Indian Journal of Modern Research and Reviews

This Journal is a member of the *'Committee on Publication Ethics'*

Online ISSN:2584-184X

Research Article

Recent Advances in Nanomaterials: Synthesis Methods, Characterization Techniques, and Applications in Dye-Sensitized Solar Cells

Hasan M. Marhoon [1*], Mohammed Talib [2]

[1,2] The University of Kufa, Faculty of Science, Department of Chemistry, P.O. Box 21, An-Najaf, Iraq

Corresponding Author: *Hasan M. Marhoon

DOI: https://doi.org/10.5281/zenodo.18709770

Abstract

Nanomaterials have garnered significant scientific attention due to their unique physical, chemical, optical, and electronic properties, which often surpass those of their bulk counterparts. These properties have enabled a wide range of applications across various fields, including electronics, biomedical sciences, environmental technologies, and renewable energy systems. This study provides a comprehensive overview of nanomaterials, including their classification, structural properties, and extraction methods, as well as top-down and bottom-up fabrication approaches, with a particular focus on electronic synthesis methods. Furthermore, key characterisation techniques are discussed, including X-ray diffraction (XRD), scanning electron microscopy (SEM), transmission electron microscopy (TEM), atomic force microscopy (AFM), ultraviolet-visible spectroscopy, and Fourier transform infrared spectroscopy (FTIR). Special attention should be paid to metal oxide-based nanomaterials, particularly TiO_2 and SnO_2 nanoparticles, due to their promising optical and electronic properties. Furthermore, the review highlights the role of nanomaterials in enhancing the efficiency of dye-sensitive sodium cells (DSSCs) and the viscosity of natural dyes, such as chlorophyll, and environmentally friendly pigments. This overview underscores the potential of nanomaterials in developing renewable energy technologies and the significant progress being made in the field of sustainable energy development.

Manuscript Information

- **ISSN No:** 2584-184X
- **Received:** 26-12-2025
- **Accepted:** 12-02-2026
- **Published:** 19-02-2026
- **MRR:**4(2); 2026: 262-276
- **©2026, All Rights Reserved**
- **Plagiarism Checked:** Yes
- **Peer Review Process:** Yes

How to Cite this Article

Marhoon H M, Talib M. Recent Advances in Nanomaterials: Synthesis Methods, Characterization Techniques, and Applications in Dye-Sensitized Solar Cells. Indian J Mod Res Rev. 2026;4(2):262-276.

Access this Article Online

www.multiarticlesjournal.com

KEYWORDS: Nanomaterial; Solar Cell; Electrochemical Deposition; DSSCs

1. INTRODUCTION

1-1Nanoscience and Nanotechnology

Nanoscience is the branch of science that studies the phenomena that occur at the nanoscale (one in a billion) in terms of size and structural shape [(1)]. Nanotechnology is one of the most important developments in 21st-century science, and it involves the nanoscale design and engineering of a wide range of materials, including metals, metal oxides, polymers, chalcogenides, and so on [(2)].

1-2 Nanomaterials and Nanoparticles

Nanomaterials have enticed researchers for the past five decades due to their enormous consequences in a variety of fields such as electronics, photonics, and medicine .

© 2026 Hasan M. Marhoon, Mohammed Talib. This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC BY NC ND).https://creativecommons.org/licenses/by/4.0/

Nanomaterials have been produced and are now used in a wide range of applications [3]. Nanomaterials are materials with external or internal structures in nanoscales; nanoparticles are types of nanomaterials; and objects with at least two dimensions in nanoscales are known as nanoparticles[4]. Nano-dimensional materials (size range of 100 nm) can be defined as a transitional state or a bridge between materials at the atomic (or molecular) level and bulk materials, which have chemically, physically, and electronically distinct properties [5]. As a result of their use in the most important applications, the key components of nanomaterials are nanoparticles, nanowires, and nanotubes [6].

Nanoparticles' physical and chemical properties are influenced not only by their size, but also by their composition, which is likely to be organic (polymers), bio-organic (lipids), inorganic (metals, metal oxides,...), or a combination of the two[7-8]. As a result, the shape of nanoparticles has an effect on their physical properties[10]. Nanoparticles have much larger surface areas than bulk particles, and the surface area of nanoparticles is determined by their size and shape[11].

1-3 Classification of Nanomaterials

Nanomaterials are usually classified based on their dimensions, shape, composition, uniformity, and agglomeration. Based on the dimensionality of the nanoparticles, nanomaterials can be graded as 0-D, 1-D, 2-D, or 3-D.

1-3-1 Zero-Dimension Nanomaterials (0D)

All dimensions in the nanoscale dimension are 0-D[12]. Several research groups have produced particle arrays (quantum dots), heterogeneous particle arrays, core-shell quantum dots, hollow balls, and nanoscale lenses[13]. Nanomaterials are very interested in them because of their unique electrical, optical, and magnetic properties, which give them a wide range of applications[14].

1-3-2 One-Dimension Nanomaterials(1D)

Nanotubes, fibres, filaments, whiskers, spirals, and belts are examples of one-dimensional nanomaterials that exist beyond the nanoscale[15].

1-3-3 Two-Dimension Nanomaterials(2D)

They have one dimension at the nanometer scale, and the other two dimensions are significantly broader in comparison to the third dimension (i.e., thickness). Graphene, Nano layers, Nano clays, Nano sheets, Nano films, platelet-like structure, Nano flakes, Nanoplatelets, and silicate Nano platelets are only a few examples. The area of the Nano film or coating is measured in square centimetres. The thickness, however, is 1–100 nm[16].

1-3-4 Three-Dimension Nanomaterials(3D)

Outside of the Nano spectrum, 3-D nanomaterials have all three dimensions. Nano granules, Nano clays, and equiaxed nanoparticles are examples of 3-D nanomaterials. These materials' dimensions are all outside the nanometer scale[17].

1-4 Types of Nanomaterials

1-4-1Carbon-Based Nanomaterials

Fullerenes, carbon nanotubes, graphene and its derivatives, graphene oxide, Nano diamonds, and carbon quantum dots are all carbon-based nanomaterials. Carbon nanomaterials have piqued interest in a variety of areas, including biomedical applications, outstanding mechanical, optical, and chemical properties, and extraordinary structural dimensions[18]. Since a single carbon atom can form several valence bonds, each with its own orbital hybridisation, carbon has a variety of structural shapes. Carbon nanomaterial is one of the materials that has been investigated the most[19].CNPs have shown great promise in a wide range of electrochemical applications, from energy storage and conversion (fuel cells, batteries, and super capacitors) to electrochemical sensing, due to their inherent electrochemical properties, large specific surface area, electrocatalytic properties, assisted electron transfer, and exceptional electrical conductivity[20].

1-4-2 Composite-Based Nanomaterials

A composite is a substance made up of at least two different components that have been mixed to get the best of all worlds. Composite nanoparticles are novel materials that have recently sparked increased interest due to their scientific and technological significance. They are used in a wide range of applications, including catalysts that require a great deal of precision and function. Packaging includes metal-semiconductor junctions, optical filters, and polymer film modifiers[21]. Ion poisoning, electrical composition, physical blending, film casting, dipping coating, layer by layer) aggregation, on-site preparing, co-precipitation, colloidal aggregation, or covalent binding are some of the processes used to make such nanocomposites[22].

1-5 Properties of Nanomaterials

1-5-1 Chemical Properties

There is a connection between compound structure and electronic properties in both nanoscale and microscale materials. Because of the underlying network, any changes in the structure due to changes in molecule size would alter the electronic property. The first ionisation energy is described as the least vitalityneeded to evacuate a peripheral electron (IE1). Because of the electron affinity, which is usually large for smaller nuclear groups as compared to mass particle. Ultrafine powders used in catalysis can increase the rate, selectivity, and efficacy of a synthetic reaction in ignition or blends where waste and contamination are minimised. Gold (Au) nanoparticles,
for example, have a crystalline structure that is mostly face-centred cubic (fcc). However, when the size of Au is reduced to 5 nm, the Au forms an icosahedral shape and demonstrates enhanced synergist reactivity[23].

1-5-2 Mechanical Properties

Nanomaterials 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

© 2026 Hasan M. Marhoon, Mohammed Talib. This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC BY NC ND).https://creativecommons.org/licenses/by/4.0/

the grain to some extent, forming an intra-granular structure that improves grain boundaries and improves the material's mechanical properties. To categorise their possible engineering uses and industrial developments [24].

1-5-3 Electronic Properties

Nanomaterials 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 materials 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 materials[45]. Nanoparticles' electronic properties can vary from those of their bulk shape due to confinement effects caused solely by their finite size and because they are structurally distinct[25].

1-5-4 Optical Properties

The optical properties of nanomaterials are particularly significant to research due to their nanoscale dimension and the presence of surface Plasmon resonance character. Height, shape, surface functionalization, doping, and interactions with other materials, among other factors, all have a significant impact on these properties. The variations in the optical energy band spectrum, which influence the surface plasmon resonance of nanomaterials, cause size-dependent optical activity[26].

1-5-5 Thermal Properties

The thermal properties of nanomaterials 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[27]. The thermal conductivity of NPs is well known to be greater than that of solid-shaped fluids. Copper, for example, has a Thermal conductivity is 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 [28].

1-6 Preparation Methods of Nanomaterials

1- chemical techniques: Hydrothermal, sol-gel, sonochemical, coprecipitation, electrospinning, microemulsion, chemical reduction, and wet chemical processes are among the chemical techniques [29].

2- physical techniques: discharge, photochemical impregnation, laser ablation, ball milling, liquid vapour deposition, inert gas condensation Sputtering, and electrochemical approaches are among the physical techniques[30].

