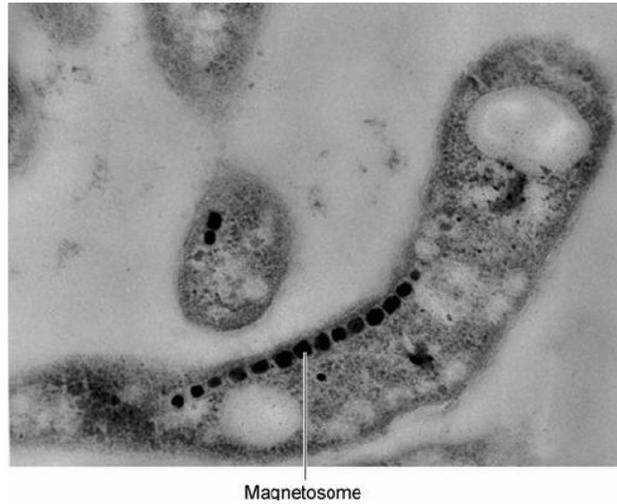


Natural Sources of Nanomaterials

- Nanomaterials are not only synthesized artificially in laboratories; they also occur **naturally in the environment**. These naturally occurring nanomaterials are formed through **biological, geological, and atmospheric processes**. They play important roles in nature and have inspired many modern nanotechnology applications. **Classification of Natural Nanomaterials**
- Natural nanomaterials can be broadly classified into:
 1. Biological sources
 2. Geological sources
 3. Atmospheric sources

1. Biological Sources of Nanomaterials

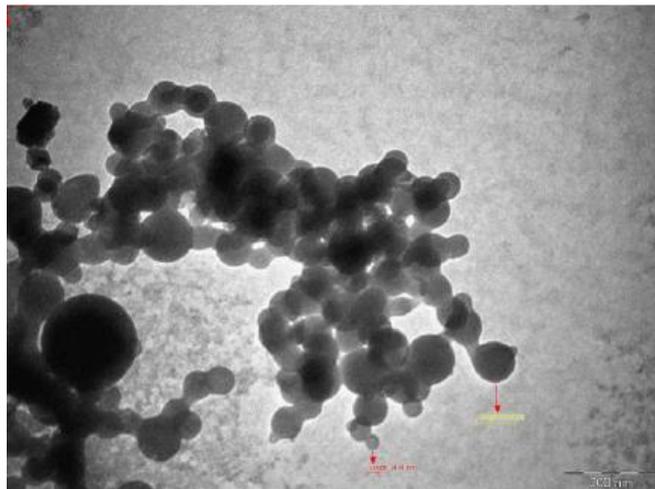
Magnetotactic bacteria produce magnetic nanoparticles for navigation



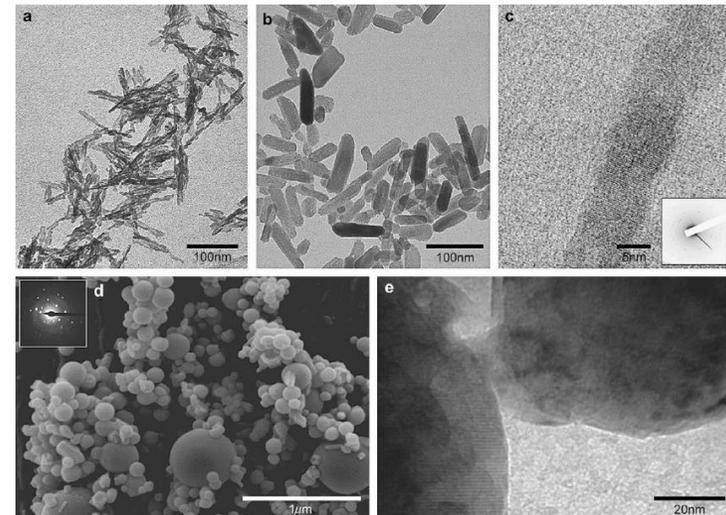
Diatoms (microscopic algae) form silica nanostructures



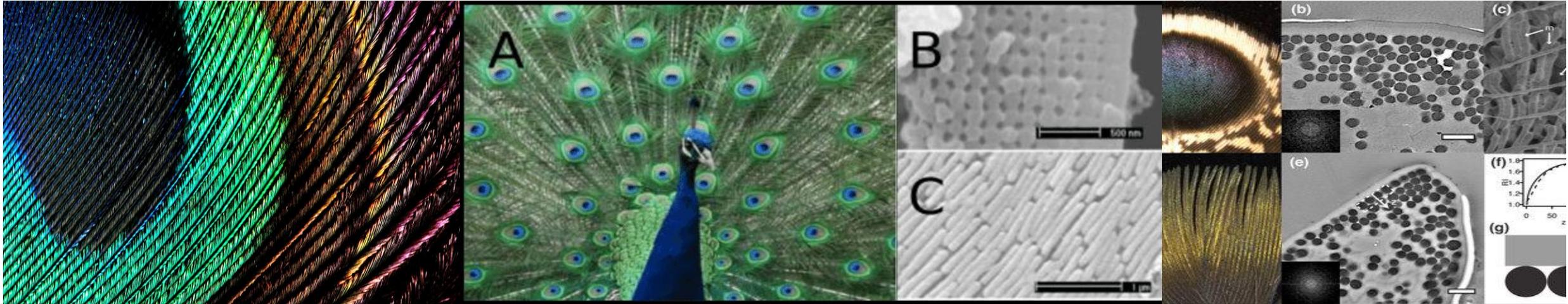
Bones and teeth contain hydroxyapatite nanoparticles



