Module-5

Nanotechnology — Nanotechnology is a brach of material science in which nanoparticles with specific intended properties are synthesized or produced by the application of physical or chemical processes. The standard definition of a nanoparticle is a particle whose average dimensions are <100 nm. These materials have a wide range of application in the fields of health care, agriculture, electronics, automobiles, and environmented due to their unique physical, chemical, thermal, and electrical properties.

Nanomaterials: Nanomaterials may be classified as those materials which have at least one of their dimensions in the nanometric range, below which there is significant variation in the property of interest compared to microcrystalline materials.

Nanomaterials can be metals, ceramics, polymers or composites. ~~Nanotechnology is an~~ The term 'nano-technology' was first coined by Norio Taniguchi in 1974 to describe semiconductor processes such as thin film deposition and ion beam milling, where the features can be controlled at the nanometric level.

Materials in the nanometre-scale exhibit uniquely different physical, chemical and mechanical properties compared to bulk materials. For example, Gold, under ordinary conditions is a yellow, inert metal, capable of conducing electricity. If a centimetre-long gold foil is taken and broken into a dozen equal pieces, the pieces will still appear golden yellow. However, when the pieces are broken down about a million times, into bits just a few nanometres wide, almost every characteristic changes. Nano-gold no longer glitters with a golden yellow metallic lustre. Reflected light of gold nanoparticles varies in colour, depending upon their dimensions. Particle that are about 50 nm in diameter appear blue or purple, at 25 nm they are red, and at 1 nm they are orange.

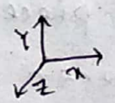
Classification of nanomaterial based on the number of dimensions: –

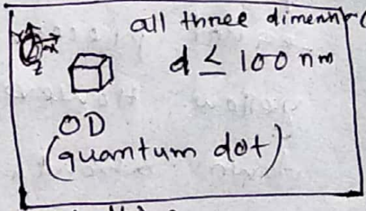
* Classification is based on the number of dimensions, which are not confined to the nanoscale range (< 100 nm).

1. Zero-dimensional (0-D),
2. one-dimensional (1-D),
3. two-dimensional (2-D),
4. three-dimensional (3-D)

0-D :- All dimensions (x, y, z) at nanoscale

~~A condi~~ In zero-dimensional (0D) nanomaterials all the dimensions are measured within the nanoscale (no dimensions are larger than 100 nm). Most commonly, 0D nanomaterials are nanoparticles.





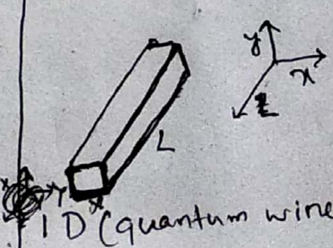
Nanoparticles can:

(i) Be amorphous or crystalline
(ii) Be single crystalline or polycrystalline
(iii) Be composed of single or multi-chemical elements.
(iv) Exhibit various shapes and forms
(v) Exist individually or incorporated in a matrix
(vi) Be metallic, ceramic, or polymeric.

one-dimensional (1-D) nanomaterials

Two dimensions (x, y) at nanoscale, other dimension (L) is not

d ≤ 100 nm



1D (quantum wire).

Example: - Nanowires, nanorods, and nanotubes.

(*) One dimension that is outside the nanoscale.

(*) This leads to needle like-shaped nanomaterials.

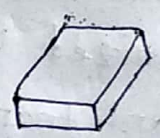
(*) 1-D materials include nanotubes, nanorods, and nanowires.

(*) 1-D nanomaterials can be
(i) Amorphous or crystalline
(ii) Single crystalline or polycrystalline
(iii) Chemically pure or impure
(iv) standalone materials or embedded in within another medium.
(v) Metallic, ceramic, or polymeric.

Two-dimensional nanomaterials (2-D) :-

(*) One dimension (say t) at nano-scale, other two dimensions (L_X, L_Y) are not.

$t \leq 100$ nm



2D (quantum well).

(*) Two of the dimensions are not confined to the nanoscale.

(*) 2-D nanomaterials exhibic plate-like shapes.

(*) Two-dimensional nanomaterials include nanofilms, nanolayers, and nanocoatings.