1-7 The Electrochemical Methods

Electrochemical techniques are strategies for dealing with electrochemical reactions that occur as an electrical current is passed through a solution in an electrochemical cell. The electrochemical methods of nanoparticle preparation have many advantages over other methods, including the ability to regulate the morphology and size of nanoparticles by controlling electrical and chemical parameters, low expense, shortened time to product output, high performance, and the lack of contamination concerns, as well as very selective processes[31]. Ions pass through a solution under the influence of an electric field in the electrochemical phase. In general, an electrochemical device consists of two electrodes (cathode and anode) immersed in an electrolytic cell solution with small components and a power supply interaction. Between the two electrodes, the voltage is calculated.

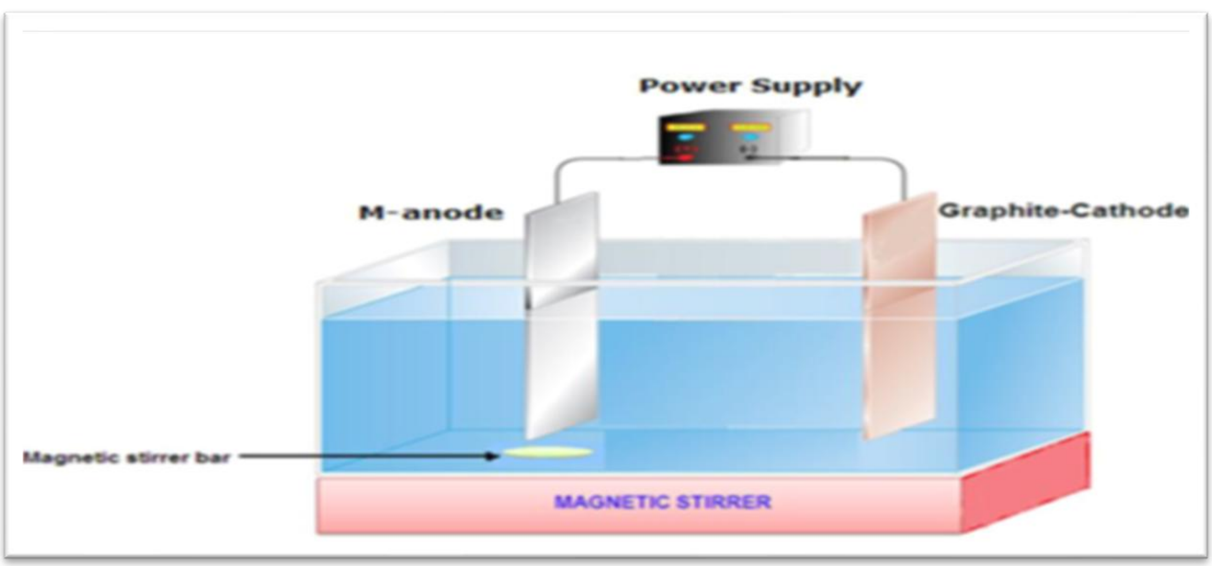

Figure 1: electrochemical system

© 2026 Hasan M. Marhoon, Mohammed Talib. This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC BY NC ND).https://creativecommons.org/licenses/by/4.0/

Electrochemical techniques are used in the literature for the preparation of nanomaterials. Among them are; precipition of Pb and Zn –doped SnSe films by using the electrodeposition method, the morphologies which were obtained: ball, rod, and wire-like structured shapes[32]. The electrochemical approach was used to make nanobelts, nanobars, nanodisks, and aggregated SnO_2 nanoparticles[33]. Palladium rod-like structures were synthesised using an electrochemical process[34]. Electrochemical reduction was used to make cobalt nanoparticles from (cobalt dibromide 2,2-bipyridine (bpy) complexes. Co nanoparticles with nanosizes of (9-10) nm and (30-32) nm are the sample. The system was shaped like a cylinder. The controllable electrochemical method was used to make silver nanoparticles with a size of (2-13) nm; the size of the NPs was controlled by varying electrochemical precipitation conditions, surfactant form and concentrations, and ionic liquids. The electrochemical co-reduction process of Mo(IV) and S(II) was used to create special flower-like and sheet-like nanostructured MoS_2. The kind of stabilisers used in the electrochemical fabrication of spherical form Se-NPs in three nanosize structures (sucrose, PVP, and SDS) was studied. The addition of cetanetrimethyl ammonium bromide (CTAB) to spherical NPs synthesised in the presence of sucrose, resulting in a transition in shape to urchin-like structures through electrostatic assembly, led to the synthesis of (85, 43, and 60) nm particle sizes.

1-8 Methods for Synthesis of Nanomaterials

1-8-1 The Top-Down Method

“The 'predict-then-act' strategy is often referred to as the 'top-down' approach"[35].

As the name implies, top-down methods begin with a bulk material and then break it down into smaller parts using mechanical, chemical, or some other type of energy. This method is identical to carving a stone statue out of a big block of stone. The top-down approach is used to collect a large amount of bulk material. The carving and shaping process continues until the final shape is achieved. High-energy ball milling, mechanical-chemical processing, etching, electroexplosion, sputtering, lithography, and laser ablation are all methods for making nanomaterials from bulk materials [36].

1-8-2 The Bottom-Up Method

The concept of molecular self-assembly, which is similar to nanoscale physical and chemical interactions that assemble primary building blocks into macroscopic structures, is the subject of bottom-up approaches. Non-covalent bonds such as hydrogen and ionic bonds, van der Waals forces, and hydrogen bonds mediated by water are among the molecular interactions[37]. Bottom-up methods include scaling down materials segments (to the nuclear level), followed by a self-assembly process that leads to the formation of nanostructures. During self-gathering, physical forces at the nanoscale are used to join units into a larger, more robust structure. Bottom-up methods include scaling down materials segments (to the nuclear level), followed by a self-assembly process that leads to the formation of nanostructures. During self-gathering, physical forces at the nanoscale are used to join units into a larger, more robust structure[38].

1-9 Metal Oxide Nanoparticles

Another form of nanoparticle is metal oxide nanoparticles, which are commonly synthesised and extensively examined. Metal targets such as copper (Cu), iron (Fe), aluminum (Al), zinc (Zn), titanium (Ti), nickel (Ni), tin (Sn), cobalt (Co), cerium (Ce), yttrium (Y), gadolinium (Gd), bismuth (Bi), and others have been used to make a wide range of metal oxide nanoparticles[39]. Metal oxide nanoparticles are widely used in catalysis, photocatalysis, sensors, and other applications[40]. Metal oxide nanoparticles have some major advantages:

(i) variations in surface properties that cause a significant increase in the band gap, which affects nanoparticle conductivity and chemical behaviour.

(ii) structural modifications to account for changes in lattice symmetry and cell parameters due to the effect of quantum confinement.

(iii) changes in electrochemical characteristics due to the effect of quantum confinement [41]. Metal oxide nanoparticles are commonly used in a variety of applications, including cosmetics, electronics, water, electricity, building, and healthcare. As a result, the protection, fate, and behaviour of metal oxide nanomaterials are frequently of great concern to humans and the environment[42].

1-10 TiO_2 Nanoparticles

Because of their unique properties, such as high specific surface area, chemical stability, and electrochemical activity at the nanoscale, transition metal oxide nanostructures have been extensively used for promising applications in applied science and technology.TiO_2 and other transitional metal oxide nanoparticles have been studied extensively in recent years for their outstanding performance in solar cells, biomedical devices, quantum dots, sensors, photo catalysis, solar cells, and UV protection, among other applications[43]. The control of particle size, morphology, and crystallinity is one of the most important factors in the synthesis of such nanoparticles, and numerous methods of synthesis have been established to achieve this goal; some of the most studied approaches include the sono-chemical process, sol-gel method, laser ablation, electrochemical method, chemical precipitation, and treatment with surfactants[44].

Figure 2 shows the three major crystalline structures of titanium dioxide (TiO_2): rutile, anatase, and brookite, as well as other structures such as cotunnite, which has been synthesised at high pressures: rutile (tetragonal), anatase (tetragonal), and brookite[45]. Rutile is the stable form, whereas anatase and brookite are metastable and can be converted to rutile by heating. Anatase is the step that is typically found in TiO_2 sol-gel synthesis.

© 2026 Hasan M. Marhoon, Mohammed Talib. This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC BY NC ND).https://creativecommons.org/licenses/by/4.0/

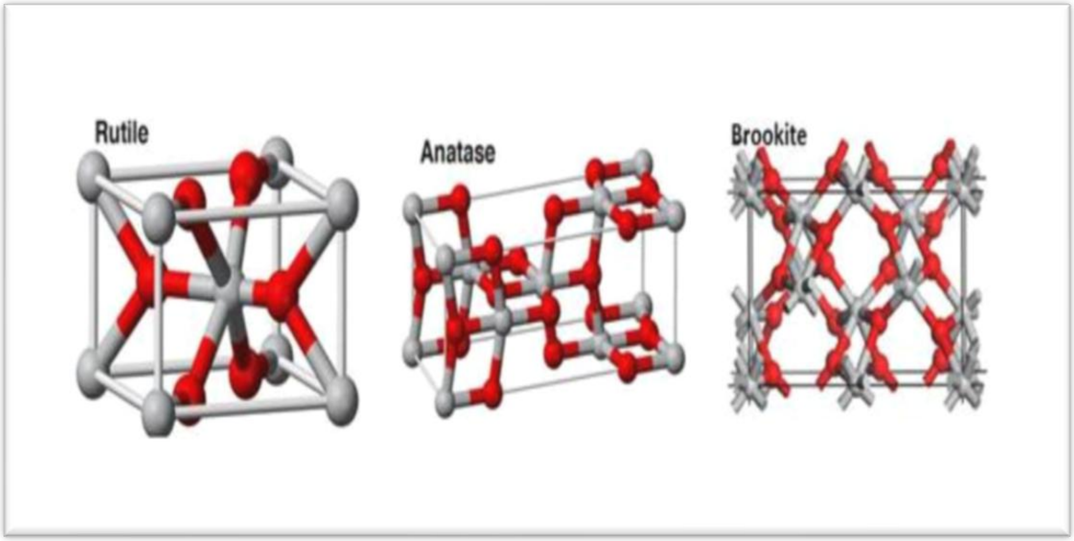

Figure 2: TiO2 structures: Rutile, Anatase, and Brookite.