Microbes forming metal nanoparticles inside or outside cells



Peacock Feather – Natural Photonic Nanostructure



Why Peacock Feather is a Nanomaterial Example

- Peacock feathers show **bright, iridescent colors** without using pigments.
- The colors arise due to **nanoscale periodic structures** in the feather barbules.
- These nanostructures interact with light and produce **structural coloration**.

Nanoscience Explanation

- Feather contains layers of melanin rods and air gaps arranged at nanometer scale.
- Light undergoes interference and reflection.
- Different wavelengths produce different colors.

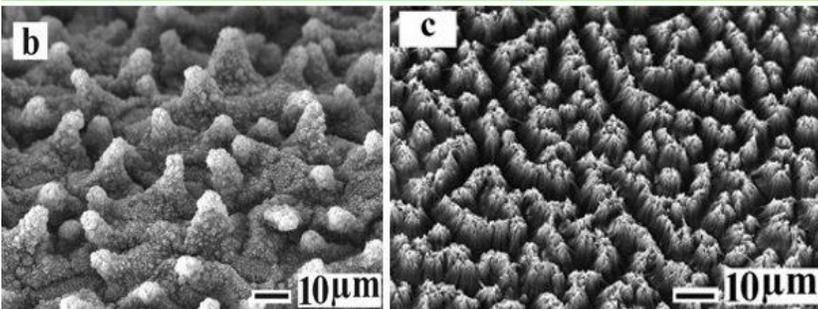
Lotus Leaf – Natural Superhydrophobic Nanostructure

Why Lotus Leaf is a Nanomaterial Example

- Lotus leaves remain **clean even in muddy water**.
- This is due to **micro- and nano-scale rough structures** plus a waxy coating.
- Known as the **Lotus Effect**.

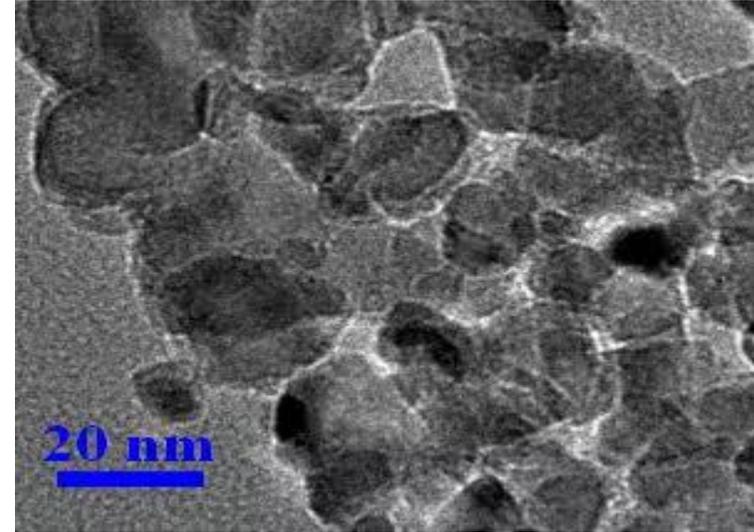
Nanoscience Explanation (Simple)

- Leaf surface has **nano-sized bumps**.
- Water droplets roll off, carrying dirt away.
- Results in **superhydrophobic (water-repellent) behavior**.

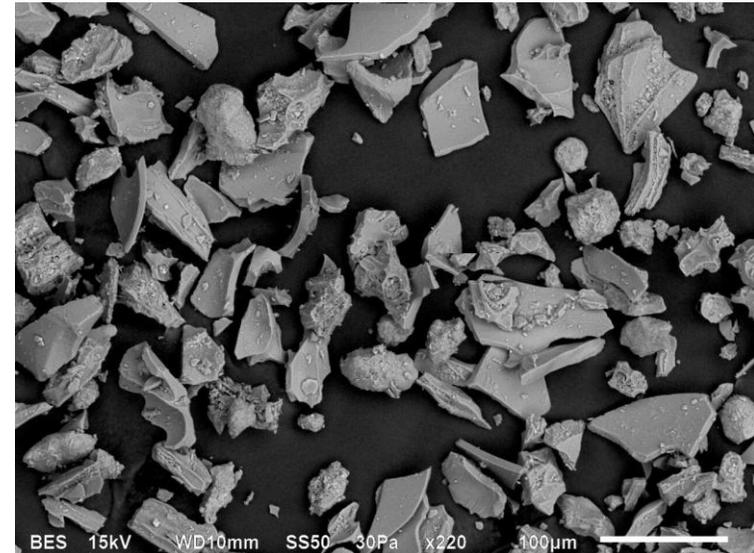


2. Geological Sources of Nanomaterials

Clay Nanoparticles — tiny mineral plates in soil that act like natural nanomaterials.

