Nanoscience and Nanotechnology

- Introduction and types of nano materials(0,1,2 & 3-Dimensional)
- Nanoparticles, Nanofibers, nanowires, carbon nanotubes, Graphene, Mxene, quantum dots and their uses
- Preparation of nanomaterials(Top down Approach and bottom up Approach)
- Ball Milling
- Exfoliation
- Physical Vapor Deposition
- Chemical Vapor Deposition

Prepared by Shobha Sigdel
Advanced college of Engineering & Management

Nanoscience and Nanotechnology

- Nano, Greek word, meaning Dwarf(something very small)
- 1nm is one billionth of meters(10^{-9}m)
- Father of Nanotechnology:- Physicist Richard Feynman (1959)
- Nanoscience is the study about chemistry, physics, biology and materials science in which material's properties are studied in nanoscale range.
- Nanotechnology is an emerging multidisciplinary field that is focused on controlling size and shape and engineering materials in nano level to achieve attractive properties.
- To achieve new and extraordinary properties of materials, to design and develop smart advanced functional materials, obtaining similar properties by engineering material reducing size in nanoscale(bioinspired and biomimetic process) are the main goal of nanotechnology.
- In nanostructure of materials, dimension is reduced which leads to increase in surface energy through increase in surface area.

Nanoscience and Nanotechnology

- Generally, nanomaterials are materials with 1-100 nm in one dimensions and exhibits entirely different from their bulk materials.

- Materials in nanoscale exhibit different properties compared to their bulk size. For examples,

i)Bulk gold(Au) does not show catalytic properties but nanoparticles of Au show excellent catalytic properties.

ii) Semiconductor materials become insulator in nanomaterials.

iii) The melting point is sufficiently decreased as compared to their bulk size.

iv) Ferromagnetic properties of bulk material is lost in nanometer scale size.

Application of Nanotechnology

- Drug delivery
- Fabrication
- Reactivity of materials
- Strength of materials
- Molecular manufacturing
- Micro nano electromechanical system
- Environmental remediation and energy production and storage

Types of nanomaterials

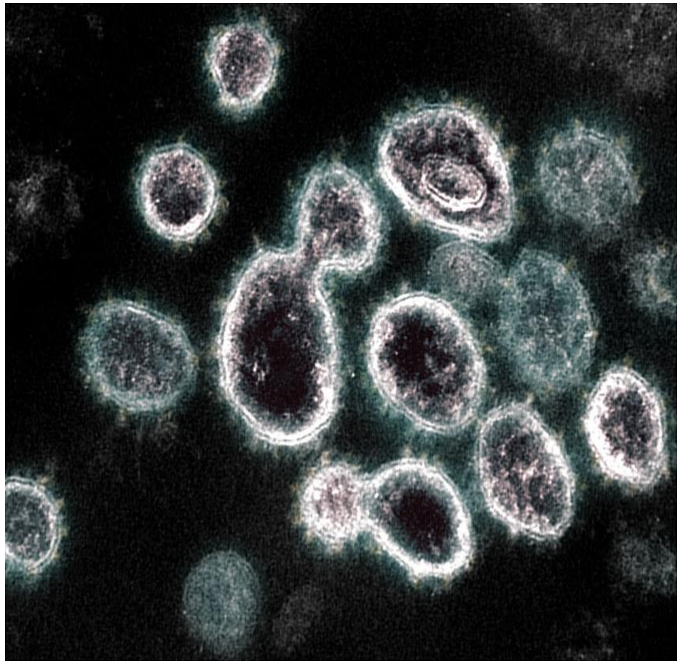
- Nanomaterials can be classified, on the basis of dimension parameter, into following four types.

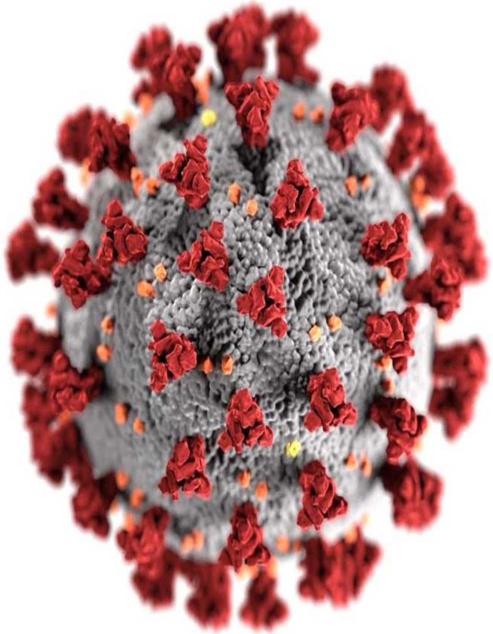
a. Zero dimensional nanomaterial
b. One dimensional nanomaterial
c. Two dimensional nanomaterial
d. Three dimensional nanomaterial

<u>Zero dimensional nanomaterial :-</u>

- ➢ Materials having less than 100nm in all dimensions are called zero dimensional or 0-D nanomaterials.
- ➢ Also called nanoparticles.
- ➢ For example:- SARS-CoV(Revere respiratory Syndrome Corona Virus) andTiO2 present in sunscreen cream

Zero dimensional nanomaterials





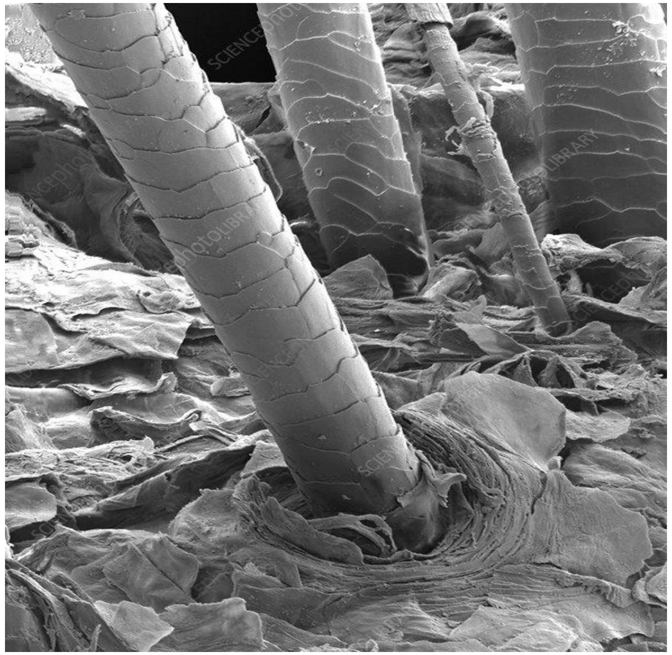


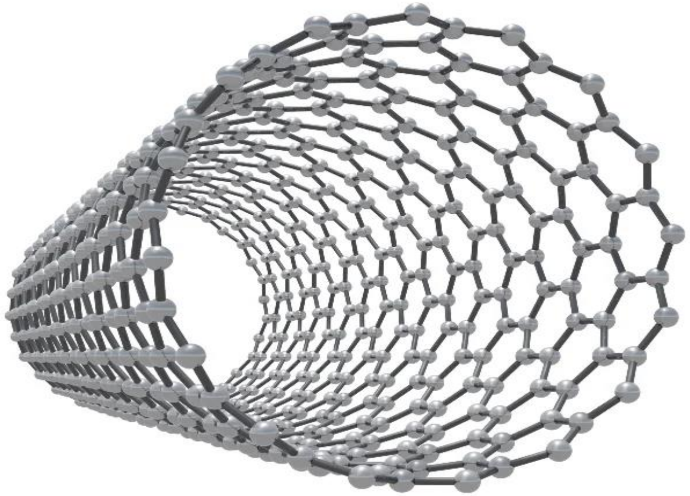
Fig:-Electron microscopy image of SARS-CoV

Fig:- Electron microscopy image of human hair

One - dimensional nanomaterials

- Materials having less than 100nm in any two dimensions and one dimension is out of nanoscale are called one dimensional or 1-D nanomaterials.
- Nanofibers, nanotubes, nanorods and nanowires having one of their dimensions less than 100nm are one dimensional nanomaterials.
- They are characterized by hollow or solid fiber structures.
- Carbon nanotubes and carbon nanofibers are two carbon based 1D nanomaterials.
- For examples:- carbon nanotubes.