Any physical and chemical properties of the three main TiO2 structures are described in Table 1.
Only rutile and anatase, including their three stable structures, play some position on DSSCs. All structures have a titanium atom surrounded by six oxygen atoms in a more or less twisted octahedral arrangement. The two bonds between the titanium and oxygen atoms at the apices of the octahedron are significantly longer in each configuration [46].

Table 1: TiO2 bulk properties [47].

Crystal Structure	System	Space Group	Lattice constant (nm) A	B	c	c/a
Rutile	Tetragonal	$D_{4h}^{14} - P4_2 / mnm$	0.4584	--	0.2953	0.644
Anatase	Tetragonal	$D_{4h}^{19} - I4_1 / amd$	0.3733	--	0.937	2.51
Brookite	Rhombohedral	$D_{2h}^{15} - Pbca$	0.5436	0.9166	0.5135	0.944
	Density (Kg/m³)	Band gap Energy (eV)			Standard heat capacity (J/mol °C)	
Rutile	4240	3.0 Indirect			55.06	
Anatase	3830	3.2 Indirect			55.52	
Brookite	4170	----			298.15	

Nanomaterials have recently gained a lot of interest as a way to improve the efficiency of biopolymer-based films[48]. Amongthem, nano-TiO2has been widely utilised because of its low price, non-toxicity, and light stability. When added to food packaging, Nano-TiO2 can withstand pressure during food processing and transportation[49]. Furthermore, nano-TiO2 has a high UV blocking ability. Nano-TiO2 has the ability to minimise light transmittance in the UV-A, UV-B, and visible light areas, which helps to resist photoinduced oxidative degradation in food packaging systems[50].

1-11 SnO_2 Nanoparticles

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[51]. Since ancient times, tin oxide colloids have been used as pigments. For example, they were already used in cosmetic creams in ancient Rome, as discovered during an archaeological dig in London[52].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

© 2026 Hasan M. Marhoon, Mohammed Talib. This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC BY NC ND).https://creativecommons.org/licenses/by/4.0/

medium not only for advanced optoelectronic applications like solar cells or light-emitting diodes, but also as a pigment in glasses and ceramic glazes[53,54].SnO2films of various thicknesses can be added to glasses and ceramics to improve abrasion resistance (films of <0.1μm)[55,56]. 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[57-59]. The semiconductor SnO2 has long been used to identify flammable and poisonous gases such as alcohol[60].

A semiconductor's optical properties are determined. Extrinsic and inherent influences are also there. The photoluminescence is a form of luminescence that occurs when light is absorbed. 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[61]. For the synthesis of SnO_2 nanostructures, various methods have been developed, including the vapour-liquid-solid (VLS) method, calcination process, chemical vapour deposition, thermal evaporation, hydrothermal process, laser ablation technique, sol-gel method, and solvothermal method[62,63]. For the processing of SnO_2 nanoparticles, the current study uses the sol-gel process[64].

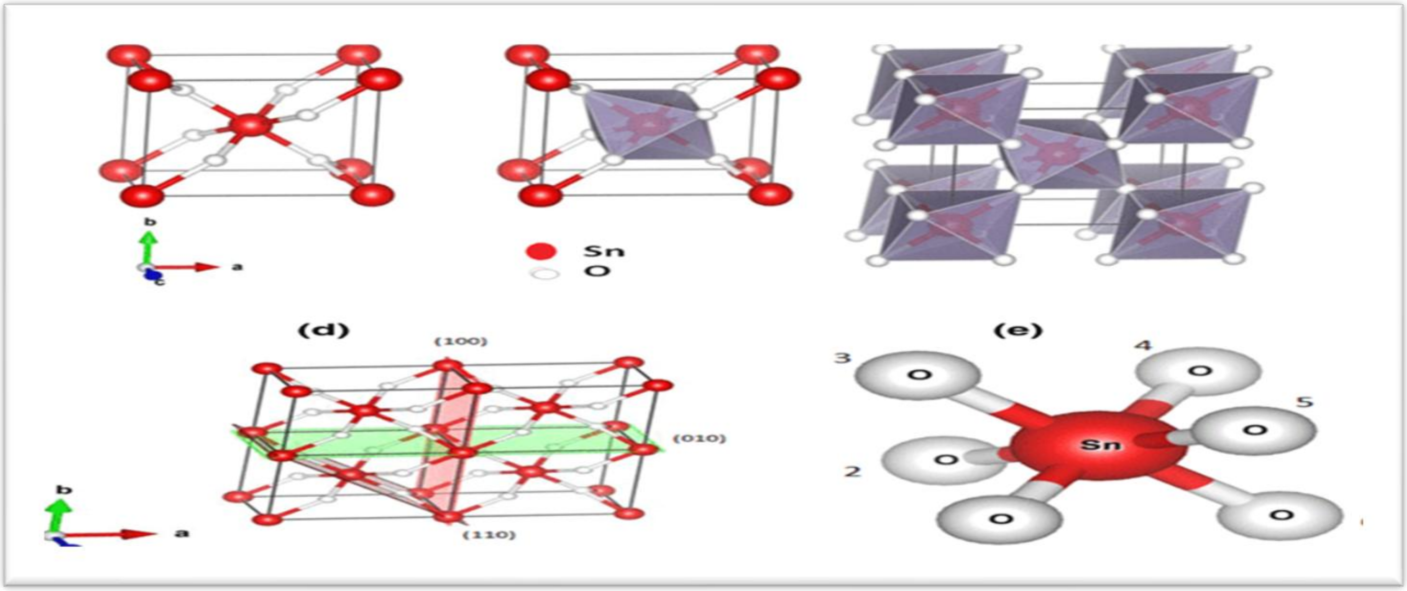

Figure 3: The structural model of SnO_2: a position of tin and oxygen atoms in a tetragonal lattice, b octahedron formed by coordination of one tin and six oxygen atoms, c many octahedron present in the tetragonal lattice, diffraction planes in the tetragonal lattice, and e indication of numbers on oxygen atoms to locate their positions [65].

1-12 Characterisation of Nanomaterials

1-12-1 The Atomic Force Microscope

AFM is an effective tool that can be used to capture both high-resolution images on several different types of solid surfaces as well as the vertical and lateral force between a sharp tip and the surface," according to the article[66]. Atomic force microscopy (AFM) has shown the ability to generate high-resolution pictures, allowing us to see the arrangement of individual atoms in a sample or the composition of individual molecules[67]. Since it does not need conductive materials, it is a basic technique that can be used in the air or under vacuum and is useful even on surfaces filled with oxides[68]. Instead, the Scan Force Microscope (SFM) is used to determine the force between the tip and the sample in the atomic force microscope. An aqueous drawing is given force between the tip and the sample as a function of the distance between the tip and the sample. Three distinct structures may be identified:(A) Where the tip is far from the surface, the force between the tip and the sample is ignored; (B) when the distance between the tip and the sample is negligible, an enticing(negative) force occurs between the tip and the sample. (C) There is a heavy repulsive force between the tip and the sample for very short distances[69]. The probe is attached to a cantilever that deflects when it comes into contact with something; the deflection is determined by the "beam rebound" method of reflecting a laser beam. The topography of the soil is thus precisely determined by the cantilever deflections. Multiple peaks are identified by varying colour (red, white, purple, etc.) or grayscale gradients on the topography map. A multicoloured surface topology picture is created in this manner, which can be very useful in defining and measuring parameters under investigation [70].

© 2026 Hasan M. Marhoon, Mohammed Talib. This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC BY NC ND).https://creativecommons.org/licenses/by/4.0/

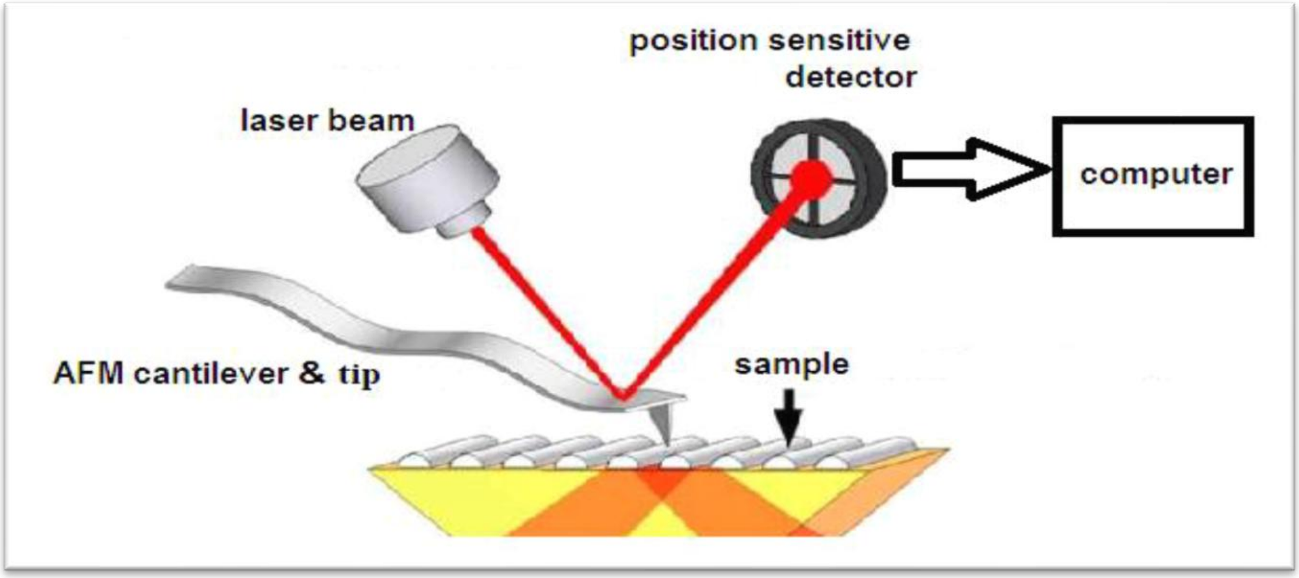

Figure 4: The essential parts of AFM-technique [71].

