Lecture 6

Types of Nanoparticles/Nanomaterials and Chemical synthesis

Types of Nanoparticles

Most current nanoparticles/ nanomaterials could be organized into four types:

- Carbon Based Materials
- Metal Based Materials
- Dendrimers
- Composites/ Nanohybrids

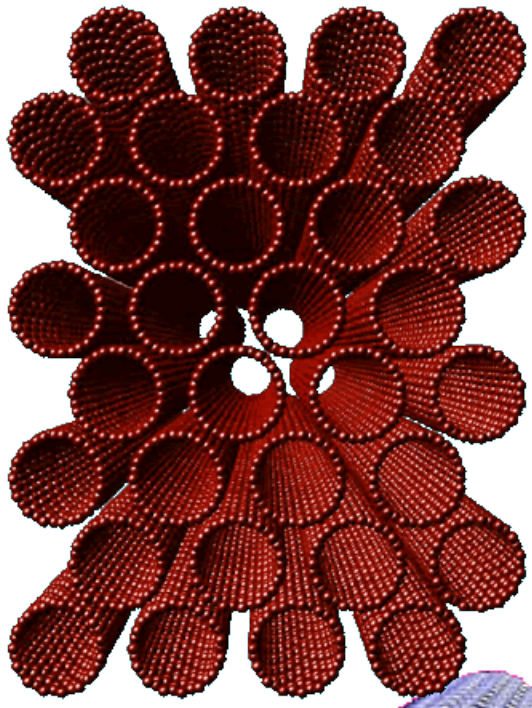
Carbon Nanotubes (CNTs)

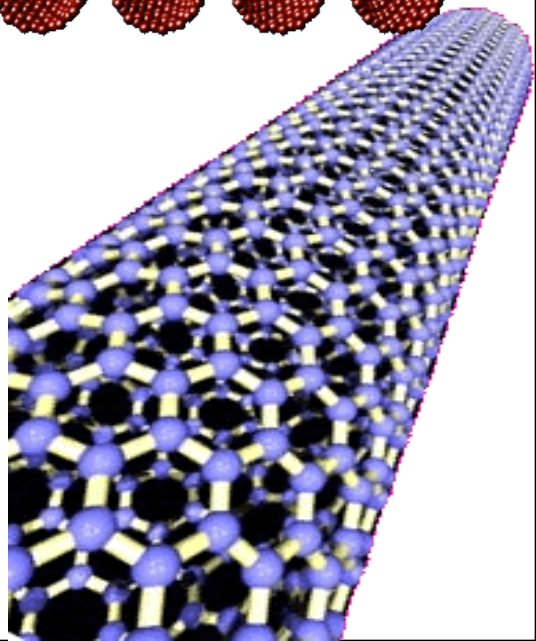
CNT is a tubular form of carbon with diameter as small as 1 nm. Length: few nm to microns.

CNT is configurationally equivalent to a single or multiple two dimensional graphene sheet(s) rolled into a tube (single wall vs. multiwalled).

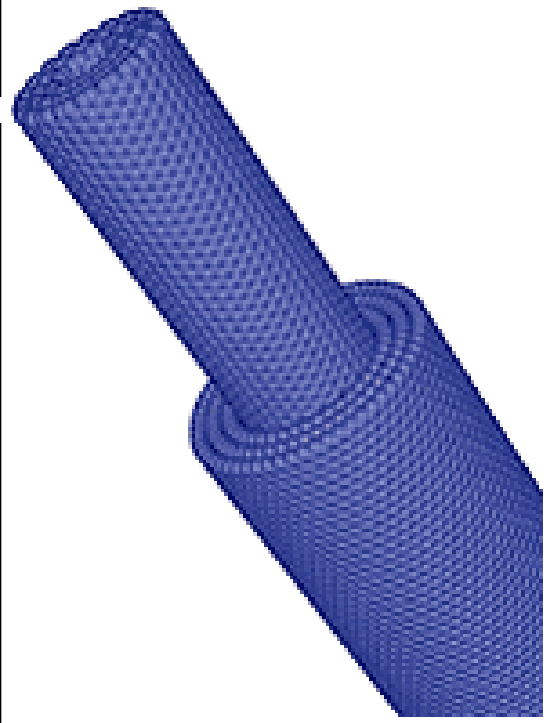
CNT exhibits extraordinary mechanical properties: Young's modulus over 1 Tera Pascal, as stiff as diamond, and tensile strength ~ 200 GPa.

