

NANOSTRUCTURES

Abstract

Nanostructures are substances or objects with at least one dimension between one and one hundred nanometers. The production, evaluation, and practical application of nanostructures are the main focuses of the numerous areas of nanotechnology. They talk on the creation and utilisation of nanostructures that are frequently researched and applied in nanotechnology in this section of the book. Simple techniques like solutions processing and sophisticated ones like enhanced lithography are used to create nanostructures. Contemporary research endeavours in the realm of nanostructure development primarily focus on the exploration of fundamental material characteristics, encompassing mechanical, electrical, and optical properties at the nanoscale. Additionally, researchers aim to innovate fresh applications within several engineering disciplines. Furthermore, significant endeavors have been made in the realm of nanostructure creation. We explore several distinctive characteristics of nanostructures in this chapter and talk about the applications were most vigorously explored.

Keywords: Nanostructures, nanotechnology, liposomes, nanosensors.

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I. INTRODUCTION

Nanostructures have been defined as "novel substances with tailored elemental sizes at the nanometer range." More and more attempts are being attempted to synthesise, comprehend, and use the materials with decreased dimensions as a result of the demands for miniaturisation. Due to the realisation that materials' properties can be altered and improved by reducing their dimensions to the nanometer regime, fascination with nanomaterials is increasing dramatically. Since the 1990s, Nanomaterials have received significant attention owing to their distinctive features that distinguish them from bulk materials. The utilization of custom-made materials has presented significant opportunities for addressing issues in many disciplines such as healthcare, the field of biotechnology optical electronics, and architecture and technology. This has enabled the development of novel, highly effective, and cost-effective devices, drugs, and instruments. It is anticipated that the new technology will concentrate on the problems of miniaturisation and energy conservation, including various current technologies. Therefore, it is not unusual to see scientists from various fields collaborating to advance the dynamically expanding field of nanomaterials [1].

1. Significance of Nanostructures: In recent times, scientists and researchers have shown significant interest in nanosized items owing to their remarkable physical, chemical, mechanical, and electrical properties [2]. The uses of nanostructures, which are characterized by their superior nanotechnology, may be readily identified.

- The growing need for energies has prompted the exploration of nanostructural components in the development of photovoltaic panels and hydrogen fuel cells, aiming to enhance their overall efficiency. The user's text does not contain any information to rewrite in an academic manner. The potential replacement of silicon with carbon nanotubes in the field of nanoelectronics is being explored as a means to produce microchips and devices that are both lighter and more efficient. The utilization of these renewable resources can also have environmentally favorable effects and contribute to the mitigation of CO₂ emissions, a pressing concern in contemporary society.
- Biocompatible tunnelling nanotubes are useful for monitoring health parameters and delivering medications to specific sites in nanomedicine. The production of operational organically or synthesized nano-structural elements for medical implanted gadgets poses challenges; yet, progress is being made in the development of artificial joints, larynxes, bone prostheses, pacemakers, and other similar structures [3]. In order to improve air quality, hazardous gases emitted by industries and vehicles undergo a conversion process facilitated by catalysts composed of nanoparticles.
- Various nanoscale structures, such as rods, rings, beams, plates, and shells, have been employed to establish the fundamental structural elements of numerous nanoelectromechanical systems (NEMS). A few examples of NEMS-based devices with prospective uses in different areas of nanotechnology, such as nanoelectronics, nanomachines, and nanomaterials, are nanomechanical resonators, electromechanical nanoactuators, nanoscale mass sensors, and nano energy harvesters.

- It is important to look into the dynamic properties of these nanostructures under mechanical loads, pressures, or even stresses from the outside world [4]. On top of being difficult, doing exact research on this scale is also time-consuming and expensive. As a result, various scholars from all over the world have been drawn to deal with these challenging issues by using continuum-based models and simulations associated with molecular dynamics, which are discussed in the following chapter.

2. Changes in Properties [1]: Based on the characteristics of the materials, it can be observed that all types of materials, including metals, semiconductors, and insulators, demonstrate physio-chemical properties that are dependent on their size, provided that they are below a certain threshold dimension. In the case of most materials, their size typically falls below the threshold of 100 nanometers. Hence, the dimensions of particles exert influence on numerous characteristics, encompassing geometric arrangement, chemical connectivity, ionization potential, electronic and optical qualities, mechanical resilience, melting point, and magnetic behavior.

- **Mechanical Characteristics:** Research has revealed that nanocrystalline materials exhibit a reduction in their elastic moduli and densities, typically by a magnitude of 30% or less. The observed phenomenon could perhaps be attributed to a substantial amount of unoccupied space at the boundary between materials, as well as a rise in the average distance between atoms. The reduction in size is associated with a corresponding increase in hardness or strength by a factor of approximately 4-5. The diffusivity of nanoparticles exhibits a twofold increase relative to its initial value. Multiple interfaces facilitate pathways for diffusion. At reduced temperatures, the augmented diffusivity contributes to the improved sintering capability.
- **Thermal Properties:** It has been discovered that the melting point decreases as particle size increases. It might be cut in half from its original size. When the size of particles is decreased, the specific heat and thermal expansion may rise by 50% or more.
- **Optical Characteristics:** By varying the size of the nanoparticles, materials' colour and transparency can be altered. Since they are controllable, processing parameters can be used. The absorption spectra of materials change towards higher energies and for small particles as their effective band gaps widen; this may result in progressive absorption as the size of the nanocrystals decreases. The phenomenon of enhanced luminescence and rapid reaction in devices can be attributed to the reduction in nanocrystal size, which induces alterations in the electrical structure. This finding holds significance for the development of rapid responding systems that radiate the desired color. Nanoparticles have the potential to be utilized in laser systems due to their ability to function at lower threshold levels. The Raman spectra of nanoparticles are influenced by the confinement effects of both photons and phonons. Nonlinear optical properties have been seen in semiconductor clusters embedded within a glass or polymer matrix.
- **Magnetic Characteristics:** Nanomaterials have distinct magnetic properties due to their high surface to volume ratio and enhanced anisotropy compared to polycrystalline materials. Consequently, nanomaterials demonstrate reduced

