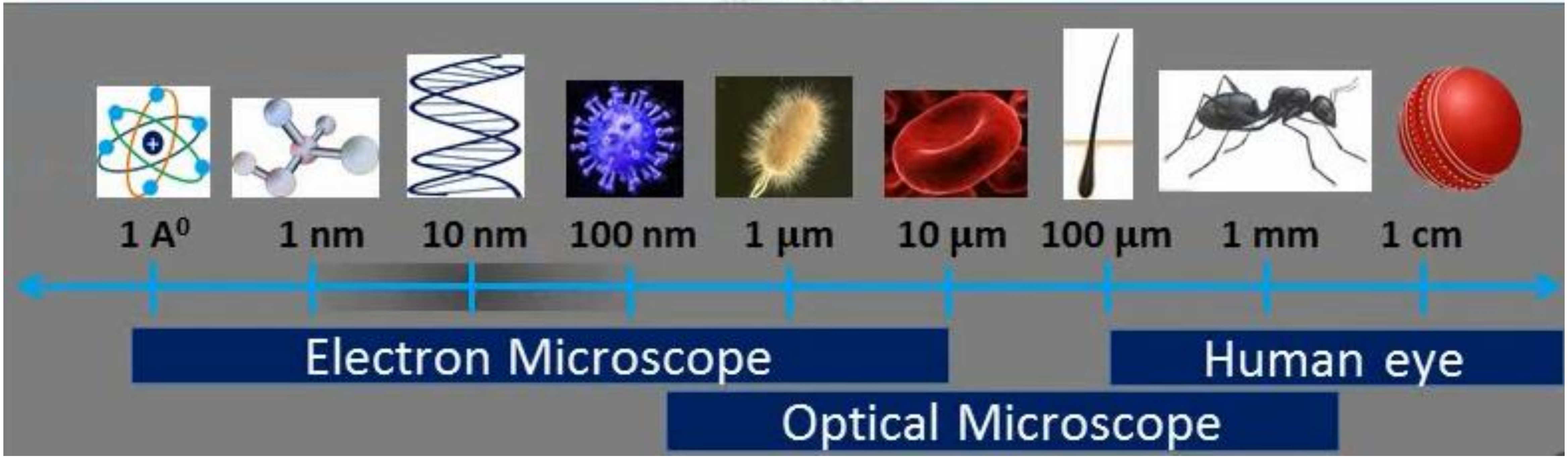
Module 5: NanoTechnology

The techniques involved in the preparation, characterization and use of the properties of nano materials in different applications are collectively called as nanotechnology.

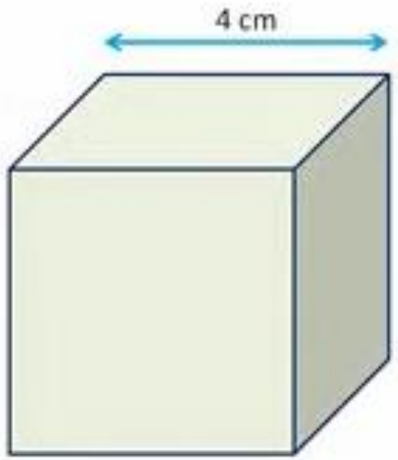


Properties change at nanoscale

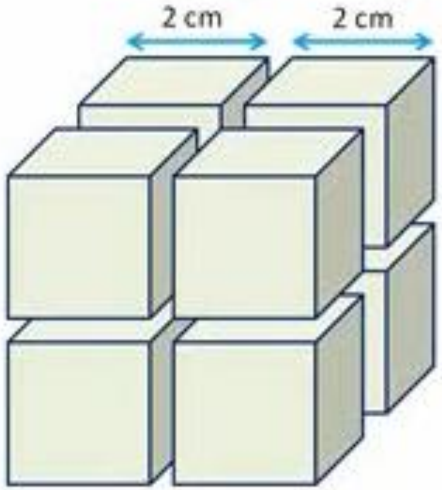
- At nano scale, optical, thermal, mechanical, electrical, magnetic, dynamic properties of the materials change.
- New properties can be used in variety of applications in different fields like –
  - food processing,
  - medicine,
  - automobiles,
  - paint technology,
  - computer technology,
  - robotics,
  - space technology etc.

Surface area to Volume Ratio

- Nanoparticles of a material show different properties compared to larger particles of the same material.
- Forces of attraction between surfaces can appear to be weak on a larger scale, but on a nanoscale they are strong.



Surface area = (4 cm x 4 cm x 6 faces) = 96 cm^2
Volume = (4 cm x 4 cm x 4 cm) = 64 cm^3



Surface area = (2 cm x 2 cm x 6 faces x 8 cubes) = 192 cm^2
Volume = (4 cm x 4 cm x 4 cm) = 64 cm^3

One reason for this is the **surface area to volume ratio**.

In nanoparticles this is very large. Atoms on the surface of a material are often more reactive than those in the centre, so a larger surface area means the material is more reactive.

Properties change at nanoscale

❑Optical Properties

- When light is incident on the material, it can be absorbed or scattered.
- If the size of material is less than 20 nm, absorption is significant and if the size greater than 100 nm, scattering is significant.
- Thus by designing the nanoparticle of different sizes, optimal amount of absorption or scattering can be achieved.
- This may result different colour for the particles of different sizes of nanoparticles.

e.g. Opaque substances at the bulk level, become transparent at nano level (copper)

Gold nanospheres of 50 nm are green in colour and of 100 nm size appear orange in colour and at bulk level it is yellow.

