

Review Article

Solar cell application via Metal oxide nanoparticles

Aqeel Mahdi Jreo Alduhaidahawi^a and Ahmed Hussein Mohammed Al-antaki^a

a-Department of Chemistry, Faculty of Science, University of Kufa, Najaf 54001, Iraq.

Email: aqeelm.alduhaidahawi@uokufa.edu.iq

Email: Ahmed.alantaki@uokufa.edu.iq

Abstract

This review explains types of metal oxide nanoparticles which are used with solar cell application such as Aluminum Oxide Nanoparticle (Al_2O_3 NPs), Titanium dioxide Nanoparticle (TiO_2 NPs), Tin oxide nanoparticles (SnO_2 NPs), copper oxide nanoparticles (CuO NPs) and Zinc oxide nanoparticles (ZnO NPs). The researchers could create above metal oxide nanoparticles of nanoscience via nanotechnology so we would mention that types of metal oxide nanoparticles with solar cell application. The physical properties of the metal oxide would change after fragmentation from metal plate by using laser ablation, Sol-Gel technology or electrochemical. On the other way, the metal salt could oxidize by using chemical reaction methods such as microwave, sonication bath, thermal methods or mechanical methods. Other properties of metal oxide nanoparticles such as Chemical, mechanical, electronic, optical and thermal give the scientists big area to use them with solar cell application to make different things in our life. The solar cell is clean technology to convert the sun energy to electric energy without any side effect such as toxic gas, waste product...etc. The researchers develop this application via adding many different types of dyes to the cell to get high efficiency.

Keywords: Nanoparticles, Nanoscience, metal oxide, solar cell

Introduction

1. Nanoscience and Nanotechnology

Nanoscience and nanotechnology are among the most important modern sciences that shine in the twenty-first century, despite their ancient discoveries dating back to 600 years BC, when carbon nanotubes and cementite nanowires were found in the microstructures of wootz steel made in ancient India. Nanoscience can be defined as that science that deals with the scale (1 - 100 nanometers), which is one billionth of a meter. Nanoscience has very wide applications in chemistry, physics, biology, medicine, astronomy, industry, and other sciences. We hardly see anything in our current world without nanoscience being involved, as nanotechnology, on its small scale (1-100 part per billion), gives high specifications, properties, and efficiency unlike another measurement (1).

2. Nanoparticle and Nanomaterial

Nanomaterials and nanoparticles are very popular with a large number of researchers in various fields of life because they are distinguished from their counterparts of non-nano materials and particles. Nanoparticles and materials are characterized by different physical and chemical properties that make them more efficient than their counterparts of non-nano materials and in all fields such as agriculture, industry, medicine and engineering. And chemistry, physics, pharmacy, astronomy, and cosmetics, which made researchers in the field of education and other fields race against time to replace large-sized materials and compounds with nano-sized materials. In order for us to be able to say that this material is a nanomaterial, it must be at least one of its three dimensions within the nanoscale. Which is smaller than 100 nanometers. Multiple forms can be observed within this scale, such as nanofibers, nanowires, nanotubes, and bucky balls (2).

3. Diametrically Classification of Nanoparticles

Nanomaterials can be classified based on their three dimensions (size) within the nanoscale (1 - 100 nanometers), into a nanomaterial with all dimensions within the nanoscale, symbolized by the symbol zero dimension (0D) Bucky ball, such as fullerene, and a nanomaterial with one dimension outside the nanoscale, symbolized by the symbol one dimension (1D) such as nanotube, nanofiber, nanorod, gold nanowires and a nanomaterial with two dimensions outside the nanoscale and symbolized by the symbol two dimension (2D) such as graphene, and last but not least a nanomaterial whose dimensions are all outside the nanoscale (1 - 100) nanometers but within its components are either... Among its components is a

nanomaterial, or there is a nanomaterial on its surface marked with the symbol three dimension (3D). The figure 1 below shows the types of nanomaterials in terms of dimensions (3).

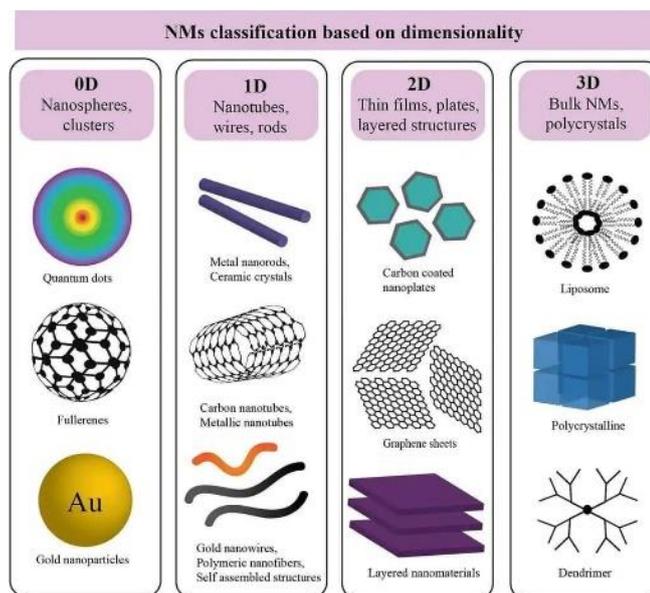


Figure 1: Classification of nanoparticles in function of their dimensionality (4).

