven for future use.

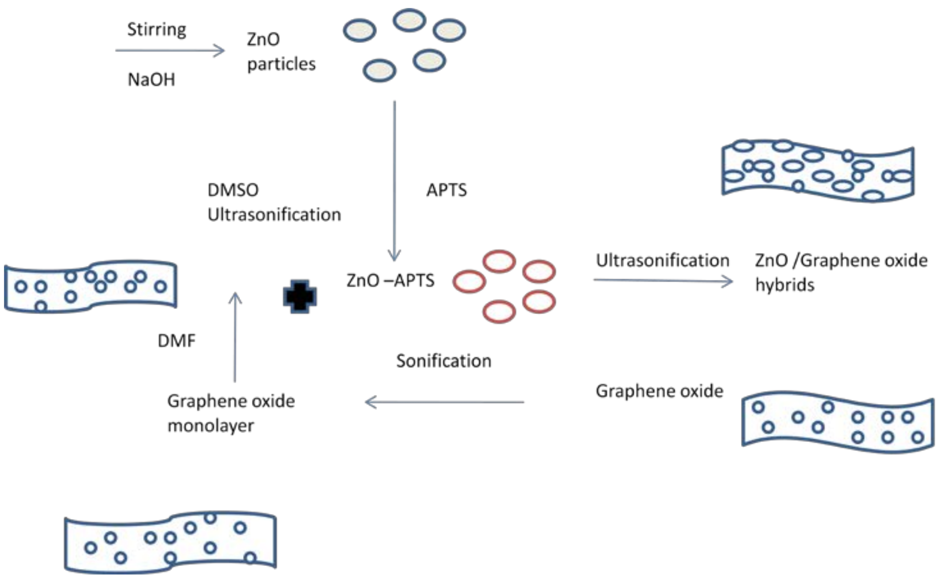

Figure 2 Modification of Zinc oxide using Graphene oxide

IV. APPLICATIONS OF ZINC OXIDE

Because of its various properties, both chemical and physical, zinc oxide is widely used in many areas. It plays an important role in a very wide range of applications, ranging from tyres to ceramics, from pharmaceuticals to agriculture, and from paints to chemicals.

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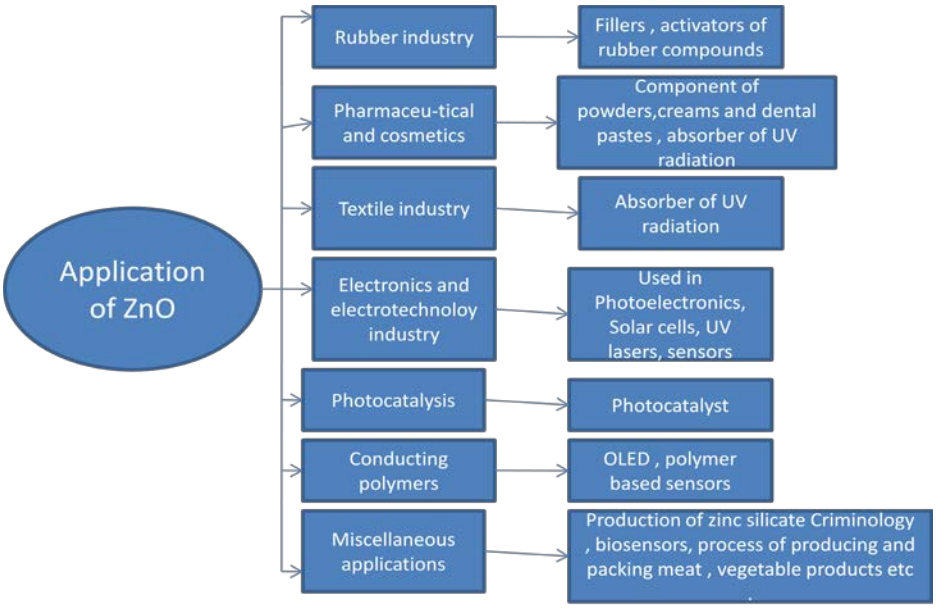

Figure3. Schematic representation of all the application of ZnO

Rubber industry

Global production of zinc oxide amounts to about 105 tons per year, and a major portion is consumed by the rubber industry to manufacture various different cross-linked rubber products.**[**20]

The thermal conductivity of pure silicon rubber is relatively low , it can be improved by adding thermal conducting fillers that includes metal powder, metal oxides and inorganic particles.For e.g. Al_2O_3, MgO, ZnOetc.As we know , ZnO nanoparticles tend to aggeregate and form large size particles in polymer matrix.It happens due to weak interaction between surface of nanoparticles and the polymer.