1-12-2 Scanning Electron Microscopes (SEM)

Photos from a scanning electron microscope (SEM) are generated by scanning the beam while watching the signal from an electron detector on a television or computer monitor. SEM is widely used to study the microstructure and chemistry of a wide range of materials. A reservoir of electrons, electromagnetic lenses, and the flexible knowledge collected from various sources are the key components of the SEM[72]. An electron microscope that scans field emissions can have a resolution of(1 nm) [73]. When the sample is struck by the accelerated main electrons, secondary electrons are released, as seen in thefigure below. A positively charged electron detector collects these secondary electrons, resulting in a three-dimensional image of the sample. Electrons are emitted at the top of the column, accelerated down the column, and then moved through a series of lenses and apertures to create a centred beam of electrons that reaches the sample surface. The sample is put on a stage in the chamber region, and both the column and the chamber are evacuated by a combination of pumps unless the microscope is designed to operate at low vacuums [74]. Figure 5 below shows the installation of a scanning electron microscope.

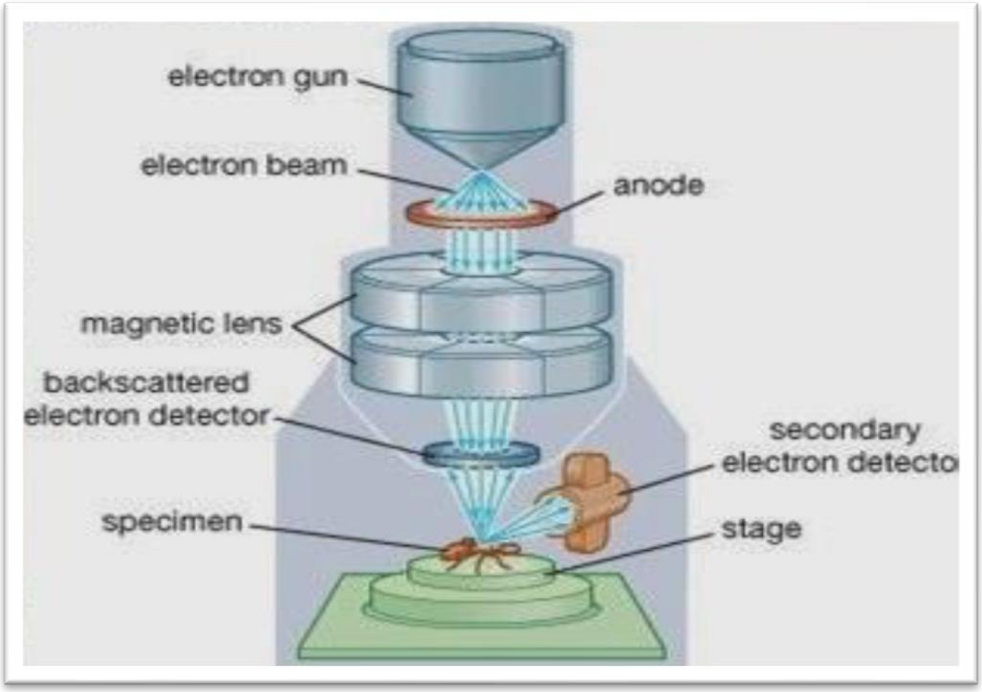

Figure 5: The essential parts of SEM-technique

© 2026 Hasan M. Marhoon, Mohammed Talib. This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC BY NC ND).https://creativecommons.org/licenses/by/4.0/

1-12-3 Transmission Electron Microscopy

The term "transmission electron microscopy" (TEM) refers to the electron diffraction and imaging techniques that a transmission electron microscope can perform. Transmission electron microscopy (TEM) can be described as an instrument that is specifically designed to investigate the visualisation of samples or samples within dimensions ranging from $1*10^{-6}$m (1 micrometre) to $1*10^{-9}$m (1 nanometer). This kind of electron microscope has the ability to reveal highly complex levels of detail that are difficult to accomplish with traditional light magnifying instruments(75). A Transmission Electron Microscope (TEM) examines materials for morphological, compositional, and crystallographic detail using energetic electrons.TEMs generate two-dimensional images with a high target resolution, allowing for a wide variety of applications in education, research, and industry. The absorption of electrons in the film, due to the thickness and structure of the material, distinguishes TEM images at lower magnifications(76). The TEMs operate by producing an electron beam in a vacuum chamber using a tungsten filament, as seen in the diagram below. The released electrons are accelerated by an electric field that often focuses the beam broadly. The beam is then guided through the sample material. The sample is a very thin slice of substance that has been carefully prepared (less than 100 nm). Electrons moving through the sample collided with a phosphorous screen, CCD, or film, creating an image. More electrons are passing in where the sample density is lower, and the picture becomes sharper. A darker picture is generated in regions where the sample is denser and therefore fewer electrons travel through (77).

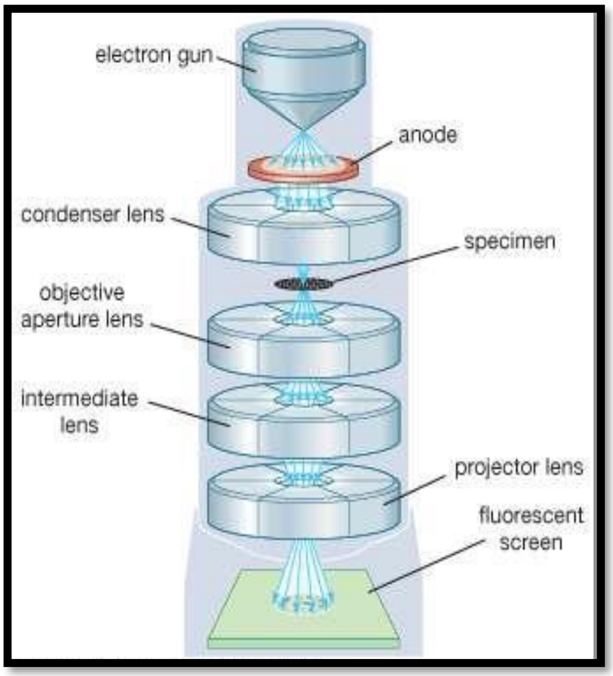

Figure 6: The Essential Parts of TEM-Technique (78)

1-12-4 X-Ray Diffraction

X-ray diffraction (XRD) is an effective nondestructive crystalline material characterisation tool. It contains data on structures, phases, desired crystal orientations (texture), and other structural parameters, including average grain size, crystallinity, strain, and crystal defects(79). When a collimated pulse of electromagnetic waves with a wavelength equal to interatomic distances interacts with the periodic continuum of molecules in a crystal, it causes diffraction(80).XRD is the technique of choice for determining strain conditions in thin films because it offers unparalleled accuracy in atomic spacing measurements. Since XRD is non-contact and non-destructive, it is ideal for in situ research. Nanomaterials have a microstructure that is similar to critical length scales of physical phenomena, giving them unique mechanical, optical, and electronic properties (81). When radiation with a wavelength equal to atomic spacingsis dispersedspecularly by the atoms of a crystalline structure and undergoes positive interference, this is known as Bragg diffraction. The waves in a crystalline solid are dispersed by the interplanar distance d between lattice planes. Since the difference between the direction lengths of the two waves is equal to an integer multiple of the wavelength, when the dispersed waves interact constructively, they stay in phase.2dsin is the direction differential between two waves undergoing interference, where is the glancing angle (see figure on the right; note that this varies from Snell's law, where is determined from the surface normal. Because of the combined effect of reflection in successive crystallographic planes (h,k,l) of the crystalline lattice, the effect of constructive or destructive interference becomes stronger (as described by Miller notation). This results in Bragg's rule, which specifies the conditions under which constructive interference is at its most efficient (82).

© 2026 Hasan M. Marhoon, Mohammed Talib. This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC BY NC ND).https://creativecommons.org/licenses/by/4.0/

$n\lambda=2d\sin\theta$ ………………………………………… (1-1)
where n is an integer
λ is the wavelength of the X-rays
d is the interplanar spacing generating the diffraction
θ is the diffraction angle[83].

The wavelength of incident X-rays, the angle of incidence of the beam, and the distance between the planes of atoms in a crystal lattice are all defined by this law[84].

