PHYSICS OF SEMICONDUCTORS (03019201BS01)

UNIT IV

Low Dimensional materials

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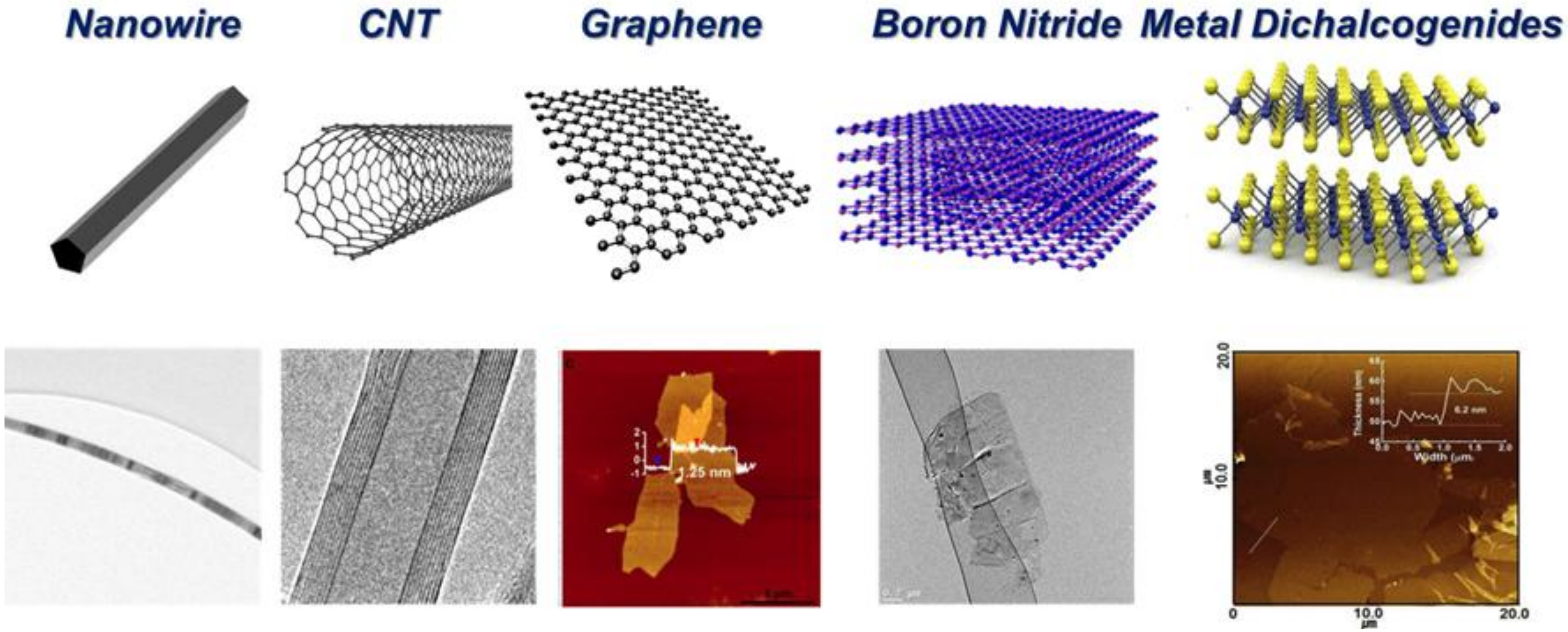
Low Dimensional materials

Low dimensional materials refer to solids where one or more of the three spatial dimensions are comparable to the de Broglie wavelength of electrons, typically in the nanometer range, which allows for the observation of quantum effects.

Some examples of low dimensional materials and their microscopic images are shown below.



Low Dimensional materials

CONTENTS:

Introducing NANO ------- 10^{-9} m

- Basic characteristic of Nanomaterials
- classification: Quantum Dot, Quantum well , Quantum Wire
- Properties at nano level
- Quantum confinement
- Synthesis of Nano – top down and bottom up approach
- Novel Materials and their applications

Micro Vs Nano

What are micromaterials

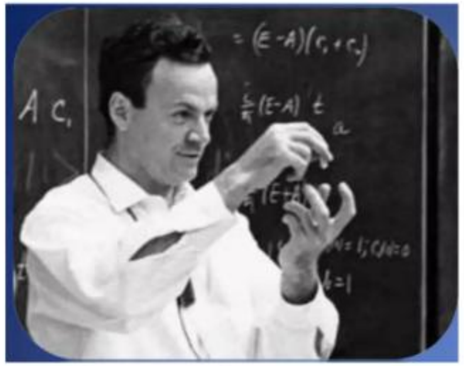
Micromaterials are characterised by the presence of at least one dimension, such as length, diameter, or thickness, on the order of 5 micrometers (µm) or when the grain size within a material falls within the same range of 5 micrometres. They are used in integrated circuits, medical implants, sensors, and miniature optical devices.

Nanomaterials are the materials in which at least one dimension is less than approximately 100 nanometers.

Nanomaterials are commonly defined as materials with an average grain size less than 100 nanometers.

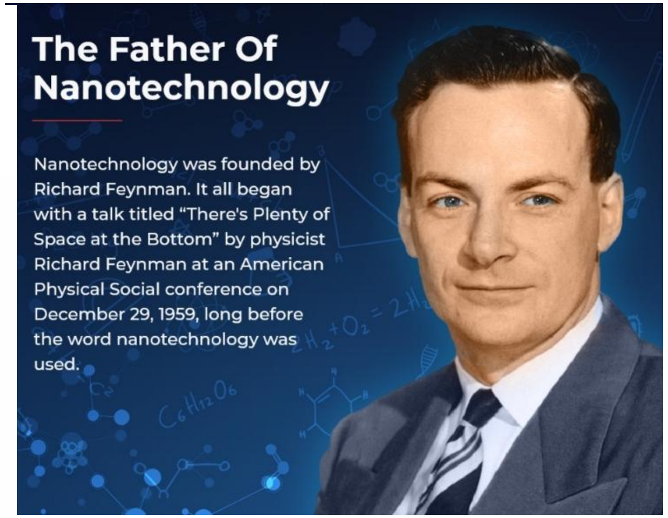
A nanometer is one millionth of a millimeter -approximately 100,000 times smaller than the diameter of a human hair.

Nano pioneers



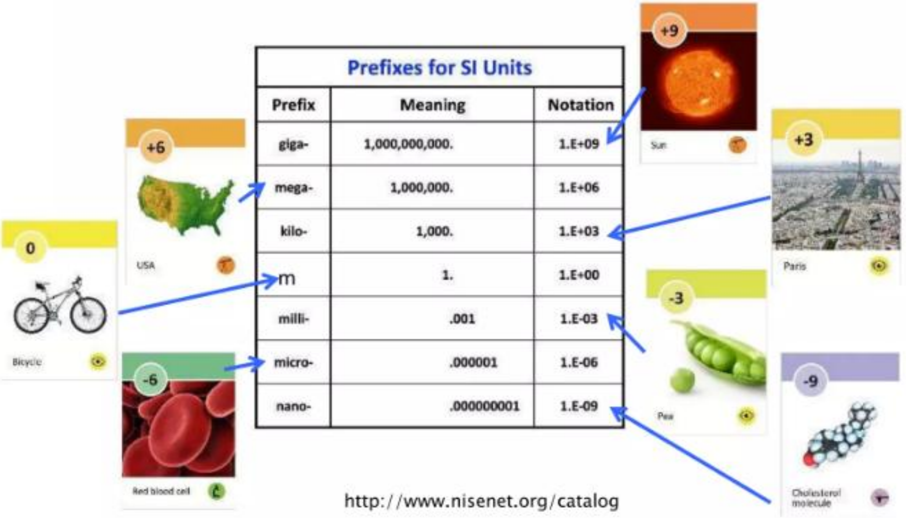
Father of nano technology
Nobel Laureate-1965
Richard Feynman, Physicist

Norio Taniguchi,
coined the term "Nanotechnology" (1974)



Ability to control or manipulate at atomic scale

How Big is a Nanometer?



Prefix	Meaning	Notation
giga-	1,000,000,000.	1.E+09
mega-	1,000,000.	1.E+06
kilo-	1,000.	1.E+03
m	1.	1.E+00
milli-	.001	1.E-03
micro-	.000001	1.E-06
nano-	.000000001	1.E-09

"Those who control materials control technology"- *Eiji Kobayashi, Panasonic*

What are Nanomaterials?

‘Nanomaterial’ means a natural, incidental or manufactured material containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for 50 % or more of the particles in the number size distribution, one or more external dimensions is in the size range1–100 nm.

E.g. **fullerenes**, **graphene flakes** and **single wall carbon nanotubes**

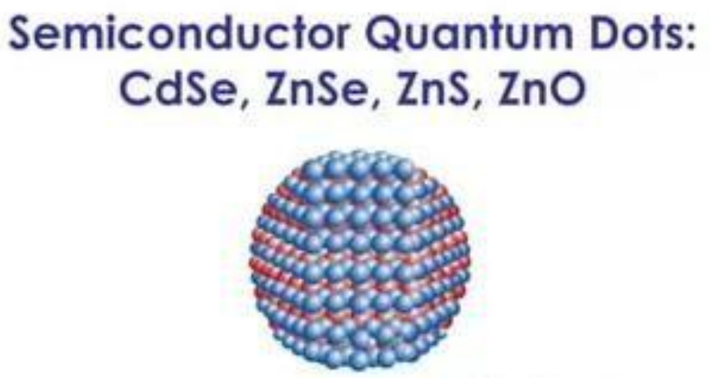
‘Particle’, ‘agglomerate’ and ‘aggregate’ are defined as follows:

(a) ‘**particle**’ means a minute piece of matter with defined physical boundaries;
(b) ‘**agglomerate**’ means a collection of weakly bound particles where the resulting external surface area is similar to the sum of the surface areas of the individual components;
(c) ‘**aggregate**’ means a particle comprising of strongly bound or fused particles.

Types of Nanomaterials

For the better understanding, nanomaterials are again organized into two types as follows:

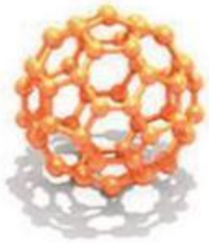
i. Carbon based materials
ii. Metal and Semiconductor based materials



(i) Carbon based materials: These are composed of carbon, taking the form of hollow spheres, ellipsoids or tubes.


Nanotube

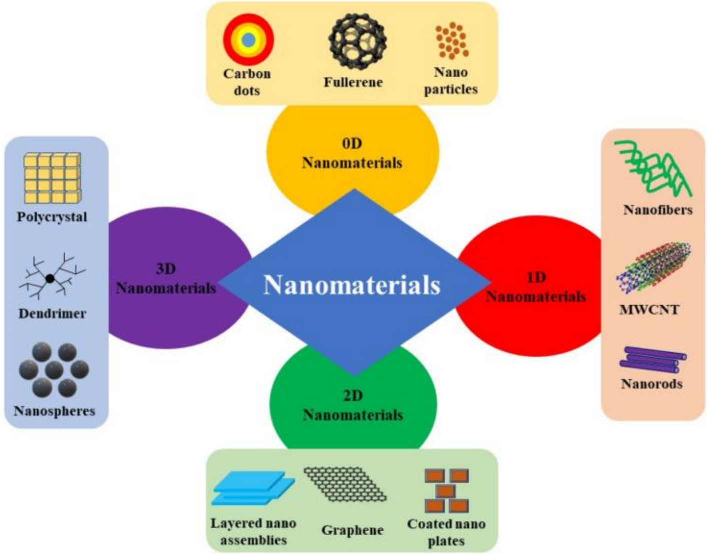
- The spherical and ellipsoidal forms are referred as fullerenes, while cylindrical forms are called nanotubes.


Fullerene

(ii) Metal and Semiconductor based materials: These include quantum dots, nanogold, nanosilver and metal oxides like TiO_2.

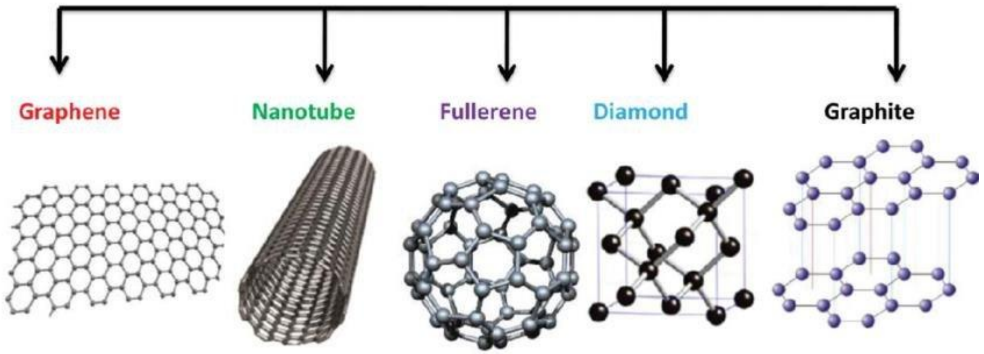
- A quantum dot is a closely packed semiconductor crystal comprised of hundreds or thousands of atoms, whose size is on the order of a few nanometers to a few hundred nanometers.

Carbon nanomaterials



The three new materials, graphene, carbon nanotubes and fullerenes, can be called "nanocarbon".

Allotropes of Carbon



Graphite -
Naturally occurring form of crystalline carbon known for its unique properties, including excellent electrical conductivity, softness, and layered structure

Graphene - is simply one of the many parallel sheets constituting graphite; graphite is made up of endlessly repeating stacks of graphene. It is flexible, lightweight, but strong and has excellent thermal and electrical conductivity.

- The C60 molecule has been named **fullerene** after the architect and inventor R.Buckminister Fuller, who geodesic dome that resembles the structure of C60.
- has 12 pentagonal (5 sided) and 20 hexagonal (6sided) faces symmetrically arrayed to form a molecular ball

Rolling up graphene into the smallest possible tube makes a **single-walled carbon nanotube,** and **curling** it up into the smallest possible sphere makes a **fullerene**

Classification of Nanomaterials

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

(1) zero-dimensional (0-D),

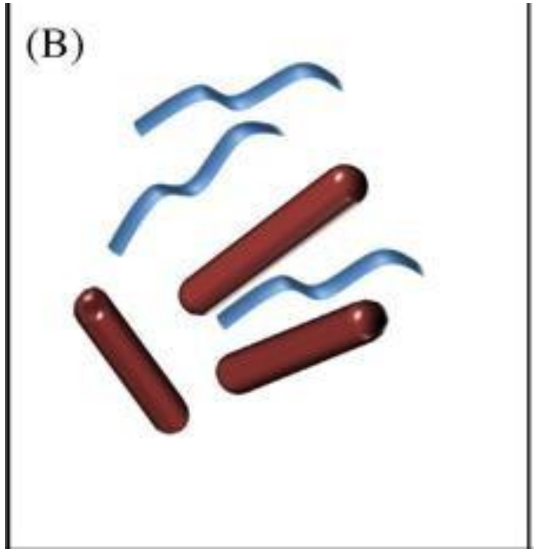
(2) one-dimensional (1-D),

(3) two-dimensional (2-D), and

(4) three-dimensional (3-D).