4. Properties of Nanoparticles

Nanoparticles are characterized by unique physical and chemical specifications, which make researchers and manufacturers race to replace ordinary materials with nanoscale particles in all aspects of life. The reason is due to the high efficiency in terms of electrical and thermal conductivity, hardness, durability, absorption and desorption, low cost, and catalytic potential, which we will discuss through Physical and chemical properties (5).

4.1 Physical Properties

Nanoscale particles have different physical properties from their non-nano counterparts in terms of surface area, which is considered the most important property in the physical properties, in addition to the rest of the properties, such as the melting point, electrical and thermal conductivity, and the mechanical properties of the material. Nanomaterials have a large surface area when measured in relation to volume for example, if we assume that there is a sphere, it can be proven that the smaller the radius of the sphere, the greater the surface area. That is, the smaller the size has an effect in increasing the surface area. with radius r . Then its surface area is $A = 4\pi r^2$ and its volume is $V = \frac{4}{3}\pi r^3$. The ratio of surface area to volume of the

spherical particle is $= \frac{A}{V} = \frac{4\pi r^2}{\frac{4}{3}\pi r^3} = \frac{3}{r}$. Thus, this equation is the ratio of surface area of particles to volume increases with the radius decreases, and this is what happens when materials transform from macroscopic particles to nanoparticles where the radius decreases and thus the surface area is larger. Increasing the surface area leads to an increase in catalytic sites, which in turn makes the nanoparticles more reactive than non-nano particles. As for the melting point, nanoparticles are characterized by a low melting point compared to bulk particles, due to the increase in surface energy due to the decrease in size down to nanoscale size. This is observed in many metals such as gold, copper, lead, and other metals when they are converted into nanoscale form, for example. The example observes the metal Ge, whose melting point in its bulk form is about 930 c°, while when germanium Ge is in the form of nanowires on the scale of (10 to 100) nanometers with one dimension, the melting temperature drops to 650 c° (6). As for the other physical properties, they are the mechanical properties, that mean durability, hardness, plasticity, ductility, strain, fatigue, stress, hardness, fragility, etc. The nanoparticles showed high efficiency compared to bulk materials, the reason for the high efficiency in mechanical properties is attributed to the lack of The presence of impurities in nanoparticles on the scale (10-100 nm) from the inside and outside compared to bulk materials (7). In terms of optical properties, nanoparticles are distinguished from their bulk counterparts by unique optical properties, as they are characterized by an electric field close to the edges and increased absorption at longer wavelengths compared to their coatings, in addition to a change in many optical properties such as reflection, refraction and dispersion, which has made them widely used in many applications. Among the fields, such as solar energy and fields related to space, biology, chemical detection and data storage (8).

4.2 Chemical Properties

The decrease in size, down to the nano-size, plays a fundamental role in the chemical reactions of nanoparticles, as it was observed that the reaction speed increased several times if compared to bulk particles. The catalytic activity and the ability to oxidize and reduce also increased as a result of increasing the surface area to volume ratio, which in turn leads to reducing the activation energy and thus increasing Reaction speed (9).

4.3 Mechanical Properties

Nanoparticles have excellent mechanical properties due to the length, surface, and quantum effects of nanoparticles. As nanoparticles are added to a particular material,

they can refine the grain to some extent, forming an intra-granular structure that improves grain boundaries and improves the particle's mechanical properties. To categorize their possible engineering uses and industrial developments (10).

4.4 Electronic Properties

Nanoparticles have a significantly higher energy density than bulk materials. Because of its wide surface area, the substance (surface). By running a current through both of these particles or adding an electrical field, an optical absorption spectrum can be entered or an established range can be modified. In applications that require electrical energy, both conventional and rechargeable batteries are often used. Nano-crystalline materials are ideal for battery reconnect boards because they can store far more energy than conventional particles (11). Nanoparticles' electronic properties can vary from those of their bulk shape because confinement impacts caused solely by their distinct size of structure (12).

4.5 Optical Properties

The optical properties of nanoparticles are particularly significant to research due to their nano- dimension and the surface of the nanoparticle has Plasmon resonance. Height, shape, functional on the surface, doping, and composite with other materials, among other factors, all have a significant impact on these properties. The variations in the optical band gap of the energy spectrum, which occurs the surface Plasmon resonance of nanoparticles, causes size-dependent optical activity (13).

4.6 Thermal Properties

The thermal properties of nanoparticles include the reduction of typical temperatures such as freezing, glass transformation, oxidation, evaporation, and sintering temperatures, which are caused by the increased number of free-like surface atoms (14).

The thermal conductivity of NPs is well known to be greater than that of solid-shaped fluids. Copper, for example, has a thermal conductivity 700 times greater than water and 3000 times greater than engine oil at room temperature. In addition, oxides like alumina transport fluids and liquids containing small molecules for a variety of common fluids. Since heat transfer happens on the particle surface, particles with a broad total surface area are preferred. Suspension stability is also improved by the large overall surface area (15).

5. Methods for Synthesis of nanoparticles

Methods for the synthesis of nanoparticles can be divided according to the size

of the particles through which the synthesis is carried out into two methods: bottom-to-up synthesis and top-to-down synthesis. Several types of methods branch out from these methods (16) which will be explained below and shown in figure 2 (17).

5.1 Top-Down Approach

Utilizing this approach, nanomaterials are synthesized from bulk sizes, such as through techniques like pulsed laser deposition, grinding, mechanical chemical preparation, pulsed wire discharge, chemical deposition, and Sol-Gel technology (18).