Properties change at nanoscale

❑ Mechanical Properties

- The mechanical properties like hardness, elasticity, adhesion, friction improve as the material size is decreased to nano scale.
- Lubrication improves at the nanoscale.
- Ductility of nanomaterial may be high at high temperatures.

Properties change at nanoscale

❑Electrical Properties

- Electrical conductivity of material is altered when it is reduced to nano size.
- It is possible to invent nano materials having desired conductivity.

e.g. In ceramics, the electrical conductivity increases with decrease in nanoparticle size and

In metals, electrical conductivity decreases with decrease in nanoparticle size.

Properties change at nanoscale

❑Structural Properties

- In nanoparticles surface area to volume ratio is very large.
- Atoms on the surface of a material are often more reactive than those in the centre, so a larger surface area means the material is more reactive.
- Forces of attraction between surfaces can appear to be weak on a larger scale, but on a nanoscale they are strong.
- This may lead to different surface morphology, changes in crystal structure etc.

Properties change at nanoscale

	Macroscale	Nanoscale
Copper	Opaque	Transparent
Platinum	Inert	Catalytic
Aluminuim	Stable	Combustible
Gold	Solid at room temperature	Liquid at room temperature
Silicon	Insulator	Conductor

$$D_f + D_c = 3$$

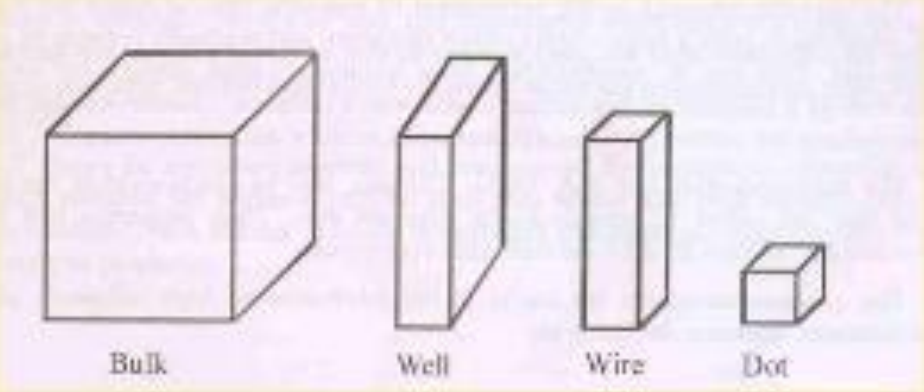
Structure	Degree of Confinement (D_c)	Degree of freedom (D_f)
Bulk Material	0D	3D
Quantum Well	1D	2D
Quantum Wire	2D	1D
Quantum Dot	3D	0D

Quantum Well, Wire & Dot

Quantum Well -If one dimension of a bulk materials is reduced to nano scale & other dimensions remain same, then the structure is called quantum well

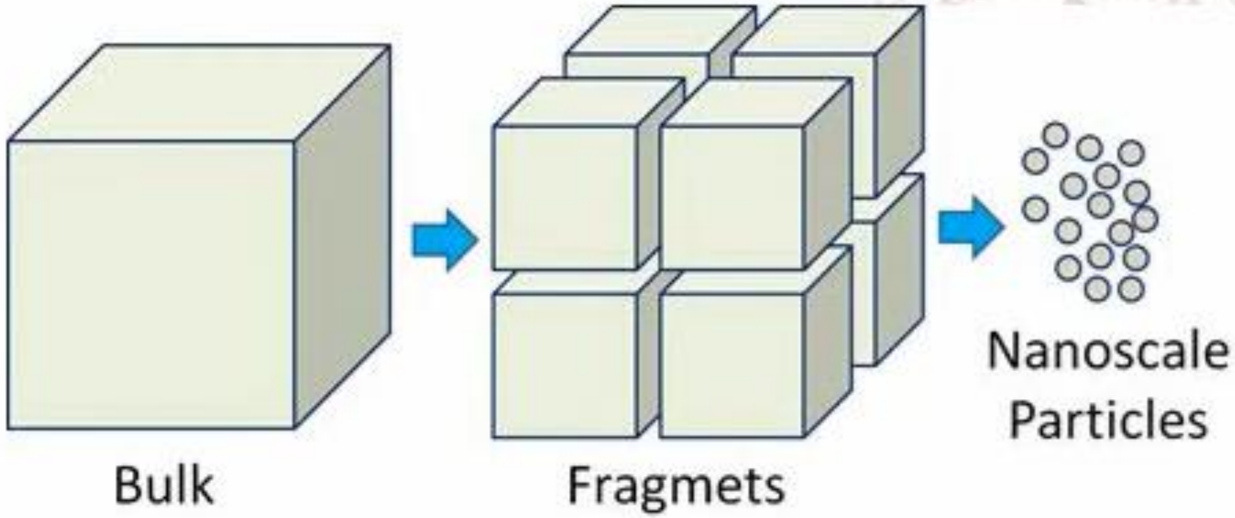
Quantum Wire - If two dimensions of a bulk materials are reduced to nano scale & other dimension remains same, then the structure is called quantum wire