This problem was solved by using modification techniques applied to improve interaction between surface of nanoparticles and the polymer.In the work of Yuan *et al*. [21], in order to prepare the silicone rubber with high thermal conductivity, and surface-modified ZnO nanoparticles containing the vinyl silane group are mixed into the silicone rubber via a hydrosilylation reaction during the curing process. The corresponding structure, morphology and properties of the silicone rubber/ZnO were investigated. Yuan et al. synthesized ZnO nanoparticles (with an average size below 10 nm) by a sol-gel procedure. Next the silicone

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coupling agent VTES was successfully incorporated onto the surface of the nanoparticles. The Silicone rubber nanocomposites showed better mechanical properties and higher thermal conductivity due to the formation of a cross-linking structure with the silicone rubber matrix and better dispersion in that matrix.Zinc oxide is a very effective and commonly used cross linking agent for carboxylated elastomers It can be used to produce vulcanizates with high tensile strength, tear resistance, hardness and hysteresis.

Przybyszewska*et a*l. [22] used zinc oxides with different surface areas, particle sizes and morphologies like spheres, whiskers, snowflakes as cross linking agents of carboxylated nitrile elastomer, in order to determine the relationship between the characteristics of zinc oxide and its activity in the cross linking process. They concluded that the use of zinc oxide nanoparticles produced vulcanizates with better mechanical properties and higher crosslink density, as compared with vulcanizates cross linked with micro-sized zinc oxide, which is used commercially as a cross linking agent.

The Pharmaceutical and Cosmetic Industries

Zinc oxide is widely used in the production of various kinds of medicines due to its disinfecting , antibacterial and drying properties. At the present time it is applied locally, usually in the form of ointments and creams, and more rarely in the form of dusting powders and liquid powders. ZnO has properties which accelerate wound healing, and so it is used in dermatological substances against inflammation and itching. In higher concentrations it has a peeling effect. It is also used in suppositories. In addition it is used in dentistry, chiefly as a component of dental pastes, and also for temporary fillings. [23]

Sun creams also contained nanoparticles of ZnO or TiO_2, they contained thick preparations which did not rub easily into the skin and which were cosmetically unattractive. Due to their ability to absorb UVA and UVB radiation, these products began to be used in creams. A new cream formula, containing a combination of ZnO and TiO_2, solved the problem of an insufficiently white layer and produced a new medium which is more transparent, less adhesive and much more easily rubbed into the skin.[24] zinc oxides are extremely good media in sun creams, since they absorb UV radiation, do not irritate the skin, and are easily absorbed into the skin.

ISSN: 2229-6913 (Print), ISSN: 2320-0332 (Online) -, Web Presence: http://ijoes.vidyapublications.com

Being inexpensive and convenient, fluorescence imaging has been widely used in preclinical research. Since ZnOnanomaterials exhibit efficient excitonic blue and near-UV emission, which can also have green luminescence related to oxygen vacancies , many reports exist in the literature on the use of ZnOnanomaterials for cellular imaging.ZnOnanomaterials are versatile nanoplatforms for not onlybioimaging but also drug delivery applications, due to their large surface area, versatile surface chemistry, phototoxic effect, among others. In vitro studies have shown that ZnO nanoparticles can be highly toxic to cancer cells or bacteria and leukemic T cells.Therefore, not only have ZnOnanomaterials been investigated as drug/gene delivery vehicles, they have also been studied for cancer therapy.