saturation magnetization values while exhibiting significantly higher coercive values. The Curie temperature of ferromagnetic materials exhibits a decrease as the size of the nanoparticles rises, resulting in the persistence of paramagnetic characteristics in the material, despite the presence of superparamagnetic capabilities below the typical Curie temperature. Every individual particle within the nanocrystalline phase is comprised of a solitary ferromagnetic domain.

- **Electrical Characteristics:** The electrical attributes of materials are influenced by their size in the nanometer range. Reducing the size of nanocrystals leads to a decrease in electrical conductivity. Additionally, when the scale is reduced to approximately 20 nm, ferroelectric materials such as PbTiO_3 lose their ferroelectric properties. Similarly, superconducting materials like $\text{YBa}_2\text{Cu}_3\text{O}_7$ exhibit a decrease in transition temperature and lose their superconductivity at smaller scales. This phenomenon has significantly enhanced the feasibility of synthesizing and designing materials with desired properties. It is important to note that the characteristics of materials are always dependent on size above a certain threshold for a given material. The reduced dimension in these materials must be smaller compared to either the mean free path distribution frequency for ions within the elements or the state consistent diameter.
- 3. Reasons for Novel Properties:** The properties of nanomaterials can be customised by varying the size and are frequently superior to those of traditional coarse-grained materials [1]. Three elements in particular are the key drivers of changes in nanomaterials' properties:
- **A rise in the Surface-to-Volume Ratio:** Atoms and molecules at surfaces or interfaces display distinct properties because of their diverse environments and bonding arrangements. The fraction of surface atoms in micron-sized particles is less than 10^{-8} , hence they have little impact. Inversely related to particle size, the relative number of atoms on the surface rises as size decreases. The fraction of surface atoms is high at small diameters (of the order of a few hundred nm), and this has a significant impact on the characteristics.
 - **Quantum Size Effect:** Since a particle's size is similar to the phase coherent length of an electron, the energy spectra is quantized into three separate levels. The observable phenomenon becomes apparent when dealing with particles on the scale of several tens of nanometers. The energetic states of metals are discretized due to the presence of N electrons and an energy spacing of E_f/N , where E_f represents the Fermi energy. When the distance between particles exceeds the thermal energy, the energy levels become quantized. The quantum size effect in semiconductor nanoparticles is particularly pronounced as a result of the relatively moderate magnitude of the forbidden energy gap. The quantum size effect enhances the optimum band gap, hence influencing the optical and electrical properties by the exclusion of energy levels in close proximity to the boundary of the bands of valence and conduction.
 - **Lattice Contraction:** The reduction in lattice parameters can occur at nanoscale dimensions, often on the sequence of a few nanometers, due to the presence of interatomic forces acting within the material. Within this particular range of sizes, it has been shown that there are structural phase transitions, namely the transition from a

cubic structure to a hexagonal structure. The manipulation of material properties at the nanoscale enables the creation of materials and devices with enhanced or novel traits and capabilities. Due to their extensive variety of applications across many devices and their capacity to enhance effectiveness, these elements have facilitated the development of novel technologies.

II. CLASSIFICATION OF NANO STRUCTURES

Nanomaterials can be defined as “elements that possess either an exterior measurement within the nanoscale range (about 1-100 nm) or an internal or surface structure at the nanoscale level”. According to the International Organisation for Standardisation (ISO), this includes internal and surface structures [5].

Nanostructured materials were categorised in the following ways by Richard W. Seigel, professor and director of the department of material science and engineering at Rensselaer Polytechnic Institute and a fellow of the Material Science Society (MRS):

- 1. Zero-Dimensional:** Zero-dimensional materials are those with all dimensions that are smaller than 100 nm, or at the nanoscale. Small clusters made up of a few to about 100 metal atoms, as well as typical spherical metal nanoparticles. Examples include fullerenes, nanoclusters, quantum dots, and nanodots.
- 2. One Dimensional:** These materials have one dimension that is larger than 100 nm and are not nanoscale materials. One dimension sees significant increase, whilst the other two see just modest expansion. Examples include carbon nanotubes (CNT), nanowires, nanorods, nanotubes, nanowires, nanobelts, and nanopillars.
- 3. Two-Dimensional:** These are substances that do not have nanoscale dimensions. (Two dimensions are larger than 100nm). The shapes in this class resemble plates. Graphene, nanofilms, nanoplates, nanonetworks, planar triangles, hexagons, and discs are a few examples.
- 4. Three Dimensional:** Materials that are three dimensional are those that do not have any dimensions that are restricted to the nanoscale. (Each of the three dimensions exceeds 100 nm. All three dimensions experience significant growth, as do more complex structures such different polyhedral and combinations of OD, 1D, and 2D nanostructures. Examples include nanoparticle dispersion, a bundle of nanowires, graphite, diamond, nanosponge, and nanocomposite materials.

