REVIEW ARTICLE

Review on the Recent Applications of Nanomaterials in Energy, Environment and Health Care

M.Sumathi[1*], P.Rekha[2], M.Mohan[3*], A.Prakasam[4], P.M.Anbarasan[5], V.Aroulmoji[3*]

[1]Department of Physics, Mahendra Arts and Science College (Autonomous), Namakkal (Dt) – 637 501, Tamilnadu, India
[2]Departamento de Ingeniería Mecánica, Universidad de Tarapacá, Avda. General Velasquez 1775- Arica, Chile
[3]Centre for Research & Development, Mahendra Engineering College (Autonomous), Mallasamudram, Namakkal (Dt) - 637 503, Tamil Nadu, India
[4]PG and Research Department of Physics, Thiruvalluvar Government Arts College, Rasipuram - 637401, Tamilnadu, India
[5]Centre for New and Renewable Energy Studies (CNRES), Department of Physics, Periyar University, Salem - 636011, Tamil Nadu, India

ABSTRACT: This review centers on the significance of the advancement of nanotechnology in today's world. The emergence of nanotechnology in the last three years seems to surprise everyone. Nanomaterials are synthesized with facile techniques that satisfy the user's requirements with their unique characteristics. Nanomaterials are very novel in their properties at the atomic level. An exceptional characteristic of nanomaterials, such as their tiny size, various shapes, higher surface-to-volume ratio, surface plasmon resonance, optical properties, mechanical and electrical stability, etc., solves real practical issues. Based on dimension, nanomaterials are categorized. They are generated by either bottom-up or top-down methods. All industries search for well-developed technologies that could provide an efficient result with minimum loss. This could be achieved by employing the appropriate nanomaterials, which offer great accuracy. Nanomaterials are used in various industries, especially in the medical field, for diagnosis and treatment necessities in equipment, instruments (coating agents), and drugs and medicines, respectively. Also, nanomaterials extend their hand to energy storage (fuel cells, hydrogen evolution reactions, etc.), the environment, cosmetics, painting, sensors, etc. This review provides detailed information on the nanomaterial synthesis procedure, characteristics, and different applications from a state-of-the-art approach. Finally, a summary of the challenges and prospects of nanomaterials is added for further prospects in the field of nanotechnology.

KEYWORDS: nanomaterials, nanotechnology, medical application, fuel cell, sensor, environment

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INTRODUCTION

Nanoscience and nanotechnology are fascinating fields that deal with studying and manipulating matter on a tiny scale; typically at the nanometer level (A nanometer is one billionth of a meter in diameter). Nanotechnology is a rising innovation that empowers researchers to create modern materials and items at the atomic level. Nanotechnology truly implies any innovation that is performed on a nanoscale. The study of materials at the atomic, molecular, and macromolecular scales, where their properties fundamentally differ from those at larger scales, is known as nanoscience. On the other hand, nanotechnologies are the creation, characterization, design, and use of structures, apparatuses, and frameworks through the control of size and shape at the nanoscale. Nanotechnology is characterized as the design, characterization, generation, and application of structures, devices, and frameworks by controlling shape and estimate at the nanometer scale. It includes the creation and use of natural, physical and chemical systems at dimension scales ranging from measurements of submicrons to those of individual molecules or atoms, as well as the incorporation of the resultant nanostructures into larger systems [1].

**Corresponding Authors: sumathinano8@gmail.com / mohanrtt@gmail.com*
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Nanotechnology has demonstrated itself as a benefit in the innovation of semiconductor, information technology, cellular and atomic science, material innovation, energy systems, manufacturing, equipment, natural applications, nanoelectronics, biotechnology, and biomedical applications. It is seen as the subsequent industrial revolution and is anticipated to have a significant influence on the economy, society, and quality of life soon [2]. Nanotechnology is a multidisciplinary scientific approach that has experienced accelerated development in modern times [3,4]. The obvious need for further miniaturization of optical and electronic devices is one of the main factors driving modern research in nanomaterials. Nanotechnology in medicine enables drug delivery, improved medical imaging, and drug rehabilitation through the advancement of tissue engineering nanoscale scaffolds. This review mainly focuses on the recent advancement of nanomaterial applications in the fields of energy production, material synthesis, microbial cell factories, cosmetics, environmental applications, and medical applications. It further describes the sharp and essential development of nanomaterials and their applications to concentrate wide area of science and technological applications.

Nanomaterials

Generally, nanomaterials have structured components with at least one dimension less than 100 nm (1 nm = 10^{-9}m) and often exhibit distinctly different physical and chemical properties in comparison to their micron-sized counterparts [5]. In nanoparticles, the various material properties, such as electrical, mechanical, optical, magnetic, etc., can be selectively controlled by engineering the size, morphology, and composition of the particles [6]. It is possible to produce nanostructure materials using a variety of synthesis methods in various forms, like thin films, powder, quantum wires, quantum wells, quantum dots, etc. The generation of carbon nanostructures is related to the famous applications in Bucky ball. Conventional materials have grains varying in size anywhere from hundreds of microns (μm) to millimeters (mm). A nano-crystalline material has grains in the order of 1-100 nm. The average size of the atom is of the order of 1 to 2 Å in radius. One nanometer comprises 10 Å, and hence, in one nanometer (nm), there may be 3-5 atoms, depending on the atomic radii [7,8]. The most intuitive 'nano-size' effect is produced due to the dominance of surface atoms in the nanomaterials. There are atoms that have dangling bonds or a disorder of atomic arrangement at the outermost surface, and this is compensated within a crystal by the strained lattice parameters of the surface atoms with their penultimate atoms.