One - dimensional nanomaterials



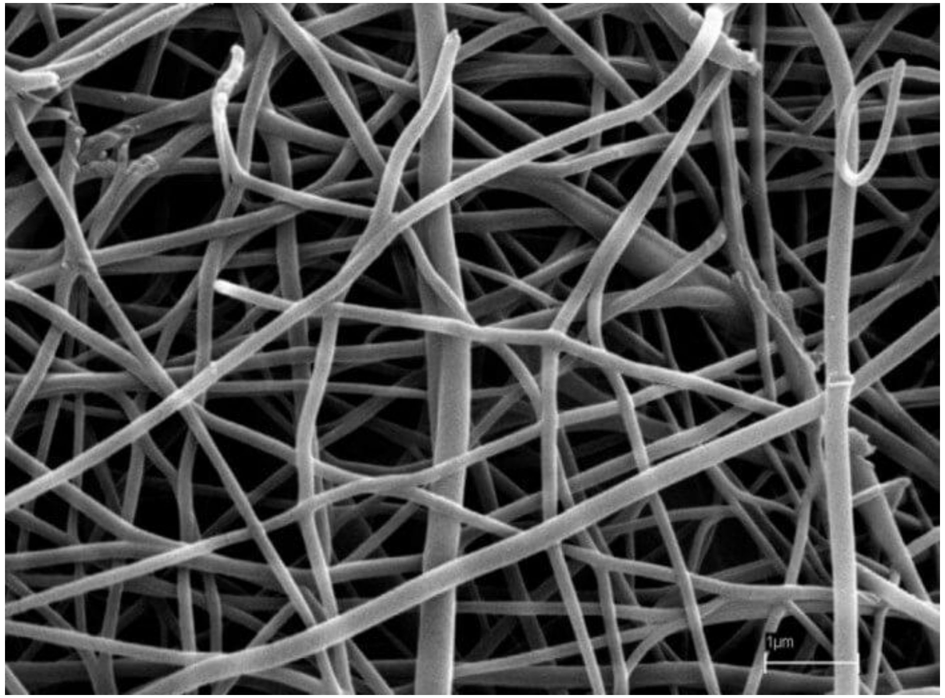


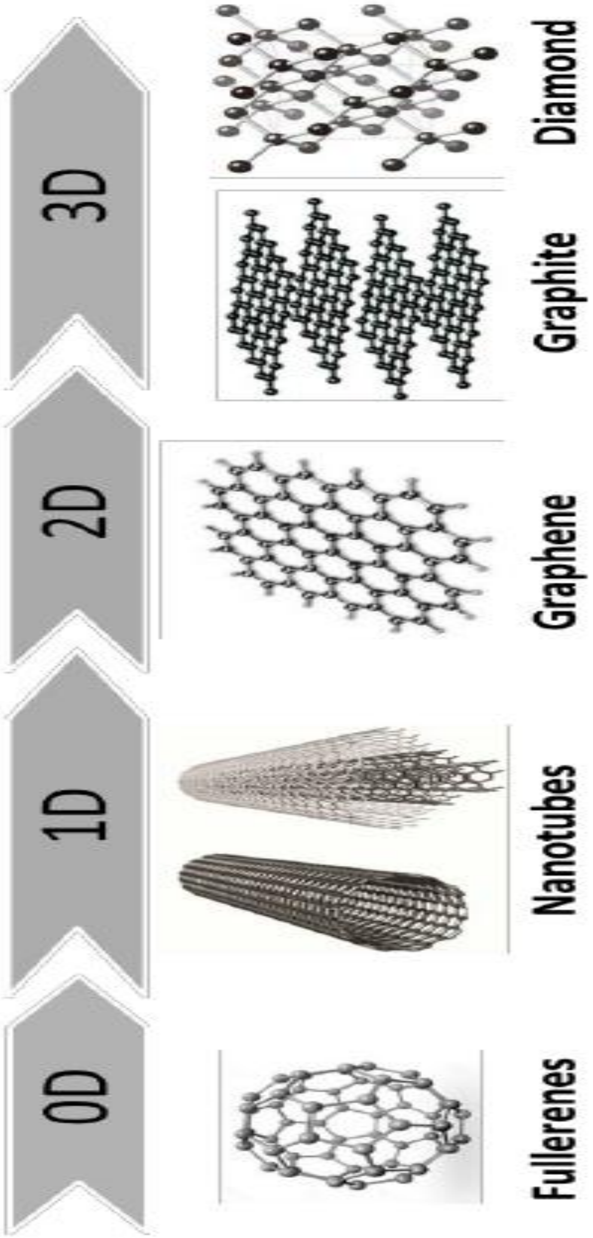
Fig:- Carbon nanotube and carbon nanofibers