CNT can be metallic or semiconducting, depending on (m-n)/3 is an integer (metallic) or not (semiconductor).



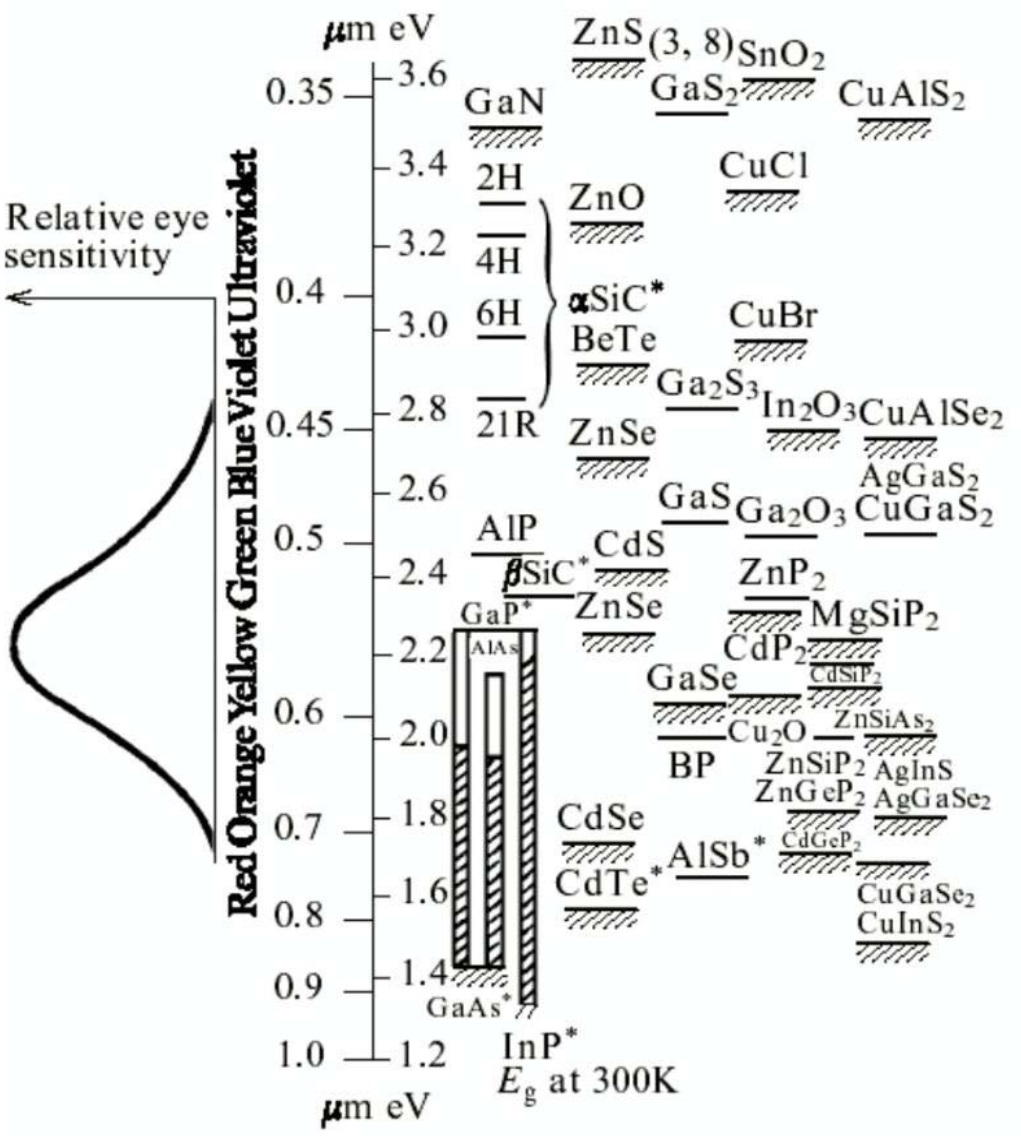


CNTs Applications



- High strength composites
- Cables, tethers, beams
- Multifunctional materials
- Functionalize and use as polymer back bone
  - plastics with enhanced properties like “blow molded steel”
- Heat exchangers, radiators, thermal barriers, cryotanks
- Radiation shielding (with H_2 or Boron storage)
- Filter membranes, catalyst supports
- Body armor, space suits