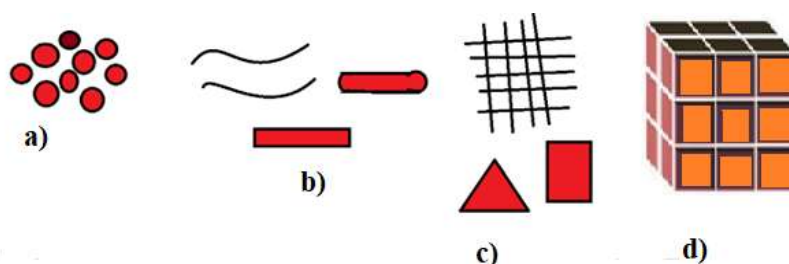


Figure 1: Classification of Nanoparticles. a) Zero-dimensional b) One dimensional c) Two-dimensional d) Three dimensional

III. METHODS TO CREATE NANOSTRUCTURES: TOP-DOWN FABRICATION OF NANOSTRUCTURES

There are numerous ways to create nanomaterials. These techniques are divided into two groups: top-down and bottom-up approaches. Depending on the stage of the raw material, the techniques are categorised. The initial substance is solid in the Top-Down class of procedures, whereas the starting material in Bottom-Up techniques is either gaseous or liquid. A subtractive method known as a top-down approach involves breaking down a large starting material into smaller, nanoscale components. Bottom-up approaches are additive processes that begin with precursor molecules or atoms and then combine to create nanoscale structures [6]. Nanostructures are constructed using a bottom-up strategy, atom by atom or molecule by molecule. Depending on the need, we must choose a suitable preparation strategy.

1. Top-Down Design Model: By beginning with massive level elements and then reducing them down to the nanometer range dimensions, top-down nanoparticle synthesis processes offer intriguing new possibilities to approach the nanoscale. These tactics entail the physical destruction of the source of material using the high-energy procedures shown in Fig 2. This chapter describes several different top-down approach types.

- **Ball Milling:** Ball milling, commonly referred to as mechanical grinding, is an easy and well-liked technique. Here, the components are ground into ultra-fine powders. One of the most crucial industrial techniques for creating nanomaterials is this one. This approach has a lot of benefits, including a scalable architecture, low maintenance requirements, and a compact design. It operates on the idea of impact. The balls' impact as they fall from the top of the chamber holding the source material results in the size decrease.
- **Etching:** Chemical etching is the process of eliminating the outermost layer from a metal or plastic surfaces through chemical erosion. One or more chemical reactions take place throughout this phase, consuming the original reactants and creating new species. Etchants are the substances used in etching. The wafer that needs to be etched can be submerged in an etchant bath throughout this procedure. For etching semiconductor oxide thin films, etchants such as HCl, HNO₃, H₂SO₄, and H₃PO₄ are typically utilised.
- **Nanolithography:** The lithography process entails the transfer of an intended design from an existing slide, plate, or mask onto a different medium. Nanolithography is a widely recognized top-down approach utilized for the fabrication of nanostructured materials and patterns. The fundamental principles underlying nanolithography techniques involve the application of accumulation, concealment, etching, or writing processes to create specific patterns on the surface of a solid material, with dimensions on the nanoscale scale. The present technique employs radiation exposure as a means to concurrently transmit a pattern or design onto the surface of a device. The technique can be classified into four categories, namely photolithography, X-ray lithography, electron-beam lithography, and ion beam lithography, based on the specific radiation sources employed for exposure.

2. Bottom-Up Design Model: The method of nanofabrication, known as bottom-up or self-assembly, involves the assembling of basic components into more intricate structures by the utilization of chemical or physical forces operating at the nanoscale. The utilization of bottom-up methods in nanofabrication has become increasingly prominent as the dimensions of components continue to decrease, making it a valuable complement to top-down approaches. In biological systems, chemical forces have been employed by nature to construct the essential structures necessary for existence. Bottom-up techniques draw inspiration from this phenomenon. Scientists are currently endeavoring to replicate nature's ability to produce discrete clusters of specific atoms, which can then autonomously arrange themselves into more intricate formations.

- **Physical Vapour Deposition (PVD):** Vacuum evaporation is widely recognized as a prominent physical vapor deposition technique. The source material intended for deposition is subjected to thermal energy through several heat sources, including direct resistance, eddy current, electron beam, laser beam, or arc discharge. As a consequence of this phenomenon, the source material undergoes evaporation under a high vacuum environment. The utilization of a vacuum facilitates the unobstructed migration of vapor particles towards the base layer, which causes them to undergo condensation, resulting in the formation of a thin layer of solid coating.
- **Chemical Vapour Deposition (CVD):** Heat and evaporation are applied to the material precursor. Atoms and molecules are currently in a gaseous state. In either a homogeneous or heterogeneous reaction, the atoms or molecules deposit on a solid surface. We are able to create defect-free, very pure nanomaterials by CVD.
- **Sol-Gel Synthesis:** The sol-gel method is a suitable wet chemical technique for the production of nanoparticles, particularly oxides, and nanocrystalline thin films. Due to its utilization in high-volume production at low costs, this technology exhibits superiority over all other currently employed methods. This process is based on inorganic polymerization reactions, including hydrolysis, polycondensation, gelation, ageing, drying, and calcinations or sintering. The process of electrochemical synthesis involves the use of electrical energy to drive chemical reactions and produce desired compounds. Electrochemical deposition is a process that involves the reduction of metal cations through the application of an electric current, resulting in the formation of a uniform and adherent metal layer on an electrode. An alternative term for this process is electroplating. The process of nuclear layer development The subclass of chemical vapour deposition is employed for the purpose of depositing films with exceptionally low thickness. In the context of Atomic Layer Deposition (ALD), a surface modification technique, it is observed that two specific chemicals, referred to as precursors, have a sequential and self-limiting reaction with the surface of a given material. The surface possesses a finite number of reactive sites that are capable of interacting with the molecules of the reactant.

