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A critical review on types, production, and applications of Nano structured materials

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Abstract

Nanotechnology is developing rapidly because of the major breakthroughs made in many industries, such as electronics, energy, medicine, cosmetics, food engineering, telecommunications, and agriculture. Nanotechnology terminology gained prominence and became a catch-all for everything high-tech in the materials field. Nanomaterials have unique properties related to optical, magnetic, electrical, and physical aspects because of their small size, comprised response, durability, surface area, sensitiveness, and persistence. Nanoscale matter is distinct from matter in the solid, liquid, gaseous, and plasma states due to its size and forms. When creating thin films, target materials range in thickness from a few nanometers to several microns. Due to its numerous applications, thin film technology is receiving a lot of attention globally. When compared to traditional films made of the same material, these features give the films amazing properties and functions. Due to their versatility, flexibility, low weight, and cost-effectiveness, patterned polymer thin films are indispensable parts of numerous applications in different gadgets. Nanostructured thin film technology has a very promising future. This study provides an in-depth analysis of nanomaterials, including their types, properties, methods of synthesis, and applications across various industries.

Keywords: Nanomaterials, Nanoscale, Nanofilms, Nanostructured, Synthesis

Full length article **Corresponding Author*, e-mail: Iqrashahid215@gmail.com

1. Introduction

The term nanos, which translates to "very small," can be used to describe a dwarf. Recall that in a global system of units, the prefix nano denotes a subset of a unit. The terms "nano" and "nanometer," for instance, refer to billionths of a Kelvin, billionths of a liter and millionths of a milliliter, respectively, and "nano liter" and "nano meter," respectively. In the modern world, such innovations which include the use of solar sunlight, energy conservation, and techniques to ensure safe air and H_2O are extremely valuable. The products' shelf life needs to be ensured. But manufacturers are under pressure to produce more goods and packaging that is recyclable or biodegradable due to growing environmental and ecological concerns [1]. Many years ago, photolithographic approaches were extensively utilized to create tiny particles designs. Observing, measuring, and manipulating materials at the nanoscale level is one of the most difficult tasks for researchers and scientists working in the fields of nanotechnology and nanoscience. A low-dimensional material created by assembling atomic, molecular, or ionic species with a final thickness in the nm range is essentially what is meant to be understood as a thin film. Almost any material can be used to create nano-thin films, opening a wide range of potential applications. Photosensitive resist films are partially blocked by masks during photolithography exposure to light. As such, the decomposition reactions or triggered polymerization (negative photoresist) only occur in the exposed areas. By etching once the photoresist film has developed, the design can be transferred to the bottom layer by layer [2]. Ultimately, important obstacles and future guidelines for patterning polymer lightweight films will be presented for advancement. A viable and dependable method of organizing the materials is through thin films. As technology has advanced, its significance has increased contributes to device miniaturization [3]. Thin films with nanostructures have a wide range of possible uses in different industries. They can be utilized to make holograms, filters, polarizers, and anti-reflective coatings, for instance, in optics. They can be used in electronics to make memory devices, diodes, capacitors, and transistors. They can be used to make fuel cells, batteries, or supercapacitors for energy storage. They can be utilized in sensors to produce pressure, gas, or biosensors. As barrier materials, nanoclays and nanofilms are used to stop microbes from spoiling food and oxygen from absorbing it.

Food drying and spoiling are prevented and minimized with the use of these particular films. Applications for thin film coatings are numerous and serve a variety of functions. They can be used to add layers of metallization to semiconductor wafers, produce a specific level of reflectivity on a lens, and shield displays from scuffs and the elements. Thin films are characterized by different spectroscopic techniques, and they provide useful information also with some advantages and disadvantages are shown in Table 1. The synthesis, characterization, and modeling of these constrained structures for diverse applications became more challenging as a result. When it comes to obtaining materials with the right qualities for the intended uses, and structures in regards to dimensions and form are crucial [4].

Films that are of concern for use in clean technology usually have thicknesses that fall between 10 nm and 10 mm. They can be supported by stiff metal, flexible materials such as metal barriers, or substrates made of glass or plastic. Moreover, they may be a dielectric layer metal-based, or semiconducting [5]. Currently, between 80 and 90% of solar cell manufacturing is based on silicon technology, which has proven to be a dependable fabrication process for photovoltaic (PV) modules [6]. Nanotechnology structures have uses in almost every sector of the economy. Due to their enhanced selectivity and sensitivity, nanostructures can be used to observe tiny particles, like pollutants and explosives. As a result of their ability to navigate through our bodies and identify abnormalities, nanoparticles have the potential to treat deadly illnesses like cancer. Nanotechnology is full of possibilities, and we must use it wisely to advance both the environment and humankind in a way that is both safe and sustainable. The demand for energy and water has significantly increased due to the sharp rise in the world's population. Fossil fuels, or traditional energy resources, are typically used extensively; nevertheless, they often result in significant emissions of greenhouse gases [7].

2. Classification of nanomaterials based on their origin

In addition to being categorized according to dimensions and materials, Nano particles can also be categorized according to their origin, either as natural or synthetic.

2.1. Natural nanomaterials

Biological species or human activity in the environment produces natural nanomaterials. It is simple to synthesize synthetic coatings from renewable resources with unique tiny and tiny particles designs and characteristics for uses in technology. Natural nanomaterials are created in the natural world by either human activity or biological species. It is possible to create artificial surfaces for technological applications using natural sources that have distinctive characteristics and designs at the smallest of scales. Every sphere on Earth, including the earth's crust, biological community, surroundings, and the water sphere contain naturally occurring nanomaterials, regardless of human activity. The spheres that comprise Earth are made up of naturally occurring meteorites the biosphere, which is made up of microbes and organisms of greater complexity, such as humans [8].

2.2. Synthetic nanomaterials

Manual pounding vehicle discharge, cigarettes, or chemical, biological, physical, or combination synthesis are some of the methods used to create synthetic (engineered) nanomaterials. In recent years, concerns regarding risk assessment strategies have been raised by the growing production, release, and application of engineered nanomaterials in buyer goods and manufacturing processes. These risk evaluation techniques prove to be very helpful in predicting the actions and results of engineered nanoparticles in a range of environmentally friendly media. Determining whether engineered nanoscale migrants behave differently from natural NMs in response to their environment or whether their behavior can be predicted using current knowledge is the main challenge for them. Currently, a range of sources Designed nanomaterials are materials that have been linked to possible uses [9].

3. Currently available nanomaterials

3.1. Materials based on carbon

These tiny materials, which can be found as empty sphere-shaped, elliptical, or vessels, are mostly made of carbon. Carbon nanomaterials that are ellipsoidal and spherical are called fullerenes, and those that are cylindrical are called nanotubes. Stronger and softer substances, better films and coatings, and electronic uses are just a few of the numerous possible uses for these particles. Bucky balls are fullerenes, which are spherical and ellipsoidal carbon nanomaterial compositions. The spherical structure known as fullerenes has diameters of up to 8.2 nm for single layers and 4 to 36 nm for fillers with several layers, which are made up of 28–1500 carbon atoms. These NMs can be hollow tubes, ellipsoids, or spheres, and they usually contain carbon. Nanomaterials based on carbon include carbon nanotubes, carbon nanofibers, graphene fullerenes, and carbon worms. The main techniques for creating these materials from carbon are the use of chemical vapor deposition plasma departure, and laser treatment [10]. Materials based on metals**.** These tiny substances comprise, among other things, quantum dots, nanogold, nanosilver, and oxides of iron like titanium dioxide. Semiconductor manufacturer crystals in the range of several nanometers to a few hundred nanometers across are called quantum dot crystals. Each one of them is composed of hundreds or thousands of atoms. Atomic dots can have their sizes changed to alter their visual characteristics [11].

