NANO MATERIALS

- Nanomaterials are newly developed materials with the grain size in the range 1 to 100 nm at least in one dimension. 1nm=one billionth of a meter (10^{-9}m).
- Nanomateriasl are categorized according to their dimensions

Classification of Nanomaterials

Nanomaterials dimension	Examples
All three dimensions < 100 nm	Nanoparticles, quantum dots, nanoshells, nanorings, microcapsules
Two dimensions < 100 nm	Nanotubes, fibres, nanowires
One dimension < 100 nm	Thin films, layers and coatings

- **Nanoscience** is the study of materials that exhibit remarkable properties, functionality and phenomena due to the influence of small dimensions.
- **Nanotechnologies** are the design, characterization, production and application of structures, devices and systems by controlling shape and size at the nanometer scale.
- Some **good examples** to bring to the classroom:

Our **fingernails grow** at the rate of 1 nm per second;

The **head of a pin** is about 1 000 000 nm in diameter;

A **human hair** is about 80 000 nm in diameter;

A **DNA molecule** is 1–2 nm wide;

The **transistor** of a latest-generation Pentium Core Duo processor is 45 nm.

Synthesis of nanomaterials

- The nano materials are synthesized into two categories, namely
  - ➢ Top-down process
  - ➢ Bottom-up process

Top-down process

- In the top-down process, a bulk material is crushed into fine particles.
- Example: 1.Ball milling 2.Laser ablation 3.sputtering
  4. Plasma arcing 5.Electron beam evaporation 6.Photolithography

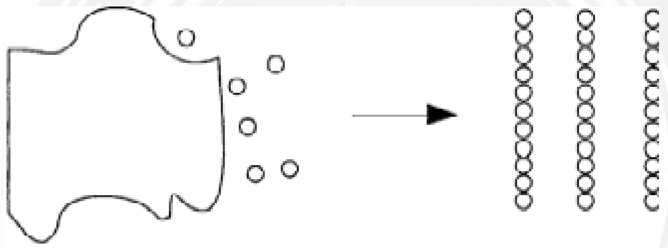


Figure 5.11 Top-down process

Bottom-up process

❖ In this process, nano materials are produced by arranging atom by atom.

❖ Example: 1. Chemical vapor deposition 2. Sol- gel method 3. Electro deposition, etc.

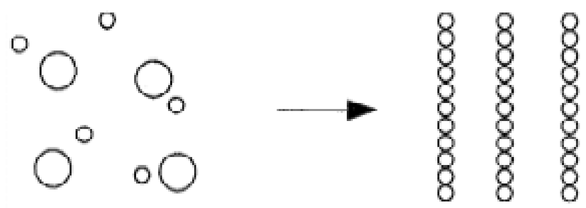


Figure 5.12 Bottom-up process

Laser ablation method

- Pulsed Laser technique is a thin film deposition technique.
- PLD consists of an ultra-high vacuum chamber where graphite target and substrate are attached parallel to each other.
- When laser pulse of suitable wavelength and sufficient energy falls on the graphite target. The surface of the target is then heated up and the material is vaporized.
- High energy species are emitted from the surface.
- The argon gas present inside the vacuum chamber is used to sweep the carbon atoms towards the collector.
- It is then deposited as a thin film on a substrate.
- The quality of the film grown, the size of the nano particles and the rate of deposition depend on various lattice parameters such as the laser energy and pulse duration.