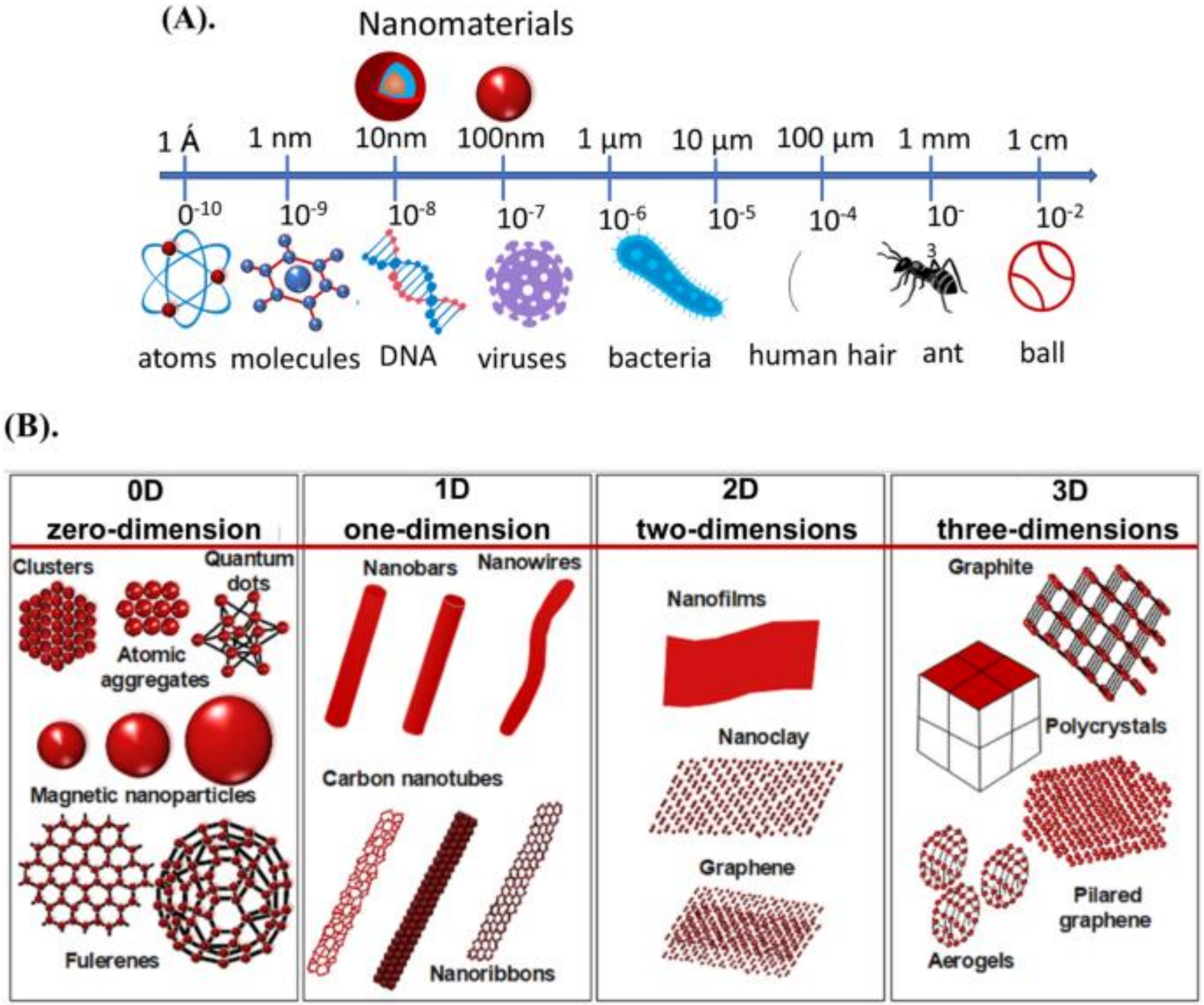
Two dimensional nanomaterials

- Materials having less than 100nm in one of the dimensions and remaining two dimensions are out of nanoscale are called two dimensional nanomaterials or 2-D nanomaterials.
- Characterized by a layered or sheet structures.
- Layered structure of 2D nanomaterials serves as the building block for the construction of nanofluidic channels that can be suitably applied for catalysis, biosensor and electrochemical energy conversion processes.
- For examples:- Graphene,MXene and Hexagonal boron nitride

Three dimensional nanomaterials

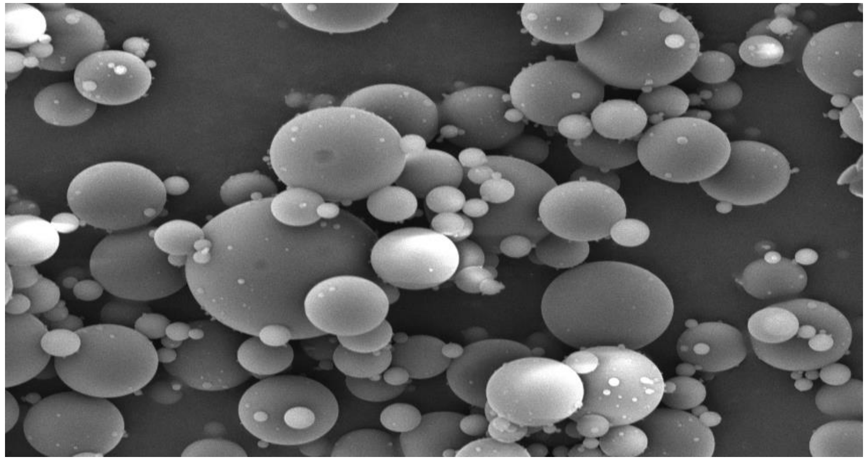
- These are not confined to the nanoscale in any dimension or dimension range.
- Also called bulk materials.
- These are not characterized by a well defined geometry.
- They are derived from nanoparticles(0D), nanowires(1D) or nanosheet(2D).
- For example:- Aerogel, foams,Fibres and Metal organic framework(MOFs)
- Metal organic framework are crystalline structure in which metal ion or cluster is coordinated to organic ligands forming porous and well defined frameworks.


3D
2D
1D
0D
Diamond
Graphite
Graphene
Nanotubes
Fullerenes


(A).
Nanomaterials
1 Á
1 nm
10nm
100nm
1 µm
10 µm
100 µm
1 mm
1 cm
0-10
10-9
10-8
10-7
10-6
10-5
10-4
10-
3
10-2
atoms
molecules
DNA
viruses
bacteria
human hair
ant
ball
(B).
0D
zero-dimension
1D
one-dimension
2D
two-dimensions
3D
three-dimensions
Clusters
Quantum dots
Atomic aggregates
Magnetic nanoparticles
Fulerenes
Nanobars
Nanowires
Carbon nanotubes
Nanoribbons
Nanofilms
Nanoclay
Graphene
Graphite
Polycrystals
Pilared graphene
Aerogels

Nanoparticles

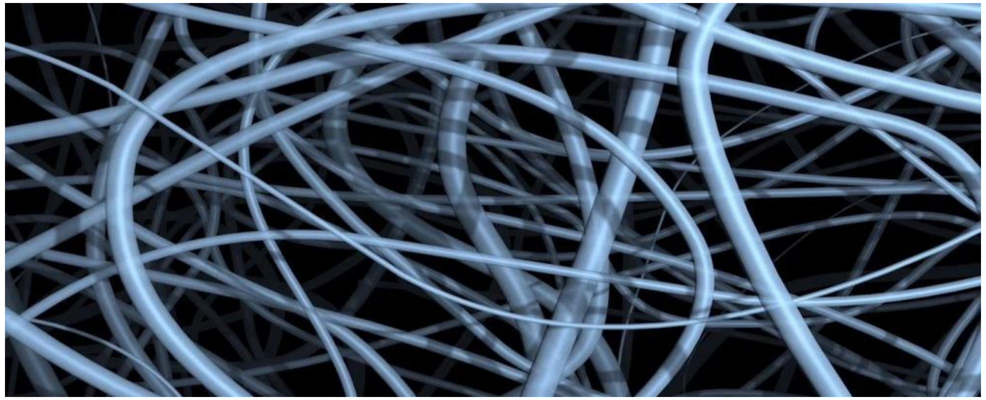
- They are 0D nanomaterials
- Key component of different type of nanomaterials.
- Due to spherical shape and high surface area to volume ratio, these particles have a wide range of application in the field of healthcare technology, environmental remediation and energy production and storage.
- Nanoparticles possess high surface to volume ratios which makes them highly reactive with distinct characteristics.