5.2 Bottom-Up Approach

This technique involves forming nanomaterials by aggregating particles to attain dimensions on the nanoscale. Notably, it is known for its cost-effectiveness and high purity. Additionally, external variables like pressure and temperature can be manipulated to generate diverse types of nanomaterials (19).

The electrochemical method is one of the synthesis techniques that operates from bottom to top. Its low cost, high purity, and ease of controlling external parameters make it an effective approach for nanomaterial synthesis (20). Due to these numerous advantages, it has been selected as the method of choice in our study for the synthesis of nano-sized aluminum oxide and titanium dioxide.

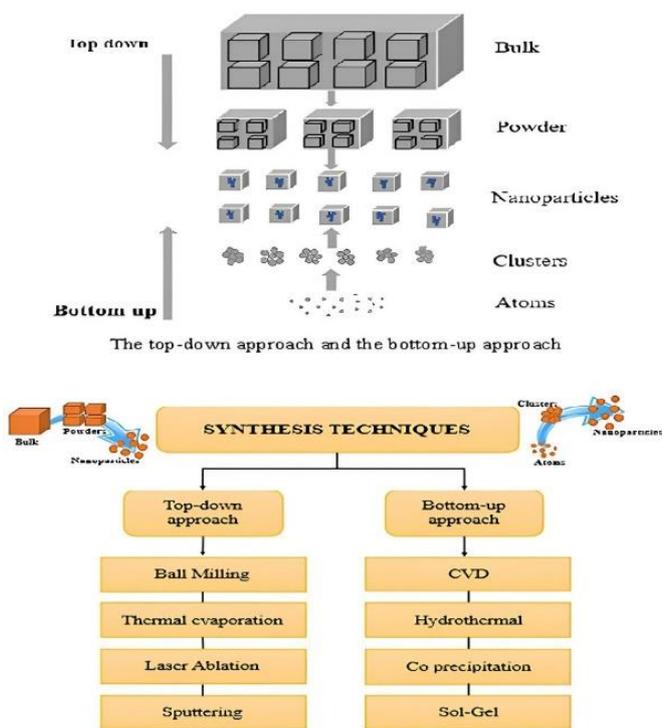


Figure 2: Presentation showing of the different techniques to produce nanoparticles (21).

6. Types of Metal Oxide Nanoparticles

Contingent upon their morphology, size, and chemical characteristics, NPs are classified into several groups. This paper would show many types of metal oxide such as nanoparticles. Nano metal oxides are among the most common materials due to their wide-ranging applications in various fields. Their high purity, minimal impurities, stability, and electron abundance make them a focal point for researchers. These characteristics, including their high stability and electron abundance, render them excellent materials for numerous applications such as catalysts, optical sensors, effective drug carriers, water sanitizers, and various other diverse areas of life that require detailed explanations. In this context, we will delve into two types of oxides: nano-sized aluminum oxide and nano titanium dioxide (22).

6.1 Aluminum Oxide Nanoparticle (Al_2O_3 NPs)

It has been established that the transformation of matter from bulk size to nano size, involving an increase in surface area as the size decreases to the nano scale, imparts distinctive qualities and properties from chemical, physical, and biological perspectives. These unique characteristics have piqued the interest of researchers, leading to its recognition as a fundamental material for research and development, subsequently finding broad and diverse applications. Nano aluminum oxide (Al_2O_3 NPs) is among the materials subjected to extensive study by researchers, who have identified its properties and advantages, integrating them into various applications. Aluminum metal boasts several advantages, including its lightweight nature, high strength, corrosion resistance, electrical and thermal conductivity. These attributes have contributed to its utilization in numerous applications, ranging from catalysts to optoelectronic instruments. Numerous metastable polymorphs of Al_2O_3 are widely recognized to exist, including transition alumina like γ , η , δ , θ , and χ phases, alongside the thermodynamically stable α - Al_2O_3 form, known as corundum. From a technological standpoint, the amorphous (am), gamma (γ), and alpha (α) forms of Al_2O_3 are particularly intriguing and hold the greatest interest for various applications, which can be synthesized through various methods such as solid-phase, liquid-phase, and gas-phase processes. Gamma structures, known for their high surface area, find applications as catalysts, whereas alpha structures, characterized by polycrystalline, are suitable for use in glass and ceramic applications, figure 3 (23).

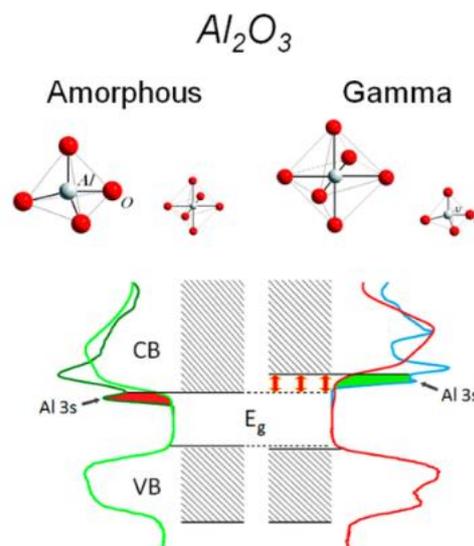


Figure 3: Al_2O_3 amorphous and gamma structure (23)

