Manonmaniam Sundaranar University,

Directorate of Distance & Continuing Education,

Tirunelveli - 627 012 Tamil Nadu, India

OPEN AND DISTANCE LEARNING(ODL) PROGRAMMES

(FOR THOSE WHO JOINED THE PROGRAMMES FROM THE ACADEMIC YEAR 2023–2024)

III YEAR

B.Sc. Physics

Course Material

ELECTIVE-VI- JEPH61

NANO SCIENCE AND NANO TECHNOLOGY

(Credits – 2)

Prepared

By

Dr. S. Shailajha

Assistant Professor

Department of Physics

Manonmaniam Sundaranar University

Tirunelveli – 12

UNIT:1

Nano-Science and Nano-Technology

1.1 Introduction to nanoscience and nanotechnology

Nanoscience is the systematic study of matter, structures, and phenomena at the nanometre scale. A nanometre is one-billionth of a metre, written as 1 nm = 10^{-9} m. At this length scale, the behaviour of matter is strongly influenced by atomic arrangement, surface effects, and quantum mechanical restrictions on the motion of electrons. Nanotechnology is the design, fabrication, characterization, and application of materials, devices, and systems whose important structural features lie in the nanoscale range, commonly taken as approximately 1 to 100 nm. The discipline connects physics, chemistry, materials science, biology, electronics, and engineering.

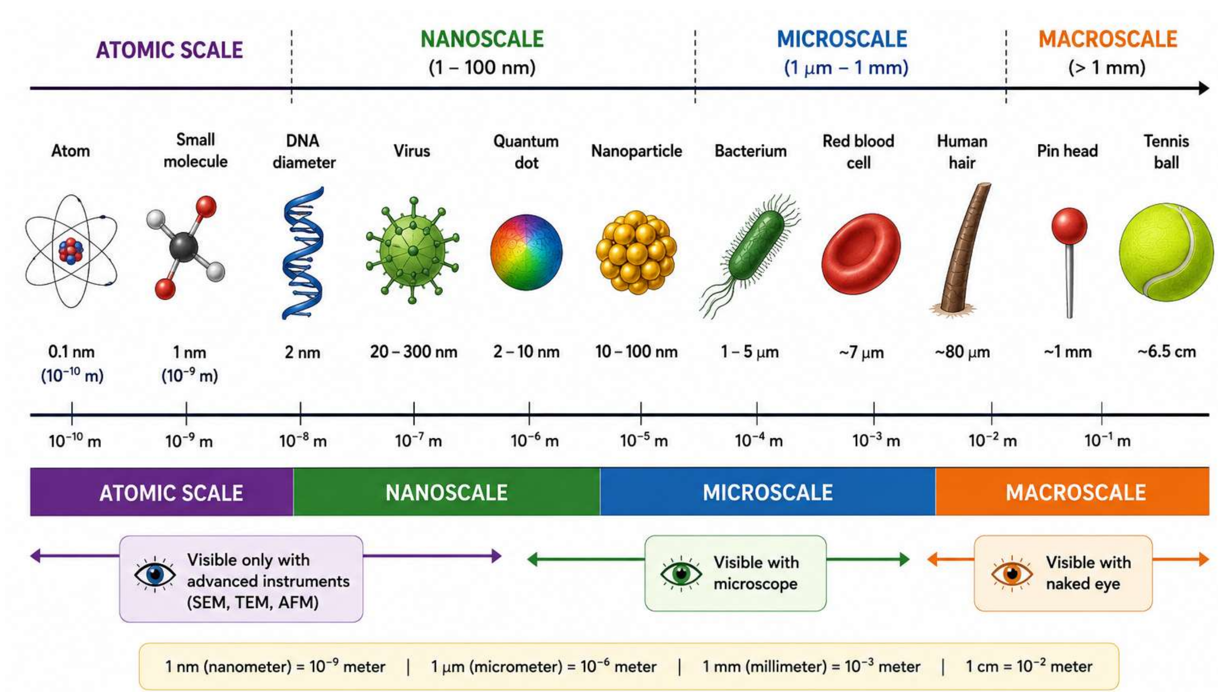

Figure 1.1 Position of the nanoscale in relation to familiar length scales.

1.2 Distinction between nanoscience and nanotechnology

Aspect	Nanoscience	Nanotechnology
Meaning	Study of nanoscale materials and phenomena.	Application of nanoscale knowledge to create useful materials, devices, and systems.
Main focus	Understanding structure-property relationships.	Design, fabrication, optimization, and practical use.
Typical question	Why do properties change at nanoscale?	How can nanoscale properties be used for a device or process?
Example	Studying quantum confinement in semiconductor nanoparticles.	Using quantum dots in displays, bioimaging, or solar cells.

1.3 Nanoscale behaviour

The properties of nanomaterials differ from bulk materials mainly because the relative importance of surface atoms increases and because electrons are confined within very small dimensions. These effects are negligible in many bulk solids but become significant as particle size approaches the nanometre range.

1.3.1 Surface-to-volume ratio

When a material is divided into very small particles, the total surface area increases sharply. A large fraction of atoms then lies at or near the surface rather than in the interior. Surface atoms have fewer neighbouring atoms and therefore possess higher surface energy. This makes nanomaterials more reactive and more sensitive to their environment. The high surface-to-volume ratio is responsible for many important features of nanomaterials, including enhanced catalytic activity, rapid chemical interaction, improved adsorption, and increased sensitivity in sensors.

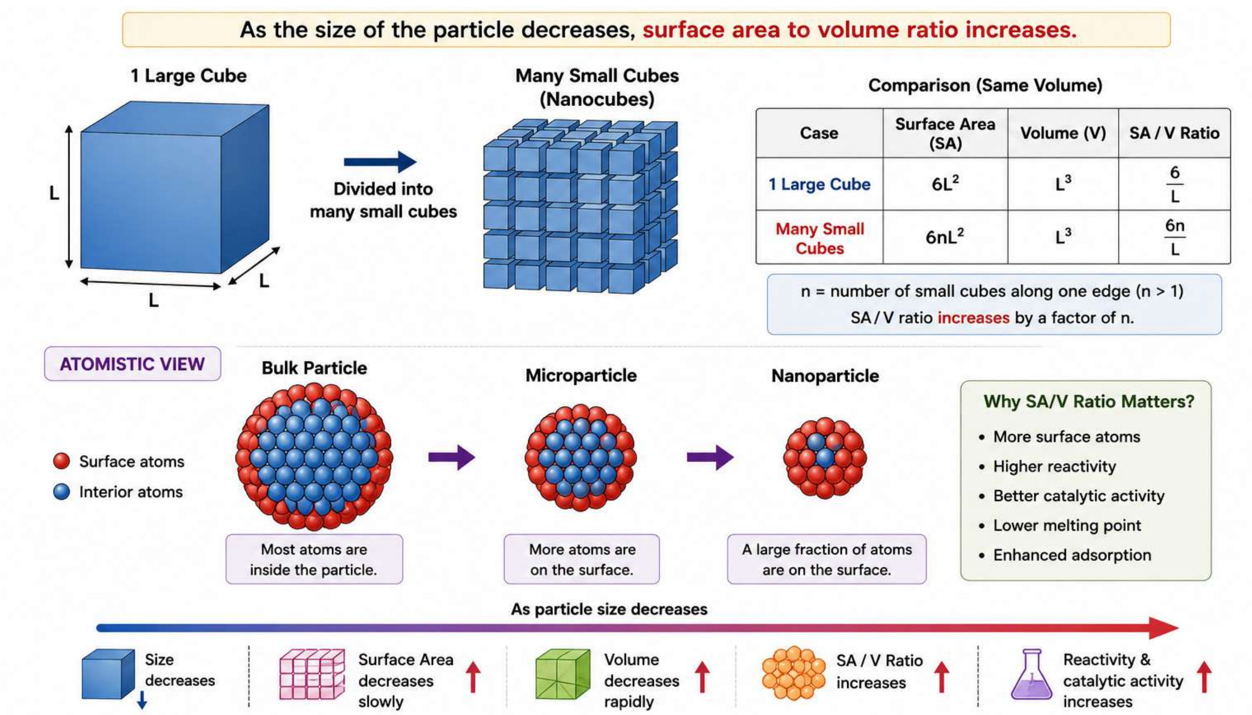

Figure 1.2 This image represents how surface-to-volume ratio related with particle size

1.3.2 Quantum size effect

In bulk materials, electrons can occupy a very large number of closely spaced energy states. In nanometre-sized structures, the available space for electron motion becomes limited. This restriction is known as quantum confinement. It causes the electronic energy levels to become more discrete and may change the optical, electrical, and magnetic behaviour of the material.

A common example is the size-dependent colour of semiconductor quantum dots. By changing the size of the quantum dot, the energy gap and therefore the colour of emitted light can be tuned.

1.4 Nanostructures and their classification

Nanostructures are systems in which at least one dimension lies in the nanometer range. They are commonly classified according to the number of dimensions that are confined to the nanoscale.

Class	Dimensional feature	Examples	Important applications
0D	All three dimensions are within the nanoscale range.	Nanoparticles, quantum dots, nanoclusters.	Bioimaging, drug delivery, catalysis, optoelectronics.
1D	Two dimensions are nanoscale; one dimension is extended.	Nanowires, nanorods, carbon nanotubes.	Sensors, nanoelectronics, field emission, composites.
2D	One dimension, usually thickness, is nanoscale.	Thin films, graphene, nanosheets.	Coatings, flexible electronics, membranes, solar cells.
3D	Bulk material assembled from nanoscale building blocks.	Nanocomposites, nanoporous solids.	Structural materials, filters, energy devices, catalysts.

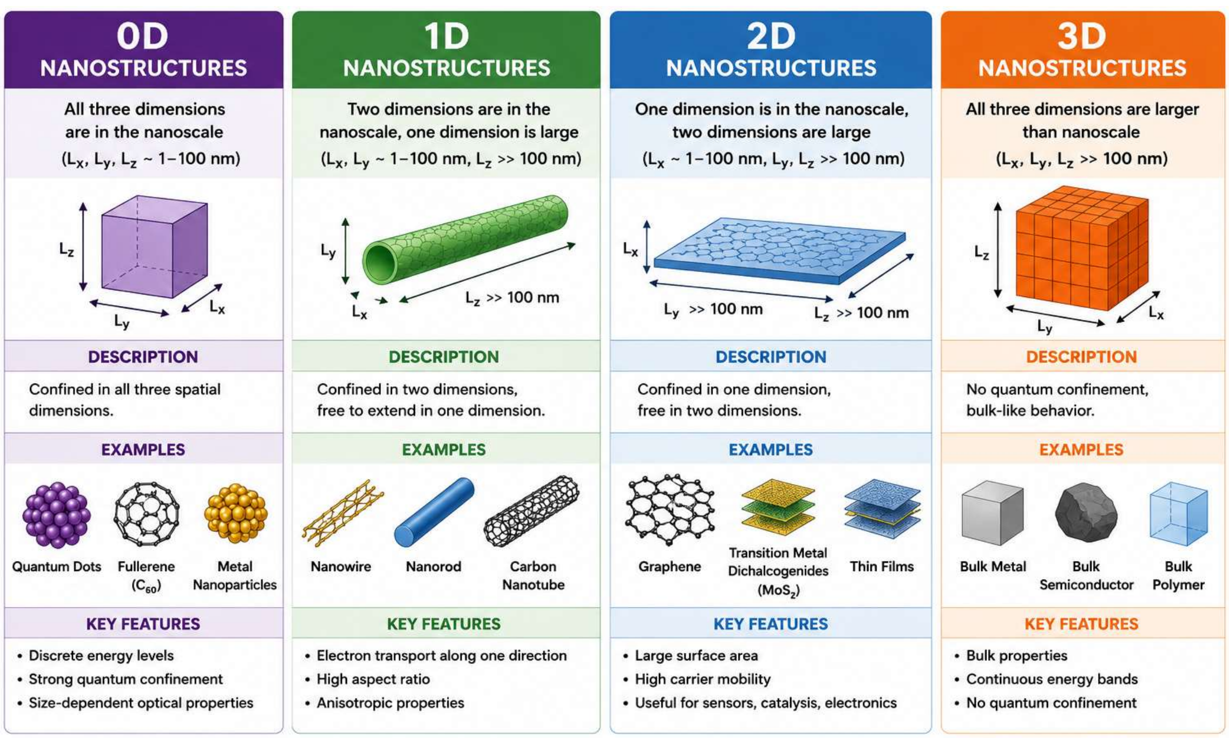

Figure 1.3 *This shows the Dimensional classification of nanostructures.*

1.4.1 Zero-dimensional nanostructures

Zero-dimensional nanostructures have nanoscale dimensions in all directions. Nanoparticles and quantum dots belong to this category. Because electrons and atoms are confined in all three spatial directions, such systems often show strong size-dependent optical and electronic properties.

1.4.2 One-dimensional nanostructures

One-dimensional nanostructures have two dimensions in the nanometer range and one extended direction. Nanowires, nanorods, and nanotubes are examples. Their elongated geometry supports charge transport, mechanical reinforcement, and directional sensing.

1.4.3 Two-dimensional and three-dimensional nanostructures

Two-dimensional nanostructures are very thin sheets or films, while three-dimensional nanostructures are bulk systems built from nanoscale units. These categories are important in coatings, membranes, composite materials, and energy technologies.

1.5 Excitons

An **exciton** is a bound state of an electron and a hole that are attracted to each other by electrostatic (Coulomb) force inside a semiconductor or insulator. When a material absorbs a photon with sufficient energy, an electron is excited from the valence band to the conduction band, leaving behind a positively charged hole. The electron and hole remain bound together and move through the material as a single quasiparticle called an exciton.