3.2. Dendrimers

These tiny materials consist of branching polymers at the nanoscale. Dendrimers have many chains ends on their surface that can be engineered to carry out particular chemical tasks. Catalysis could benefit from this feature as well. Furthermore, drug delivery may find use for three-dimensional dendrimers owing to their internal cavities that might accommodate other molecules [12].

3.3. Combines

In Combines nanoparticles are in combination with larger, bulkier materials or additional nanoparticles. From packaging materials to automobile components, nanoparticles such as small clays are currently being added to a variety of items, to improve mechanical, thermal, barrier, and flame-resistant characteristics. Single-phase or Composite nanostructures may be made by combining multiphase tiny particles with additional nanoparticles, bigger, bigger content or additional complex shapes (like metal-organic structures). Any mixture of large components made of pottery, polymer, or metallic, carbon, or organic nanoparticles can be used to generate the composites [13].

4. Classification on dimension Based

4.1. Zero-dimensional nanomaterial

These materials fall into one of two categories: They either have a non-dimensional outside the nanometric range (30 nm) or all three measurements (x, y, and z) contained within the confines of the nanoscale. 0D nanomaterials include fillers, QDs, and nanoparticles. They can be metallic or ceramic, opaque or transparent, single transparent or multifaceted., and they can also take on a variety of other forms and shapes [14].

4.2. One-dimensional nanomaterials

ID nanomaterials: A tiny structures diameter that is greater than 10 nm falls outside the non-metric category.), but the other two dimensions (x, y) of the nanomaterials are within the nanoscale range. One type of needle-shaped nanomaterial is a one-dimensional nanomaterial, comprising thin films, nanowires, nanohorns, nanotubes, and nanofibers. They can be isolated materials, chemically pure or impure, opaque or crystallized, alone or multifaceted, or encased within another substance such as metal-based, porcelain, or crystalline. Polymeric, ceramic, or metallic 1D nanoparticles are feasible [14].

4.3. Two-dimensional nanomaterials

A single dimension, denoted as 1D (x), exists at the nanoscale, spanning from 1 to 100 nm. Conversely, the two dimensions of 2D nanomaterials exhibit plate-like shapes beyond the nanometer range. Two-dimensional materials that exhibit nanostructure include coatings, thin-film multilayers, nanowalls or sheets unbound fragments, cables containers, fibers, and particles with nanoscale particle density. Their classification based on dimensions is shown in figure 1. Crystalline or amorphous, composed of various chemicals, two-dimensional nanomaterials can be placed on a substrate or incorporated into a surrounding matrix of substance that is polymeric, metallic, or both [14].

Three-dimensional nanomaterials.

Materials referred to as bulk materials or three-dimensional nanomaterials do not fall into any aspect or range of measurements in the tiny category. Above 100 nm, 3D nanomaterials have three arbitrary dimensions because the main component is made up of different components that are contained within the nanometer scale. However, all a 3D material's dimensions are greater than 100 nm and fall outside of the nanometer range. This structure consists of multiple nanolayers with interfaces formed by the close contact of 0-dimension, one direction, and 2-dimensional structural elements, distributed nanoparticles, and bundles of nanowires and nanotubes. Three-dimensional nanomaterials include colloids, lightweight films with atomic-scale permeability, and free small particles with various structures [14].

5. History and Development of Nanomaterial

Nanomaterials can be found naturally in radioactive decay, ocean spray, volcanic ash, forest fire combustion products, and weathering of rocks that contain metals or anions. Nanoparticles and nanostructured materials are thought to have derived from rock fragments that were created during the earliest known astronomical event, which created the Earth and the entire universe. Natural nanoparticles have been involved in the evolution of life on Earth from the earliest cells to the human species. Since the dawn of time, humans have created and used nanomaterials and their derivatives. Owing substantial developments in methods for examining nanomaterials [15]. It is now achievable to evaluate all forms of nanomaterials, examine their sources in Earth systems, and better frame the future effects of these materials on the environment and human health. Modern nanotechnology began in the 1960s, while the contemporary era of nanomaterials development terminated in 1960. One of the most exciting new technologies of the twenty-first century is nanotechnology. More than 4,500 years ago, humans already took advantage of the reinforcement that natural asbestos nanofibers could provide for ceramic matrixes Approximately 4,000 The use of nanomaterials for hair dye by the Ancient Egyptians dates back thousands of years. PbS NPs with a diameter of roughly 5 nm were produced by an artificial chemical process [16].

6. Sources of nanomaterials

6.1. Unexpected nanoparticles

Burning forests, Earthquakes, and reactions involving sunlight are just a few of the natural processes that result in the production of natural nanoparticles. Furthermore, the composition of nanoparticles found in nature regularly includes the shedding of skin and hair from plants and animals. Significant quantities of nanoparticulate matter have been observed to be generated by natural calamities such as thunderstorms, earthquakes, and forestry fires, all of which have a substantial effect on global air quality. Likewise, the burning of charcoal, transportation, and industrial processes are a few human endeavors that lead to the production of synthetic nanoparticles. Ninety percent of the airborne aerosols are produced naturally, with only ten percent resulting from the actions of humans [17].

6.2. Naturally produced nanomaterials

Complex living organisms such as humans, animals, birds, and plants, as well as microorganisms like bacteria, algae, and viruses, contain nanoparticles and nanostructures in addition to accidental and artificial nanomaterials. The morphology of these naturally occurring nanomaterials can now be more easily identified thanks to advancements in nanomaterial visualization equipment, which will ultimately improve our comprehension of these organisms. Maintaining the use of microorganisms in advantageous therapeutic ways requires an understanding of the small structures that these living things contain. Insects have evolved nanostructures that make them resistant to harsh environmental conditions [18].

6.3. Engineered nanoparticles

The production of this substance is caused by anthropogenic activities such as producing chemicals, the welding process, simple combustion in cooking, automobiles, petroleum coal and oil to produce electricity, aircraft motors, and the processing and burning of ore of nanoparticles. Hence, these artificial nanoparticles represent a novel class of nanoparticles that could have detrimental problems on human life style and their surroundings. Sunscreen, toothpaste, sporting goods, and commercial cosmetics all contain nanomaterials such as carbon. Nano particles TiO_2 Nano particles [19], and hydroxyapatites [20].

6.4. Plant nanostructures and nanoparticles

Wood is composed of natural fibers, which are thought of as mobile data arranged bio-composites. Fibers made from natural materials are combinations of fibers made of cellulosic material at the nanoscale. At the microscopic level, the most fundamental kind of cellulosic fibrils are between 100 and 1000 nm long and consist of both crystalline and transparent parts. The fundamental hierarchical structure of various natural fibers, including wood, with nanofibrillar components is accountable for their extraordinary strength and performance characteristics [21]. Nanotechnology facilitates the separation of nano cellulose from natural sources, but it also calls for an assortment of processes that are technological, chemical, and other. The resulting small particles of the material may take on various morphologies, including entangled networks (nanofibers) or rod-like NPs [22].

6.5. Insect nanostructures and nanoparticles

The structural blocks that make up bugs flap layers range in thickness from 0.5 µm to 1 mm. Intricate circulation also form the caterpillar's wings, providing exceptional stability to the entire wing structure [23]. The fundamental component of the wings of bugs is a chain-like transparent cellulose a polymer, which supports the outer layer and permits the application of forces during flight [24]. Between the vein and wing junctions is a unique material called resilin, which increases the flexibility of the wing [25]. The vascular structure and the substance of their floating wings supported the regular and longer colonization flights [26].