Inorganic Nanowires



- All these have been grown as 2-d thin films in the last three decades
- Current focus is to grow 1-d Nanowires

Motivation

- One-dimensional quantum confinement
- Bandgap varies with wire diameter
- Single crystal with well-defined surface structural properties
- Tunable electronic properties by doping
- Truly bottom-up integration possible

Down to 0.4 eV

V.S. Vavilov (1994)

Fine particle Technology

- Common powders:
  - Cement, fertilizer, face powder, table salt, sugar, detergents, coffee creamer, baking soda…
- Products in which powder incorporation is obvious
  - Paint, tooth paste, lipstick, mascara, chewing gum, magnetic recording media, slick magazine covers, floor coverings, automobile tires…

- There is always an optimum particle size
  - Taste of peanut butter affected by particle size
  - Extremely fine amorphous silica is added to control the ketchup flow
  - Medical tablets dissolve in our system at a rate controlled by particle size
  - Pigment size controls the saturation and brilliance of paints
  - Effectiveness of odor removers controlled by the surface area of adsorbents.

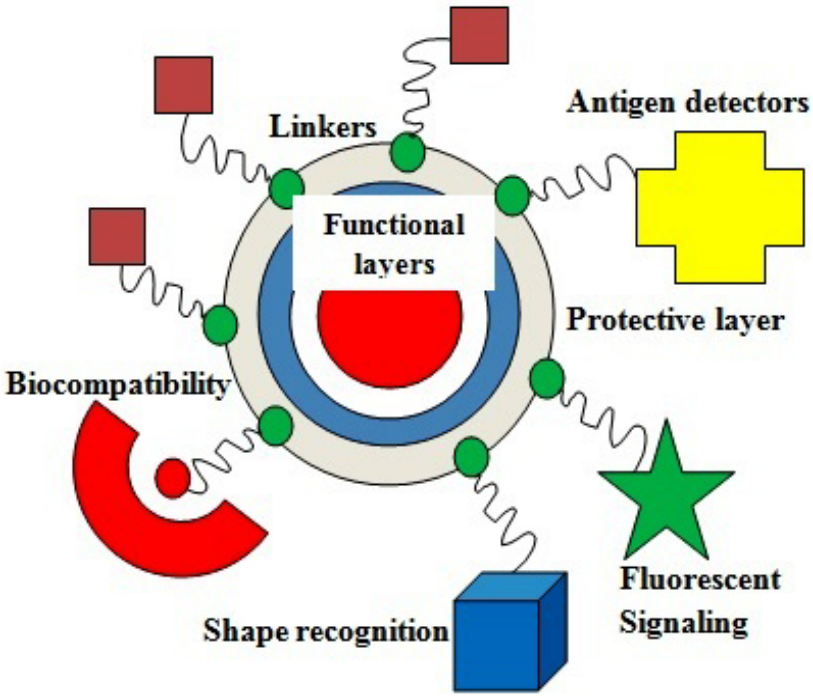
From: Analytical methods in Fine Particle Technology, Webb and Orr

Dendrimers

- Tree-like polymers, branching out from a central core and subdividing into hierarchical branching units

  - Not more than 15 nm in size, Mol. Wt very high
  - Very dense surface surrounding a relatively hollow core (vs. the linear structure in traditional polymers)
  - Surface may consist of acids or amines ⇒ route to attach functional groups
    ⇒ control/modify properties
  -

- Applications
  - Drug delivery
  - Gene therapy, cancer therapy
  - Antimicrobial and Antiviral agents