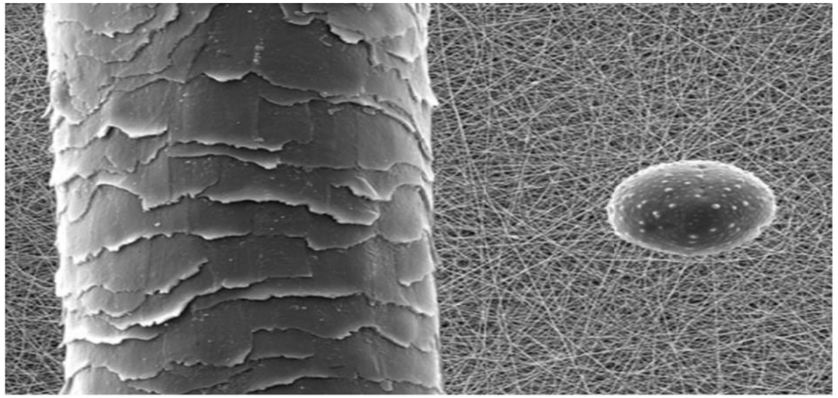


- It is single particle or species whose diameter ranges from 1 to few tens of nanomaterials.

Nanofibers

- One dimensional nanomaterials.
- Nanofibers are fabricated from polymeric materials using different methods such as template synthesis, drawing, self assembly, phase separation and electrospinning.

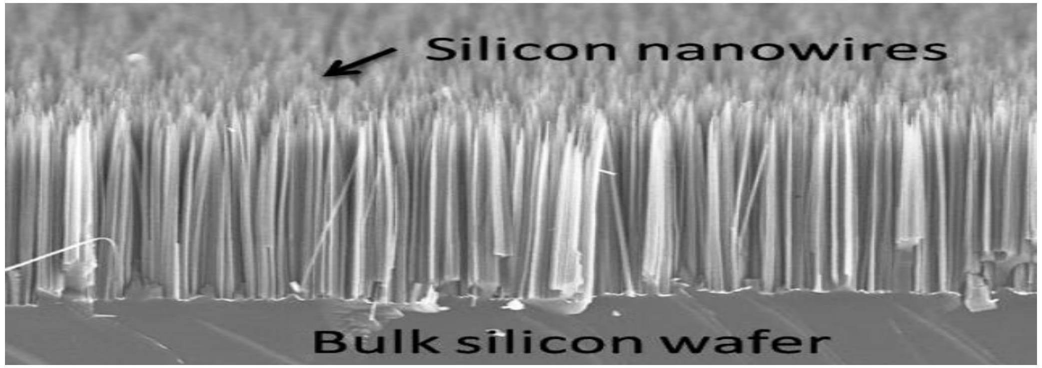


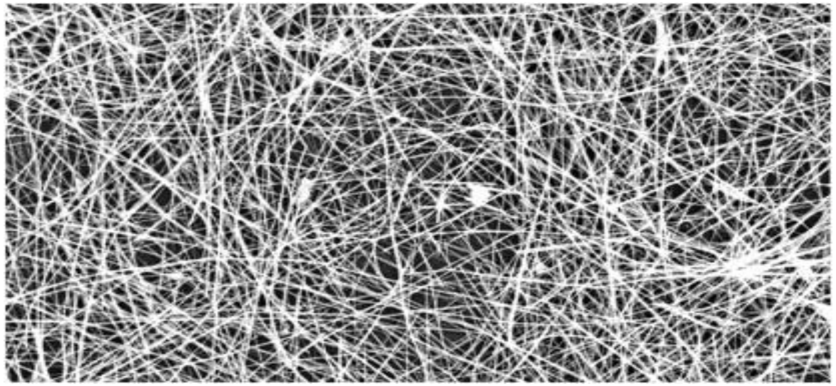


- As different polymer is used to make nanofibers, there are several applications of polymeric nanofibers in the field of tissue engineering, air and liquid filtration, sensor devices, drug delivery, wound dressing, electrical conductors, protecting clothing's etc.

Nanowires

- Nanowires are also one dimensional nanostructures.
- Nanowires and nanofibers are almost similar.
- Nanowires are usually used in ceramics and metals whereas nanofibers are used in the broad sense like polymer, carbon, ceramics and metals.

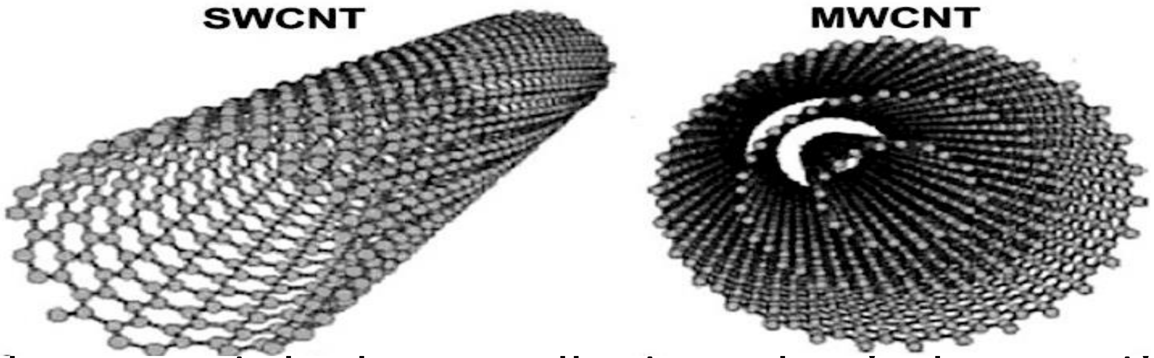




- Generally nanowires are made by cobalt, copper, silver, silicon and gold.
- As high surface area, excellent mechanical flexibility, easy pathway of electron transfer and extent life cycle, they are used in energy storage and conservation, solar steam generation, adsorbent, photocatalysis, thermal insulators and pressure senser.

Carbon nanotubes

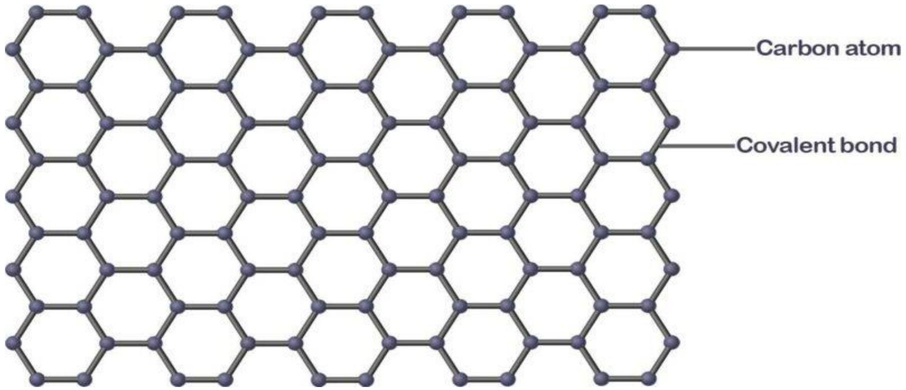
- Carbon nanotubes(CNTs) are cylindrical molecules that consist of rolled-up sheets of single layer carbon atoms.
- They can be single walled(SWCNTs) and multiwalled(MWCNTs).
- Carbon nanotube is one of the allotropic form of carbon.
- SWCNTs is composed of single atomic layer of carbon atoms whereas MWCNTs consist of two or more concentric layer of carbon atom.