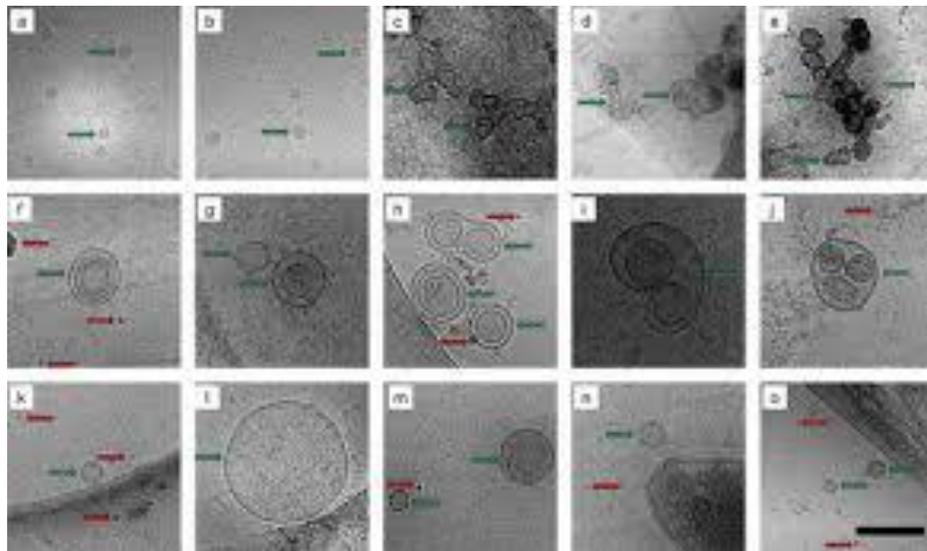


Volcanic Ash Nanoparticles — formed during eruptions; very fine nano-sized particles in the atmosphere and soil.

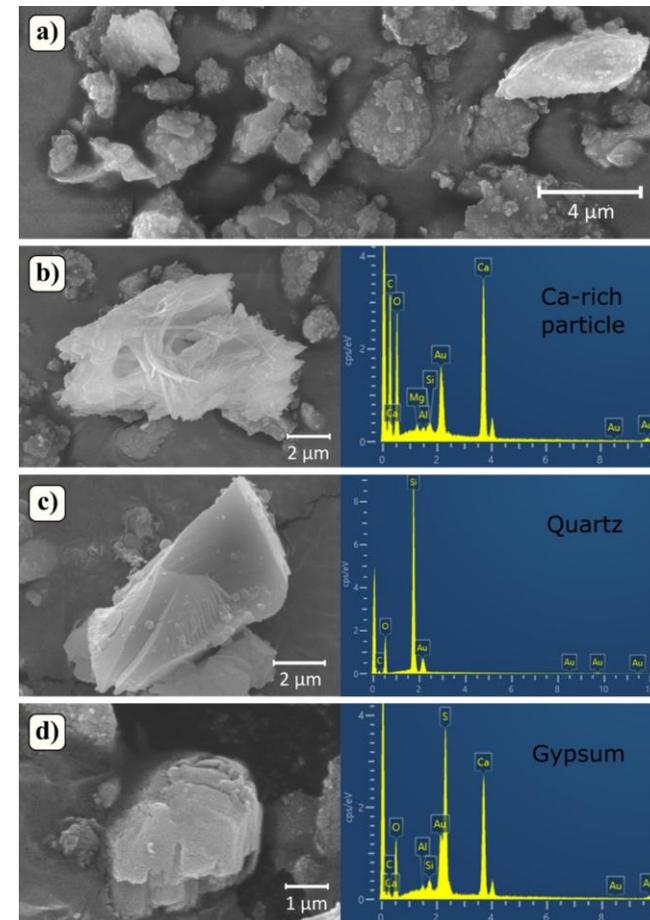


3. Atmospheric Sources of Nanomaterials

Sea Spray Aerosol Nanoparticles: Tiny salt and organic particles formed when ocean waves burst and spray water droplets into the air.



Desert Dust Nanoparticles: Wind-blown dust that includes nano-sized clay and mineral particles.