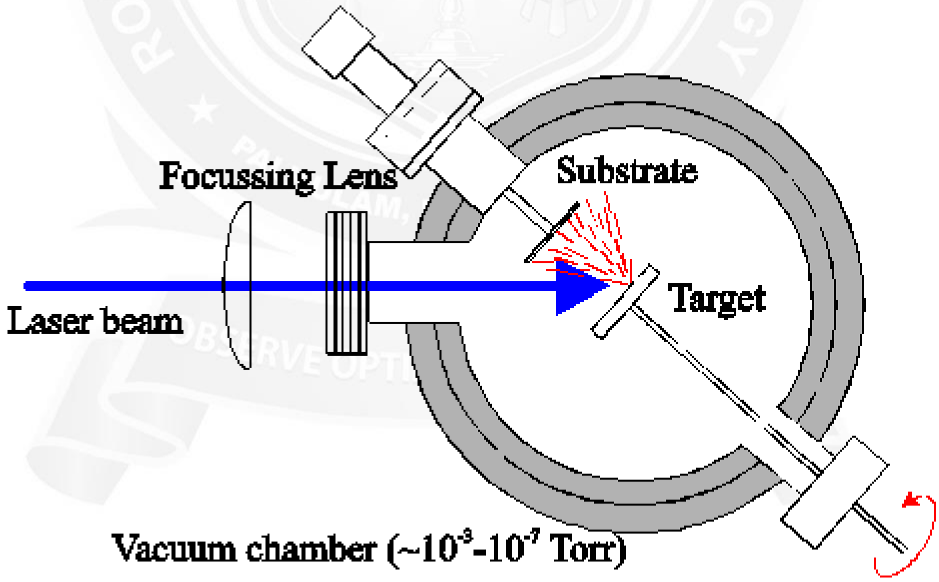


Figure 5.13 Laser ablation method

Advantages

- Flexible, esay to implement
- Growth in any environment
- The process is controlled by temperature and laser output power

Disadvantages

- Uneven coverage
- Not well suited for large scale film growth

Applications

- To produce high quality thin films and nano particles

Chemical Vapour Deposition

- CVD is a chemical method used to produce nano materials.
- The CVD apparatus consists of quartz tube container, tubular furnace , tungsten boat, inert gas and silicon substrate.
- The silicon substrate is placed inside the a tungsten boat. The whole set up is kept inside the quartz tube.
- The quartz tube container is maintained the inert atmosphere.
- The reactants are admitted into the container and it is maintaied at suitable temperature.
- The hot atoms collide with cold atoms and undergo condensation through nucleation and form small clusters.
- The thin film coating is formed on the silicon substrate because of chemical reaction. The unused gases flow through the outlet.
- The hydrogen reduction of silicon tetra chloride, is used to produce the epitaxial growth of pure silicon.The chemical reaction involved is

$$SiCl_4 + 2H_2 \rightarrow Si + 4HCl$$

Advantages

- CVD is a low cost and high yield method
- High purity nano materials are prepared
- Both SWNTs and MWNTs can be produced

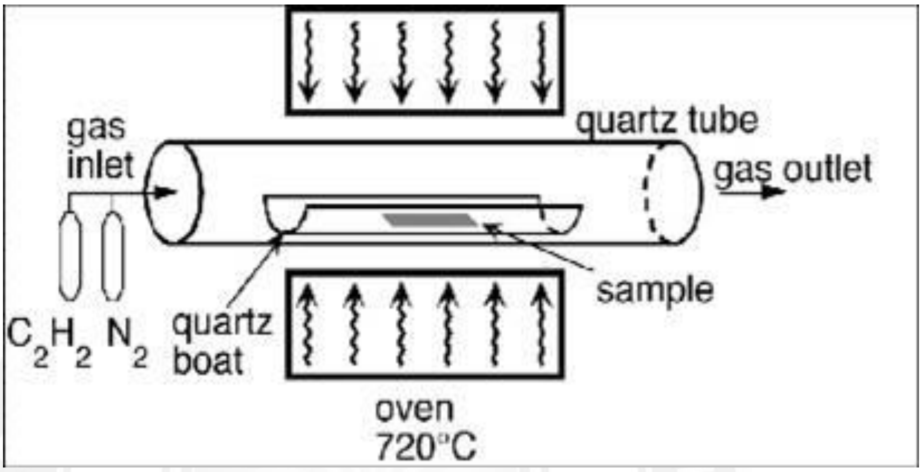


Figure 5.14 Chemical Vapour Deposition

Disadvantages

- Control of size depends on many parameters
- Control of shape is also difficult

Applications

Ics, Nano sensors, opto electronic devices

Properties of nano materials

Physical properties

- Interparticle spacing decreases with decrease in grain size
- Melting point reduces with decrease in particle size
- Ionisation potential changes with cluster size of the nano materials
- Increase surface to volume ratio causes decrease in interparticle spacing

Mechanical properties

- If the grains are nano scale, many of their mechanical properties such as hardness, elastic modulus, fracture toughness and fatigue strength are modified.
- Very high ductility and super elasticity behavior at low temperature

Magnetic properties

- Mano materials are more magnetic than bulk materials
- Exhibit giant magneto resistance

Electronic properties

- Energy bands will be very narrow
- Electrical conductivity increases with reduction in particle size

Optical properties

- Gold nano particles of 100 nm appear orange in colour while 50 nm nano spheres appear green

Applications

Energy technology

- ✓ Nano particles of Ni, Pd and Pt are useful in hydrogen storage devices
- ✓ Fabrication of ionic batteries
- ✓ Addition of nano particles Ceria to diesel fuel improves fuel economy
- ✓ Magnetic refrigeration

