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Significant Applications of Zinc Oxide Nanoparticle in Various Fields

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Abstract

Nanotechnology is a field of passionate research activity due to ability of potential applications in several area. Nanotechnology includes the research and engineering of new materials at the nanoscale level. The broad applications of nanoscale metal oxide particles are among the available nanomaterials because of their unique excellent properties. The indispensable properties of metal oxide nanoparticles are physical properties like high surface area, small size, high reactivity and optical properties, higher ductility at elevated temperatures, cold welding properties, superparamagnetic properties, electric properties, unique catalytic, sensitivity, and selective activity. Metal oxide nanoparticles exhibit peculiar adsorptive properties and fast diffuseness and they are unstable in critical conditions. Among many metal oxide nanomaterials, Zinc oxide (ZnO) nanomaterials have emerged as an adaptable material in various fields due to their unique properties and extensive applications. This review article provides thorough information about advance applications of ZnO nanomaterials across diverse domains. It has gained significant attention in various applications, particularly in drug delivery systems, agriculture and food industry, cosmetics, textiles, tissue engineering, health care, paints, antibacterial agents, bioimaging, environmental remediation.

Keywords: Nanomaterial, zinc oxide, cosmetics, agriculture, food, textile, health.

Introduction

During the last two decades, the progression of nanotechnology and nanomaterials has developed significantly. Nanoparticles are defined as a distinct nano-object with all three Cartesian dimensions less than 100 nm. However, expansive definition of nanomaterial is a nano-object with just one of its characteristic dimensions in the range 1-100 nm. Its other dimensions can be different in range, but the lower limit of 1 nm is defined because atomic bond lengths are reached at 0.1 nm. There are many types of nanoparticles, including metal nanoparticles, metal oxide nanoparticles, liposomes, dendrimers, polymer nanoparticles, magnetic nanoparticles, micelles, and others. Special attention in the development of nanoparticles of metals and metal oxides is because of their unique features, such as smaller particle size, large surface-to-volume ratio, distinctive physicochemical properties and adjustable morphological properties. These characteristics make them capable for use in various fields, including microbiology, material science, environmental protection, optics, electronics, and biomedical sciences. The most commonly engineered nanoparticles include copper, silver, zinc, platinum, gold, and magnesium. Among metal oxides such as cerium oxide, zinc oxide, titanium oxide, copper oxide, and silver oxide are significantly studied. To increase the stability and biocompatibility of nanoparticles, they are often coated or doped with organic materials [1, 2, 3].

Zinc oxide nanoparticles are one of the metal oxides which is a competent, premium and multifaceted inorganic compound due to protean physical and chemical characteristics. They have unique optical properties because of broad band gap and high refractive index, high chemical stability, a broadened radiation absorption spectrum, high electrochemical coupling coefficient, and high photostability and biocompatibility. ZnO nanoparticles have been extensively synthesized and applied in different commercial and consumer products, including paints, ceramics, cement, packaging, plastics, glass, ointments, textiles, lubricants, adhesives, sealants, pigments, batteries, ferrites, fire retardants, cosmetics, sunscreens and in foods as a source of zinc nutrient. ZnO nanoparticles have significant antibacterial properties due to their small size [4, 5].

Structure of ZnO NPs: ZnO is a prominent wide band gap II-VI semiconductor in the field of materials science because zinc and oxygen are members of the second and sixth groups of the periodic table. Its large bandgap, or 3.37 eV, is on the borderline between ionic and covalent semiconductors. The Zinc oxide has a wurtzite (B4) crystal structure, having a hexagonal unit cell with a lattice parameter a = 0.325 nm and c=0.512 nm. The distance between the Zn^{2+} ion and O^{2-} ion along the c-axis is 0.1992 nm, and the distance between these two ions along the other three axes is 0.1973 nm. With its hexagonal wurtzite structure, each anion is surrounded by four cations at the corners of the tetrahedron, which exhibits tetrahedral coordination and hence displays the sp^3 covalent bonding [6, 7].