Quantum Dot - If all dimensions of a bulk materials are reduced to nano scale, then the structure is called quantum dot



Module 5: NanoTechnology

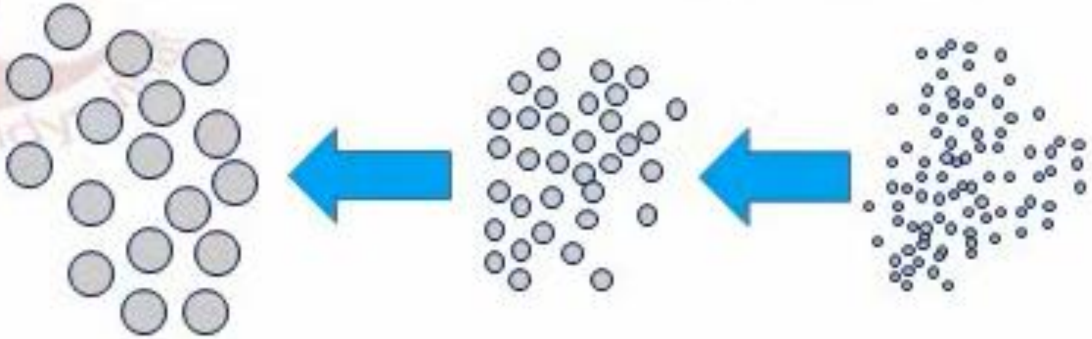
Top Down Approach

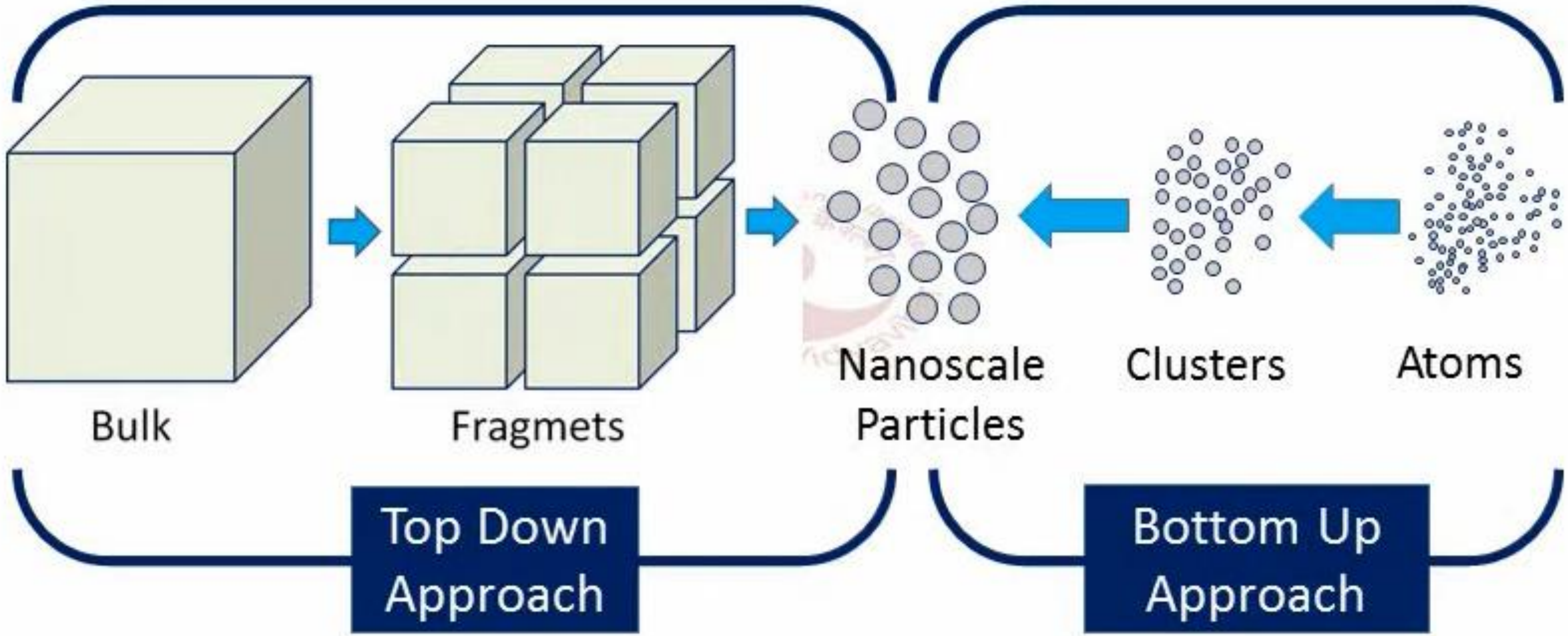


- It is a physical process.
- In top down approach, a large scale object is progressively reduced in dimensions.
- It consists of ultra fine micro machining of materials using lithography, epitaxy and etching.
- This method is time consuming and relatively costly.

- This is a chemical process.
- In bottom up approach, different materials and devices are constructed from molecular components on their own which do not require any external agent to assemble them.
- They chemically assemble themselves by recognising the molecules of their own type.
- This approach starts by collection and combination of atoms and molecules to build complex structures.