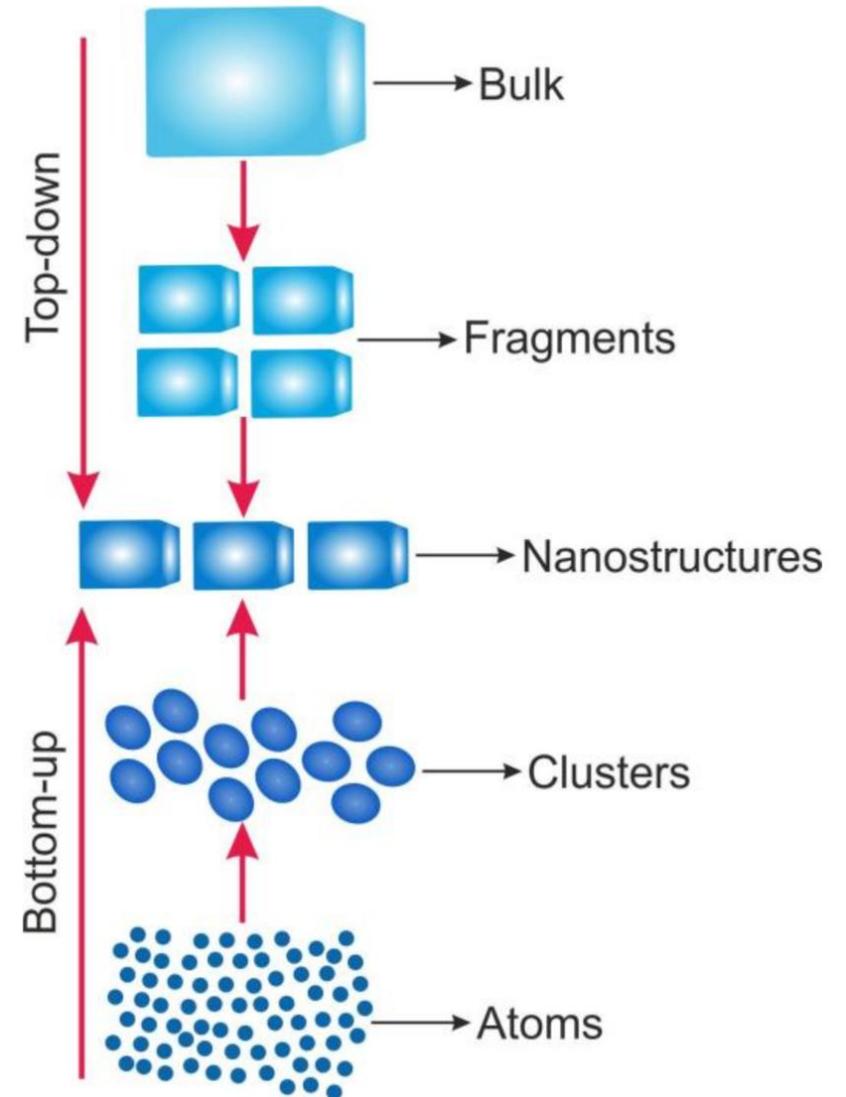
Man-Made (Artificial / Engineered) Nanomaterials

- **Man-made nanomaterials are intentionally synthesized materials in which at least one dimension lies in the range of 1–100 nm. Unlike naturally occurring nanomaterials, these are produced under controlled laboratory or industrial conditions to achieve specific size, shape, and properties.**
- **The purpose of synthesizing nanomaterials artificially is to:**
 - a. Control particle size and morphology**
 - b. Tailor physical and chemical properties**
 - c. Produce materials suitable for technological applications**

Classification of Man-Made Nanomaterials (Based on Synthesis Approach)

These are two types based on method of synthesis applied:

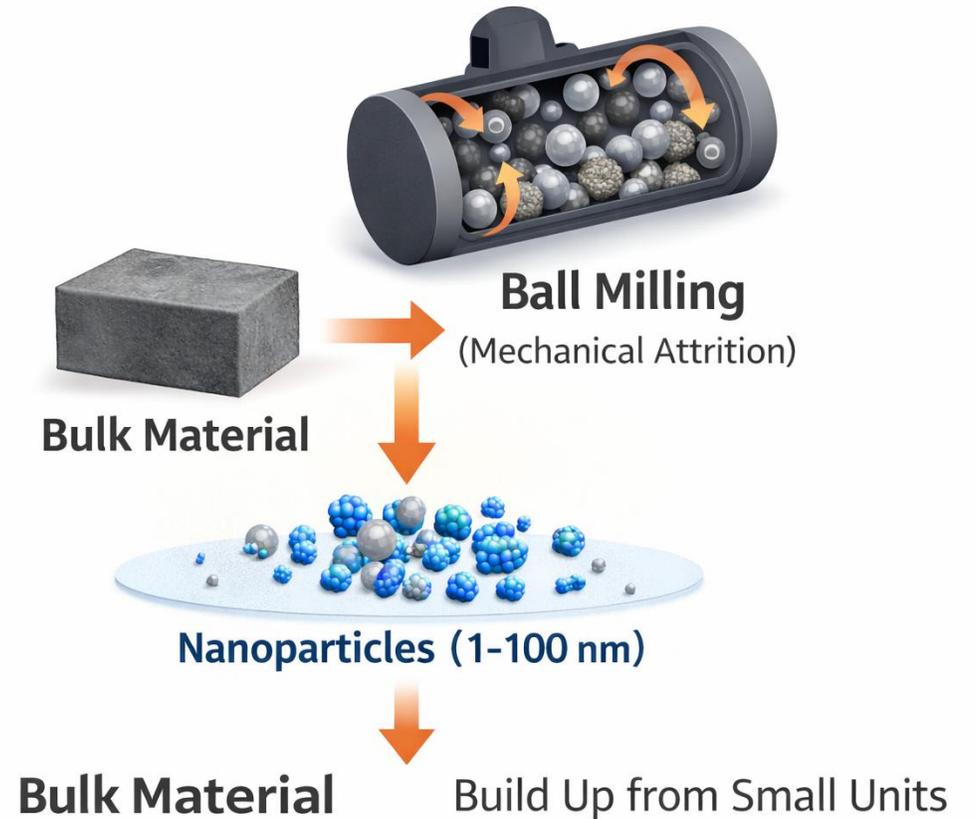
1. Top Down method bulk materials are broken down into nanoscale particles using physical or mechanical processes.
2. Bottom Up method nanomaterials are built atom-by-atom or molecule-by-molecule through chemical reactions or self-assembly.