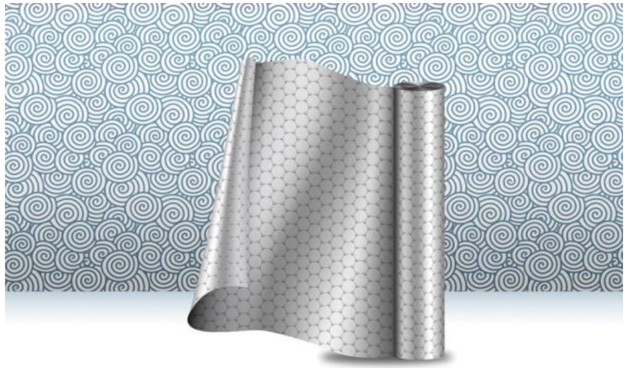


- Carbon nanotube has excellent mechanical properties due to SP^2hybridized carbon bonds.
- They are used in light weight parts which need high mechanical strength.
- Due to their good electrical, thermal and mechanical properties, they are used in nano-transistor, nanoantenna, hard tissue surgery, composite materials and energy storage etc.

Graphene

- A graphene is monoatomic layer of carbon atoms in which SP2 hybridized carbon atoms are bonded together by covalent bonds forming hexagonal honeycombs like 2D sheet.
- Graphene is a materials that is extracted from graphite and it is made up of pure carbon atom.
- It is tough, flexible, light weight and with a high resistance.





- It is 200 times more resistant than steel and 5 times lighter than aluminum.
- Due to the outstanding features of graphene it has several applications in the following fields like sensor application, medical application, energy application and structural application

MXenes

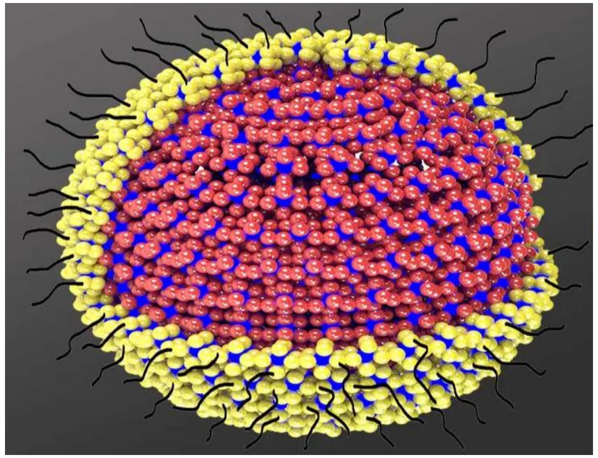
- Mxenes are a class of two dimensional inorganic compounds, that consist of atomically thin layers of transition metal carbides, nitrides or carbonitrides.
- Mxenes are often represented by a general formula $M_{n+1}X_n$ where M means transition metals, X means carbon or nitrogen atoms and n has 1 to 4 value.

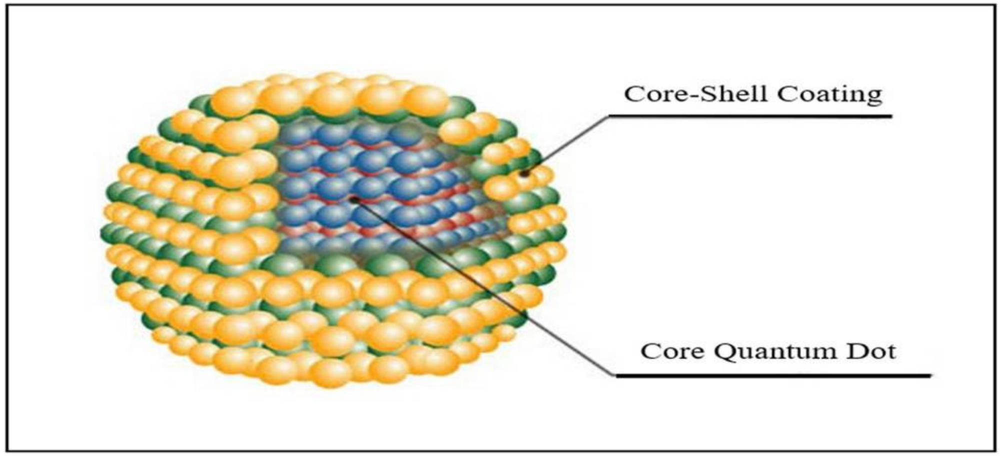
Fig:-Ti3C2 Mxene material

- Mxene can be produced by selective etching of strongly bonded layered present in carbide and nitrogen solids.
- Mxene can shown many interesting properties like electronic, optical, mechanical, electrochemical.
- Due to these unique features, Mxene can be used in sensors, Biomedicines, photo and chemical therapy, CT and MR imaging, Drug delivery, catalysis , electrochemical capacitors etc.

Quantum dots

- Quantum dots are semiconductor materials with a diameter of 1-10 nm and having fluorescent properties.
- Quantum dots(QR) are nanostructures containing few conduction band electrons and valence band holes or both bound into excitation.
- Quantum dots are able to absorb 10-50 times more photons then organic dyes at the same excitation condition. Therefore QDs significantly improve brightness.