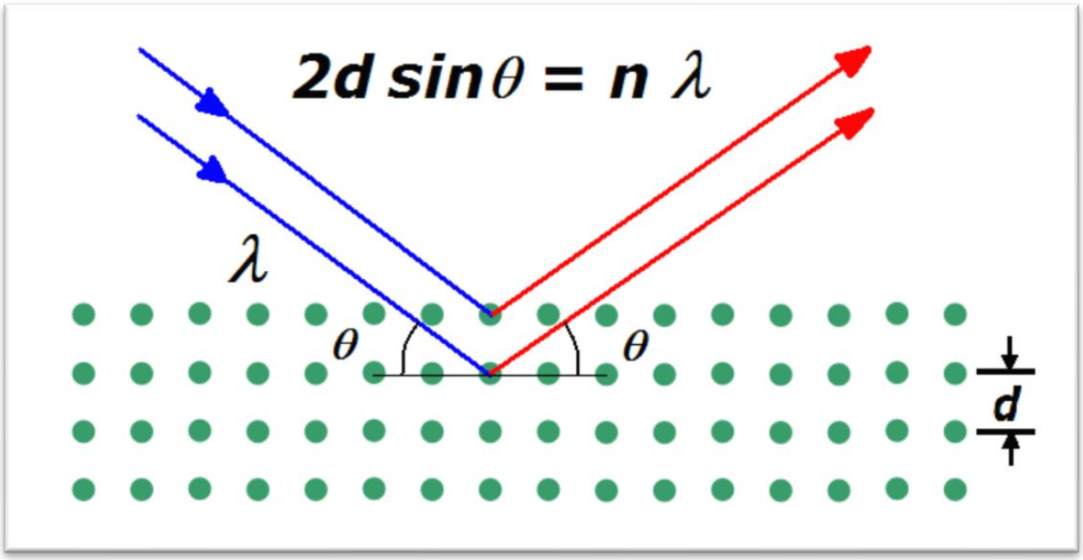

Figure 7: Thin Film Diffraction Experimental Setup [88]

1-12-5 UV-Visible Spectroscopy

UV-Visible spectroscopy is widely recognised as the most efficient spectrophotometric method for examining compound varieties. This method calculates electromagnetic radiation interference (EMR) between various wavelengths of matter. The fundamentals of UV-VIS spectroscopy, spectra origins, and electronic transition forms are all covered in UV-VIS spectroscopy. While UV-VIS spectroscopy works well and produces accurate results, understanding the components of UV-VIS spectroscopy and their individual roles in the proper operation of a UV-VIS spectrophotometer is challenging. In UV-Visible spectroscopy, light absorption is the fundamental phenomenon[89]. UV-vis spectroscopy has a wide range of applications and can be used to measure things like active pharmaceutical ingredient dissolution, compound stabilisation, reaction kinetics, metal or ligand binding, and quantitative analysis[90]. UV-visible spectroscopy is a technique that is simpler, smoother, more available, and more realistic[119]. The Lambert-Beer law governs the amount of energy consumed by a material.

$A=d\ \alpha$…………(1-2)

Where A is the film absorbance
d is film thickness
α is the absorption coefficient of incident light
According to the tauc process, the optical band gap (Eg) was determined using solid-state UV-Visible spectrophotometry.
The high absorption region is the most important absorption region for calculating Example, and the optical absorption coefficient can be calculated using the following equation[91,92].

$\alpha h\upsilon = K\ (h\upsilon - Eg)^n$ ………………(1-3)

where K is a constant, hυ is the incident photon energy in (eV), Eg: the optical energy band gap, n: index theoretically has 2 or 0.5 for the direct or indirect allowed transition, respectively.

1-12-6 FT-IR Spectroscopy

The physico-chemical method of Fourier transform infrared spectroscopy (FT-IR) is based on the vibration study of a molecule excited by IR radiation at a certain wavelength range[93]. It is commonly used to describe a variety of nanoparticles, including metallic nanoparticles, carbon nanomaterials, core-shell, and hybrid nanoparticles[94].FTIR measures the motion and passage of particles affected by infrared radiation at various wavelengths. This approach measures structural variations in the molecular bond between microorganisms and metal atoms, allowing researchers to learn more about their interactions[95]. One of the most important advantages of infrared spectroscopy is that it can analyse almost any object in any area. Liquids, solutions, pastes, powders, films, fibers, gases, and textures, to name a few, will all be investigated with the right sampling methodology[96]. The FTIR peaks are minimal and can be compared with the vibration in the molecule of a certain chemical bond in many cases (or functional group) [97].

1-13 Solar Cells

A solar cell is a battery that transforms solar energy into electricity, a green energy source that will help to alleviate the global energy crisis[98]. The scale and structure of nanoparticles determine the performance of solar cells[99]. The efficiency of solar cells is improved as the size of nanoparticles is reduced, as

© 2026 Hasan M. Marhoon, Mohammed Talib. This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC BY NC ND).https://creativecommons.org/licenses/by/4.0/

a result of lower reflectivity and a larger surface area exposed to light[100]. Solar energy offers a plentiful supply of free heat and power for practical applications. Solar energy, in contrast to non-renewable energy sources, is environmentally sustainable, producing almost no pollution. As a result, solar energy is widely regarded as the most long-term solution to the global energy crisis[101]. Solar energy has a lot of promise and capability to fulfil the world's future green energy needs. The average cumulative solar radiation is approximately 3*1024 joules[102].

A photovoltaic (PV) cell must have three essential characteristics to function:

1. Light absorption that results in electron-hole pairs or excitons .

2. The isolation of opposite-type charge carrier.[103]The extraction of such carriers to an external circuit on their own.

3. The spatial distribution of nanoparticles within the solar cell film, as well as their relative location, are important factors in determining the device's performance[104]. Using nanoparticles, solar cells may be made cheaper and more effective[105]**.**

1-13-1Types of Solar Cell

Solar cells are usually divided into four generations based on the date of manufacture and the materials used. Solar cells made of single and multicrystalline silicon from the first century are the most common on the market. Second-generation solar cells were created in response to the high material consumption and high cost of silicon solar cells. To save material, the average film thickness for this generation was reduced to a few nanometers to tens of micrometres. Others also tried dye-sensitised solar cells (DSSCs), perovskite, organic solar cells, photographic chemical plates, QDs, nanostructures, and nano-batteries. The fourth generation of solar cells was classified as a conjectural generation made of composites[106].

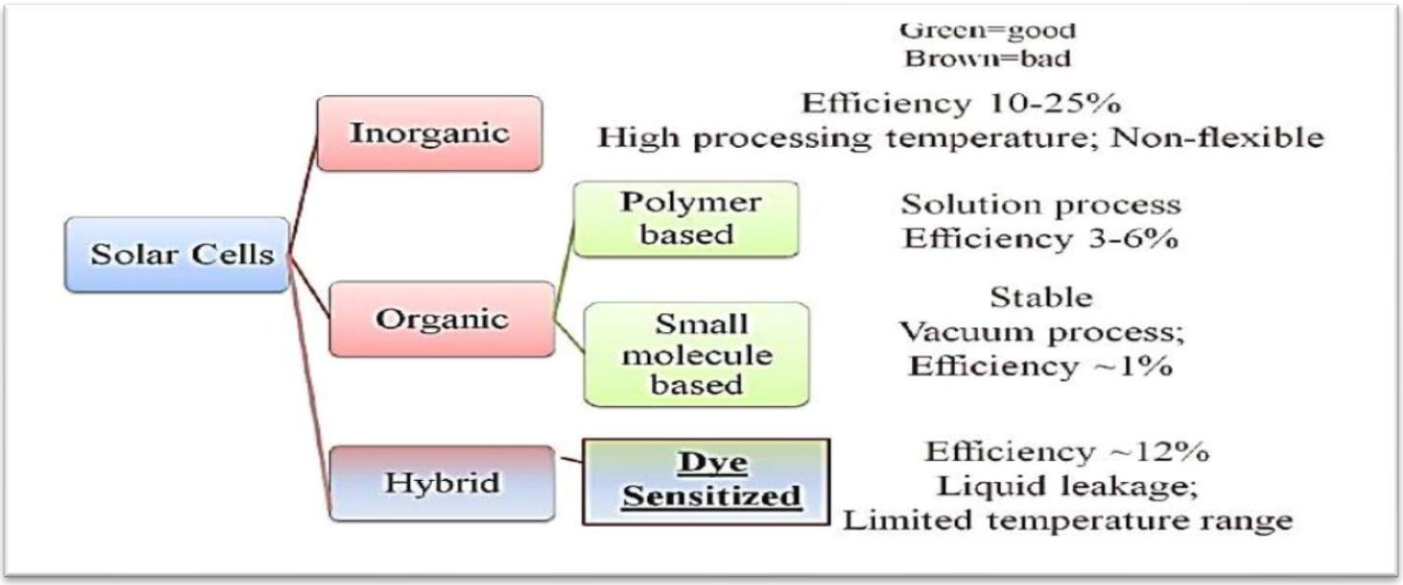

Figure 8: Types of solar cells [107]

1-13-1-1 Dye-Sensitised Solar Cells (DSSCs)

DSSC, also known as Grätzel solar cells, don't need high-quality material and have a low production cost. Nanocrystals, dyestuffs, counter electrodes, and semiconductive electrolytes make up DSSC. The effectiveness of the resulting DSSC can be influenced by these four main components[108]. It is a solar photovoltaic cell of the third generation that transforms solar radiation into electrical energy[109]. The dye and the substance transferred by the charge carrier communicate more effectively in this process[110]. A DSSC converts light into electrical potential in three steps: as light falls on a colour, photoexcitations begin, and electrons pass to the semiconductor's conductive band. Color atoms are oxidised by electrons provided by the electrolyte in a redox reaction, and then proceed through the circuit through the external load electrons[111]. Solar cells made of dye-sensitised nanostructured metal oxides have the ability to convert solar energy at a low cost, and they are now being thoroughly studied [112]. The dye is the photoactive component of the photovoltaic system, which harvests incident light and converts it to an electron. The optimal feature of the dye will be to cover alarge portion of the solar spectrum. From 400 to 800 nm, more than half of the solar energy is released in the field[113]. Because of their ability to convert renewable solar energy into electricity at a low price/output ratio, DSSCs have sparked a lot of interest in various science and technical applications[114].In a DSSC, the dye is the most important component. At a wavelength of around 800 nm, the ideal photosensitizer absorbs all of the light on the semiconductor surface[115].