The Textile Industry

The textile industry offers a vast potential for the commercialization of products based on nanotechnology . In particular, water repellent and self-cleaning textiles are very promising for military applications. Also in the business, self-cleaning and water repellent textiles are very helpful for preventing unwanted stains on clothes. Protection of the body from the harmful UV portion of sunlight is another important field. Many scientists have been working on self-cleaning, waterrepellent and UV-blocking textiles .[25]

Zinc oxide is biologically compatible, so it has important in textile industry . Nanostructured ZnO coatings are more air-permeable and efficient as UV-blockers compared with their bulk counterparts . Therefore, ZnO nanostructures have become very attractive as UV-protective textile coatings. Different methods have been reported for the production of UV-protecting textiles utilizing ZnO nanostructures. For instance, ZnO nanoparticles grown by hydrothermal method in SiO2-coated cotton fabric showed excellent UV-blocking properties.[26]

The Electronics and Electrotechnology Industries

ZnO is an attractive material for applications in electronics, photonics ,acoustics and sensing.ZnO also exhibits the phenomenon of luminescence ,Because of this property it is used in FED (field emission display) equipment, such as televisions. It is more resistant to UV rays, and also has higher electrical conductivity. The photoluminescent properties of zinc

ISSN: 2229-6913 (Print), ISSN: 2320-0332 (Online) -, Web Presence: http://ijoes.vidyapublications.com

oxide depend on the size of crystals of the compound, defects in the crystalline structure, and also on temperature [27]. ZnO is a semiconductor, and thin films made of that material display high conductivity and excellent permeability by visible rays. These properties mean that it can be used for the production of light-permeable electrodes in solar batteries. It also has potential uses as a transparent electrode in photovoltaic and electroluminescent equipment, and is a promising material for UV-emitting devices.[28]

ZnOnanorod and nanowire FET sensors may create chance for highly sensitive and selective real –time detection of a wide variety of gas molecules and biomolecules.The principal of gas sensor depends upon the nature of gas molecules and modification of nanowire FET conductivity. The zinc oxide used in the production of such equipment is obtained by a variety of methods (chemical vapour deposition, aerosol pyrolysis or oxidation of metallic zinc); it is important to control the process temperature, since this determines the properties of the product.[29]

One of the most important applications of zinc oxide in electronics is in the production of varistors. These are resistors with a non-linear current-voltage characteristic, where current density increasesrapidly when the electrical field reaches a particular defined value. They are used, among other things, as lightning protectors, to protect high-voltage lines, and in electrical equipment providing protection against atmospheric and network voltage surges. These applications require a material of high compactness, since only such a material can guarantee the stability and repeatability of the characteristics of elements made from it.[30]

Besides semiconducting properties, ZnOnanomaterials also exhibit various desirable traits for biosensing such as high catalytic efficiency, strong adsorption capability, and high isoelectric point (IEP; ~9.5) which are suitable for adsorption of certain proteins.Furthermore, high surface area, good biocompatibility/stability, low toxicity, and high electron transfer capability also make them promising nanomaterials for biosensor.[4]

Photocatalysis

The photocatalytic properties of zinc oxide, titanium dioxide ($ZnO-TiO_2$) composite were investigated by Guo et al. [31]. ZnO was obtained in solution, this being a low-temperature and low-cost method. The properties and photocatalytic applications of the ZnO obtained in this way were studied. A sample was placed on a Petri dish containing an aqueous solution of methyl orange (pH 6.7). While being exposed to UV radiation the solution was mixed and stimulated by sunlight with or without polycarbonate filters. Absorption was measured immediately before exposure to UV and at set time intervals, using a UV/Vis spectrometer. These tests showed that the ZnOnanorods have similar photocatalytic properties (with UV) or slightly better properties) compared with TiO2 nanotubes. However, coating the surface of ZnO with a layer of TiO2 causes deterioration of the photocatalytic properties, possibly due to an increase in the quantity of defects.It is concluded that photocatalytic properties of ZnO can be influenced by coating with various substances and by the thickness of such coating.

