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TOP-DOWN AND BOTTOM-UP APPROACHES FOR SYNTHESIS OF NANOMATERIALS

Synthesis of nanomaterials and nanostructures are the important aspect of nanoscience and nanotechnology. New physical properties and applications of nanomaterials are only possible when nanostructured materials are made available with desired size, shape, morphology, crystal structure and chemical composition. These notes provide a clear and concise understanding on Top-down and Bottom-up approaches for synthesis of nanomaterials.

Introduction:

- ✓ Nanotechnology is an emerging area of research which has a potential in replacement of conventional micron technologies and gives size dependent properties of the functional materials.

- ✓ The interest in nanoscience (science of low dimensional systems) is a realization of a famous statement by Feynman that "There's a Plenty of Room at the Bottom".

- ✓ Based on Feynman's idea, K. E. Drexler advanced the idea of "molecular nanotechnology" in 1986 in the book *Engines of Creation*, where he postulated the concept of using nanoscale molecular structures to act in a machine like manner to guide and activate the synthesis of larger molecules.

- ✓ When the dimension of a material is reduced from a large size, the properties remain the same at first, then small changes occur, until finally, when the size drops below 100 nm, dramatic changes in properties can occur.

- ✓ If only one dimension of a three-dimensional nanostructure is of nanoscale, the structure is referred to as a quantum well; if two dimensions are of nanometer scale, the structure is referred to as a quantum wire; and if all three dimensions are of nanometer scale, the structure is referred to as a quantum dot.Hence a quantum dot has all three dimensions in the nanorange and is the ultimate example of nanomaterials.

- ✓ The word quantum is associated with these three types of nanostructures because changes in properties arise from the physics of quantum-mechanics.

Key issues in the fabrication of Nanomaterials:

The interest in synthesis of nanomaterials has grown because of their distinct optical, magnetic, electronic, mechanical, and chemical properties compared with those of the bulk materials.

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The fabrication and process are the key issues in nanoscience and nanotechnology to explore the novel properties and phenomena of nanomaterials to realize their potential applications in science and technology. Many technological approaches/methods have been explored to fabricate nanomaterials.

Followings are the key issues or challenges in the fabrication of nanostructured materials using any process or technique:

- **Can you Control the particle size ?**
- **Can you control the shape of nanoparticles ?**
- **Can you control the structure either crystalline or amorphous?**
- **Particle size distribution (monodespersive: all particles are of same size).**

Semiconductor Nanoparticles

Nanoparticle have recently attracted significant attention from the materials science community. Nanoparticle, particles of the material with diameter in range 1 to 20 nm, promise to play a significant role in developing technologies.

- ✓ They exhibit unique physical properties that give rise to many potential applicaltions in areas such as nonlinear optics, luminescence, elctronics, catalyst, solar energy conversion, and optoelectronics .
- ✓ Two fundamental factors, both related to the size of the individual nanocrystal are responsible for these unique properties. The first is the large surface to volume ratio, and the second factor is the quantum confinement effect.
- ✓ The wide band gap II-VI semiconductor are of current interest. For optoelectronics applications such as blue lasers, light emitting diodes, photonic crystals and optical devieces based on non linear properties.
- ✓ The properties of semiconductor nanoparticles strongly depend on its size, shape, composition, crystallinity and structure.
- ✓ It is a great challenge and prominent aim to precisely control these parameters of nanoparticles for the synthetic nanotechnologists.
- ✓ The exposure of exact size and shape controlled synthesis of nanostructure materials is becoming a great challenge for the nanotechnologists.

Magnetic Nanoparticles:

- ✓ Magnetic materials are also strongly affected by the small size scale of nanoparticles. Magnetic nanoparticles are being looked at for applications in cancer diagnosis and treatment.

- ✓ Before widespread usage of nanoparticles in medicine can be realized, a number of technical challenges must be met.

- ✓ These include, though are not limited to, synthesizing uniformly sized, nontoxic particles and coating the particles to make them attach to specific tissues.

- ✓ The ferromagnetic (superparamagnetic) nanoparticles can be manipulated by magnetic fields; they offer the potential to be a powerful tool for medicine and pharmacology.

- ✓ In order for magnetic nanoparticles to be used within the body, they must meet several stringent criteria. Some of these criteria are biocompatibility, ease of dispersion into solution for injection, and most importantly, nontoxicity.

- ✓ In addition, the surfaces of the particles must be able to be functionalized to attach and agglomerate into specific, targeted tissues.