Common Top-Down Techniques

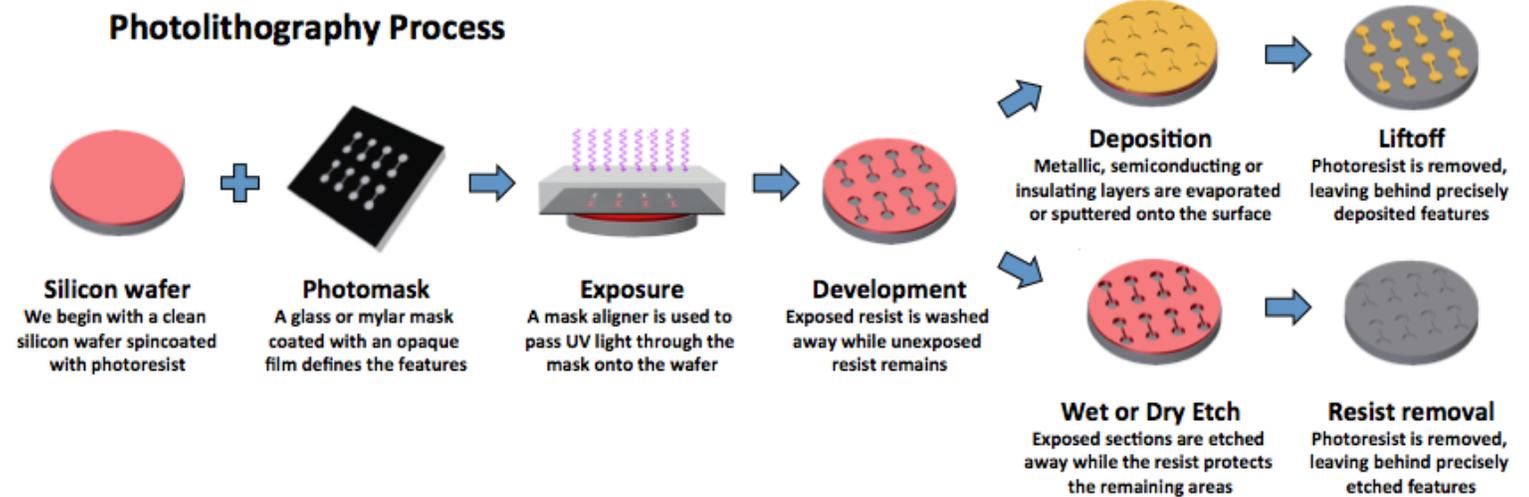
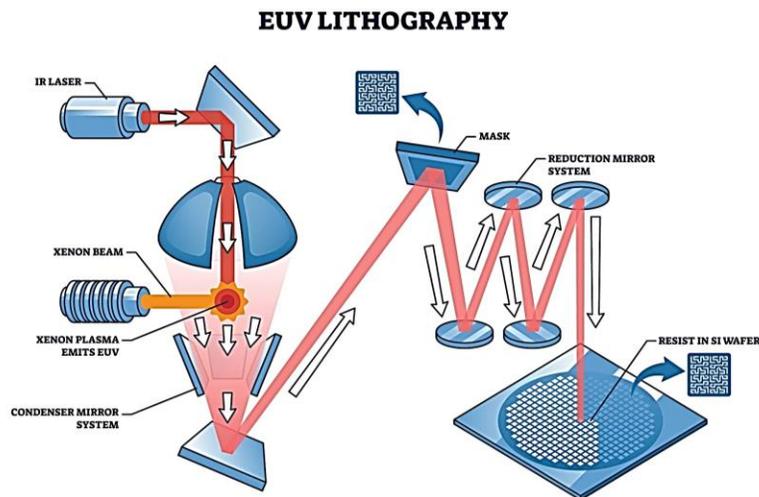
1. Ball Milling (Mechanical Attrition)

- Bulk material is placed in a rotating container with hard balls. Repeated collision breaks material into nanoparticles.
- A rotating milling chamber containing hard balls (steel/ceramic)
- Bulk material particles trapped between balls
- Repeated impact, friction, and collision
- Progressive size reduction → micro → nano