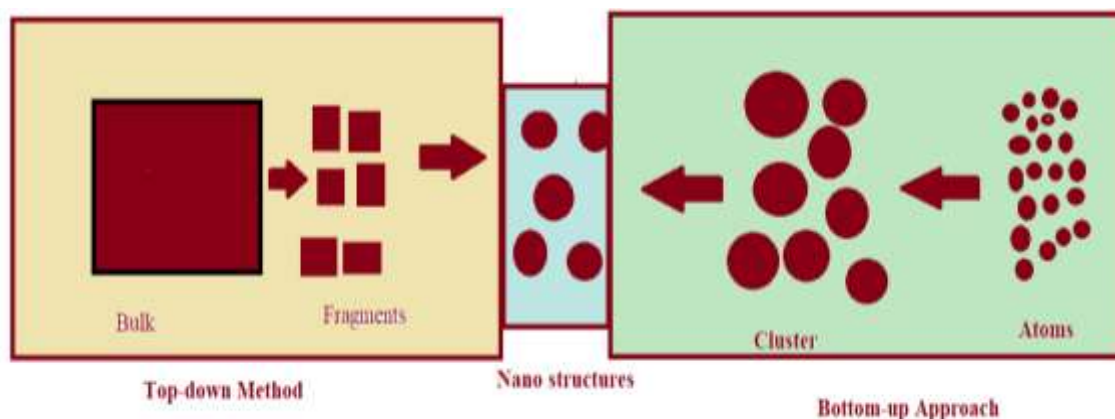


Figure 2: Top-down and Bottom-up Approaches of fabrication of nanostructures

IV. CHARACTERIZATION OF NANOSTRUCTURES

The characterisation of nanostructures typically involves specialised tools and unique approaches due to their exceedingly small dimensions. Nanostructures are typically described in terms of their morphology and form. Various imaging techniques are commonly used to gather this information. Because these two techniques complement one another, most high-resolution imaging techniques are based on the same principles as high-resolution lithography techniques. Tightly focused photon or electron beams scan the nanostructures during high-resolution imaging to create an image. This idea is the foundation of methods like scanning electron microscopy (SEM), near-field scanning optical microscopy (NSOM), and plasmonic imaging. High-resolution imaging, such as that produced by the atomic-force microscope (AFM), the scanning tunnelling microscope (STM), and its variants, can also be obtained if a sharp mechanical tip is utilised. Nanostructures can also be explored and captured via electron transmission. When a high-energy electron beam pierces a thin layer of nanostructures, this property is used in the transmission electron microscope (TEM) to attain atomic-level resolution. It is frequently necessary to create a special device structure to operate as an interface between the individual nanostructure and the macroscopic measuring system when characterising individual nanostructures. For instance, the patterning of contact electrodes is necessary for the electrical characterisation of certain nanoparticles or nanowires. Due to the nanostructures' incredibly small size, this is quite difficult. Measurement difficulty can be increased by additional elements, like extremely low signal levels. In the probe station, sophisticated environmental chambers and highly sensitive electrical devices are typically required for nanostructure characterization.

V. APPLICATION OF NANO STRUCTURES

- 1. Application of Nano Structures in Food Industries:** The discipline of food science and technology encompasses four main categories that hold potential for various applications: packaging, process technology, anti-microbials, and food ingredients. The application of this concept to the field of food can be categorized as either "direct" or "indirect." The term "direct use," when explicitly acknowledged, pertains to the integration of nanostructured chemicals and materials into food products [7]. Direct applications of various compounds in cosmetic products include scents, colouring agents, antioxidants, preservatives, as well as biologically active substances such as vitamins, omega-3 fatty

acids, and polyphenols, among others. Indirect applications can be observed in the utilization of nanostructured materials in packaging and sensors, as well as in the utilization of nanostructured catalysts for the hydration of lipids. Consequently, the bulk of applications pertaining to nanostructured materials can be categorized within this classification. Nevertheless, it is important to underscore that the utilization of nanostructures can potentially lead to their inadvertent contact with food, as they are promptly incorporated into the food matrix to facilitate the production of food, for instance, by the catalyzed hydration of lipids with decreased trans-fatty acid concentration.