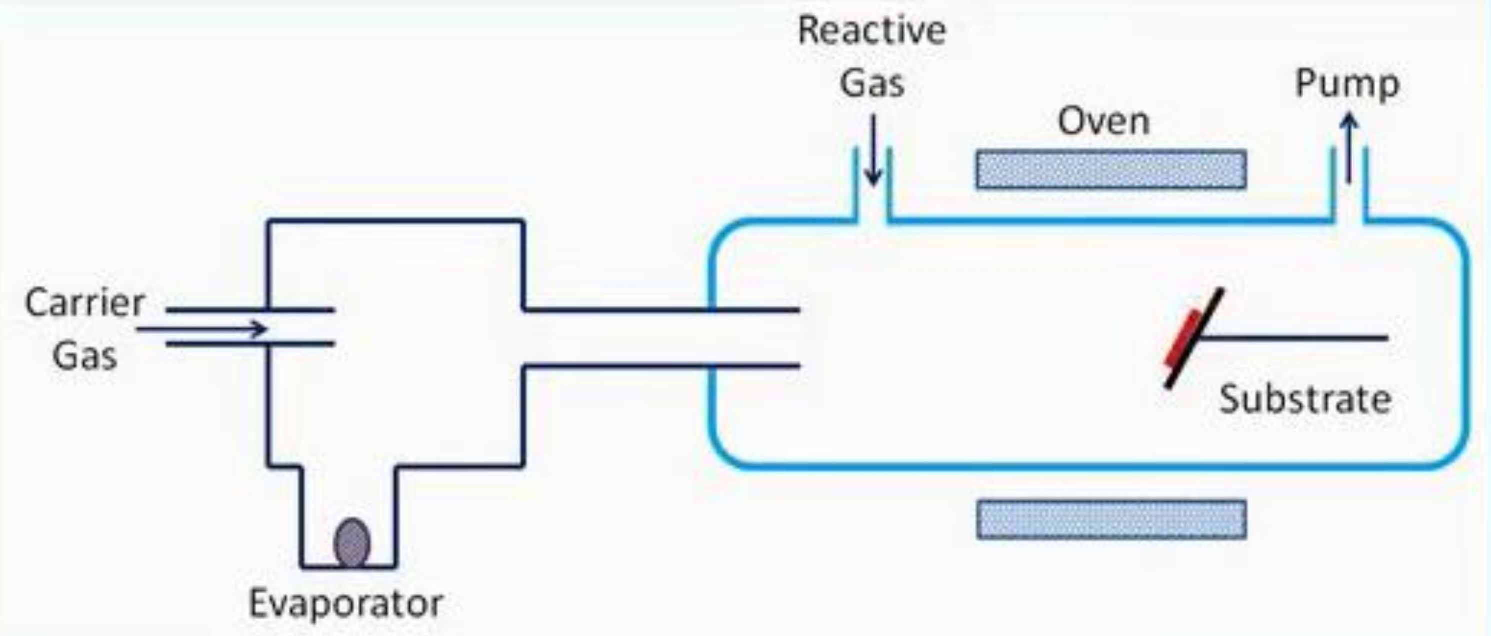
Bottom Up Approach




Bulk
Fragmets
Nanoscale Particles
Clusters
Atoms
Top Down Approach
Bottom Up Approach

Module 5: NanoTechnology

Chemical Vapour Deposition Method



- To avoid undesired chemical reactions, the substrate surface temperature, deposition time, pressure and type of surface is carefully selected.

- Bottom up Approach
- Substrate is exposed to one or more volatile precursors (chemicals) which react and/or decompose on the substrate surface to produce desired compound.
- By-products are removed by carrier gas flow through the reaction chamber.
- CVD is used to produce high purity, high performance solid materials.

STEPS INVOLVED IN CHEMICAL VAPOUR DEPOSITION

Transport of reactants by forced convection to the deposition region

Transport of reactants by diffusion from the main gas stream to the substrate surface.