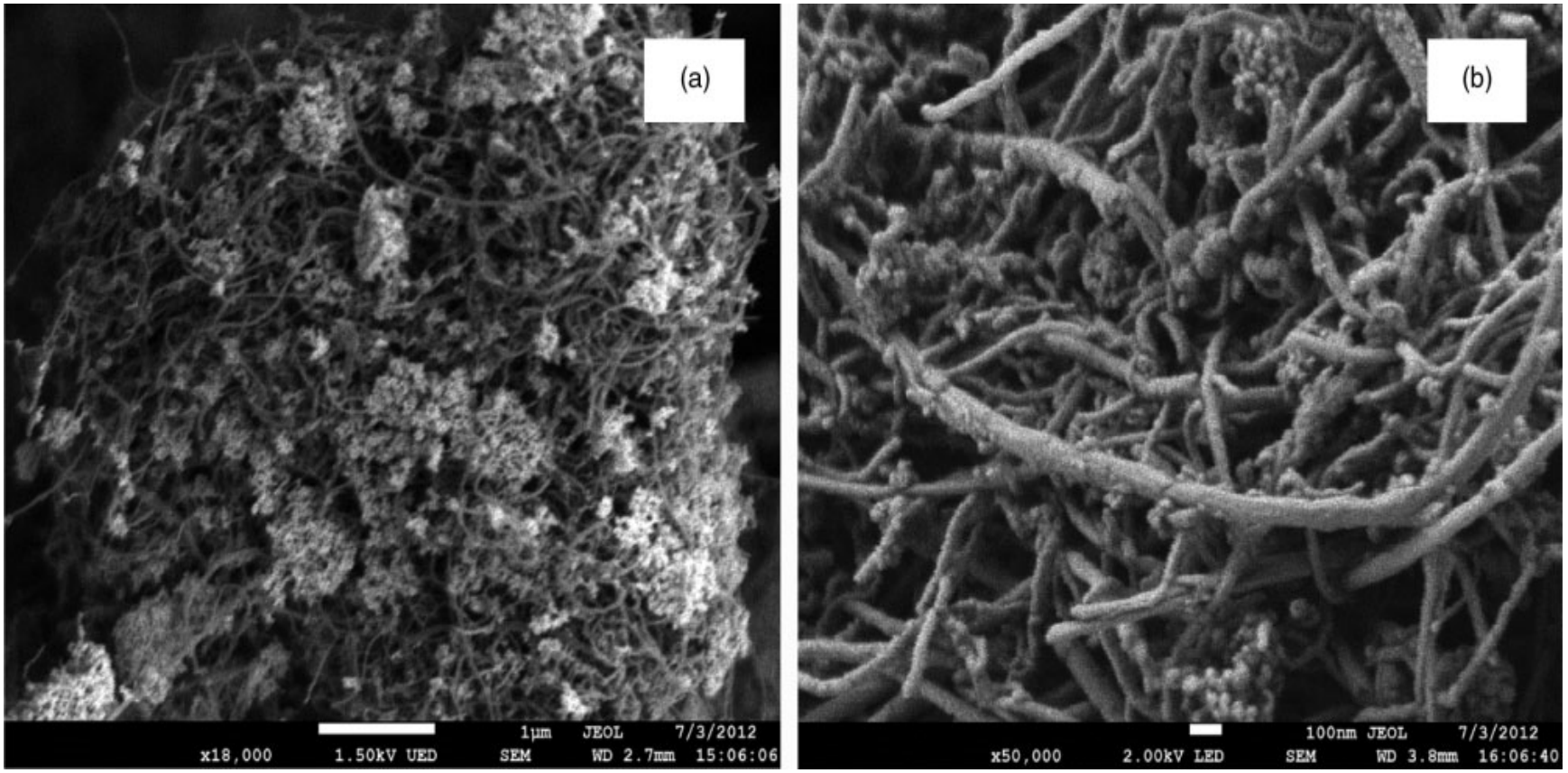


Composites / Nanohybrids

Non covalent hybrid assemblies of functionalized nanoparticles / nano- clays with metallic or polymeric system- Through Electrostatic adhesion/ Adsorption.