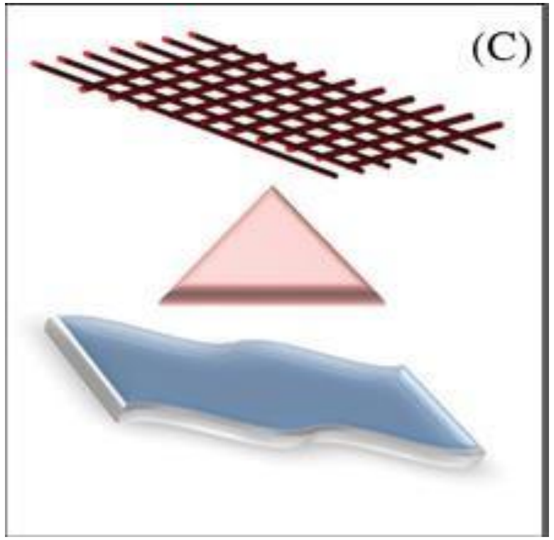
Classification of Nanomaterials

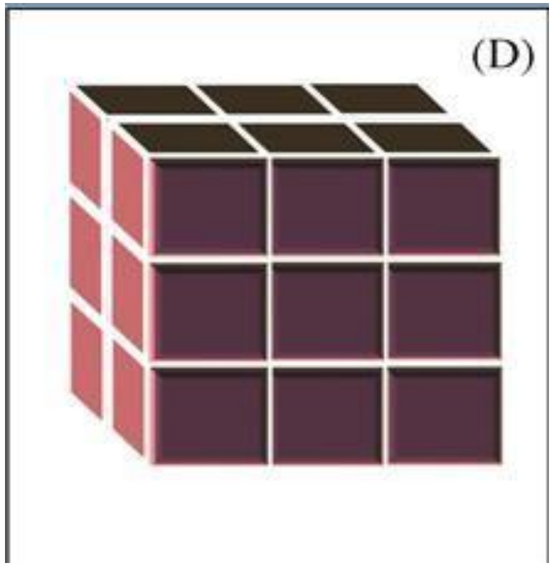
Dimensions	Criteria	Examples
Zero-dimensional (0-D)	The nanostructure has all dimensions in the nanometer range.	Nanoparticles, Quantum dots , nanodots
One-dimensional (1-D)	One dimension of the nanostructure is outside the nanometer range.	Nanowires, nanorods, nanotubes



Classification of Nanomaterials

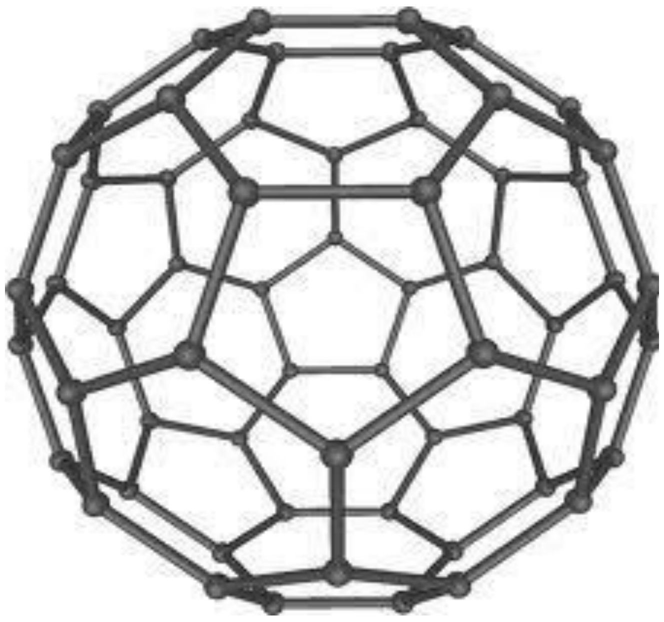
Dimensions	Criteria	Examples
Two-dimensional (2-D)	Two dimensions of the nanostructure are outside the nanometer range.	Coatings, thin-film- multilayers
Three-dimensional (3-D)	Three dimensions of the nanostructure are outside the nanometer range.	Bulk

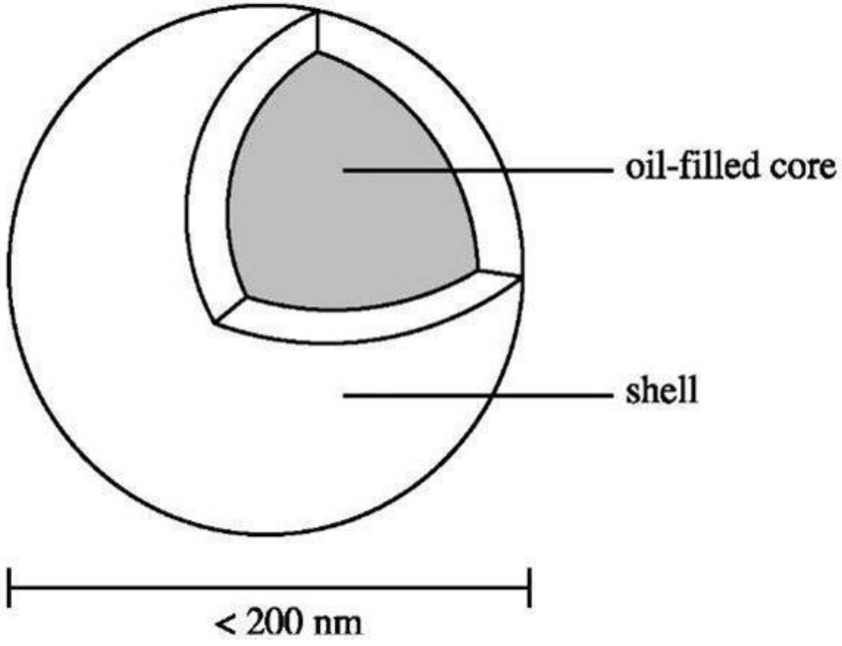


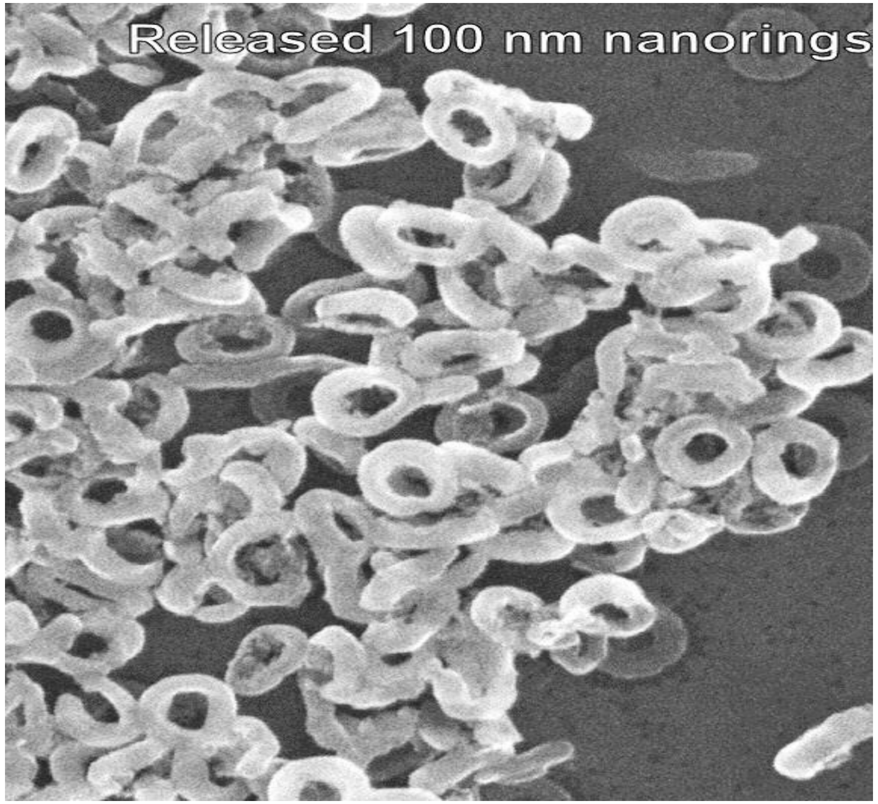


0-D Nanomaterials

- Materials wherein all the dimensions are measured within the nanoscale (no dimensions, or 0-D > 100 nm).
- e.g. Nanoparticles; Nanograins; Nanoshells; Nanocapsules; Nanorings; Fullerenes; collidal particles; quantum dots

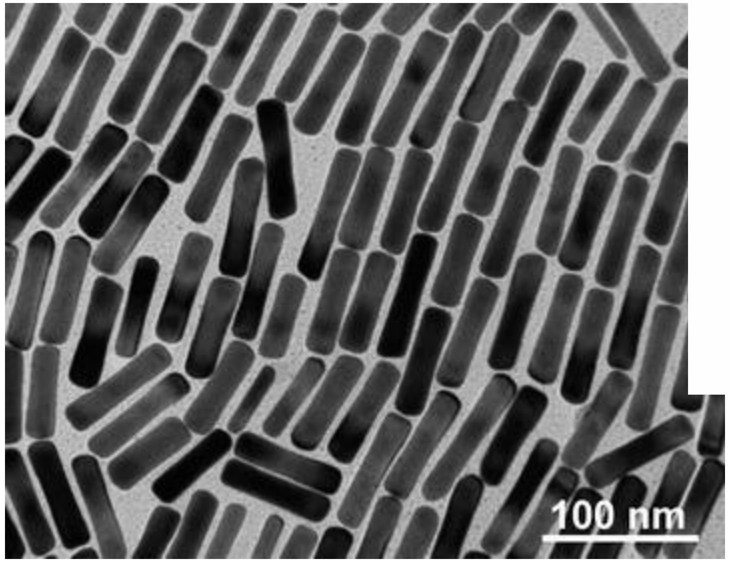


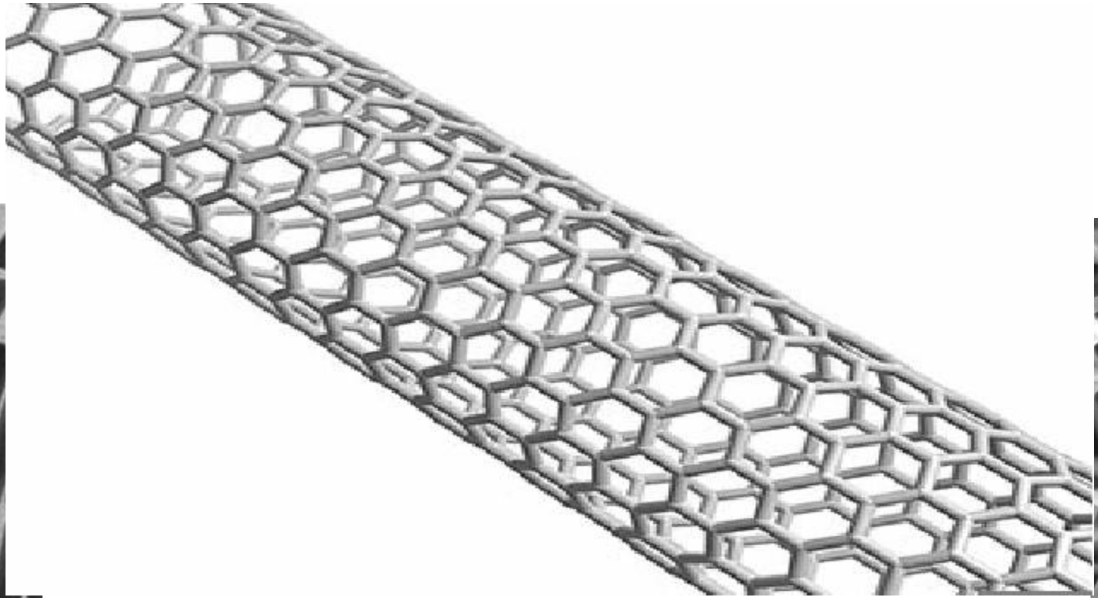
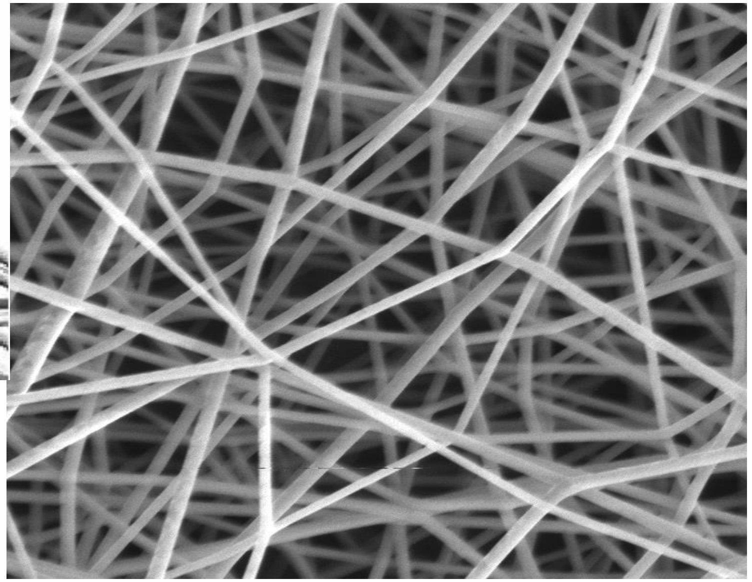




1-D Nanomaterials

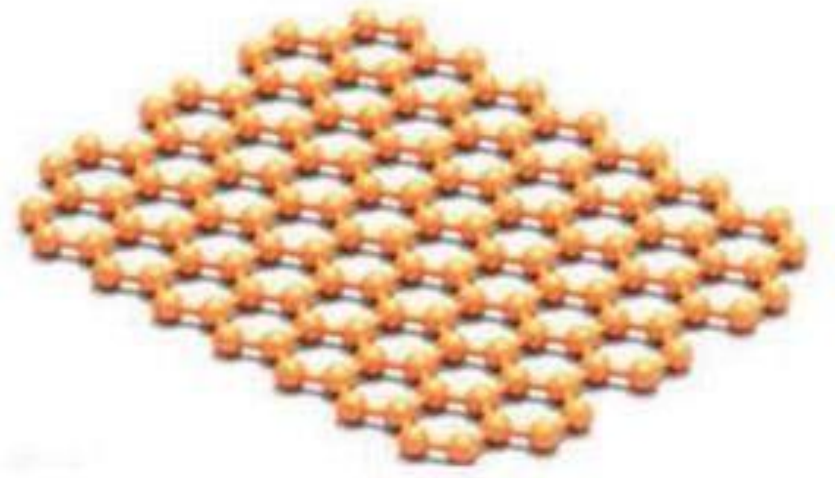
- One dimension is outside the nanoscale (1-D > 100 nm).
- This leads to needle like-shaped nanomaterials.
- **Examples:** Nanorods; Nanofilaments; Nanotubes; quantum wires; nano wires

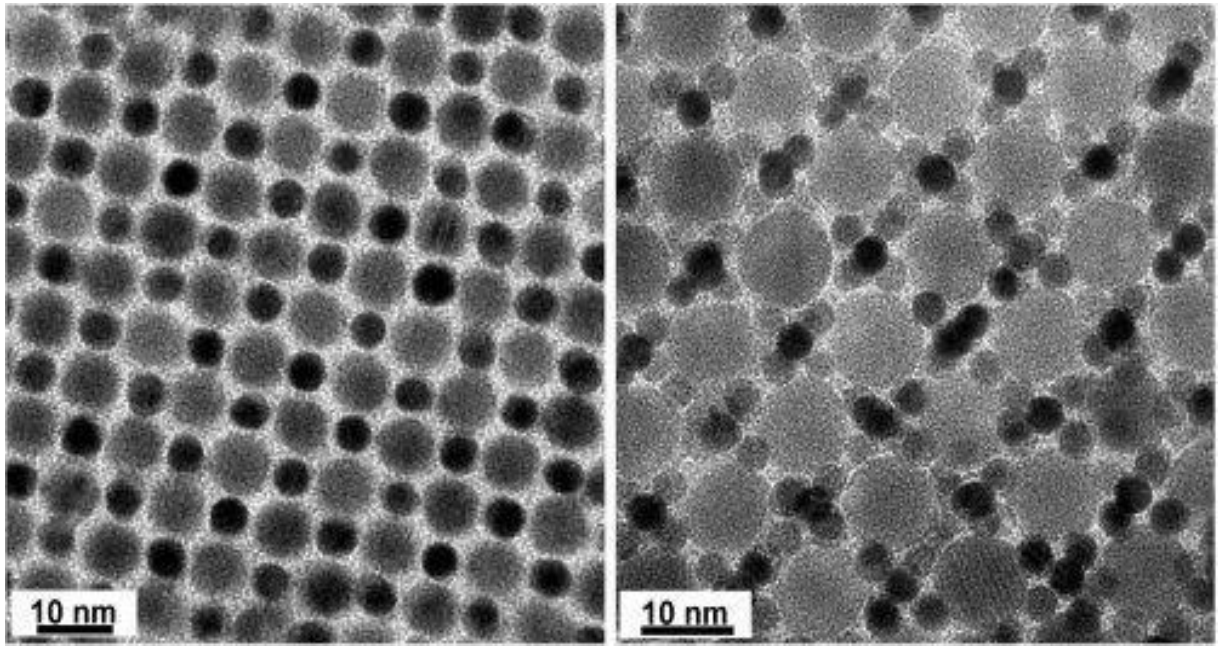


2-D Nanomaterials

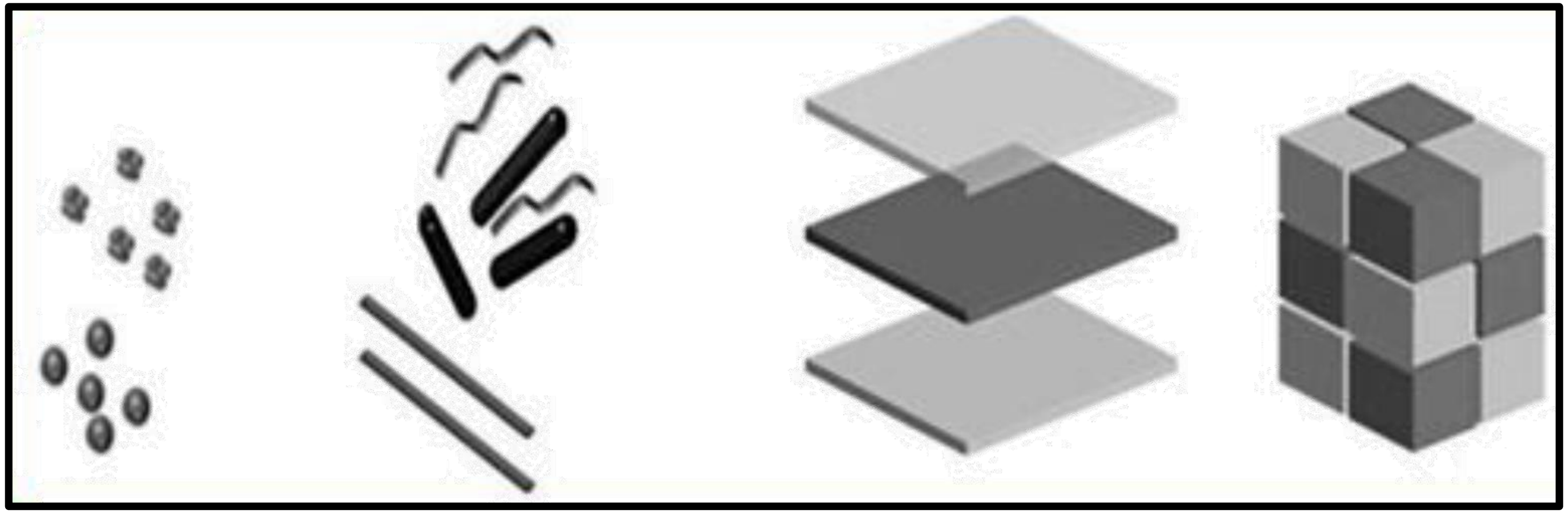
- Two of the dimensions are not confined to the nanoscale.
- 2-D nanomaterials exhibit plate-like shapes.
- Examples: nanofilms, nanolayers, nanocoatings, discs; ultrathin films; quantum wells