6.2 Titanium dioxide Nanoparticle (TiO_2 NPs)

Nano-titanium oxide (TiO_2 NPs) stands out as one of the nano-oxides widely employed in photo catalysis and electronic instruments due to its status as an n-type semiconductor, with an energy gap ranging between 3.2 to 3.35. Additionally, it finds applications across various sectors including paints, plastics, printing inks, and cosmetics, particularly in sunscreen formulations. Structurally, it manifests in crystalline forms such as anatase, the most prevalent, as well as rutile and brookite, the rarest. Furthermore, it can be encountered in a non-crystalline state, figure 4(24). Nano-oxides find extensive applications, yet they are concurrently regarded as hazardous substances owing to their minute nano-scale, which poses risks to humans and animals via ingestion, inhalation, or dermal contact. Research has demonstrated the adverse effects of nano-titanium oxide on human health, with instances of workers exposed to polyacrylate particles experiencing health issues. Exposure to nanoparticles combined with titanium oxide in printing facilities has led to acute respiratory distress. Additionally, exposure to titanium oxide has resulted in various clinical manifestations including skin rash, facial, hand, and forearm swelling, as well as pleural and pericardial effusions, hypoxemia, and cancer. Furthermore, studies have revealed the accumulation of titanium oxide in organs such as the liver, heart, spleen, lungs, kidneys, digestive system, and cardiac muscle upon ingestion or inhalation (25).

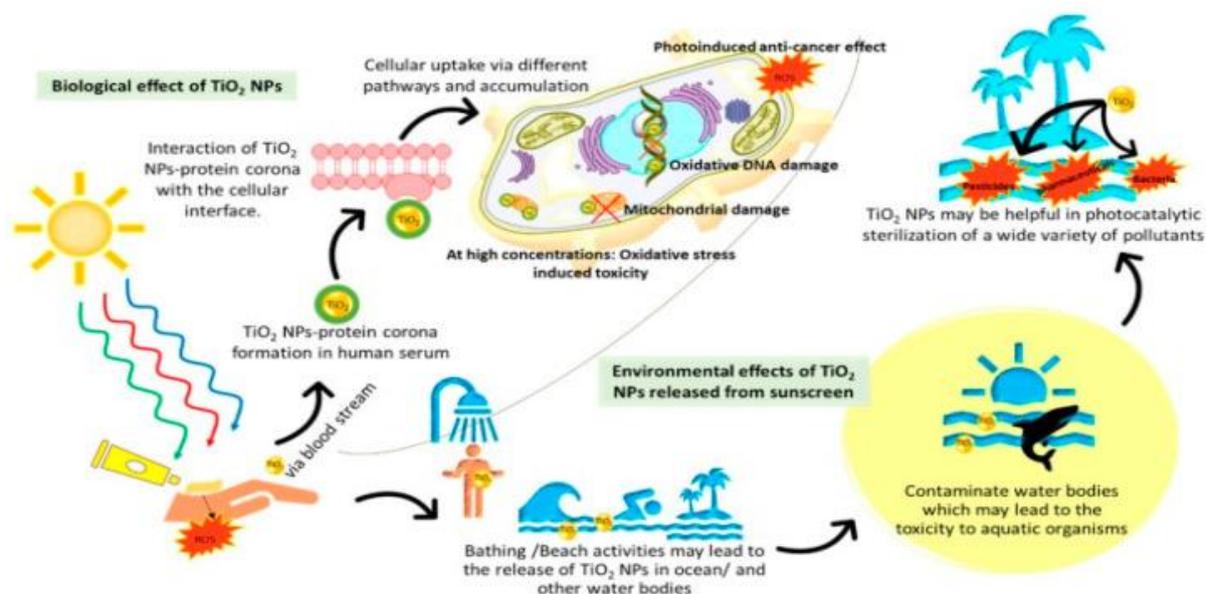


Figure 4: application of TiO_2 on the environmental and biology (24)

6.3 Tin oxide Nanoparticles (SnO_2 NPs)

The unusual physical properties of semiconductor nanoparticles, such as quantum scale effects, nonlinear optical properties, and luminescence, have attracted a lot of interest in the last decade (26). Since ancient times, tin oxide colloids have been used as pigments. For example, they were already used in cosmetic creams in Antic Rome, as discovered during an archeological dig in London (27). Tin(IV) oxide is extremely translucent in the visible portion of the electromagnetic spectrum, but it absorbs infrared radiation; these properties, along with its poor electrical resistance, make SnO_2 a good medium not only for advanced optoelectronic applications like solar cells or light emitting diodes, but also as a pigment in glasses and ceramic glazes(28,29). SnO_2 films of various thicknesses can be added to glasses and ceramics to improve abrasion resistance (films of $<0.1\mu\text{m}$) (30,31).

Tin dioxide (SnO_2) is a common n-type semiconductor material with a 3.6 eV band gap. Photocatalysis, solar panels, conductive transparent glass, and toxic gas detection have all used nano-sized SnO_2 (32-35). The semiconductor SnO_2 has long been used to identify flammable and poisonous gases such as alcohol(36). A semiconductor's optical properties are determined by Extrinsic and inherent influences are also there. The photoluminescence is a form of luminescence that occurs when light. The continuum is an effective method for determining the crystalline structure ability of the products and the presence of impurities in them as well as fine exciton structures (37). For the synthesis of SnO_2 nanostructures, various methods have been developed, including the vapour-liquid-solid (VLS) method, calcinations process,

chemical vapour deposition, thermal evaporation, hydrothermal process, laser ablation technique, sol-gel method, and solvothermal method (38,39). For the processing of SnO₂ nanoparticles, the current study uses the sol-gel process (40).

