IILM University, Greater NOIDA

Dr. Nidhi Puri

Physics
Nanomaterials

Nanomaterials

- Density of states in 0D, 1D and 2D. Low dimensional systems: Quantum well, Quantum wire, Quantum dots, Nanomaterials and its properties, Classification of Nanomaterials, Carbon nanotubes, Semiconductor nanomaterials, Graphene, Characterization techniques (basic ideas): Scanning Electron Microscopy and Transmission Scanning Electron microscopy.

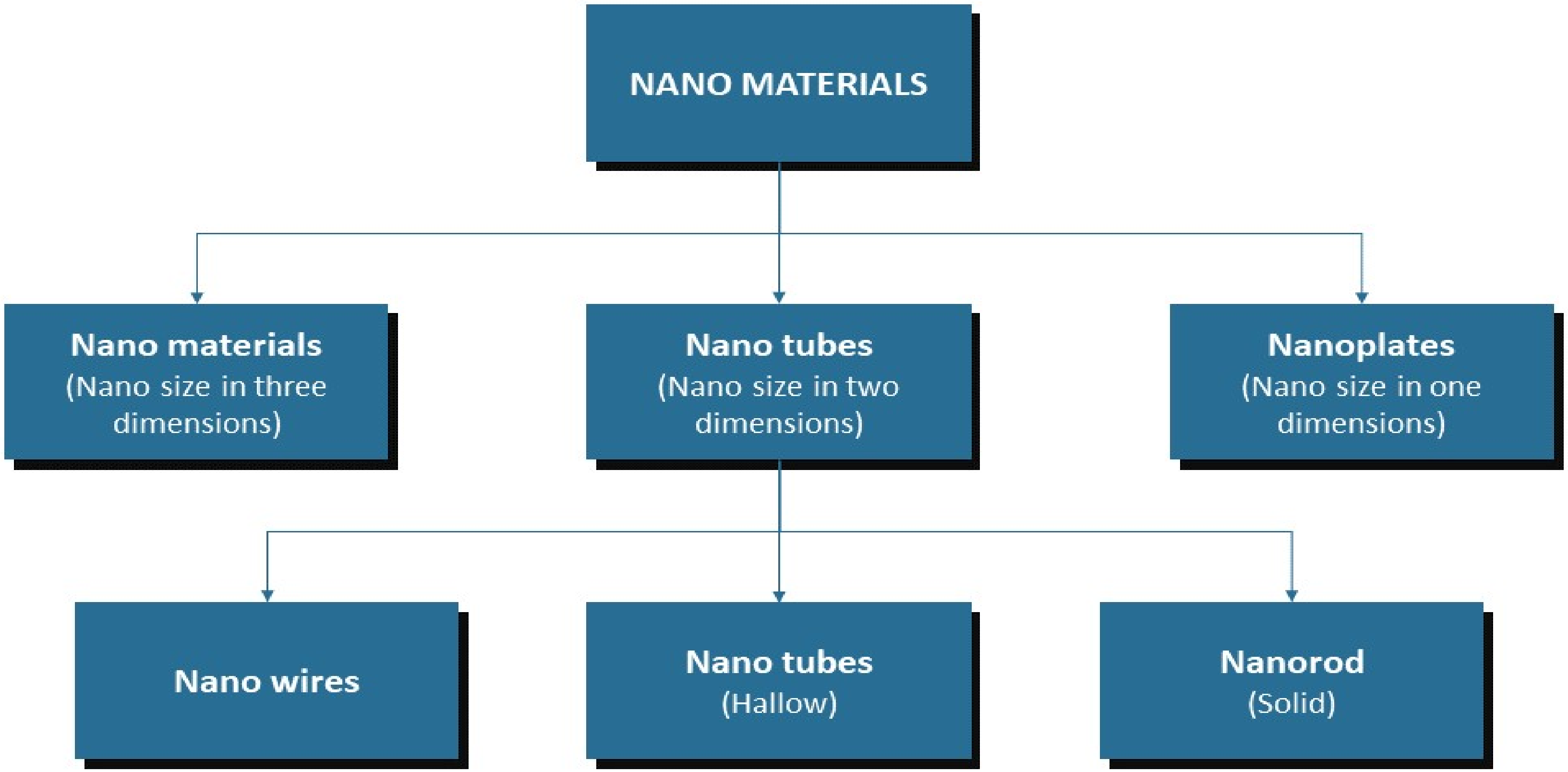
NANOMATERIALS

- **Nanomaterials** are application with morphological features smaller than a one tenth of a micrometer in at least one dimension.
- **Nanoscience** is the study of fundamental principles of molecules and structure with atleast 1-D of 1-100 nm.
- **Nanotechnology** is the study of devices with nano dimensions.
- Because of the decrement in particle size, some physical and mechanical properties of the Nanomaterials will be changed greatly.
- Materials reduced to the nanoscale can suddenly show very different properties compared to what they exhibit on a macroscale, enabling unique applications.

NANOMATERIALS BEHAVE DIFFERENTLY

- **Nanomaterials** are those materials which have atleast one dimension between 1-100 nm.
- Nanoparticles exhibit unique properties due to their **high** surface area to volume (**S/V**) ratio.