- ✓ This would allow magnetic nanoparticles to function in a wide range of applications from drug targeting to improved resolution for nuclear magnetic resonance imaging

- ✓ Recently it has been proposed that the nanoparticles could be used to treat cancers through a treatment called thermotherapy or hyperthermia.

- ✓ Iron oxides are one group of magnetic nanoparticles that meet the stringent requirements for insertion into the body.

Methods of synthesis of nanomaterials:

Nanostructure materials have attracted a great deal of attention because their physical, chemical, electronic and magnetic properties show dramatic change from higher dimensional counterparts and depends on their shape and size.

- Many techniques have been developed to synthesize and fabricate nanostructure materials with controlled shape, size, dimensionality and structure.

- The performance of materials depends on their properties. The properties in tern depend on the atomic structure, composition, microstructure, defects and interfaces which are controlled by thermodynamics and kinetics of the synthesis.

Classification of Techniques for synthesis of Nanomaterials
There are two general approaches for the synthesis of nanomaterials as shown in Figure 2:

a) Top- down approach
b) Bottom–up approach.

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(a) Top-down approach

Top-down approach involves the breaking down of the bulk material into nanosized structures or particles.

Top-down synthesis techniques are extension of those that have been used for producing micron sized particles.

Top-down approaches are inherently simpler and depend either on removal or division of bulk material or on miniaturization of bulk fabrication processes to produce the desired structure with appropriate properties.

The biggest problem with the top-down approach is the imperfection of surface structure.

For example, nanowires made by lithography are not smooth and may contain a lot of impurities and structural defects on its surface. Examples of such techniques are high-energy wet ball milling, electron beam lithography, atomic force manipulation, gas-phase condensation, aerosol spray, etc.

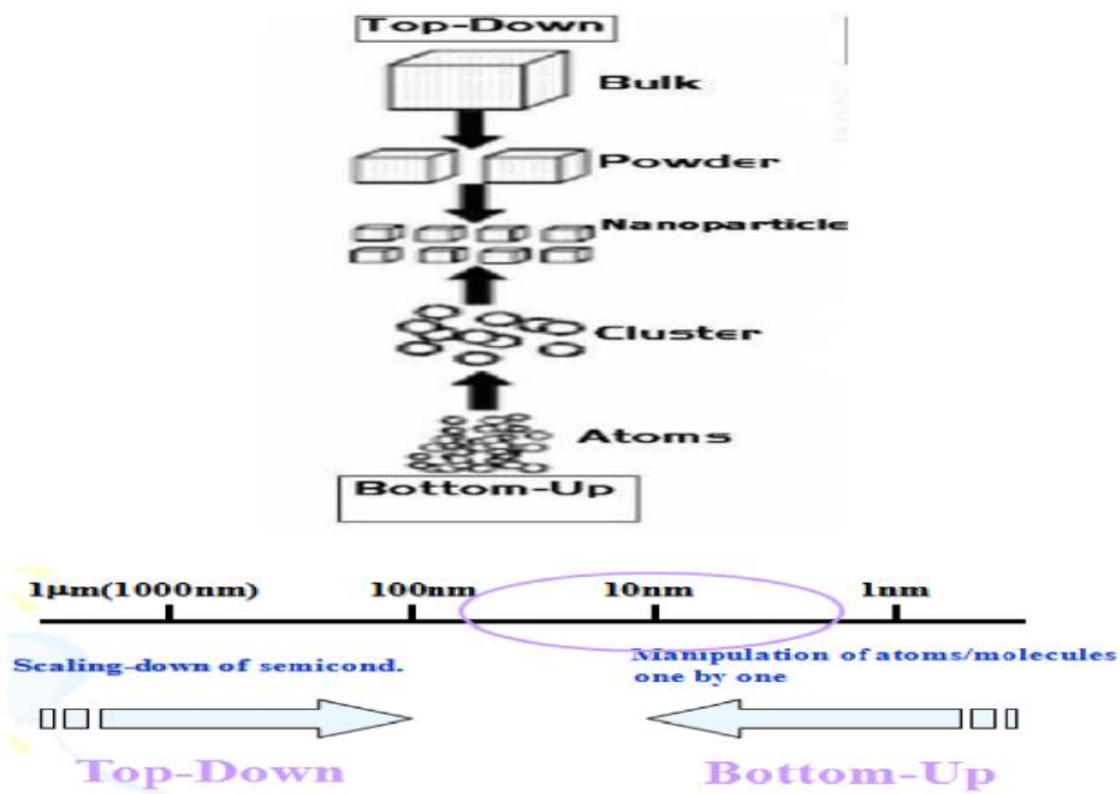

Figure 2: Schematic representation of 'top-down' and 'bottom-up' approaches for synthesis of nanoscale materials.