Nanostructured materials are denoted as condensed bulk materials made up of grains with grain sizes in the nanometer size range, while nano-phase materials are usually dispersive nanoparticles. When compared to bulk materials, the characteristics of nanoparticles differ dramatically. The primary cause of this is the materials' nanoscale size, which makes them: Compared to similar bulk materials, there are four advantages: (1) a high proportion of surface atoms; (2) high surface energy; (3) spatial confinement; and (4) decreased defects [9]. Because of their extraordinarily high surface area-to-volume ratio, a significant portion of nanomaterials are made up of surface or interfacial atoms [10]. The surface characteristics of nanoparticles will influence the overall material when the diameters of the nanomaterials are similar to the Debye length. After shrinking to a size where the particle's surface is separated by a distance equal to the order of the electrons' wavelengths, the nanomaterial [11] is complete. A particle in a box subjected to quantum mechanical treatment can be used to describe the energy levels in such a scenario, termed the "quantum size effect."Such size effects modify the electrical, mechanical, optical, magnetic, and thermodynamic properties of nanomaterials [12].

Classification of Nanostructures

Nanomaterials can be broadly categorized into four groups based on the shape of their crystallites or grains: (1) three-dimensional (3D) nanomaterials, such as zeolites or molecular sieves with cages like nanopores; (2) two-dimensional (2D) nanomaterials, such as thin films and quantum wells; (3) one-dimensional (1D) nanomaterials, such as quantum wire, quantum rod, etc.; and (4) zero-dimensional (0D) nanomaterials, such as quantum dots. Equiaxed granules of nanoscale size make up 3D nanomaterials. The electrons in this instance are delocalized and are free to travel in the x, y, and z directions. The electrons in two dimensions are confined in one direction (z) and delocalized in two directions (x and y). The electrons in 1D are confined in two dimensions (x and y) and delocalized in one direction (z).

Four groups of Nanostructures:

Zero-dimensional (0D) nanostructures:

They are structures or materials that do not allow free particle transportation in any direction and confine electrons in three dimensions. This group includes colloidal particles, nanoparticles, and semiconductor quantum dots (QDs).

One-dimensional (1D) nanostructures: Materials that restrict electrons in two dimensions or structures that prevent free particle mobility in two dimensions are examples of one-dimensional (1D) nanostructures, Nanorods, nanowires, nanotubes, nano filaments, *etc*.

Two-dimensional (2D) nanostructure: Materials such as nanodiscs or platelets, thin films on surfaces, and multilayered materials show electron confinement in one dimension or the structure does not allow free particle mobility in one dimension.

Three-dimensional (3D) nanostructure: Three-dimensional nanomaterials are materials in the nanophase that are made up of nanometer-sized equi axed grains.

Properties of Nanomaterials - Size Effect

The size range of nanocrystals is in between the macroscopic bulk and the molecular size regimes. While research on the shape-facet-dependent catalytic behaviour of nanocrystals is laborious, the size-dependent catalytic characteristics of these materials have attracted more studies. It is observed that a nanoparticle's reactivity rises as its size decreases, that a nanophase's melting temperature is significantly lower than that of its bulk equivalent, and that a nanoparticle's color particularly that of a semiconductor-varies as it becomes smaller. Depending on its size, a particle may occasionally exhibit metallic or semi-conducting behaviour. Because of the size effect, the particle's finite size constrains the electrons' spatial dispersion, resulting in quantized energy levels. Applications for this quantum confinement may be found in non-linear optics, optoelectronics, and semiconductors [13-15].

Optical Properties

Nanomaterials' optical characteristics are among their most intriguing and practical features. Photo catalysis, photo electrochemistry, solar cells, displays, lasers, sensors, imaging, optical detectors, phosphors, and biomedicine are among the applications that rely on the optical characteristics of nanomaterials. The size, shape, and surface features of a material, along with additional factors like doping and interactions with other nanostructures or the surrounding environment, all affect its optical properties. Similarly, metal nanostructures' optical characteristics can be significantly impacted by their form. Figure 1 exemplifies the difference in the optical properties of metal and semiconductor nanoparticles.

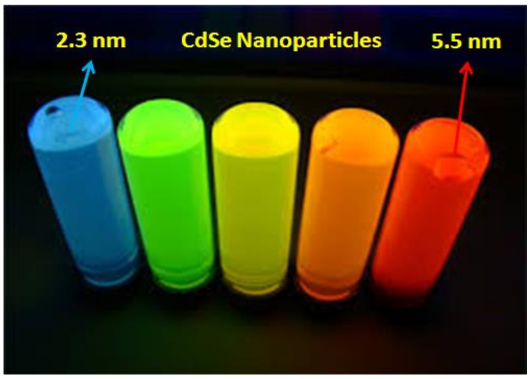

Figure 1 Fluorescence emission of (CdSe) ZnS quantum dots of various sizes and absorption spectra of various sizes and shapes of gold nanoparticles

The need to modify the size of CdSe semiconductor nanoparticles is to vary their optical characteristics. Gold nanospheres demonstrate the optical characteristics of massive metal nanoparticles. Anisotropic magnetic nanoparticles have garnered a lot of attention lately because of their possible uses in the administration of medication, biomedical imaging, and magnetic data storage. Anisotropic nanoparticles can also be used to create materials with tailored optical properties, such as plasmonic nanoparticles that have strong light-matter interactions and are used in sensors, solar cells, and other optoelectronic devices. For instance, a spherical nanoparticle would be isotropic, as its properties would be the same in all directions. However, a nanoparticle with an elongated or asymmetric shape, such as a nanorod or nanowire, would be anisotropic.