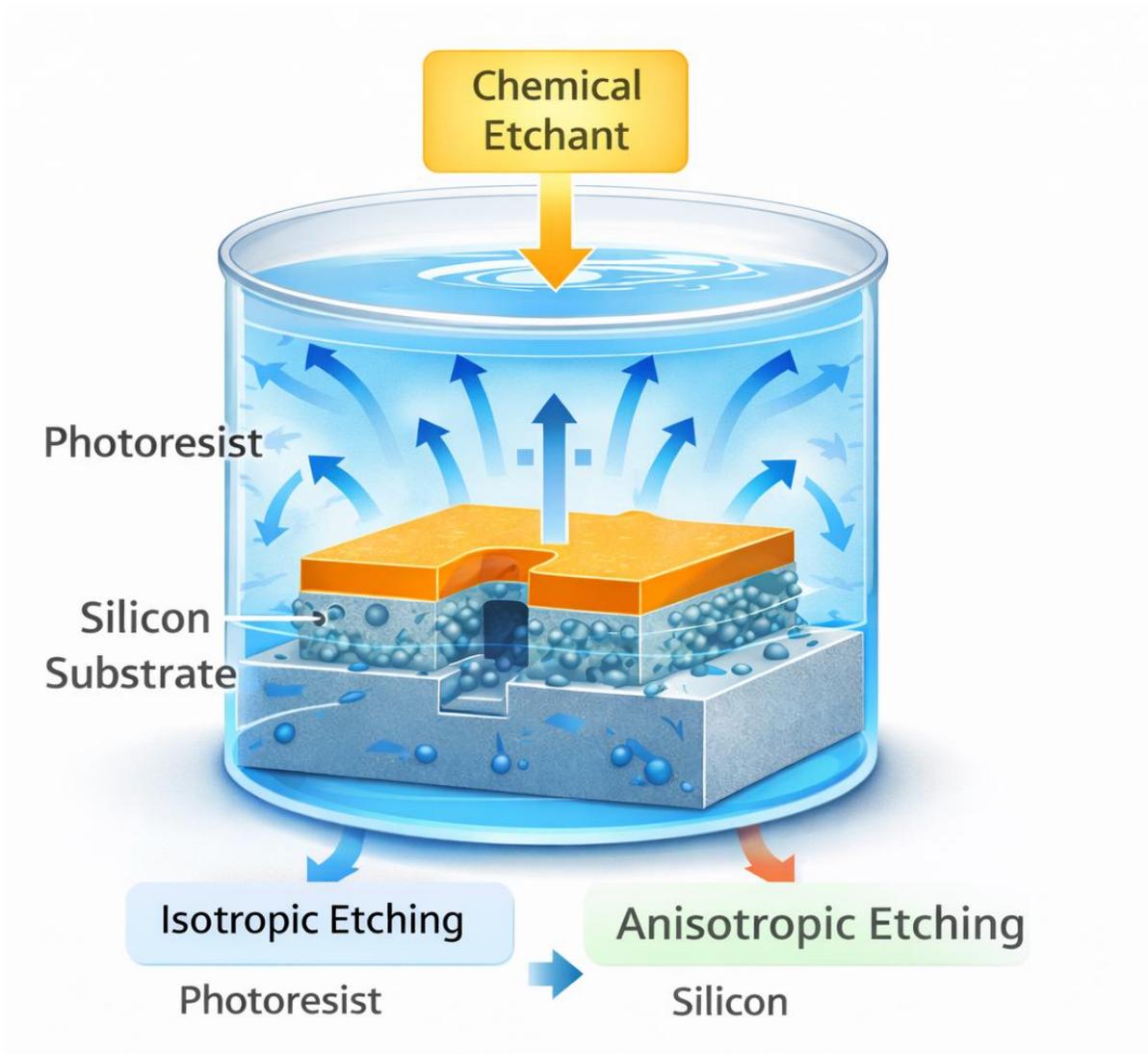
2. Lithography

- Lithography is a top-down nanofabrication technique in which nano-sized patterns are transferred onto a surface using light, electrons, or ions, followed by chemical processing. Widely used in microelectronics and nanotechnology.
- A patterned mask and an energy source (light/electron beam) are used to selectively expose a photoresist-coated substrate. The exposed regions are chemically developed to create nano-patterns.
- Types of Lithography
 1. Photolithography: Uses ultraviolet (UV) light. Most common industrial method.
 2. Electron Beam Lithography (EBL): Uses focused electron beam. High resolution.
 3. Nanoimprint Lithography: Pattern pressed mechanically into resist.