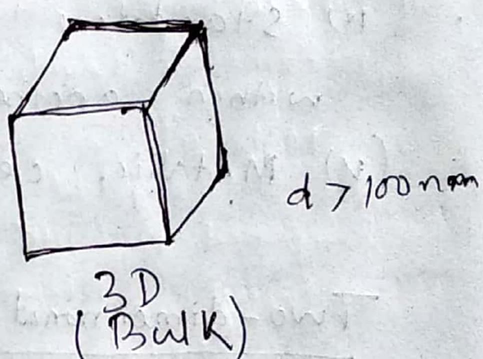
(*) 2-D nanomaterials can be:
(i) Amorphous or crystalline
(ii) Made up of various chemical compositions.

* used as a single layer or multilayer structures
* Deposited on a substrate.
* Integrated in a surrounding matrix material.
* Metallic, ceramic, or polymeric.

~~Three~~

Three-dimensional (3-D) nanomaterials:-

* Bulk nanomaterials are materials that are not confined to the nanoscale in any dimensions.



* These materials are thus characterized by having three arbitrarily dimensions above 100 nm.
* Materials posses a nanocrystalline structure or involve the presence of features at the nanoscale.
* In terms of nanocrystalline structure, bulk nanomaterials can be composed of a multiple arrangement of nanosize crystals, most typically in different orientations.
* with respect to the presence of features at the nanoscale, 3-D nanomaterials can contain dispersions of nanoparticles, bundles of nanowires, and nanotubes as well as multinanolayers.

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Top-down and Bottom-up approaches of nanomaterials synthesis:-

Two approaches
1. Bottom-up approache
2. Top-down approach

Bottom-up Approach

* In the bottom-up approach, molecular components arrange themselves into more complex assemblies atom-by-atom, molecule-by-molecule, cluster-by-cluster from the bottom (e.g., growth of a crystal).

* Molecular components arrange themselves into some useful conformation using the concept of molecular self-assembly.
* For example, synthesis of nanoparticles by colloid dispersion.

Top-Down Approach

* In this approach nanoscale devices ~~can~~ are created by using larger externally-controlled devices to ~~the~~ direct their assembly.

* The top-down approach often uses the traditional workshop or microfabrication methods in which externally-controlled tools are used to cut, mill and shape materials into the desired shape and order.
* Attrition and milling for making nanoparticles are ~~typically~~ typical top-down processes.

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Introductory idea on synthesis of nanomaterials via green synthetic route.

There are several methods available to synthesize nanomaterials. For example, inorganic nanomaterials such as metal oxides and nano-clays are synthesized by wet chemistry, sol-gel, chemical microemulsion, hydrothermal, solvothermal, microwaveassisted combustion, sono-chemical, and direct precipitation. On the other hand, nanocellulose are prepared by acid hydrolysis, biological (enzyme treatment), mechanical, and chemo-mechanical treatments. In the case of carbonaceous nanomaterials, arc discharge (AD), laser ablation, and chemical vapour deposition (CVD) techniques are widely used methods. But for graphene nanosheets chemical, mechanical, and ~~tem~~ thermal exfoliation techniques are used.

Moreover, the current research is focusing on the synthesis of nanomaterials by using green methods. Green methods involve the use of natural resources as a starting material and/or plant extracts in the case of metal oxides nanoparticles production as reducing agent.
For example, Mokhena and Luyt prepared silver nanoparticles form chitosan, a stabilizing and reducing agent. and

used them to impregnate electrospun nanofibers. The synthesized silver nano-particles showed antibacterial activity against both Gram-negative and Gram-positive bacteria. Furthermore, silver nanoparticles were believed to be nontoxic, biosafe, and biocompatible with acceptable water vapor permeability within a range of required levels for treatment of injuries and wounds.

Green Synthesis

Green synthesis is an emerging area in the field of bionanotechnology and provides economic and environmental benefits as an alternative to chemical and physical methods. In this method, nontoxic safe reagents which are eco-friendly and biosafe are used. Various natural resources available in nature such as plant extracts, cyclodextrin, chitosan, and many more have been studied for the synthesis of metal oxide nanoparticles. The use of plant extracts in the green synthesis of metal oxide nanoparticles has drawn a considerable attention as a straight forward approach.