© 2026 Hasan M. Marhoon, Mohammed Talib. This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC BY NC ND).https://creativecommons.org/licenses/by/4.0/

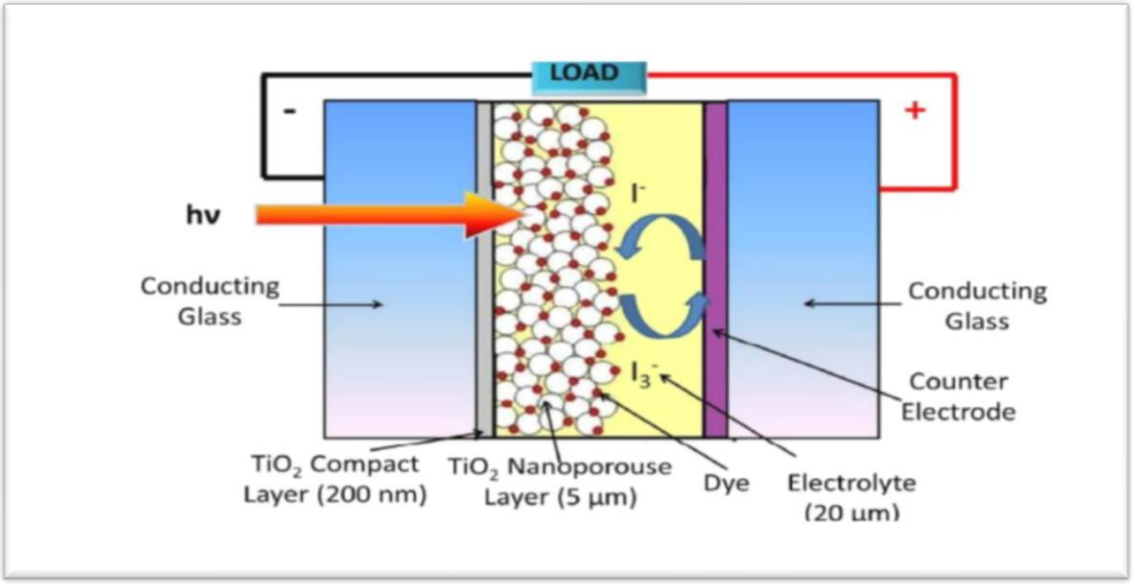

Figure 9: Structure of dye-sensitised solar cells **(DSSCs)** [116].

1-13-2 Natural Dyes

Since it uses clear methods, chlorophyll can be the most cost-effective option for fabricating DSSCs with dye sensitisers. Because of their ability to absorb light over a wide area of the visible spectrum, chlorophylls and their derivatives are appealing for use as dye photo-sensitisers in DSSCs[117]. Chlorophyll absorbs red, blue, and violet wavelengths of light and only reflects the green spectrum to provide the hue. The visible region's high absorption peaks at 420 nm and 660 nm wavelengths can be used as a natural sensitiser in the visible light range[118]. Many natural dyes, such as anthocyanins, chlorophylls, carotenoids, flavonoids, and cyanines, have been used as sensitisers in DSSCs[119].

1- chlorophyll

Chlorophyll is a green-colored dye found in plant leaves and green stems that is responsible for the absorption of light energy during photosynthesis[120]. Essentially, the most common chlorophylls are Chl-a (C55H72O5N4Mg, cyan), Chl-b (C55H70O6N4Mg, chartreuse), and Chl-c (C35H28O5N4Mg, bluegreen .(Chl-a and Chl-b are the most widely distributed chlorophylls in plants(see Fig. 10)[121].

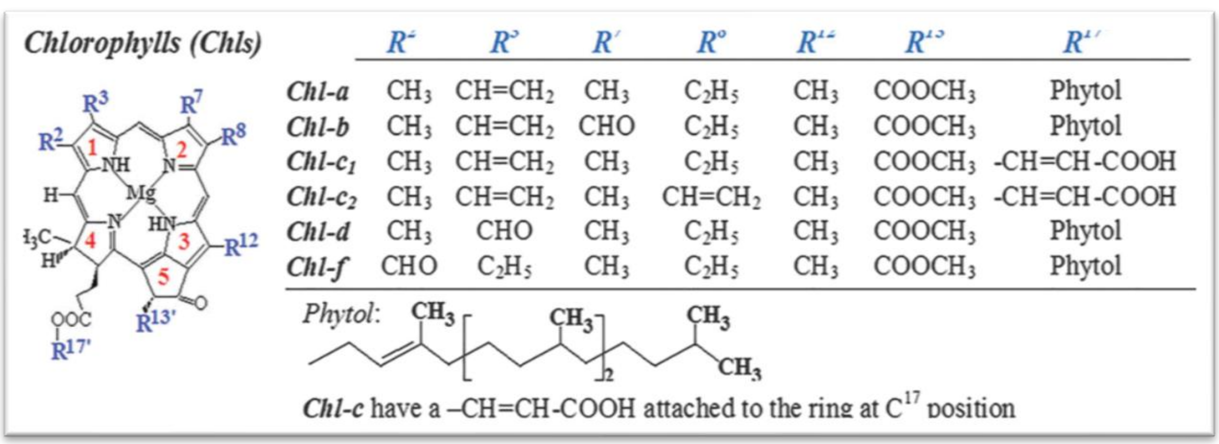

Figure 10: Basic structures and the oxidation state of natural chlorophylls: Chl-a, Chl-b, Chl-c, Chl-c1 and Chl-c2, Chl-d and Chl-f[122].

CONCLUSION

Nanomaterials are a rapidly growing field of research due to their modified properties and diverse applications in modern technologies. The development of various fabrication methods has allowed precise control over the size, shape, and structural properties of nanoparticles, which directly affects their functional characteristics. Characterisation tools such as X-ray diffraction (XRD), scanning electron microscopy (SEM), transmission electron microscopy (TEM), atomic scanning microscopy (ASM), ultraviolet-visible spectroscopy, and Fourier transform infrared spectroscopy (FTIR) play a crucial role in understanding the physical and chemical properties of

© 2026 Hasan M. Marhoon, Mohammed Talib. This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC BY NC ND).https://creativecommons.org/licenses/by/4.0/

nanomaterials. Metal oxide nanoparticles, in particular titanium dioxide (TiO_2) and tin dioxide (SnO_2), have demonstrated significant potential in photovoltaic and energy applications. In particular, the integration of nanomaterials into dye-sensitised solar cells has significantly improved energy conversion efficiency while reducing manufacturing costs. Despite these advances, further research is still needed to improve the stability, scalability, and environmental safety of nanomaterials. Further advances in nanotechnology are expected to play a crucial role in solving global energy problems and developing sustainable technologies.

REFERENCES

1. Dowling A. *Nanoscience and nanotechnology: opportunities and uncertainties*. London: The Royal Society and The Royal Academy of Engineering; 2004.
2. Bhushan B. *Springer handbook of nanotechnology*. Springer; 2010. p. 1.
3. Mishra YK, Murugan NA, Kotakoski J, Adam J. Progress in electronics and photonics with nanomaterials. Vacuum. 2017;146:304-307.
4. Bulke F. Synthesis and characterisation of copper oxide nanoparticles and investigation of their effects on the vitality and metabolism of astrocytes [PhD thesis]. Bremen: University of Bremen; 2015.
5. Hornyak GL, Tibbals HF, Dutta J, Moore JJ. *Introduction to nanoscience and nanotechnology*. Taylor & Francis Group; 2009. p. 1-54.
6. Benoit F, Taberna PL, Arurault L, Bonino JP, Céline G, Pierre B. Electrophoretic impregnation of porous anodic aluminium oxide film by silica nanoparticles. Colloids Surf A Physicochem Eng Asp. 2012;415:187-194.
7. Akhtar MS, Panwar J, Yun YS. Biogenic synthesis of metallic nanoparticles by plant extracts. ACS Sustain Chem Eng. 2013;1:591-602.
8. Allouche J. Synthesis of organic and bioorganic nanoparticles: An overview of the preparation methods. In: Brayner R, Fiévet F, Coradin T, editors. *Nanomaterials: A danger or a promise?* London: Springer; 2013. p. 27-74.
9. Cupaioli FA, Zucca FA, Boraschi D, Zecca L. Engineered nanoparticles: How brain-friendly is this new guest? Prog Neurobiol. 2014;119-120:20-38.
10. Jo DH, Kim JH, Lee TG. Size, surface charge, and shape determine the therapeutic effects of nanoparticles on brain and retinal diseases. Nanomedicine. 2015;11:1603-1611.
11. Kettler K, Veltman K, van de Meent D, van Wezel A, Hendriks AJ. Cellular uptake of nanoparticles as determined by particle properties, experimental conditions, and cell type. Environ Toxicol Chem. 2014;33:481-492.
12. Parameswaranpillai J, Hameed N, Kurian T, Yu Y. *Nanocomposite materials: synthesis, properties and applications*. CRC Press; 2016.
13. Tiwari JN, Tiwari RN, Kim KS. Zero-, one-, two- and three-dimensional nanostructured materials for advanced electrochemical energy devices. Prog Mater Sci. 2012;57(4):724-803.
14. Cao H. *Synthesis and applications of inorganic nanostructures*. John Wiley & Sons; 2017.
15. Malhotra BD, Ali MA. Nanomaterials in biosensors: fundamentals and applications. In: *Nanomaterials for Biosensors*. 2018. p. 1.
16. Goyal RK. *Nanomaterials and nanocomposites: synthesis, properties, characterisation techniques, and applications*. CRC Press; 2017.
17. Khan WS, Hamadneh NN, Khan WA. Polymer nanocomposites–synthesis techniques, classification and properties. In: *Science and Applications of Tailored Nanostructures*. 2016. p. 50.
18. Patel KD, Singh RK, Kim HW. Carbon-based nanomaterials as an emerging platform for theranostics. Mater Horiz. 2019;6(3):434-469.
19. Ray S, Chiou J, Pong W, Tsai MH. The electronic properties of nanomaterials elucidated by synchrotron radiation-based spectroscopy. Crit Rev Solid State Mater Sci. 2006;31(4):91-110.
20. Asadian E, Ghalkhani M, Shahrokhian S. Electrochemical sensing based on carbon nanoparticles: A review. Sens Actuators B Chem. 2019.
21. Calandra P, La Parola V, Turco Liveri V, Lidorikis E, Finocchi F. Composite nanoparticles. J Chem. 2013;2013.
22. do Céu Teixeira M, Santini A, Souto EB. Delivery of antimicrobials by chitosan-composed therapeutic nanostructures. In: *Nanostructures for Antimicrobial Therapy*. 2017. p. 203-222.
23. Bashir S, Liu J. Nanomaterials and their application. In: *Advanced Nanomaterials and Their Applications in Renewable Energy*. Amsterdam; 2015. p. 1-50.
24. Wu Q, Miao WS, Gao HJ, Hui D. Mechanical properties of nanomaterials: A review. Nanotechnol Rev. 2020;9(1):259-273.
25. Murty BS, Shankar P, Raj B, Rath BB, Murday J. Unique properties of nanomaterials. In: *Textbook of Nanoscience and Nanotechnology*. 2013. p. 29-65.
26. Gilbert B, Huang F, Zhang H, Waychunas GA, Banfield JF. Nanoparticles: strained and stiff. Science. 2004;305(5684):651-654.
27. Karak N. Fundamentals of nanomaterials and polymer nanocomposites. In: *Nanomaterials and Polymer Nanocomposites*. 2019. p. 1-45.
28. Dolez PI. Nanomaterials definitions, classifications, and applications. In: *Nanoengineering*. 2015. p. 3-40.
29. Khan I, Saeed K, Khan I. Nanoparticles: Properties, applications and toxicities. Arab J Chem. 2019;12(7):908-931.
30. Lawrence MJ, Kolodziej A, Rodriguez P. Controllable synthesis of nanostructured metal oxide and oxyhydroxide materials via electrochemical methods. Curr Opin Electrochem. 2018.
31. Kumar DD, Arasu AV. A comprehensive review of preparation, characterisation, properties and stability of hybrid nanofluids. Renew Sustain Energy Rev. 2018;81:1669-1689.