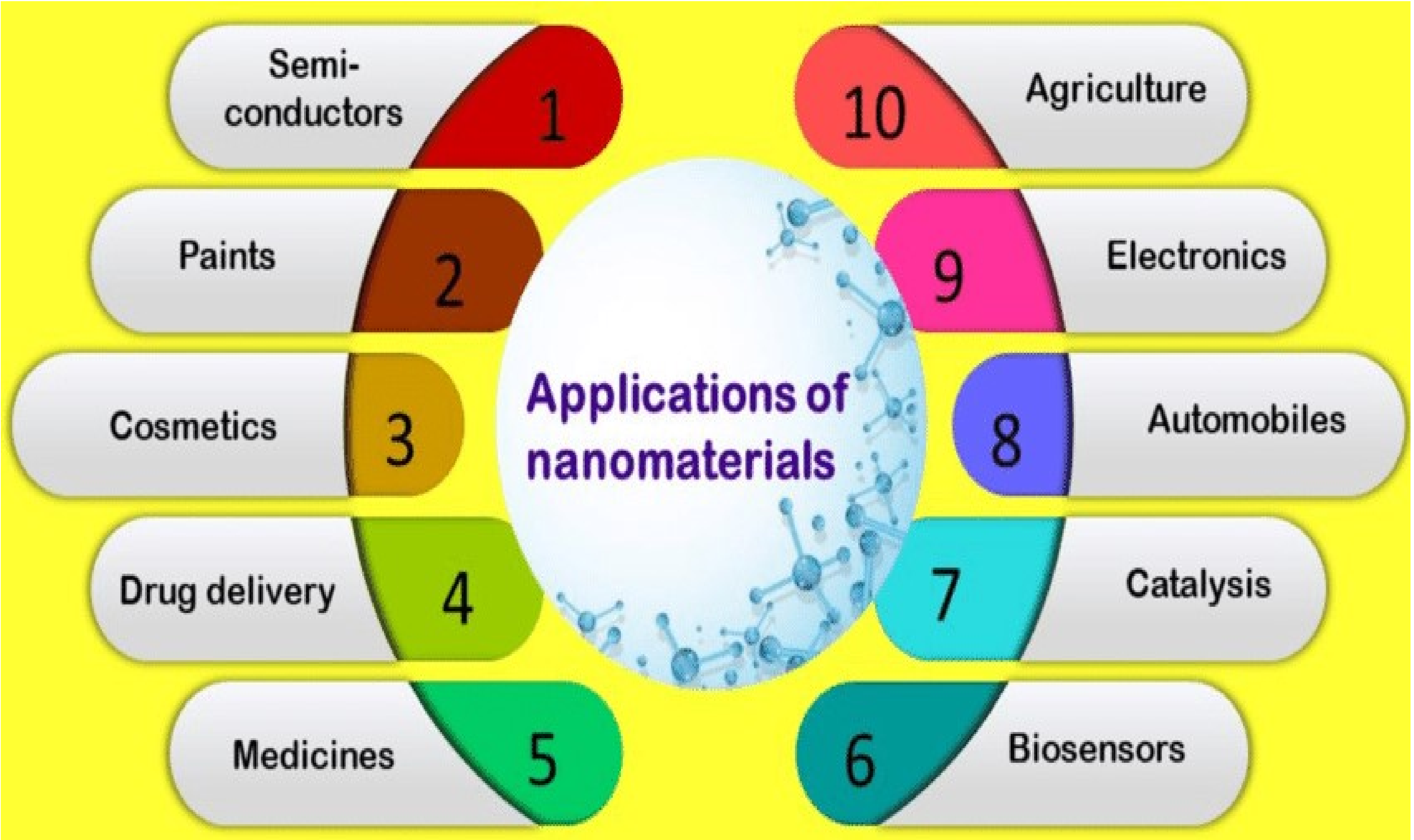
CLASSIFICATION OF NANOMATERIALS



PHYSICAL PROPERTIES OF NANOMATERIALS

- **Electrical conductivity:** The **high conductivity** is due to minimum defect in their structure. The electrical conductivity lies between metallic to semiconducting materials.
- **Thermal conductivity:** It is high due to vibrations of covalent bonds which is ten times greater than metals.
- **Mechanical properties:** Nano materials are one or two order of magnitude higher than that of single crystals in the bulk form, due to reduced probability of defects. They are stronger, harder, and withstand extreme strain. They can be used in cutting tools, automobiles, aircraft components etc.
- **Magnetic properties:** Nanomaterials are distinctly different from that of bulk materials. Ferromagnetism of bulk material disappears and transfers to super magnetism in the nanometer scale due to huge surface energy.
- **Optical prperties:** These materials are small enough to confine their electrons and produce quantum effects. Eg: Gold NPs appear deep red to black in solution.

APPLICATIONS OF NANOMATERIALS



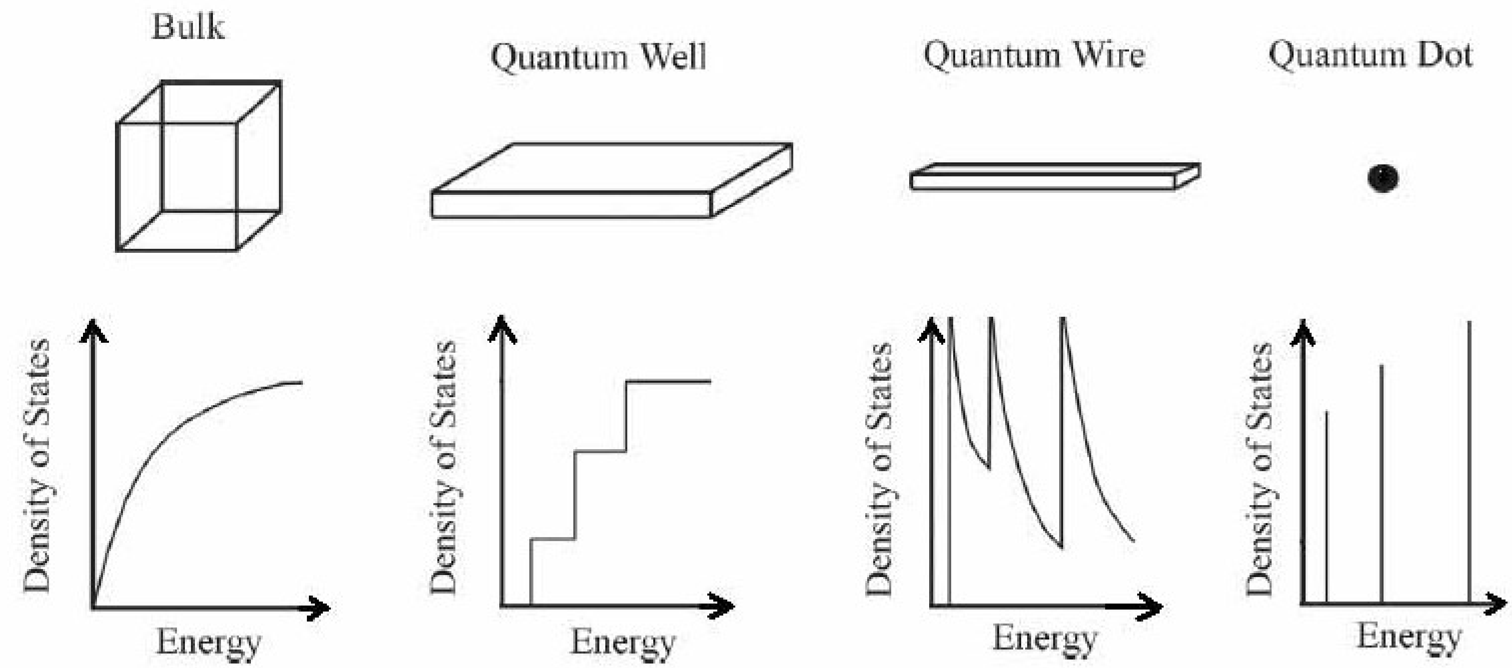
Disadvantages of Nanomaterials

- Impurity
- Difficulty in synthesis, isolation and application
- Instability of the particles
- Involves use of harsh toxic solvents in the preparation process
- May trigger immune response and allergic reactions
- Extensive use of poly(vinyl alcohol) as stabilizer may have toxicity issues

QUANTUM DOTS, QUANTUM WIRES AND QUANTUM WELL

Bulk Material : It is a **three dimensional structure** in which there is no confinement along any direction. All of its dimensions are larger than the exciton Bohr radius. The particle is free to move throughout the volume of the material. No quantization of the particle motion occurs *i.e.*, particle have a continuous range of energies between a minimum and maximum.