6.6. Nanoparticles and nanostructures in animals and birds

Climbing vertical walls and clinging are abilities shared by animals (insects of the Kingdom Animalia) with varying body weights, such as geckos, flies, and spiders. Their modeled outer shell gives the insect's legs a robust mechanism and the ability to attach by coordinating with its substrate a perspective. A deep microscopy investigation reveals a significant opposite expanding influence in these connection gadgets. It has been found that sub-micrometric equipment guarantees adherence, while micrometer-sized final sets are necessary for flying and caterpillars. The relationship between insect body weight and setae trend can be better understood through the use of the contact mechanics principle, which demonstrates that adhesion causes contacts to split into finer subcontacts [27].

6.7 Nanoparticles and nanostructures in the human body

The nanostructures that make up the human body serve as vital to its regular functioning. Nanostructures including DNA, proteins, enzymes, and antibodies form it. Moreover, viruses and bacteria are examples of microorganisms that are nanostructures that can infect humans and cause disease. According to some studies, bone can even be classified as a nanomaterial made of organic collagen and hierarchical inorganic nano-hydroxyapatite [28].

7. Deposition techniques for nanostructured thin films

7.1 Evaporation methods

Among all the methods for depositing thin films, evaporation is one of the oldest. It is still widely used in industry and academia to deposit semiconductor materials, with thermal evaporation or vacuum evaporation being the most used. This method's basic working principle is converting a substance transitioning from a solid state to a steam and back again on a particular substrate while it is in a vacuum or other controlled environment [29].

7.2 Vacuum evaporation

The simplest method for submitting amorphous thin films, particularly chalcogenide films like MnS [30], CdSSe, Ge-Te-Ga [31], and many more on a variety of substrates, is vacuum evaporation. The material is thermally diminished during the process and then compresses back into a solid state on the substrate. $CuInSe_2$ polycrystalline thin film was deposited using the Boeing solar cell fabrication technique. Usually, the Cu and Se precursor evaporates to deposit the bottom layer. The liquid phase was used to inject in while maintaining a constant substrate temperature of 490 °C. The mechanism underlying this injection is due to the presence of a low-temperature Cu-Se phase, and the liquid phase's dissolution of In and Se promotes growth [32].

7.3 Layer by Layer Deposition (LbL)

The LbL (layer by layer) self-assembly technique uses electrostatic, hydrogen bonding, or covalent bonding interactions to enable the alternate displacement of complementary species on a substrate. Within the thin film, different layers overlap and penetrate one another. Numerous species, such as proteins, enzymes, nanoparticles, polyelectrolytes, and many more, are capable of deposition [33].

7.4 Physical vacuum deposition

PVD, or partial vacuum deposition, is a type of atomistic deposition that involves thin-film deposition techniques that need the condensation of vaporized material on solid surface under partial vacuum. This process involves the physical release of atoms or molecules into a low-pressure, gaseous, or plasma environment, followed by their condensation and nucleation onto a substrate. Ions or plasma are typically present in the phase vapor. Reactive deposition is the term for the process wherein reactive gas is added to the vapor during the deposition process. Thin films with thicknesses ranging from a few nanometers to a thousand nanometers are deposited using PVD processes [34].