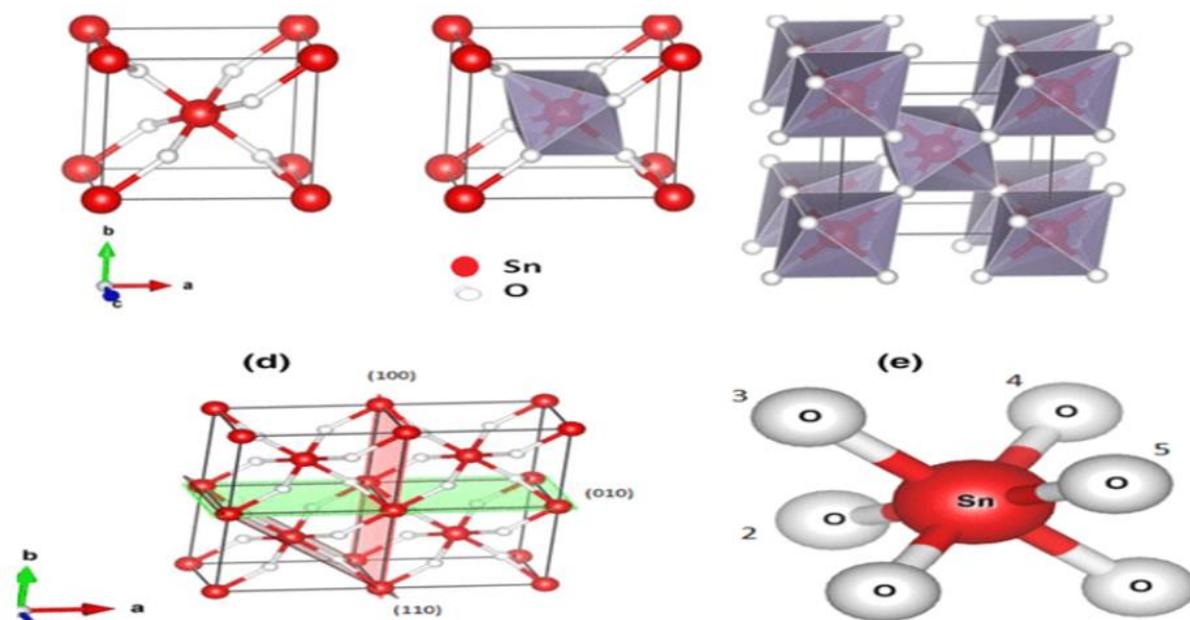


Figure 5 :The structural model of SnO₂: a position of tin and oxy-gen atoms in tetragonal lattice, b octahedron formed by coordi-nation of one tin and six oxygen atoms, c many octahedron present in tetragonal lattice, ddiffraction planes in tetragonal lattice, and e indication of num-bers on oxy-gen atoms to locate their positions (41).

6.4 Copper oxide Nanoparticles (CuO NPs)

Nanostructures of transition metal oxides have been widely used with promising applications in applied science and technology due to their special features such as high specific surface area, chemical stability, and electrochemical behavior at the nanoscale. Copper related oxides such as a cupric oxide (CuO) have several significant properties among different transition metal oxides (42). Specific transitional metal oxide nanoparticles such CuO, have been extensively investigated in recent years for their excellent performance in solar cells, biomedical, quantum dots, sensor, photo catalysis, solar cells, and UV defense, etc (43). The CuO-NPs have a wide range of uses. The copper oxide nanoparticles demonstrate superior catalytic and selective behavior relative to ordinary copper oxide powder. It exerts excellent antimicrobial activity against different bacterial strains. CuO-NPs are used in pigment removal, fabrication of nano-membranes, gas sensors, semiconductors, organic stimulation, conversion of solar energy, and much more (44) one of the most

important factors in the synthesis of such nanoparticles is the regulation of particle size, morphology, and crystallinity, and various methods of synthesis have been developed to achieve this objective; some of the most studied approaches include the sono-chemical method, sol-gel method, laser ablation, electrochemical method, chemical precipitation and treated using surfactants (45). CuO nanoparticles are of great interest because of their potential applications in a wide range of fields, including electronic and optoelectronic devices, such as microelectromechanical systems, field effect transistors, electrochemical cells, gas sensors, magnetic storage media, solar cells, field emitters, and catalyst nanodes (46).

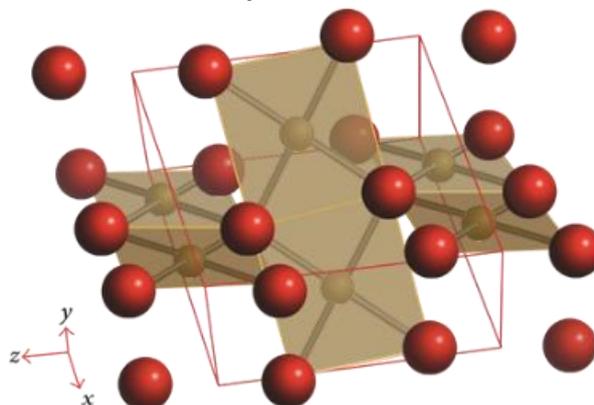


Figure 6: Solid state structure of CuO (47).