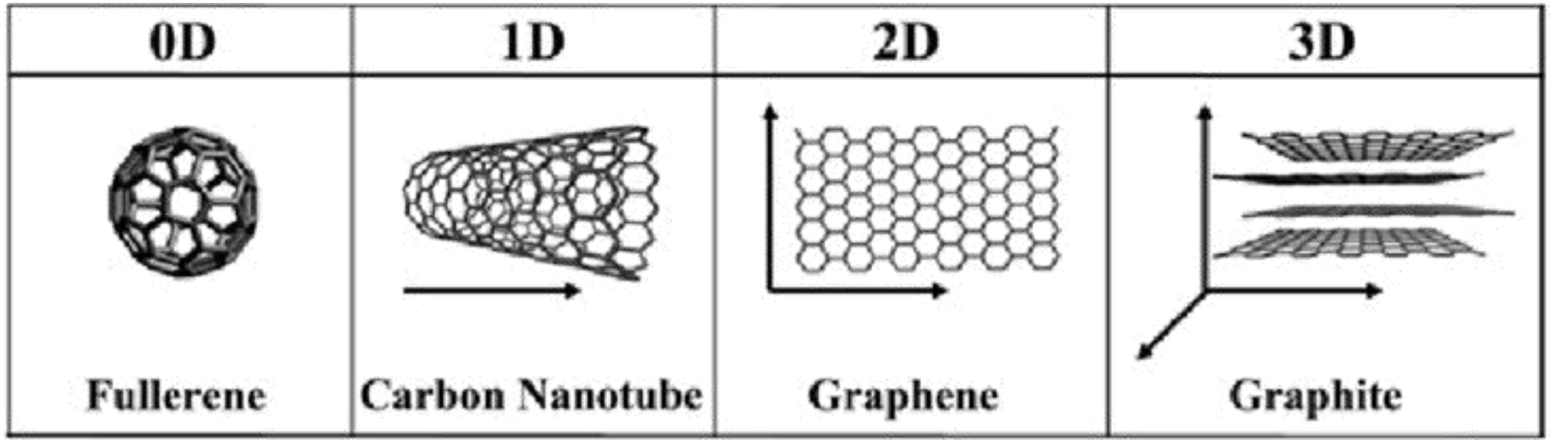

Graphene



3-D Nanomaterials

- Bulk nanomaterials are materials that are not confined to the nanoscale in any dimension.
- Bulk nanomaterials can be composed of a multiple arrangement of nanosize crystals, most typically in different orientations.

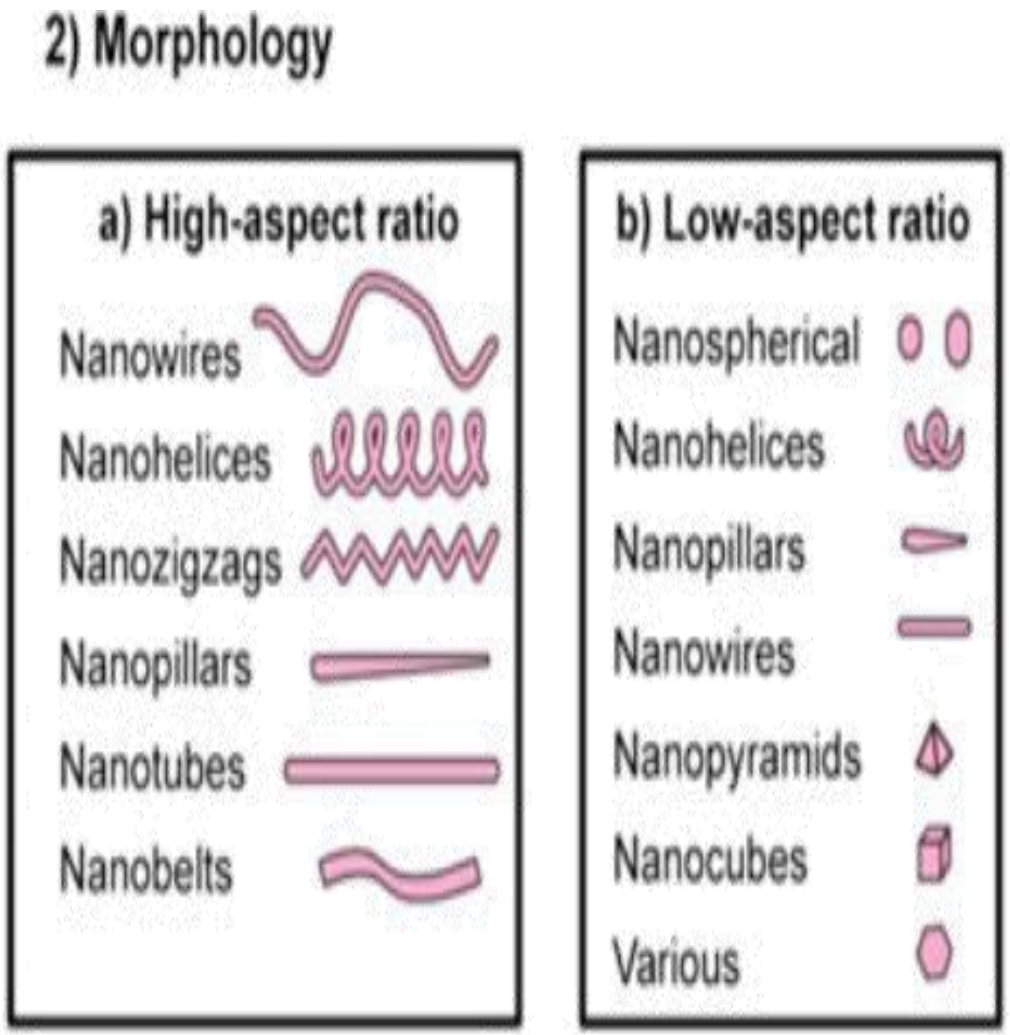




Classification of Nanomaterials

Based on Morphology:

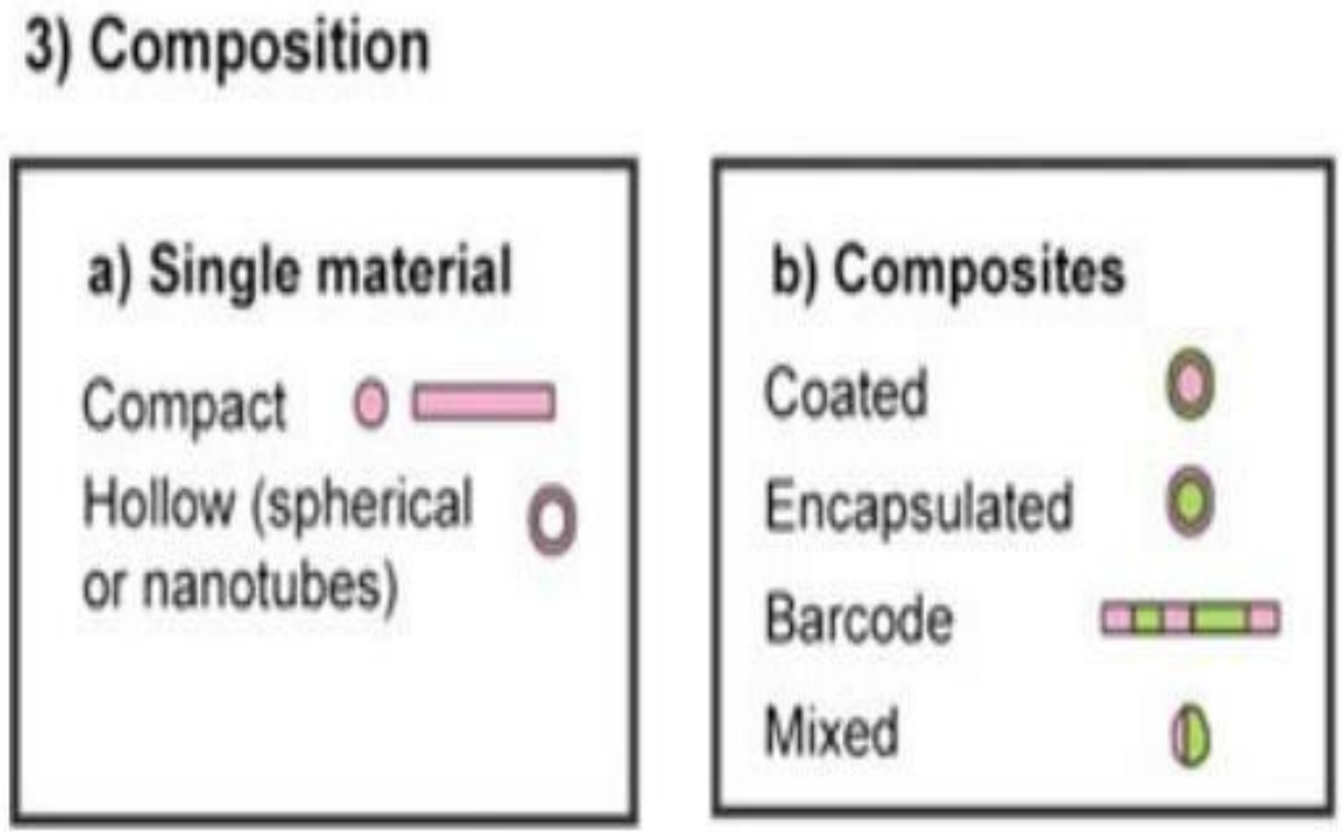
- Classified as (1) low-aspect ratio particles (2) high-aspect ratio particles
- The high aspect ratio nanoparticles can have different shapes, such as nanowires, nanohelices, nanozigzags, nanopillars, nanotubes, or nanobelts.
- The low aspect ratio nanoparticles can have many shapes as well, such as spherical, helical, pillar-like, pyramidal, cubes, among others.



Based on Composition:

- According to their composition, Nanoparticles can be made of a single material or composite materials.
- nanoparticles made of a single material, can be (i) compact or (ii) hollow.

- Nanomaterials can also be comprised of two or more materials (composites) that can be as (i) coatings, (ii) encapsulated, (iii) barcode, or (iv) mixed.



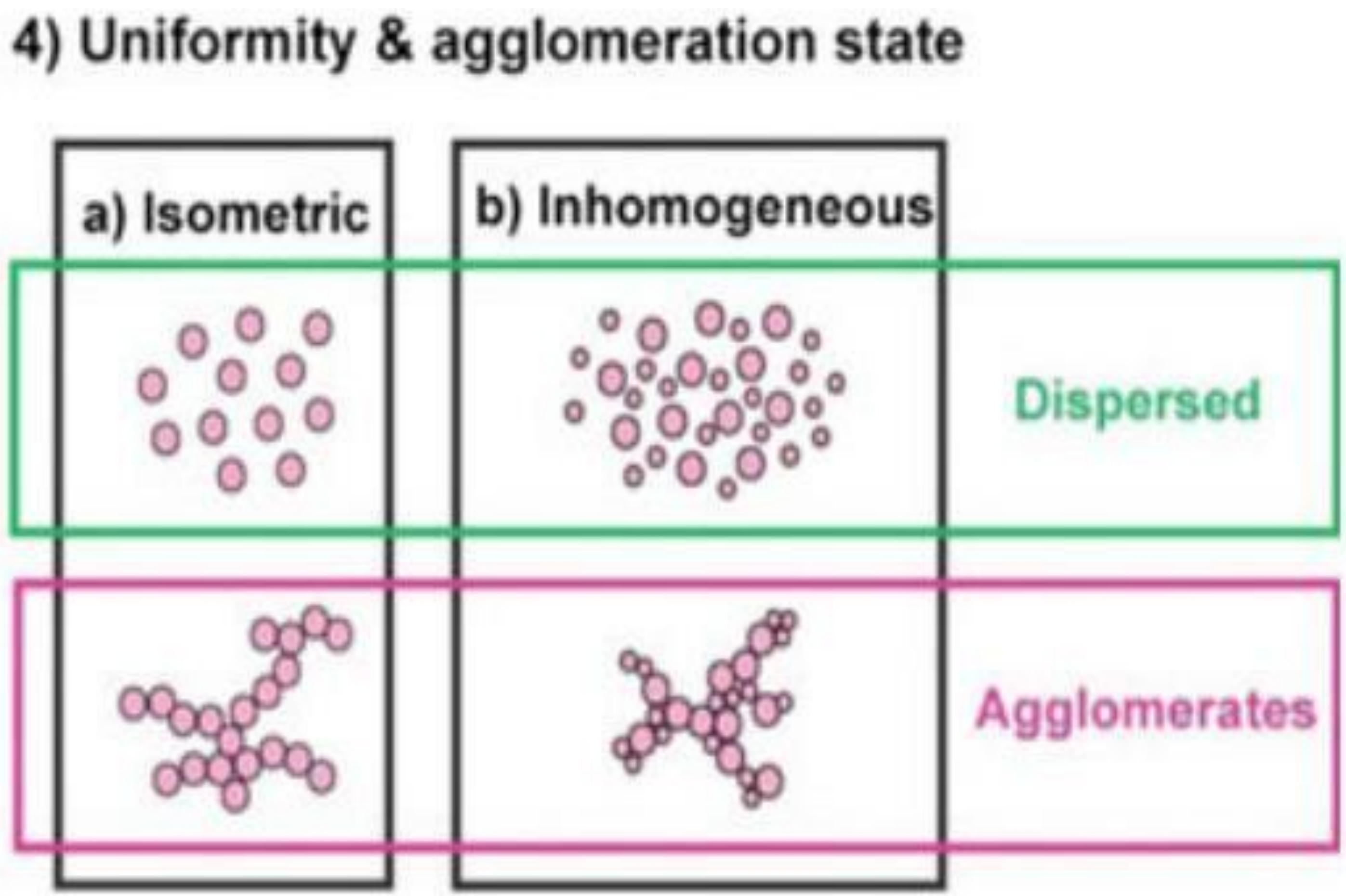
Classification of Nanomaterials

Based on Uniformity and agglomeration State

- According to their uniformity, nanoparticles can be classified as isometric and inhomogeneous.

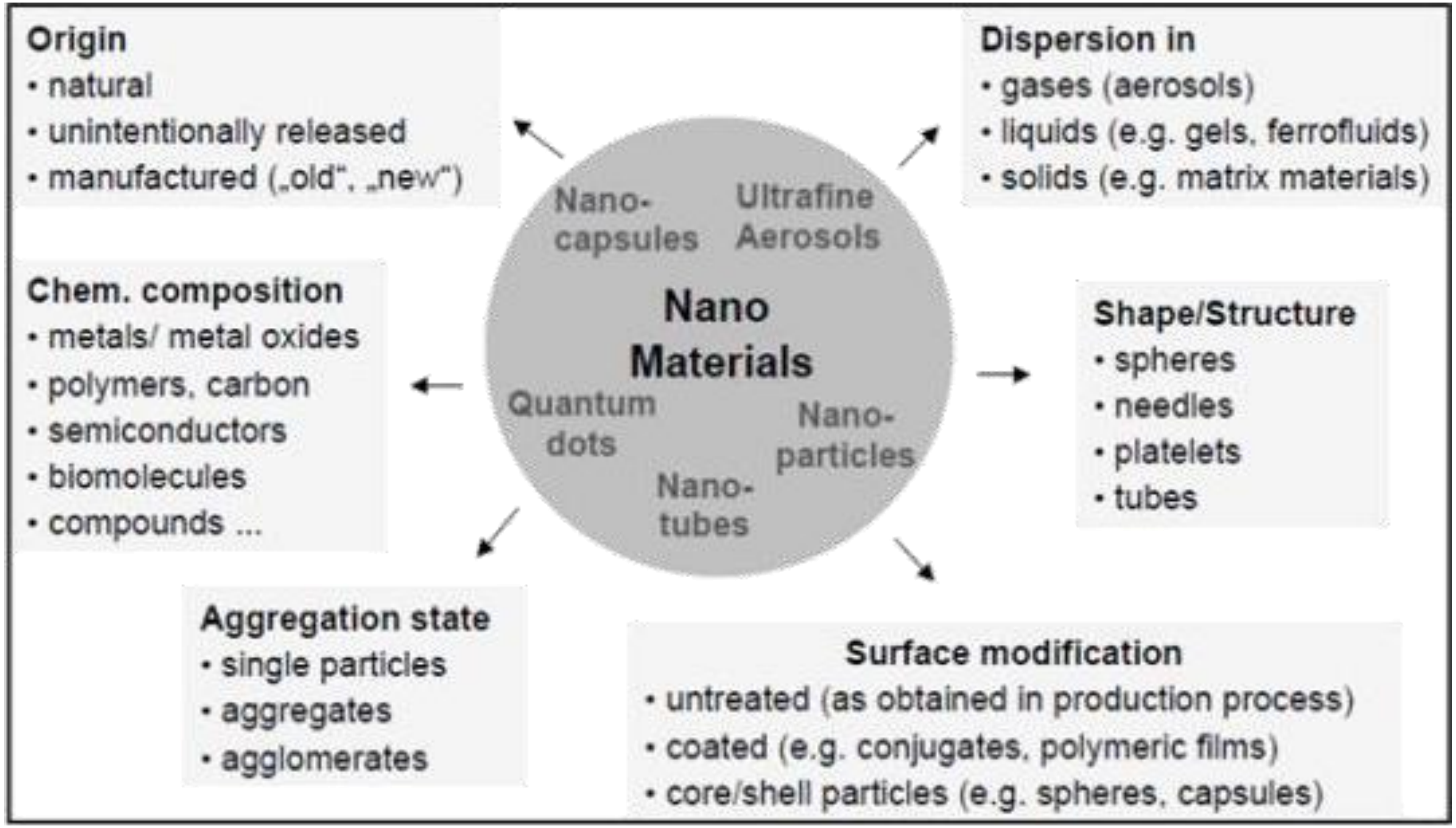
- From the point of view of their agglomeration status, nanoparticles can be dispersed or agglomerate.