Material technology

- Carbon nano particles are used as a filler to reinforce car tyres and car bumpers
- Nano Tio_2 is hydrophobic and antibacterial and they used in self-cleaning windows, paints
- Used in cosmetics, food and agriculture

Bio medical

- Silver nano particles are used as bone cement, surgical instruments, wound dressings
- Cancer cell detection, artificial heart valves and implant materials
- Nano robots inserted into our body can modify neuron networks of brain
- Nano titania is used in many sun screens to block harmful UV rays
- Bio sensitive nano particles are used for tagging of DNA and DNA chips
- Controlled drug delivery

Electrical and Electronics

- Used for fabricating nano transistors, multilayer capacitors, quantum computing, display technology, photonic crystals, fast logic gates and solar cells.
- Nano magnets are used in high density magnetic recording, CDs, mobiles, lap-tops, RAM and READ/WRITE heads.
- Molecular nano technology is aimed to device robotic machines, molecular size power sources and batteries

Mechanical Engineering

- Since they are stronger, lighter etc., they are used to make hard metals.
- Smart magnetic fluids are used in vacuum seals, magnetic separators etc.
- They are also used in Giant Magneto Resistant (GMR) spin valves.
- Nano- MEMS (Micro-Electro Mechanical Systems) are used in ICs, optical switches, pressure sensors, mass sensors etc.

Carbon Nanotubes

The Amazing and Versatile Carbon – Chemical basis for life

- ✓ With an atomic number of 6, Carbon is the 4th most abundant element in the Universe by mass after (Hydrogen Helium and Oxygen). It forms more compounds that any other element, with almost 10 million pure organic compounds.

- ✓ Graphite consists of hexagonal honeycomb like arrangement of carbon atoms. a single hexagonal sheet like layer of graphite is known as Graphene.
- ✓ Carbon Nanotubes were discovered in 1991 by Sumio Iijima. Carbon Nanotubes like fullerenes (C_{60}), grapheme and nanotubes are great interest for the current research as well as for future applications.

Definition

- ✓ Carbon Nanotubes are molecular-scale tubes of graphene with large potential applications. They are long, flexible, and thin cylinders of carbon having a very broad range of electronic, thermal, physical, and structural properties.

Types of CNTs

CNTs are classified by its diameter, length, and chirality. They are

1. Single Wall Carbon Nanotubes (SWCNTs)
2. Multiple Wall Carbon Nanotubes (MWCNTs)

Single-walled carbon nanotube structure

- ✓ Single-walled carbon nanotubes consist of one tube of Graphite. SWCNTs diameter range from 0.5 nm to 2.0 nm and their length is few μm.
- ✓ This can be formed in three different designs:

  Armchair structure,

  Chiral structure, and

  Zigzag structure.

- ✓ The different ways of rolling the graphite sheet gives different single-walled nanotube's structure.
- ✓ A single-walled nanotube's structure is represented by a pair of indices (n,m) called the chiral vector.

The chiral vector is represented by

$$C_h = na_1 + ma_2$$

- ✓ Where n and m are positive integers

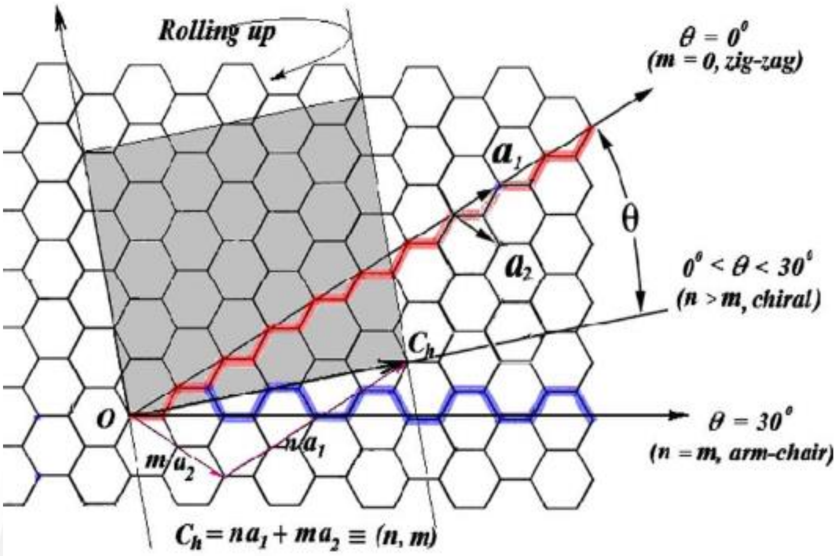
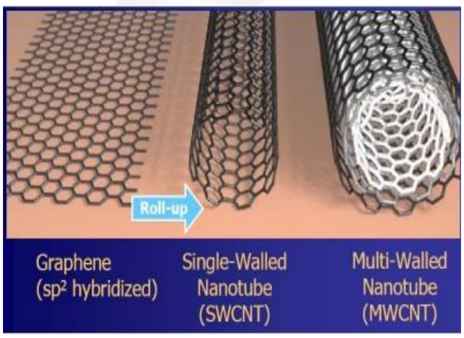