© 2026 Hasan M. Marhoon, Mohammed Talib. This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC BY NC ND).https://creativecommons.org/licenses/by/4.0/

32. Shelke PD, Rajbhoj AS. Electrochemical synthesis and photocatalytic application of mesoporous γ-Al2O3 nanoparticles. Der Chem. Sin. 2017;8(5):482-486.
33. Sheini FJ, Cheraghizade M, Yousefi R. Electrochemical synthesis and optoelectronic properties of Pb- and Zn-doped nanostructured SnSe films. Appl Surf Sci. 2018;443:345-353.
34. Rezalou S, Öznülüer T, Demir Ü. One-pot electrochemical fabrication of single-crystalline SnO nanostructures on Si and ITO substrates for catalytic, sensor and energy storage applications. Appl Surf Sci. 2018;448:510-521.
35. Dasa AK, Kimb NH, Pradhana D, Huic D, Lee JH. Electrochemical synthesis of palladium nanorods: An efficient electrocatalyst for methanol and hydrazine electro-oxidation. Compos Part B. 2018;144:11-18.
36. Li Y, Qiang Q, Zheng X, Wang Z. Controllable electrochemical synthesis of Ag nanoparticles in ionic liquid microemulsions. Electrochem Commun. 2015;58:41-45.
37. Liu YH, Jing XY, Zhang ML, Yan Y, Ji D, Li P, et al. Electrochemical synthesis and tribological properties of flower-like and sheet-like MoS2 in LiCl-KCl-(NH4)6Mo7O24-KSCN melt. Electrochim Acta. 2018;271:252-260.
38. Ye X, Chen L, Liu L, Bai Y. Electrochemical synthesis of selenium nanoparticles and formation of sea urchin-like selenium nanoparticles by electrostatic assembly. Mater Lett. 2017;196:381-384.
39. Blöschl G, Viglione A, Montanari A. Emerging approaches to hydrological risk management in a changing world. 2013.
40. Wang X, Chen X. Novel nanomaterials for biomedical, environmental and energy applications. 2018.
41. Ambrosio L. *Biomedical composites*. Woodhead Publishing; 2017.
42. Satyanarayana T, Reddy SS. Methods of nanomaterials.
43. Wang S, Gao L. Laser-driven nanomaterials and laser-enabled nanofabrication for industrial applications. In: *Industrial Applications of Nanomaterials*. 2019. p. 181-203.
44. Tian Z, Ge X, Wang Y, Xu J. Nanoparticles and nanocomposites with microfluidic technology. In: *Polymer-Based Multifunctional Nanocomposites and Their Applications*. 2019. p. 1-33.
45. Immanuel S, Aparna T, Sivasubramanian R. Graphene–metal oxide nanocomposite modified electrochemical sensors. In: *Graphene-Based Electrochemical Sensors for Biomolecules*. 2019. p. 113-138.
46. Naqvi S, Kumar V, Gopinath P. Nanomaterial toxicity: A challenge to end users. In: *Applications of Nanomaterials*. 2018. p. 315-343.
47. Jayaprakash N, Suresh R, Rajalakshmi S, Raja S, Sundaravadivel E, Gayathri M, et al. One-step synthesis, characterisation, photocatalytic and biomedical applications of ZnO nanoplates. Mater Technol. 2020;35(2):112-124.
48. Grigore ME, Biscu ER, Holban AM, Gestal MC, Grumezescu AM. Methods of synthesis, properties and biomedical applications of CuO nanoparticles. Pharmaceuticals. 2016;9(4):75.
49. Jasim KE. Dye sensitised solar cells—working principles, challenges and opportunities. In: *Solar Cells*. 2011;2.
50. Jasim KE. Dye sensitised solar cells—working principles, challenges and opportunities. In: *Solar Cells*. 2011;2.
51. Diebold U. The surface science of TiO2. Surf Sci Rep. 2003;48:53-229.
52. George J, Siddaramaiah. High-performance edible nanocomposite films containing bacterial cellulose nanocrystals. Carbohydr Polym. 2012;87(3):2031-2037.
53. Feng XX, Zhang LL, Chen JY, Guo YH, Zhang HP, Jia CI. Preparation and characterisation of novel nanocomposite films formed from silk fibroin and nano-TiO2. Int J Biol Macromol. 2007;40(2):105-111.
54. Arora A, Padua GW. Nanocomposites in food packaging. J Food Sci. 2010;75(1):R43-R49.
55. Li Y, Jiang Y, Liu F, Ren F, Zhao G, Leng X. Fabrication and characterisation of TiO2/whey protein isolate nanocomposite film. Food Hydrocoll. 2011;25(5):1098-1104.
56. Uchida Y, Matsui K. Optical properties of ZnS: Mn nanoparticles in sol-gel glasses. Stud Surf Sci Catal. 2001;132:331-334.
57. Evershed RP, Berstan R, Grew F, Copley MS, Charmant AJH, Barham E, et al. Nature. 2004;432:35-36.
58. Greenwood NN, Earnshaw A. *Chemistry of the elements*. 2nd ed. Oxford: Butterworth-Heinemann; 1997.
59. Batzill M, Diebold U. The surface and materials science of tin oxide. Prog Surf Sci. 2005;79:47-154.
60. Holleman AF, Wiberg E. *Inorganic chemistry*. 102nd ed. Berlin: De Gruyter; 2007.
61. Judd SM. Thin solid films. Thin Solid Films. 1981;77:13-20.
62. Kim SP, Choi MY, Choi HC. Photocatalytic activity of SnO2 nanoparticles in methylene blue degradation. Mater Res Bull. 2016;74:85-89.
63. Jiang Q, Zhang XW, You JB. SnO2: A wonderful electron transport layer for perovskite solar cells. Small. 2018;14:1801154.
64. Li BJ, Yang GY, Huang LJ, Zu W, Ren NF. Performance optimisation of SnO2:F thin films under quasi-vacuum laser annealing. Appl Surf Sci. 2020;509:145334.
65. Phuoc PH, Huang CM, Toan NV, Duy NV, Hoa ND, Hieu NV. One-step fabrication of SnO2 porous nanofiber gas sensors for sub-ppm H2S detection. Sens Actuators A. 2020;303:111722.
66. Sun P, Cao Y, Liu J, Sun YF, Ma J, Lu GY. Dispersive SnO2 nanosheets: Hydrothermal synthesis and gas sensing properties. Sens Actuators B. 2011;156:779-783.
67. Luo SH, Fan JY, Liu WL, Zhang M, Song ZT, Liu CL, et al. Synthesis and low-temperature photoluminescence properties of SnO2 nanowires and nanobelts. Nanotechnology. 2006;17:1695-1699.