6.5 Zinc oxide Nanoparticles (ZnO NPs)

Semiconductor nanoparticles have gained much attention in the past decade because of their peculiar physical properties such as quantum size effects, nonlinear optical properties and luminescence (48). Zinc oxide nanoparticles (ZnO NPs) are popularly used in different fields as one of the most common metal oxide nanoparticles due to their unusual physical and chemical properties (49). Zinc oxide (ZnO) also called as n-type II–VI semiconductor (50). ZnO NPs are present in sunscreens, pigments, food additives, and biosensors. A variety of researchers investigated the toxic effects of these modified ZnO NPs in different cell lines and animal models (51). ¹¹ ZnO is a semiconductor with a small bandgap (3.3eV) and high binding exaction energy and is plentiful in nature and environmentally friendly. These characteristics make this material desirable for any use, including solar cells, optical coatings, photo catalyst, and electrical devices (52). ZnO synthesis focuses mainly on the sol – gel method (solution method) or the hydrothermal method. Most of the literature for ZnO nanoparticles is based on the solution method since the solution method provides a low cost and environmentally friendly synthetic path. In addition, the synthesis of ZnO nanoparticles in the solution requires a well-defined

shape and size of ZnO nanoparticles (53) The main advantages of using ZnO nanoparticles compared with organic or bulk oxide are their chemical stability, thermal resistance, robustness, and long shelf life (54). ZnO nanofillers are of great importance in the use of organic coatings in steel corrosion safety (55). At ambient pressure and temperature, ZnO crystallizes in the wurtzite (B4 type) structure, as shown in figure 1.1. This is a hexagonal lattice, belonging to the space group P63mc, and is characterized by two interconnecting sublattices of Zn²⁺ and O²⁻, such that each Zn ion is surrounded by a tetrahedral of O ions, and vice-versa (56)²²

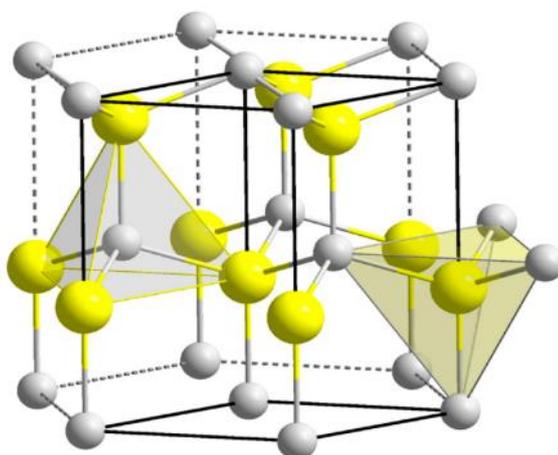


Figure 7: ZnO wurtzite cell, Zn in yellow, O in grey, the tetrahedral coordination is shown for both types of atoms. (57)

7. Solar Cell

A solar cell is a device that converts solar energy into electricity, a clean and vital source of renewable energy, and that can help to overcome the global energy crisis. While commercial solar cells exhibit good performance and durability, there are still many ways to improve solar cell performance and cost through collaborations between scientists, technicians and industrial workers (58). Solar energy provides an ample amount and free of charge heat and electricity for useful real-life applications. In comparison, unlike non-renewable energy sources, solar energy is environmentally friendly, generating virtually zero emissions. Solar energy is therefore seen worldwide as the most sustainable solution to the energy crisis (59). Solar energy has great potential and capabilities to meet the global need for renewable energy in the future. The total solar radiation is about 3×10^{24} joules annually (60). Current solar cells cannot turn all incoming light into useful energy, as some of the light can escape back into the air from the cell. In addition, sunlight comes in many different colors and the cell may be more efficient in converting bluish light while making reddish light less efficient (61). The operation of a photovoltaic (PV) cell requires 3 basic attributes:

1. The absorption of light, generating either electron-hole pairs or exactions.
2. The separation of charge carriers of opposite types.
3. The separate extraction of those carriers to an external circuit (62).

8. Classification of Solar Cells

Solar cells are typically categorized into four groups according to the date and types of materials used to make them. The most growing solar cells on the market are solar cells of the first century that consist of single and multicrystalline silicone. Solar cells of the second generation were developed as a reaction to the heavy usage of material and the expense of silicone solar cells. The average film thickness for this generation was reduced to a few nanometers to tens of micrometers to reduce the material consumption. Also, other researchers have attempted to use dye-sensitized solar cells (DSSCs), perovskite, organic solar cells. Solar cells of the fourth generation fell into the class of conjectural generation made of composites (63).

9. Dye-Sensitized Solar Cells (DSSCs)

It is the third generation solar photovoltaic cell that converts the visible light into electrical energy (62). Also known as Grätzel solar cells, DSSC does not require high-quality content and usually low cost of development. DSSC consists of nanocrystals, dyestuffs, counter electrodes, and electrolytes that are semiconductive. Such four major components can affect the efficacy of the resulting DSSC (64) This method is based on enhanced interaction between the dye and the material transmitted by the charge carrier (65). A DSSC has three significant steps by which it transforms over light into electrical vitality: when light falls on a color, it starts the photo excitations and makes electrons move to the conductive band of the semiconductor. Color atoms are oxidized by electrons supplied by the electrolyte by redox reaction and eventually pass via the external load electrons to complete the circuit (66). Solar cells based on dye-sensitized nanostructured metal oxides are potential for low-cost conversion of solar energy and are now rigorously investigated (67). The dye is the photoactive portion of the photovoltaic system that harvests incident light for the conversion of a photon to the electron. The dye 's ideal function would cover a wide range of the solar spectrum. Over 50 percent of solar energy is emitted from 400 to 800 nm in the region (68). A mesoporous semiconductor with high mobility of electrons, a sufficient isoelectric point, high dye adsorption, and a band structure that fits other cell components and acts as a charged transporter. A liquid or solid electrolyte that supplies electrons to the dye molecules through a redox couple reaction (69). DSSCs have taken a huge interest in various scientific and technological applications because of their ability to turn renewable solar energy into

electricity at a low price / performance ratio (70). A sensitizer is the most critical feature in a DSSC and an optimal sensitizer absorbs all the light on the semiconductor surface at a wavelength of approximately 920 nm (71).