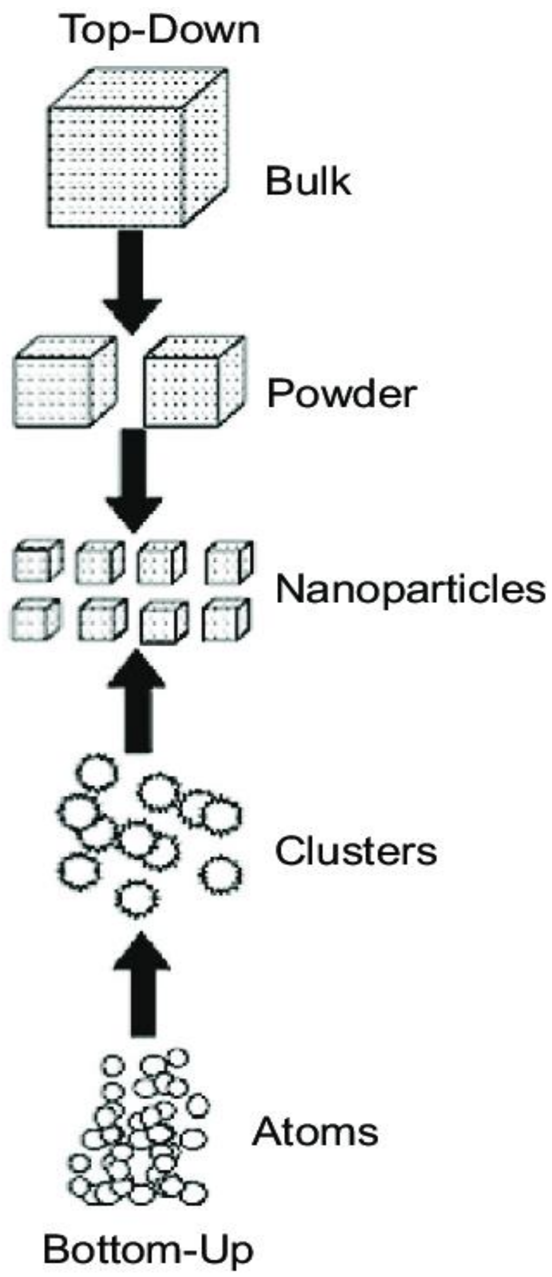


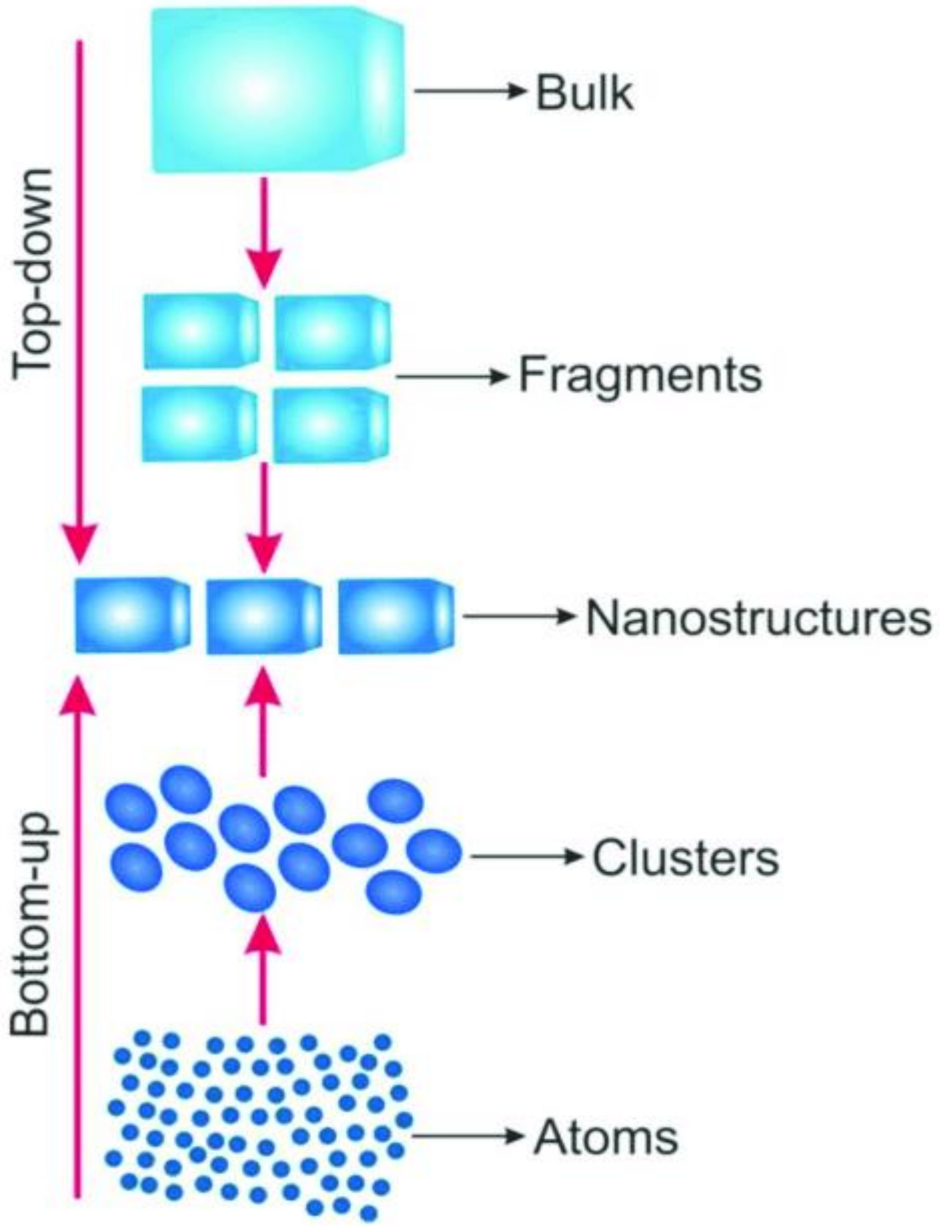
- QDs are 1000 times more stable than organic dyes against photobleaching.
- QDs are used in lasers, photodetectors LEDs, photovoltaic devices, biosensor and bioimaging etc.

Preparation of Nanomaterials

- Nanomaterials can be prepared or synthesized by using following two approaches.

Top-down approach	**Bottom –up approach**
1. Mechanical milling(Ball Milling) 2. Mechanical exfoliation 3. Nanolithography 4. Chemical etching	1. Physical Vapor Deposition 2. Chemical Vapor Deposition 3. Atomic Vapor Deposition 4. Self Assembly 5. Sol-gel process 6. Wet chemical methods