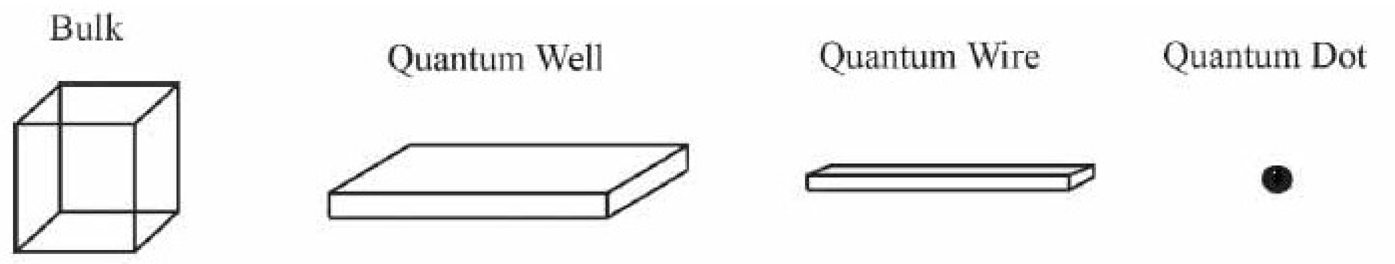
Low dimensional structures are classified on the basis of number of reduced dimensions they possess. Dimensionality refers to the number of degrees of freedom possessed by the particle.



1. Quantum Well : It is a **two-dimensional nanostructure** in which there is confinement along one direction and particle is free to move in other two directions (*i.e.*, in a plane). Particle possess discrete (or quantized) energies associated with the confinement dimension. Particle energies are continuous along the other two (unconfined) dimensions.

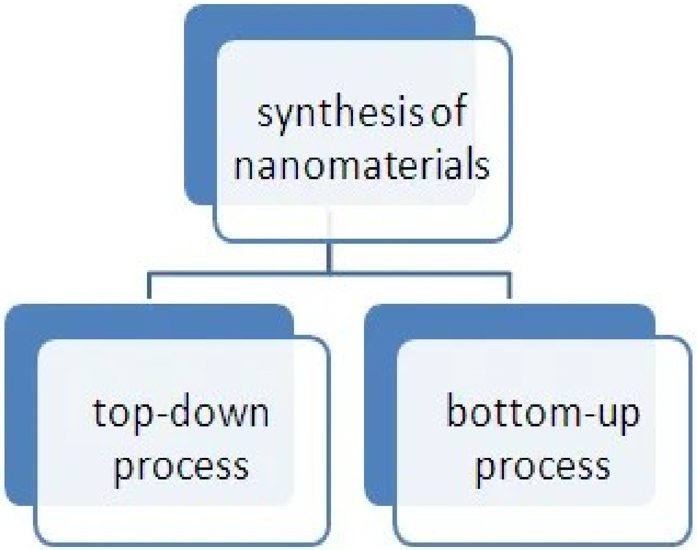
2. Quantum Wire : It is a **one dimensional nanostructure** in which there is confinement along two directions and particle is free to move in the third direction. Particle has discrete energies associated with these two directions of confinement and continuous along the third (unconfined) direction.

3. Quantum Dot : The extreme case in which confinement of the particle occurs in all the three directions, results in a **zero-dimensional nanostructure**, called quantum dot. In this case, the number of degrees of freedom of the particle is zero. Particle has discrete energies associated with its motion along all the three directions. Examples of zero dimensional objects are-nanoparticles, clusters, colloids, nanocrystals, and fullerenes. Quantum dots are composed of several to a few thousand atoms.