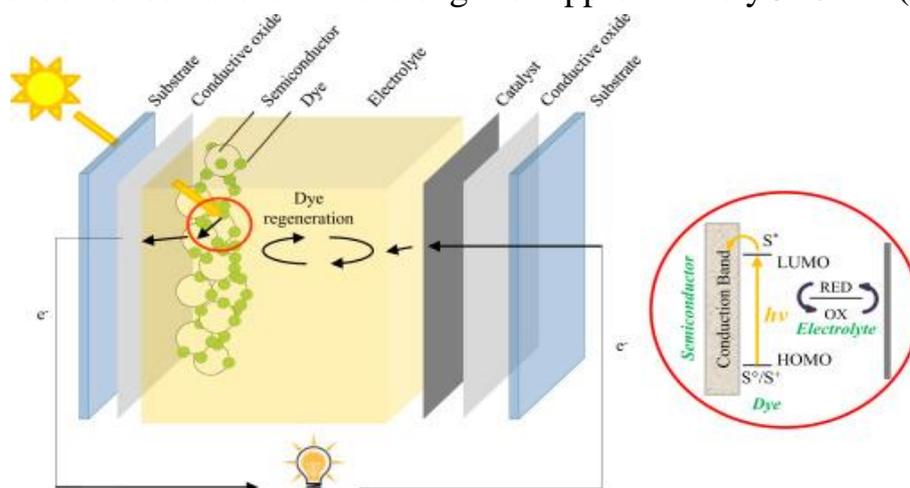


Figure 8: The structure of dye-sensitized solar cells (DSSCs) (72).

9.1 Natural Dyes

Natural dyes could add to solar cell as sensitizers in DSSCs, including anthocyanin, chlorophylls, carotenoids, flavonoids and cyanines (73). The dyes must be stable under the sun energy and give high efficiency of the cell. Chlorophyll can absorb light from red, blue and violet wavelengths and obtains its color by reflecting the green wavelength. The strong absorption peaks in the visible region located at 420 nm and 660 nm wavelengths that can be used as a natural sensitizer in the visible light range (74). Chlorophyll may be the most economic choice for fabricating DSSCs with dye sensitizers because it uses simple processes. Chlorophylls and their derivatives are attractive for use in DSSCs as dye photo-sensitizers because of their ability to absorb light over a broad region of the visible spectrum (75). Anthocyanin is a natural plant pigment and also known as flavonoids. The molecule of this group can absorb the yellow, green and blue portions of the visible spectrum for which dye appears purplish red (76).

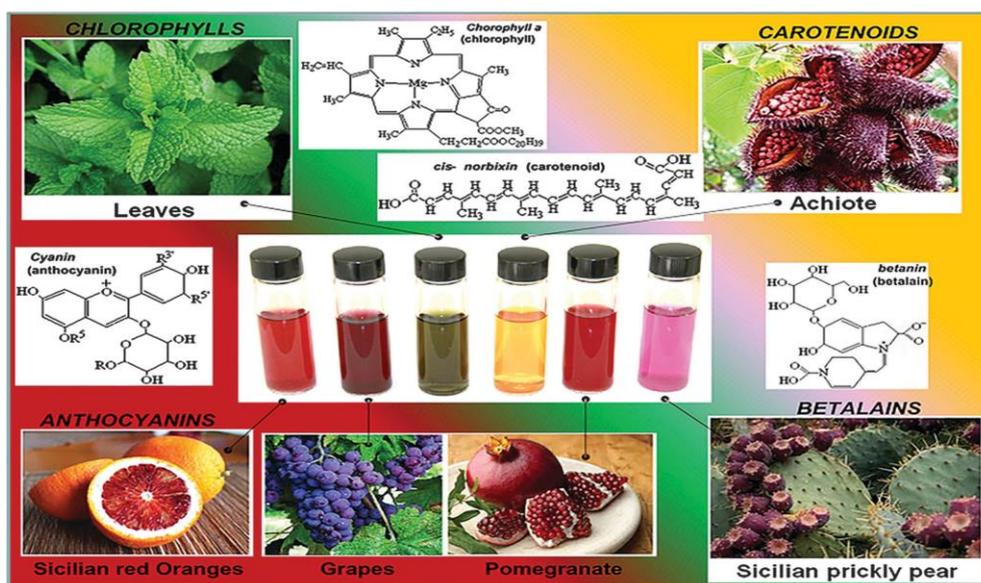


Figure 9: Dyes derived from chlorophylls, anthocyanins, betalains and carotenoids showing colors covering the entire visible portion of the electromagnetic spectrum. In the figure are also seen the pictures of the dyes and the molecular structures of chlorophyll a, cyanin (anthocyanin), betanin (betalain) and cis-norbixin respectively (77).

9.2 Organometallic dyes

Organometallic dyes are composed of transition metals Ru, Os, Ir, etc, and organics. Ru (II) metal always remains a rational preference for DSSC applications, figure 10 (78).