Structural Properties

It is vital to take into account the ratio of atoms, free surface area, or an internal border like the grain boundary in a nanocrystalline solid in order to comprehend changes seen in systems of smaller size. The specific surface area (m^2g^{-1}) and surface area to volume ratio (S/V) of a system both rise sharply for particles with a diameter of less than 100 nm. These quantities are inversely related to particle size. It is evident that when an atom is at the surface, there are fewer nearest neighbour atoms, which results in variations in bonding (which cause surface tension, a well-known phenomenon) and electrical structure. A significant fraction of all atoms in tiny, isolated nanoparticles will be found at or close to the surface. It would be predicted that such structural variations in smaller dimensions would have distinct characteristics from those in the bulk.

Thermal properties

The significant alteration in inter-atomic gap and surface energy with nanoparticle size has a noticeable impact on thermal characteristics. An example of a bulk thermodynamic property that has been shown to quickly decline for particle sizes less than 10 nm is the melting point of gold particles. A continuous matrix containing the metallic nanocrystals is evident from the high melting point of the smaller particles.

Chemical Properties

The variation in electrical characteristics is inextricably connected to the structural change as a function of particle size. Small atomic clusters often have a larger ionization potential than similar bulk materials, which is the energy needed to remove one electron. Moreover, significant variations in the ionization potential are seen in relation to cluster size. Because of their extremely high surface area-to-volume ratios and perhaps distinct crystallographic structures, nanoscale objects like nanoparticles and nanolayers may change in chemical reactivity. Chemical processes can be catalyzed more quickly, selectively, and efficiently by employing finely separated nanoscale systems. Smaller than 5 nm sized of gold nanoparticles have been shown to take on icosahedral shapes as opposed to the typical face-centered cubic configuration. Catalytic activity has increased astronomically along with this structural alteration.

Mechanical Properties

The mechanical properties of nanoparticles describe bulk metallic and ceramic materials that are affected by superplasticity, porosity, grain size, and filled polymer composites. It covers particle-filled polymers, platelet-filled polymer-based nano composites, and composites based on carbon nanotubes. Because it is difficult to create macroscopic structures with a high density and a grain size in the range of less than 100 nm, the study of the mechanical characteristics of nanomaterials is, to some degree, only of very basic interest. Based on their industrial relevance, the two materials, neither of which is created by pressing or sintering, have garnered far more attention. These materials include highly plastic-deformed metals with amazing characteristics, and polymers that have been modified by adding nanoparticles or nanotubes to increase their mechanical behaviours. Unfortunately, the latter are not often recognized as nanomaterials due to their higher grain size.

Most of the time, significant experimental challenges in generating specimens with precisely specified grain sizes and porosities impede experimental research on the mechanical characteristics of bulk nanomaterials. Thus, a thorough knowledge of the mechanical characteristics of these materials necessitates the use of model simulations and molecular dynamic investigations.

Electrical Properties

The electrical properties of nanomaterials are highly dependent on their size, shape, and structure, which can differ significantly from those of bulk materials. Some of the key electrical properties of nanomaterials include the quantum confinement effect, surface effects, electrical conductivity, dielectric properties, magneto resistance, and superconductivity. Overall, the electrical properties of nanomaterials are important in a wide range of applications, from electronics and energy storage to sensing and biomedical applications. The unique properties of nanomaterials can be exploited for the development of new and improved technologies.

Synthesis of Nanomaterials

The creation of economical and ecologically secure methods for the production of nanomaterials is the most difficult aspect of the field of nanotechnology research. One might categorize the approaches to nanomaterial synthesis into two main groups based on the principles of "top-down" and "bottom-up" approaches (Figure 2). The goal of the top-down method is to directly build nanodevices on silicon (or other semiconductor) chips by using X-ray or electron beam lithography. Atoms, or molecules, are used as building blocks to create nanostructures using the bottom-up technique. The synthesis of nanomaterials is subdivided into physical, chemical, biological, and bio-inspired approaches that allow further classification. A flow chart indicating the different methods of nonmaterial's synthesis is shown in Figure 3.