ZnO nanoparticles with Conduting Polymers

ZnO has received much attention in recent years due to its diverse properties. It is a direct wide bandgap semiconductor (E_g = 3.4 eV) with large exciton binding energy (~60 meV), suggesting that it is a promising candidate for stable room temperature luminescent and lasing devices.ZnONanomaterials are attractive dopants to polymers because of their high surface reactivity, which is attributed to very large surface-to-volume ratio. Moreover, they possess intriguing properties associated with quantum confinement effects, making their interaction with different polymers a subject of great interest.[32]

Polymeric-based light emitting device is one type of OLED, which stands for organic light emitting diode. Photon is generated in the polymer emissive layer (EL), which should possess excellent photoluminescence (PL) propertieIt should be realized that the realization of high efficient OLEDs depends not only on the electronic and optical properties of the EL material, but also on the control of charge transport in the device. One of the benefits of doping polymers in OLED with ZnO nanostructures is the improvement in charge carrier transport. It has been reported that by incorporating ZnOnanorods with the EL material low threshold voltage and higher electroluminescence efficiency is obtained.

Polymer based conductivity sensors is one other application of conducting polymers doped with ZnO.The operation of a metal oxide sensor is based on the dependence of the conductivity to O_2 molecules adsorbed on its surface. For n-type metal oxides such as ZnO or

ISSN: 2229-6913 (Print), ISSN: 2320-0332 (Online) -, Web Presence: http://ijoes.vidyapublications.com

TiO_2, O_2 molecules capture electrons on the surface or at the grain boundaries resulting in the decrease of conductivity.Trapped electrons at the grain boundaries also produce potential barriers between grains that impede current flow. When exposed to reducing gas like H_2, CH_4, CO , the adsorbed O_2 molecules react with the gas and release the captured electrons. This increases the conductivity of the sensing material.[33]

Miscellaneous Applications

Apart from the applications mentioned above, zinc oxide can also be used in other branches of industry, including for example concrete production. The addition of zinc oxide improves the process time and the resistance of concrete to the action of water. Also, the addition of ZnO to Portland cement slows down hardening and quenching.

ZnO is also used for the production of typographical and offset inks. It imparts good printing properties (high fluidity). The addition of ZnO means that the inks have better covering power, pure shade and high durability, and prevents darkening.

Zinc oxide is also used in pigments to produce shine.It is added to many food products, including breakfast cereals. ZnO is used as a source of zinc, which is an essential nutrient. Thanks to their special chemical and antifungal properties, zinc oxide and its derivatives are also used in the process of producing and packing meat products (e.g., meat and fish) and vegetable products[34]

ZnO and its derivatives suppress the development and growth of fungi and moulds. Zinc oxide is added to fungicides to improve their effectiveness. Zinc oxide is also being used increasingly often as an animal feed additive, as it supports the correct growth of animals. It is also used as an artificial fertilizer.[35]

ZnO and its derivatives are also used as an additive to car lubricating oils, reducing consumption and oxygen corrosion. In the future, advantage may also be taken of the adhesive properties of ZnO[36]

Zinc oxide also has uses in criminology, in mechanical fingerprint analysis. It is also an ingredient in cigarette filters, as it selectively removes certain components from tobacco smoke. Filters are made of charcoal impregnated with ZnO and Fe_2O_3, which remove significant quantities of HCN and H_2S from tobacco smoke without producing a smell.

CONCLUSION

Zinc oxide is unique, multifunctional material due to its many properties, a wide range of UV absorption, and high photostability, biocompatibility and biodegradability.ZnO nanoparticle can also be obtained with aofways , which determine its use in new materials and potential applications in a wide range of fields of technology.Development of method of synthesization of CrystalineZnOis interesting area nowdays in science.

ZnO have various applications in different fields. The use of such materials can provide, among other more durable ceramics, transparent solar filters blocking infrared and ultraviolet radiation, and catalysts. These materials are also useful in biomedical research and in the diagnosis and treatment of diseases. They can be used to deliver medicines directly to diseased cells, in a way that avoids adverse effects.

The literature has been given here shows that Zinc oxide due to its unique properties classed as multifunctional substance.Zinc oxide properties such as high chemical stability, high electrochemical coupling coefficient, broad range of radiation absorption and high photostability, makes it a multifunctional material. The continuous growth of ZnO can be expected in future time that leads development of new applications of ZnO.

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