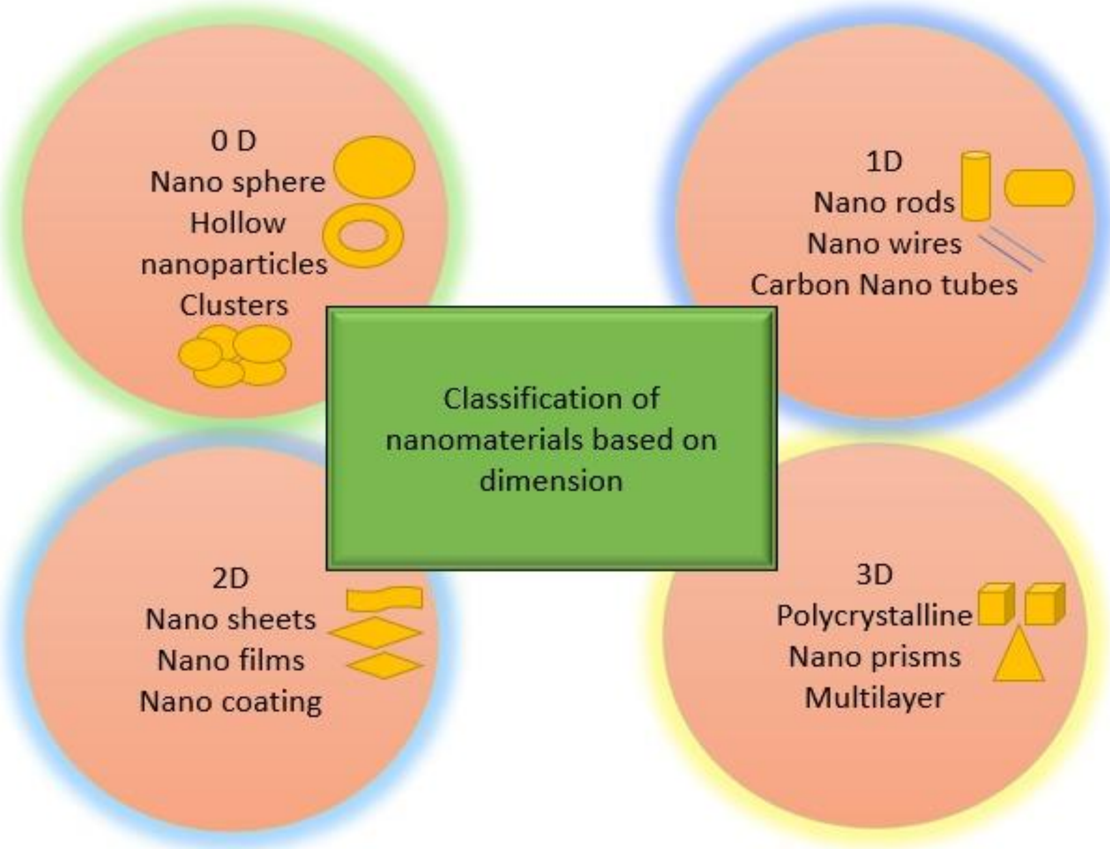

Figure 1: Classification of nanomaterials based on dimensions

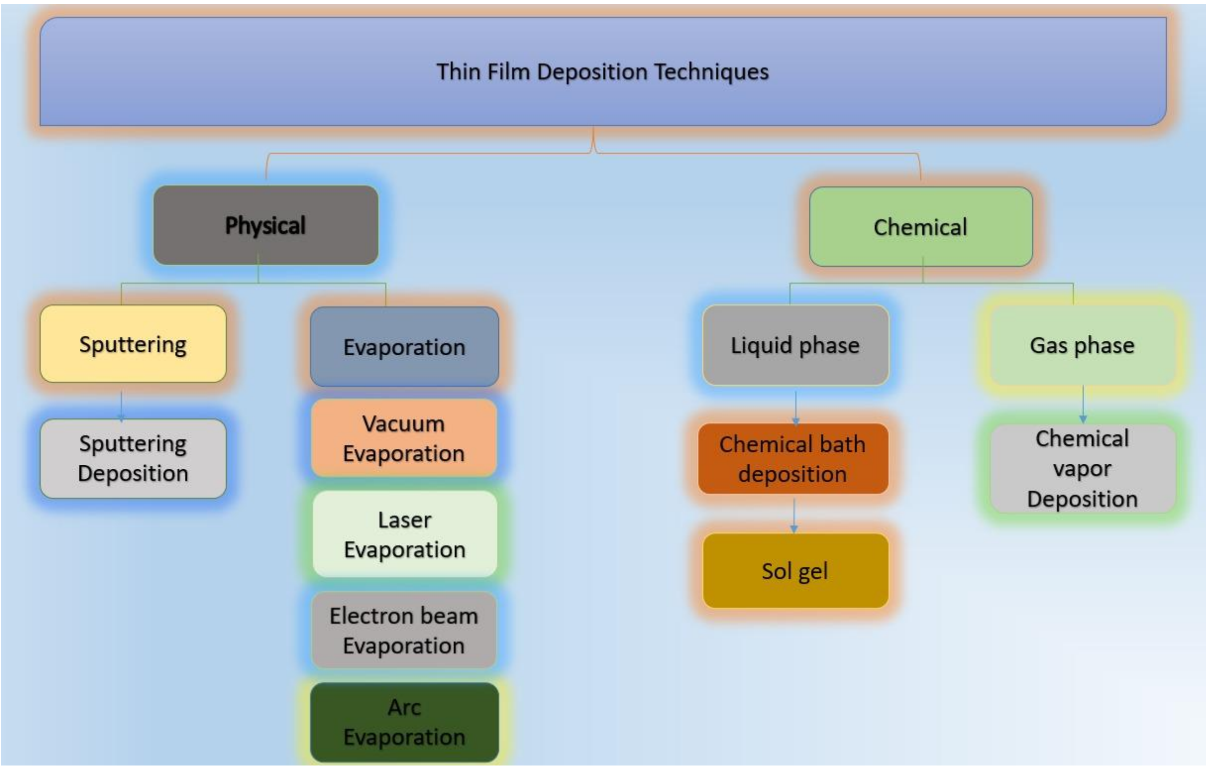

Figure 2: Thin film deposition techniques

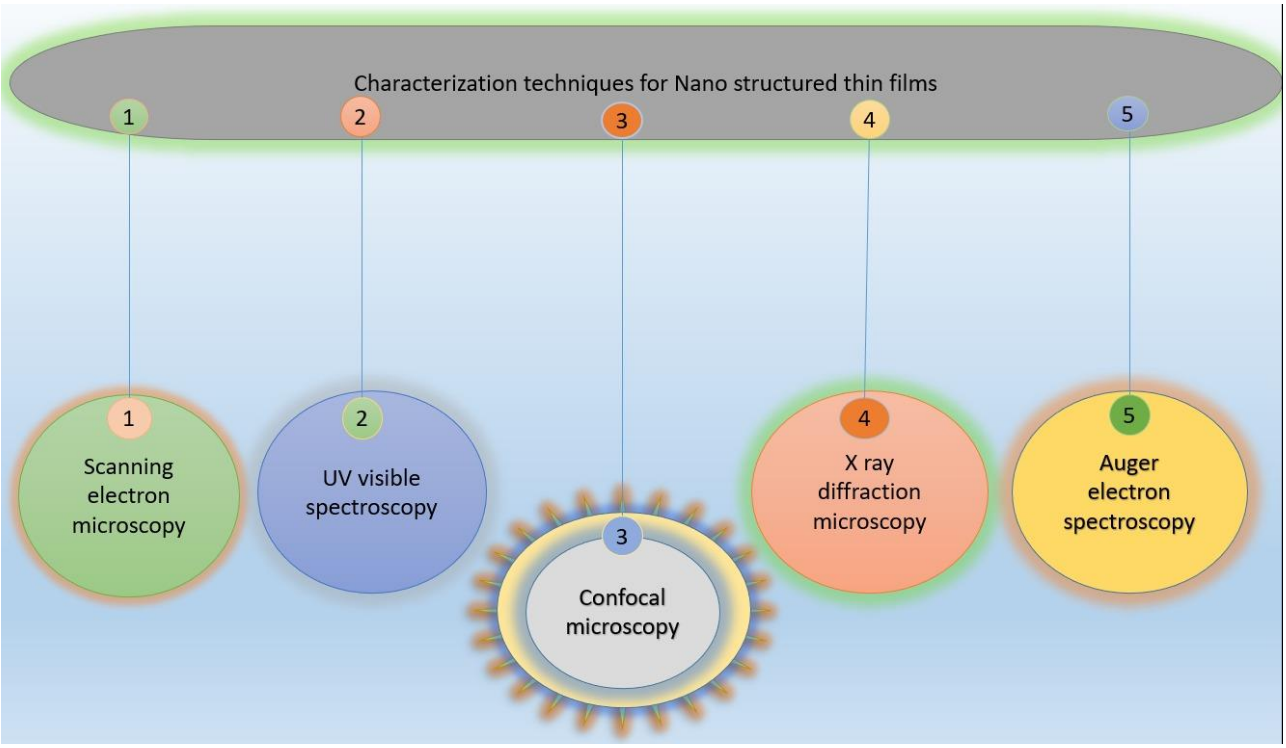

Figure 3: Characterization techniques for Nano-structured thin films

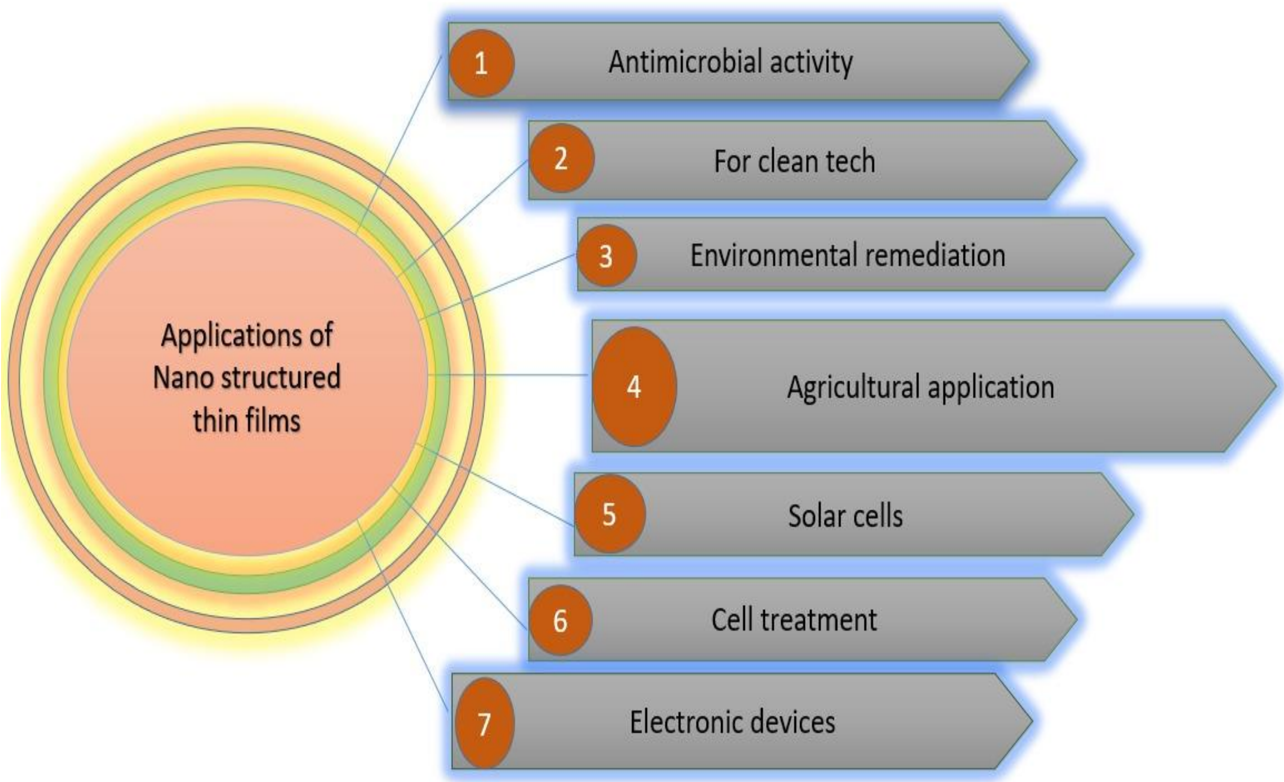

Figure 4: Applications of Nano thin films

Table 1: Characterization by spectroscopic techniques

Methods	Information obtained	Advantages	Disadvantages
Transmission electron microscopy	Size and shape of sample	Real shape of particle sample is obtained	Difficult to estimate average structure
XPS using x rays	Informed about surface layers of thin films	Non-destructive technique	High vacuum required
Auger electron spectroscopy	Informed about electronic structure of materials	3D map of sample	Special handling required and difficult to quantify
XRD	Crystalline structure	Minimal preparation required	Expensive and low sensitivity
Scanning electron microscopy	Size and shape of sample obtained	Easy to operate	Expensive
UV visible spectroscopy	Concentration and shape measured	Non-destructive and simple and high throughput	Time taking