SYNTHESIS OF NANOMATERIALS

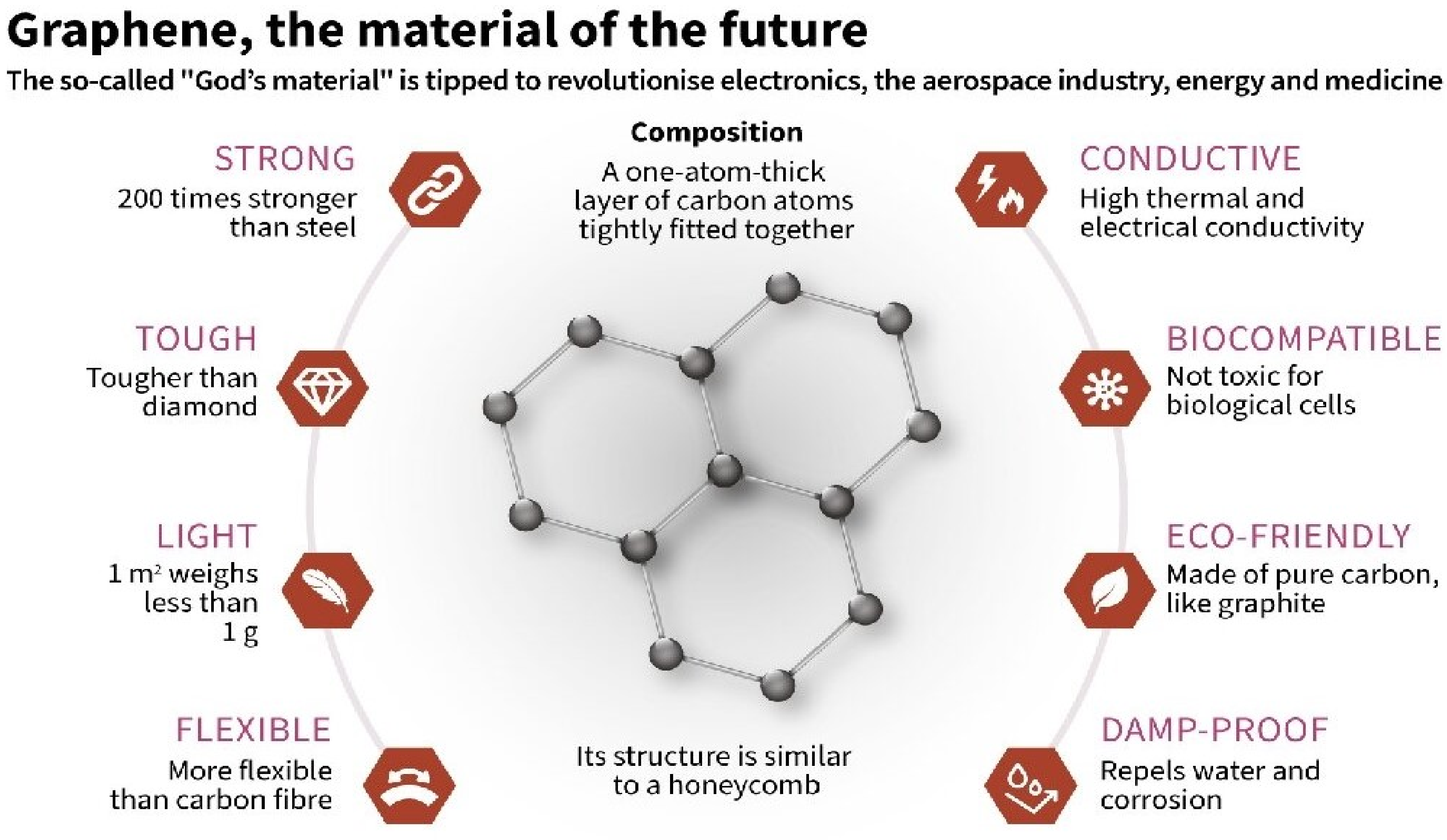
- Few methods of a **TOP-DOWN** process are
  - Ball milling
  - Plasma arching
  - Laser sputtering
  - Vapour destination



- Few methods of a **BOTTOM-UP** process are
  - Sol-gel
  - Colloidal
  - Electrodeposition

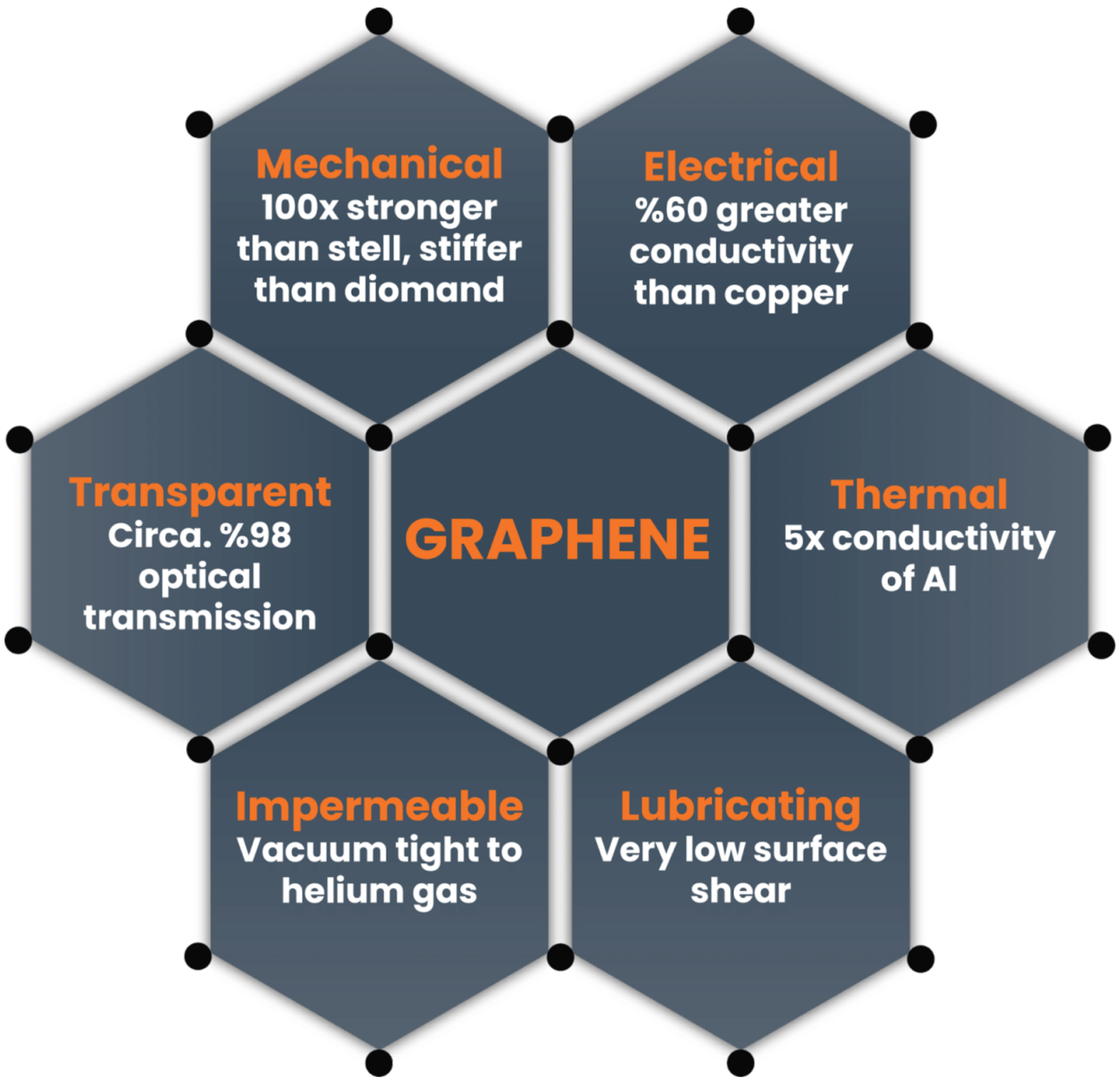
GRAPHENE

- Graphene (G) is an allotrope of carbon like diamond
- 2D atomically thick single layer of sp2 carbon atoms



