Societal Impacts of Advances in Nanomaterials

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Abstract: ***The nanomaterials have their internal or surface structure less than 100 nanometers. On basis of composition, properties, and applications, the nanomaterials are classified into polymers, ceramics, and composites. The nanomaterials made extraordinary changes in the physical world on basis of their unique optical, magnetic, and chemical properties. Nanomaterials continue to make progress in the field of catalysis, sensors, environmental remediation, renewable energy, medical science, industry, innovations, etc. The nanomaterials are continuously shaping the society with the positive consequences mainly in environmental protection, ethical fairness, social security, sustainable development, and healthcare.***

Keywords: Characterization, ceramics, composites, nanomaterials, societal impact

1. Introduction

Matter is something which occupies the space. It means matter and space are complementary to each other. Material is a matter from which any physical object is made, this can be a substance or mixture of substances. Material science is the analytical study of structure and characteristics of the materials. It is an interdisciplinary field which incorporates the elements of physics, chemistry, and engineering. Material science is the study of composition, properties, and applications of materials. The development of the material science is continuously going on from bronze period (3300 BC - 1200 BC) to yet and will be going on in future for the welfare of human beings. There are positive and negative both aspects of the progress of material science. Material science has played an important role to raise the life style of the people, but we should not forget that all the wars are fought with weapons which are also made with help of materials. Depending upon size of the smallest unit, the materials are classified in two categories; Bulk materials and nanomaterials. The bulk materials have internal structure or surface structure greater than 100 nm. The examples of bulk materials are plastering sand, cement, gravel, ore, slag, salts etc. Nanomaterials have properties which are extremely size dependent. The examples of nanomaterials are titanium dioxide, nanozymes, nanoparticles, graphene, etc. [1 - 2].

Materials scientists are interested in the properties of materials so that their behaviour can be expected. The mechanical properties of a material Bending, stretching, compactness, elasticity, etc. are describe how it behaves when a force is applied on the material [3]. Chemical properties define reactions of materials in different environments. The properties of materials depend upon how the materials are synthesized. If the synthesis method is changed, the grain structure of the materials is changed so that, the properties of materials are also changed [4]. Nanomaterials are one of them which have influenced human society the most. Alloys, polymers, ceramics, etc. have made revolutionary changes in the human life.

2. Nanomaterials

Polymers, ceramics, and composites are three different types of nanomaterials based upon their composition, properties, and applications [5].

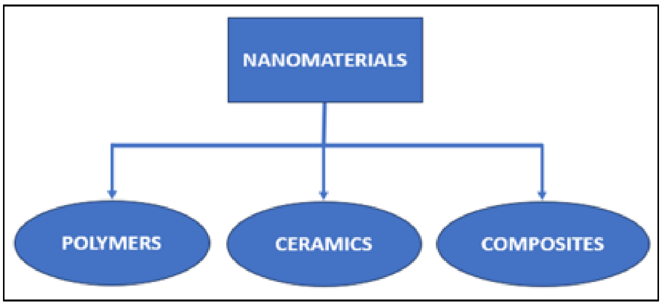

Figure 1: Types of Nanomaterials

2.1 Polymers

Polymers are defined as multiple of simpler chemical units - monomers. Polymers are synthetic or natural substances having very large molecules. For example, cellulose, nucleic acids, and proteins. However, they constitute the basis of such minerals as quartz, feldspar, and diamond and such man - made materials as glass, concrete, plastics, rubber, and paper. Polymers, on the other hand, are large molecules made up of repeating subunits called monomers. The natural polymers are like proteins and DNA, while synthetic polymers are like plastics and rubbers. Polymers have light weight, low melting points, and are good insulators of heat and electricity.

2.2 Ceramics

Generally, ceramic materials are inorganic, non - metallic oxide, nitride, or carbide materials. Ceramic materials have properties of brittleness, hardness, strongness in compression, and weakness in shearing and tension. They are considered highly resistant with chemical erosion and high temperature. Ceramics are having typically crystalline in nature. Examples of ceramics are pottery, bricks, tiles, glass, etc. In jet engines, space vehicles, cutting tools, etc. where the working at high temperature is done, the ceramics are often used.

2.3 Composites

Composites are produced by combining two or more different types of materials. The composites possess unique properties different from the properties of their constituents. The constituent materials retain their separate identities in the composite. Composites are designed in such a way that they are strong and have lightweight. Composites are widely used in the aircraft, cars, and boats. Composites have a wide range of applications by virtue of their specific electrical and thermal properties.