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(b) Bottom-up approach

- ✓ The alternative approach, which has the potential of creating less waste and hence the more economical, is the 'bottom- up'.
- ✓ Bottom-up approach refers to the build up of a material from the bottom: atom-by-atom, molecule-by-molecule, or cluster-by cluster.
- ✓ Many of these techniques are still under development or are just beginning to be used for commercial production of nanopowders.
- ✓ Oraganometallic chemical route, revere-micelle route, sol-gel synthesis, colloidal precipitation, hydrothermal synthesis, template assisted sol-gel, electrodeposition etc, are some of the well- known bottom–up techniques reported for the preparation of luminescent nanoparticals.

Concluding Remarks:

- ✓ ***A number of techniques have been explored to synthesis nanomaterials of desired size, shape and orientation.***
- ✓ ***Broadly these technical approaches can be grouped as Top-down and Bottom-up approaches.***
- ✓ ***Both approaches play very important roles in device industry as well in nanoproducts and have their own merits and demerits.***
- ✓ ***The biggest problem with top-down approach (physical methods) is the imperfection of the surface structure.***
- ✓ ***Such imperfections would have a significant impact on the physical and chemical properties of nanostructures and nanomaterials.***
- ✓ ***Among the top-down and bottom-up approaches, the bottom-up approach is more accepted in synthesis of nanoparticles due to many merits as fewer defects, more homogenous chemical composition and better ordering.***
- ✓ ***It is found that the Gibbs free energy, thermodynamic equilibrium and kinetic methods are the main strategies of nanoparticles synthesis in bottom-up approach.***

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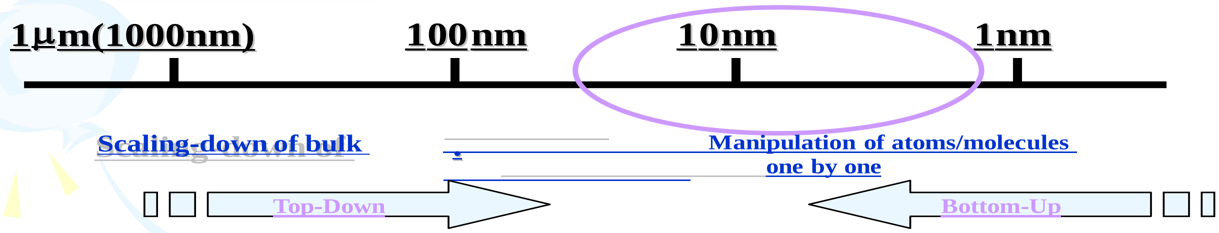
Nano fabrication

Top-down making nanoscale structures by machining, coating, atomisation, lithography and etching techniques. (Physical methods)

Bottom-up ("Molecular nanotechnology") applies to building organic and inorganic structures atom-by-atom and molecule-by-molecule. (Chemical methods)

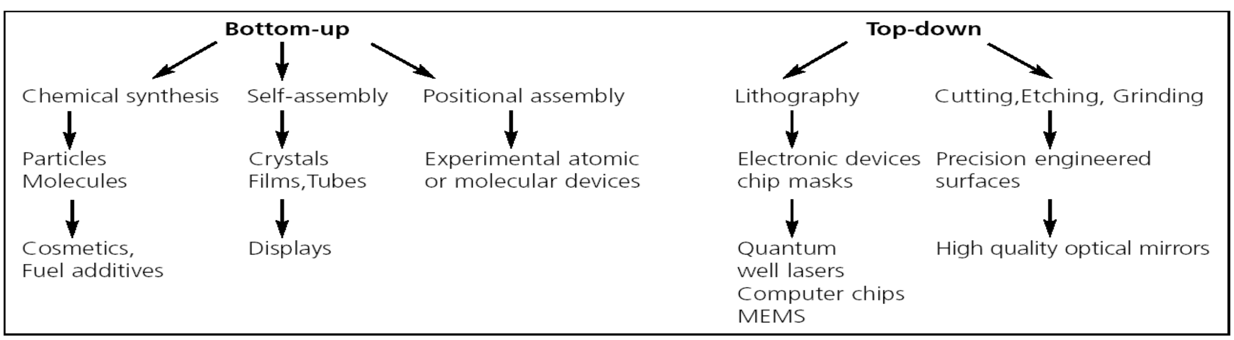


- **Nature employs nanotechnology to build DNA, proteins, enzymes etc.**

It is the ultimate technology.

- ***"Nanotechnology is already all around us if you know where to look"***
    - ***("Nature" is the master nanotechnologist)***

Nano fabrication



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