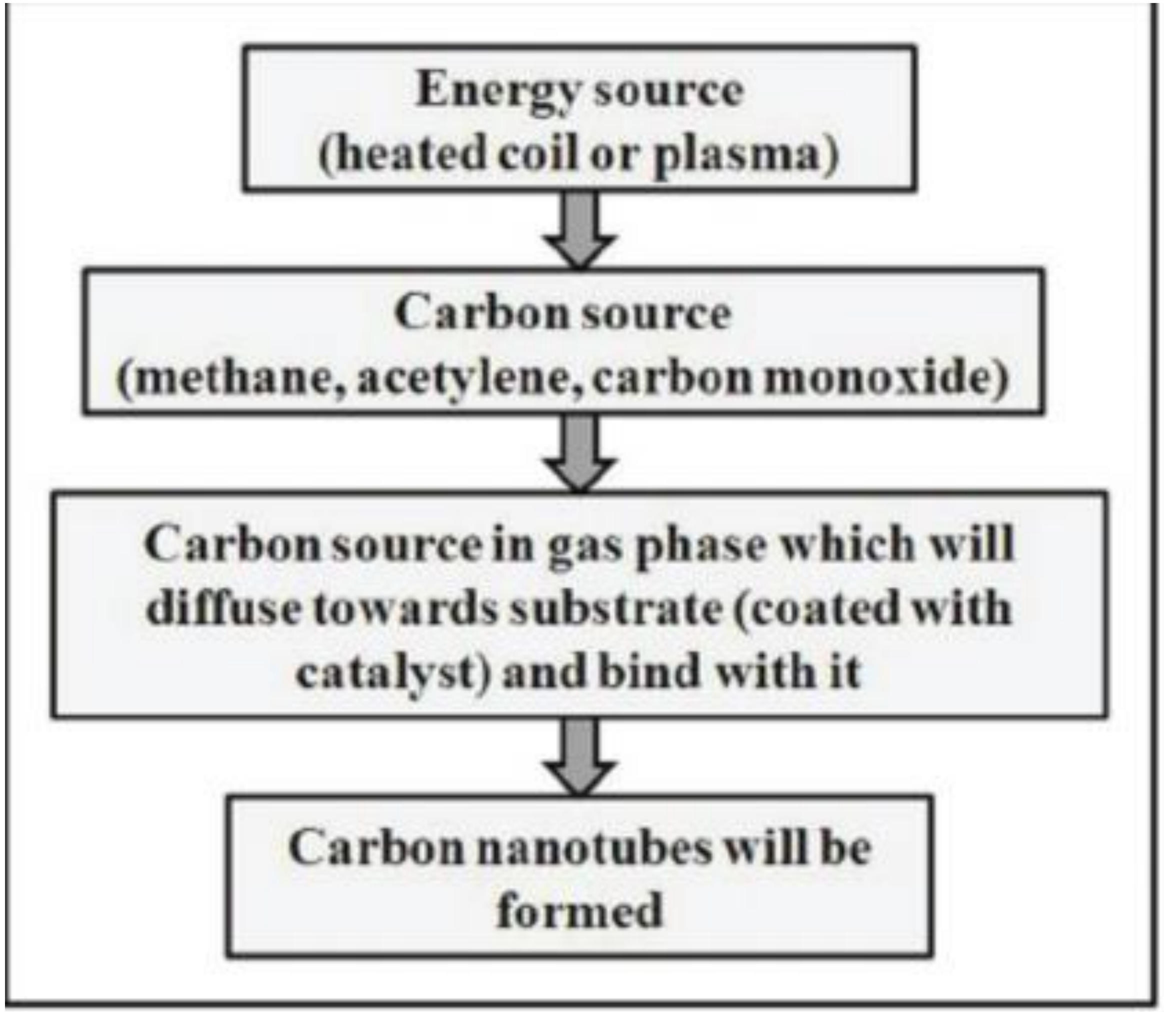
Adsorption of reactants in the wafer (substrate) surface.

Chemical decomposition and other surface reactions take place.

Desorption of by-products from the surface

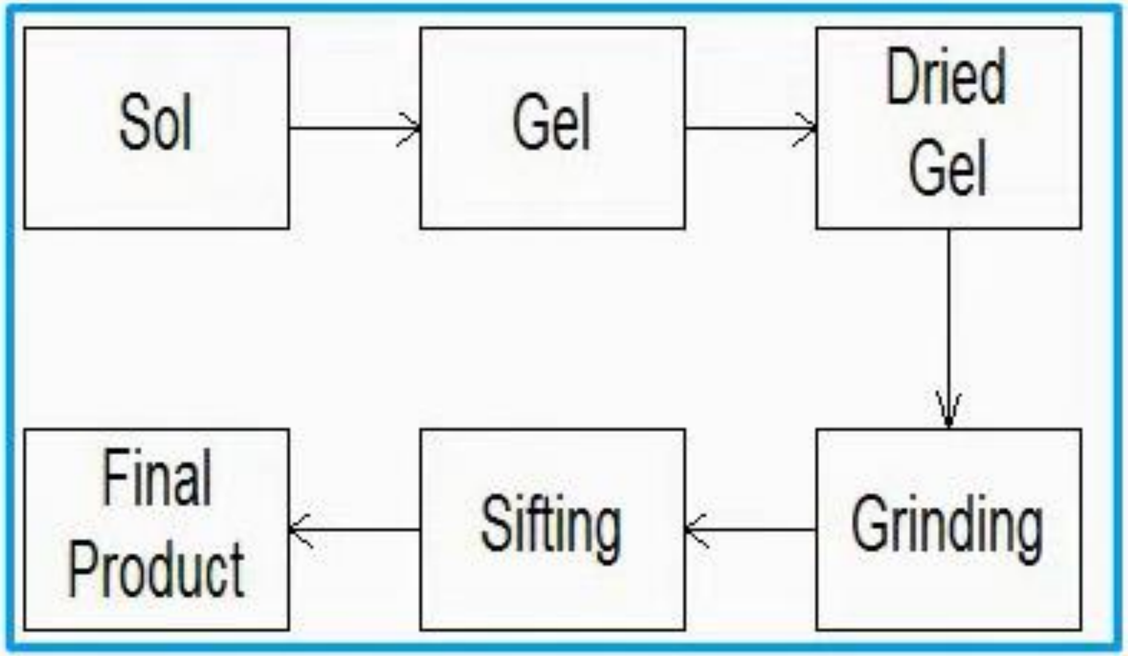
Transport of by-products by diffusion

Transport of by-products by forced convection away from the deposition region.