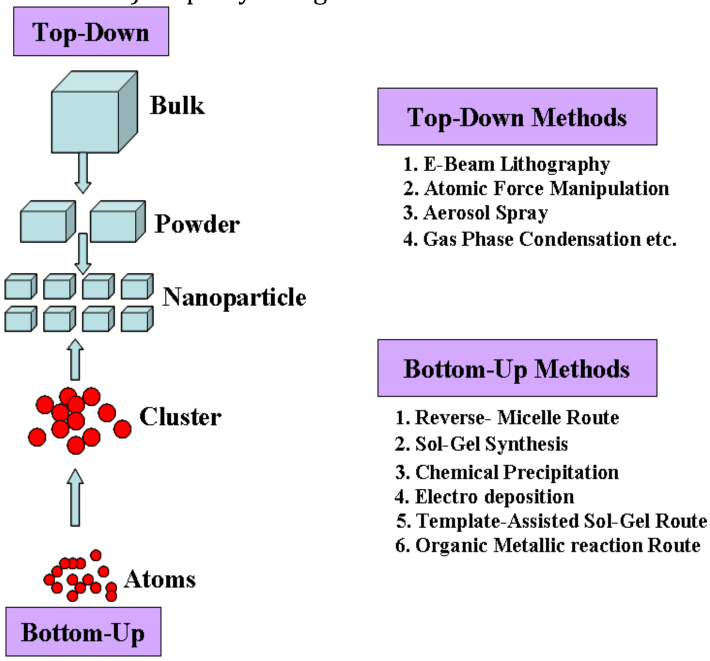

Fig. 2 Schematic representation of Top-Down and Bottom-Up approaches

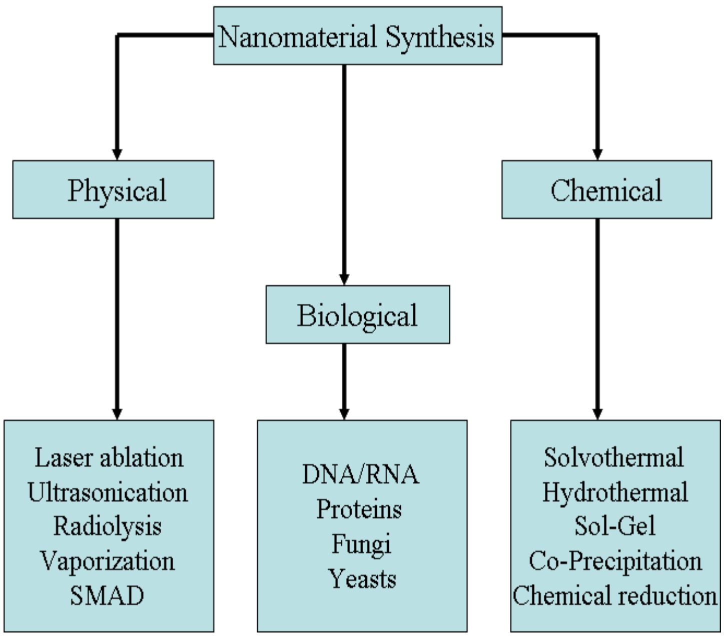

Figure 3: Schematic outline of the various approaches for the synthesis of nanoparticles

Many physical techniques, including vapour deposition [16,17], thermal breakdown [18], spray pyrolysis [19], photo-irradiation [20], laser ablation [21], ultrasonication [22], radiolysis [23], and solvated metal atom dispersion [24], have been effectively used for the production of nanomaterials. Chemical techniques are commonly recognized for the production of nanomaterials, however, since they have significant benefits over physical approaches. Chemical techniques can be used to create nanomaterials such as metals, metal oxides, and semiconductor nanoparticles. These procedures include either reducing or oxidizing metal ions or precipitating the necessary composites through the right chemical process. A capping agent may be needed when using chemical procedures to limit the development of particles at the nanoscale level. Better stability, assembly, and control over the size and shape of nanomaterials are achieved by the application of capping molecules. Various capping agents, ranging from basic ions to diverse proteins, have been utilized to ensure the stability of nanomaterials. Depending on their intended uses, nanomaterials can be synthesized using either organic or aqueous media using chemical processes.

Phase transfer of chemically synthesized metal nanoparticles in aqueous dispersion to organic medium is a simple process. Therefore, chemical precipitation and microwave irradiation method have been mostly used to synthesis SnO_2 nanostructures with different dopants.

Importance of Nanomaterials

More attention has been given to nanomaterials due to their unique electrical, optical, mechanical, and magnetic capabilities. Some examples are given below:

- When compared to coarse-grained ceramics, nanophase ceramics are more ductile at higher temperatures.

- Numerous non-linear optical characteristics have been observed in nanostructured semiconductors. Semiconductor Q-particles also show quantum confinement effects, which may lead to special properties like luminescence in silicon powders and silicon germanium quantum dots as infrared optoelectronic devices. Nanostructured semiconductors are used as window layers in solar cells.

- Particle-sized metallic powders have been utilized in the creation of dense components, gas-tight materials, and porous coatings. Their ductility and cold welding qualities make them ideal for metal-to-metal bonding, particularly in the electronics sector.

- It is expected that in magnetic nanophase materials, single nanosized magnetic particles are mono-domains; the grains correspond with domains, while boundaries, on the contrary, and correspond to disordered walls. Very small particles have special atomic structures with discrete electronic states, which give rise to special properties in addition to the super-paramagnetism behavior. Magnetic nano composites have been used for mechanical force transfer (ferro fluids), high-density information storage, and magnetic refrigeration.

- Catalytic applications are significantly impacted by nanostructured metal clusters and colloids with either a mono- or plurimetallic composition. They served as precursors for new types of heterogeneous catalysts (cortex catalysts) and have been shown to offer substantial advantages concerning activity, selectivity, and lifetime in chemical transformations and electrocatalysis (fuel cells). Enantioselective catalysis was also achieved by using chiral modifiers on the surface of nanoscale metal particles.

- There is an increasing trend to use nanostructured metal-oxide thin films to create gas sensors (NO_x, CO, CO_2, CH_4, and aromatic hydrocarbons) with enhanced sensitivity and selectivity. Nanostructured manganese oxide (MnO_2) finds application for rechargeable batteries for cars or consumer goods. Nanocrystalline silicon films for highly transparent contacts in thin-film solar cells and nano-structured titanium oxide porous films are used for their high transmission and significant surface area enhancement, leading to strong absorption in dye-sensitive solar cells.