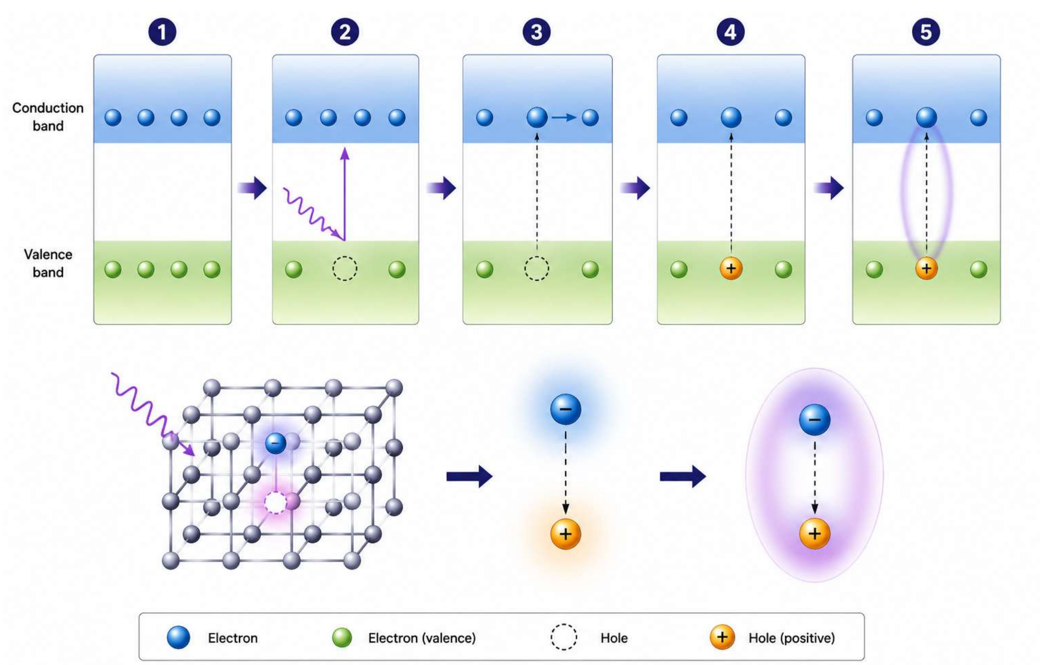

Figure 1.4 This image represents how excitons are formed inside a semi-conductor

Excitons play an important role in the optical properties of semiconductors and nanomaterials. In nanoparticles and quantum dots, the confinement of excitons becomes stronger due to the small particle size, leading to changes in absorption and emission spectra. This is one of the reasons why nanomaterials exhibit size-dependent optical properties. Excitons are widely used in devices such as solar cells, light-emitting diodes (LEDs), lasers, and photodetectors.

1.6 Quantum Confinement

Quantum confinement is the phenomenon that occurs when the size of a semiconductor particle becomes so small (typically a few nanometers) that the motion of electrons and holes is restricted in one or more dimensions. As a result, the continuous energy bands of the bulk material split into discrete energy levels, similar to those of atoms.

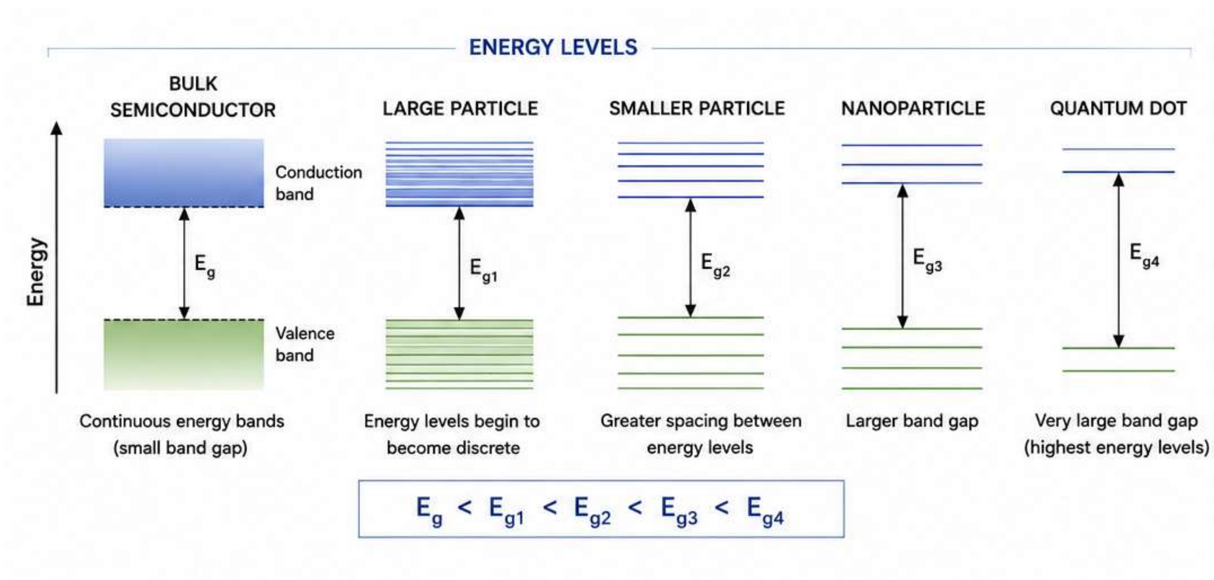

__Figure 1.5__ This Image shows how band gap energy varies with particle size

In bulk materials, electrons can move freely and occupy a nearly continuous range of energies. However, when the particle size becomes comparable to the **exciton Bohr radius**, the electron and hole are confined within a very small region. This confinement increases the energy required for electronic transitions, causing the **band gap energy to increase as particle size decreases**.

1.7 Metal-Based Nanoparticles

Metal-based nanoparticles are one of the most important classes of nanomaterials and include both **metal nanoparticles** and **metal oxide nanoparticles**. These nanoparticles typically have dimensions between 1 and 100 nm and exhibit unique physical, chemical, optical, electrical, and catalytic properties due to their small size and large surface area. Depending on their composition, metal-based nanoparticles can be broadly classified into pure metal nanoparticles and metal oxide nanoparticles.

Metal nanoparticles are composed entirely of metallic elements such as gold (Au), silver (Ag), platinum (Pt), palladium (Pd), and copper (Cu). These nanoparticles are known for their excellent electrical conductivity, catalytic activity, and unique optical properties, particularly surface plasmon resonance. Gold and silver nanoparticles are widely used in biosensors, medical diagnostics, imaging, and drug delivery applications.

Metal oxide nanoparticles consist of metals chemically combined with oxygen. Common examples include titanium dioxide (TiO_2), zinc oxide (ZnO), iron oxide (Fe_3O_4), and aluminium oxide (Al_2O_3). These nanoparticles often exhibit semiconductor behaviour, photocatalytic activity, magnetic properties, and high chemical stability. Metal oxide nanoparticles are extensively used in solar cells, gas sensors, water purification systems, sunscreens, and biomedical applications.

1.8. Nanocomposites (Non-Polymer-Based)

Non-polymer-based nanocomposites are composite materials in which the matrix is **not a polymer**, but instead a **metal, ceramic, or carbon-based material**, reinforced with nanoscale fillers such as nanoparticles, nanotubes, nanofibers, or graphene. The incorporation of nanomaterials significantly improves the mechanical, thermal, electrical, optical, and chemical properties of the host material. Depending on the matrix material, non-polymer nanocomposites are generally classified into **metal matrix nanocomposites (MMNCs)** and **ceramic matrix nanocomposites (CMNCs)**.

In **metal matrix nanocomposites**, metals such as aluminium, magnesium, copper, or titanium serve as the matrix, while nanoparticles like Al_2O_3, SiC, CNTs, or graphene act as reinforcements. These composites exhibit enhanced strength, hardness, wear resistance, and thermal stability. In **ceramic matrix nanocomposites**, ceramic materials such as Al_2O_3, ZrO_2, or Si_3N_4 are reinforced with nanoscale fillers to improve toughness, fracture resistance, and high-temperature performance.

Because of their superior properties, non-polymer-based nanocomposites are widely used in aerospace components, automotive parts, cutting tools, biomedical implants, electronic devices, and high-temperature structural applications.

Examples

Matrix	Nanofiller	Nanocomposite
Aluminium	SiC nanoparticles	Al–SiC nanocomposite
Aluminium	CNTs	Al–CNT nanocomposite
Copper	Graphene	Cu–Graphene nanocomposite
Al_2O_3	ZrO_2 nanoparticles	Al_2O_3–ZrO_2 nanocomposite
TiO_2	CNTs	TiO_2–CNT nanocomposite

1.9. Carbon nanostructures

Carbon is one of the most important elements in nanotechnology because it forms several stable nanoscale structures. Its ability to form strong covalent bonds and different hybridized arrangements allows the formation of fullerenes, carbon nanotubes, graphene, and carbon nanofibres.

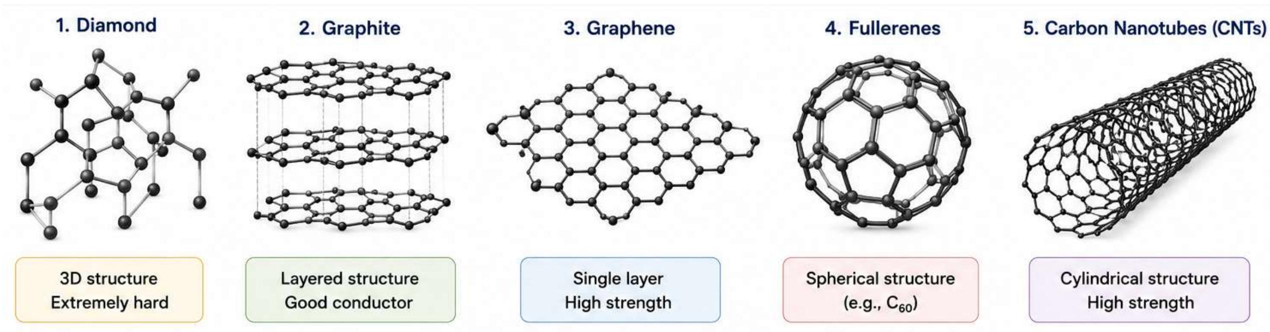

Figure 1.6 *Simplified representation of Diamond, Graphene, Graphite, fullerene, CNTs.*

1.9.1 Fullerene

Fullerenes are closed cage-like molecules made entirely of carbon atoms. The best-known fullerene is C60, which contains sixty carbon atoms arranged in a nearly spherical structure. The shape resembles a football, with a network of pentagons and hexagons.

Fullerenes are notable for their nanoscale size, high symmetry, electron-accepting ability, and chemical reactivity. They have been studied for applications in organic solar cells, drug delivery research, lubricants, superconducting materials, and antioxidant systems.

1.9.2 Carbon nanotubes

Carbon nanotubes are cylindrical carbon nanostructures that can be understood as graphene sheets rolled into tubes. They possess very high tensile strength, excellent thermal conductivity, and useful electrical properties. Depending on their structure, carbon nanotubes may behave as metals or semiconductors.

There are two major types of carbon nanotubes: single-walled carbon nanotubes and multi-walled carbon nanotubes.

1.9.3 Single-walled carbon nanotubes

A single-walled carbon nanotube consists of one cylindrical graphene wall. Its diameter is typically of the order of one to a few nanometres. SWCNTs are important in nanoelectronics, sensors, field-effect transistors, transparent conductors, and high-strength composites.

1.9.4 Multi-walled carbon nanotubes

Multi-Walled Carbon Nanotubes (MWCNTs) are cylindrical nanostructures consisting of **multiple concentric graphene sheets rolled into tubes**, one inside another, similar to the layers of an onion. The spacing between adjacent walls is approximately **0.34 nm**, which is similar to the interlayer spacing in graphite. MWCNTs typically have diameters ranging from **2 to 100 nm** and lengths that can extend to several micrometers.

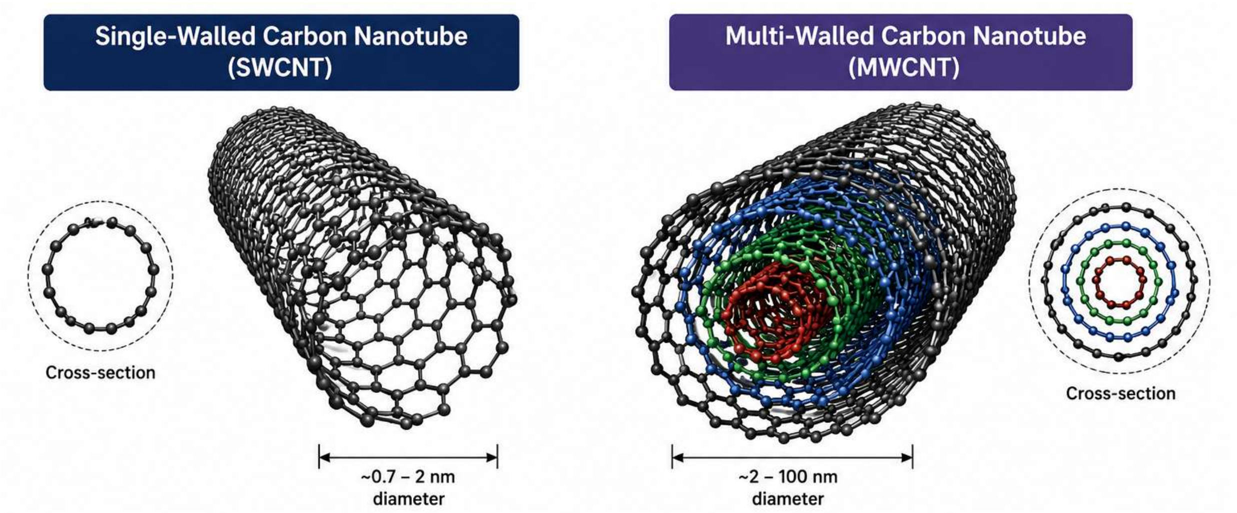

Figure 1.7 Visual Representation of SWCNT and MWCNT

Due to their unique structure, MWCNTs exhibit excellent mechanical strength, high thermal conductivity, good electrical conductivity, and remarkable chemical stability. The presence of multiple walls makes them more robust and resistant to structural defects than single-walled carbon nanotubes (SWCNTs). These properties make MWCNTs attractive for a wide range of applications, including reinforcement in composite materials, energy storage devices, sensors, field emission displays, nanoelectronics, and biomedical engineering.

Property	SWCNT	MWCNT
Basic structure	Single rolled graphene cylinder.	Several concentric graphene cylinders.
Diameter	Usually smaller.	Usually larger.
Production	More difficult to obtain with high purity.	Comparatively easier to produce in bulk.
Cost	Generally higher.	Generally lower.
Common uses	Nanoelectronics, sensors, research devices.	Composites, coatings, batteries, supercapacitors.

1.10. Key terms

Term	Meaning
Nanoscale	Length scale approximately between 1 and 100 nm.
Nanomaterial	Material with at least one dimension or structural feature in the nanoscale range.
Surface-to-volume ratio	Ratio that describes the amount of surface area available compared with the volume of a material.
Quantum confinement	Restriction of electron motion in very small structures, leading to discrete energy levels.
Quantum dot	Semiconductor nanoparticle with size-dependent optical and electronic properties.
Fullerene	Closed cage-like carbon molecule, such as C60.
Carbon nanotube	Cylindrical nanoscale structure formed from rolled graphene sheets.

1.11. Chapter summary

- Nanoscience studies materials and phenomena at the nanometre scale, while nanotechnology applies this knowledge to practical systems.
- Nanomaterials show special behaviour because of high surface-to-volume ratio and quantum size effects.
- Nanostructures are classified as 0D, 1D, 2D, and 3D according to dimensional confinement.
- Quantum dots are semiconductor nanoparticles with size-tunable optical properties.
- Nanocomposites combine nanoscale fillers with a matrix to improve material performance.
- Important carbon nanostructures include fullerenes, SWCNTs, and MWCNTs.