- **Nanosensors:** Smart packaging employs polymer materials and nanodevices or nanosensors to effectively monitor the presence of chemicals and foodborne pathogens throughout the processes of storage and transportation. Smart packaging ensures both the authenticity of the food product and the integrity of the food container. Moreover, these devices have the capability to capture and store historical timestamps, temperature data, and expiration dates. Several recent studies have indicated that nanosensors has the capability to detect toxic substances and foodborne pathogens within packaging materials. Moreover, nanoparticles (NPs) have the potential to serve as nanostructured transducers in biosensor devices. Nanosensors have been developed for the purpose of investigating food, taste perception, drinking water quality, and clinical diagnostics as well. A cost-effective nano bioluminescent spray was developed for the purpose of identifying microbial contamination. This spray exhibits a reaction with bacteria present in food, resulting in the emission of visible light. A novel biosensor utilizing micromechanical oscillators has been developed to monitor the development of *Escherichia coli* germs. Nanocantilevers are utilized in the context of pathogen detection. The fundamental basis of the detection approach lies in the observed changes in resonance frequency as a result of incremental mass accumulation on a cantilever array. This method has the capability to rapidly identify *E. coli* within a span of one hour, significantly outperforming the conventional plating procedure that necessitates a minimum of 24 hours. Cantilevers have the capability to detect variations in temperature, surface tension, and mass. A diverse range of toxins and microbes can be detected through the integration of an assortment of cantilevers, each equipped with distinct molecular identification elements, onto a unified microchip platform. Molecular imprinted polymers and nanomaterials are now being developed for food quality monitoring, with the ability to effectively identify small molecules, large proteins, and macromolecules. Recently, there has been a development in the production of imprinted core shell nanoparticles with a silica core for the purpose of detecting tert-butylhydroquinone in food. Nanosensors fabricated by the employment of molecular imprinted polymer technology encompass a variety of substances, including trypsin, glucose, catechol, and ascorbic acid.
- **Food Packaging:** Nanotechnology plays a crucial role in safeguarding food safety and extending the shelf life of packaged food by effectively mitigating food deterioration and minimizing nutrient loss. In addition to serving as a passive shield against environmental factors, active packaging plays a constructive role in the preservation of food. The subject matter primarily pertains to packaging solutions that demonstrate adaptability in response to environmental fluctuations. These entities

serve as gas scavengers or perform the role of releasing advantageous compounds such as antibacterial or antioxidant agents. Certain packaging systems, such as antimicrobials, oxygen scavengers, and enzyme immobilisation systems, enhance food stability through the mechanisms of interaction described above. Controlled-release packaging represents a further application of active packaging, wherein nanocomposites can be utilized as delivery systems to support the controlled migration of beneficial additives such as vitamins, minerals, and probiotics within food products. Silver nanoparticles (AgNPs) are employed in packaging materials with the aim of extending the shelf life of food products through the elimination of microorganisms within a time frame of 6 minutes. Food packaging has utilized nylon nanocomposites as a means to maintain freshness and prevent the diffusion of odors. These nanocomposites function as effective barriers against the movement of oxygen and carbon dioxide. Multilayer polyethylene terephthalate (PET) bottles, commonly employed for the containment of beer and other alcoholic beverages, serve as a prevalent exemplification. Metal and metal oxide nanoparticles (NPs) are employed as antimicrobial agents in the context of nanocomposites for food packaging, namely in active packaging applications. Titanium dioxide, zinc oxide, copper, copper oxide, and silver-based nanofillers are utilized in various applications owing to their inherent antibacterial properties. The utilization of nanofillers based on TiO₂ and SiO₂ is prevalent in the development of self-cleaning surfaces. Among the several types of nanoparticles (NPs) that exist, silver NPs are particularly prominent due to their efficacy against a wide range of microorganisms. The mechanisms behind the antibacterial properties of silver agents encompass several processes, such as adherence to cellular surfaces, disruption of cell membranes, induction of DNA damage, and liberation of silver ions. The antibacterial efficacy of metal nanostructures is predominantly determined by many factors, including as their dimensions, morphology, internalization capability, and chemical modifications. According to prior research conducted by various scholars, including our own previous investigations, it has been shown that these nanostructures had the capability to penetrate both the internal and external membranes of bacterial cells. The literature largely acknowledges three primary pathways of bacterial toxicity associated with metal-containing nanomaterials: the internalization of metal ions leading to intracellular ATP depletion, the generation of reactive oxygen species (ROS) resulting in cellular oxidative damage, and the impairment of bacterial membranes. Reactive oxygen species (ROS) encompass a range of chemical entities, including free radicals such as superoxide anion (O₂⁻), hydroxyl radical (OH), as well as nonradical molecules like hydrogen peroxide (H₂O₂) and singlet oxygen (O₂). Titanium dioxide possesses a multitude of applications, encompassing its utilization as a UV blocker, pigment, photocatalyst, and antibacterial agent. Moreover, titanium dioxide nanoparticles (TiO₂ NPs) are employed in the realm of food packaging due to their efficacy in combating microorganisms responsible for food spoilage. Furthermore, it has been suggested that the maintenance of cleanliness on packing surfaces in indoor lighting conditions can be achieved by enveloping them with plastic material incorporating zinc oxide (ZnO) nanoparticles (NPs). When subjected to UV irradiation, the incorporation of TiO₂ nanoparticles (NPs) into different polymers was employed to produce films with oxygen scavenging properties. Nevertheless, this approach exhibits some limitations, primarily attributed to the photocatalytic behavior of TiO₂ NPs. This enhanced activity under UV light is a consequence of their elevated bandgap. The primary mechanism by which TiO₂ nanoparticles induce toxicity is by

generating reactive oxygen species (ROS) when exposed to visible and UV light, a phenomenon known as photocatalytic activity. This process leads to lipid peroxidation and subsequent cell death due to oxidative stress. Based on available research, it has been observed that the incorporation of graphene nanoplate-based nanocomposites in food packaging materials has resulted in notable improvements in terms of heat resistance and barrier properties. The utilization of carbon nanotubes and nanofibers is limited in the domain of food packaging due to their elevated cost and the challenges associated with manufacturing dispersions, despite their advantageous mechanical and electrical properties. In order to improve the barrier and mechanical properties, a number of biodegradable polymers composed of starch-based materials incorporate nanoclays, specifically montmorillonite nanoparticles. Montmorillonite, often known as bentonite, is widely recognized as the prevailing nanoclay variant for enhancing gas barrier properties. Its incorporation into polymers has been observed to effectively restrict gas permeability. Furthermore, it is easily accessible and available at a reasonable cost. Starch clay is comprised of certain biodegradable nanocomposites that have been employed in diverse applications.