Table 2: Deposition techniques with advantage and disadvantage

Deposition Techniques	Advantages	Disadvantages
Electron beam Evaporation	Production rate high	% Yield is low
Chemical vapor deposition technique	Deposition rate high with thick coating	High temperature required
Sol gel method	High adhesive strength	Expensive
Hydrothermal deposition	Control size distribution	Expensive and some safety issue
Pulsed laser deposition	Porous coating	Expensive
Sputtering evaporation	High deposition rate	Difficult to control deposition
Physical vapor deposition	Dense coating	Low coating rate
Chemical deposition	Throughput high	Reactive gas toxicity

The process of photovoltaic deposition (PVD) consists of three stages: evaporation, sputtering, or ion bombardment of the material to be applied. Development of the film on the surface. After being carried across the substrate, the transported atom or molecule will begin to grow through a variety of processes. The process parameters that determine the density or porosity of thin films deposited by PVD methods are temperature and pressure, which have the greatest effects on the structure. PVD films can also be used in hybrid forms with other deposition techniques, for multilayer deposition coatings, and for very thick deposits [35].

7.5. Electron beam evaporation (EBV)

EBV is a manual method. The filament produces an electron beam, which is transmitted via magnetic and electric fields to strike the target. The target is then struck and vaporized in a vacuum environment. The EBV technique is used to prepare a variety of materials, including metals [36], oxides amorphous and crystalline semiconductors [37], and molecular materials [38]. Typically, 4N-ZnO pellets were used in an electron beam evaporation process to deposit ZnO thin films on the quartz substrate. The temperature of deposition then altered, ranging from 200C to 400C. The films were annealed for one hour at 500, 600, and 800 degrees Celsius deposition [39]. PLD (pulsed laser deposition) involves vaporizing a material with a laser beam, such as KrF (248 nm) or XeCl (308 nm), with the goal of depositing the material on thin films inside a vacuum chamber. Several factors influence thin-film quality, including the laser's wavelength, energy, target-to-substrate distance, duration of the pulse, and substrate temperature [40]. Different deposition techniques have some advantages and disadvantages that are summarized in table 2.

7.6. Chemical deposition techniques

Although physical thin film deposition techniques are more costly and demand a lot of goals, they yield excellent thin films. Good-quality thin films can be produced economically and widely using chemical deposition techniques. Solution chemistry, pH, and viscosity all affect film deposition Chemical vacuum deposition and chemical-based bath deposit are two common methods of chemical deposition., electrodeposition, sol-gel, and spray pyrolysis [41].

7..7 Sputter deposition

A common physical vapor deposition technique for depositing specific materials onto pre-existing CNT films to create composite films is sputter deposition. The fundamental process is as follows: high-energy plasma ions (often argon) strike the target, causing atoms to be ejected from the surface and deposited onto a film of carbon nanotubes. It is possible to sputter elements, alloys, and compounds onto CNT film to create controlled thin layers. The time-consuming nature of the deposition in comparison to other methods is a drawback. There are several applications in various fields for depositing metal or metal oxide nanoparticles onto carbon nanotube (CNT) films. Magnetron sputtering was used to deposit Au, Ag, and Pt nanoparticles at the tips and sidewalls of CNTs, achieving electrochemical and electrocatalytic properties [42].

7.8. Sol gel technique

It is a well-known wet-chemical technique that is frequently employed to create transition metal oxide. For materials with numerous components, it improves homogeneity and requires less temperature. The steps in the process include making a suspension of colloids and converting it into solid or dense gel forms. Using alkoxides, this method produces a macromolecular oxide network through the hydrolysis of the alkoxy group, which is then followed by polycondensation reactions. Thin film deposition can be succeeded in using the techniques:

(i) Dip coating
(ii) Spin Coating
(iii) Spraying

The dip-coating mesthod. An outdated commercial thin film deposition technique is dip-coating. It produces a uniform thickness of up to 1 mm by carefully engulfing the substrate in the sol to be coated and then pulling it out.Spin-coating approach. Thin film deposition is carried out via spin coating, in which the coating area is perpendicular to the substrates' spin. One benefit of this coating is that it can quickly and easily create very uniform films with layers of thickness ranging from nanometers to microns [43].

7.9. Chemical bath deposition technique

Physical methods of thin film deposition are costly and need a lot of target, but they yield thin films with higher quality. Chemical deposition techniques are popular and affordable methods to create thin films with good quality. The pH level, solution chemistry, and viscosity all affect film deposition. Chemical vapor deposition (CVD), electrodeposition, sol-gel, spray pyrolysis technique, and chemical bath deposition are the common chemical deposition methods.

7.10. Electrochemical synthesis

Electrochemical synthesis is a cost-effective method for generating thin films with high ratios of surface area to volume because it does not require expensive equipment. The creation of WO_3 thin films and their photo-electrocatalytic water oxidation have been examined by electrochemical processes such as cathodic electrode position and electrochemical anodization were widely used to create WO_3 thin films. The metal serves as the anode during electrochemical anodization, which can be achieved by using potentials and/or current densities [44]. By altering the preparation conditions, properties of nanostructured WO_3, such as size, thickness, and composition, can be impacted [45].

7.11. Arc vapor deposition

Arc vapor deposition is a deposition technique that vaporizes an anodic or cathodic electrode using an electric arc at high current and low voltage, then deposits the vaporized material on a substrate. To accelerate the film ions to the surface and to produce highly ionized vaporized material, the substrate is typically biased. An arc that traverses the target's surface is created to produce flux. Atoms from the target materials are ejected by the arc strikes and condensed as a thin film coating on the substrate. It differs from vacuum or thermal evaporation in that a significant percentage of the metal atoms are ionized. It can be used for hard decorative surface-coating operations and is dependable for the formation of a thick coating due to its significant proportion of ionized atoms [46].

7.12. Hydrothermal method

One of the many successful strategies for creating nanomaterials is the hydrothermal method. When compared to other methods, the hydrothermal method's advantage, which uses crystalline structures that are deposited at a relatively high rate is that it works at relatively low temperatures. On the other hand, controlling the chemical composition is very difficult at times. For this reason, the hydrothermal method is being used to improve the thin film's crystallinity. Even though this method required two steps to obtain a thin film, its goal was to regulate the formation and development of the material to obtain greater crystallized substances. Technique is less commonly employed in the synthesis of thin films [47].

7.13. Chemical vapor deposition (CVD)

Chemical vapor deposition, also known as (CVD) is the process of creating thin films from gaseous phase through chemical reactions. Thermal discharge plasma treatment or electric discharge plasma treatment initiates or starts the reaction or deposition. A few complexes and reducing substances, like ammonia complexes, as well as other halogenated substances, like fluorides, bromides, and chlorides, as well as some organometallic substances, are utilized to start the activation process of a chemical reaction that results in the deposition of a metallic component. After dissolving [29].The volatile component exits the reaction chamber and the volatile compound or component evaporates, responds and contributions on the substrate's surface. Temperature, which normally ranges from 1100 C to 350 C, is important in CVD [48].