1.12. Objective Questions

1. The unique properties of nanomaterials arise mainly due to
A) High density
B) Large grain size
C) Large surface-to-volume ratio and quantum confinement
D) High melting point

2. Which of the following is a zero-dimensional (0D) nanostructure?
A) Carbon nanotube
B) Graphene

C) Quantum dot
D) Thin film

3. An exciton is
A) Electron–proton pair
B) Electron–neutron pair
C) Bound electron–hole pair
D) Hole–photon pair

4. Quantum confinement occurs when
A) Particle size becomes very large
B) Particle size becomes comparable to the electron wavelength
C) Temperature becomes very high
D) Pressure becomes very high

5. Fullerene (C_{60}) has a
A) Cylindrical structure
B) Layered structure
C) Spherical cage-like structure
D) Cubic structure

6. Graphene is an example of
A) 0D nanostructure
B) 1D nanostructure
C) 2D nanostructure
D) 3D nanostructure

7. Multi-Walled Carbon Nanotube (MWCNT) consists of
A) One graphene cylinder
B) Two graphene sheets only
C) Multiple concentric graphene cylinders
D) Graphene and fullerene

Answers

C – Large surface-to-volume ratio and quantum confinement
C – Quantum dot
C – Bound electron–hole pair
B – Particle size becomes comparable to the electron wavelength
C – Spherical cage-like structure
C – 2D nanostructure
C – Multiple concentric graphene cylinders

1.13 Review questions

Short Answer Questions

1. Define nanoscience and nanotechnology.
2. What is meant by the nanoscale?
3. State two reasons why nanomaterials differ from bulk materials.
4. Define surface-to-volume ratio.
5. What is quantum confinement?
6. Give two examples each of 0D and 1D nanostructures.
7. What is a quantum dot?
8. Write two applications of carbon nanotubes.

Long Answer questions

9. Explain the importance of surface-to-volume ratio and quantum size effect in nanomaterials.
10. Classify nanostructures based on dimensionality with suitable examples.
11. Describe the structure, properties, and applications of fullerene.
12. Explain carbon nanotubes and distinguish between SWCNTs and MWCNTs.
13. Discuss the importance of carbon nanostructures in nanotechnology.

UNIT:2

Properties of Nano-Materials

2.1 Introduction

Nanomaterials exhibit physical, chemical, optical, electrical, and magnetic properties that are significantly different from those of their bulk counterparts. These unique properties arise mainly due to the large surface-to-volume ratio and quantum confinement effects present at the nanoscale. As the particle size decreases to the nanometer range, a larger fraction of atoms are located on the surface, resulting in enhanced reactivity and altered material behaviour. Consequently, nanomaterials often possess improved mechanical strength, unusual optical characteristics, enhanced magnetic behaviour, and modified dielectric properties. Understanding these properties is essential for designing nanomaterials for applications in electronics, medicine, sensors, energy storage, catalysis, and environmental technologies.

2.2 Mechanical Behaviour

Mechanical behaviour refers to the response of a material when subjected to external forces such as tension, compression, bending, or impact. Nanomaterials exhibit mechanical properties that are often superior to those of conventional bulk materials due to their extremely small grain size, high surface area, and reduced defect concentration. As the grain size decreases to the nanometer range, the movement of dislocations becomes more difficult, resulting in increased strength and hardness. Consequently, nanomaterials often possess high tensile strength, improved wear resistance, enhanced toughness, and excellent elastic properties.

Carbon nanotubes and graphene are notable examples of nanomaterials with exceptional mechanical performance, exhibiting strengths several times greater than that of steel while remaining lightweight. These remarkable mechanical characteristics make nanomaterials highly suitable for applications in aerospace, automotive engineering, structural materials, protective coatings, and advanced composite materials.

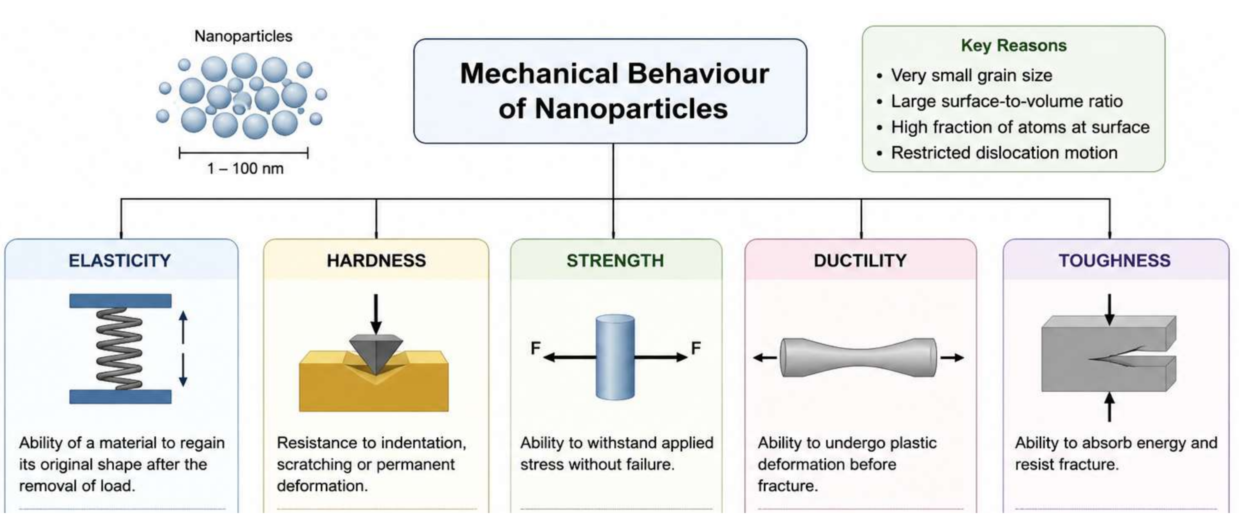

Figure 2.1 Mechanical Properties of Nanoparticles

2.2.1 Elastic Properties of Nanomaterials

Elasticity is the ability of a material to return to its original shape and size after the removal of an applied force. The elastic properties of a material describe its resistance to deformation under stress and are commonly characterized by parameters such as **Young's modulus**, **shear modulus**, and **bulk modulus**. Nanomaterials often exhibit enhanced elastic behaviour compared to their bulk counterparts due to their small grain size, high surface area, and reduced number of structural defects. In particular, carbon nanotubes and graphene possess exceptionally high Young's modulus values, indicating remarkable stiffness and resistance to elastic deformation. The superior elastic properties of nanomaterials make them suitable for applications in flexible electronics, nanosensors, high-strength composites, and advanced structural materials.

Young's Modulus

The stiffness of a material is measured by Young's modulus:

$$E = \frac{Stress}{Strain}$$

where:

- **E** = Young's modulus
- **Stress** = Force applied per unit area
- **Strain** = Fractional change in length

A higher value of Young's modulus indicates a stiffer material with greater resistance to elastic deformation.

2.2.2 Hardness and Strength

Hardness is the ability of a material to resist scratching, indentation, abrasion, or permanent deformation. Nanomaterials generally exhibit higher hardness than their bulk counterparts because the reduction in grain size increases the number of grain boundaries, which hinder the movement of dislocations. This phenomenon results in improved resistance to wear and deformation. Nanocrystalline metals, ceramic nanoparticles, and nanocomposites often possess exceptional hardness, making them suitable for protective coatings, cutting tools, and wear-resistant surfaces.

Strength is the ability of a material to withstand an applied load or stress without breaking or undergoing permanent deformation. Nanomaterials often possess exceptionally high strength because of their small grain size, reduced defect concentration, and strong atomic bonding. Carbon nanotubes and graphene are notable examples, exhibiting tensile strengths far greater than those of conventional engineering materials such as steel while remaining lightweight. The high strength of nanomaterials makes them attractive for applications in aerospace, automotive components, structural materials, and advanced composites.

2.2.3 Ductility and Toughness

Ductility is the ability of a material to undergo significant plastic deformation before fracture. It is often measured by the extent to which a material can be stretched into a wire without breaking. In nanomaterials, ductility depends strongly on grain size, crystal structure, and the presence of defects. While many nanomaterials exhibit very high strength, their ductility may decrease because the movement of dislocations becomes restricted. However, specially designed nanocomposites and nanostructured alloys can achieve a desirable combination of high strength and good ductility. Ductile nanomaterials are particularly important in structural and engineering applications where deformation without failure is required.

Toughness is the ability of a material to absorb energy and resist fracture when subjected to stress or impact. It represents the combined effect of strength and ductility. A tough material can withstand considerable deformation and absorb a large amount of energy before breaking. Nanomaterials and nanocomposites often exhibit improved toughness because nanoparticles can hinder crack initiation and propagation, thereby increasing resistance to fracture. Enhanced toughness is particularly important in aerospace components, protective coatings, biomedical implants, and advanced structural materials.

2.3 Optical Properties of Nanomaterials

Optical properties describe how a material interacts with electromagnetic radiation, particularly visible, ultraviolet (UV), and infrared (IR) light. Nanomaterials exhibit unique optical properties that differ significantly from those of bulk materials due to their small size, large surface-to-volume ratio, and quantum confinement effects. As the particle size decreases to the nanometer range, the absorption, transmission, scattering, reflection, and emission of light become strongly dependent on particle size and shape. Consequently, nanomaterials may display unusual colours, enhanced luminescence, and size-dependent optical behaviour.

One of the most remarkable optical phenomena observed in nanomaterials is the change in colour with particle size. For example, bulk gold appears yellow, whereas gold nanoparticles can appear red, purple, or blue depending on their size. Similarly, semiconductor nanoparticles known as quantum dots emit different colours of light depending on their dimensions because the band gap energy changes with particle size.

2.3.1 Surface Plasmon Resonance (SPR)

Surface Plasmon Resonance (SPR) is a unique optical phenomenon observed in metallic nanoparticles such as gold (Au) and silver (Ag). It arises when the conduction electrons present on the surface of a metal nanoparticle collectively oscillate in resonance with the electric field of incident light. At a particular frequency of light, these electrons absorb and scatter light very strongly, producing intense colours and enhanced optical properties.

In bulk metals, electrons move freely throughout the material. However, in metal nanoparticles, the electrons are confined within a very small volume. When light strikes the nanoparticle, the electric field of the light causes the surface electrons to oscillate collectively. When the frequency of these oscillations matches the frequency of the incident light, resonance occurs, resulting in maximum absorption and scattering of light. This phenomenon is known as **Surface Plasmon Resonance (SPR)**.

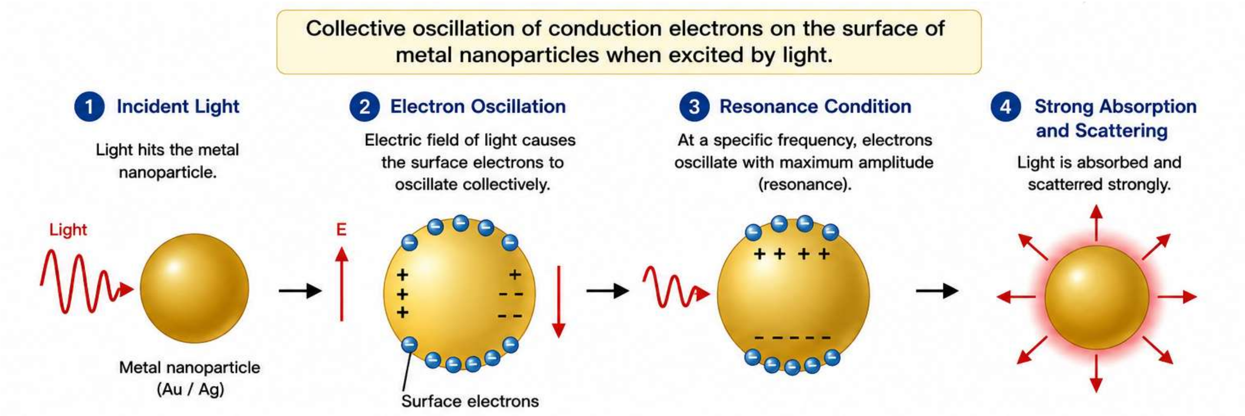

Figure 2.2 Surface Plasmon Resonance

The SPR effect depends strongly on the size, shape, composition, and surrounding environment of the nanoparticles. For example, gold nanoparticles can appear red, purple, or blue depending on their size because the SPR wavelength changes with particle size. This size-dependent colour change is one of the most striking optical properties of metallic nanoparticles.

SPR is widely used in biosensors, chemical sensors, medical diagnostics, imaging, environmental monitoring, and nanophotonic devices because it enables highly sensitive detection of small changes occurring near the nanoparticle surface.

2.5 Electrical Properties of Nanomaterials

Electrical properties describe the behaviour of a material when subjected to an electric field or electric current. Nanomaterials exhibit electrical characteristics that are often very different from those of bulk materials because of their small size, large surface area, and quantum confinement effects. At the nanoscale, the movement of electrons can be significantly altered, leading to changes in conductivity, resistivity, electron mobility, and charge transport mechanisms.

In bulk materials, electrons move through a continuous lattice of atoms. However, in nanomaterials, the dimensions become comparable to the mean free path of electrons, and quantum effects begin to dominate. As a result, electrical conductivity may either increase or decrease depending on the material, particle size, and structure. Metallic nanoparticles generally exhibit high electrical conductivity, while semiconductor nanoparticles display size-dependent electrical behavior due to changes in band gap energy.

Carbon nanotubes and graphene are among the most electrically conductive nanomaterials known. Their unique atomic structure allows electrons to move with very little resistance, making them attractive for nanoelectronics, transistors, sensors, flexible displays, and energy storage devices.

The electrical properties of nanomaterials are also strongly influenced by surface effects because a large fraction of atoms are located at the surface. These surface atoms can interact with surrounding molecules, making nanomaterials highly sensitive and useful in chemical and biological sensors.

2.5.1 Dielectric Materials and Dielectric Properties

A **dielectric material** is an electrical insulator that can be polarized when placed in an electric field. When an external electric field is applied, the positive and negative charges within the dielectric material become slightly displaced, creating electric dipoles. Although dielectric materials do not conduct electricity, they can store electrical energy and influence the behavior of electric fields. At the nanoscale, dielectric materials often exhibit enhanced dielectric properties due to increased surface area, interface effects, and changes in polarization mechanisms.

The **dielectric properties** of a material describe its ability to store and dissipate electrical energy in the presence of an electric field. The most important dielectric property is the **dielectric constant (relative permittivity)**, which indicates how effectively a material can store electrical energy compared to vacuum. Nanostructured dielectric materials often possess improved dielectric constants and enhanced energy storage capabilities, making them valuable in capacitors, memory devices, sensors, and microelectronic applications.