Applications of Nanomaterials

Nanomaterials are widely used in batteries, cosmetics, electronics, fuel cells, pharmaceuticals and supercapacitors. The superior chemical, physical and mechanical properties of nanomaterials, as well as their superior formability, make them different from traditional materials.

Medical Applications

Researchers studying biology and medicine have made use of the special qualities of nanomaterials for a range of purposes, such as the creation of innovative contrast agents for cell imaging and medicines to cure cancer and other illnesses. This multidisciplinary field is referred to by terms like biomedical nanotechnology, bio-nanotechnology, and nanomedicine. Nanomaterials can be made more functional by fusing them with biologically active structures or molecules. Nanomaterials are comparable in size to the majority of biological molecules and structures. Thus, nanoparticles can be used in biomedicine both in vivo and in vitro. The creation of diagnostic tools, magnetic resonance imaging contrast agents, analytical tools, pathogen detection, physical therapy applications, and drug delivery vehicles are the results of the integration of nanomaterials in medicine, as shown in Figure 4.

The sheet-like structure, increased surface area, and functional significance of graphene nanomaterials have attracted scientists to perform their role in the development of biomedical applications [25,26]. Drug delivery systems require more functional roles and various functional features of graphene exhibit biological properties in a controllable manner. Graphene nanomaterials show their anticancer properties through their mode of functionalization, biocompatibility, and in vivo circulation during drug delivery. For example, polymer-conjugated graphene is able to produce drug delivery systems and create opportunities to develop novel drugs with high loading capacities [27,28]. Graphene is found to be an appropriate nanomaterial, showing physical, chemical, optically attractive, electrically favourable, and mechanically stable properties. The properties elaborated on the applications of these graphene materials as sensors [29,30], antiviral activity [31], biosensors [32], cancer therapy [33] and medical applications [34]. Graphene also shows efficient oxidative and photothermal properties with a low cost implied by its use in the area of drug delivery, and it has a high loading capacity through its layered structure to possess drug molecules [35]. Application of graphene nanomaterials in the medical field exhibits some drawbacks, including toxicity, damaging the plasma membrane of intact cells, immune cells, and hemolytic activity [36-38]. To overcome all the problems when using graphene in biomedical applications, functionalization of graphene surfaces with appropriate polymers was used. Polyethylene glycol (PEG) was used to conjugate the nanomaterial in order to reduce its toxicity and increase stability under the cytophysiological nature [39].

In addition to PEG, many polymers can be used in the pharmaceutical industry to improve stability, solubility, drug delivery capacity, and other physiochemical properties, which comprise hyaluronic acid (HA), chitosan, polyethylamine, and polyglycerol [40-42]. Quantum dots (QD) appear to have optically, electronically, and magnetically attractive properties that extend to targeting ligands in tumor cells, the synthesis of monoclonal antibodies, and specific proteins acting as biomarkers. New-generation imaging was performed with the use of QDs to find tumor cells. Size-specific properties and similarity of these nanoparticles involved in biomedical imaging [43-44]. Nanomaterials support the cells to get medications and act as pharmaceutical agents with less treatment costs [45]. Abraxane and other nano-drugs were used to treat breast cancer [46], pancreatic cancer [47], and other cancers; Sirolimus (rapamycin), a mammalian target of rapamycin (mTOR) inhibitor with immunosuppressive. It is an anti-angiogenic, anti-restenosis, antifungal, anti-proliferative, and anti-inflammatory properties (AzadehHaeri), was developed in part due to nanotechnology [48].

The application of nanomaterials in tissue engineering is enormously increasing. Periodontal treatment involves repairing and restoring damaged tissues, producing coating material, and acting as antibacterial material [49]. The peripheral nervous system (PNS), which consists of motor and sensory neurons, and the central nervous system (CNS), which includes the brain and spinal cord, make up the nervous system. Both the CNS and PNS do not have the natural capacity to regenerate their cells. The treatment of injured and damaged cells during the course of the disease is a challenging task due to their histo compatibility and immunological rejection. Nervous tissue engineering using nanomaterials is found to be the better option, which extends polymer scaffolds, nanoparticles, and hydrogels to act as biocompatible, biodegradable materials with high permeability [50].

Figure 4 various applications of nanomaterials in medicine

Nanomaterial-based treatment using bone marrow tissue engineering for irreversibly injured patients through scaffolds of bone marrow and mechanical and biological strategies [51-52]. Three-dimensional (3D) scaffolds of bone marrow tissue engineering strengthen and organize the tissues in a natural manner [53]. Skin is the natural physiological barrier safeguarding humans from external environmental conditions. During injury, the intact skin is opened, and it is perfectly closed by regenerating the damaged skin cells and ensuring the protection function of the skin. The repair needs to communicate the physiological network and be regulated in multiple organizations [54]. Healing of wounds is a complex physiological and histological process that includes regulation of the vascular system, inflammation, maturation of cells, and its proliferation potential [55]. The functionalization capacity, easy synthesis, and localization of Plasmon bands increased the demand for gold nanoparticles in the area of pathology detection [56-57]. Gold nanoparticles were utilized to detect Escherichia coli through synthetically prepared DNA and 16S rRNA [58].