- **Encapsulated Food Components and Edible Supplements:** Currently, there exists a range of nutritional supplements and nutraceuticals that incorporate nanosized components and additives, including vitamins, antimicrobials, antioxidants, and preservatives. These formulations aim to enhance flavor, facilitate absorption, and improve the bioavailability of these substances. The application of nanotechnology holds promise for the integration of functional food. The carriers incorporate several nutraceuticals, such as lycopene, beta-carotenes, and phytosterols, in order to mitigate the accumulation of cholesterol. The use of nano selenium in a green tea beverage leads to a range of health benefits as a result of enhanced selenium absorption. The utilization of nanocapsules for packaging materials at the nanoscale confers several functionalities to the final product, such as the ability to regulate the release of the encapsulated core. Hence, encapsulated compounds have several advantages, including extended storage duration, enhanced stability, sustained delivery of several active ingredients, and regulated release triggered by pH levels. The nano-delivery system comprises many functional components, including vitamins, antioxidants, probiotics, carotenoids, preservatives, omega fatty acids, proteins, peptides, and lipids, with carbohydrates. The meals' utility and stability are enhanced as a result of their consumption in a modified state. The enhancement of solubility, stability, and bioavailability of foods can be achieved by the utilization of lipid-based nanoencapsulation, thereby mitigating undesirable interactions with other constituents present in the meal. Nanoliposomes and nanocochleates have emerged as highly promising lipid-based carriers for antioxidants. Furthermore, the utilization of nanoliposomes enables the precise and regulated delivery of nutraceuticals, minerals, enzymes, vitamins, antimicrobials, and additives. The utilization of nano cochleates has the potential to enhance the nutritional composition of processed meals through the stabilization of micronutrients. Nano-encapsulated probiotics possess the ability to be administered to targeted gastrointestinal sites, hence exerting control over immune responses. An exemplary illustration of the aforementioned utilization can be observed in the case of Tip-Top Up bread in Western Australia, whereby the product is fortified with omega-3 fatty acids. HydraCel, a naturally occurring mineral product with a particle size of 5 nm, has the ability to reduce the surface tension of potable

water. This property enables the augmentation of water and nutrient absorption within the human body. A-lactalbumin, a milk protein that has undergone hydrolysis, functions as a carrier for nutrients. It also acts as a means of transporting sensitive food items, such as casein micelles, and is used in the encapsulation of bioactive products, such as dextrans. Additionally, hydrophobically modified starch is employed in the encapsulation of curcumin. These are examples of nano encapsulated products.

2. Application of Nano Structures in Pharmaceutical Industries

- **Liposomes:** The initial development of liposomes occurred approximately four decades ago. Phospholipids such as phosphatidylcholine, phosphatidylglycerol, phosphatidylethanolamine, and phosphatidylserine, which have found use in several fields including biology, biochemistry, medicine, food, and cosmetics, were utilized in the fabrication of these minute synthetic vesicles measuring 50–100nm. The properties of liposomes are influenced by various factors, including the lipid employed, its composition, production method, size, and surface charge. Liposomes have been employed as drug delivery systems due to their ability to prevent pharmaceutical degradation, mitigate unwanted effects, and facilitate targeted drug delivery to specific sites of action. Nevertheless, liposomes have several limitations, including inadequate storage stability, rapid release of water-soluble drugs when exposed to blood components, and restricted encapsulation efficacy. Following oral or parenteral administration, the process of surface modification can potentially enhance stability and structural integrity in the presence of abrasive bioenvironments. The blood circulation period of liposomes can be extended through the attachment of polymers such as poly (methacrylic acid-co-stearyl methacrylate) and polyethylene glycol units. Additionally, the achievement of target-specific drug delivery and stability can be facilitated by conjugating liposomes to antibodies or ligands such as lectins. Liposomes have been employed in drug delivery applications, encompassing transdermal administration to enhance the skin permeability of drugs characterized by high molecular weight and limited water solubility. Additionally, liposomes serve as carriers for drug delivery, effectively mitigating toxicity concerns associated with certain drugs like gentamicin. Furthermore, liposomes have been utilized in ocular drug delivery and the treatment of parasitic infections. Nevertheless, solid lipid nanoparticles (SLNs) present a compelling alternative due to their inherent stability, scalability, and commercial feasibility. Transferosomes, ethosomes, niosomes, and marinosomes are vesicular structures that are mostly employed for transdermal delivery purposes. Ethosomes are a type of liposomes characterized by a high ethanol content, typically reaching up to 45%. On the other hand, transferosomes are liposomes that incorporate surfactant molecules, specifically edge activators such as sodium chlorate. Marinosomes are liposomes derived from a naturally occurring marine lipid extract characterized by a significant proportion of poly (unsaturated) fatty acids (PUFAs). In contrast, niosomes are vesicles formed using non-ionic surfactants [8].
- **Dendrimers:** Dendrimers are highly branching nanostructures with an inner core that are made from macromolecules like polyamidoamine (PAMAM), polypropylene, and poly-aryl ether. Although most of the particles are less than 10nm, the size range of the particles is 1 to 100nm [8]. Studies on dendrimers began around 20 years ago,