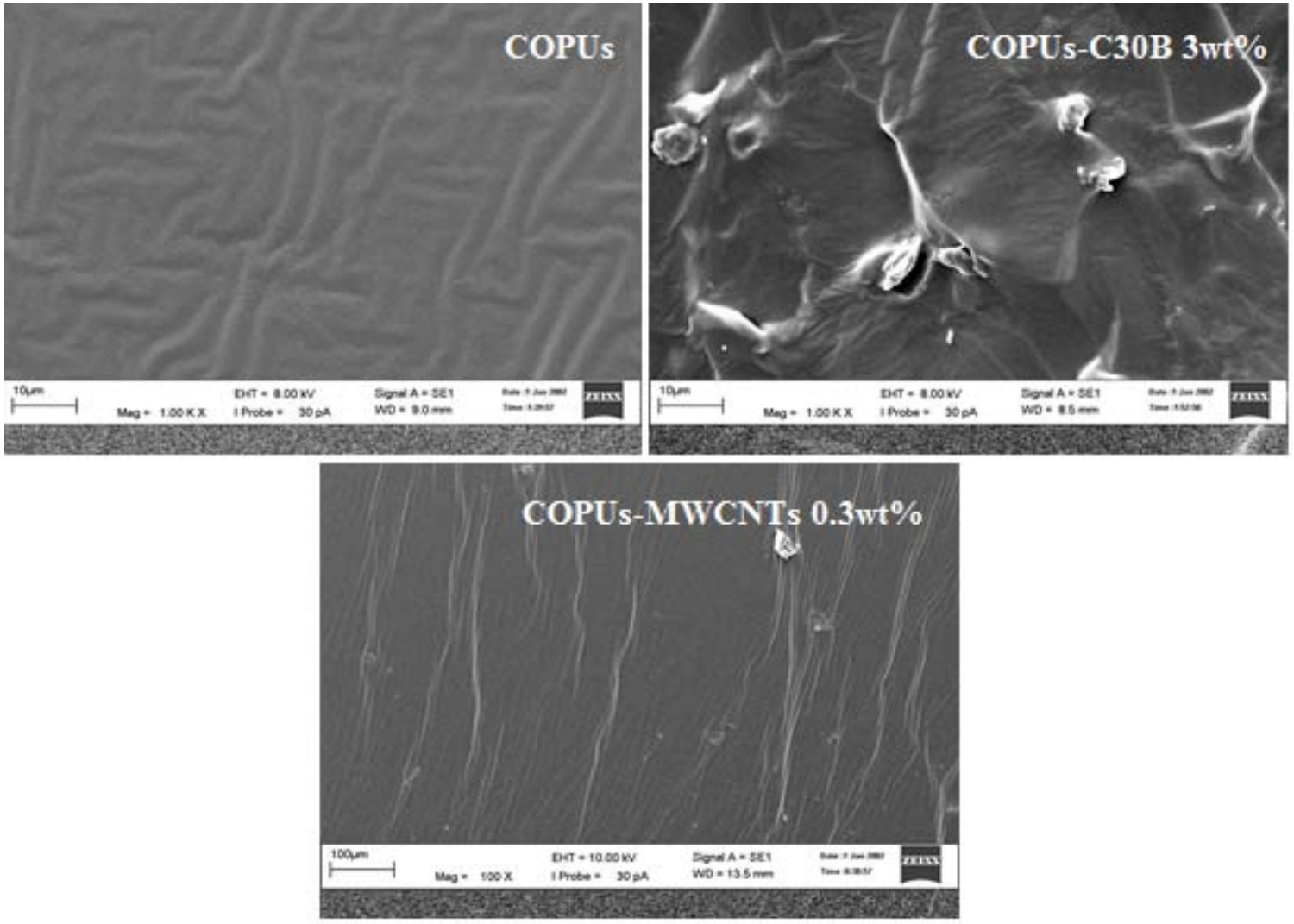
Impressive advanced Industrial applications. Polyurethanes and separation processes.

Metallic Nanocomposites



FESEM images of maghemite–multiwalled carbon nanotube nanohybrids (a) Lower magnification (b) Higher magnification.