Energy source
(heated coil or plasma)
Carbon source
(methane, acetylene, carbon monoxide)
Carbon source in gas phase which will diffuse towards substrate (coated with catalyst) and bind with it
Carbon nanotubes will be formed

Module 5: NanoTechnology

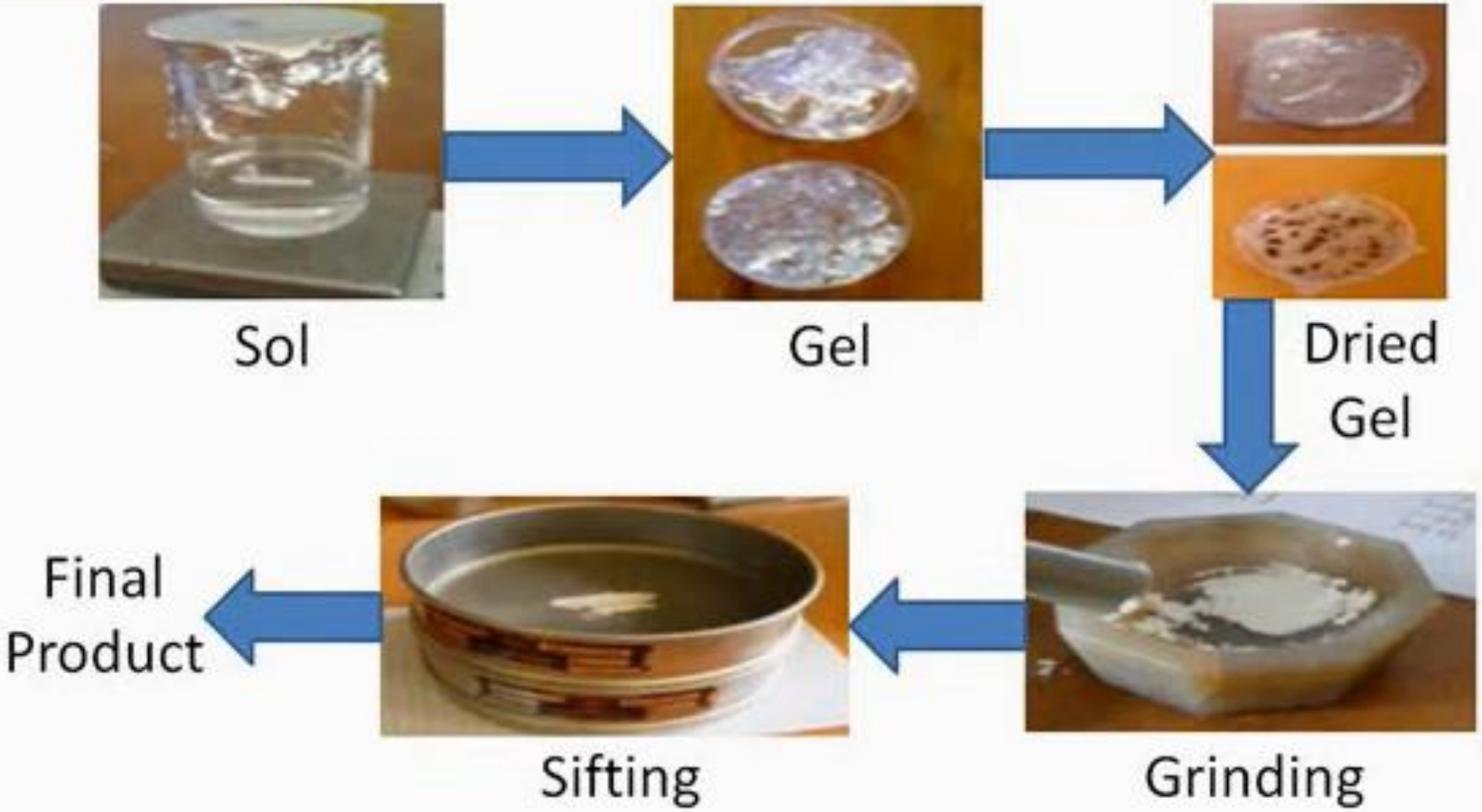
Sol-gel Process

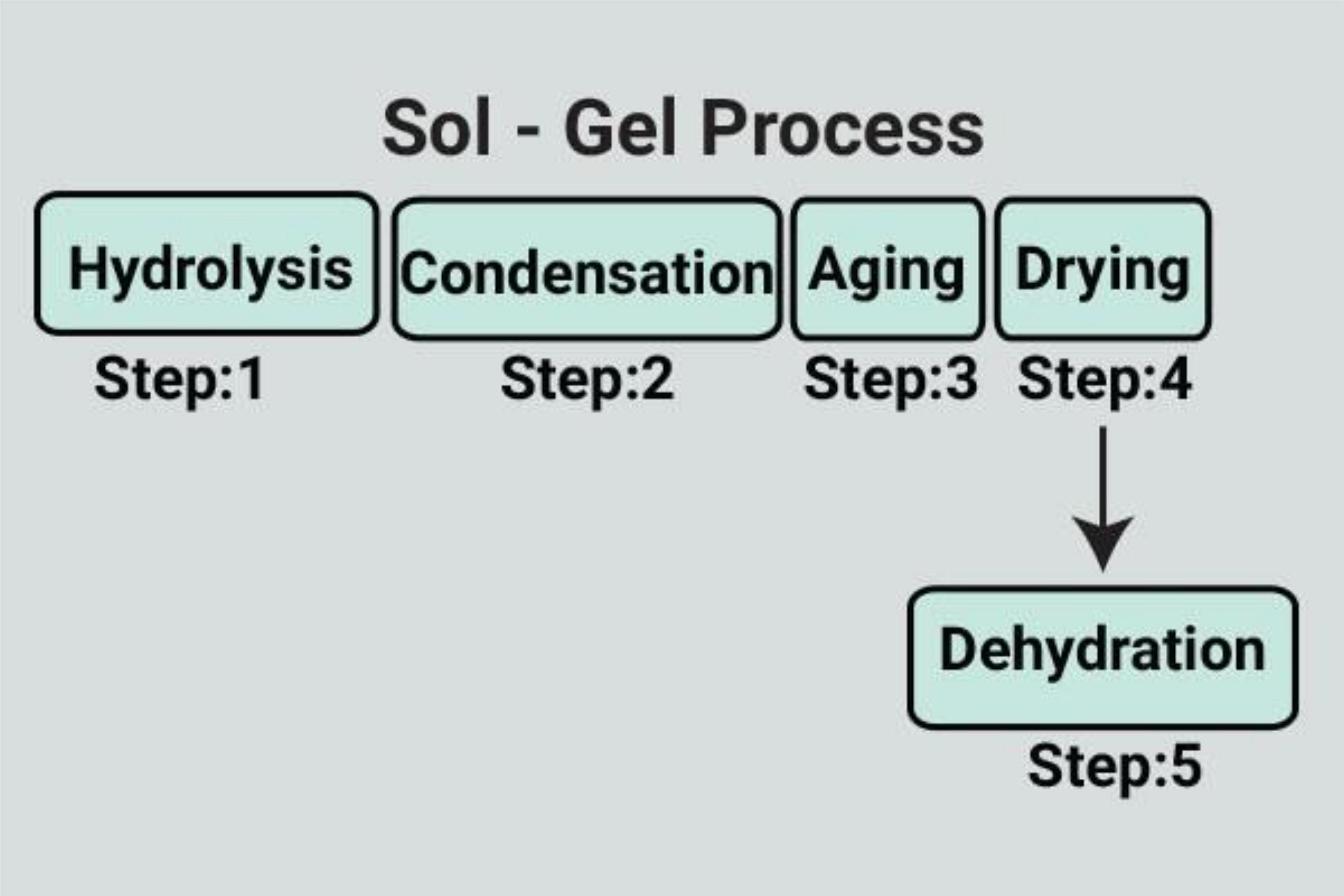


- Bottom-up approach.
- chemical process
- A sol is a colloidal (the dispersed phase in which size of the particles is so small that gravitational forces do not exist. Only Van der Waals forces and surface charges are present).
- A gel is a semi-rigid mass that forms when the solvent from the sol begins to evaporate and the particles or the ions left behind begin to join together in a continuous network.

S.No.	Dispersed Phase	Dispersion Medium	Type of Colloidal Solution	Examples
1.	Solid	Solid	Solid sol.	Gemstones,
2.	Solid	Liquid	Sol	Paints, muddy water, gold sol, starch sol, arsenious Sulphide sol.
3.	Solid	Gas	Aerosol of solids	Smoke, dust in air
4.	Liquid	Solid	Gel	Jellies, Cheese
5.	Liquid	Liquid	Emulsion	Milk, Cream
6.	Liquid	Gas	Aerosol	Mist, fog, cloud
7.	Gas	Solid	Solid foam	Foam rubber, pumice stone
8.	Gas	Liquid	Foam	Froth, whipped cream