The solubility of carbon nanotubes (CNT) is of paramount importance in the usefulness of various applications, and it is integrated into organic, inorganic, and biological-based systems. It is grouped into three subcategories, which include the chemical groups attached covalently in π-bond conjugation, absorption by non-covalent bonding with more functionally active molecules, and the inner empty cavity with endohedral filling [59]. In one of the studies, carbon nanotubes (CNT) and hyaluronic acid (HA) were covalently conjugated to improve the biocompatibility and cellular penetration capability of the CNT and enable drug delivery potential [60]. Moreover, the CNT enzyme is assembled to amplify the protein and DNA electrical properties, and this composite molecule is elaborately applicable to medical diagnosis [61]. In addition to carbon-based nanoparticles, metals, and metal oxides, magnetic nanoparticles have gained attention in the biomedical field. The magnetic nanoparticles are used in theranostic applications. It is used in bio-molecule extraction, molecule detection, drug delivery, hyperthermia, imaging studies, etc. especially in the oncology division due to their unique features. These features include mainly biocompatibility, nontoxicity, induced magnetic moments, and surface functionalization. Recently, advanced hybrid magnetic materials along with artificial intelligence (AI) were employed in real time disease diagnosis and treatment. In order to utilize magnetic nanoparticles effectively, it is essential to understand their interaction with the environment and living creatures. The design, synthesis, functionalization, dose optimization, loading, and toxicity evaluation of magnetic nanoparticles and their hybrids are optimized by artificial intelligence [62].

Environmental Remediation: Nanoparticles can be used to clean up pollutants

Nanomaterials have been used to create new materials for water purification, air filtration, and soil remediation. For example, nanoparticles can be used to remove contaminants from water or to break down pollutants in soil. The process of synthesis yields new materials with customized characteristics and chemical attributes, such as nanoparticles with unique chemical environments (ligands) or optical attributes. In the near term, chemical expertise might be helpful in the long run to create unique "nanomaterials" Because of its capacity to produce specific new materials, nanotechnology may be used to understand all chemical production. Nanomaterials also have incredibly broad grain boundaries in comparison to their grain size. Their mechanical, chemical, and physical characteristics are therefore very active. In order to reduce environmental pollution from burning coal and petrol, nanoparticles can be employed as catalysts in power production equipment and automotive catalytic converters to react with harmful gases like nitrogen oxide and carbon monoxide. This is possible because nanomaterials have increased chemical activity [63].

Industrial discharge and emissions from automobiles are major sources of pollutants causing environmental problems [64]. Air pollutants, including oxides of nitrates (NOx), sulphates, and persistant organic pollutants (POPs), are a health hazard to human beings [65]. Heavy metals like lead (Pb) cause immediate or chronic damage with respect to the dosage of exposure and their existence in the environment [66]. Inhalation of pollutants like carbon monoxide is highly poisonous. Some heavy metals, like lead, cause poisoning, either immediate or chronic, depending on the exposure level [66]. Various methods, including assimilation on the surface, absorption, catalytic reactions, and filtration, are employed to eliminate different kinds of pollutants [67]. Mohan et al., [68] consolidated emerging contaminants like pharmaceutical and personal care products from municipal wastewater, domestic solid waste, farmlands, and industries. It causes many hazardous effects, especially endocrine disruption for all the organisms exposed to those contaminants.

High surface area to volume ratio of nanomaterials increased the characteristics like biological, geological, and chemical reactions more than macromaterials [69]. Carbon nanotubes, oxides of ferric and titanium, engineering nanomaterials, and nanocomposites are involved in removing soil pollutants through immobilization [70]. Nanomaterials have a high surface area and increased chemical and biological activity when compared to macromaterials. The maximum efficiency of nanomaterials improved its properties [69]. Nanomaterials are used for remediation in the presence of engineered nanomaterials to improve environmental quality by reducing contaminants like noxious chemicals, pesticides, and heavy metals, including pharmaceuticals or personal care products (PPCPs), as emerging contaminants. The availability of nanomaterials such as polymers, carbon, silica, and other materials present in the environment can be analyzed through nano remediation [71]. Polymer nanotechnology is engaged in the treatment of water, which covers nanomembranes, nanofilters, nanocomposites, and nanoparticles [72].

Many more nanomaterials are potentially applied for the remediation of contaminants and are applicable for removing various pollutants [73]. Titanium oxide materials are used for the removal of contaminants. Chen et al. [74] have demonstrated the fabrication of a wide range of titanate nanotubes (TNTs), such as acidic, basic, and neutral nanotubes, through the hydrothermal method of nanomaterial production. Rasalingam et al., [75] recorded the separation method of TiO2-SiO using the silica source from bamboo materials. It has more significant photoactivity because of the rate of degradation of methylene blue. Microbes with nanoparticles play an efficient role in removing environmental contaminants with low cost and no toxicity [76]. Mohan et al., highlighted the system-enabled microbial whole cell factory using modern methods, including omics technology, genome modelling, and bioengineered tools [77]. Further, they listed the sustainable production of nanomaterials through organic synthesis using bacterial biofilms.