Polymeric Nanocomposites



The SEM images of the surfaces of Pristine PU, PUs - C30B (nanoclay) nanocomposites with 3wt% and PUs - MWCNTs nanocomposites with 0.3wt%

Top-down Approaches

- 10 ~ 1000 nm; broad size distribution
- varied particle shape or geometry
- Impurities
- form nano-composites and nano-grained bulk materials (lower sintering temperature)

Bottom-up Approaches

- **Chemical synthesis**

- **Two approaches**

  - **thermodynamic equilibrium approach**
    - generation of supersaturation
    - nucleation
    - subsequent growth

  - **kinetic approach**
    - limiting the amount of precursors for the growth
    - confining in a limited space

Nuclei

- formation favor:
  - high initial concentration or supersaturation
  - low viscosity
  - low critical energy barrier
- uniform nanoparticle size:
  - same time formation
  - abruptly high supersaturation -> quickly brought below the minimum nucleation concentration

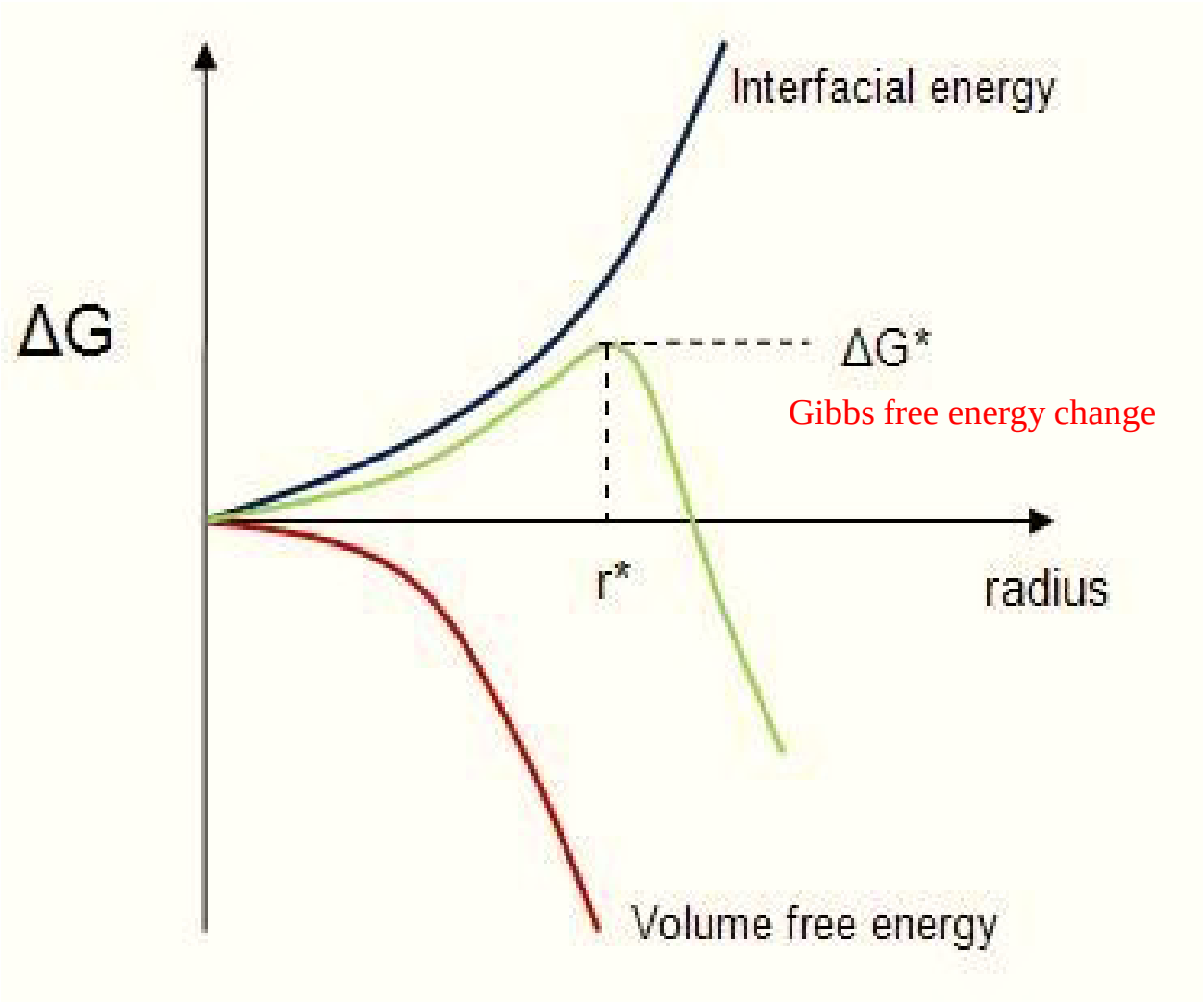
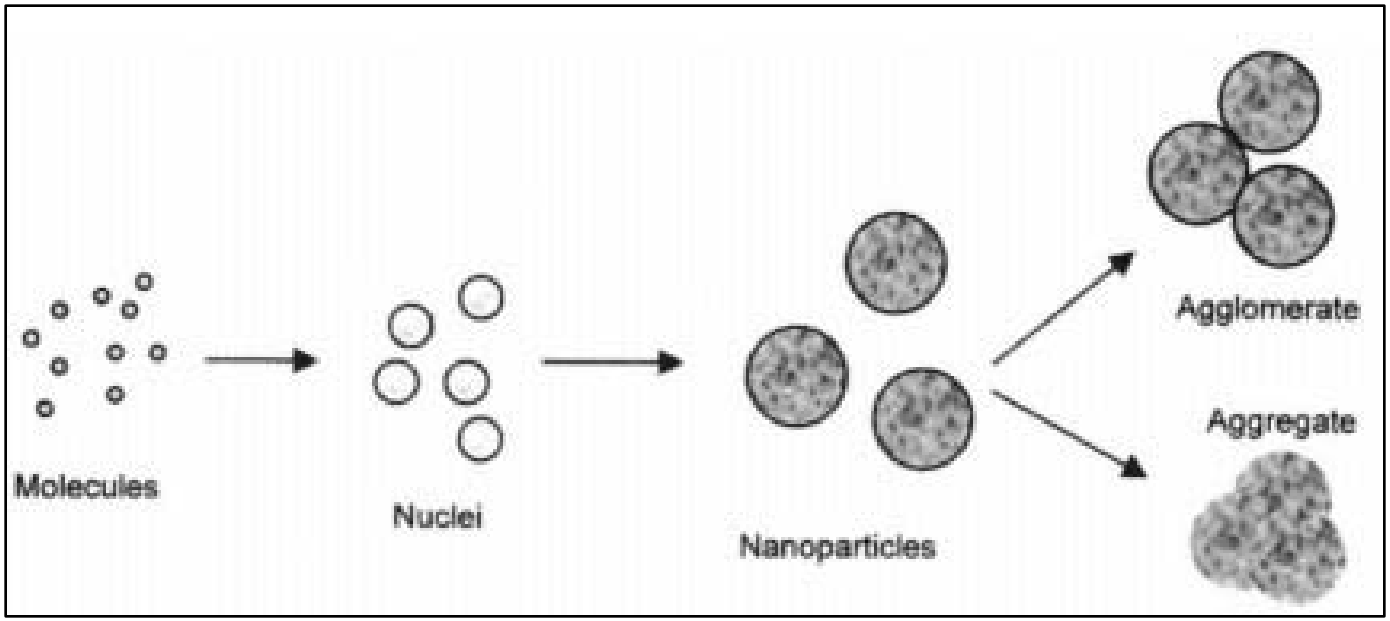


Fig. Schematic Illustrating change in volume free energy, surface free energy and a total free energy ,as function of nucleus radius.