Particles or precipitates are formed because of a chemical response that has begun in the state of gas. The kinetics of the reaction, surface preparation, purity of the precursor, reaction temperature, gas circulation rate, and the container conditions all have a significant impact on the quality of the thin films. It is also possible to perform the accumulation under vacuum, at normal, high, or low pressure, to guarantee that it is carried out in an inert, low-temperature environment. Plasma activation significantly reduces the reaction temperature required to finish a reaction. The outer accumulation is typically controlled reaction meaning that the angle circulation of the incoming reactants determines how thick the film grows, which should be very low, making more direction-dependent deposition possible than with PVD techniques [5].

7.14. Liquid phase deposition

Among the wet techniques for creating metallic oxide films that are thin is the LPD process. The benefit of these methods is that they can be applied to a variety of substrates to produce a metal oxide or alkaline thin-layer formation by just submerging them in the salt solution in water. As a result, one unique technique for producing various types of metal oxide thin films is the LPD method. The LPD is an extremely straightforward method that does not need any specially made equipment, like a high vacuum system, in contrast to gas phase processes. Furthermore, under atmospheric circumstances, it can be effortlessly applied to a broad variety of substrate types with broad surfaces and intricate surface forms [49]. Thin films are deposited by different techniques are shown in figure 2

8. Methods for characterizing nanomaterials and thin films

Regarding their physicochemical properties, nanomaterials vary in terms of shape magnitude, configuration, weight of molecules, characteristics of the surface, the ability to dissolve, and long-term reliability. The primary fundamental variables that characterize physiological performance are these traits. Thus, during the development stage, it is necessary to characterize nanomaterials to guarantee the dependability and safety of nanomedicines. Because they affect the behavior and circulation of nanomaterials in vivo, respectively, their unique physico-chemical properties are important. Therefore, identifying their distinctive traits is essential. Body tissues and cells physically interact either entirely or partially with nanostructures. distinct from traditional pharmaceuticals, so it's critical to employ trustworthy and appropriate nanoparticle characterization techniques that support providing a route for controlling harmful effects, value, and protection [50].

The main criterion that establishes a nanomaterial's suitability for use in the biomedical industry is biocompatibility. Thus, it is imperative to conduct biocompatibility research employing potential characterization methods. To evaluate nanostructured components in their different forms bulk, thin layers, and tiny particles, for instance specific techniques that offer a sufficient spatial resolution to conduct these components' fundamental and chemical properties must be used. In order to evaluate nanostructured components in their different forms bulk, thin layers, and tiny particles, for instance specific techniques that offer a sufficient spatial resolution to conduct these components' fundamental and chemical properties must be used. [51].Characterization techniques for nanostructured materials are shown in figure 3

8.1. Scanning electron microscopy with field emission

Narrower probing beams are produced by the electromagnetic emitting cathode section of a SEM's electron weapon, which reduces sample charge and enhances spatial resolution. These devices are known as field-emitting scanning electron microscopes. Looks like a cylinder column mounted on a desk. The column provides support for the electron beam. When scanning electron micrographs were used to analyze micellar surfaces, there were problems with resolution because the sample had to have a metal layer on top due to previous technologies [52].

8.2. Scanning probe microscopy (SPM)

Many basic and applied fields currently use scanning probe microscopy (SPM). In the field of nanoscience, it is a significant discovery. Its use in fundamental physics has fundamentally altered our understanding of matter at the atomic and nanoscale levels. Many SPM techniques have been developed as a result of variations on STM and AFM. These methods rely on adding nanosensors to the point or combining different electromagnetic energies at the interface between the point and sample. SPM-based techniques are able to obtain images of biological structures in motion that are not possible with traditional microscopies due to their exceptionally low signal-to-noise ratio. Scanning tunneling is one of several techniques collectively referred to as scanning probe microscopy [53].

8.3. Confocal microscopy

One technique to improve the contrast of microscope images is to use confocal microscopy, especially for objects with substantial thickness. Its advantages over traditional optical microscopy include better image quality regulated level of concentration, as well as the capacity to collect visual portions from materials with thick layers. Confocal microscopy devices are currently offered by more than fifteen vendors, including Zeiss, Biorad, Leica, and Nikon. Confocal microscopy is now widely used, especially to see how layers function and to view the structures of life. Since confocal microscopy only uses the maximum resolution of the focus to illuminate a small portion of the material, it is more efficient than conventional microscopy. Mode locked oscillators are projected laser sources that are most frequently used. with a pulse time of about 100 fs and a wavelength of about 800 nm [54].

8.4. X-ray diffraction (XRD)

These days, crystalline structures and atomic spacings are commonly studied using X-ray diffraction. It provides details on phases, topologies, and desired textures in addition to other structural data such as strain, lattice parameters, average grain diameters, and crystallinity. Not much has changed in terms of the equipment used for diffraction data experiments since the late 1940s. Peak intensities are determined by atomic dispersion within the crystal lattice. An X-ray tube, a sample stage, and an X-ray detecting sensor are the three main parts of an X-ray diffractometer. The biogenic silica nanoparticles that were synthesized showed an XRD plot with a peak value at 22 that matched amorphous silica nanoparticles; no additional impurities were found. [55]. The diffractogram result shows that the modified ZnO nanostructures retain their relative intensity and atomic spacing [56].

8.5. X-ray photoelectron spectroscopy (XPS)

A greater number of academics can now use X-ray photoelectron spectroscopy (XPS), as it has become one of the most widely used techniques for surface characterization thanks to improved equipment usability. This technique involves firing x-rays at the sample surface and measuring the electrons that reflect from it. It will be considered in kinetic energy computation. This approach works very well from the research sample because of its surface sensitivity and capacity to provide chemical data frames. Except for helium and hydrogen, practically all materials and elements can be used with this technique. In the 1960s, Kai Siegbahn created the first XPS. He received the Nobel Prize in 1981 for his contributions to high magnification spectroscopy, also known as electron spectroscopy for chemical analysis, or ESCA [57].

8.6. Auger electron spectroscopy (AES)

Auger electron spectroscopy is a noninvasive core-level electron spectroscopy technique that can be used to semi-quantitatively ascertain the elemental formation of thin films, interfaces, and surfaces. Recent advances have expanded the application of AES beyond elemental formation analysis of the substrate. For example, Auger electron spin polarization is helpful when studying magnetic solid surfaces. Moreover, data pertaining to femtosecond charges and kinetics can be obtained from examinations using resonant Auger electron spectroscopy. The results of studies employing resonant Auger electron spectroscopy also provide information relevant to the kinetics of charge carriers in femtoseconds. Additionally, auger electron diffraction can be used to identify surface morphology [58].

8.7. UV-VIS (ultraviolet-visible) spectroscopy

The parts of an ultraviolet spectrophotometer are a monochromator, detector, reference and sample beams, and light source. A sample of the compound is exposed to UV light from a light source, such as a Xenon lamp, to determine the ultraviolet spectrum of the compound. The reference beam in a spectrophotometer moves from the light source to the detector without encountering the sample. The sample is exposed to UV light whose wavelength is constantly changing through interaction with the sample beam. Energy is absorbed when it raises an electron to a higher molecular orbital by an amount equal to the emission wavelength. The brightness ratio between the reference and sample beams is recorded by the detector. The computer searches for the greatest distance between two beams in order to determine the wavelength at which the sample absorbed a significant amount of UV light [59].

8.8. Photoelectron spectroscopy (XPS) using X-rays

With the use of light and an empirical formula, X-ray photoelectron spectroscopy is a quantitative spectroscopic method for surface chemical analysis that determines the elemental composition, chemical state, and electronic state of the elements on a material's surface (up to 10 nm). In some applications, different XPS image types are used to determine the distributions of components and chemical states as a function of surface position. Accurate calibration of the XPS device's energy scale is necessary, as is proper control or correction of the non-conductor recharging process during XPS measurements [60].