Sol-gel Process



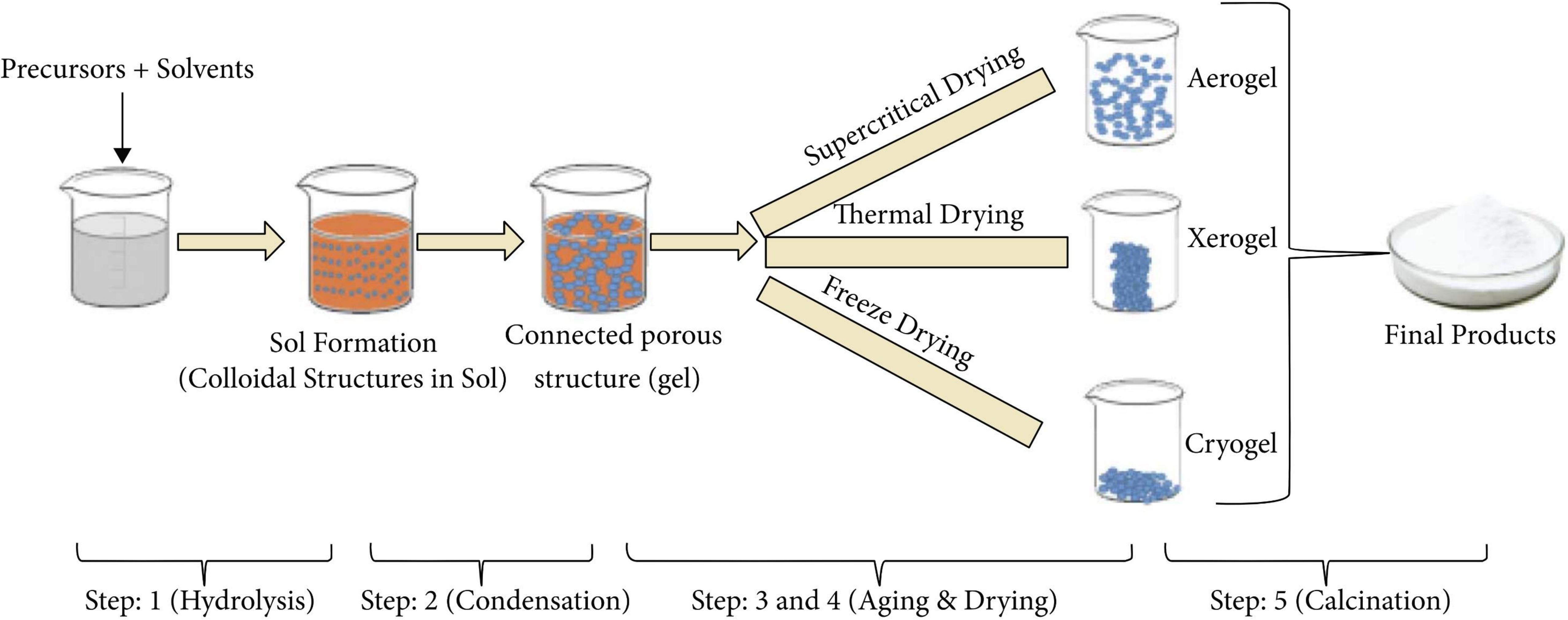

Sol - Gel Process
Hydrolysis
Step:1
Condensation
Step:2
Aging
Step:3
Drying
Step:4
Dehydration
Step:5

Module 5: NanoTechnology

Sol-gel Process

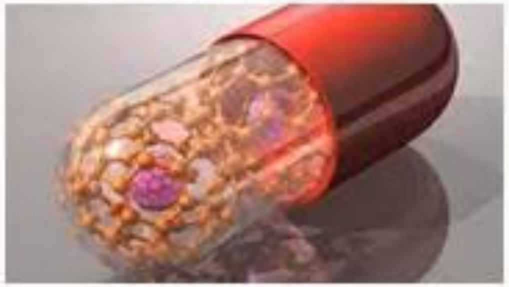
Advantages

- ✓ The sol–gel approach is a cheap and low-temperature technique that allows the fine control of the product's chemical composition.
- ✓ Even small quantities of dopants can be introduced in the sol and end up uniformly dispersed in the final product.
- ✓ Rate of reaction can be easily controlled by maintaining temperature.


Precursors + Solvents
Sol Formation
(Colloidal Structures in Sol)
Connected porous
structure (gel)
Supercritical Drying
Thermal Drying
Freeze Drying
Aerogel
Xerogel
Cryogel
Final Products
Step: 1 (Hydrolysis)
Step: 2 (Condensation)
Step: 3 and 4 (Aging & Drying)
Step: 5 (Calcination)

Applications of NanoTechnology

1. In Medicines
   - ✓ Targeted drug delivery
   - ✓ Reduces side effect
   - ✓ Early diagnosis of decease

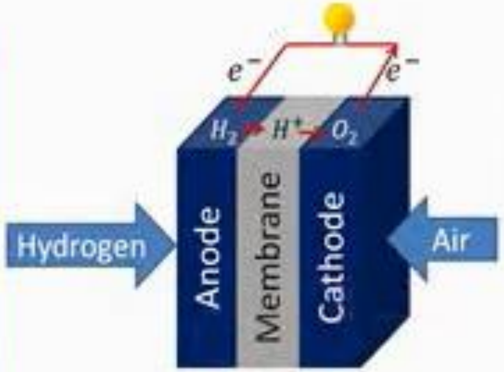


2. In Electronics
   - ✓ Reduced Power Consumption
   - ✓ Less Size and weight of components
   - ✓ Smaller and faster processors

Applications of NanoTechnology

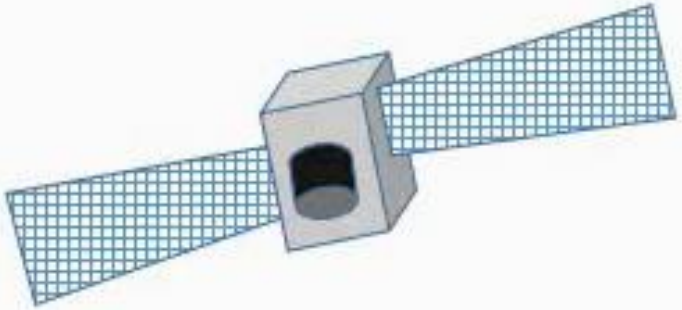
3. In Energy

- ✓ Reduce cost of catalysts in fuel cells
- ✓ Can increase efficiency of solar cells
- ✓ Increased energy density of batteries



4. In Space Technology

- ✓ Lightweight spacecraft
- ✓ Reduction in rocket fuel
- ✓ Larger material strength
- ✓ Low temperature coefficient of expansion



Applications of NanoTechnology

5. In Automobiles

- ✓ High strength of metal
- ✓ Increased fuel efficiency
- ✓ Quality of paints

6. Environmental

- ✓ Sensors detecting pollution level
- ✓ Harmful emissions can be controlled

7. Textiles

- ✓ Water repellent clothes
- ✓ Wrinkle free clothes