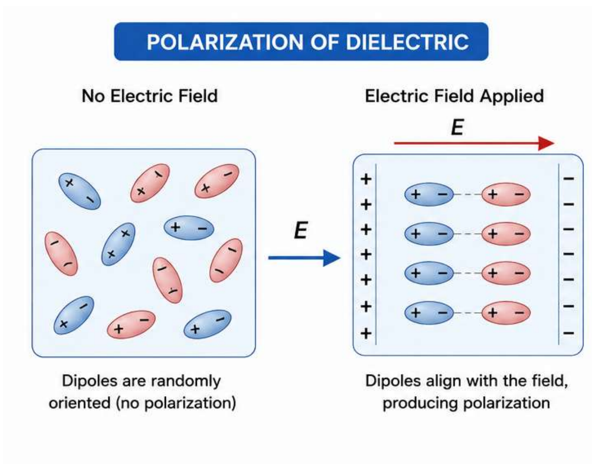

Figure 2.3 Polarization of Dielectric Material

Dielectric Constant

$$\varepsilon_r = \frac{\varepsilon}{\varepsilon_0}$$

where:

- **ε_r** = Relative permittivity (dielectric constant)
- **ε** = Permittivity of the material
- **ε_0** = Permittivity of free space

A higher dielectric constant indicates a greater ability to store electrical energy.

Examples of Dielectric Materials

- Silicon dioxide (SiO_2)
- Titanium dioxide (TiO_2)

2.6 Magnetic Properties of Nanomaterials

Magnetic properties describe the behaviour of a material in the presence of an external magnetic field. When materials are reduced to the nanometer scale, their magnetic behaviour can differ significantly from that of bulk materials due to size effects, surface effects, and changes in magnetic domain structure. Nanomaterials often exhibit enhanced magnetic properties because a large fraction of atoms are located on the surface, where atomic interactions differ from those in the interior.

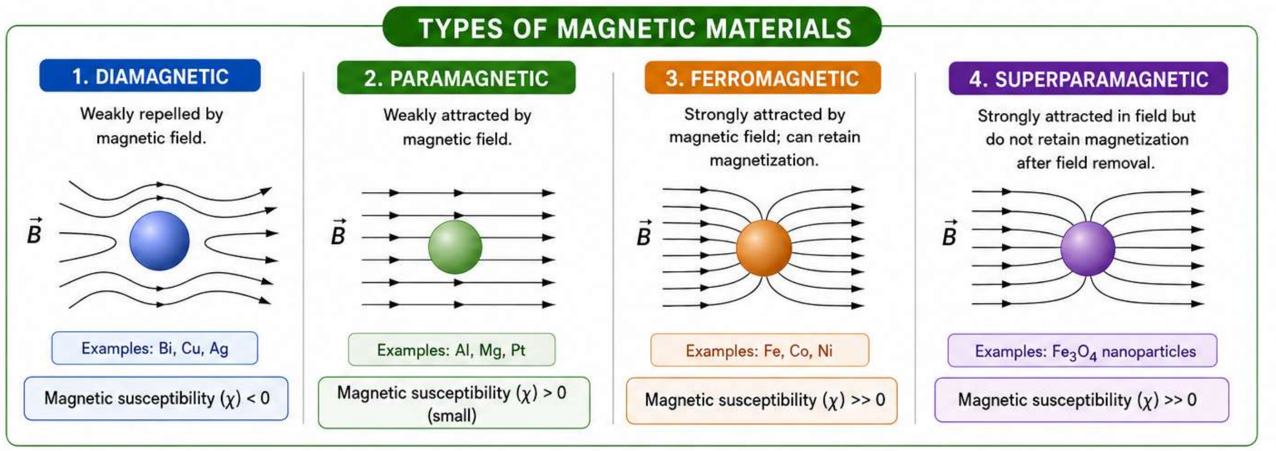

Figure 2.4 *Types of Magnetic Materials*

In bulk ferromagnetic materials such as iron, cobalt, and nickel, the material is divided into many magnetic domains, each having its own direction of magnetization. As the particle size decreases to the nanoscale, the number of magnetic domains decreases. Below a critical size, the nanoparticle may consist of a **single magnetic domain**, causing its magnetic behaviour to change dramatically. This can lead to phenomena such as increased magnetic anisotropy, enhanced magnetization, and super paramagnetism.

Magnetic nanomaterials are generally classified as:

- **Diamagnetic materials** – Weakly repelled by a magnetic field.
- **Paramagnetic materials** – Weakly attracted by a magnetic field.
- **Ferromagnetic materials** – Strongly attracted and can retain magnetization.
- **Superparamagnetic materials** – Nanoparticles that become strongly magnetized in an external field but lose their magnetization when the field is removed.

Common magnetic nanoparticles include iron oxide (Fe_3O_4), cobalt, nickel, and ferrite nanoparticles. These materials are widely used in magnetic recording devices, data storage, magnetic sensors, biomedical imaging (MRI), targeted drug delivery, and environmental remediation.

2.7 Super paramagnetism

Super paramagnetism is a special magnetic phenomenon observed in **very small ferromagnetic or ferrimagnetic nanoparticles**, typically with sizes below about 10–30 nm. In bulk magnetic materials, many magnetic domains exist, each magnetized in different directions. However, when the particle size is reduced below a critical value, the nanoparticle becomes a **single magnetic domain**. At this scale, thermal energy can randomly flip the direction of magnetization, causing the nanoparticle to behave differently from ordinary ferromagnetic materials.

In the presence of an external magnetic field, superparamagnetic nanoparticles become strongly magnetized, similar to ferromagnetic materials. However, unlike ferromagnets, they **do not retain any permanent magnetization when the external magnetic field is removed**. This means that the particles do not exhibit magnetic hysteresis, remanence, or coercivity. As a result, superparamagnetic nanoparticles can be easily magnetized and demagnetized, making them highly useful in technological and biomedical applications.

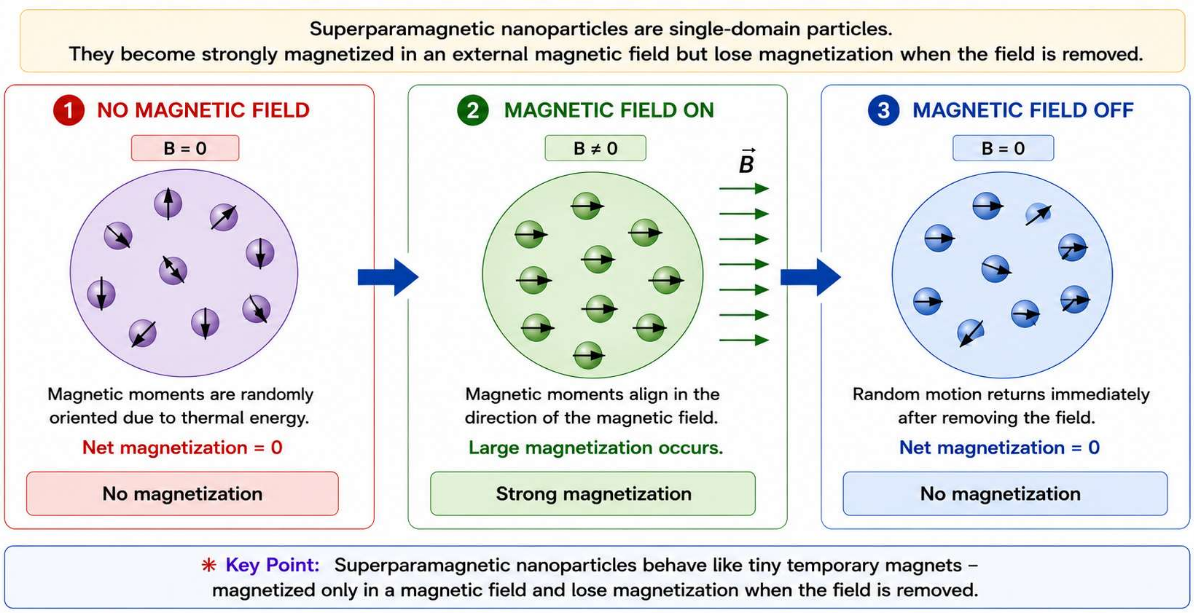

Figure 2.5 This Visual shows how Super paramagnetism works

Iron oxide nanoparticles (Fe_3O_4 and γ-Fe_2O_3) are among the most common examples of superparamagnetic materials. Their ability to respond strongly to magnetic fields without remaining permanently magnetized makes them ideal for magnetic resonance imaging (MRI), targeted drug delivery, magnetic separation, biosensors, and hyperthermia treatment of cancer.

2.8 Properties of Carbon Nanotubes (CNTs)

Carbon Nanotubes (CNTs) are cylindrical nanostructures formed by rolling a graphene sheet into a seamless tube. They possess extraordinary mechanical, electrical, thermal, and chemical properties, making them one of the most important nanomaterials in modern science and technology. Depending on the number of graphene layers, CNTs are classified as **Single-Walled Carbon Nanotubes (SWCNTs)** and **Multi-Walled Carbon Nanotubes (MWCNTs)**.

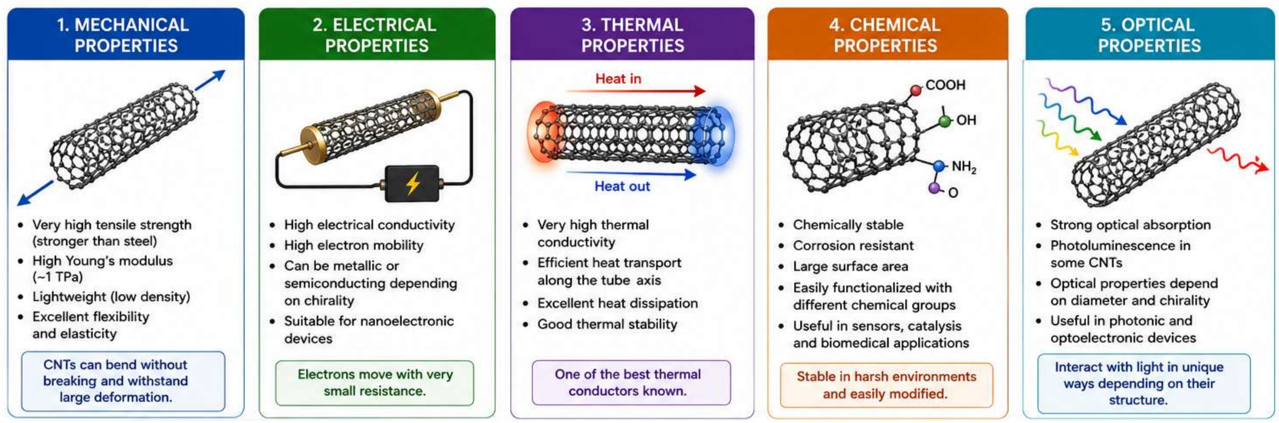

Figure 2.6 *Properties of Carbon-Nano-Tubes*

Mechanical Properties

Carbon nanotubes possess exceptionally high strength and stiffness due to the strong covalent carbon-carbon bonds in their structure. Their tensile strength is much greater than that of steel while their density is significantly lower. CNTs also exhibit excellent flexibility and elasticity, allowing them to bend without breaking.

Key Features

- Very high tensile strength
- High Young's modulus (~1 TPa)
- Lightweight
- Excellent flexibility

Electrical Properties

CNTs can behave either as metals or semiconductors depending on their atomic arrangement (chirality). They exhibit very high electrical conductivity and allow electrons to move with minimal resistance.

Key Features

- High electrical conductivity
- High electron mobility
- Metallic or semiconducting behaviour

- Suitable for nanoelectronic devices

Thermal Properties

Carbon nanotubes are among the best thermal conductors known. Heat can be transported efficiently along the tube axis due to strong carbon-carbon bonding.

Key Features

- Very high thermal conductivity
- Excellent heat dissipation
- Good thermal stability

Chemical Properties

CNTs possess high chemical stability and corrosion resistance. Their large surface area allows chemical functionalization, making them useful in sensors and biomedical applications.

Key Features

- Chemically stable
- Corrosion resistant
- Large surface area
- Easily functionalized

Optical Properties

CNTs interact strongly with light and exhibit unique absorption and emission characteristics. Their optical properties depend on diameter, chirality, and electronic structure.

Key Features

- Strong optical absorption
- Photoluminescence in some CNTs
- Useful in photonic devices

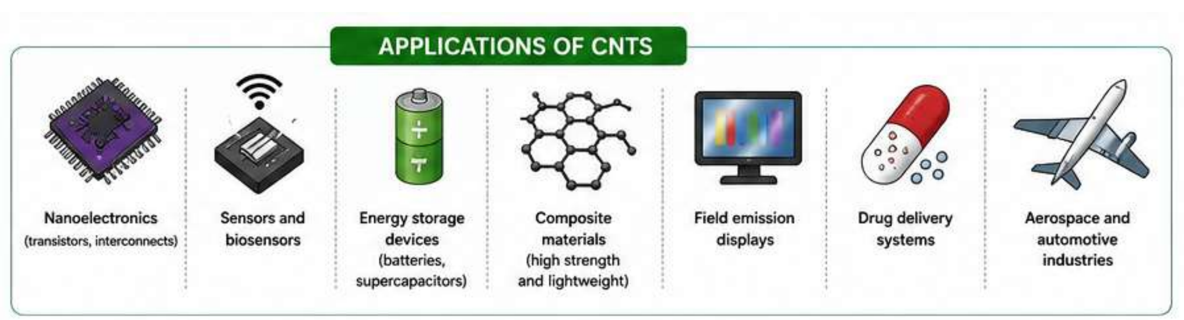

Figure 2.7 Applications of carbon-Nano-tubes

Summary of CNT Properties

Property	Characteristics
Mechanical	High strength, stiffness, flexibility
Electrical	High conductivity, metallic or semiconducting
Thermal	Excellent thermal conductivity
Chemical	High stability, corrosion resistance
Optical	Strong light absorption and emission

Applications of CNTs

- Nanoelectronics
- Sensors and biosensors
- Energy storage devices
- Composite materials
- Drug delivery systems
- Aerospace and automotive industries

2.9 Objective Questions

1. The ability of a material to regain its original shape after removal of an external force is called

A) Hardness
B) Toughness
C) Elasticity
D) Strength

2. Surface Plasmon Resonance (SPR) arises due to the collective oscillation of

A) Protons
B) Neutrons
C) Surface electrons
D) Ions

3. A dielectric material is

A) A good conductor of electricity
B) An electrical insulator that can be polarized in an electric field

C) A magnetic material
D) A semiconductor only

4. Which of the following is a superparamagnetic material?

A) Bulk iron
B) Bulk cobalt
C) Fe_3O_4 nanoparticles
D) Copper

5. Superparamagnetic nanoparticles

A) Retain permanent magnetization after field removal
B) Become strongly magnetized only in an external magnetic field
C) Are weakly repelled by magnetic fields
D) Are non-magnetic

6. Carbon nanotubes exhibit exceptionally high

A) Density
B) Radioactivity
C) Mechanical strength and electrical conductivity
D) Thermal expansion

7. Carbon nanotubes can behave as

A) Only insulators
B) Only metals
C) Metals or semiconductors
D) Superconductors only

Answers

1. **C** – Elasticity
2. **C** – Surface electrons
3. **B** – An electrical insulator that can be polarized in an electric field
4. **C** – Fe_3O_4 nanoparticles
5. **B** – Become strongly magnetized only in an external magnetic field
6. **C** – Mechanical strength and electrical conductivity
7. **C** – Metals or semiconductors

2.10. Key Terms

Term	Meaning
Elasticity	Ability of a material to regain its original shape after deformation.
Hardness	Resistance to scratching or indentation.
Strength	Ability to withstand applied force without breaking.
Ductility	Ability to be stretched without breaking.
Toughness	Ability to absorb energy before fracture.
Surface Plasmon Resonance (SPR)	Collective oscillation of electrons in metal nanoparticles when light falls on them.
Dielectric Material	Electrical insulator that can store electrical energy.
Dielectric Constant	Measure of a material's ability to store electrical energy.
Diamagnetism	Weak repulsion by a magnetic field.
Paramagnetism	Weak attraction by a magnetic field.
Ferromagnetism	Strong attraction and retention of magnetization.
Super paramagnetism	Temporary magnetization shown by very small magnetic nanoparticles.
Carbon Nanotube (CNT)	Cylindrical nanostructure made of carbon atoms.
SWCNT	Carbon nanotube with a single wall.
MWCNT	Carbon nanotube with multiple walls.