8.9. Electron microscopy (TEM) for transmission

Transmission electron microscopy, or TEM, made its debut more than a century ago and has since developed into a foundation for characterization in all fields and subfields of science. TEM provides large-scale, directly resolved structural data as well as the behavior of events ranging in size from atoms to microns, which is extremely fundamental and helpful to society [61]. Examining small features, typically with diameters less than 100 nm, and in certain circumstances even at the atomic scale, is made easier with the help of TEM technology. In the year 1931, German engineer Max Knoll founded the TEM. Its resolution was only about 17X on the original TEM. By developing similar microscopes, Marton and his colleagues in Brussels were able to take the first images of nuclei in 1934 [61].

9. Nanostructured and nano thin film applications

Different applications of nano thin films are shown in figure 4.

9.1. Food packing

Historically, inert barriers have been generated by the materials used in packaging, which interact with the food as little as possible. However, the food industry has had to make changes over time to conform to new packaging standards that demand sufficient shelf life for goods. But with people ending up more concerned about the environment and ecology, producers are under pressure to create more products and packaging that is recyclable or biodegradable [62]. As a result, new packaging technologies have been developed, including interactive packaging, packaging with altered atmospheres, and creative packaging that makes use of cutting-edge nanotechnology [63].Biodegradable films and coatings have been developed to help lessen the environmental harm caused by regular food packaging's slow degradation, which is used to preserve and protect food [64].

9.2. Activity of antioxidants

Lipid peroxidation can change the taste and smell of food, reduce its nutritional value, and make customers reject or devalue the meal. Therefore, when searching for methods to preserve meat products, measuring antioxidant activity became crucial [1]. After two days of storage, the films' free radical neutralization activity rose sharply, from 34% to 47% after sixteen days, indicating that they may have long-term antioxidant potential [65]. The study's findings demonstrated that films containing liposomes and caraway seed extract exhibited wider antioxidant activity than films containing only nanochitosan [66] .

9.3. Antimicrobial activity

Gram-positive and Gram-negative bacteria were among the variety of microorganisms against which antimicrobial activity was assessed. The most often used Gram-positive bacteria were Staphylococcus aureus and lactic acid bacteria, while the most frequently used Gram-negative bacteria were *Pseudomonas* and *Escherichia coli*. These microorganisms are the most prevalent because food is the most likely medium for their transmission, according to [67] 22 of the 27 publications that made up this analysis looked at the antimicrobial properties of meat products, packaging, or films in a particular way. A few of these papers reviewed the movies' effectiveness in fighting Staphylococcus aureus; one such study was conducted by [68]. Chitosan films containing nanocellulose had inhibitory effects on S. aureus during the investigation. A study had been carried out by [69] to evaluate the antimicrobial activity of meat products. Functionalized nanoparticle-containing ethylene vinyl acetate (VAS) films were smothered over the samples. On the sixth day of the analysis, the S. aureus counts were 99% lower, in accordance with the results. Positive results were observed against lactic acid bacteria in several studies, including the [70] study. The efficacy of zinc oxide nanoparticle containing films and essential oil of basil leaves against bacteria in sea bass fish was evaluated. Based on the results, lactic acid bacteria growth was inhibited when meat was preserved with film. When liposomes were combined with chitosan films that contained nanoencapsulated satureja essential oil and applied to lamb meat, further noted successful results against lactic acid bacteria. The essential oil was nanoencapsulated in liposomes, according to the author, which enhanced the films' antimicrobial activity [71].

9.4. Applications for sensing

Noble metal nanoparticles are essential for applications involving chemical and biological sensing. Noble metal nanostructures' distinct photoelectric qualities and improved biocompatibility have rekindled interest in sensing technology research. Nanoparticles' exceptional capacity to absorb light and the fluorescence that analytes produce make them an excellent choose for sensing applications [72]. Sensors are devices that can detect even minute modifications to the system. For instance, biological receptors on the surface of electronic transducers translate chemical signals into electrical signals, a function known as biosensors [73]. Utilized Au/Ag nanoparticles with citrate caps to create hydrogen peroxide sensors. P-Benzene Diboronic Acid created gold nanoparticles between citrate and boronic acid based on the fundamental principle of interest. Because gold nanoparticles have a high conductivity, their electron transfer resistance decreases [74].

9.5. Drug delivery technology

Numerous medications have been delivered to the appropriate location within the human body via the use of nanoparticles. Their unique quality caught people's attention. To increase the potential uses of nanomaterials in medicine, their optical characteristics can be changed. These tunable features can be used to develop nanoparticle based smart systems. These inventive technologies are able to precisely identify which tissues require medication at the appropriate time. In the biomedical field, nanotubes have recently been used to deliver specific drugs and destroy microorganisms. They reduce the toxicity of medications and have no negative danger. Consequently, it is beneficial in the treatment of diabetes, cancer, AIDS, and other sicknesses [75].

9.6. Treatment of cancer

The most common reason of death is cancer. This complicated illness is influenced by both hereditary and environmental factors. Many cancer patients have had their lives saved by chemotherapy, but the non-specific nature of the drugs used in the cure damages healthy tissues and cells permanently [76]. Douglas Hanahan and Weinberg regard cancer as a disease that comprises many different conditions [77]. A smart nanoparticle method is intended to target the delivery of medication at a particular site. The cleverly created nanoparticles only adhere to damaged cells. Chemotherapy has a calming impact on healthy cells and normal tissues [78].

9.7. Environmental remediation

The air, water, and soil can all be cleaned with nanoparticles. They are employed in the treatment of oil spills, sludge, wastewater from cities and industries, and surface water. Zeolites, sometimes referred to as well-defined molecular sieves, are employed in the oil refining process. The unique materials known as zeoliticimidazolate frameworks (ZIFs) resemble crystals and are joined by imidazolate ligands to form tetrahedral bands, like ZnN4 and CoN_4 [78].They are widely used in the removal of heavy metals, radionuclides, gasses, and environmental pollutants due to their adjustable pore sizes. Nanoparticles are an efficient way to filter and disinfect wastewater. Nanofiltration is a newer method for water filtration. The dairy and food industries make considerable use of it [79]. Moreover, nanoremediation which entails injecting nanoparticles into designated areas can be used to clean up soil contamination. Recently, there has been the development of outstanding performance, multifaceted nanotechnology with a high specific surface area and an elevated level of interaction with different pollutants. This is an important indicator of the effectiveness of nanomaterials in the processes of photo degradation and adsorption. It has been demonstrated that high-performance nanomaterials-based functional materials work well as the adsorb for porous membranes. Membranes made of multifunctional nanocomposite materials have been the focus of water purification technology. The filtering or cleansing devices also have a number of drawbacks, such as nanotoxicity and cytotoxicity [80].

9.8. For Clean tech

Thin film and nanostructured coating applications in clean technology, including solar energy and energy efficiency, are growing in relevance. The primary preparation technologies, their features, and the reasons behind this are covered in this tutorial overview. The emphasis is on vacuum or plasma-based processes, mainly sputtering and evaporation, though many other methods are also discussed. A full review of the large-scale deposition is given, along with a few expectations for future developments. Taking into account the population of the world, which was roughly one billion in 1800, grew to approximately 2.5 billion in 1950, and is currently projected to be seven billion (2012) [81]. Researchers analyzed the importance of clean technology. It is estimated that population growth will reach an astounding ten billion people or more by 2100, and that it will not slow down until then. The Third World's population boom has been accompanied by rising living standards, and it is only natural for them to want access to the same facilities and way of life as their more affluent counterparts. The inevitable outcome is that there is tremendous pressure on the world's natural resources, leading to the unsustainable use of various resources such as fuel, water, minerals, and other resources [80].