3. Advances in nanomaterials

Due to having unique mechanical, electromagnetic, optical and thermophysical properties, the nanomaterials have wide applications in present scenario of the world. Advances in nanomaterials have made revolutionary changes in the following main fields [6 - 8]: -

1) **Catalysis**: Due to high activity, selectivity and productivity of nanomaterials, the nanotechnology has become an emerging field of modern science. Due to high surface - to - volume ratio, surface geometric effect, the electronic effect, and the quantum size effect the nanocatalysts are highly active. With help of catalytic reagents, we can enhance the selectivity of a reaction that potentially avoids the unwanted side reactions leading to a green technology. With help of catalyst, different products in medicines, fine chemicals, polymers, fibres, fuels, paints, lubricants, and a countless of other value - added products become more feasible. Platinum (Pt), has rich electronic structure and catalytic activities, so that it is frequently used in automobile exhaust gas treatment, solid oxide fuel cell, petroleum refining, organic synthesis, and hydrogen production.
2) **Sensors**: The nanomaterials are widely used to design the electrochemical sensing devices for medical diagnostics, environment, and food safety. By virtue of the optical properties, the silver nanoparticles are being used as the functional component in various products and sensors. Nanomaterials greatly influenced the area of biosensors, by virtue of their high sensitivity, selectivity, and the miniaturization of sensor devices. The fluorescent nanomaterials are being used for developing new biosensors for glucose sensing. Carbon nanotubes are being used in gas sensors, small molecular sensors, electrochemical detectors, and chromatographic applications.
3) **Environmental remediation**: Heavy metals, organic pollutants, inorganic anions, and bacteria are environmental pollutants which should be removed in the welfare of human beings. Presently the photocatalytic degradation by metal oxide nanoparticles such as TiO_2 is successfully applied in the contaminant degradation of environment. Photocatalytic activities of TiO_2 NCs have developed great interest of the researchers in the field of environmental remediation. The main characteristics of TiO_2 NCs are high specific - surface area, proper electronic band structure, high quantum efficiency, chemical innerness, and stability. Using hydrolysis technique, the TiO_2 NCs are used to remove cyanide from the waste water. TiO_2 activated carbon composites are applied in degradation of β - naphthol from the wastewater and its photo catalytic behaviour of TiO_2 is studied. Although a lot of research work on TiO_2 NCs has been done, still more work needs to be done.
4) **Renewable energy**: The proton - conducting solid oxide fuel cells (SOFCs) have been considered as a potential substitute for clean energy generation. The efficacy of fuel cells mostly relies on its fundamental components, such as the electrolyte and electrodes. The durability and densification of electrolytes significantly influence the efficiency of fuel cells. Consequently, the synthesis of an extremely stable dense electrolyte is a crucial phase in the manufacturing of fuel cells. Trivalent acceptor - doped barium cerate ($BaCeO_3$) is a commonly utilized electrolyte material in proton - conducting solid oxide fuel cells (PC - SOFCs). However, $BaCeO_3$ is not a chemically and thermally stable material which limits its practical applications. In addition, trivalent acceptor - doped barium zirconate ($BaZrO_3$) ceramic has been proposed as an alternative electrolyte material for fuel cell applications for several years, owing to its exceptional chemical stability, low thermal expansion coefficient, and favourable ionic conductivity. Furthermore, the development of a low - cost, very dense electrolyte with accepter - doped $BaZrO_3$ is a significant difficulty due to the higher sintering temperature of this refractory material. There remains a potential to decrease the sintering temperature and duration for the effective production of proton - conducting solid oxide fuel cells (SOFCs).
5) **Medical science**: By virtue of broad - acting and potent antibacterial activity of silver nanoparticles, their applications are emerged in disinfecting the medical devices and in nanomedicine. Biocompatible gold nanoparticles are introduced in nanomedicine because of their size dependent chemical, electronic and optical properties. Targeted drug delivery with help of Quantum dots, Fe_3O_4 and ZnO nanomaterials specially in cancer treatment is very efficient therapy which targets only the affected cells or part so that the side effects become minimized. Gold nanoparticles are widely used as contrast agents in cellular or molecular imaging. Biosensors are effectively used to detect the blood glucose level, bacteria, viruses, pollutants, and pathogens.
6) **Industry**: nanomaterials play a crucial role in various industries, including aerospace, automotive, electronics, healthcare, energy, construction, and manufacturing. By developing materials tailored to specific applications, material scientists contribute to the advancement and competitiveness of these industries.
7) **Innovation**: Nanomaterials drive technological innovation by developing new materials with enhanced properties and performance characteristics. These innovations enable the creation of new technologies, products, and solutions that improve our quality of life and address global challenges.