GRAPHENE AND PROPERTIES

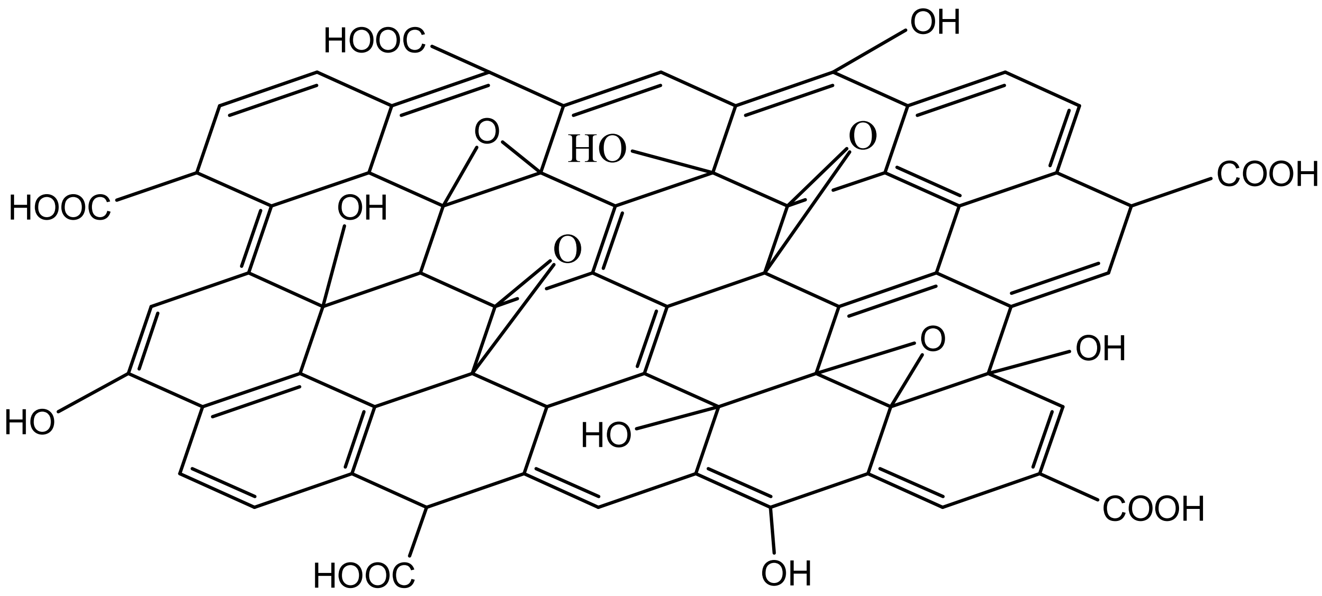
❖2D atomically thick single layer of sp2 carbon atoms.
❖Outstanding electrical conductivity (higher than Cu) and high electron mobility.
❖Great thermal conductivity (higher than Cu).
❖One of the strongest materials on Earth.
❖Low light absorption (aprox. 2,3%).
❖Insoluble in water.



GRAPHENE OXIDE

- Graphene Oxide (GO) is the oxidated form of G:

Functional groups are arbitrarily located and randomly aggregated



CARBON NANOTUBES

- CNT is a tubular form of carbon with diameter as small as 1nm.

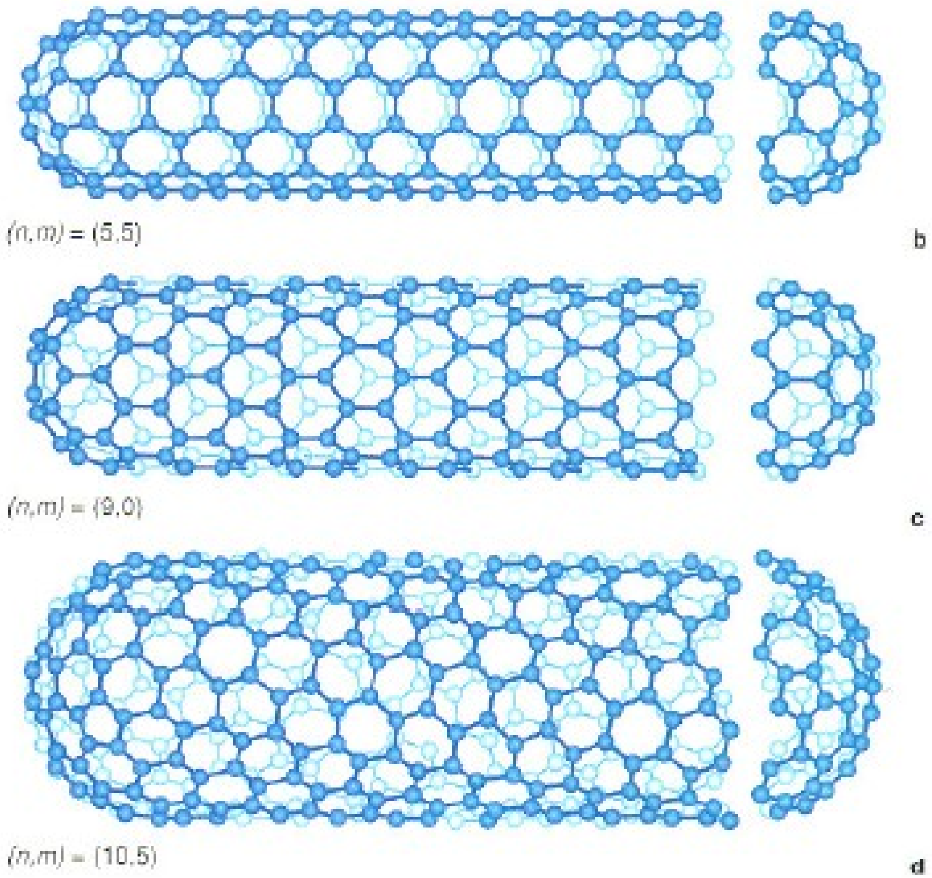
  Length: few nm to microns.

- CNT is configurationally equivalent to a two dimensional graphene sheet rolled into a tube.

- CNT is characterized by its Chiral Vector: $\mathbf{C}_h = n\,\hat{a}_1 + m\,\hat{a}_2$,

  where angle θ is Chiral Angle with respect to the zigzag axis.

- Types of CNT
  1. Single Wall CNT (SWCNT)
  2. Multiple Wall CNT (MWCNT)
  3. Can be metallic or semiconducting depending on their geometry.