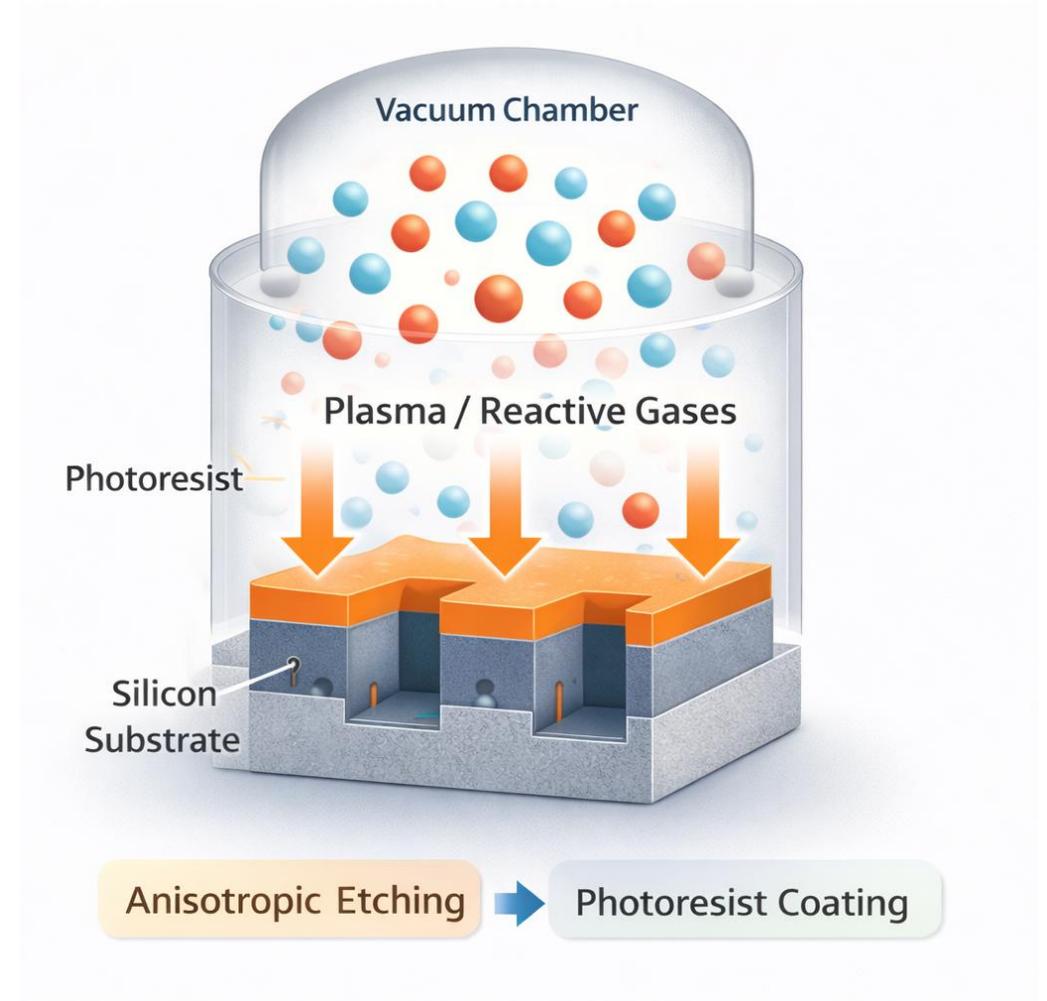


3. Etching

- Etching is a top-down nanofabrication process used to remove selected portions of material from a surface to create micro- and nano-scale patterns. It is widely used in semiconductor and nanotechnology industries.
- In etching, a protected surface (photoresist-coated) is exposed to chemical or plasma etchants. The unprotected regions are dissolved or vaporized, leaving behind a patterned surface.
- Types of Etching:
 1. Wet Etching: Uses liquid chemical solutions. Example etchants: acids, bases. Etching occurs in all directions
 2. Dry Etching: Uses gases or plasma. Includes plasma etching and reactive ion etching (RIE).
More directional and controlled