2.11. Chapter Summary

- Nanomaterials show unique properties because of their nanoscale size.
- Mechanical properties include elasticity, hardness, strength, ductility, and toughness.
- Optical properties depend on the interaction of nanomaterials with light.
- Surface Plasmon Resonance (SPR) is responsible for the unique colours of metal nanoparticles.
- Dielectric materials are electrical insulators that can store electrical energy.
- Magnetic nanomaterials can be diamagnetic, paramagnetic, ferromagnetic, or superparamagnetic.

- Super paramagnetism occurs in very small magnetic nanoparticles that become magnetized only when an external magnetic field is applied.
- Carbon nanotubes possess high strength, excellent electrical conductivity, and high thermal conductivity.
- Carbon nanotubes are classified into Single-Walled Carbon Nanotubes (SWCNTs) and Multi-Walled Carbon Nanotubes (MWCNTs).
- The unique properties of nanomaterials make them useful in electronics, sensors, medicine, energy storage, and engineering applications.

2.12. Review Questions

Short Answer Questions

1. What is elasticity? Explain its importance in nanomaterials.
2. Define hardness and strength. How do they differ?
3. What is Surface Plasmon Resonance (SPR)?
4. Define dielectric material and dielectric constant.
5. Distinguish between diamagnetic and paramagnetic materials.
6. What is super paramagnetism?
7. Differentiate between SWCNT and MWCNT.
8. Mention any four important properties of carbon nanotubes.

Long Answer Questions

1. Explain the mechanical behaviour of nanomaterials. Discuss elasticity, hardness, strength, ductility, and toughness.
2. Describe the optical properties of nanomaterials and explain the phenomenon of Surface Plasmon Resonance (SPR).
3. What are dielectric materials? Discuss dielectric properties and their applications in energy storage devices.
4. Explain the magnetic properties of nanomaterials. Differentiate between diamagnetic, paramagnetic, ferromagnetic, and superparamagnetic materials.
5. Discuss the structure and properties of carbon nanotubes (CNTs). Explain the differences between SWCNTs and MWCNTs and their applications.

UNIT:3

Fabrication Methods and Vacuum Techniques

Fabrication Methods and Vacuum Techniques

3.1 Introduction

The unique properties of nanomaterials depend strongly on their size, shape, composition, and structure. Therefore, controlled methods are required to synthesize nanomaterials with desired characteristics. The techniques used to produce nanomaterials are known as **fabrication methods**. Depending on the approach used, nanomaterials can be fabricated by building structures atom-by-atom or by reducing larger materials to nanoscale dimensions. In addition, many fabrication processes require a controlled vacuum environment to prevent contamination and ensure high-quality nanomaterial growth. Fabrication methods and vacuum techniques therefore play a crucial role in nanoscience and nanotechnology.

3.2 Top-Down and Bottom-Up Approaches

Nanomaterials can be synthesized using two fundamental approaches: **Top-Down** and **Bottom-Up**. These approaches differ in the way nanoscale structures are produced. The top-down approach starts with bulk materials and reduces them to nanoscale dimensions, whereas the bottom-up approach builds nanostructures atom-by-atom or molecule-by-molecule. Both methods are widely used in nanotechnology depending on the desired application and material properties.

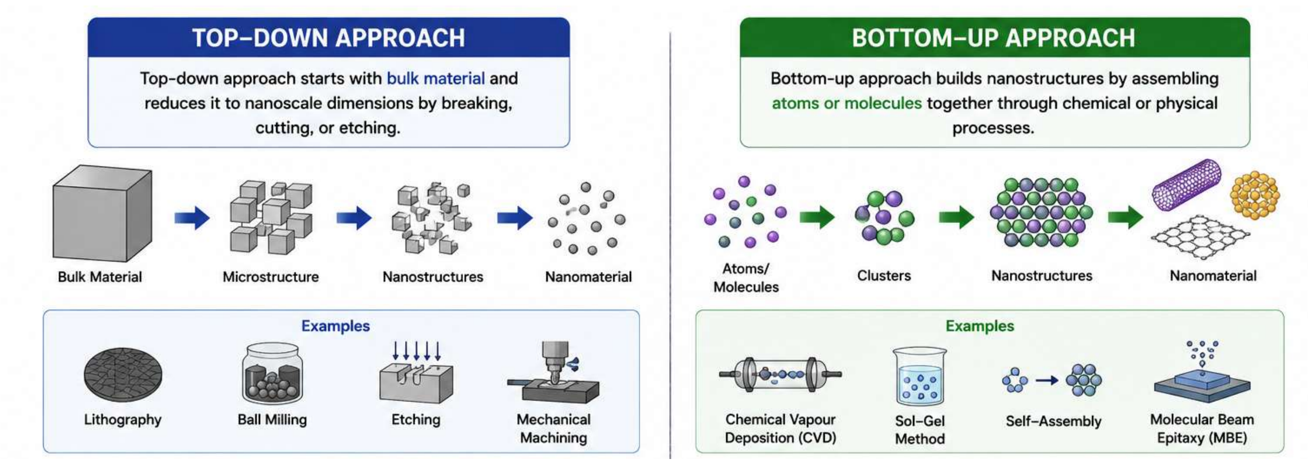

Figure 3.1 *Top-down and Bottom-up Approaches in Nanomaterial Synthesis*

Top-Down Approach

The **Top-Down Approach** involves breaking down a bulk material into smaller and smaller pieces until nanoscale structures are obtained. This approach uses physical techniques to reduce the size of larger materials.

Principle

Bulk Material → Microstructure → Nanostructure

Examples

- Lithography

- Ball Milling
- Etching
- Mechanical Machining

Advantages

- Suitable for large-scale production
- Well-established fabrication methods
- Good dimensional control

Disadvantages

- Material wastage
- Introduction of structural defects
- Limited control at atomic scale

Applications

- Semiconductor device fabrication
- Nano-patterning
- Microelectronics

Bottom-Up Approach

The **Bottom-Up Approach** involves assembling atoms, molecules, or clusters to form nanostructures. It is based on the concept of building materials from the atomic level.

Principle

Atoms/Molecules → Nanostructures → Nanomaterials

Examples

- Chemical Vapour Deposition (CVD)
- Sol-Gel Method
- Self-Assembly
- Molecular Beam Epitaxy (MBE)

Advantages

- Better control of particle size and shape
- High purity materials
- Fewer structural defects

Disadvantages

- Complex fabrication process
- Difficult large-scale production
- Longer processing time

Applications

- Carbon nanotube synthesis
- Quantum dot fabrication
- Nanocoatings

Comparison

Top-Down Approach	Bottom-Up Approach
Starts from bulk material	Starts from atoms or molecules
Material is reduced in size	Material is built atom-by-atom
Physical methods are commonly used	Chemical methods are commonly used
More structural defects	Fewer structural defects
Material wastage is higher	Material wastage is lower
Example: Lithography	Example: Chemical Vapour Deposition

3.3 Electrochemical Method

The **Electrochemical Method** is a bottom-up synthesis technique used for the preparation of nanoparticles, nanowires, thin films, and nanocoatings. In this method, chemical reactions are driven by an electric current passing through an electrolyte solution. Metal ions present in the electrolyte are reduced at the electrode surface, resulting in the formation of nanomaterials.

The process typically consists of two electrodes immersed in an electrolyte solution containing metal ions. When a voltage is applied, reduction occurs at the cathode and oxidation occurs at the anode. Metal ions gain electrons and deposit on the cathode as nanoscale particles or thin films. By controlling parameters such as voltage, current density, temperature, electrolyte concentration, and deposition time, the size and morphology of the nanomaterials can be precisely controlled.

Principle

Metal ions in solution + Electric current → Nanomaterial deposition

Example:

$$Cu^{2+} + 2e^{-} \rightarrow Cu$$

Copper ions gain electrons and deposit as metallic copper on the cathode.

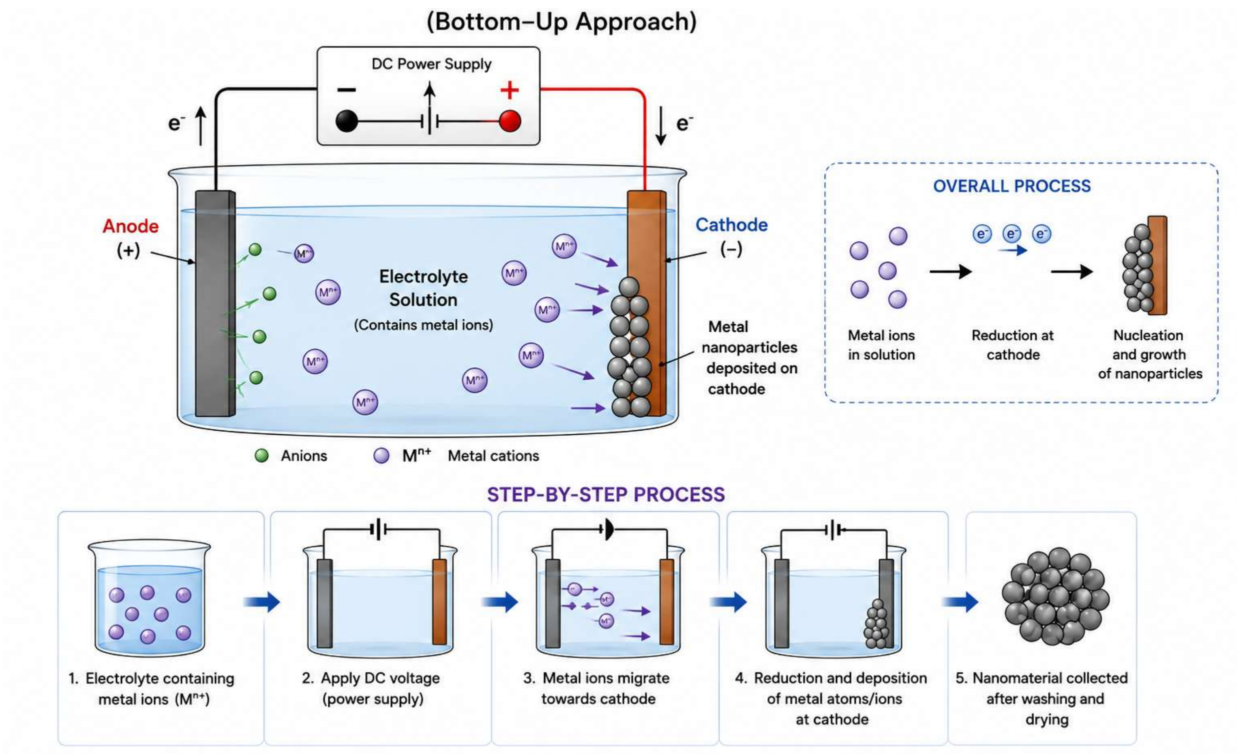

Figure 3.2 Electrochemical Method in Nano-material Synthesis

Experimental Setup

The electrochemical cell consists of:

- **Anode (+)**: Oxidation occurs.
- **Cathode (−)**: Reduction and nanoparticle deposition occur.
- **Electrolyte**: Contains metal ions.
- **DC Power Supply**: Provides electric current.

Advantages

- Simple and cost-effective technique.
- Good control over particle size and shape.
- High purity products.

3.4 Chemical Vapour Deposition (CVD)

Chemical Vapour Deposition (CVD) is a **bottom-up fabrication technique** used to produce thin films, nanoparticles, nanowires, graphene, and carbon nanotubes. In this method, gaseous precursor chemicals are introduced into a reaction chamber containing a heated substrate. The gases undergo chemical reactions or decomposition on the substrate surface, forming a solid material while the by-products are removed as gases.

Working Principle

Precursor Gas → Chemical Reaction on Heated Substrate → Solid Film/Nanomaterial

Process Steps

1. Precursor gases are introduced into the reaction chamber.
2. The substrate is heated to a suitable temperature.
3. Chemical reactions occur on the substrate surface.
4. A thin film or nanomaterial is deposited.
5. By-product gases are removed from the chamber.