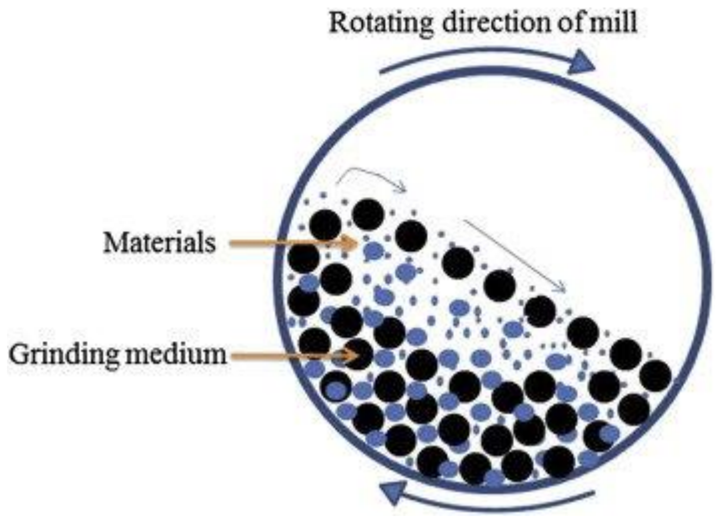

Top-Down
Bulk
Powder
Nanoparticles
Clusters
Atoms
Bottom-Up

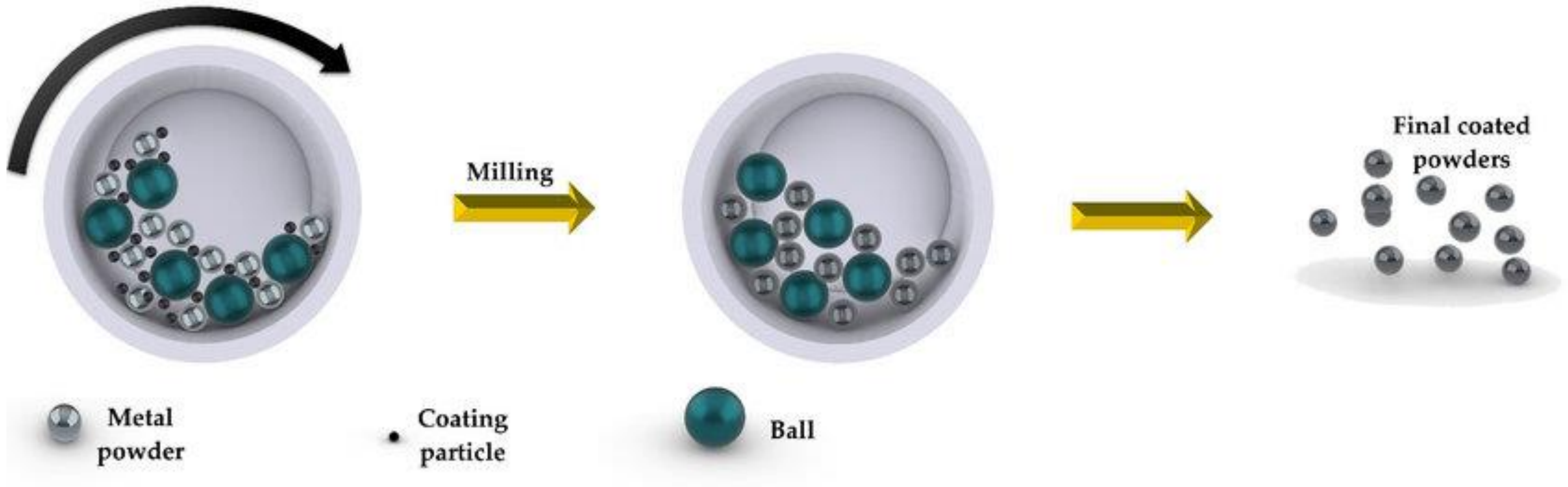

Top-down
Bottom-up
Bulk
Fragments
Nanostructures
Clusters
Atoms

Ball Milling

- Ball milling is a grinding method that grinds bulk material into extremely fine powders.
- It is a top-down approach of nanoparticle synthesis which includes mechanical breakdown of large substances into smaller one.
- Ball milling process is old method. It has been used in many applications before the commercialization of Nanotechnology.
- This ball milling process consist of ball of steel, silicon carbide or tungsten carbide in mill(drum) chamber or container.
- As container is rotated continuously the ball kept inside the container is also rotated.
- The materials(bulk in size) from which nanoparticle is to be formed is kept inside the stainless steel container.
- As the mill is rotated, the bulk material will be crushed into smaller and smaller size.
- In this process, ball provides large amount of energy to grind the materials into nano size.

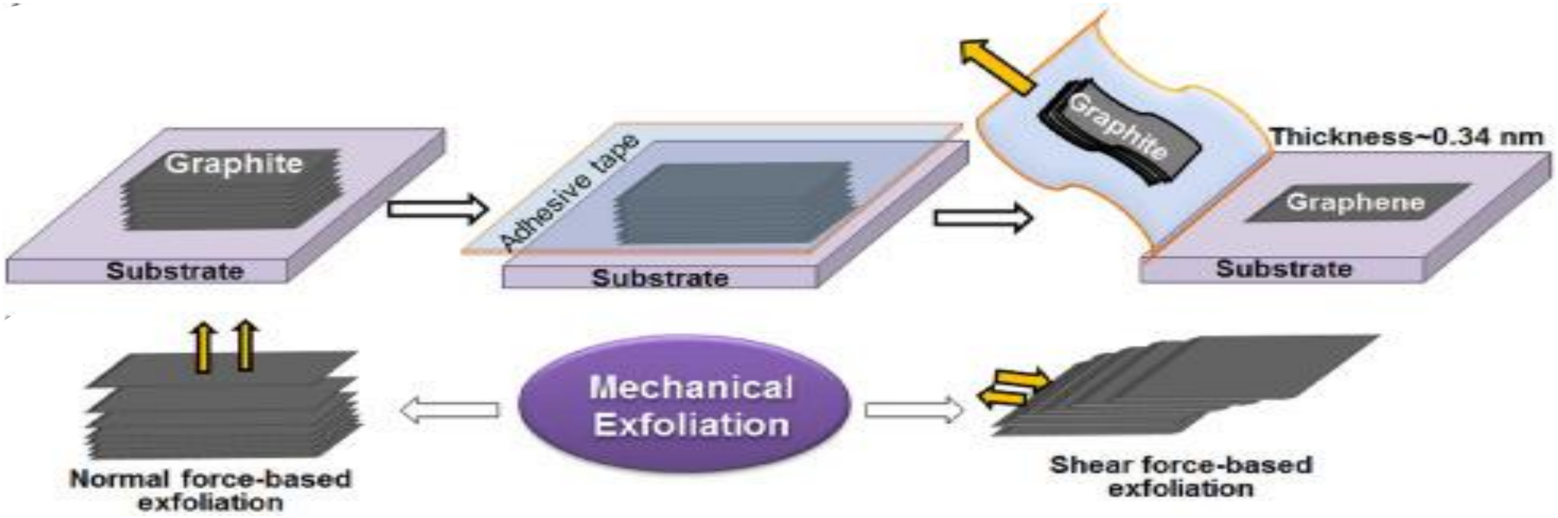
Ball milling





Mechanical Exfoliation

- Mechanical exfoliation is the most commonly used top-down approach for easy production of high quality 2D nanomaterials such as graphene.
- This process typically involves breaking of week bonds of multilayer graphene(graphite) to single layered graphene(2 dimensional material).



- The extraction of graphene sheets from graphite using an adhesive tape is the mechanical exfoliation.
- This process basically depends on the direction of force applied and categorize as:- Normal force based and shear force based exfoliation.

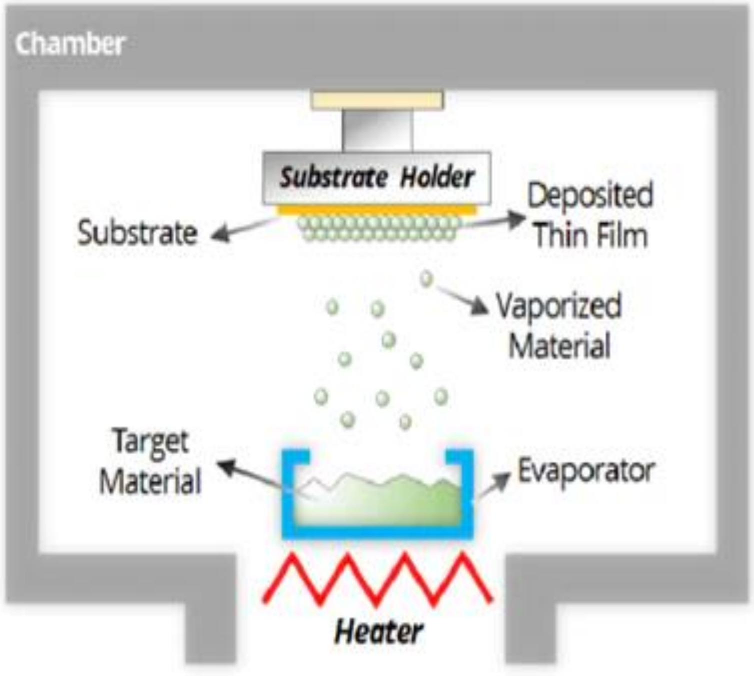
Physical vapor deposition(PVD)

- Physical vapor deposition follows the bottom up approach.
- Generally it is used for the preparation of thin film nanomaterials by controlling the processing condition at nanometer scale.
- The first step in PVD take place by the generation of Vapor.
- The vapor can be produced by evaporation & sputtering method.
- In this process, targeted material is heated and atoms or molecules are evaporated under inert atmosphere.
- The vapor obtain in this way is condensed into nanoparticles by cooling under low temperature.
- From this method, nanowires, nanorods etc. can be prepared.