Synthesis Methods of ZnO Nanoparticles: The synthesis of nanoparticles can be achieved using physical, chemical, and biological methods, each one has its advantages and disadvantages. Synthesis of nanoparticles has two basic approaches one is top-down and the other is bottom-up. To obtain correct morphology, some key techniques for the preparation of ZnO nanoparticles are Hydrothermal Method, Precipitation Method, Sol-Gel Method, Chemical Vapour Deposition Method, Biological Synthesis Method, Physical Vapour Deposition Method, Ultra Sonic Irradiation Method,

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Laser Ablation Method, Chemical bath deposition, and many others [8].

Characterization of Nanoparticles: Nanomaterials are characterized to investigate various physical and chemical properties, and involve multiple methods to acquire all fundamental characteristics. Characterization is usually carried out by applying different methods, such as UV-Visible spectroscopy, Fourier Transform Infrared Spectroscopy (FT-IR), Scanning Electron Microscope (SEM), Transmission Electron Microscope (TEM), X-ray diffraction (XRD), and other methods, such as Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Optical properties are examined by UV-Visible spectrophotometry. The FT-IR method is used to evaluate the chemical bonds on the surface of the nanoparticle in order to assess the presence of individual components. SEM analyzes the surface morphology, topography, and composition of nanoparticles, while TEM is used to know the exact size and shape of nanoparticles. The XRD methodology is used to study the crystal structure and chemical nature of the components used for synthesis [9, 10].

Various Applications of Zinc Oxide Nanoparticles

a) **Applications of ZnO NPs in the Food Industry:** Zinc oxide nanoparticles have great importance in the food industry to kill or reduce the activity of harmful microorganisms. The antibacterial properties of ZnO nanoparticles may improve food quality, which causes a direct impact on human health. ZnO nanoparticles have a positive charge which destroys cell membranes through electrostatic forces. They can improve the shelf life of food by generating reactive oxygen species and by releasing zinc ions which disrupt cellular metabolism. Spraying ZnO nanoparticles extends tomatoes shelf life by increasing their lycopene content and edible film with ZnO improves the shelf life of bread. ZnO can improve food flavour and also protect food from deterioration. ZnO nanoparticles can be used as zinc fortifiers in processed foods. ZnO nanoparticles play a vital role in food processing, storage and packaging because of their unique properties [11, 12, 13].

b) **Applications of ZnO NPs in Agriculture Sector:** ZnO nanoparticles are one of the most engineered inorganic nanoparticles and have been utilized in various related sectors, with special interest in the agriculture sector with the potential because of its versatile characteristics. ZnO nanoparticles help to grow roots and shoot fresh and dry weight. ZnO NPs can improve carbon and nitrogen metabolism and cellular metabolism. They can support plant to tolerate environmental stress. They can regulate the antioxidant systems in plants. ZnO NPs help harmonize the beneficial microbes and nutrient cycles. They can modulate genes involved in oxidative stress. They can enhance the synthesis of photosynthetic pigments. ZnO NPs can increase the yield and nutritional value of plants. They can reduce environmental contamination. ZnO NPs are superior to traditional zinc salt fertilzers. ZnO NPs can promote environmentally benign agriculture processes like seed priming. They can assist farmers in making decisions that minimize negative environmental impacts [14, 15, 16].