Armchair (n,m) = (5,5)
$\theta = 30°$

Zig Zag (n,m) = (9,0)
$\theta = 0°$

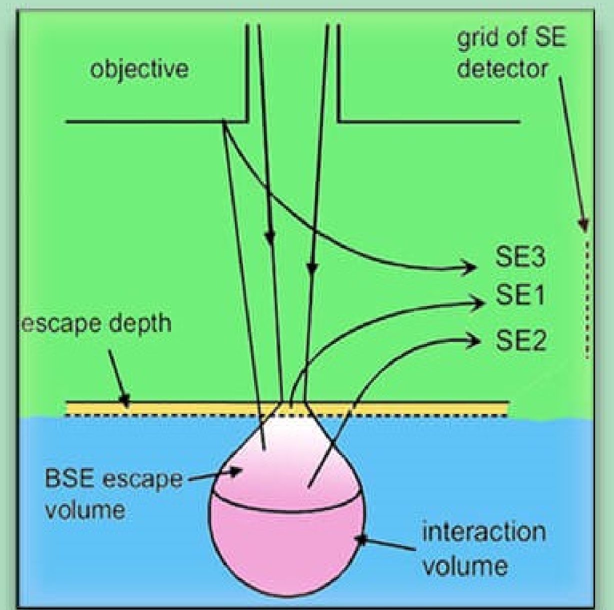
Chiral (n,m) = (10,5)
$0° < \theta < 30°$

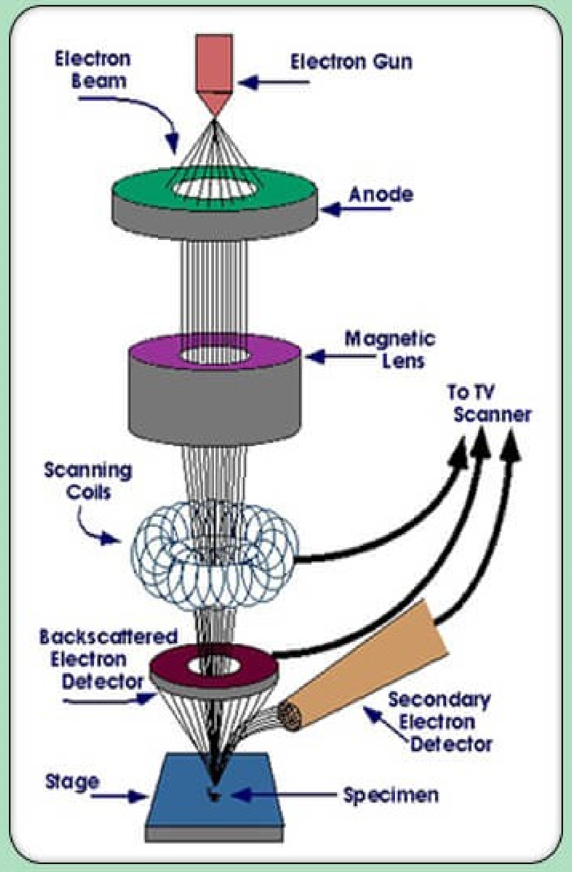
CNT PROPERTIES

- Carbon nanotubes (CNTs) have unique qualities, such as high surface-to-volume ratios, increased conductivity and strength, biocompatibility, ease of functionalization, optical properties, and so on.

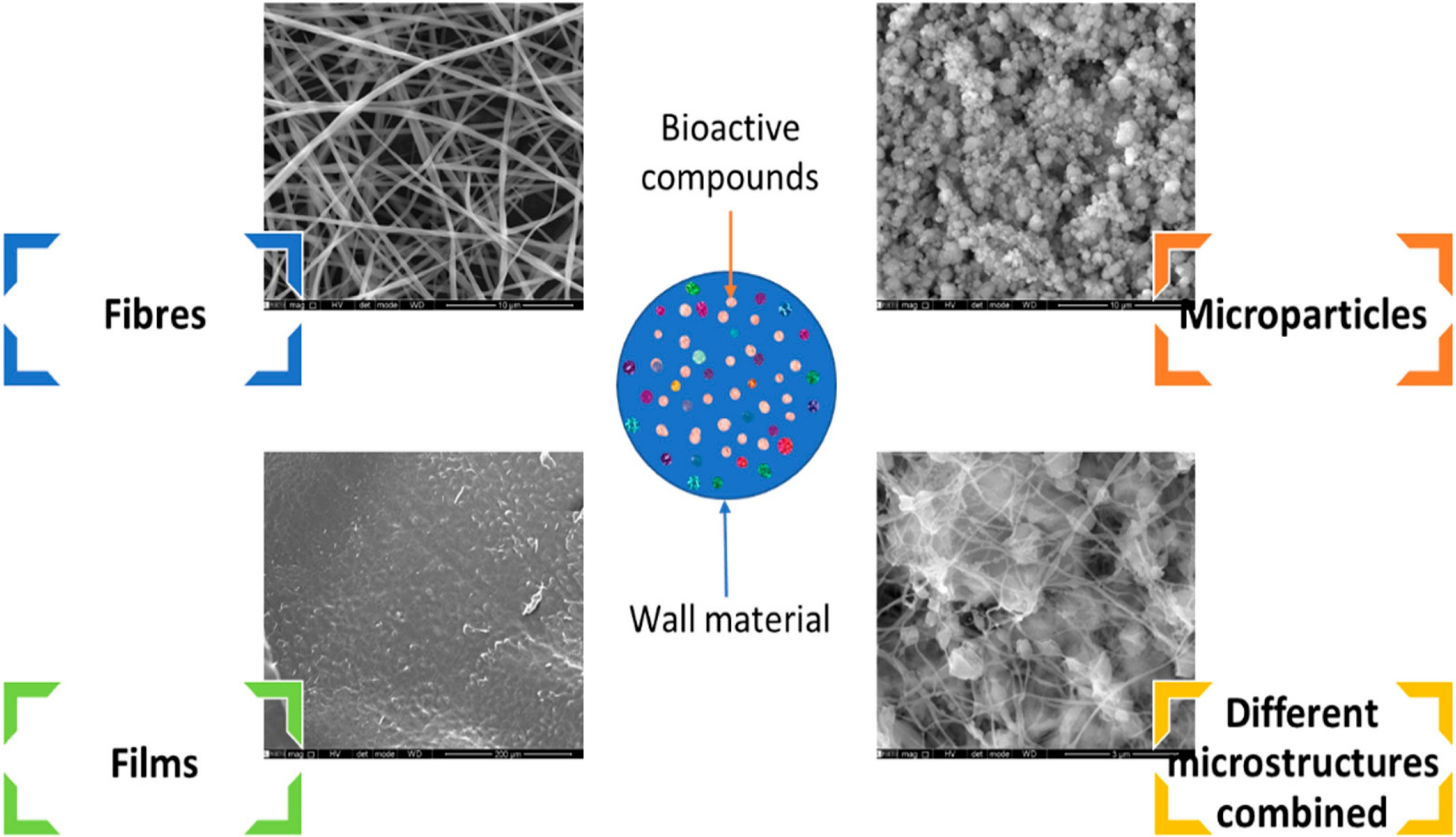
SCANNING ELECTRON MICROSCOPY (SEM)