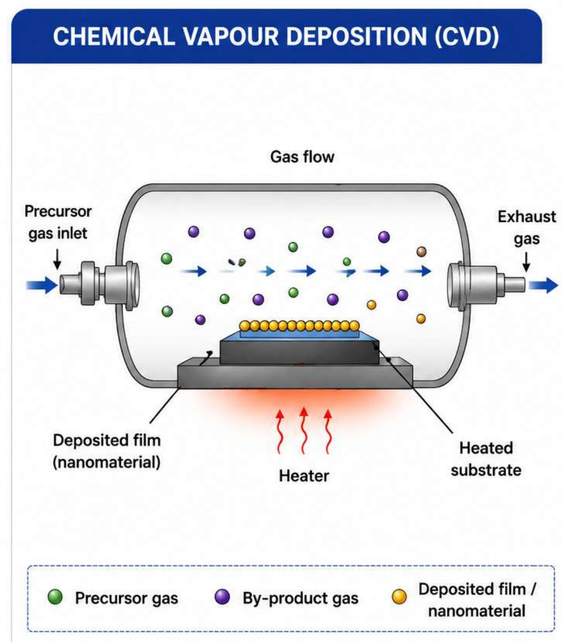

Figure 3.3 Chemical Vapour Deposition (CVD) Method

Applications

- Carbon nanotube synthesis
- Graphene growth
- Thin-film deposition
- Semiconductor fabrication
- Protective coatings

3.5 Physical Vapour Deposition (PVD)

Physical Vapour Deposition (PVD) is a **vacuum-based fabrication technique** used to deposit thin films and coatings. In this method, a solid source material is converted into vapour by physical processes such as heating, evaporation, or sputtering. The vapour travels through a vacuum chamber and condenses onto a substrate, forming a thin film.

Working Principle

Solid Material → Vapour → Condensation on Substrate → Thin Film

Process Steps

1. Source material is placed in a vacuum chamber.
2. The material is vaporized by heating or sputtering.
3. Vapour particles travel through the vacuum.
4. Vapour condenses on the substrate surface.
5. A thin film is formed.

Applications

- Optical coatings
- Decorative coatings
- Semiconductor devices
- Hard protective coatings
- Solar cells

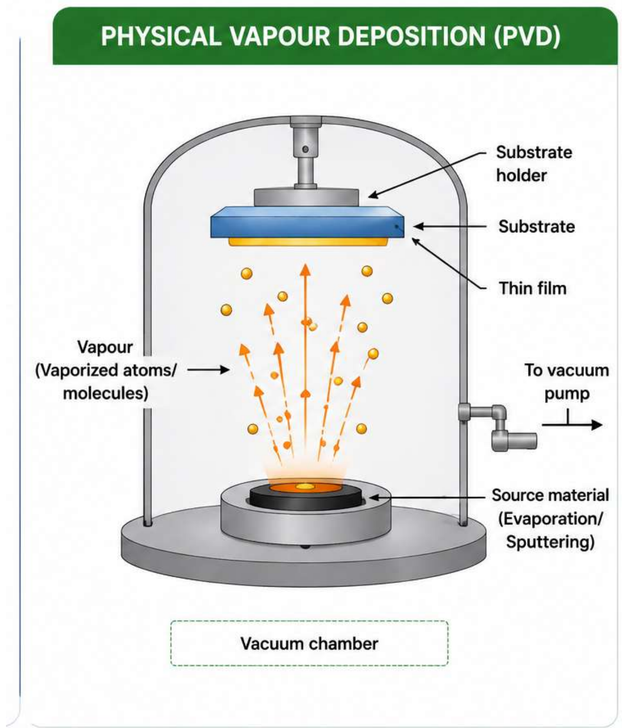

Figure 3.5 Physical Vapour Deposition

3.6 Thermal Evaporation Method

Thermal Evaporation is one of the simplest and most widely used **Physical Vapour Deposition (PVD)** techniques for depositing thin films and nanostructured coatings. In this method, a source material is heated in a high-vacuum chamber until it evaporates. The vapour atoms travel through the vacuum and condense on a cooler substrate, forming a thin film.

Because the process occurs under vacuum, the evaporated atoms can travel freely without colliding with air molecules, resulting in high-purity film deposition.

Principle

Solid Material → Heating → Vapour Formation → Condensation on Substrate → Thin Film

Working Process

1. The source material is placed in a crucible or evaporation boat.
2. The chamber is evacuated to a high vacuum.
3. The source material is heated electrically until it evaporates.
4. Vapour atoms travel through the vacuum chamber.
5. The vapour condenses on the substrate surface.
6. A thin film is formed.

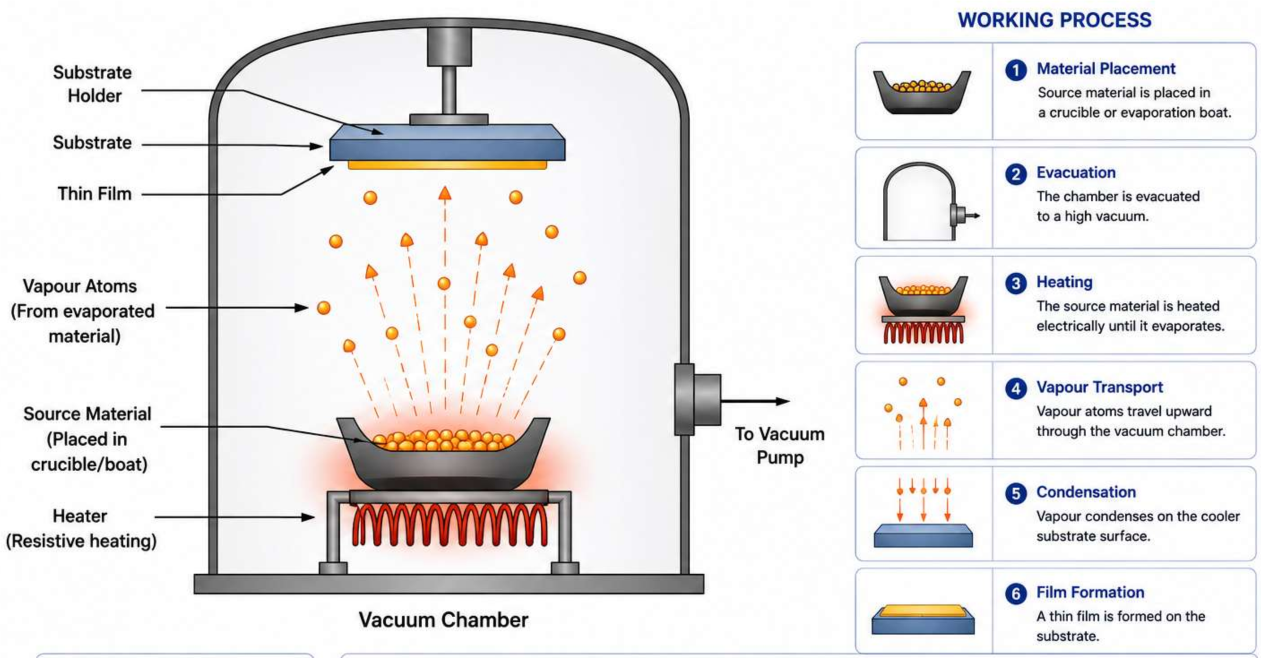

Figure 3.6 *Thermal Evaporation Method*

Advantages

- Simple and inexpensive.
- High-purity films.
- Good deposition rate.
- Suitable for metals and thin films.

Disadvantages

- Requires high vacuum.
- Poor step coverage on complex surfaces.
- Difficult to deposit some high-melting-point materials.

Applications

- Metal thin-film coatings
- Optical coatings
- Semiconductor devices
- Solar cells
- Mirrors and reflective coatings

3.7 Lithography: Photolithography

Photolithography is a top-down nanofabrication technique used to transfer patterns onto a substrate using light. It is one of the most important methods employed in the manufacture of microelectronic circuits, semiconductor devices, MEMS, and nanoscale structures. The technique uses ultraviolet (UV) light to selectively expose a light-sensitive material called a **photoresist**, thereby creating the desired pattern on the substrate surface.

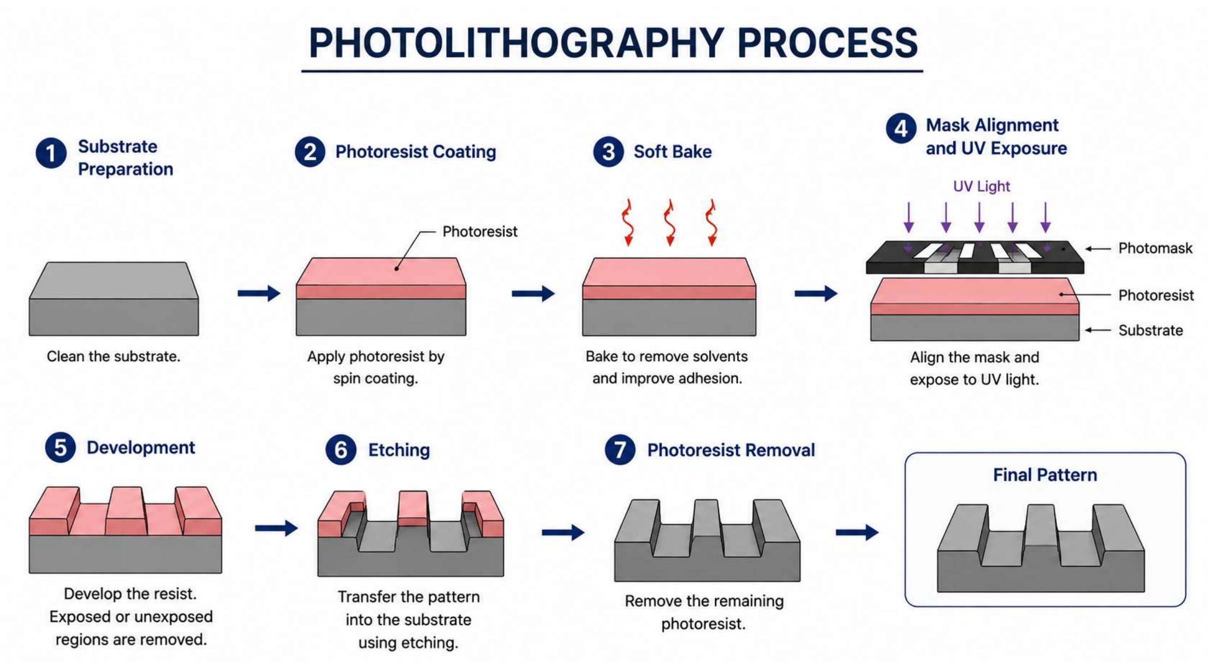

Figure 3.7 The Process of Photolithography

In photolithography, a thin layer of photoresist is first coated onto a clean substrate such as silicon. A patterned mask containing transparent and opaque regions is then placed above the photoresist. When UV light passes through the mask, only selected regions of the photoresist are exposed. After development, either the exposed or unexposed regions are removed depending on the type of photoresist used. The resulting pattern can then be transferred to the substrate by etching or deposition processes.

3.8 Sol-Gel Method

The **Sol-Gel Method** is a bottom-up chemical synthesis technique used for the preparation of nanoparticles, nanocomposites, ceramic materials, thin films, and coatings. In this method, a colloidal solution called a **sol** is converted into a three-dimensional network called a **gel** through hydrolysis and condensation reactions. After drying and heat treatment, nanomaterials with controlled size and composition are obtained.

The sol-gel process offers excellent control over particle size, purity, and chemical composition, making it one of the most widely used methods for synthesizing oxide nanomaterials such as TiO_2, SiO_2, ZnO, and Al_2O_3 nanoparticles.

Principle

Precursor Solution → Sol → Gel → Drying → Calcination → Nanomaterial

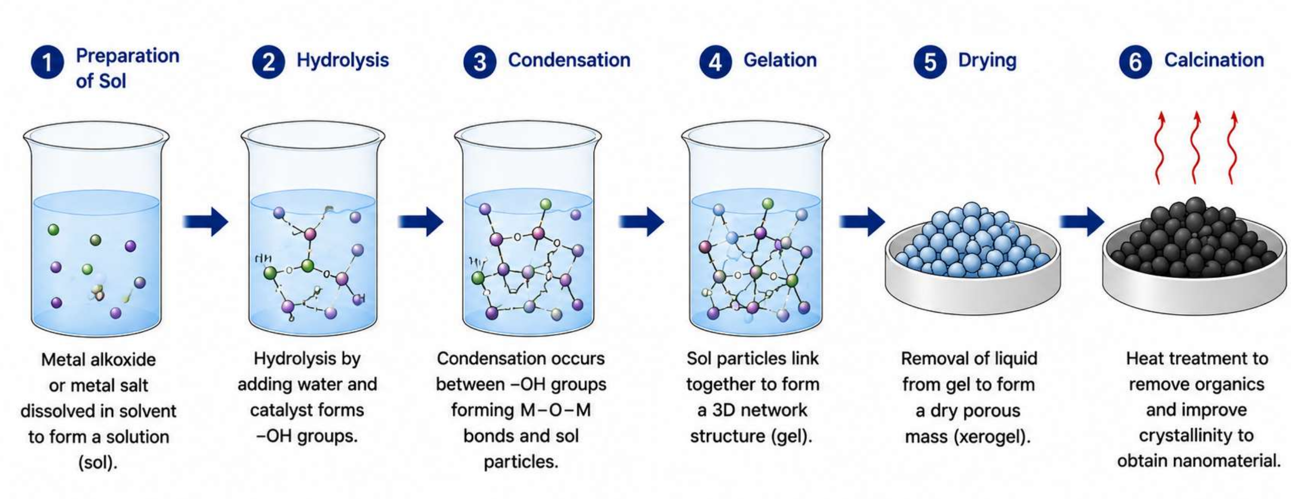

Figure 3.8 Sol-Gel Method- Synthesis of Nanoparticles

Process Steps

1. Preparation of Sol

Metal alkoxides or metal salts are dissolved in a suitable solvent to form a colloidal solution (sol).

2. Hydrolysis and Condensation

Chemical reactions lead to the formation of a three-dimensional network structure.

3. Gel Formation

The sol gradually transforms into a gel containing both liquid and solid phases.

4. Drying

The liquid phase is removed, producing a porous solid.

5. Calcination

Heat treatment removes residual organic compounds and improves crystallinity.

6. Nanomaterial Formation

Nanoparticles or nanostructured materials are obtained.

Advantages

- High purity products and Uniform particle size
- Low processing temperature
- Good control over composition and Cost-effective

3.9 Synthesis of Carbon Nanotubes (CNTs)

Carbon Nanotubes (CNTs) are cylindrical nanostructures made entirely of carbon atoms arranged in a hexagonal lattice. They are commonly synthesized using **Chemical Vapour Deposition (CVD)**, which is the most widely used method because it is simple, cost-effective, and suitable for large-scale production.

In the CVD process, a carbon-containing gas such as methane (CH_4), acetylene (C_2H_2), or ethylene (C_2H_4) is passed over metal catalyst nanoparticles like iron (Fe), cobalt (Co), or nickel (Ni) at high temperatures. The hydrocarbon gas decomposes on the catalyst surface, releasing carbon atoms. These carbon atoms dissolve into the catalyst particles and subsequently precipitate out, forming tubular graphene structures known as carbon nanotubes.