Further, magnetic materials are emerging as an exotic tool in environmental remediation. Functionalized magnetic nanomaterials have found their path in the removal of heavy metals and radionuclide pollutants from the environment. Recently, Aberdeen et al. (2023) proposed the phosphate magnetic nanomaterial, which was probed for the removal of heavy metal ions present in industrial wastewater [78]. Also, magnetic nanomaterials are used in the removal of organic and inorganic substances through photocatalytic activity in the treatment of wastewater. The multifunctionalized magnetic nanomaterial $CoFe_2O_4$ has been created by Vijaylakshmi et al., for efficient dye degradation as well as an appropriate electrode for energy storage applications [79]. Sumathi et al., reported the high capable visible light driven photocatalytic activity of WO3/g-C3N4 hetrostructure catalysts synthesized by a novel one step microwave irradiation method. The authors suggested that the improved photocatalytic activity of the g-C3N4/WO3 composites is due to the synergistic effect of g-C3N4 and WO3 was considered to lead to improved photogenerated carrier separation [80].

ENERGY APPLICATIONS

An electrochemical energy conversion device, a fuel cell, transforms chemical energy from an anode (fuel) and cathode (oxidant) directly into electrical energy, as observed in Fig. 5. Through reactions between an oxidant and a fuel that are sparked in the presence of an electrolyte, cell energy is produced internally. Electrodes are the electrodes of a fuel cell. A fuel cell electrode's performance can be enhanced by employing more active electrocatalysts or by strengthening the electrode's physical structure. Maximum contact between the catalyst, reactant gas, and electrolyte, sample surface area, ease of gas movement and excellent electrical conductance are all necessary for effective electrode construction. It should be possible for the structure to reduce losses in this way. In recent decades, there has been an increasing interest in fuel cells due to factors such as environmental pollution, expanding global energy demands, and the depletion of fossil resources. An essential technical answer for developing a low-carbon built environment is fuel cell technology, which has minimal emissions and great performance.

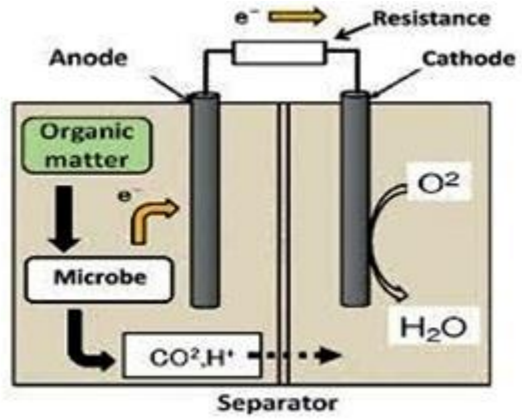

Fig. 5 Schematic representation of microbial fuel cell

Phosphors for High-Definition TV

The size of a pixel has a significant impact on a television's or monitor's resolution. These pixels are mainly composed of substances found within the cathode ray tube (CRT) called "phosphors," which illuminate when exposed to an electron stream. As the phosphors, or pixel size, decrease, the resolution increases. Sol-gel-synthesized nanocrystalline lead telluride, zinc sulphide, cadmium sulphide, and zinc selenide are potential options to increase TV monitor resolution. It is intended that the use of nanophosphors would lower the cost of these displays, making the purchase of personal computers and high-definition televisions (HDTVs) more accessible [81-84].

Next-Generation Computer Chips

Miniaturisation, or the reduction of circuit sizes, including transistors, resistors, and capacitors, has always been a goal of the microelectronics industry. Microprocessors in these devices can work faster by reducing their size, allowing calculations to be made faster. Microelectronics is now turning to nanoelectronics [85]. But there are some obstacles to these advances, including the lack of availability of ultra-rich precursors to make these products; large amounts of heat generated by microprocessors that are difficult to dissipate due to their speed; and the short period between inactivity (bad faith). Nanomaterials prepared from multiple points help the industry to overcome these problems by providing manufacturers with nanocrystalline starting materials, ultra-high purity materials, materials with better thermal conductivity, and long-range junctions (micro-connections between components in the processor) [86].

Cosmetics Applications

Long-term UV exposure can lead to cancer and skin burns. Sunscreen lotions with nano-TiO2 eliminate stickiness while offering increased sun protection factor (SPF). The fact that ZnO and TiO2 nanoskin blocks rest on the skin instead of piercing it gives them an additional benefit. As a result, they successfully block UV light for extended periods of time. Furthermore, they are translucent, maintaining the natural colour of the skin while outperforming traditional skin creams. Smijs and Pavel [87] reviewed the importance of titanium dioxide and zinc oxide nanoparticles in sunscreens, focusing on their safety and efficacy. When microscopic TiO2 and ZnO particles are replaced with NPs, there is a significant effect on the UV attenuation of sunscreen, and the safety of NPs was evaluated [88]. The combination of micro- and nano-sized ZnO dispersions with nano-sized TiO2 particles can be beneficial. Ibrahim et al.,[88] synthesized a lignin-based TiO2 compound as a free radical scavenger in sunscreen. The hydroxyl radicals that TiO2 produces are stifled by lignin/TiO2 composite sheets. Infrared, ultraviolet, 13C NMR, SEM, EDX, and XRD spectroscopy were used to characterize the composites. The authors concluded that too much lignin does not improve beauty but worsens the composition, which is not good for sunscreens and cosmetics. The importance of TiO2 nanoparticles in sunscreen and skin photo damage in vitro and in vivo was investigated by Vaudagna et al., [89], commercially available titania nanoparticles (Degussa P25) were used for simulated solar radiation in vitro and in-vivo studies. After 6 hours of exposure to P25TiO2NPs and light, cell viability and tissue integrity were affected, signs of oxidative stress markers were shown, and tissue integrity was decreased. To eliminate these disadvantages, a new biocompatible modifier was prepared based on the functionalization of TiO_2 nanoparticles with vitamin B2 according to the rapid sol-gel method.The nanomaterials currently used in cosmetic products were reviewed by Georgios Fytianos and coworkers [90]. The authors reviewed the usefulness of different types of Nanaomaterials used in cosmetic preparations, including inorganic nanoparticles, silica, nanocarbon, nanoorganic materials, nano-hydroxyapatite, silver and gold nanoparticles, nanoliposomes, solid lipid nanoparticles (SLN), nanostructured lipid carriers (NLC), dendrimers, and nanoemulsions [91].