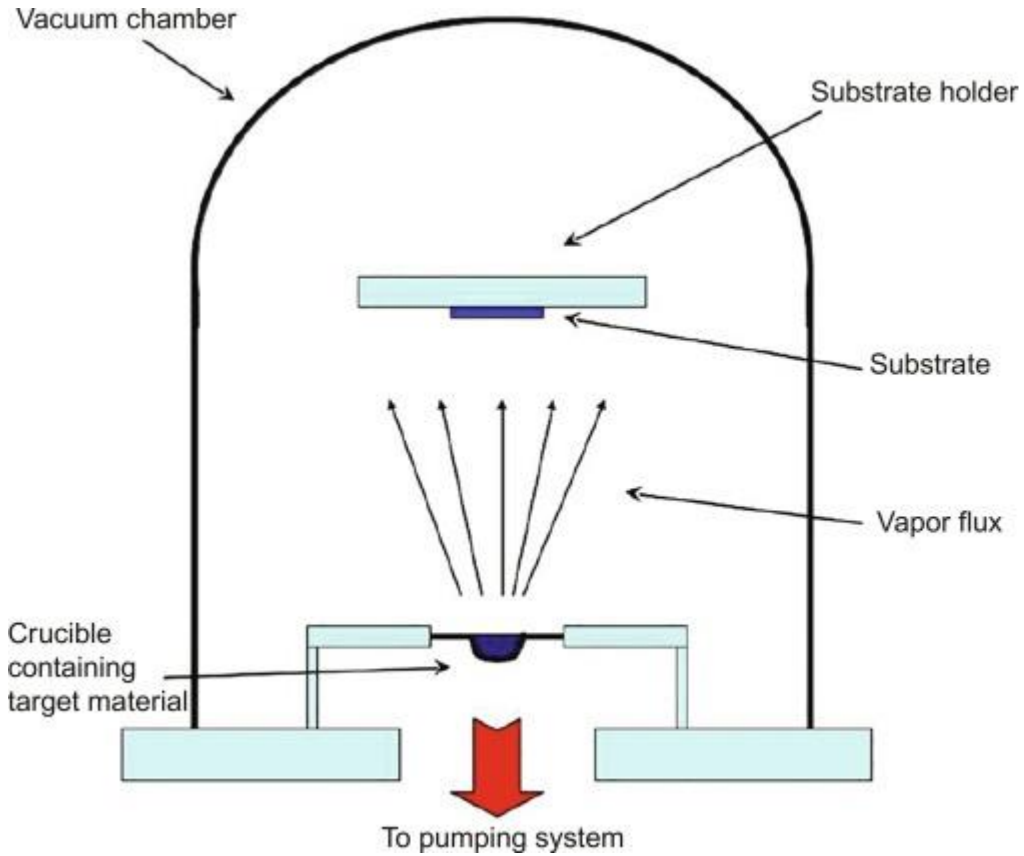
Limitation of PVD:-

- ➢It requires ultra high vacuum.
- ➢It has limitation on multicomponent system because of different melting and boiling point.

Experimental setup of PVD



Scheme of thermal evaporation deposition



Chemical vapor deposition

- It is another method of bottom up approach of nanoparticle synthesis in which solid material is deposited from a vapor by a chemical reaction occurring on or in the vicinity of a normally heated substrate surface.
- The process is often used in the semiconductor industry to produce thin films.
- CVD is a vapour deposition method used to produce high quality, high purity and high performance nanomaterials of producing thin film of nanomaterials graphene, nanofibers.
- This is very useful technique for the synthesis of inorganic thin films of 2D materials as well as high purity polymeric thin film which can be deposited on various substrate.
- In this process, the substrate is exposed to one or more volatile precursors which react and decompose on the substrate surface to produce the desired deposit.
- There are following steps in the chemical vapor deposition.

1. Transport of reacting gas molecules towards the heated surface(reactor)
2. Adsorption of the gases molecules onto the heated surface.
3. Heterogenous surface catalyzed reaction

4. Deposition of the gases molecules.
5. Transportation of the reaction products away from the surface.

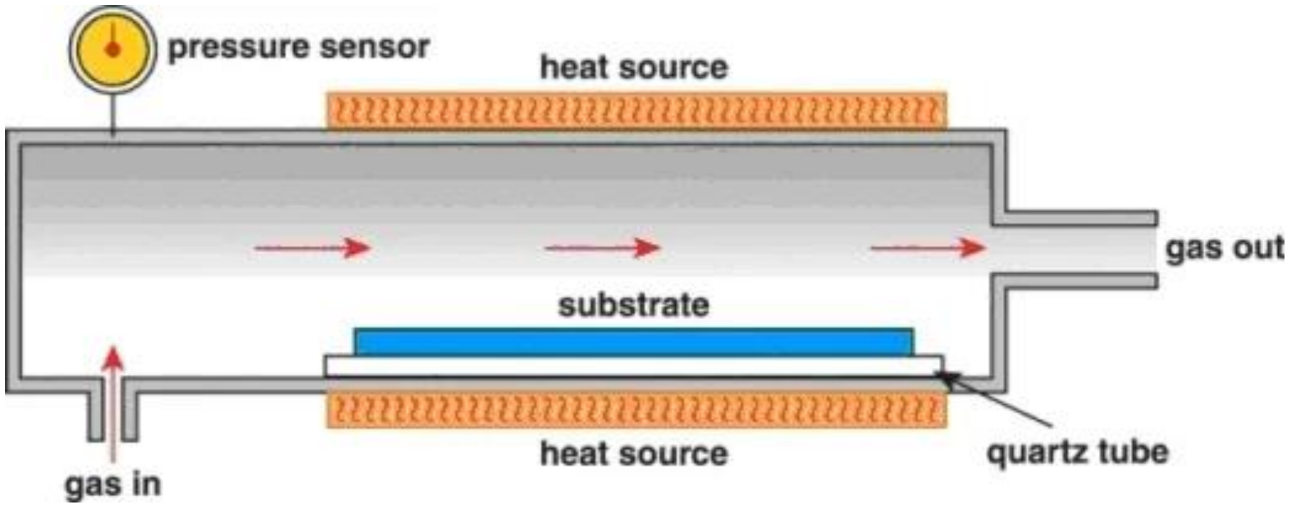


Fig:- Schematic representation of chemical vapor deposition

Limitation of CVD:-

a. It is high temperature process $(450\text{-}1050)^{o}c$ and requires high energy.
b. It is difficult to synthesis multicomponent materials by CVD technique.

Comparison between top-down & bottom-up approaches

Top down approach	Bottom up approach
1. Starting material is bulk material.	1. Starting material is atom, ions and molecule.
2.Microcrystalline material is fragmented into nanocrystalline materials by suitable method.	2. atoms, ions and molecules assemble together under suitable conditions to form nanomaterials.
3. If starting material is solid phase, it belongs to top down approach.	3. If starting material is solid or gas or liquid phase, it belongs to bottom up approach.
4. The nanomaterials are usually nonhomogeneous in size and distribution.	4. The nanomaterials are usually homogeneous in size and distribution.
5. Difficult to control shape and size.	5. Easy to control shape and size.

Distinguish between PVD and CVD

PVD	CVD
1. Physical vapor deposition	1. Chemical vapor deposition
2.Coating materials(Precursor) is in solid or liquid form.	2. Coating materials is in gas form.
3. Atoms are moving and depositing on the substrate.	3. The gaseous molecule will react the substrate.
4. Deposition occurs relatively at low temperature.	4. Deposition occurs relatively at high temperature.
5. Coating size is thinner and excellent adhesion power.	5. Coating size is thicker and good adhesion power.
6. Deposition occur by physical process.	6. Deposition occur by chemical reaction.
7. Hazardous biproduct doesn't formed	7. Generally biproducts are Hazardous.