Principle

Hydrocarbon Gas + Metal Catalyst + Heat → Carbon Nanotubes

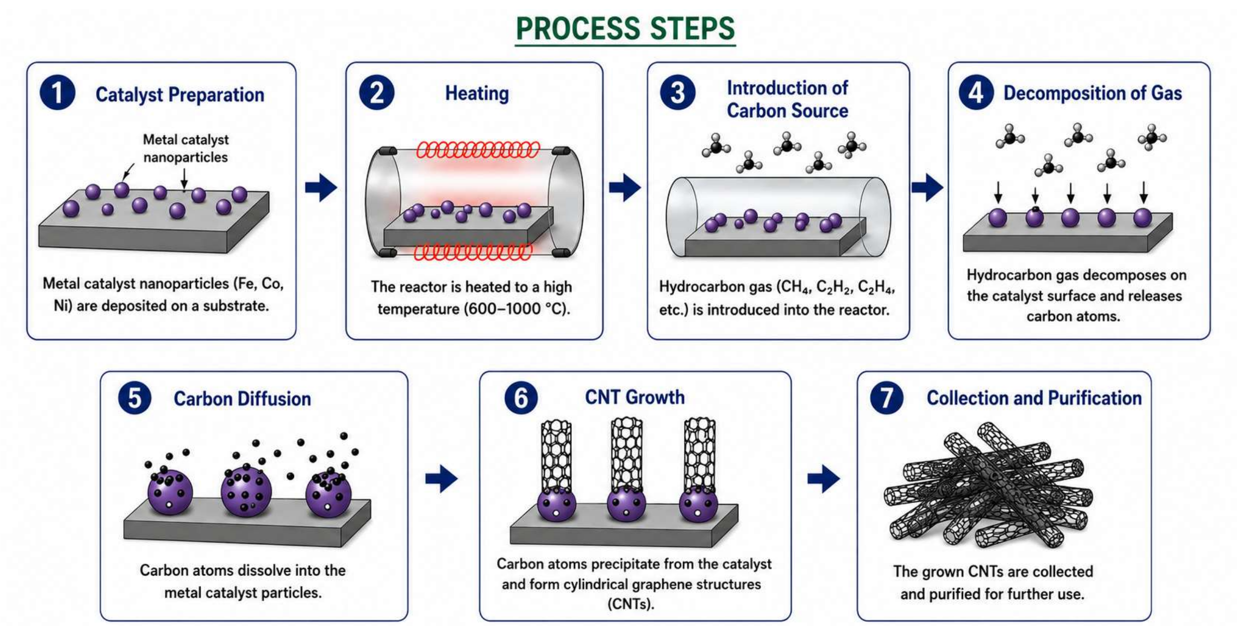

Figure 3.9 Synthesis of Carbon Nanotubes (CNTs)

Steps in CNT Synthesis by CVD

1. Catalyst Preparation

Metal nanoparticles (Fe, Co, or Ni) are deposited on a substrate.

2. Heating

The reaction chamber is heated to about **600–1000°C**.

3. Introduction of Carbon Source

Hydrocarbon gases such as methane or acetylene are introduced.

4. Decomposition of Gas

The hydrocarbon molecules decompose on the catalyst surface.

5. Carbon Diffusion

Carbon atoms dissolve into the catalyst particles.

6. CNT Growth

Carbon precipitates from the catalyst and forms nanotubes.

7. Collection and Purification

The synthesized CNTs are collected and purified.

Advantages

- High yield of CNTs
- Low production cost
- Suitable for large-scale manufacturing
- Good control over CNT growth

Applications

- Nanoelectronics
- Sensors
- Energy storage devices
- Composite materials
- Biomedical devices
- Aerospace engineering

3.10. Key Terms

Term	Meaning
Fabrication Method	Technique used to synthesize or produce nanomaterials.
Top-Down Approach	Method in which bulk materials are reduced to nanoscale dimensions.
Bottom-Up Approach	Method in which nanomaterials are built atom-by-atom or molecule-by-molecule.
Electrochemical Method	Synthesis method that uses electric current to deposit nanomaterials from an electrolyte solution.
Chemical Vapour Deposition (CVD)	Process in which gaseous precursors react on a heated substrate to form nanomaterials.
Physical Vapour Deposition (PVD)	Process in which a solid material is vaporized and deposited as a thin film under vacuum.
Thermal Evaporation	A PVD technique where a material is heated until it evaporates and deposits on a substrate.
Sol	Stable colloidal suspension of particles in a liquid.
Gel	Three-dimensional network formed from a sol.
Sol-Gel Method	Bottom-up technique that converts a sol into a gel and finally into nanomaterials.
Lithography	Pattern-transfer technique used in micro- and nanofabrication.
Photolithography	Lithography technique that uses UV light to transfer patterns onto a substrate.
Photoresist	Light-sensitive material used in photolithography.
Catalyst	Material that facilitates CNT growth without being consumed.
Carbon Nanotube (CNT) Synthesis	Process of producing CNTs, commonly by Chemical Vapour Deposition.

3.11. Chapter Summary

- Nanomaterials can be synthesized using **top-down** and **bottom-up** approaches.
- The **top-down approach** reduces bulk materials into nanoscale structures, while the **bottom-up approach** builds nanostructures from atoms and molecules.
- The **electrochemical method** uses electric current to produce nanomaterials from metal ions in solution.
- **Chemical Vapour Deposition (CVD)** forms nanomaterials through chemical reactions of precursor gases on a heated substrate.
- **Physical Vapour Deposition (PVD)** produces thin films by vaporizing a solid material and depositing it onto a substrate.
- **Thermal evaporation** is a simple PVD technique where a material is heated under vacuum until it evaporates and forms a thin film.
- The **sol-gel method** converts a liquid sol into a gel and finally into nanomaterials through drying and heat treatment.
- **Photolithography** uses UV light and a mask to transfer patterns onto a photoresist-coated substrate.
- Carbon nanotubes are commonly synthesized using **CVD**, where hydrocarbon gases decompose on metal catalysts to form nanotubes.
- These fabrication methods are widely used in nanotechnology, electronics, sensors, coatings, and semiconductor industries.

Objective Questions

1. The approach in which bulk materials are reduced to nanoscale dimensions is called

A) Bottom-up approach
B) Top-down approach
C) Sol-gel method
D) CVD

2. Which of the following is a bottom-up fabrication technique?

A) Lithography
B) Ball Milling
C) Sol-Gel Method
D) Etching

3. In the electrochemical method, nanomaterials are formed by

A) UV light exposure
B) Chemical etching

C) Reduction of metal ions using electric current
D) Mechanical grinding

4. Chemical Vapour Deposition (CVD) uses

A) Solid precursors only
B) Liquid metals only
C) Gaseous precursors
D) Mechanical force

5. Thermal evaporation is a type of

A) Photolithography
B) PVD
C) Electrochemical Method
D) Sol-Gel Method

6. The light-sensitive material used in photolithography is called

A) Catalyst
B) Electrolyte
C) Photoresist
D) Sol

7. Which method is most commonly used for the synthesis of Carbon Nanotubes (CNTs)?

A) Ball Milling
B) Sol-Gel Method
C) Chemical Vapour Deposition (CVD)
D) Photolithography

Answers

1. B) Top-down approach
2. C) Sol-Gel Method
3. C) Reduction of metal ions using electric current
4. C) Gaseous precursors
5. B) PVD
6. C) Photoresist
7. C) Chemical Vapour Deposition (CVD)

3.12 Review Questions

Short Answer Questions

1. What is meant by top-down and bottom-up approaches in nanofabrication?
2. Explain the principle of the electrochemical method.
3. What is Chemical Vapour Deposition (CVD)?
4. What is Physical Vapour Deposition (PVD)?
5. Define the sol-gel method.
6. What is photolithography? What is the role of a photoresist?
7. How are Carbon Nanotubes (CNTs) synthesized by the CVD method?

Long Answer Questions

1. Explain the top-down and bottom-up approaches for nanomaterial fabrication with suitable examples.
2. Describe the electrochemical method for nanomaterial synthesis and discuss its applications.
3. Explain Chemical Vapour Deposition (CVD) and Physical Vapour Deposition (PVD) with neat diagrams.
4. Describe the sol-gel method for the synthesis of nanomaterials with a flow chart and applications.
5. Explain photolithography and the synthesis of Carbon Nanotubes (CNTs) by the Chemical Vapour Deposition (CVD) method.

UNIT:4

Characterization Techniques

4.1 Introduction

After synthesizing nanomaterials, it is necessary to determine their size, shape, crystal structure, surface morphology, composition, and optical properties. The techniques used to study and analyze these properties are known as characterization techniques.

Characterization plays a vital role in nanotechnology because the properties of nanomaterials strongly depend on their size and structure. Various microscopic, diffraction, and spectroscopic techniques are used to obtain information about nanomaterials. Microscopy techniques provide images of the material surface and internal structure, while diffraction and spectroscopy techniques provide information about crystal structure and optical behaviour.

The major characterization techniques used in nanotechnology include:

- Atomic Force Microscopy (AFM)
- Scanning Electron Microscopy (SEM)
- Transmission Electron Microscopy (TEM)
- X-Ray Diffraction (XRD)
- UV-Visible Spectroscopy
- Photoluminescence Spectroscopy

These techniques help researchers understand the physical and chemical properties of nanomaterials and optimize them for various applications.

4.2 Atomic Force Microscopy (AFM)

Atomic Force Microscopy (AFM) is a high-resolution scanning probe microscopy technique used to study the surface morphology, roughness, particle size, and three-dimensional topography of materials at the nanometer scale. It is one of the most important characterization tools in nanotechnology because it can produce detailed surface images without requiring a vacuum environment.

AFM operates by scanning a very sharp tip attached to a flexible cantilever over the surface of a sample. As the tip moves across the surface, attractive or repulsive forces between the tip and the sample cause the cantilever to bend. A laser beam reflected from the cantilever detects these deflections, and a computer converts the information into a high-resolution three-dimensional image of the surface.

Principle

AFM works based on the measurement of **interatomic forces** between a sharp probe tip and the sample surface.

Tip–Sample Interaction → Cantilever Deflection → Laser Detection → Surface Image

Main Components of AFM

1. **Sharp Probe Tip** – Scans the sample surface.
2. **Cantilever** – Supports the tip and bends due to surface forces.
3. **Laser Source** – Detects cantilever deflection.
4. **Photodetector** – Measures reflected laser position.
5. **Piezoelectric Scanner** – Moves the tip with nanometer precision.
6. **Computer System** – Generates the surface image.

Working of AFM

1. The sample is placed on the scanning stage.
2. The sharp tip is brought close to the sample surface.
3. Interatomic forces act between the tip and the surface.
4. The cantilever bends due to these forces.
5. A laser beam reflected from the cantilever measures the deflection.
6. The detected signal is processed to generate a 3D surface image.

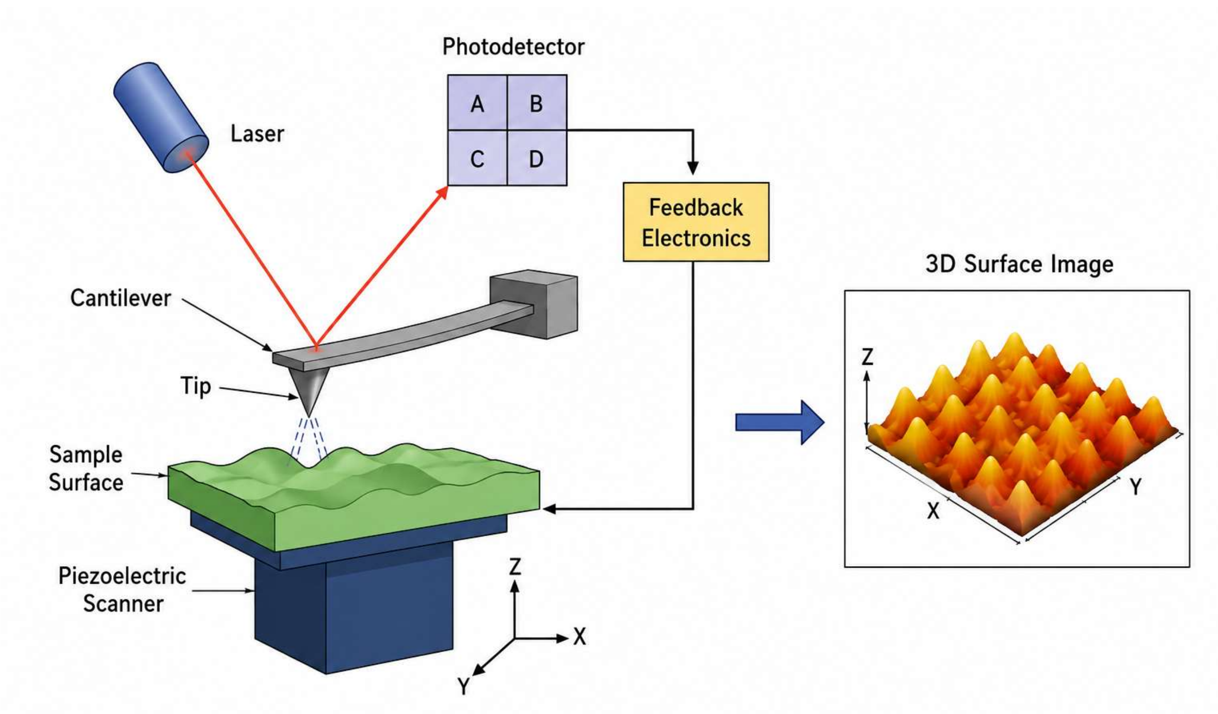

Figure 4.3 Atomic Force Microscopy (AFM)

Modes of Operation

Contact Mode - The tip remains in continuous contact with the sample surface.

Non-Contact Mode - The tip oscillates close to the surface without touching it.

Tapping Mode - The tip intermittently touches the sample during scanning.

Advantages

- Very high spatial resolution.
- Produces three-dimensional surface images.
- Operates in air, liquid, or vacuum.
- Minimal sample preparation required.
- Suitable for insulating and conducting materials.

Limitations

- Small scanning area.
- Scanning speed is relatively slow.
- Tip damage may affect image quality.

Applications

- Surface morphology analysis
- Nanoparticle size measurement
- Thin-film characterization
- Biological sample imaging
- Semiconductor surface studies
- Nanostructure analysis

4.3 Scanning Electron Microscopy (SEM)

Scanning Electron Microscopy (SEM) is a powerful characterization technique used to study the **surface morphology, shape, size, and structure** of materials at high magnification. Unlike optical microscopes that use light, SEM uses a **focused beam of electrons** to scan the sample surface and produce detailed images.

When the electron beam strikes the sample, various signals such as **secondary electrons** and **backscattered electrons** are emitted. These signals are collected by detectors and converted into high-resolution images of the sample surface.

Principle

SEM works by scanning a focused electron beam over the sample surface and detecting the emitted electrons.