9.9. Solar cells

Currently, 80–90% of solar cell technology is made of silicon-based materials [6]. In PV modules, silicon technology is the industry standard and has been shown to be reliable. The rationale behind this is that silicon is the primary constituent of bulk thin film and certain nano structured photovoltaic solar cells. But as of right now, the greatest reported efficiency for a non-concentrated silicon solar cell design is about 25%. [82]. Efficiency cannot be raised any further, not even with the application of the following approaches. Hydrocarbon treated silicon [83].The back electrodes are made of nanoparticles [84]. Applying a textured back surface reflector [85]. Leveraging a triple junction thin film solar cell with a rear reflector made of zinc oxide [86]. Utilizing concentrators on diverse substrates [87]. Implementing use of double and triple junctions [88]. Examples of nanostructured designs are quantum dots [89]. P-n junction Si micro/nanowire arrays, and nanoscale honeycomb architectures [90].

9.10. Self-cleaning and wetting control

Building functional surfaces with varying wettability can be facilitated by the micro/nano architectures produced by polymer patterning [91]. When the surface becomes more uneven, air is trapped between the water drop and the surface's cavities, enabling the Cassie-Baxter state to form, which has an improved effective contact angle and traits similar to the lotus-leaf effect [92]. For instance, a super hydrophobic surface with a water contact angle of about 140° is produced by patterning a polyurethane-acrylate film functionalized with siloxane using uniform pillars [93].

9.11. Uses for optics

Important parts of optical and optoelectronic devices are optical gratings and anti-reflection coatings [94]. In these optical fields, polymer thin film patterning tends to be necessary. Self-assembled BCPs, for instance, are widely used as templates to imprint trends deeply on silicon is a substance. It has been reported that the use of these silicon gratings increases the sensitivity of refractive index (RI) sensing [95]. The optical data storage devices, such as computer memory and storage disks, are experiencing an increase in the commercial demand for thin film coating. They operate as a barrier against temperature rise and provide a protective layer on the surface. Additionally, thin film has been widely used to coat mirrors and window glass to stop heat from escaping [96].

9.12. Cell treatment

To combat diseased cells and expedite patient recovery, live T lymphocytes, or T-cells, are injected and transplanted in mainstream cell therapies. T-cell therapies work best on fluid tumors that already have specific antigens present, and they require a time-consuming cell population preparation process. Macrophages have a greater capacity to engulf dangerous materials, like cancer cells, but following injection, they often adopt protumoral phenotypes. Additionally, it is applied in biomedicine to improve appropriate adhesion and osteointegration characteristics [97].

9.13. Adaptable energy harvesters

Energy harvesting is crucial to finding solutions to the problems of climate change and the depletion of renewable energy sources. Because of their skeletal adherence and potential for connection into smart watches, flexible energy harvesters have attracted a lot of attention. Triboelectric generators are one type of energy conversion device that produces electricity by combining the effects of electrostatic induction and frictional electrification [98].

9.14. Electronic Devices

Long-lasting, high-capacity batteries are required for portable electronic devices such as laptops, LED lights, and mobile phones. Nanoparticles are ideal for this application due to their large surface area and low recharging. Nanocomposites are used as electrolytes in nanobatteries, coupled to a probe tip. The nanorod electrode improves ionic diffusion and raises the nanobatteries' operational efficiency. The enhanced surface area that the nanoscale membrane of the nanocomposite offers is advantageous for electronics and optoelectronics. This invention revolutionized the field of surface science's ability to study ultrathin films. Electronic chip, lighting display, laser, batteries [99]. Thin film deposition has surely found enormous and vast applications in the production of electronic components such as semiconductors, single and multilayer metal conductor films, and microelectronic integrated circuits. Thin film deposition has also greatly benefited compound conductor films for semiconductors, dielectric and insulating materials, and metal refractory silicide conductors. Electronic display fabrication requires dielectric and insulating layers, luminescent or fluorescent film, and conductive and transparent films [46].

9.15. Agricultural applications

By offering fresh approache*s to* pressing agricultural and environmental issues, NPs have the potential to advance the field of agriculture [100]. In agriculture, NPs are primarily employed as nanopesticides and nanofertilizers. The inefficiency of chemical fertilizers is caused by leaching and volatilization. Farmers typically respond to these situations by applying excessive amounts of fertilizer, which raises crop productivity but has negative environmental effects [100]. On the other hand, nanofertilizers are chemical compounds with higher efficiencies that require less application than conventional fertilizers [101]. Given their demonstrated antimicrobial, insecticidal, and nematocidal properties, several NPs offer promise as chemical pesticide substitutes and as potentially .An affordable substitute for biopesticides [102].

10. Thin Film Material Market Analysis

The market for thin and ultra-thin films was estimated to be worth USD 5.8 billion in 2022 and is expected to grow at a compound annual growth rate (CAGR) of 14% from 2023 to USD 16.9 billion by 2030. Increasingly, the need for sustainable energy sources, the electronics and semiconductor industries' tendency toward miniaturization, and advancements in nanotechnology are some of the main factors propelling the global thin and ultra-thin film market. Moreover, the emergence of nanotechnology in various sectors like the food packaging, pharmaceutical, and semiconductor industries offers a fresh opportunity for the target market's expansion. In addition, the target market is expected to grow faster due to the rapidly growing demand for consumer electronics as well as higher demand from the aerospace and defense industries. Conversely, the availability of near substitutes like crystalline silicon, etc. Thin film materials are mostly used in photovoltaic cells due to their advantages over traditional crystalline silicon technology, including their light weight, flexibility, and ability to produce thinner cell variations. Due to the massive photovoltaic solar power plants located in the Asia-Pacific region, it is anticipated that this region will hold the largest market share.

11. Large-scale production and challenges

The selection of suitable production and deposition methods for nanomaterials and thin films is the primary challenge in their large-scale application. Thus, it is crucial to create scalable industrial methods and carry out research on the relationship between production and deposition parameters and the properties of thin films and nanomaterials that are obtained. The repeatability of the carried-out synthesis and deposition processes is also very important. Covering promising, recent, and innovative research trends in the synthesis and deposition of nanomaterials and thin films used in solar cells is the goal of the current research topic. Preparation costs are frequently the most significant consideration when evaluating the potential utility of thin films and nanostructured coatings to clean technology uses. The complexity of thin film production costs renders it highly dependent on production volume. Therefore, industrial production is essential [103].

12.Conclusions

Since at least the 1950s, the methods for producing thin films and nanostructured coatings have improved. Even now, this process is still evolving and progressing very quickly. One might assume that as safety improves, thin film and coating technologies might grow more important in the future, both in terms of clean technologies and alternative applications. Doctors will be able to tailor our care in the future when nanoscale devices are able to monitor our health. With nanotechnology, we can harvest environmental issues energy. Noble metal nanostructure finds a wide range of applications. Improving the functional characteristics and related features of photocatalytic thin film interfacial will be the focus of future developments in this field. Thick films of photo-catalytic materials can be produced as free-standing structures or on a substrate, and They are promising due to their tunable properties and versatile interfacial conversations. Conventional thin-film catalysts produce a large base with adjustable chemical, electrical, and catalytic characteristics. Thin films have caught the interest of many scientific and technological fields in the fields of health, energy, and the environment because of their remarkable flexibility, stability, and multifunctionality. For free-standing thin films to be effectively employed in industrial applications, their production needs to be successful. The primary requirements for regulating and improving solar cell efficiency are changes in bandgap and thin film thickness. A comparative study of multiple techniques showed that these are straightforward and affordable methods that produces thin films for use in solar cell applications more effectively than other methods regarding nanometers. To form the macroscopic bulk substrate, individual atoms and molecules must be carefully managed in the creation of nanoscale devices and materials. The study of altering matter at the atomic level is the focus of the field of nanotechnology.

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