focusing on their synthesis and physical and chemical properties; about 13 years later, research into their biological applications began. Dendrimers are distinctive due to their multivalency, sequence of branches, well-defined molecular weight, globular structure, and regulated surface activity, which increases their potential as drug delivery vehicles. Drugs can be contained inside of macromolecules thanks to their globular shapes and internal cavities. According to reports, dendrimers can enable regulated release from the inner core. But medications are integrated both internally and externally, connected to the surface. Drugs that are both hydrophilic and hydrophobic can be integrated into dendrimers due to their adaptability. Controlled dendrimer multivalency allows for the well-defined attachment of various pharmacological molecules, targeting groups, and solubilizing groups to the surfaces of the dendrimers. Dendrimers are used because of their small (10nm or less) size, simplicity in preparation, functionality, and capacity to display multiple copies of surface groups for biological recognition. Small molecules can be bound and solubilized by water soluble dendrimers, which can also be utilised as coating agents to deliver medications to specific locations while keeping them safe. Dendrimers can also be used for catalysis, delivering genes and DNA, biomimicry, and as solution phase scaffolds for combinatorial chemistry. Utilising dendrimer-drug conjugates to increase drug solubility and permeability, intracellular delivery, and therapeutic and diagnostic use for the treatment of cancer are only a few applications for drug delivery.

- **Solid Lipid Nanocarriers:** Solid lipid nanoparticles (SLN) exhibit a size distribution spanning from 50 to 1000 nm and consist of solid lipids, including glyceryl behenate (Compritol), stearic triglyceride (tristearin), cetyl palmitate, and glycerol tripalmitate (tripalmitin). Approximately a decade ago, the research community began to exhibit a keen interest in the potential scalability of SLN. The lipids employed exhibit a high degree of biocompatibility, rendering them well-tolerated by the human body. Furthermore, the implementation of high-pressure homogenization techniques facilitates the facile and cost-effective synthesis of lipids on a wide scale. SLN exhibits several noteworthy qualities, including high tolerability, precise targeting at specific sites, stability achieved through the use of surfactants or polymers, controlled release of drugs, and protection of pharmaceuticals against degradation. SLN are renowned for their relatively high-water content in the dispersions, insufficient drug loading, and drug ejection upon polymorphic change during storage. For parenteral, cutaneous, ophthalmic, oral, pulmonary, and rectal modes of delivery, SLN has been researched and developed. Nanostructured lipid carriers (NLC) were developed to get over SLN's drawbacks. NLC has enhanced drug loading, increased stability during storage, and a small amount of liquid lipids, which results in less drug ejection. For cutaneous delivery in cosmetic and dermatological applications, NLCs have been investigated. To get around the restrictions on the types of medications that might be integrated into the solid lipid matrix, lipid drug conjugate (LDC) nanoparticles were developed. SLN typically contains lipophilic medicines, however due to production-related partitioning effects, only extremely powerful hydrophilic medications that are effective at low concentrations are added to the substance. LDC makes it possible to include both hydrophilic drugs (such as doxorubicin and tobramycin) and lipophilic (e.g., progesterone and cyclosporine A) drugs.

- **Polymeric Micelles:** Micelles are formed through the spontaneous aggregation of amphiphilic surfactants or polymeric molecules, resulting in the formation of core-shell structures or vesicles in an aqueous medium. Polymeric micelles in physiological solutions exhibit greater stability compared to surfactant micelles due to their composition of amphiphilic block copolymers such as poly (ethylene oxide) poly (-benzyl-L-aspartate) and poly (N-isopropylacrylamide)-polystyrene. Approximately 24 years ago, the concept of utilizing them as vehicles for drug delivery was initially proposed. A micelle is characterized by the presence of a hydrophobic core surrounded by a hydrophilic shell composed of polymers such as poly (ethylene glycol). The hydrophilic outer layer and compact dimensions (100nm) of these nanoparticles facilitate their preferential accumulation in tumor tissues, while their hydrophobic inner core allows for the encapsulation of amphiphilic and poorly water-soluble drugs. Polymeric micelles possess the ability to penetrate anatomical regions that liposomes struggle to reach. This is due to their enhanced vascular permeability, which enables them to accumulate a higher concentration of therapeutic agents within tumorous tissues compared to unencapsulated drugs. Polymeric micelles possess the capability to effectively transport chemotherapeutic agents to tumor cells, resulting in a concentrated delivery while minimizing adverse effects in a controlled and specific manner. The suboptimal drug loading and inadequate drug integration stability of polymeric micelles, leading to premature drug release prior to reaching the intended site of action, impose constraints on their targeting efficacy. Consequently, modifying the production parameters and the architectural composition of the inner core can improve the stability of drug integration and drug loading, respectively. In order to enhance the durability of polymeric micelles, lipid moieties such as cholesterol and fatty acyl carnitines can be employed. This phenomenon is predicated on the observation that the inclusion of fatty acid acyls, such as diacyllipid, augments the hydrophobic interaction among the polymeric chains within the inner core. Polymeric micelles have been employed for the purpose of achieving targeted, intracellular, sustained, and parenteral distribution.
- **Nanocapsules:** Nanocapsules can be described as spherically shaped structures that possess a central cavity and are enveloped by a polymer membrane, which serves to contain the medication. According to the cited source [9], their existence spans across a period of more than three decades. Optimal dimensions for drug delivery systems typically range from 50 to 300 nm, since these sizes offer advantageous properties for effective drug administration. These nanoscale carriers can be employed to encapsulate lipophilic pharmaceuticals by utilizing oil-based formulations, thereby facilitating the dissolution and subsequent delivery of such drugs. The particles are taken up by the mononuclear phagocyte system, exhibiting a low density, a high capacity for loading, and a tendency to accumulate in certain organs such as the liver and spleen. Nanocapsules possess a wide range of applications, serving as confined reaction vessels, protective enclosures for cells or enzymes, transfection vectors in gene therapy, dispersants for dyes, carriers in heterogeneous catalysis, imaging agents, and vehicles for medicine delivery. Insulin, elcatonin, and salmon calcitonin are among the proteins and peptides that have demonstrated enhanced oral bioavailability. Ibuprofen is among a variety of pharmaceutical agents that can be enclosed within nanocapsules as a means of impeding disintegration, reducing systemic toxicity, achieving controlled release, and masking undesirable taste. The inclusion of drugs

within capsules post-formulation may not be feasible, as the successful release of the medication at the intended site can be hindered by its high stability and limited permeability. The nanoparticles have been engineered to exhibit pH-responsive behavior, hence enhancing their permeability.