Wet Etching

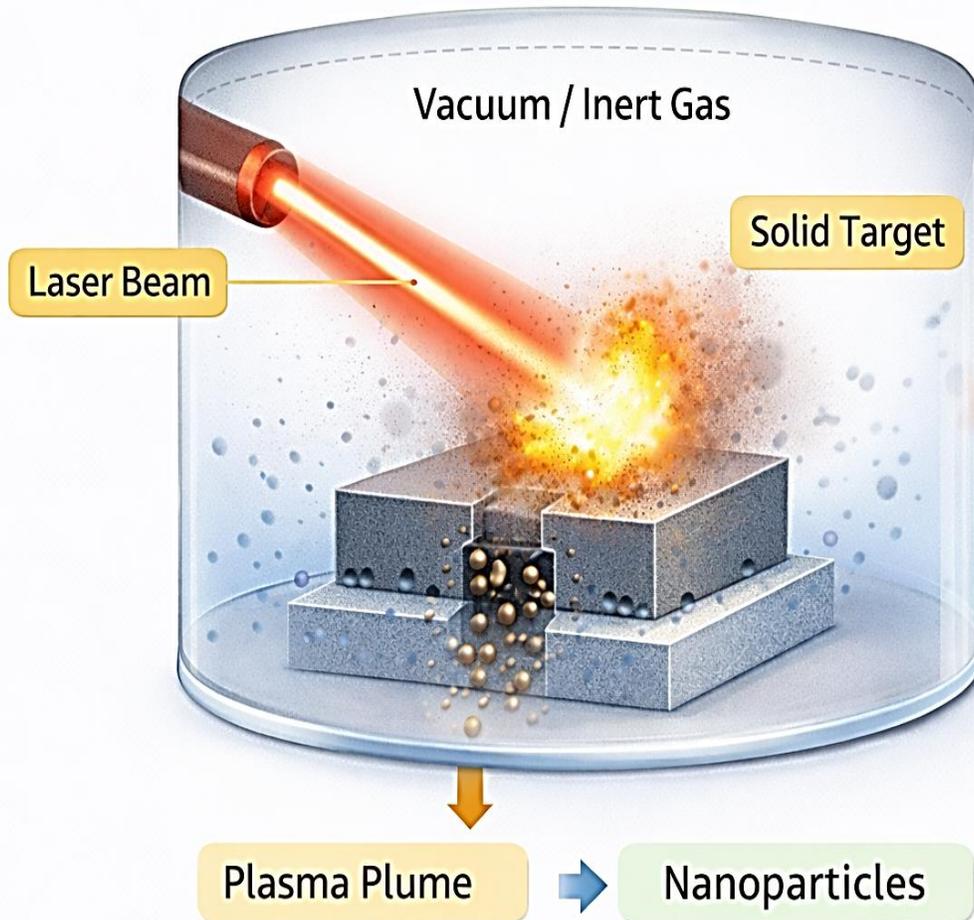


Dry Etching

4. Laser Ablation

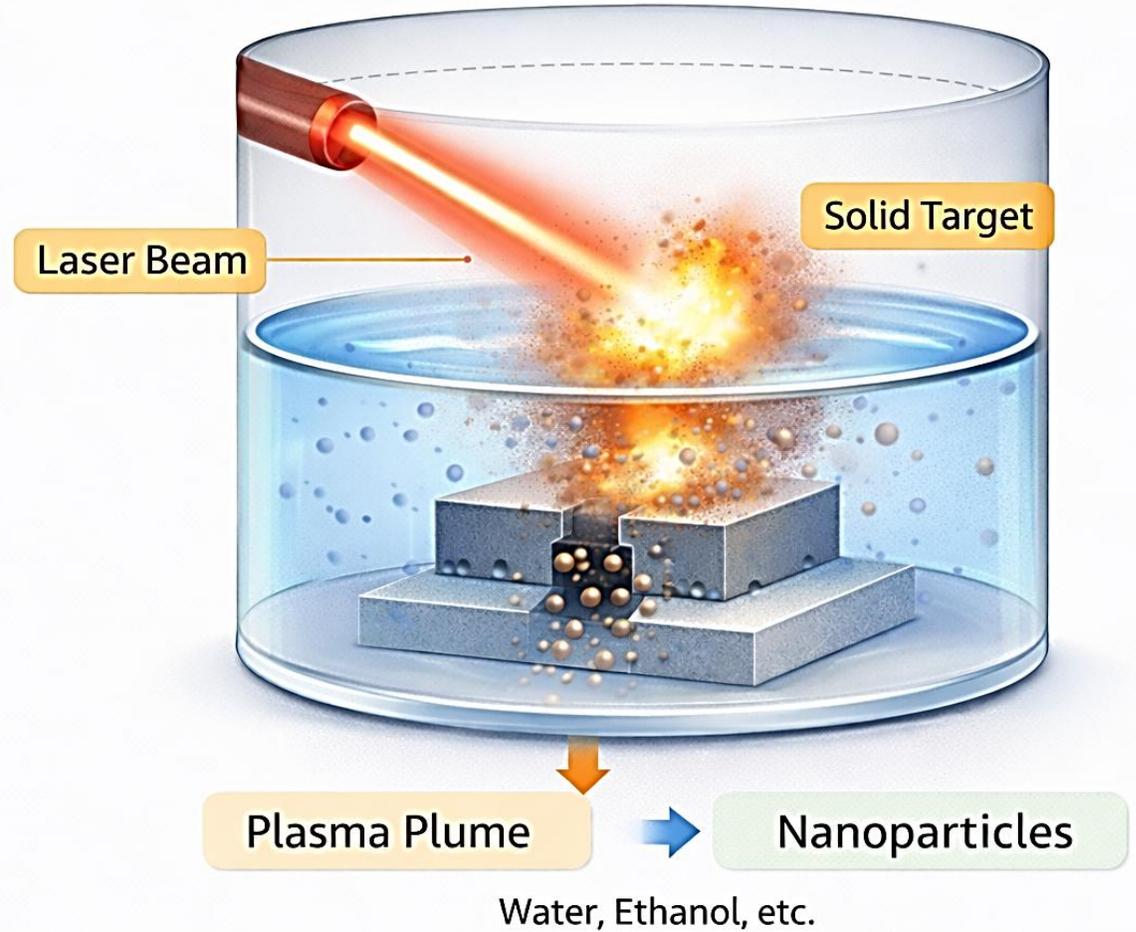
- Laser ablation is a **top-down physical method** in which a **high-energy laser beam is focused onto a solid target**, causing material to be ejected (ablated).
- The ejected species cool and condense to form **nanoparticles**. When intense laser pulses strike the surface of a material surface atoms absorb energy, material is vaporized and forms a plasma plume, the plume cools rapidly and nanoparticles are formed by condensation.
- These are two types:
 1. Laser Ablation in Vacuum / Gas: Target kept in vacuum or inert gas. Produces thin films or nanoparticles.
 2. Laser Ablation in Liquid (LAL): Target immersed in liquid (water, ethanol). Produces stable nanoparticle suspensions

LASER ABLATION IN VACUUM / GAS



Laser Ablation in Vacuum / Gas

LASER ABLATION IN LIQUID



Laser Ablation in liquid