Nanomaterial Sensors

A little variation in the concentration of the target species is all that is needed for sensors to trigger a reaction on this extremely active surface. Specialized monolayers, only a few Angstroms thick, are placed on the sensor surface and exposed to the environment. The unique functionality of these monolayers-like their ability to alter in potential when the amount of CO or anthrax is detected-is used for sensing. Nanomaterials are used as electrochemical sensors, gas sensors, biological sensors, and so on. Carbon-based nanomaterials are employed in sensing electrochemical substances due to their novel electrochemical characteristics when compared to other elements [92]. Graphene, carbon nanofibers, carbon nanotubes, carbon dots, nanodiamonds, and fullerene offer a wide range of applications by providing suitable analysis. For electrochemical sensing of carbon nanotubes, fullerene and graphene have played a key role in the development of electrodes [93]. This electrochemical sensor includes the sensing of metal ions, pollutants, and gases in the industrial field and proteins, DNA, enzymes, and immunosensors in the biomedical field [92,93]. As electrodes, carbon nanotubes of single-walled exhibited greater electron transfer, leading to the best sensing activity.Amazingly, it was demonstrated that a single-walled carbon nanotube with copper has the ability to recognize a lower quantity of hydrogen sulphide (5 ppm) in real time [92]. Similarly, ammonia gas was detected finely with a carbon nanotube multi-walled with polymer.

Nanomaterials are included in the wearable materials, along with electronic devices for developing transparent textiles. These nanomaterial-based engineered textiles were able to sense and keep the user's physical body at a favourable temperature [93]. Apart from industrial and textile applications, nanomaterial-based sensors have proved their major role in the biomedical field. Especially carbon-based nanomaterials like carbon nanotubes have proved to enhance the electrochemical activity of the biomolecules. Hence, it is necessary to make these nanomaterials functionalized properly, depending on the application, and immobilized during sensing [93]. The electrodes or probes developed with these nanomaterials have shown very good sensitivity and selectivity for the target molecules. Carbon nanotubes are employed to obtain good electrochemical sensors and act as the best DNA biosensors, enzyme sensors, and immunosensors. In a real-world scenario, various nanomaterials need to be thoroughly investigated for their characteristics in sensing applications [93].

Challenges and Future Perspective

A plethora of research works have been reported on nanomaterials in various types of employment. In the future, nanomaterials will be modified with the developed technologies to do applications effectively. These effective uses of nanomaterials require lots of investigations and face many challenges to get into real-time applications. The following points provide the important challenges that the nanomaterial world faces.Regulatory and ethical concerns surround the use of nanoparticles, particularly in consumer products and medicine.

- Ensuring the safe disposal of nanoparticles is an important consideration.
- Facile synthesis coupled with cost effectiveness and environmental friendliness is the major challenge.
- Performance of the nanomaterial can be hindered by the agglomeration of particles at the nano-level.
- The characteristic features of the nanomaterials need to be compromised, which will affect their performance.
- High surface area along with mass and electron transport processes got to be improved with three-dimensional structures.
- Nanoparticles continue to be a dynamic area of research, and their unique properties offer potential benefits in diverse fields. However, careful consideration of their environmental and health impacts is essential in their development and application.
- Biocompatibility is an important factor when considering any in vivo studies. Hence, nanomaterials can be designed safely and commercialized with a thorough understanding of how they interact with proteins, tissues, and cells.

In the near future, it is possible to attain wonderful nanomaterials with suitable nanotechnology that could satisfy and support real-time world usage. It is possible to develop nano engineered materials to yield clean, green energy with photocatalysts. These photocatalysts help in the fabrication of fuel cells, solar cells, hydrogen generation through water splitting, and hydrogen storage. In the biomedical field, nanomaterials are engaged in developing nano-based therapeutic applications.

CONCLUSION

This review guides researchers in obtaining detailed information about nanomaterials and their properties. Different methods for the preparation of nanomaterials and their applications are discussed. Nanomaterials are synthesized by biological, chemical, and physical methods were also discussed. However, despite some benefits of chemical engineering, many studies have been done on chemical synthesis. Recently, nanomaterials have been functionalized to create hybrid nanomaterials that meet these requirements. Nanomaterials are classified based on their properties, which depend on various parameters. These parameters include the experimental environment, such as temperature, pH, precursor concentration, mixing time, and synthesis method. Therefore, the size and shape of nanomaterials may vary according to these parameters. Nanomaterials create new opportunities, especially in the areas of energy, environment, and biomedicine. Nanomaterials with novel technology can improve energy systems such as fuel cells, solar cells, microbial fuel cells, hydrogen production, and storage in turn it reduces carbon and leads to achieving sustainable development goals. Future research should focus on creating super-nanomaterials that are both environmentally friendly and can solve current global problems. The practices, problems and expectations mentioned here will be helpful to researchers.

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