c) **Role of ZnO NPs in Textile Industry:** Zinc oxide is extensively used in various fields because of its unique photo-catalytic, electrical, electronic, optical, dermatological, and antibacterial properties. For these applications, the nanoparticles need to be dispersed homogeneously to prevent particle agglomeration and to increase the stability of ZnO nanoparticle dispersions. Zinc oxide nanoparticles are non-toxic and chemically stable under high temperature and have the ability to photocatalytic oxidation. ZnO nanoparticles have a large surface area-to-volume ratio that increases the effectiveness of photocatalytic oxidation activity. Traditional textile finishing processes are used to impart different properties like water resistance and stain repellent to fabric that do not show permanent effects and lose their properties after washing or use. ZnO nanoparticles can impart high durability for treated fabric because of the large surface area and high surface energy that give increased affinity to fabrics and enhancement in the durability of the desired textile functions. Because of its small size and high surface energy, ZnO nanoparticles are fixed to the fabric surface by Van der Waals forces which produce fastness to wash. For this purpose, ZnO nanoparticles can be applied by dipping the fabrics in a solution containing a specific binder. Wash fastness can be fortified with the formation of covalent bond between nanoparticles and the fabric surface and the excellent functional properties are lasted up to several washing. Other important applications of ZnO nanoparticles in textile sector are protection from UV rays, water, fire, bacteria, fungi and other hazards [17, 18, 19].

d) **Applications of ZnO NPs in cosmetic products:** zno nanoparticles are employed in many cosmetic products such as sunscreens, face powder, lipstick, lotions, and moisturiser cream and many products. ZnO NPs are used in sunscreen lotion to reflect hazardous UV rays. ZnO NPs have antimicrobial characteristics which reduce the rapid growth of micro-organisms on the skin make them beneficial for acne treatment and wound care products. They have anti-inflammatory properties which can help soothe and calm irritated skin. ZnO NPs promote wound healing by increasing collagen synthesis, improving tissue repair, and reducing inflammation. ZnO NPs, used in lip balm, can help to calm and comfort dry, chapped, or irritated lips because of their anti-inflammatory and soothing properties. ZnO NPs help lock in moisture and reduces dryness and flakiness [20, 21].

e) **Applications of ZnO NPs in Health Care:** ZnO nanoparticles have significant antibacterial properties due to their small size, which can stimulate different bactericidal mechanisms once inside the bacterial cell. Chemotherapy, radiation, and surgery have all been used to treat cancer in the past few decades, they all have a long list of negative side effects. ZnO nanoparticles destroy malignant cells without causing cytotoxicity in healthy cells. ZnO nanoparticles are regarded as harmless material for biological system. They show anticancer action by causing the production of ROS as well as promoting apoptosis. ZnO NPs can be used as an antibacterial compound due to a large specific surface area exhibiting distinctive morphology, particle size, crystallinity, and porosity, and the ability to kill a wide range of pathogens, they have a broad spectrum of antimicrobial activity against a variety of microbes. Zinc has a key role in insulin storage, biosynthesis, and secretion. ZnO NPs have good anti-diabetic efficacy by enhanced insulin levels, glucose disposal, and zinc state. They efficiently corrected diabetes-stimulated pancreatic disease and biochemical normalization of serum insulin and blood glucose. ZnO nanoparticles exhibit Anti-Inflammatory activity with effectiveness as they could permeate the deepest layers of allergic skin and also suppress local skin irritation and increase the synthesis of Immunoglobulin E antibodies in the system. ZnO nanoparticles are used in drug delivery system as an effective instrument in the therapy of many diseases including cancer. Another important application of ZnO nanoparticles is as carriers for gene transport to various cells, specialy malignant cells. Various forms of ZnO NPs which are used in bio-imaging technique to distribute genes has several benefits [1, 22, 23, 24, 25, 26].

Conclusion

Zinc Oxide Nanoparticles have become an important part of nanoparticles and nanotechnology. They have been used in different application fields like textile, cosmetics, agriculture and food industry, health care and in production of pigments, semiconductors, UV protection films, chemical sensors, modern sunscreens and hair care products. In this review, some major processes of synthesis have been discussed like sol-gel, CVD, precipitation method, biological synthesis and many other. ZnO NPs show distinct physical and chemical characteristics because of their substantial surface area and nanoscale dimensions transparency, UV absorption efficiency and chemical stability. Their nano size, shape, and structure increase their reactivity and multifunctionality. It is stated that profuse applications of ZnO nanoparticles have great features and prospective in the future and that will undoubtedly facilitate creative discoveries and propel scientific advancements.

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