- Their agglomeration state depends on their electromagnetic properties, such as surface charge and magnetism.



Characteristics of Nanomaterials / Characterization

- Shape: various shapes and structures such as spherical, needle-like, tubes, platelets, etc.
- Chemical composition: metals/ metal oxides, polymers, compounds as well as biomolecules.
- Aggregation state: Under ambient conditions nanoparticles tend to stick together and form aggregates and agglomerates: dendritic structure, chain or spherical structures (size range –micrometer).



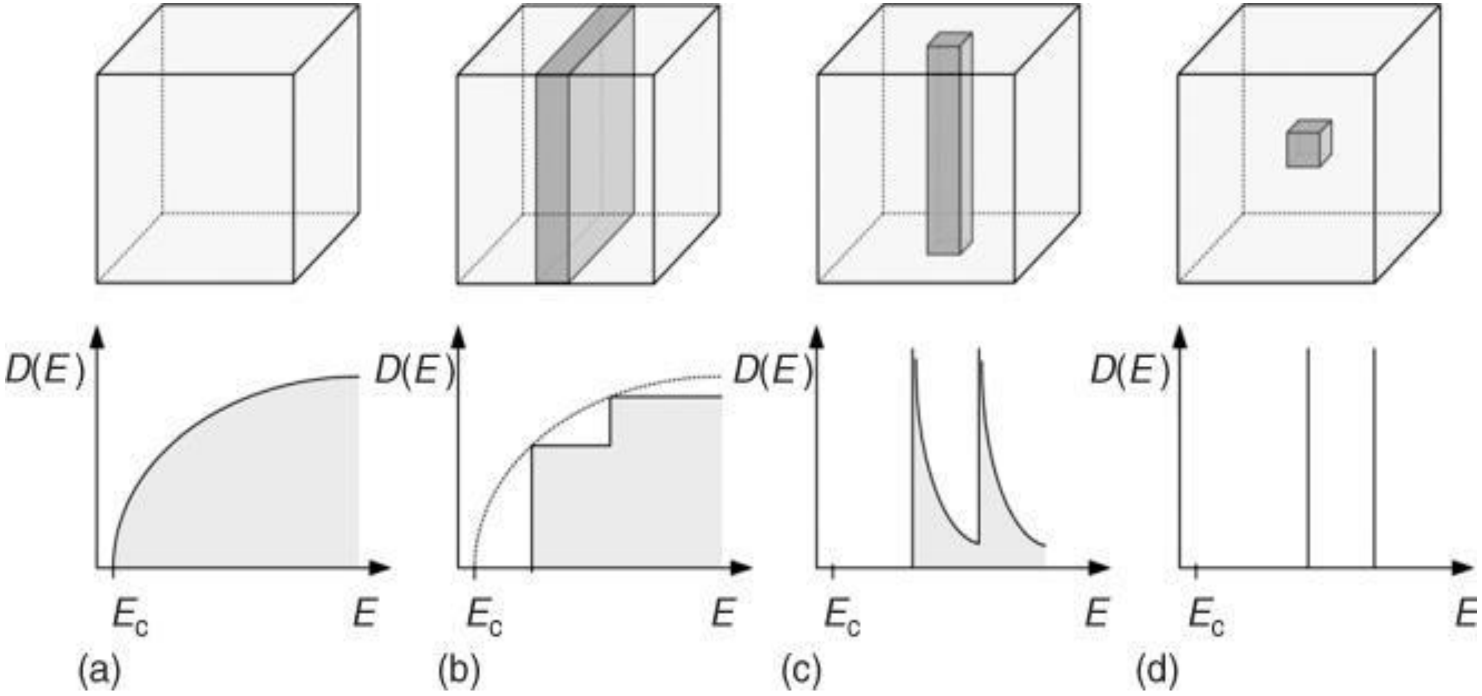
Quantum Confinement in Nanomaterials

What is confinement

Confined electronic systems in which carriers, either electrons or holes are free to move only in a restricted number of dimensions. Density of states becoming discrete along the confinement direction

What is Density of states (DOS) function ?

the number of states per interval of energy at each energy level that are available to be occupied by electrons.



3D (bulk) , desity of states, $\rho(E)\,\alpha\, E^{\frac{1}{2}}$

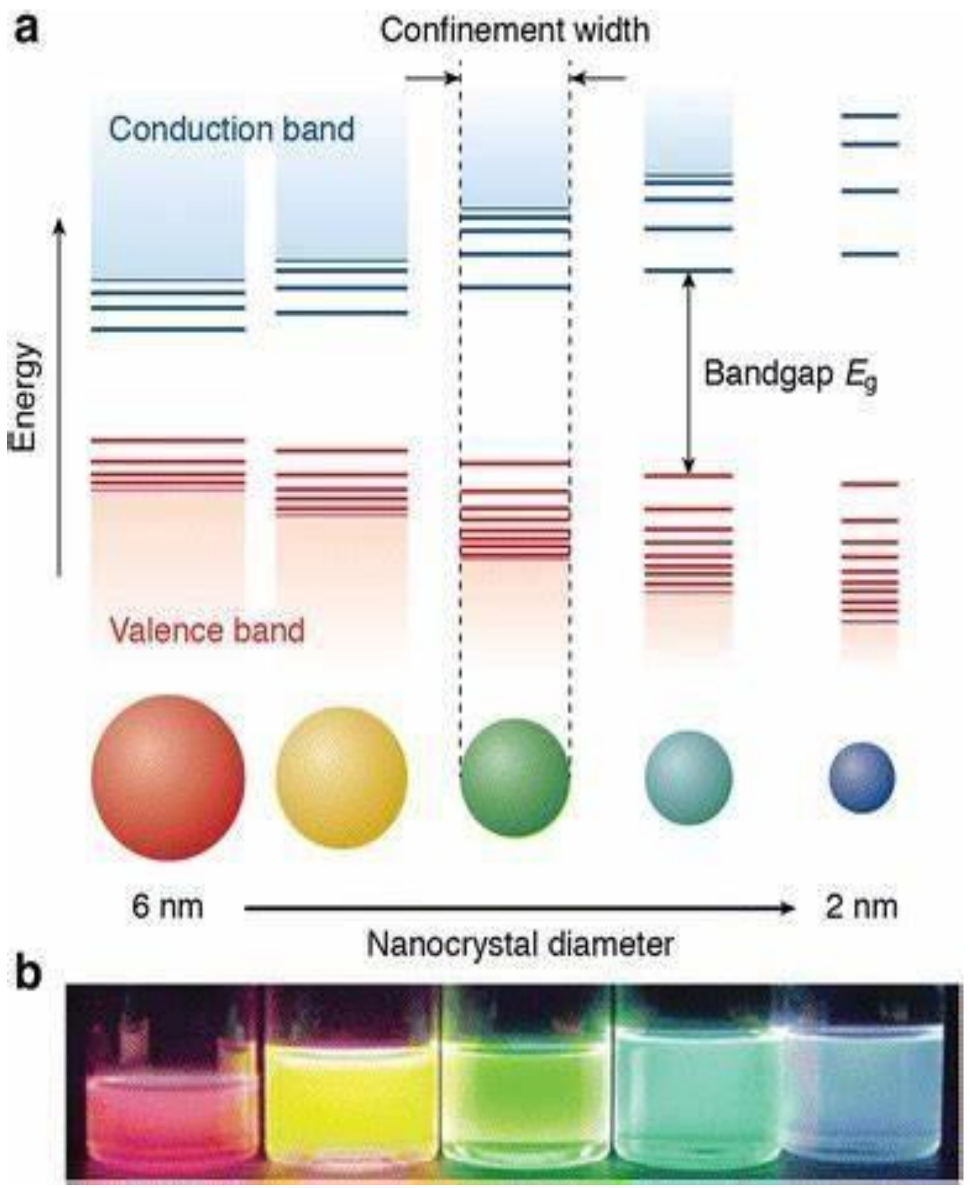
2D (Quantum well), density of state, $\rho(E)\,\alpha\, m^{*}/\pi\hbar^{2}$ (constant)

1D (Quantum wire), density of states, $\rho(E)\,\alpha\, E^{-\frac{1}{2}}$

0D (Quantum dot), density of states, $\rho(E)\,\alpha\, \delta(E)$

Quantum Confinement in Nanomaterials

- The quantum confinement effect is observed when the size of the particle is too small to be comparable to the de Broglie wavelength of the electron.
- The confinement means to confine the motion of randomly moving electron to restrict its motion. The result of this confinement in space is the quantization of their energy (discrete energy levels).
- **The energy spectrum becomes discrete measured as quanta. This situation of discrete energy levels is called quantum confinement.**
- When the material size is at nanoscale, Quantum confinement makes the energy levels discrete and this widens up the band gap, ultimately **band gap increases**. So, these affects electronic and optical properties of the nanocrystals.



OIP.SvHVb7KUtVdoXQSWrhVcQAAAAA (387×441) (bing.com)

Why nanomaterials are important?

- At the Macro Scale, the most of the properties are not, but at the nanoscale everything will change including colour, melting point, electrical properties, electronic properties, magnetic properties and chemical properties.

- This is due to the difference in the nature of interactions between atoms in nanostructures and in bulk materials. Materials reduced to the nanoscale can suddenly show very different properties compared to what they exhibit on a macroscale (bulk state).

Also, Nanomaterials have a much greater surface area to volume ratio than their conventional forms (bulk or 3D)

The various improved properties of nanomaterials have been explained below:

1. **PHYSICAL PROPERTIES**
2. **MECHANICAL PROPERTIES**
3. **THERMAL PROPERTIES**
4. **ELECTRICAL PROPERTIES**
5. **OPTICAL PROPERTIES**
6. **MAGNETIC PROPERTIES**

(1) PHYSICAL PROPERTIES

- SURFACE AREA TO VOLUME RATIO
- **SURFACE AREA TO VOLUME RATIO is very large for nanomaterials.**
- To understand this concept, consider a spherical material of radius 'r'

$$\frac{\text{Surface area of the sphere}}{\text{Volume of the sphere}} = \frac{4\pi r^2}{\frac{4}{3}\pi r^3} = \frac{3}{r}$$

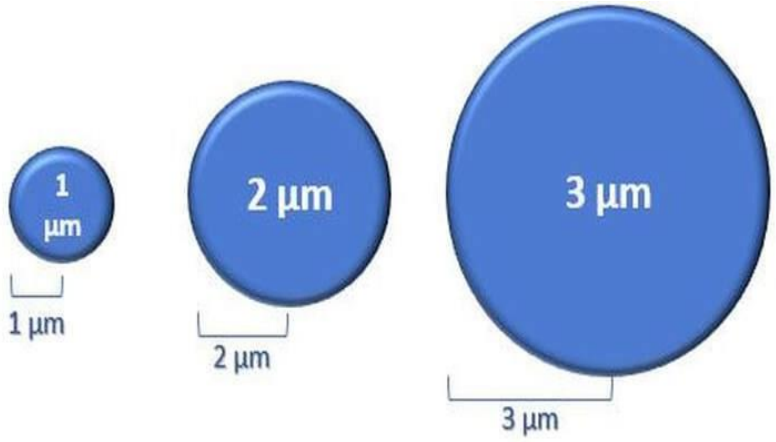
- **As the size of the sphere decreases, surface area to volume ratio increases**.

Application of surface property – drug delivery , catalysis

➢ COLOUR appearance

➢ When the material size is at nanoscale, Quantum confinement makes the energy levels discrete and this widens up the band gap, ultimately band gap increases.

➢ **With reducing size of the particle** the density of states becomes more quantized and the band gap shifts to higher energies (shorter wavelengths) and **the absorption spectrum shows a blue shift.**



$Diameter_{(sphere)}$	1 µm	2 µm	3 µm
$Surface\ Area_{(sphere)} = 4\pi r^2$	3.14 μm^2	12.56 μm^2	28.26 μm^2
$Volume_{(sphere)} = \frac{4\pi r^3}{3}$	0.52 μm^3	4.19 μm^3	14.18 μm^3
Surface Area-to-Volume Ratio	6:1	3:1	2:1

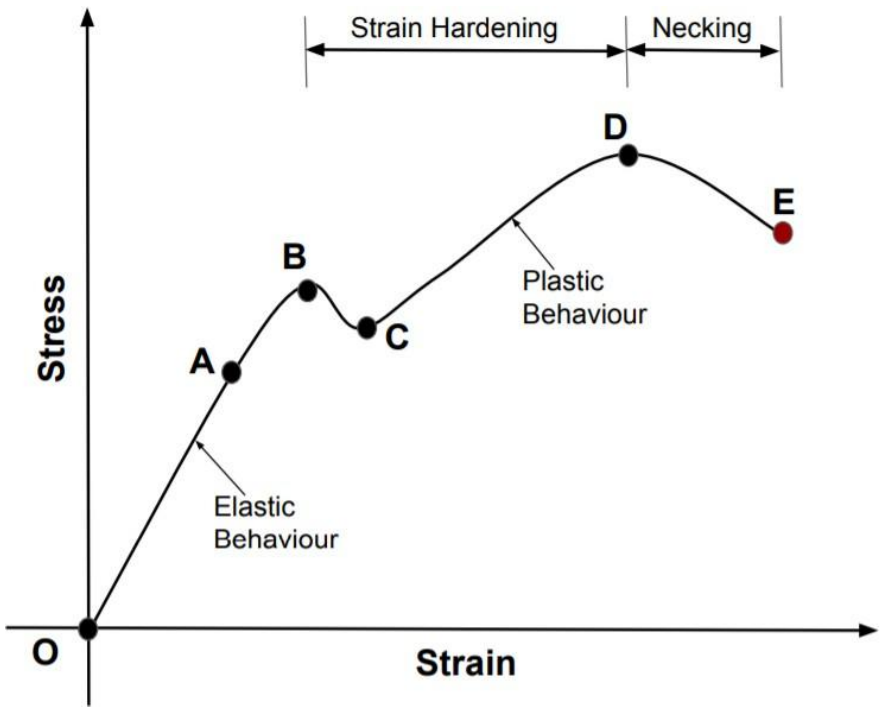
volume-to-surface-area-ratio_2.jpg (995×731) (scientistcindy.com)

(2) MECHANICAL PROPERTIES

- **ELASTICITY**
- Elasticity characterizes the ability of a material to resist elastic deformation, i.e., stiffness.
- The relationship between stress and strain are represented by a linear relationship,

$$\sigma = Y\,\varepsilon$$

- Where σ is stress, ε is strain, and Y is Young's modulus or modulus off elasticity.
- **In case of nanomaterials, this elastic relationship is nonlinear due to the nonlinear surface effect.**
- It is found that externally applied loading should be responsible for the softening of the elastic modulus of a Nano-film.



OA : Proportional Limit
B : Upper Yield Stress Point
C : Lower Yield Stress Point
D : Ultimate Stress Point
E : Fracture

[Stress-Strain-Curve-For-Ductile-Materials.png (1078×645) (smlease.com)]

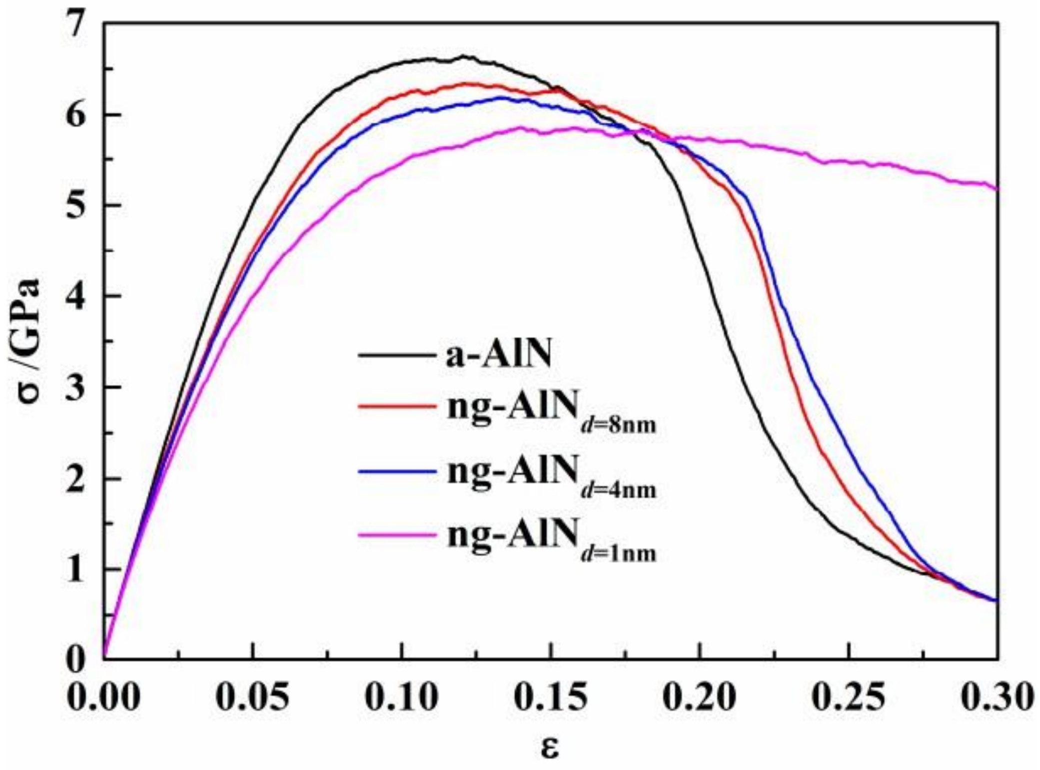
(2) MECHANICAL PROPERTIES

- **HARDNESS AND DUCTILITY**
- Yield stress, for materials with grain size d, is found to follow the Hall– Petch relation:

$\alpha_y = \alpha_0 k d^{-1/2}$, where α_0 the friction stress apposing dislocation motion and k is a constant.