© 2026 Hasan M. Marhoon, Mohammed Talib. This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC BY NC ND).https://creativecommons.org/licenses/by/4.0/

68. Chen Y, Cui X, Zhang K, Pan D, Zhang S, Wang B, et al. Chem Phys Lett. 2003;369:16.
69. Li M, Lu Q, Nuli Y, Qian X. Electrochem Solid-State Lett. 2007;10:K33.
70. Pan ZW, Dai ZR, Wang ZL. Nanobelts of semiconducting oxides. Science. 2001;291:1947.
71. Khalid MU, Khan SR, Jamil S. Morphologically controlled synthesis of cube-like tin oxide nanoparticles and their photocatalytic application. J Inorg Organomet Polym. 2018;28:168-176.
72. Ikhmayies SJ. Characterisation of nanomaterials. JOM. 2014;66(1):28-29.
73. Guo D, Xie G, Luo J. Mechanical properties of nanoparticles: basics and applications. J Phys D Appl Phys. 2013;47(1):013001.
74. Eaton P, West P. *Atomic force microscopy*. Oxford University Press, 2010.
75. Lindon JC, Tranter GE, Koppenaal D. *Encyclopedia of spectroscopy and spectrometry*. Academic Press; 2016.
76. Kim Y, Kim W, Park JW. Principles and applications of force spectroscopy using atomic force microscopy. Bull Korean Chem Soc. 2016;37(12):1895-1907.
77. Nasrollahzadeh M, Atarod M, Sajjadi M, Sajadi SM, Issaabadi Z. Plant-mediated green synthesis of nanostructures: mechanisms, characterisation, and applications. Interface Sci Technol. 2019;28:199-322.
78. Pletikapić G, DeNardis N. Application of surface analytical methods for hazardous situations in the Adriatic Sea. Nat Hazards Earth Syst Sci. 2017;17:31-44.
79. Singh AK. Experimental methodologies for the characterisation of nanoparticles. In: Singh AK, editor. *Engineered Nanoparticles: Structure, Properties and Mechanisms of Toxicity*. Academic Press; 2016. p. 125-170.
80. Zhou X, Li Y. *Atlas of oral microbiology: from healthy microflora to disease*. Academic Press; 2015.
81. Sierra CFE. Fundamentals of transmission electron microscopy: the technique with the best resolution in the world. Screen. 9:10.
82. Choudhary P, Choudhary O. Uses of transmission electron microscope in microscopy and its advantages and disadvantages. Int J Curr Microbiol Appl Sci. 2018;7:743-747.
83. Pennycook SJ, Nellist PD. *Scanning transmission electron microscopy: imaging and analysis*. Springer; 2011.
84. Alex K. Growth and optimisation of aluminium doped zinc oxide using spray pyrolysis technique. 2016.
85. Bunaciu AA, Udriştioiu EG, Aboul-Enein HY. X-ray diffraction: instrumentation and applications. Crit Rev Anal Chem. 2015;45(4):289-299.
86. Kim SH, Lee CM, Kafle K. Characterization of crystalline cellulose in biomass: basic principles, applications, and limitations of XRD, NMR, IR, Raman, and SFG. Korean J Chem Eng. 2013;30(12):2127-2141.
87. Sharma R, Bisen D, Shukla U, Sharma B. X-ray diffraction: a powerful method of characterizing nanomaterials. Recent Res Sci Technol. 2012;4(8).
88. Meyers H, Myers H. *Introductory solid state physics*. CRC Press; 1997.
89. Sampaio PGV, González MOA. Photovoltaic solar energy: conceptual framework. Renew Sustain Energy Rev. 2017;74:590-601.
90. Chauhan A, Chauhan P. Powder XRD technique and its applications in science and technology. J Anal Bioanal Tech. 2014;5(5):1-5.
91. Channam VSK. Synthesis of strongly correlated oxides and investigation of their electrical and optical properties. 2017.
92. Akash MSH, Rehman K. Ultraviolet-visible (UV-VIS) spectroscopy. In: *Essentials of Pharmaceutical Analysis*. 2020. p. 29-56.
93. Edwards AA, Alexander BD. UV-visible absorption spectroscopy: organic applications. 2017.
94. Shimamoto GG, Tubino M. Alternative methods to quantify biodiesel in diesel-biodiesel blends through UV-visible spectroscopy. Fuel. 2016;186:199-203.
95. George G, Wilson R, Joy J. Ultraviolet spectroscopy: a facile approach for the characterization of nanomaterials. In: *Spectroscopic Methods for Nanomaterials Characterization*. 2017. p. 55-72.
96. Skoog DA, West DM, Holler FJ, Crouch SR. *Fundamentals of analytical chemistry*. 9th ed. Rolin Graphics Inc.; 2014.
97. Zarnowiec P, Lechowicz L, Czerwonka G, Kaca W. Fourier transform infrared spectroscopy (FTIR) as a tool for identification of pathogenic bacteria. Curr Med Chem. 2015;22(14):1710-1718.
98. Shaislamov U, Kim H, Yang JM, Yang BL. CuO/ZnO/TiO2 photocathodes for a self-sustaining photocell. Int J Hydrogen Energy. 2020;45(11):6148-6158.
99. Faghihzadeh F, Anaya NM, Schifman LA, Oyanedel-Craver V. Fourier transform infrared spectroscopy to assess molecular-level changes in microorganisms exposed to nanoparticles. Nanotechnol Environ Eng. 2016;1(1):1.
100. Fan M, Dai D, Huang B. Fourier transform infrared spectroscopy for natural fibres. Fourier Transform Mater Anal. 2012;3:45-68.
101. Movasaghi Z, Rehman S, ur Rehman DI. Fourier transform infrared (FTIR) spectroscopy of biological tissues. Appl Spectrosc Rev. 2008;43(2):134-179.
102. Asim N, Mohammad M, Badiei M. Novel nanomaterials for solar cell devices. In: *Nanomaterials for Green Energy*. 2018. p. 227-277.
103. Bai Y, Yan L, Wang F, Yang Y, Liu H, Yin Z, et al. Boosting photocurrent of GaInP top-cell via plasmonic Au nanoparticles. Sol Energy. 2018;166:181-186.
104. Elnoby RM, Mourad MH, Elnaby SLH, Kana MTHA. Monocrystalline solar cells coated by silver nanoparticles: effect of particle size. Opt Laser Technol. 2018;101:208-215.

© 2026 Hasan M. Marhoon, Mohammed Talib. This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC BY NC ND).https://creativecommons.org/licenses/by/4.0/

105. Liao H, Deng Q, Shen Y, Wang G, Wang S, Mao Y. Theoretical analysis of BaSi2 homojunction solar cells toward high efficiency. Sol Energy. 2020;201:857-865.
106. Al-Alwani MA, Mohamad AB, Ludin NA, Kadhum AAH, Sopian K. Dye-sensitized solar cells: development and operation principles. Renew Sustain Energy Rev. 2016;65:183-213.
107. Bagher AM, Vahid MMA, Mohsen M. Types of solar cells and application. Am J Opt Photonics. 2015;3(5):94-113.
108. Deka N, Islam M, Sarswat PK, Kumar G. Enhancing solar cell efficiency with plasmonic double metal nanoparticle system. Vacuum. 2018;152:285-290.
109. Vennila R, Kamaraj P, Arthanareeswarid M, Sridharan M, Sudha G, Devikala S, et al. Biosynthesis of ZrO nanoparticles and its dye sensitized solar cell studies. Mater Today Proc. 2018;5:8691-8698.
110. Pathakoti K, Manubolu M, Hwang HM. Nanotechnology applications for environmental industry. In: *Handbook of Nanomaterials for Industrial Applications*. Elsevier; 2018. p. 894-907.
111. Wang K. Nanomaterials: from interfacial characteristics to device applications [PhD dissertation]. McMaster University; 2011.
112. Zainul R, Isara L. Preparation of dye sensitized solar cell (DSSC) using anthocyanin dyes from jengkol shell. J Phys Conf Ser. 2019.
113. Bose S, Soni V, Genwa K. Recent advances and future prospects for dye sensitized solar cells: a review. Int J Sci Res Publ. 2015;5(4):1-8.
114. Wong KV, Perilla N, Paddon A. Nanoscience and nanotechnology in solar cells. J Energy Resour Technol. 2014;136(1).
115. Ammar AM, Mohamed HS, Yousef MM, Abdel-Hafez GM, Hassanien AS, Khalil AS. Dye-sensitized solar cells based on extracted natural dyes. J Nanomater. 2019;2019.
116. Keis K, Bauer C, Boschloo G, Hagfeldt A, Westermark K, Rensmo H, et al. Nanostructured ZnO electrodes for dye-sensitized solar cells. J Photochem Photobiol A Chem. 2002;148(1-3):57-64.
117. Munukutla LV, Htun A, Radhakrishnan S, Main L, Kannan AM. Dye-sensitized solar cells. In: *Solar Cell Nanotechnology*. 2013. p. 159-184.
118. Allec SI, Kumar A, Wong BM. Linear-response and real-time TD-DFT for predicting optoelectronic properties of dye-sensitized solar cells. In: *Dye-Sensitized Solar Cells*. 2019. p. 171-201.
119. Krishna JV, Mrinalini M, Prasanthkumar S, Giribabu L. Recent advances on porphyrin dyes for dye-sensitized solar cells. In: *Dye-Sensitized Solar Cells*. 2019. p. 231-284.
120. Sen Z. Solar irradiation fundamentals. In: *Solar Energy Conversion and Photoenergy Systems*. 2009;2.
121. Wang P, Klein C, Humphry-Baker R, Zakeeruddin SM, Grätzel M. Stable ≥8% efficient nanocrystalline dye-sensitized solar cell. Appl Phys Lett. 2005;86(12):123508.
122. Syafinar R, Gomesh N, Irwanto M, Fareq M, Irwan Y. Chlorophyll pigments as natural dye for dye-sensitized solar cells (DSSC). Energy Procedia. 2015;79:896-902.

Creative Commons License

This article is an open-access article distributed under the terms and conditions of the Creative Commons Attribution–Non-Commercial–No Derivatives 4.0 International (CC BY-NC-ND 4.0) License. This license permits users to copy and redistribute the material in any medium or format for non-commercial purposes only, provided that appropriate credit is given to the original author(s) and the source. No modifications, adaptations, or derivative works are permitted.

About the corresponding author

Hasan M. Marhoon is affiliated with the Department of Chemistry, Faculty of Science, University of Kufa, An-Najaf, Iraq. His academic interests focus on chemical sciences, particularly materials and applied chemistry. He contributes to research and higher education, supporting scientific advancement and student development in the field of chemistry.

© 2026 Hasan M. Marhoon, Mohammed Talib. This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC BY NC ND).https://creativecommons.org/licenses/by/4.0/