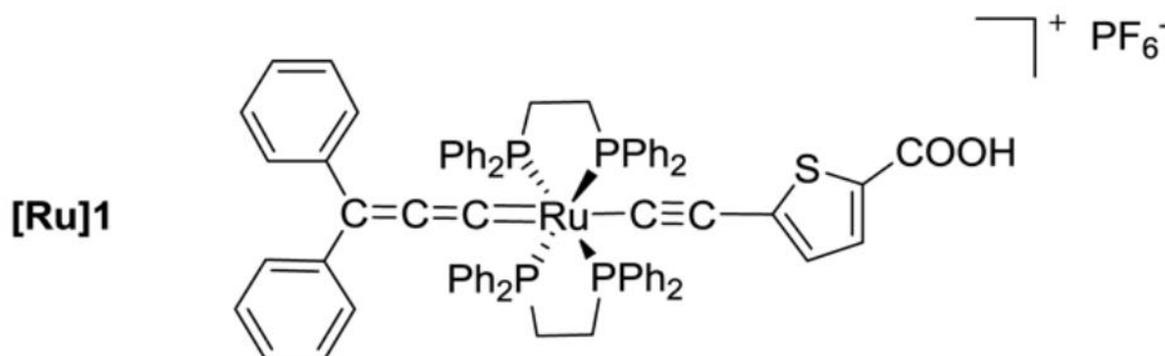


Figure 10: Organometallic dyes of $[\text{Ru}(\text{dppe})_2]^+$ (78).

10. Photoanodes

Researchers also extensively studied TiO_2 , ZnO , and their modified counterparts as photoanode materials for DSSC applications. TiO_2 and ZnO based nanowires,

nanofibers, nanorods, etc, have already been studied for DSSCs.

11. Electrolytes

The I^-/I_3^- redox couple is studied extensively by researchers as an electrolyte for DSSCs. I^-/I_3^- integrated into a polyaniline/thiourea matrix is also used for solid-state DSSC applications. This optimization has resulted in an elevated open-circuit voltage and short-circuit current density, leading to a significant increase in the PCE. A quasi solid-state DSSC has also been proposed with a stable gel electrolyte employing PEO–poly-ethylene glycol (PEG) (79).

12. Current-Voltage Characteristics

Current-voltage (I-V) gives the most important and alternative method for the assessment of the photovoltaic performance in DSSC cell. A standard illumination of air-mass 1.5 universal (AM 1.5 G) with an irradiance of 100 mW/cm² is usually used for the I-V description of DSSC. The I-V characteristics are monitored under solar irradiation by changing the external load from zero load (short-circuit conditions) to infinite load (open-circuit conditions). A typical I-V curve is presented in Figure 1.5. The most important photovoltaic parameter to evaluate the performance of DSSC devices is the overall light-to-electricity conversion efficiency (η), which is determined by the product of the short-circuit current density (J_{sc}), open-circuit voltage (V_{oc}), and fill factor (FF) divided by the intensity of the incident light (P_{in}). These three parameters J_{sc} , V_{oc} , and FF can be extracted from the IV curves. The FF is defined as the ratio of the maximum power (P_{max}) of the solar cell divided by the product of V_{oc} and J_{sc} according to equation 2.2. The P_{max} is defined as the product of J_{sc} and V_{oc} at the maximum power point (80).

$$FF = \frac{P_{mpp}}{V_{oc} \cdot I_{sc}}$$

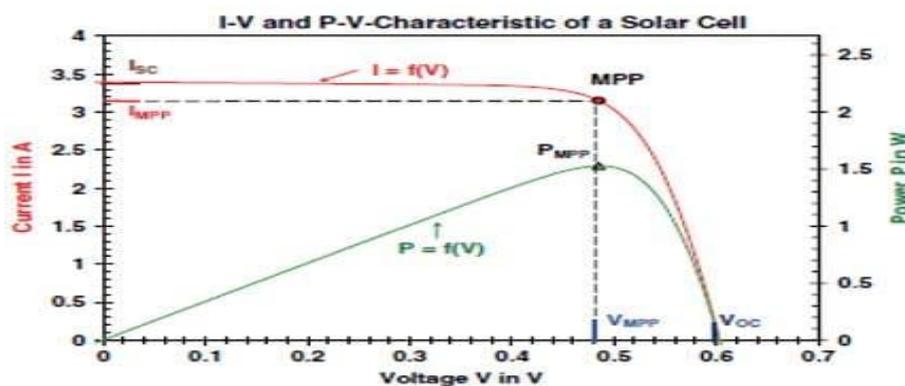


Figure 11: I-V curve (81).

Conclusion

The article shows many different of metal oxide nanoparticles and they are normally adding to solar cell as good application to convert the energy of sun to energy of electric, for example: Aluminum Oxide Nanoparticle (Al_2O_3 NPs), Titanium dioxide Nanoparticle (TiO_2 NPs), Tin oxide nanoparticles (SnO_2 NPs), copper oxide nanoparticles (CuO NPs) and Zinc oxide nanoparticles (ZnO NPs). The nanotechnology has been developing the nanoscience via various methods to make metal oxide nanoparticles which could modified physical properties, Chemical properties, mechanical properties, electronic properties, optical properties and thermal properties. These change giving the scientists wide line to insert them in solar cell application. The researchers have been used many methods to prepare these types of metal oxide nanoparticles which are laser ablation, Sol-Gel technology, electrochemical, microwave, sonication bath, thermal methods or mechanical methods. Not that is all, the scientists have added one or many dyes of cell to increase the efficiency by creating new design of the solar cell which is friend technology of environmental without toxic gas, waste product...etc.

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