Scanning Electron Microscopy



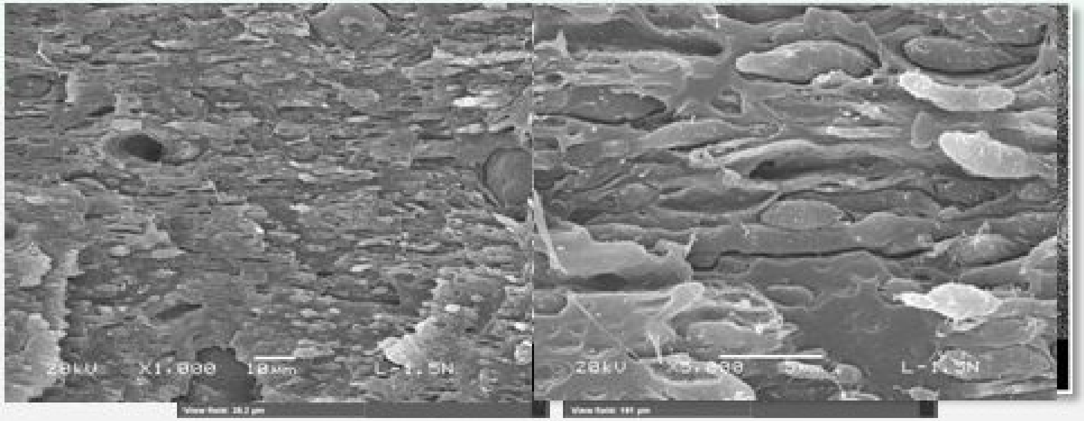


SCANNING ELECTRON MICROSCOPY (SEM)



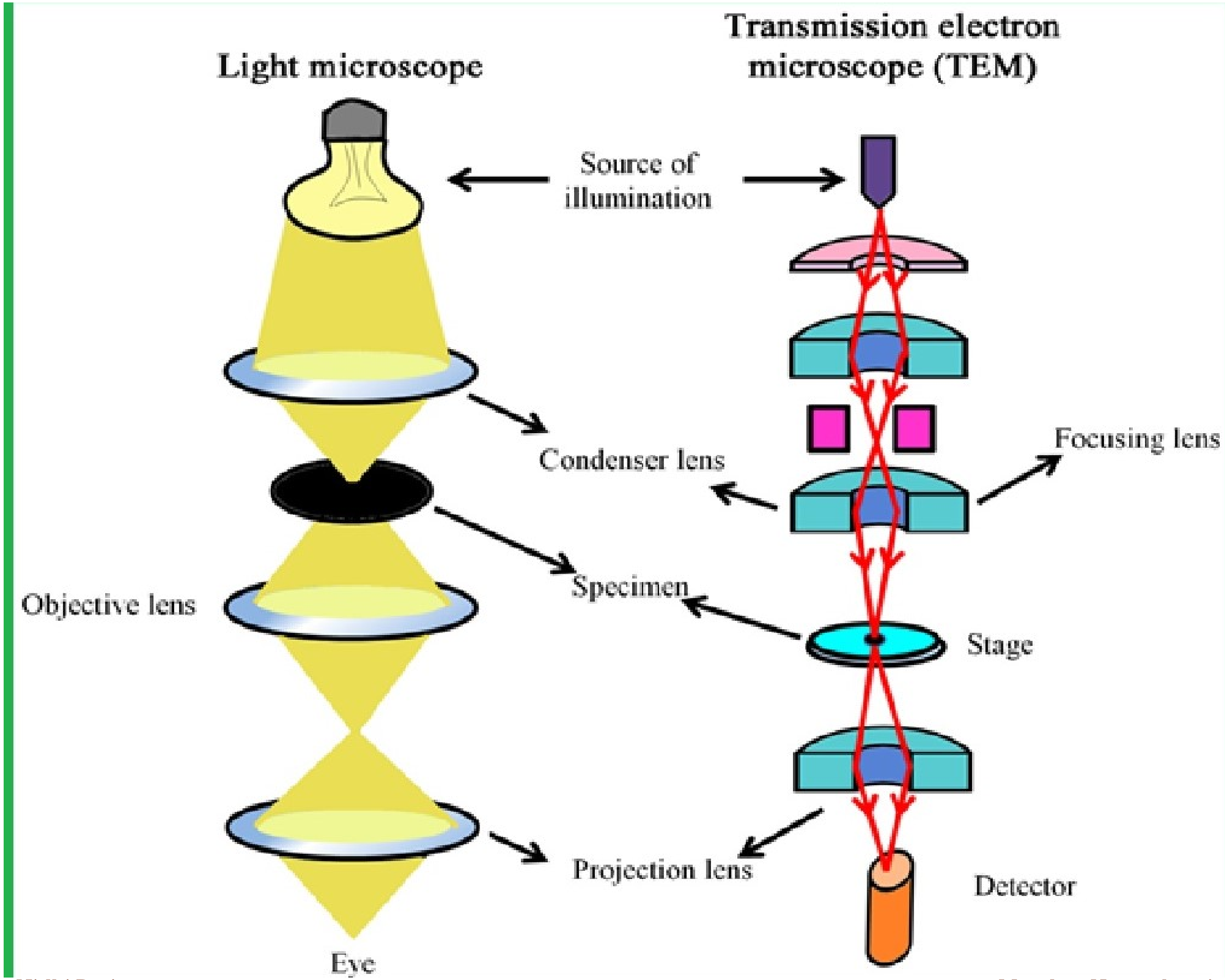
Scanning Electron Microscope (SEM)

Application



1) Surface morphology
2) Crystal structure
3) Multi-phase structure
4) Acquiring elemental maps or spot chemical analyses using EDS (Energy-Dispersive X-Ray Spectroscopy)
5) Obtaining discrimination of phases based on mean atomic number (commonly related to relative density) using BSE (Back-scattered Electron Detector)
6) Getting compositional maps based on differences in trace element "activators" (typically transition metal and rare earth elements) using CL (cathodoluminescence)