- As grain size is in the nanoscale regime (< 100 nm), **hardness increases with decreasing grain size** and can be factors of 2 to 7 times harder for pure nanostructured metals (10 nm grain size) than for large-grained (> 1 µm) metals.

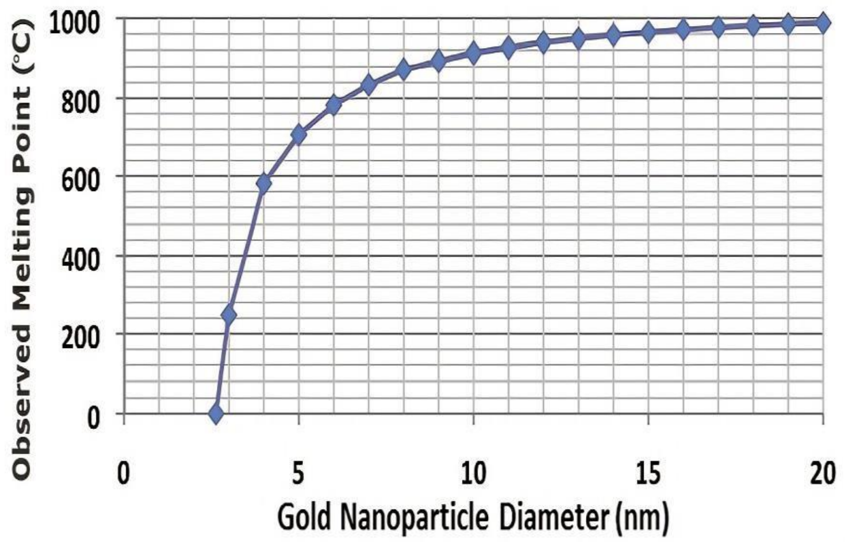
- The **large increase in yield stress (hardness) in nanocrystalline(NC) materials with size reduction** suggest that fracture stress can be lower than yield stress and **therefore it result in reduced ductility.**



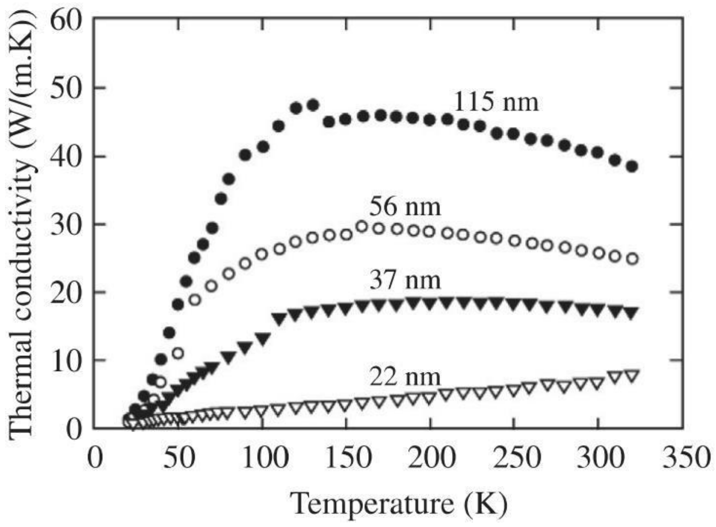
Super Ductility of Nanoglass Aluminium Nitride. Nanomaterials, 9(11), 1535 | 10.3390/nano9111535

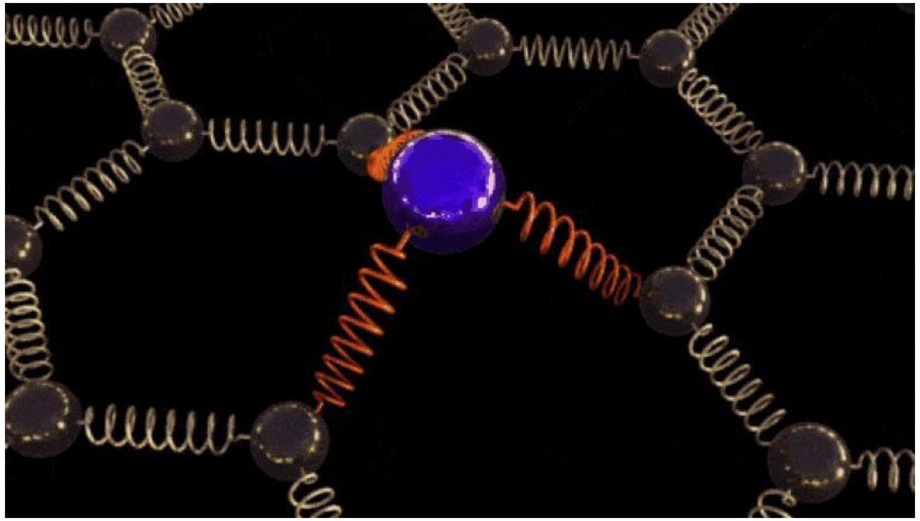
(3) THERMAL PROPERTIES

- **MELTING POINT**
- **The melting point of Nano-gold decreases from 1200 K to 800 K as the size of particles decreases from 300Å to 200Å.**
- At higher temperatures, there is breakdown in symmetry of nanoparticles due to high thermal vibrations of surface atoms in nanostructures.



- **THERMAL CONDUCTIVITY**
- **Thermal conductivity reduces with particle size.**
- The increase in thermal conductivity is explained by increase in electron mobility, the decreases in thermal conductivity after some temperature is a response to phonon scattering.





thermal vibration in nanomaterial gif - Bing

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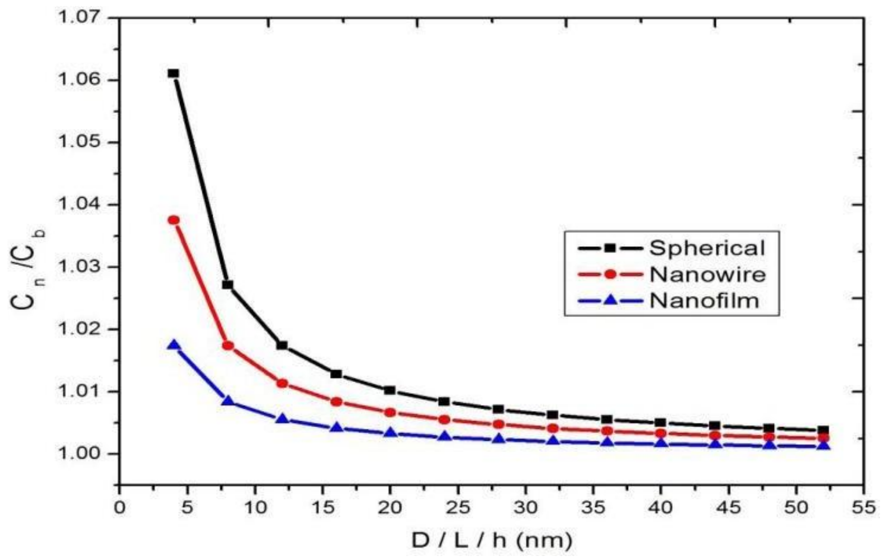
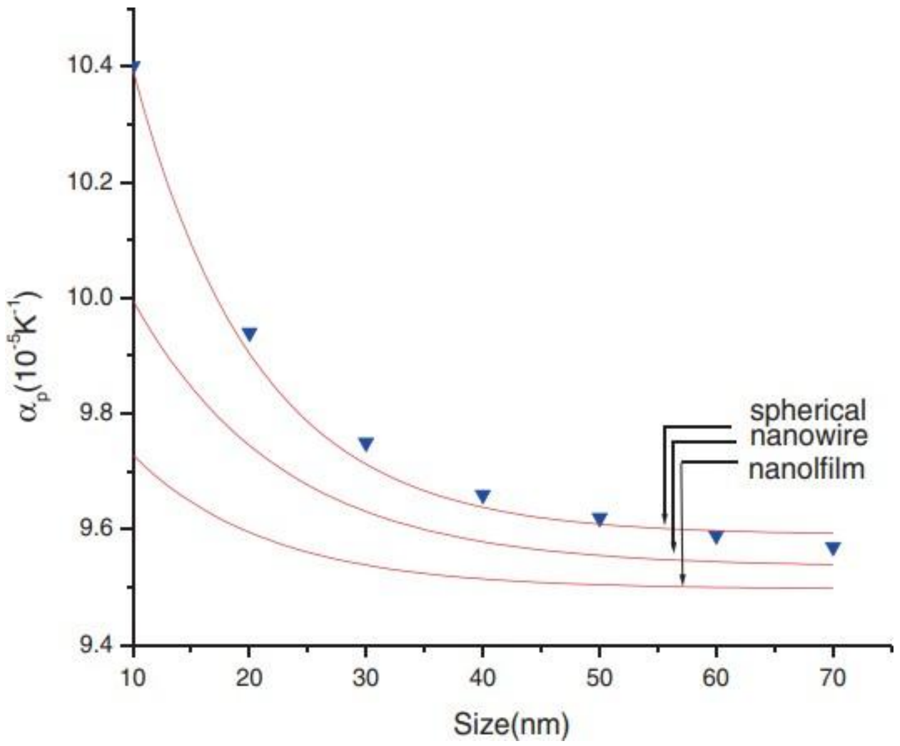
(3) THERMAL PROPERTIES



- **SPECIFIC HEAT**
- For bulk material, specific heat is a function of temperature. Moreover, for nanomaterials, the specific heat depends on temperature as well as on the size.
- The grain size less than 10nm, C_n/C_b (C_n and $C_b$is Specific Heat Capacity for Nano material and bulk material, respectively.) increases which indicates that **specific heat is inversely related to the grain size**.



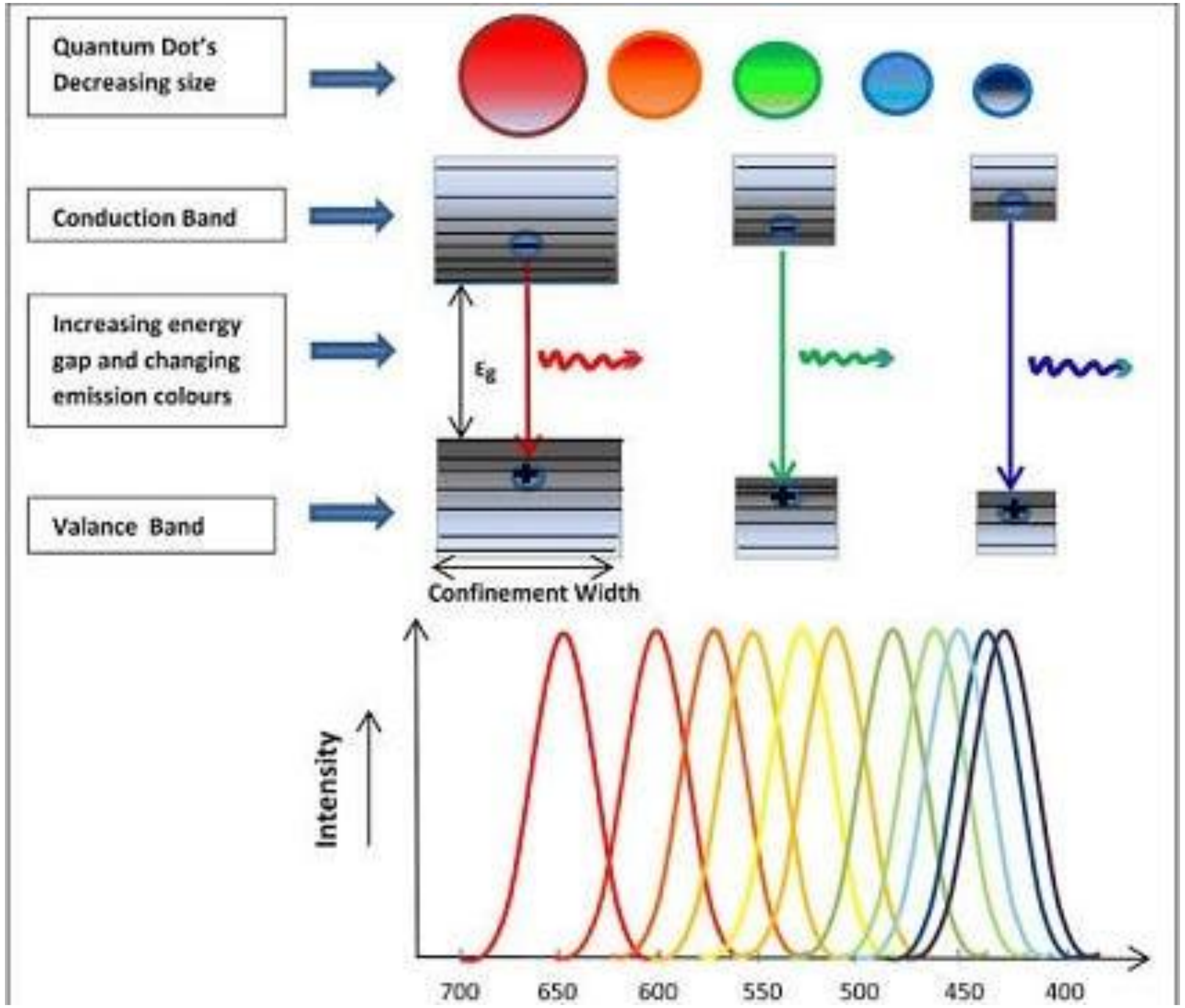
- **THERMAL EXPANSION**
- The size-dependent thermal expansion coefficient of Se for different shapes of nanomaterial (spherical, nanowire and Nano-film) with increasing grain size shown in fig.
- **It is seen that the thermal expansion coefficient increases with decreasing grain size.**

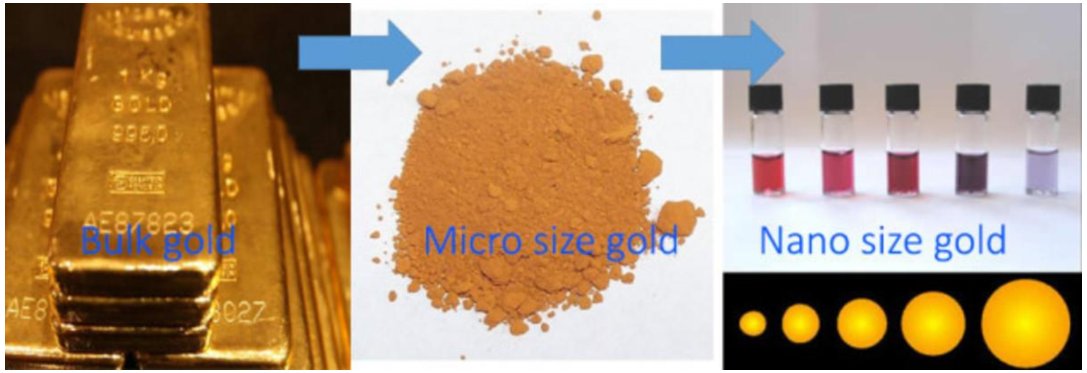
(4) ELECTRICAL PROPERTIES

- In bulk materials conduction electrons are delocalized and travel ‘freely’ till they are scattered by phonons, impurities, grain boundaries etc.
- In nanoscale conductors, two effects become important:
  - **Quantum effect**: **Continuous (‘nearly’) bands** are **replaced** with **discrete energy states**
  - **Classical effect**: **mean free path** (MFP) for **inelastic scattering becomes comparable to the size of the system** (can lead to **reduction in scattering events**).
- Energy storage applications – 5 marks
- **In semiconductors quantum confinement of both the electron and hole leads to an increase in the effective band gap of the material with decreasing crystallite size.**
  These effects can lead to altered conductivity in nanomaterials.
- **In nanoceramics and in nanomagnetic composites, electrical conductivity increases with reducing particle size**.
- **In metals, electrical conductivity decreases with reducing particle size.** By reducing the size of metal particles from bulk to nano, the energy bands become narrower and hence the ionization potential energy increases.