4. Societal Impacts

Nanomaterials contribute to energy efficiency by developing materials that enable the development of energy - efficient technologies and solutions. For example, advanced materials used in insulation, lightweighting, and renewable energy

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systems help reduce energy consumption and combat climate change. Nanomaterials contribute to the development of safe, durable, and sustainable infrastructure by developing materials and construction techniques that withstand environmental conditions and mechanical stresses. These materials help build resilient and reliable infrastructure systems. The unique optical, magnetic, and chemical properties of nanomaterials make revolutionary development in the physical world. In the light of society's wariness of unintended events and accidents that could occur when emerging technologies are adopted, researches on understanding these factors are also going on. Nanomaterials are important and affect the society directly and indirectly in the following fields mainly [9 - 10]: -

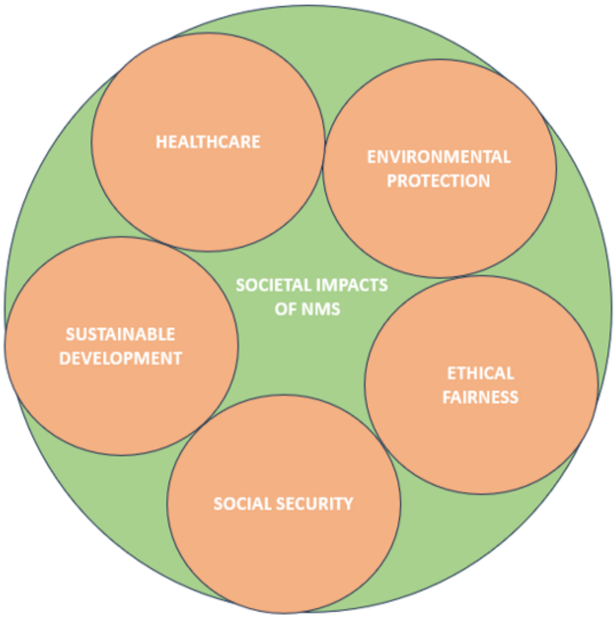

Figure 2: Societal impacts of nanomaterials

1) **Environmental Protection:** Some nanomaterials are eco - friendly photo semiconductors and their photocatalytic activity is playing important role in the field of environmental remediation. Nanomaterials like TiO_2 and its nanocomposite exhibits exclusive photo catalytic properties. They degrade hazardous contaminants of air and water both and protect our environment. Wastewater treatment for environmental preservation - based TiO_2 photocatalyst has been proven to degrade many organic pollutants effectively. TiO_2 has been widely used as photocatalytic due to its chemical stability and availability in the commercial.
2) **Ethical Fairness:** By the advancement of nanomaterials, memory storage and processing devices in computers, sensors, etc. are becoming advance continuously. They can collect the data extensively, and monitoring and updating it regularly. This leads to enhance the ethical fairness in the society, that is, to enhance the equity and transparency among people.
3) **Social security:** Social security is the protection of a person or group from discrimination, insecurity, instability, and injustice. Nanomaterials are providing the new materials with better characteristics for enhancing the storage and processing capacity of artificial intelligence, so that, there is a considerable improvement in the social level of a common man.
4) **Sustainable development:** Nanomaterials contribute to enhance the sustainability by developing materials and processes that minimize resource consumption, waste generation, and environmental impact. Sustainable materials help mitigate environmental degradation and support the transition to a more sustainable economy.
5) **Healthcare:** Nanomaterials play a critical role in healthcare and biomedical applications by developing biocompatible materials for medical devices, implants, drug delivery systems, and tissue engineering. These materials improve patient outcomes, enhance medical treatment, and support advances in healthcare technology.

Nanomaterials are being used in our daily lives for fulfilling the requirements and demands of society. Nanomaterials have a more positive impact on society than the negative. It makes our life easier and reward us by providing resources or tool that make our life much easier. Nanomaterials have affected the field of aerospace vehicles, mobiles, computers, and artificial intelligence the most. Nanomaterials have some negative impacts on the society in field of unemployment, environmental pollution, mental stress, cybercrimes etc. Our society is being shaped by nanomaterials, which has overall beneficial consequences.

5. Conclusion

Nanomaterials are materials having internal and surface structure in the order of nanometers. The structural properties and characteristics of nanomaterials are size dependent. Nanomaterials have unique mechanical, electromagnetic, optical and thermophysical properties. Nanomaterials are natural, engineered or incidental depending upon way of fabrication. Nanomaterials are synthesized with help of mechanical and chemical methods. Nanomaterials are important for driving technological innovation, advancing industry, promoting sustainability and environmental protection, enhancing energy efficiency, improving healthcare, supporting infrastructure development, and addressing global challenges. By understanding and manipulating the properties of nanomaterials, scientists contribute to the development of solutions that benefit people as well as society.

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