Figure 5.15 Rolled sheet of CNTs

- ✓ The tubes marked as (m, 0) has C-C bonds are parallel to the tube axis, at an open end; a zigzag pattern is formed and are called **Zigzag structure**.
- ✓ The tubes marked as (m=n) has C-C bonds are perpendicular to the tube axis, and are called **arm chair structure**.
- ✓ The tubes marked as (m>n) and $0^\circ < \theta < 30^\circ$, C-C bonds are inclined to the tube axis are called **chiral structure**.



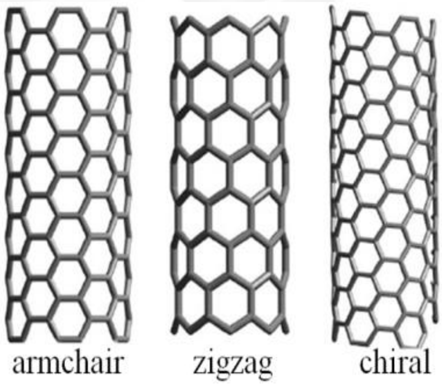


Figure 5.16 Types of CNTs

Multiple Wall Carbon Nanotubes (MWCNTs)

- ✓ Multi walled carbon nanotubes consist of several number concentric Graphite sheets. MWCNTs diameter range from 2 nm to 25 nm and their length is few μm.

Properties of CNTs

- ❖ Carbon nanotubes have a higher tensile strength than steel and Kevlar. Their strength comes from the sp^2 bonds between the individual carbon atoms. This bond is even stronger than the sp^3 bond found in diamond.
- ❖ CNTs have high electrical conductivity than copper.
- ❖ CNTs have high strength/ weight ratio. They are 20 times stronger than steel.
- ❖ Carbon nanotubes have been shown to be very good thermal conductors. The thermal conductivity of carbon nanotubes is dependent on the temperature of the tube.
- ❖ CNTs share both properties of semiconductor and metal.
- ❖ Band gap decreases with increase in diameter of CNTs.
- ❖ Pure CNTs display ferromagnetic behavior.

Methods of synthesizing CNTs

- ➢ **The various synthesizing CNTs are:**
    1. Carbon arc discharge method
    2. Laser ablation technique,
    3. Chemical Vapour Deposition (CVD) technique

Laser ablation technique

- Pulsed Laser technique is a thin film deposition technique.
- PLD consists of an ultra-high vacuum chamber where graphite target and substrate are attached parallel to each other.
- A quartz tube containing a block of graphite is heated in a furnace at $1200^\circ C$.
- A flow of argon gas is maintained throughout the reaction.
- When laser pulse of suitable wavelength and sufficient energy falls on the graphite target.
- The surface of the target is then heated up and the material is vaporized.

- High energy species are emitted from the surface.
- The argon gas present inside the vacuum chamber is used to sweep the carbon atoms towards the collector.
- It is then deposited as a thin film on a substrate.
- Ultrafast laser pulses are potential and able to prepare large amounts of SWCNTs.
- The quality of the film grown, the size of the nano particles and the rate of deposition depend on various lattice parameters such as the laser energy and pulse duration.