TRANSMISSION ELECTRON MICROSCOPY (TEM)



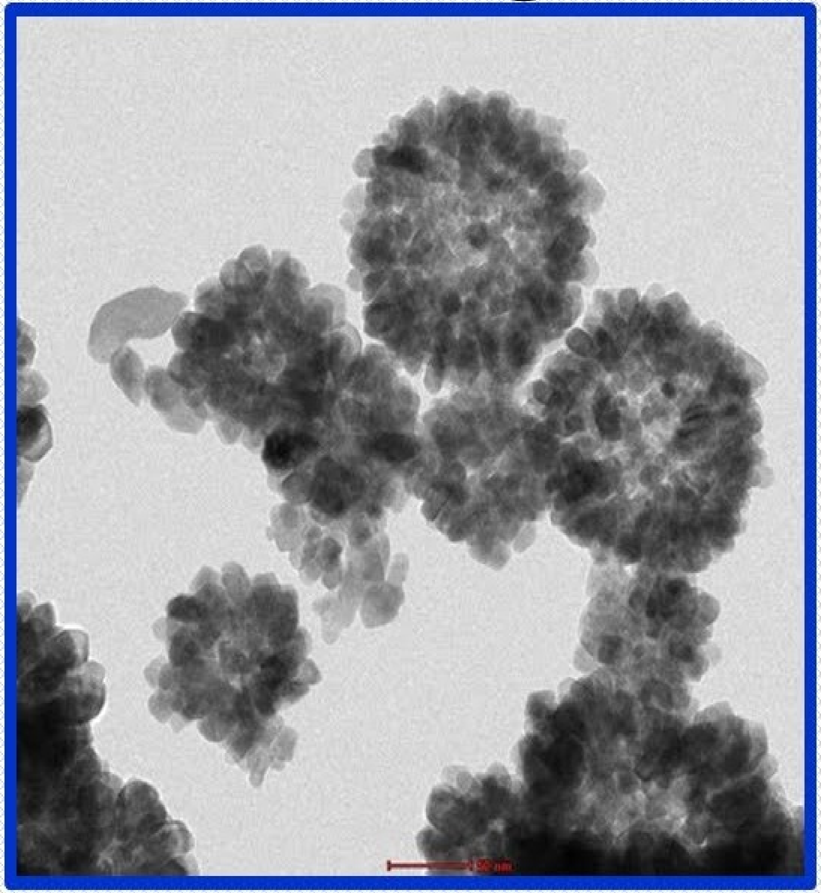
Applications of TEM

TEM

- **Conventional TEM**
  Microstructure, morphology (grain size, orientation), phase distribution and defect analysis (point defects, dislocations and grain boundaries)
- **In situ TEM**
  Irradiation and deformation experiments
  Environmental cells (corrosion)
  Phase transformations
  (hot- and cold-stage, electric field)
- **Analytical TEM (Z-contrast imaging)**
  Chemical composition-EDS, EELS, ELNES, EXELFS, Z-contrast imaging
  CBED-lattice strain, thickness, charge density
- **HRTEM**
  Lattice imaging, structure of complex materials and atomic structure of defects (interfaces)

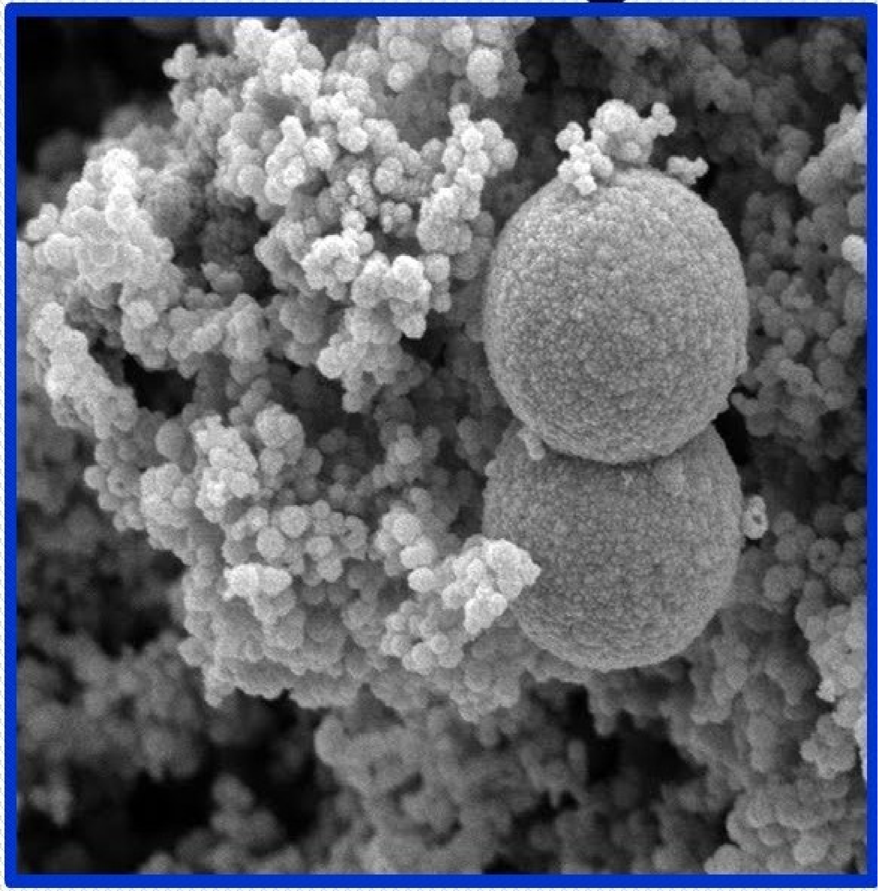
TEM VS SEM

TEM images



Vs

SEM images



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SEM

- in SEM is based on scattered electrons
- The scattered electrons in SEM produced the image of the sample after the microscope collects and counts the scattered electrons.
- SEM focuses on the sample's surface and its composition.
- SEM shows the sample bit by bit
- SEM provides a three-dimensional image
- SEM only offers 2 million as a maximum level of magnification.
- SEM has 0.4 nanometers.

TEM

- TEM is based on transmitted electrons
- In TEM, electrons are directly pointed toward the sample.
- TEM seeks to see what is inside or beyond the surface.
- TEM shows the sample as a whole.
- TEM delivers a two-dimensional picture.
- TEM has up to a 50 million magnification
- The resolution of TEM is 0.5 angstroms