- **Nanoemulsions:** Nanoemulsions are classified as droplets with diameters below 1 nm, often ranging from 20 to 200 nm. Nanoemulsions, characterized by their sub-wavelength size, exhibit transparency, while microemulsions, which possess the ability to scatter light, seem white in color. Nanoemulsions are utilized as vehicles for hydrolysable, lipophilic pharmaceuticals that possess the properties of being biodegradable and biocompatible. Sustained release administration techniques are employed for the purpose of subcutaneous injection depot formation. These substances enhance the process of stomach absorption and reduce the variability of medication levels observed within and between individuals. The comparatively high interfacial area of these substances contributes to their improved drug release profile. Nanoemulsions have been extensively investigated and developed for many delivery routes, including parenteral, oral, ocular, pulmonary, and cutaneous administration. The achievement of stability against sedimentation is attributed to the nano size of the droplets, as the rate of sedimentation resulting from gravity is comparatively slower than the rate of Brownian movement and diffusion. Nanoemulsions, as opposed to microemulsions, exhibit metastability and can undergo destabilization through two mechanisms: depletion-induced flocculation, which occurs when thickening polymers are added, and Ostwald ripening, a process in which small droplets dissolve and their mass is absorbed by larger droplets. Subsequently, the nanoemulsion will undergo a transition into an opaque state, leading to the occurrence of creaming. The process of Ostwald ripening can potentially be mitigated by introducing a minute amount of a second oil, characterized by limited solubility in the aqueous phase, together with a secondary surfactant. It is necessary to exercise control over several production-related areas as well. To prevent rapid Ostwald ripening, it is crucial to carefully select a suitable composition, control the sequential addition of ingredients, ensure the insolubility of molecules from the dispersed phase in the continuous phase, and apply shear forces in an efficient manner to facilitate the breakup of droplets.
- **Ceramic Nanoparticles:** Ceramic nanoparticles are made of inorganic materials like silica, alumina, and titania that have a porous structure. The appropriate size, shape, and porosity can be prepared for them. Their diameters are smaller than 100 nm, which allows them to escape being absorbed as foreign objects by the reticulo-endothelial system. At healthy pH and temperature, entrapped molecules including medicines, proteins, and enzymes are protected from denaturation since neither swelling nor change in porosity occurs. As a result, they distribute proteins and DNA effectively. Since these particles cannot degrade, there is a risk that they will build up in the body and have negative effects.
- **Metallic Nanoparticles:** The utilization of metallic nanoparticles for the purpose of targeted cellular distribution has been the subject of extensive research. Various types of metallic nanoparticles, such as iron oxide, gold, silver, gadolinium, and nickel, have been examined in this context [10]. Gold exhibits exceptional optical and chemical properties at the nanoscale, making it very suitable for biomedical imaging

and therapeutic purposes. The size can be adjusted within the range of 0.8 to 200nm. The modification of the surface enables the specific localization of proteins and peptides to the cellular nucleus, while also facilitating the introduction of diverse functional groups for the purposes of gene transfection and conjugation, thereby generating a gene delivery vector. The investigation of the utilization of folate, thiamine, and poly (ethylene glycol) as modifiers for gadolinium nanoparticles has been conducted in order to enhance the delivery of these nanoparticles to tumor sites. It has been noted that adding folate to a modification improves the tumour cells' ability to recognise, absorb, and retain gadolinium nanoparticles. Surface area of metallic nanoparticles is substantial, therefore including a large medication dosage. However, metallic nanoparticles' toxicity is a matter of worry.

- **Carbon Nanomaterials:** Fullerenes and carbon nanotubes are examples of this. Fullerenes are a polygonal-shaped carbon allotrope with 60 or more carbon atoms [10]. Because of their superior strength and strong electrical conductivity, nanotubes have found use. The potential medicinal uses of these materials are being investigated. Drugs and biomolecules can be delivered across cell membranes to the mitochondria using functionalized fullerenes. Because of their special qualities, such as low cytotoxicity and high biocompatibility, carbon nanotubes are frequently used as delivery systems for medicines, proteins, and genes. Carbon nanotube toxicity, however, is a matter of concern. Carbon nanotubes may result in fibrotic and inflammatory reactions.

VI. FUTURE ASPECTS

The application of nanotechnology in many fields has advanced significantly in science, while the field's development in relation to nanostructures has advanced far more slowly. This discussion encompasses the various diseases that impact both plant and animal species. The formulation scientist faces significant challenges in keeping pace with the rapid advancements in the discipline, particularly in relation to nanostructures or nanoparticles. Equipment manufacturers, material scientists, pharmaceutical researchers, and regulatory agencies have significant challenges due to the emergence of a novel research and development (R&D) domain. There is a prevailing belief that enhanced understanding and utilization of nanotechnology in the context of drug administration holds the potential to enhance treatment efficacy and promote patient compliance with medication regimens. Furthermore, the application of nanotechnology in food technologies is also anticipated to benefit from these advancements.

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