Advantages

- Flexible, esay to implement
- Growth in any environment
- The process is controlled by temperature and laser output power

Disadvantages

- Uneven coverage
- Not well suited for large scale film growth

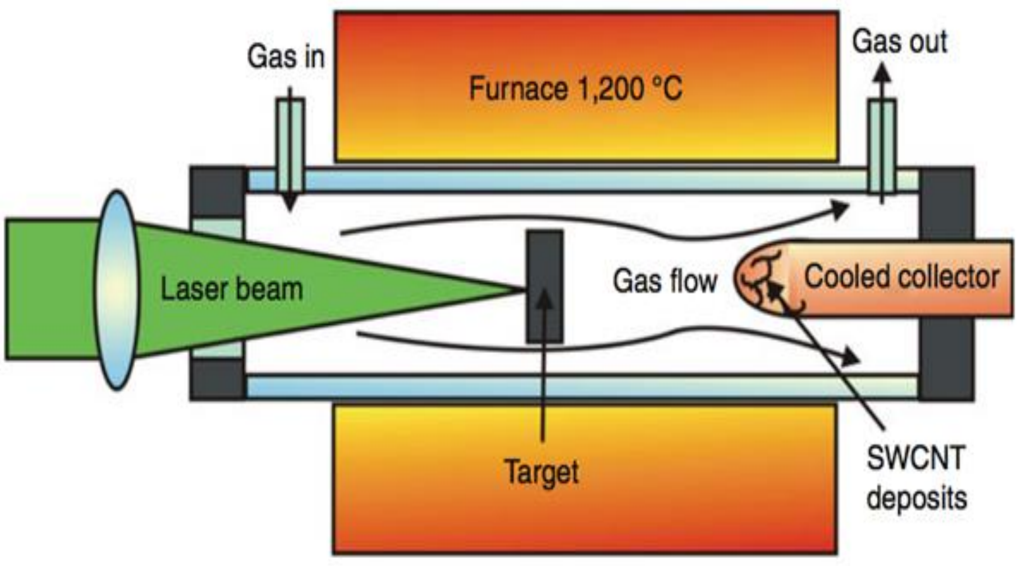


Figure 5.17 Laser Ablation technique of CNTs

Chemical Vapour Deposition (CVD) technique

Construction& working

- CVD is a chemical method used to produce carbon nanotubes.
- The CVD apparatus consists of quartz tube container, tubular furnace , tungsten boat, inert gas and silicon substrate.
- The silicon substrate is placed inside the a tungsten boat. The whole set up is kept inside the quartz tube.
- The quartz tube container is maintained the inert atmosphere.
- The reactants $(C_2H_2 \text{ and } N_2)$ are admitted into the container and it is maintaied at suitable temperature $(720^{\circ}C)$.
- The hot atoms collide with cold atoms and undergo condensation through nucleation and form small clusters.
- The thin film coating is formed on the silicon substrate because of chemical reaction. The unused gases flow through the outlet.
- The hydrogen reduction of silicon tetra chloride, is used to produce the epitaxial growth of pure silicon CNTs. The chemical reaction involved is

$$SiCl_4 + 2H_2 \rightarrow Si + 4HCl$$

Advantages

- CVD is a low cost and high yield method
- High purity nano materials are prepared
- Both SWNTs and MWNTs can be produced

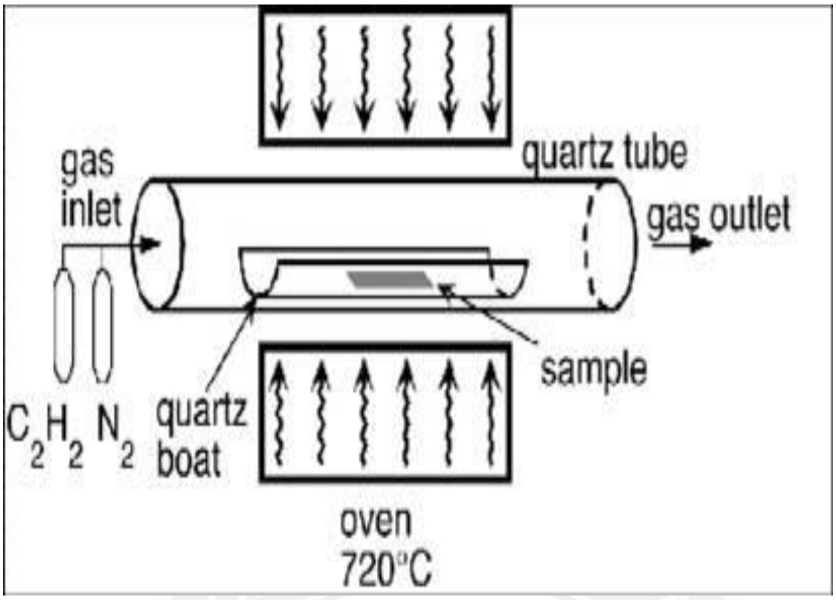


Figure 5.19 Chemical Vapour Deposition of CNTs

Disadvantages

- Control of size depends on many parameters
- Control of shape is also difficult

Applications

Ics, Nano sensors, opto electronic devices