(5) OPTICAL PROPERTIES

- Bulk metal samples absorb electromagnetic radiation (say visible region). Thin films of metals may partially transmit, just because there is insufficient material to absorb the radiation. Au films few 10s of nm thick become partially transparent.
- At very small sizes, metal nanoparticles can develop a bandgap (can become a semiconductor or insulator).
- On decreasing the size, the energy level spacing increases (Quantum Size Confinement Effect) and the band gap energy increases, shifts to higher energies (shorter wavelengths). The absorption spectrum shows a blue shift.
- In semiconductor quantum dots, optical absorption and emission shift to the blue (higher energies) as the size of the dots decreases.





Mechanism Behind the Shifts

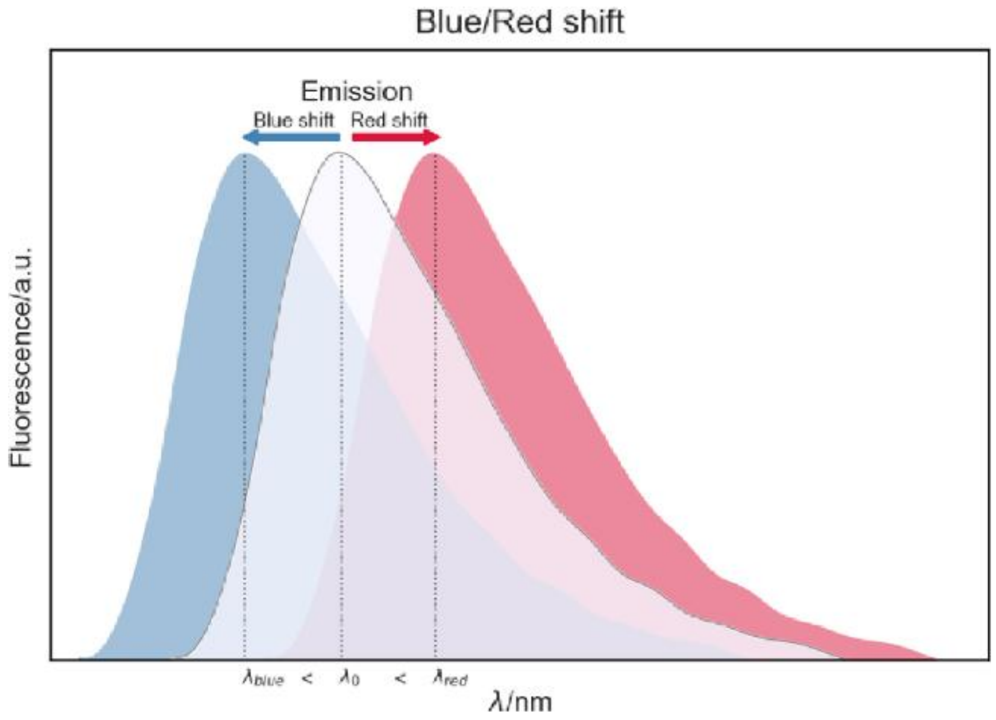
Size and Shape Effects:

The size and shape of nanoparticles significantly influence their optical properties.

Smaller nanoparticles tend to exhibit **blue shifts.**

Blue shift in nanoparticles refers to the phenomenon where the absorption edge of light shifts to shorter wavelengths (higher energy) as the size of the nanoparticle decreases, often due to quantum confinement effects.

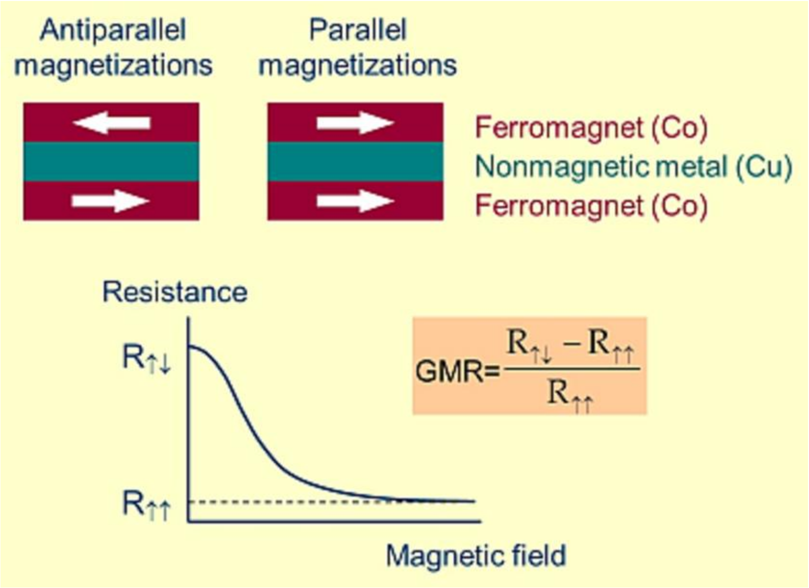
In cases, where nanoparticles are embedded in any medium which increases their polarizability, they may show red shifts. This is due to a phenomena called Surface Plasmon Resonance,(SPR) where the conduction electrons interact with the the incident light photons.



(6) MAGNETIC PROPERTIES

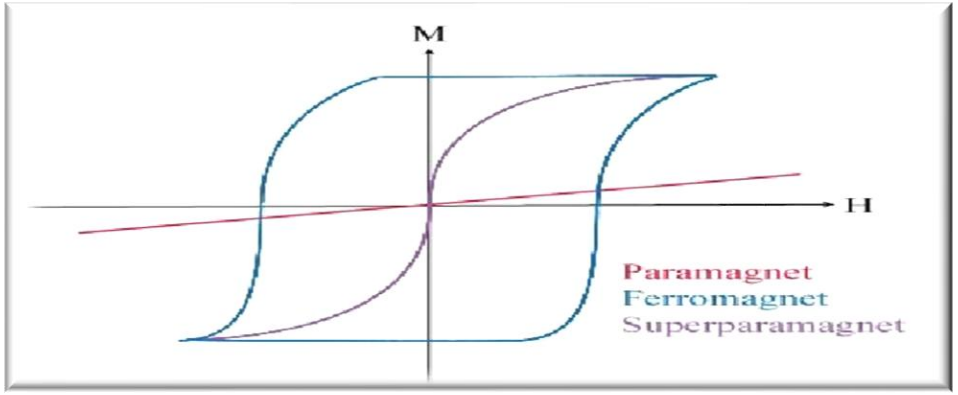
The magnetic properties of nanomaterials are different from that of bulk materials.

- **There is an increase in magnetic moment, as we decrease the dimensionality of the system.**
- **Some of the possibilities when we go from bulk to nano are:**
  - **I. Ferromagnetic particles becoming single domain.**
  - **II. Superparamagnetism in small ferromagnetic particles (i.e. particles which are ferromagnetic in bulk)**
  - **III. Giant Magnetoresistance effect in hybrids (layered structures)**
  - **IV. Antiferromagnetic particles (in bulk) behaving like ferromagnets etc.**



Examples:

- **Transition metals** are ferromagnetic in bulk but they exhibit super paramagnetism in the nanophase.
- Na, K and Rh are paramagnetic in bulk, but they are ferromagnetic in nanophase.
- Cr is anti- ferromagnetic in bulk, it shows frustrated paramagnetic property in nanophase.



SYNTHESIS OF NANOMATERIALS

Top Down approach

The top down approach refers to slicing or successive cutting of a bulk materials to get nano-sized particles.

In top down method or technique the starting materials is solid state.

Nano-materials are synthesized by breaking down bulk solid into nano-sized and provides desired shape and order.

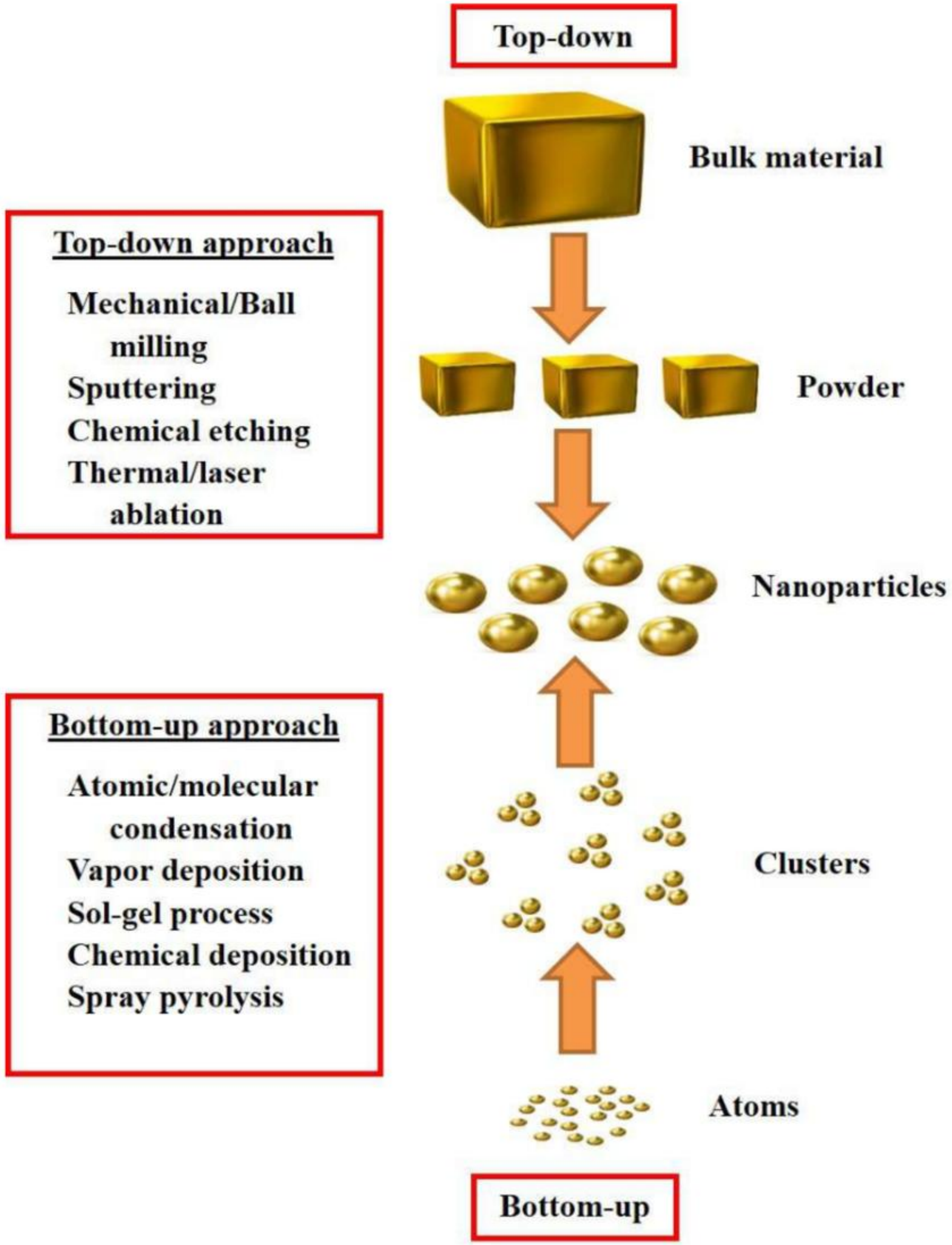
Bottom Up approach

Bottom-up approach refers to the build up of a materials from the bottom : atom by atom, molecule by molecule.

Atom by atom deposition leads to formation of self-assembly of atoms/molecule and clusters.

This clusters come together to form self-assembled monolayer on the surface of substrate.

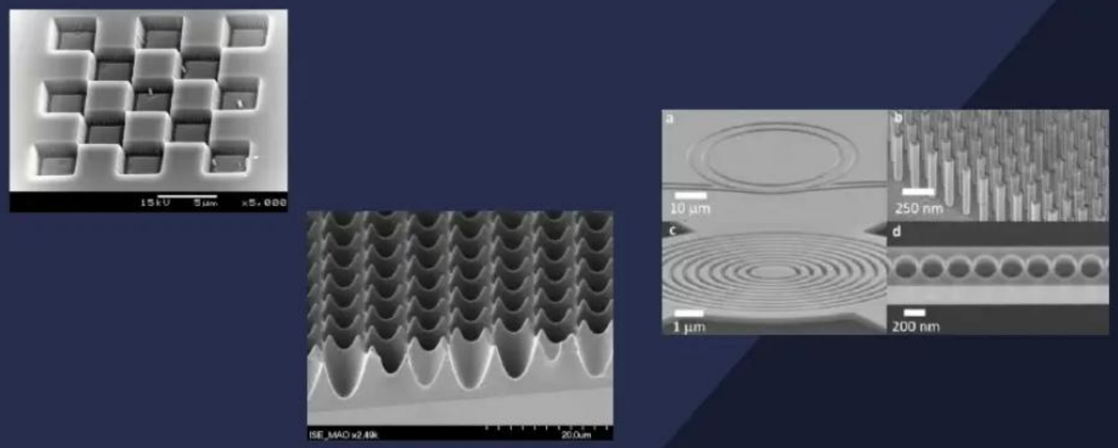
All the bottom-up technique, the starting material is either gaseous state or liquid state of matter.



Top Down approach

TOP DOWN APPROACHES

- Mechanical /Ball Milling
- Chemical etching
- Nanolithography
- Laser/Thermal ablation
- Molecular Beam Epitaxy



SEM images of nanostructures created using various nanolithography techniques

1. Nanolithography

- Refers to the process of imprinting , writing, or etching patterns on a tiny scale to build extremely small structures.
- Nanolithography is primarily used in a variety of technological fields ranging from electronics to biomedicine.
- Nanolithography is a versatile and effective technology for creating nanoscale patterns.

Top Down approach

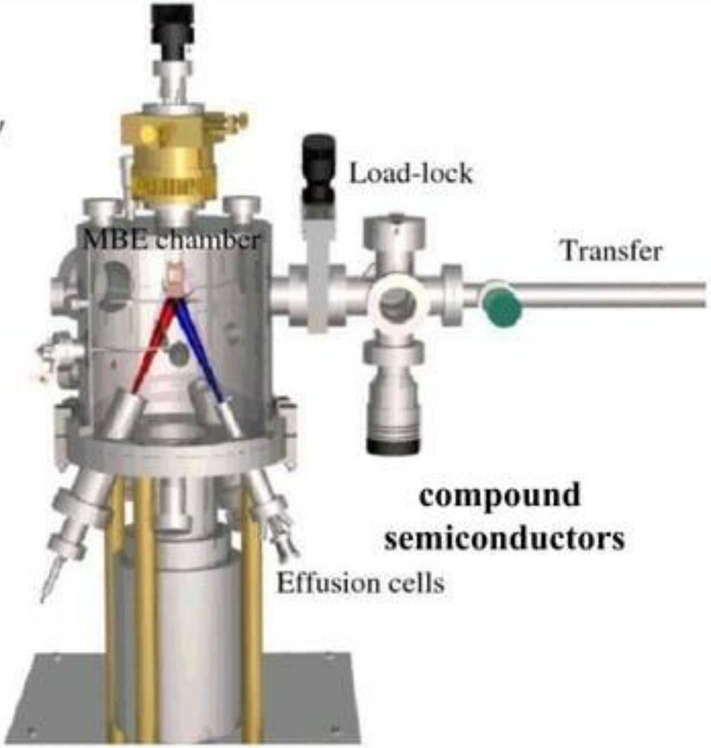
2. Molecular Beam Epitaxy

Molecular beam epitaxy (MBE)

The advantages of MBE

- Growth is preformed in UHV environment minimizing impurity incorporation;
- *In-situ* growth monitoring is possible;
- Each material is vaporized independently from its own effusion cell;
- Multiple sources are used to grow alloy films and hetero structures;
- Deposition is controlled at sub-monolayer level.

Extremely flexible technique since growth parameters are varied independently.



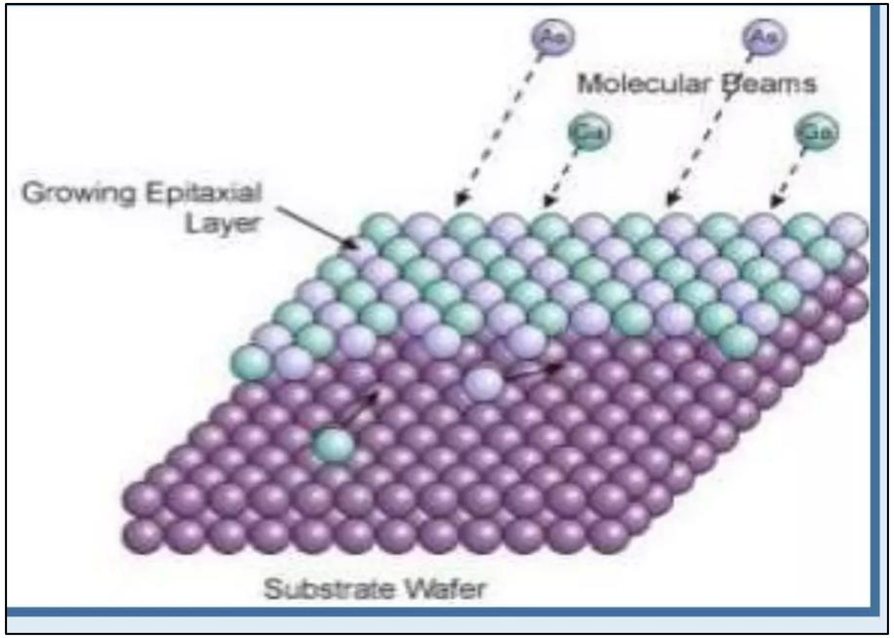
Invented in late 1960's at Bell Laboratories by J. R. Arthur and A. Y. Cho.