Stepwise presentation



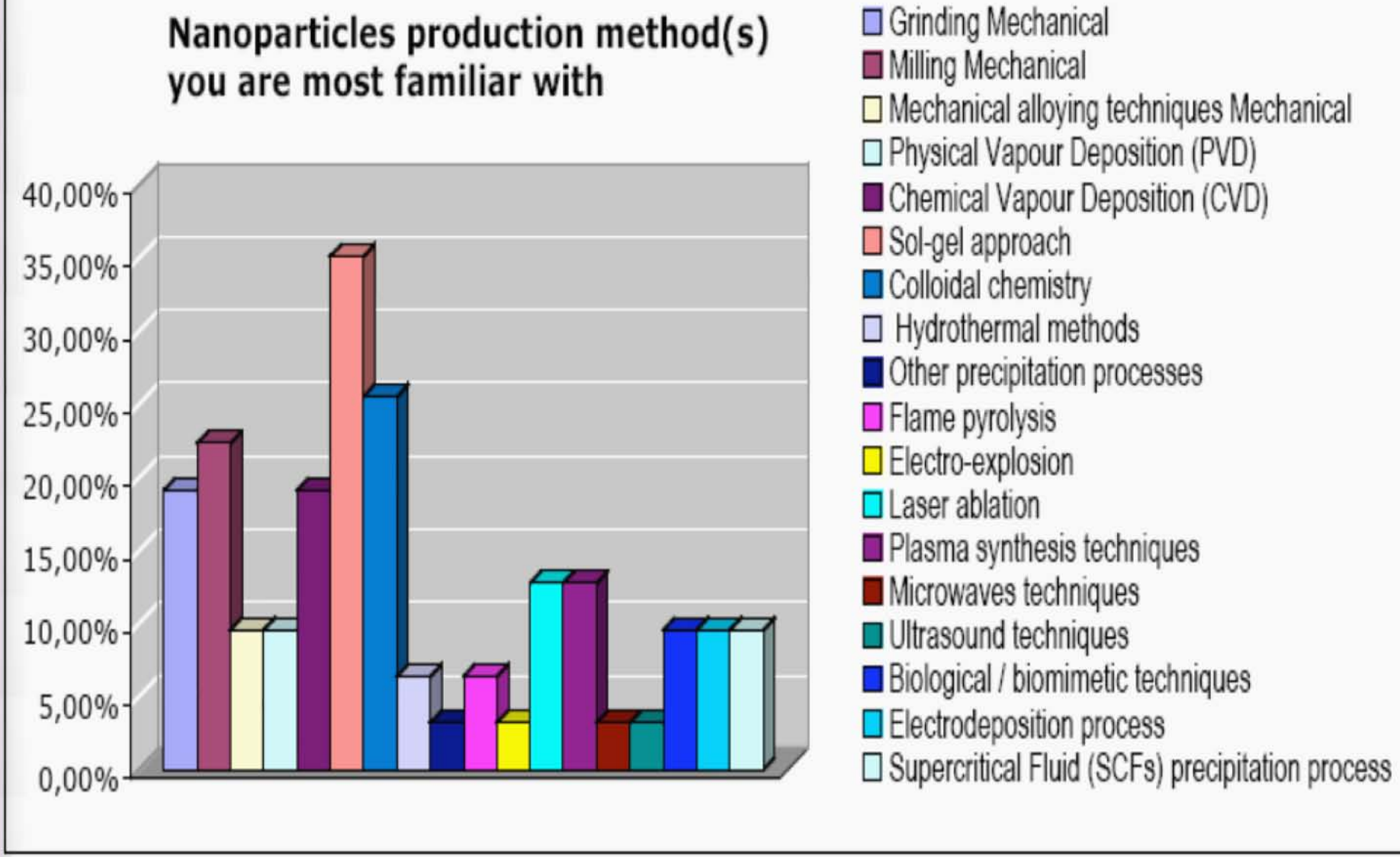
Crystal growth

- Steps
  - growth species generation
  - diffusion from bulk to the growth surface
  - adsorption
  - surface growth

Diffusion-limited growth

  - Low/controlled supply growth species concentration
  - increase the solution viscosity
  - introduction of a diffusion barrier

Nanoparticles production methods



Nano-myth

- Grey goo- a hypothetical end of the world scenario involving molecular nanotechnology in which out-of-control self-replicating robots consume all matter on Earth while building more of themselves, a scenario known as *Ecophagy.*

  ("eating the environment").