Application of nanomaterials in electronic devices :-

Need of Nanotechnology in Electronics

* Today microelectronics are used and they solve our most of the problems.
* The two exceptional disadvantages of micro electronics are:-
  (i) Physical size
  (ii) Increasing cost of fabrication of integrated circuits.
* To overcome these disadvantages nanotechnology can be used.

Nanotechnology in Electronics

* Nanoelectronics refers to the use of nanotechnology on electronic components, especially transistors.
* Nanoelectronics often refer to transistor devices that are so small that inter-atomic interactions and quantum mechanical properties need to be studied extensively.
* Besides being small and allowing more transistors to be packed into a single chip, the uniform and symmetrical structure of nanotubes allows a higher electron mobility, a higher dielectric constant (faster frequency), and a symmetrical electron/hole characteristic.

Advantages of using Nanotechnology in Electronics :-

- (*) Increasing the density of memory chips
- (*) Decreasing the weight and thickness of the screens.
- (*) Nanolithography is used for fabrication of chips.
- (*) Reducing the size of transistors used in integrated circuits.
- (*) Improving display screens on electronics devices.
- (*) Reducing power consumption.

The first transistors built in 1947 were over 1 centimeter in size; the smallest working transistor today is 7 nanometers long - over 1.4 million times smaller (1cm equals 10 million nanometers). The results of these efforts are billion-transistor processors where, once industry embraces 7 nm manufacturing techniques, 20 billion transistor-based circuits are integrated into a single chip.

- (*) Besides transistors, nanoelectronic devices play a role in data storage (memory).

Electronics and IT Applications:-

Nanotechnology has greatly contributed major advances in computing and electronics, leading to faster, smaller, and more portable systems that can manage and store larger and larger amounts of information. These continuously evolving applications include:

- Transistors, the basic switches than enable all modern computing, have gotten smaller and smaller through nanotechnology. At the turn of the century, a typical transistor was 130 to 250 nanometers in size.

  In 2014, intel created a 14 nanometer transistor, then IBM created the first ~~seven~~ 7 nanometer transistor in 2015, and then Lawrence Berkeley National Lab demonstrated a 1 nm transistor in 2016. Smaller, faster, and better transistors may mean that soon your computer's entire memory may be stored on a single tiny chip.

Application of nanomaterials in environmental fields:-

Nanotechnology is being used in several applications to improve the environment. This includes cleaning up existing pollution, improving manufacturing methods to reduce the generation of new pollution, and making alternative energy sources more cost effective.

(*) Generating less pollution during the manufacture of materials.

Example:- Silver nanoclusters as catalysts can significantly reduce the polluting byproducts generated in the process used to manufacture propylene oxide. Propylene oxide is used to produce common materials such as plastics, paint, detergents and brake fluid.

(*) Producing solar cells that generate electricity at a competitive cost.

Example- An array of silicon nanowires embedded in a polymer results in low cost but high efficiency solar cells.

(*) Increasing the electricity generated by windmills:-

Example- Epoxy containing carbon nanotubes is being used to make windmill blades.

The resulting blades are stronger and lower weight and therefore the amount of electricity generated by each windmill is greater.

(*) Cleaning up organic chemicals polluting groundwater:-

Example- Iron nanoparticles can be effective in cleaning up organic solvents that are polluting groundwater. The iron nano-particles disperse throughout the body of water and decompose the organic solvent in place. This methode can be more effective and cost significantly less than treatment methods that require the water to be pumped out of the ground.

(*) Cleaning up oil spills.

Using photocatalytic copper tungsten oxide nanoparticles to break down oil into biodegradable compounds. The nanoparticles are in a grid that provides high surface area for the reaction, is activated by sunlight and can work in water, making them useful for cleaning up oil spills.

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(*) Clearing volatile organic compounds (VOCs) from ~~air~~ air.

Example - Porous manganese oxide in which gold nanoparticles have been embedded (act as catalyst) that breaks down volatile organic compounds (VOCs) at room temperature.