What is epitaxy?

- Epitaxy is the process of growing a thin crystalline layer on a crystalline substrate.
- Epitaxial layer is always thinner than the substrate

Epitaxial grow techniques:

Vapor-Phase Epitaxy	Liquid Phase-Epitaxy	Molecular Beam Epitaxy
VPE is a modification of chemical vapor deposition	LPE is a method to grow semiconductor crystal layers from the melt on solid substrates.	MBE is based on an UHV(Ultra High Vacuum) technique.
Chemical reactions involved	Chemical reactions involved	No chemical reactions involved.



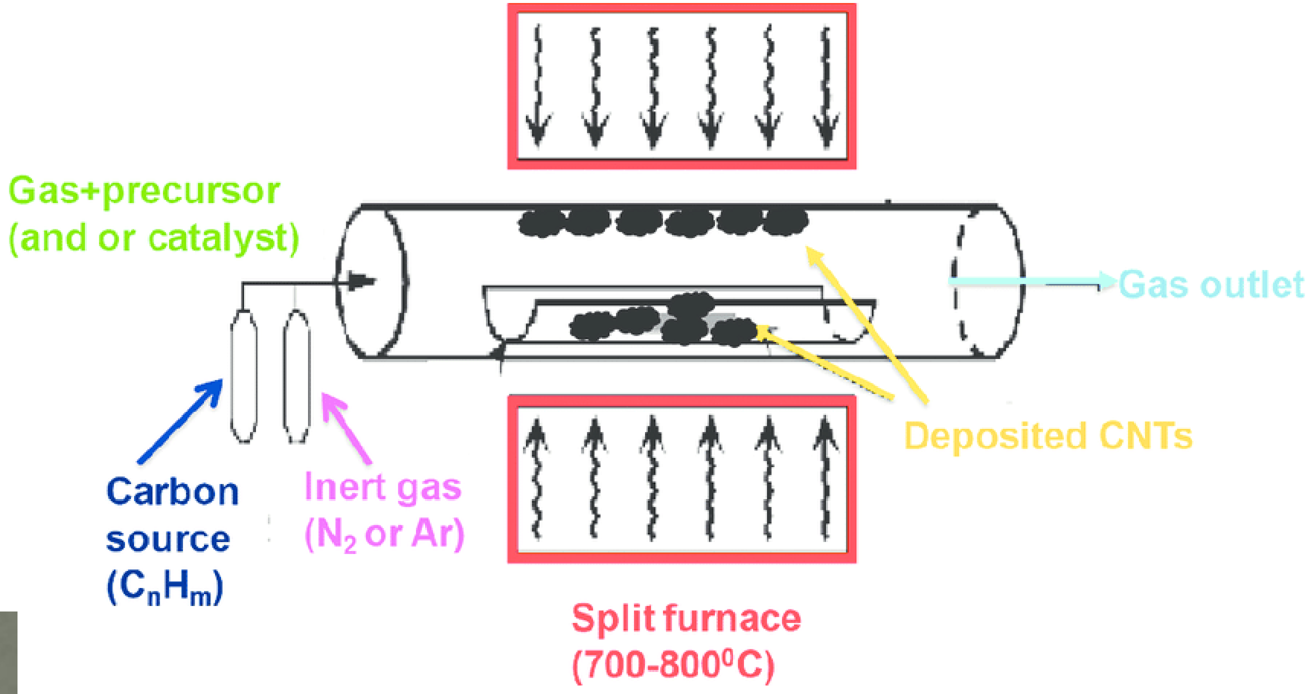
Bottom Up approach

BOTTOM UP APPROACHES

- Co-precipitation method
- Chemical vapor deposition
- Hydrothermal method
- Microwave assisted synthesis
- Sol-gel method
- Biological method
- Microemulsion
- Pyrolysis

- Chemical Vapour Deposition (CVD) is a chemical process used to produce high purity, high performance solid materials.
- In a typical CVD process, the substrate is exposed to one or more volatile precursors which react and decompose on the substrate surface to produce the desired deposit.
- During this process, volatile by-products are also produced, which are removed by gas flow through the reaction chamber.

1. Chemical Vapour Deposition



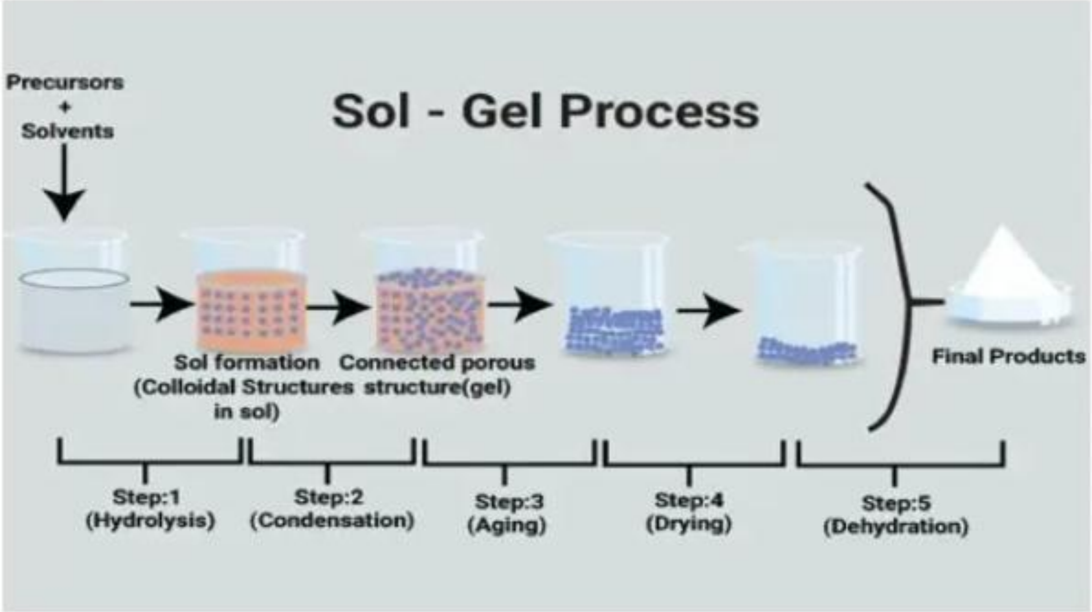
Bottom Up approach

2. Sol-gel

Sol-gel Processing

- The sol-gel process is a wet-chemical technique that uses either a chemical solution (sol short for solution) or colloidal particles (sol for nanoscale particle) to produce an integrated network (gel).

- Metal alkoxides and metal chlorides are typical precursors. They undergo hydrolysis and polycondensation reactions to form a colloid, a system composed of nanoparticles dispersed in a solvent. The sol evolves then towards the formation of an inorganic continuous network containing a liquid phase (gel).



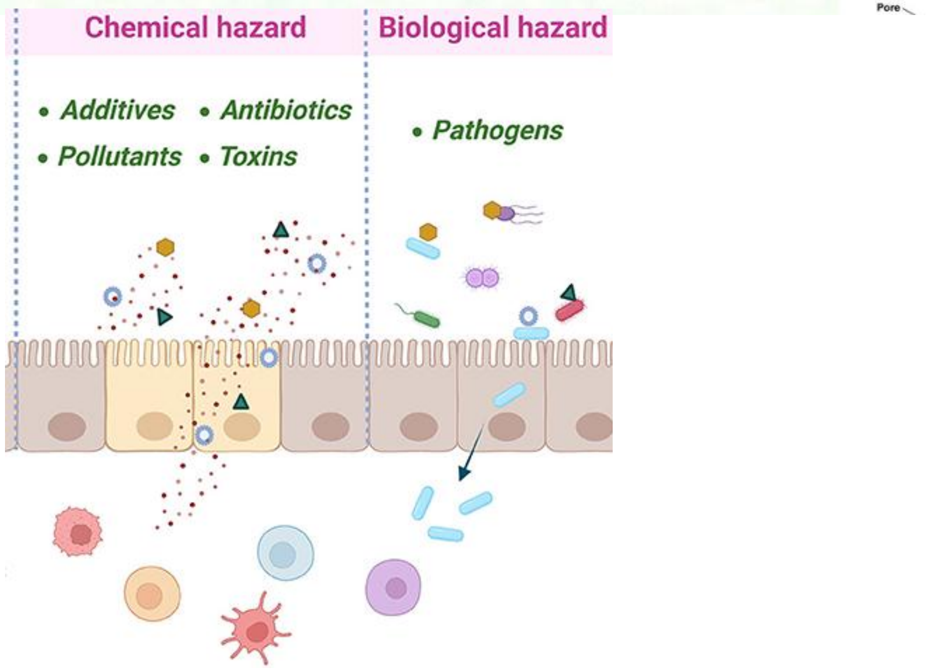
COMPARISON

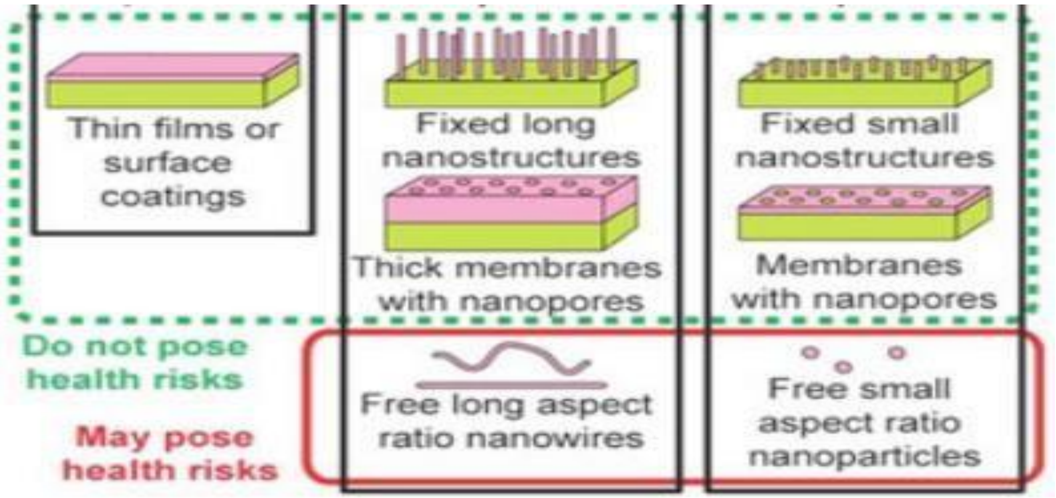
Basis for Comparison	Top-Down Approach	Bottom-Up Approach
Basic	Successive cutting or grinding of bulk material to get nanoparticles	The buildup of material from bottom: atom or molecule to get nanoparticles
Starting materials	Solid-state	The starting material is either gaseous or liquid
Processing method	Physical method	Physical and chemical methods
Advantages	• Large scale production: • Deposition over a large substrate is possible • Chemical purification is not required	• Ultra-fine nanoparticles • Deposition parameters can be controlled • Cheaper method
Disadvantages	• Broad size distribution • Varied particle shape • Control of deposition parameters is very difficult • Expensive technique	• Large scale production is difficult • Chemical purification of nanoparticles is necessary

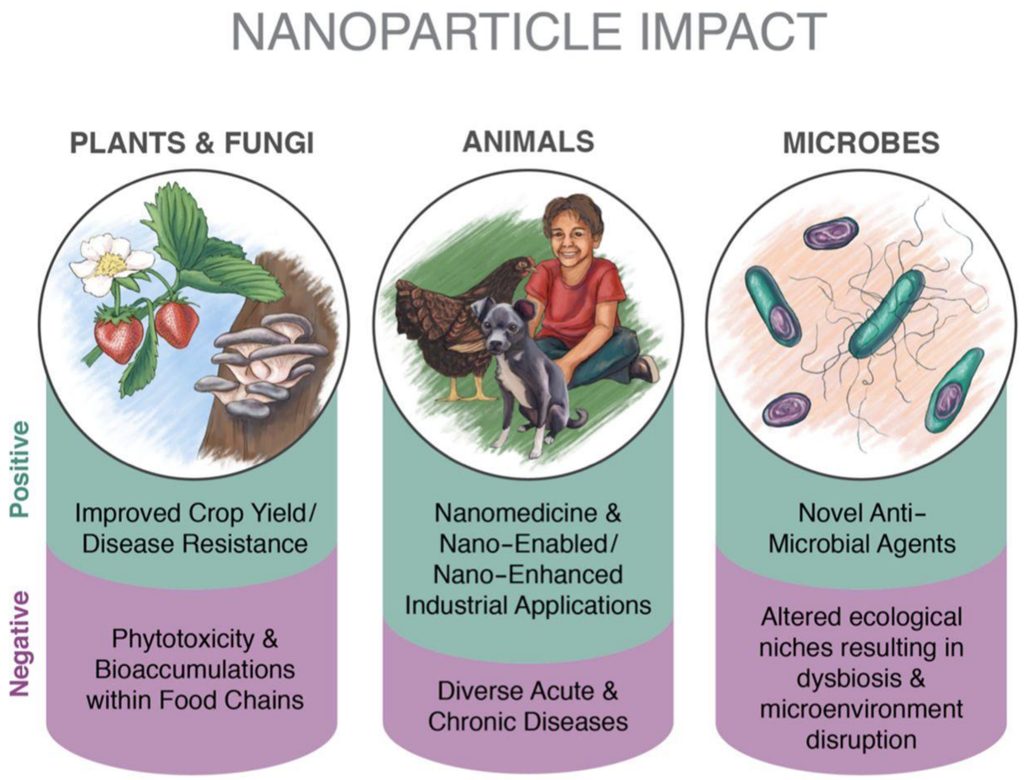
Health Risks of Nanomaterials

The nanomaterials fixed on a substrate or those with nanopores do not pose a health risk, the free nanoparticles can become airborne and may be very toxic to human health.

- Nanoparticles can enter the body by:
  - inhalation,
  - swallowing,
  - penetration through the skin







Materials of the Future- Smart Materials:

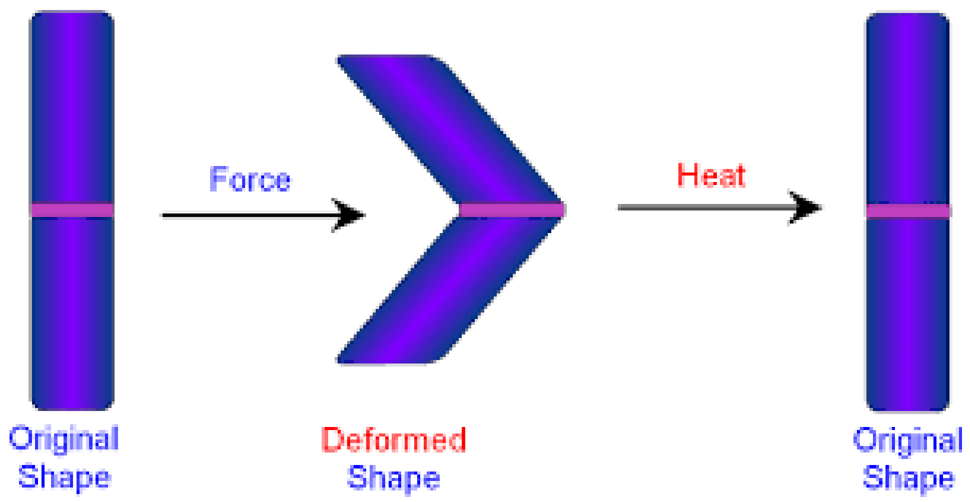
- Smart (or intelligent) materials are a group of new and state-of-the-art materials now being developed that will have a significant influence on many of our technologies.

- **Actuators may be called upon to change shape, position, natural frequency, or mechanical characteristics in response to changes in temperature, electric fields, and/or magnetic fields.**

- Four types of materials are commonly used for **actuators**: shape memory alloys, piezoelectric ceramics, magnetostrictive materials, and electrorheological/ magnetorheological fluids.

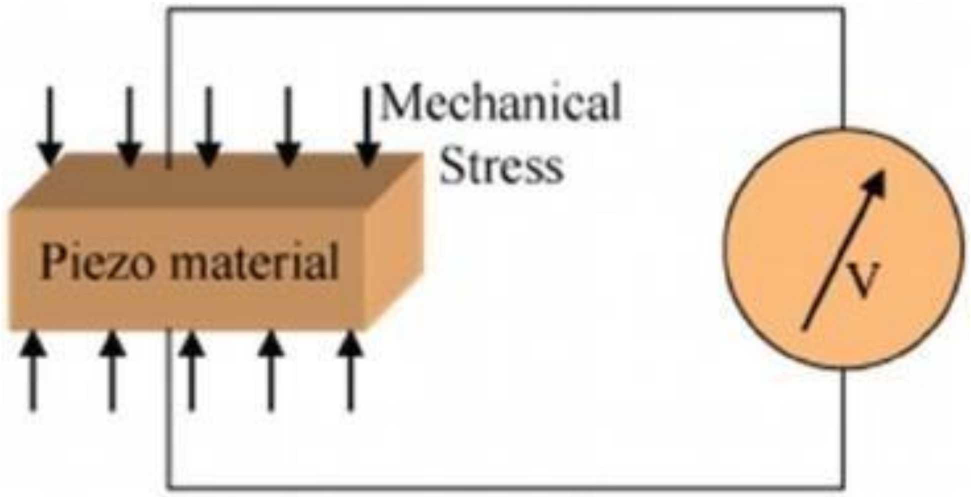
I. ***Shape memory alloys*** are metals that, after having been deformed, revert back to their original shapes when temperature is changed.

Shape memory alloy



Novel Materials

- ***Piezoelectric ceramics*** expand and contract in response to an applied electric field (or voltage); conversely, they also generate an electric field under mechanical stress.



- **Advance Application: one type of smart system is used in helicopters to reduce aerodynamic cockpit noise that is created by the rotating rotor blades.**

- Piezoelectric sensors inserted into the blades, monitor blade stresses and deformations; feedback signals from

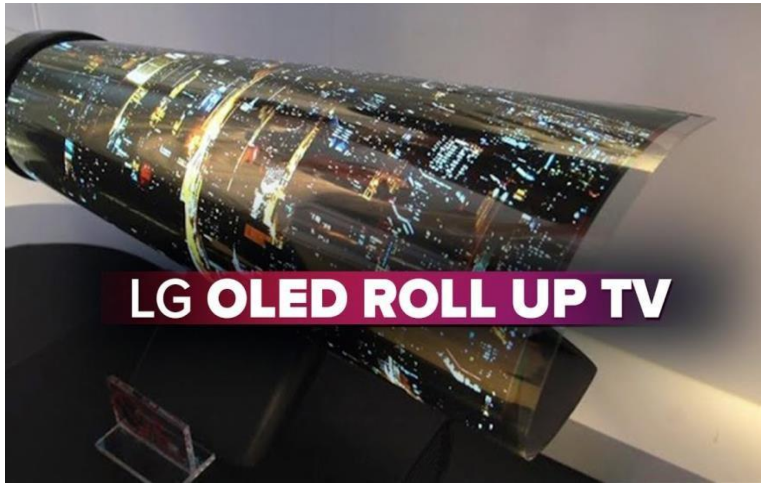
  these sensors are fed into a computer controlled adaptive device, which generates noise cancelling antidose.

Electricity generation by walking

Novel Materials - Nano - Electronics

Nanotechnology in Electronics

- Electrodes made from nanowires enable flat panel displays to be flexible as well as thinner than current flat panel displays.
- Nanolithography is used for fabrication of chips.
- The transistors are made of nanowires, that are assembled on glass or thin films of flexible plastic.
- E-paper, displays on sunglasses and map on car windshields.



Nano in broadcasting:

- **Displays:** Leads to improved display screens with better colors and performance.
- **Nanoradio** – A single CNT will function as a radio
- **NanoVNA**: testing and measuring radio frequency (RF) components like antennas and cables.
- **AV Bridge Nano**: A 4K video bar used for streaming and video conferencing
- **Quantum dot LED TV**

Novel Materials

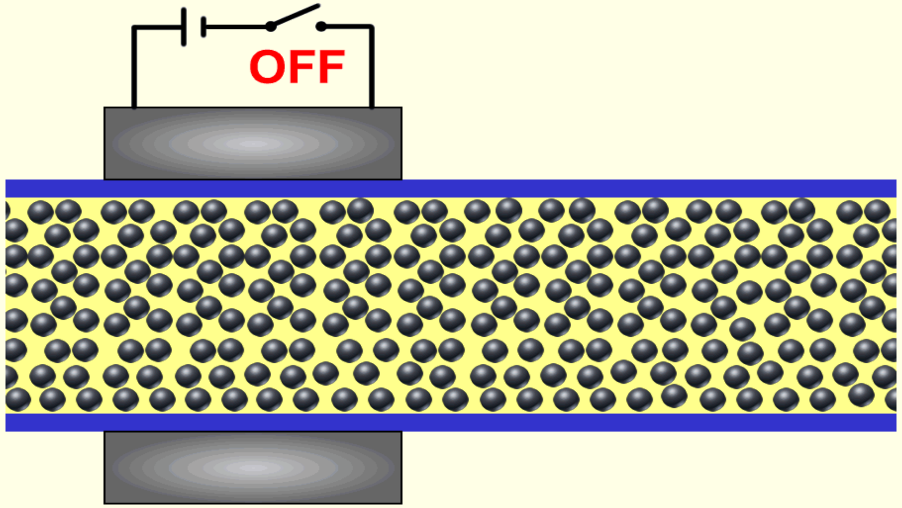
Materials of the Future- Smart Materials:

The behavior of **magnetostrictive materials** is analogous to that of the piezoelectrics, except -- responsive to magnetic fields. The electrorheological and magnetorheological fluids are liquids that experience dramatic changes in viscosity upon the application of electric and magnetic respectively.

- **Magnetorheological dampers are used to improve vehicle suspension systems**
- **provides a smoother ride and better handling**
- **help absorb vibrations in structures, such as bridges and buildings, increasing their stability and safety.**

Magnetic Field OFF Magnetic Field ON

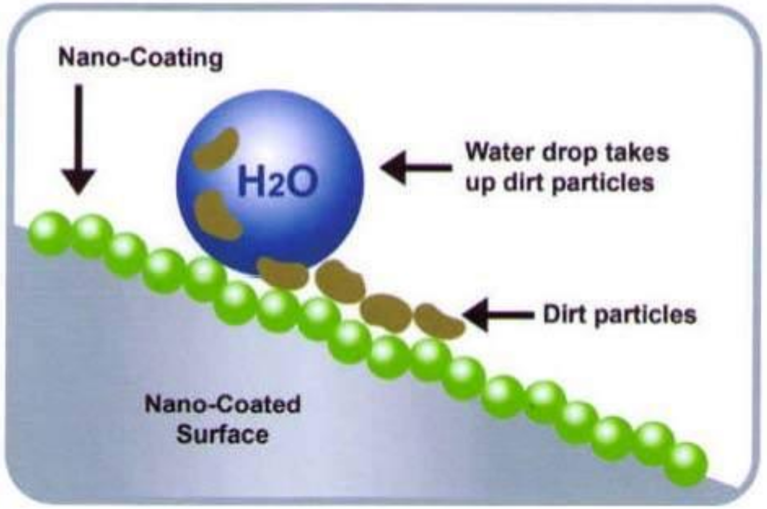
Magnetorheological Fluid



Magnetorheological Fluid

Novel Materials

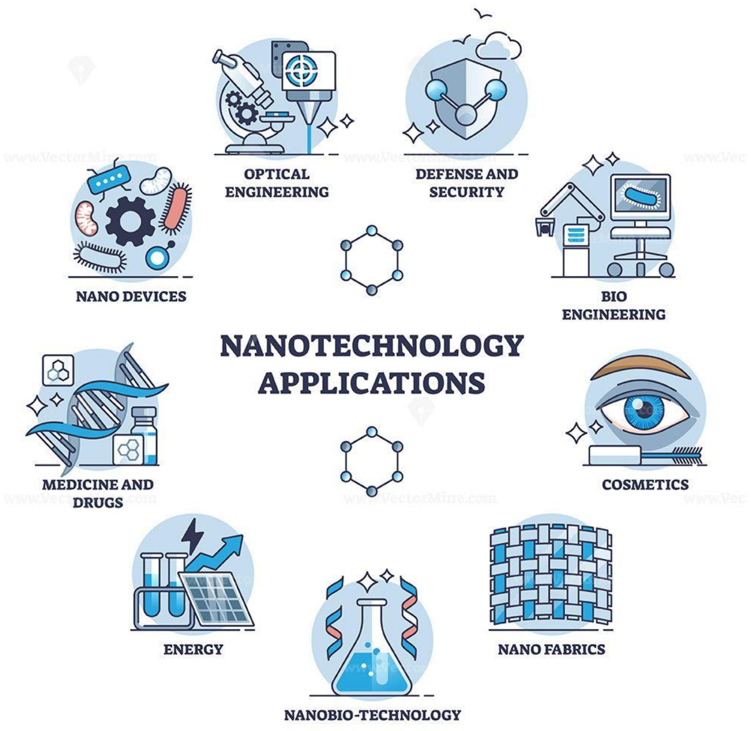
- **Commercial application of Nanomaterials , Textile industry**
- **Sunscreens, cosmetics, sporting goods, stain-resistant clothing, tires, Paints & Varnishes, medicine**
- **Nano-silver for antimicrobial properties; TiO_2 nanoparticles for self-cleaning fabrics.**
- Superhydrophobicity and self-cleaning properties are prevalent in nature in various plants (e.g. lotus).
- Due to the higher contact angle (≥150°), virtually no wetting of the surface takes place on a superhydrophobic surface, leading to the property of self-cleaning. - water repellant textiles, hydrophobicity, self cleaning, anti bacterial UV blocking fabrics

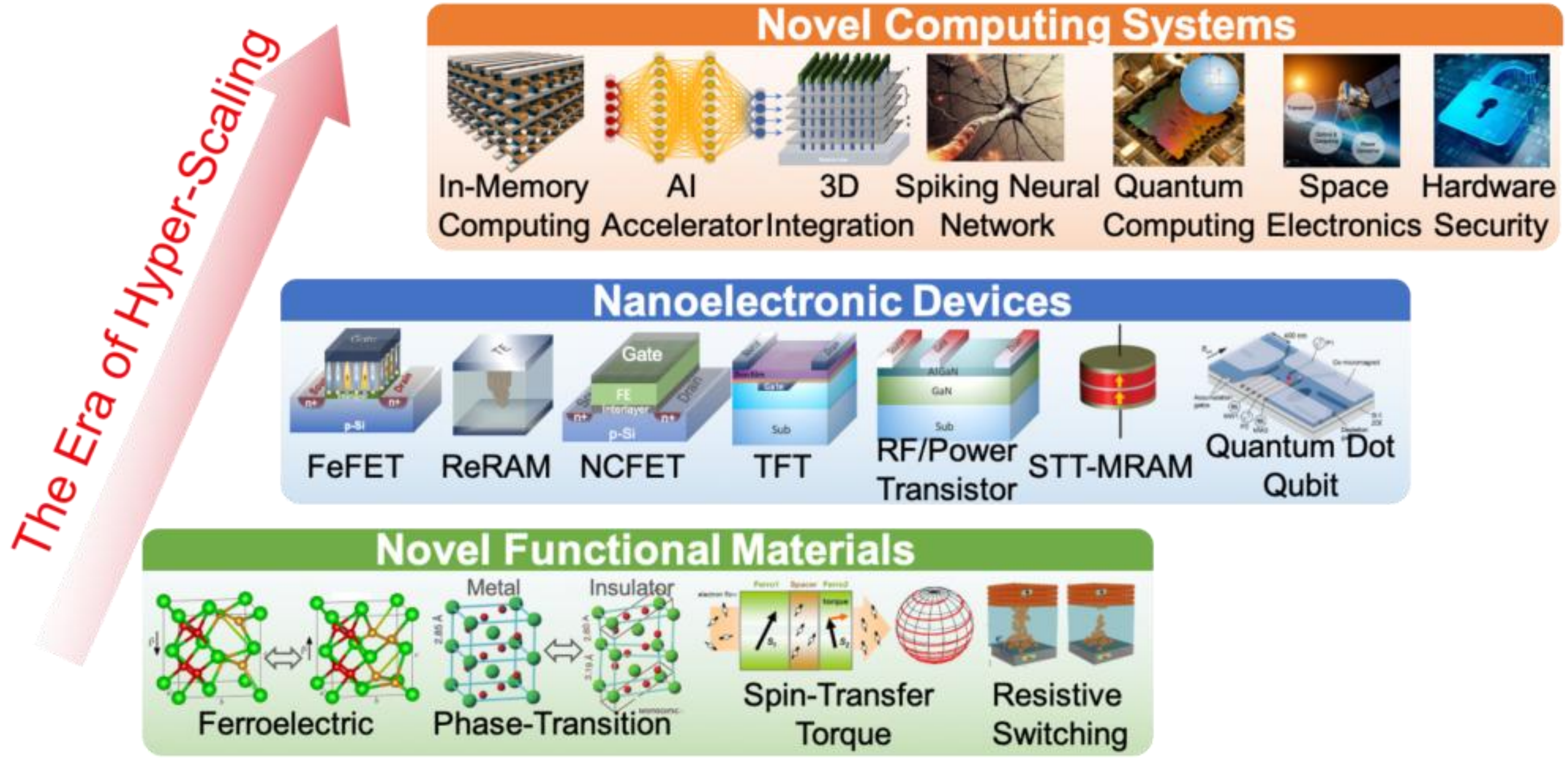


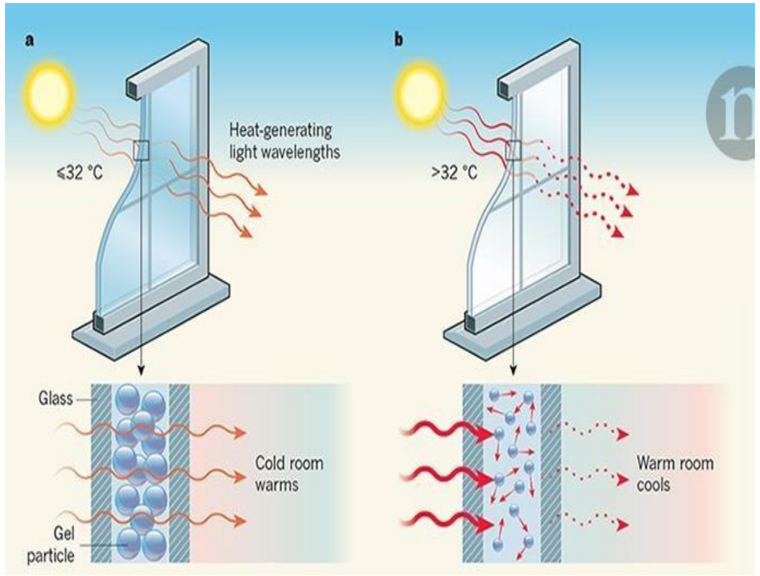
Novel Materials

Materials produced out of nanoparticles have some special features, e.g.

(i) very high ductility
(ii) very high hardness ~4 to 5 times more than usual conventional materials
(iii) transparent ceramics achievable
(iv) manipulation of colour
(v) extremely high coercivity magnets
(vi) developing conducting inks and polymer



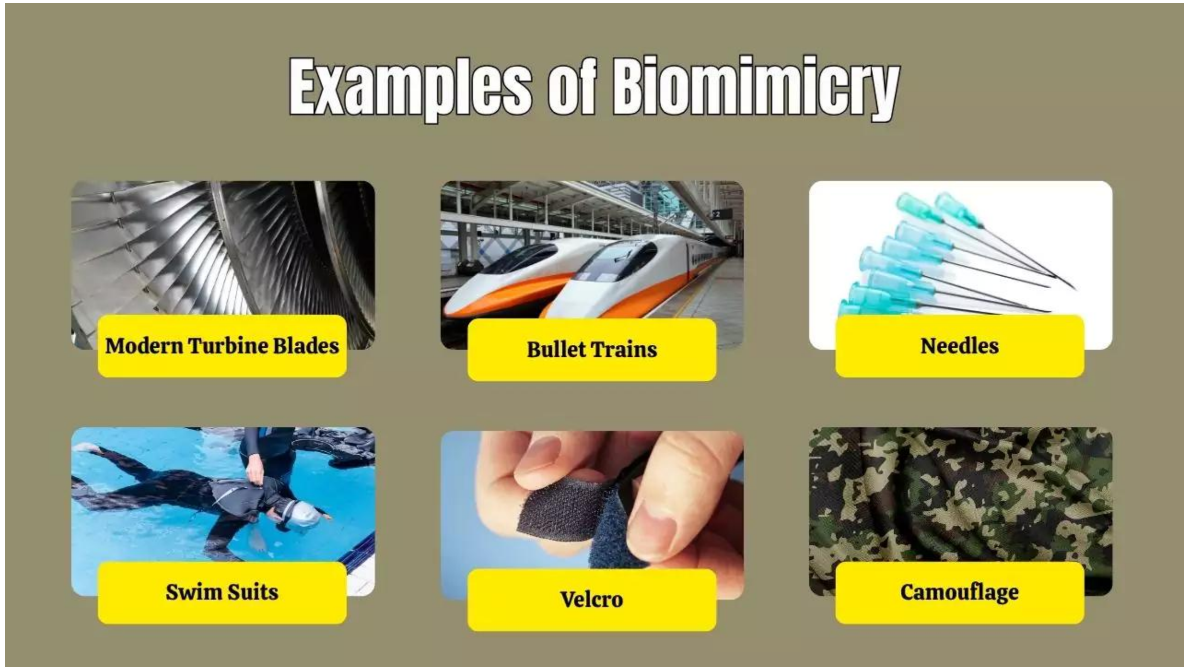




Novel Materials

Nanoengineered Materials :

- Material science has expanded from the traditional metallurgy and ceramics into new areas such as electronic polymers, Complex polymers, Smart materials, biomedical materials (for implants and other applications.



Biomimicking/Biomimicry

Design and production of materials, structures and systems that are modeled on biological entities/processes.

Biomimetics - study of nature and natural phenomena to understand the principles of underlying mechanisms, to obtain ideas from nature, and to apply concepts that may benefit science, engineering, and medicine

Photosynthesis → for newer energy harvesting method
Problem solving , human brain → neural networks
Superhydrophobicity(lotus) → Self cleaning fabrics

Nano in a glance