Electron Beam → Sample Surface → Emitted Electrons → Detector → Image

Main Components

1. Electron Gun
2. Electromagnetic Lenses
3. Scanning Coils
4. Sample Chamber
5. Electron Detectors
6. Display and Computer System

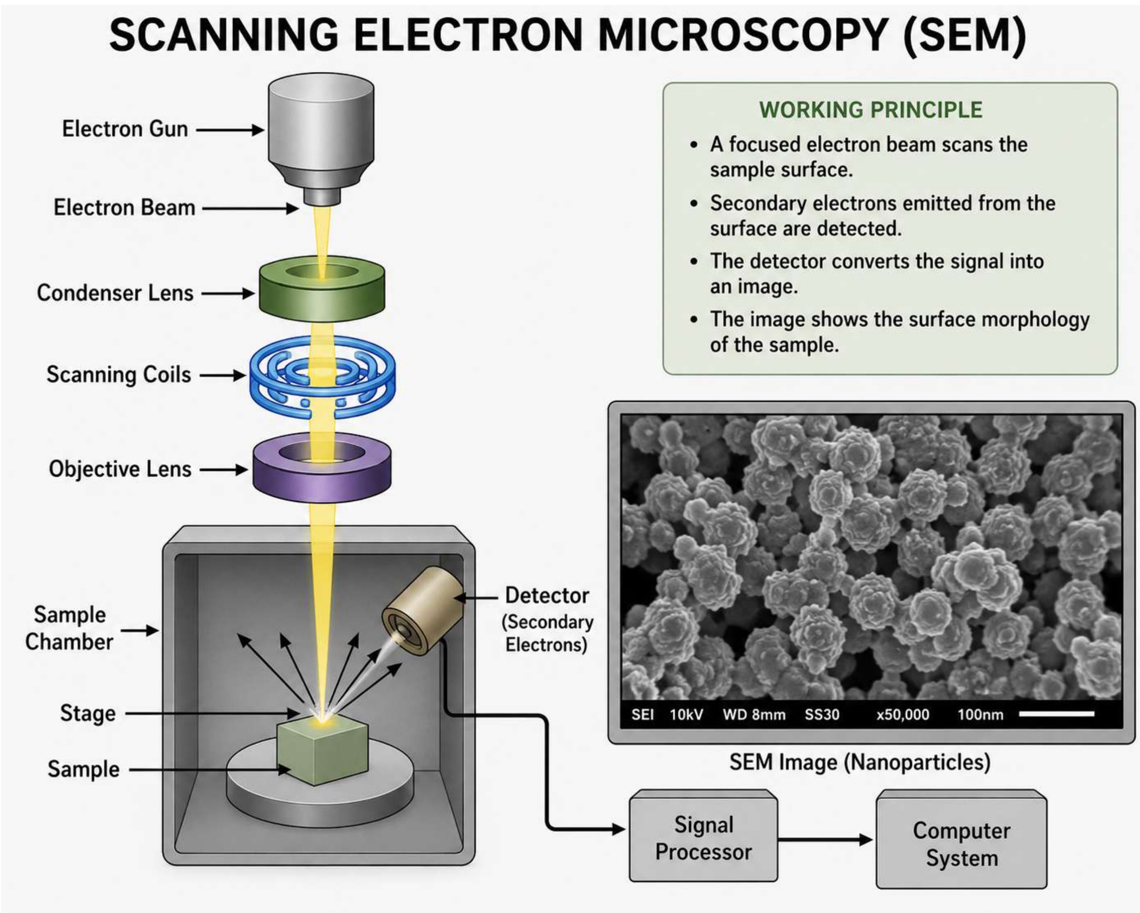

Figure 4.4 Scanning Electron Microscopy

Working

1. Electrons are generated by an electron gun.
2. The electron beam is focused using electromagnetic lenses.
3. The beam scans the sample surface.
4. Interaction between electrons and the sample produces secondary electrons.

5. Detectors collect these electrons.
6. The signal is processed to form a high-resolution image.

Advantages

- High magnification and resolution.
- Large depth of field.
- Produces detailed surface images.
- Suitable for nanomaterial characterization.

Applications

- Nanoparticle size analysis
- Surface morphology studies
- Thin-film characterization
- Failure analysis
- Semiconductor inspection

4.4 Transmission Electron Microscopy (TEM)

Transmission Electron Microscopy (TEM) is a high-resolution characterization technique used to study the **internal structure, size, shape, crystal structure, and arrangement of atoms** in nanomaterials. Unlike SEM, which images the surface, TEM allows electrons to pass through an extremely thin sample and provides information about the internal features of the material.

TEM uses a beam of high-energy electrons that is transmitted through a thin specimen. Some electrons pass through the sample while others are scattered. The transmitted electrons are focused by electromagnetic lenses to form a highly magnified image on a screen or detector.

Principle

TEM works on the principle of **electron transmission through a thin specimen**.

Electron Beam → Thin Sample → Transmitted Electrons → Image Formation

Main Components

1. Electron Gun
2. Condenser Lens
3. Thin Sample Holder
4. Objective Lens
5. Projector Lens
6. Fluorescent Screen / Detector

Working of TEM

1. Electrons are generated by the electron gun.
2. The electron beam is focused using condenser lenses.
3. The beam passes through a very thin sample.
4. Some electrons are transmitted while others are scattered.
5. The transmitted electrons are focused by objective and projector lenses.
6. A magnified image is formed on the screen or detector.

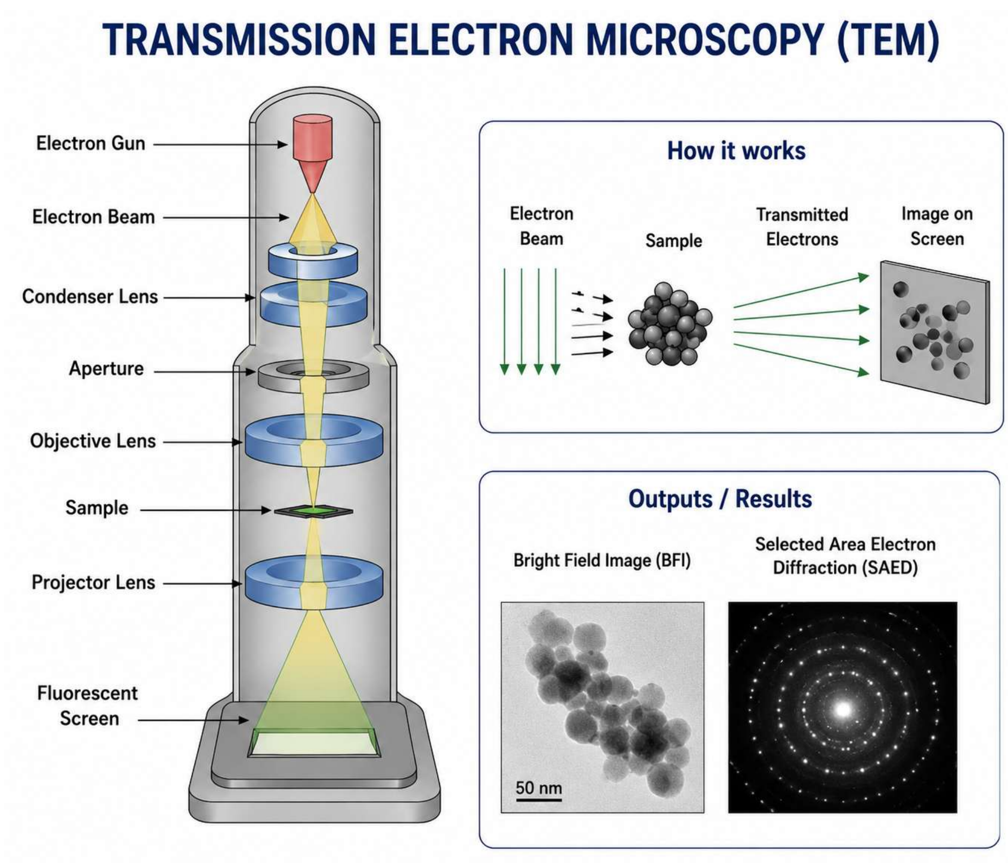

Figure 4.5 Transmission Electron Microscopy

Advantages

- Extremely high resolution.
- Can observe internal structure of nanoparticles.
- Provides crystallographic information.
- Capable of atomic-scale imaging.

Limitations

- Requires very thin samples.
- Expensive instrument.
- Complex sample preparation.
- Operates under high vacuum.

Applications

- Nanoparticle size and shape analysis
- Crystal structure determination
- Defect analysis
- Nanotube characterization
- Thin-film studies
- Materials research

Difference Between SEM and TEM

SEM	TEM
Studies surface morphology	Studies internal structure
Electrons scan the surface	Electrons pass through the sample
Produces 3D-like surface images	Produces 2D internal images
Lower resolution	Higher resolution
Thick samples can be used	Very thin samples required

4.5 Powder X-Ray Diffraction (XRD)

Determination of Structure and Grain Size Analysis

Powder X-Ray Diffraction (XRD) is one of the most important characterization techniques used to determine the **crystal structure, phase composition, lattice parameters, crystallinity, and grain size** of nanomaterials. In this technique, a powdered crystalline sample is irradiated with X-rays. The X-rays are diffracted by the crystal planes, producing a characteristic diffraction pattern.

Since every crystalline material has a unique arrangement of atoms, the diffraction pattern acts like a "fingerprint" that can be used to identify the crystal structure.

Principle of XRD

XRD is based on **Bragg's Law**:

$$n\lambda = 2d\sin\,\theta$$

where,

- **n** = order of diffraction
- **λ** = wavelength of X-rays
- **d** = interplanar spacing
- **θ** = diffraction angle

When the Bragg condition is satisfied, constructive interference occurs and a diffraction peak is observed.

Determination of Crystal Structure

The positions of XRD peaks provide information about:

- Crystal structure
- Crystal planes (hkl)
- Phase identification
- Lattice parameters
- Degree of crystallinity

Different crystal structures such as cubic, tetragonal, hexagonal, and orthorhombic produce different diffraction patterns.

Grain Size Analysis

The broadening of XRD peaks can be used to estimate the average crystallite (grain) size of nanoparticles.

The crystallite size is calculated using the **Debye–Scherrer Equation**:

$$D = \frac{0.9\lambda}{\beta\cos\,\theta}$$

where,

- **D** = Crystallite size
- **λ** = X-ray wavelength
- **β** = Full Width at Half Maximum (FWHM) of the peak
- **θ** = Bragg angle

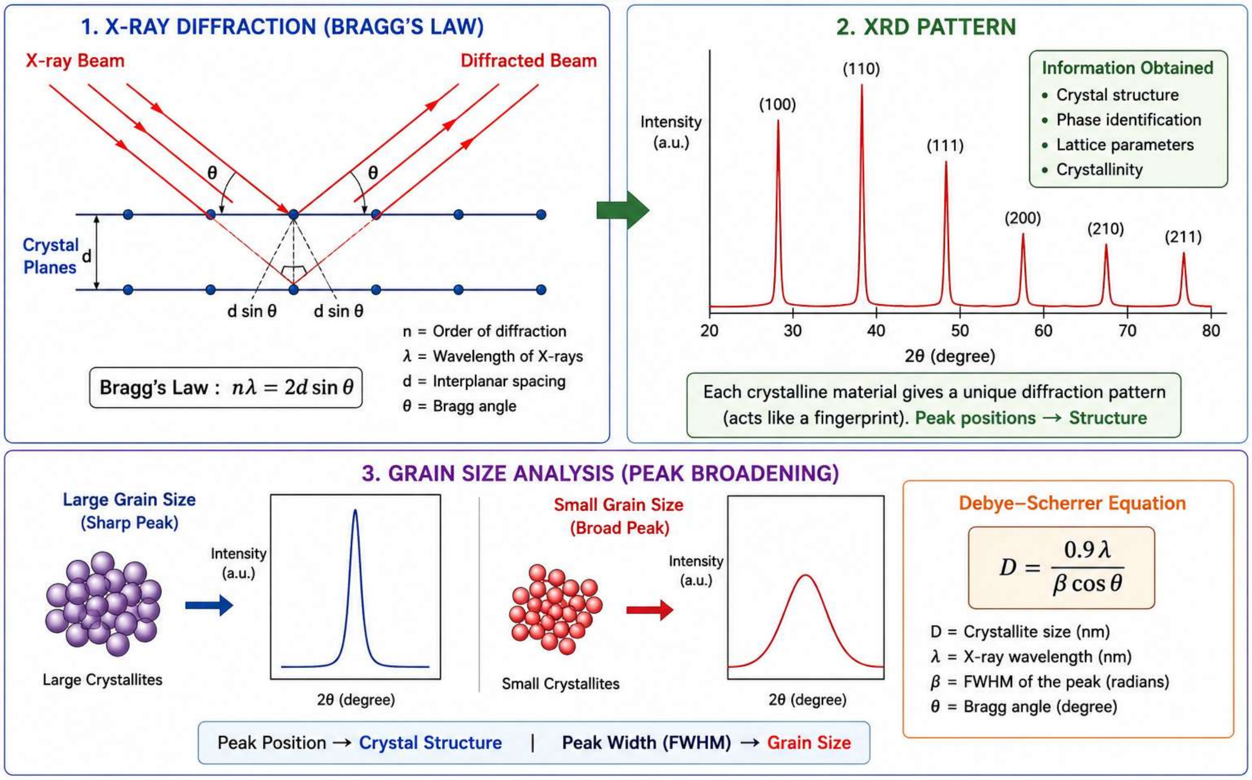

Figure 4.6 *XRD and Grain Size Analysis*

Grain Size and Peak Broadening

- Large grains → Sharp XRD peaks
- Small grains → Broad XRD peaks

Advantages of XRD

- Non-destructive technique
- Accurate crystal structure determination
- Phase identification
- Grain size estimation
- High reliability

Applications

- Nanoparticle characterization
- Crystal structure analysis
- Phase identification
- Grain size determination
- Thin-film analysis and Semiconductor materials

4.6 UV–Visible Spectroscopy

UV–Visible (UV–Vis) Spectroscopy is an optical characterization technique used to study the absorption of ultraviolet (200–400 nm) and visible (400–800 nm) light by a material. It is widely used to determine the optical properties, concentration, band gap energy, and electronic transitions of nanomaterials.

When light passes through a sample, certain wavelengths are absorbed by electrons, causing them to move from a lower energy level to a higher energy level. The amount of absorbed light is measured and displayed as an absorption spectrum.

Principle

Incident Light → Absorption by Electrons → Electronic Transition

Main Components

1. Light Source
2. Monochromator
3. Sample Holder (Cuvette)
4. Detector
5. Computer/Display

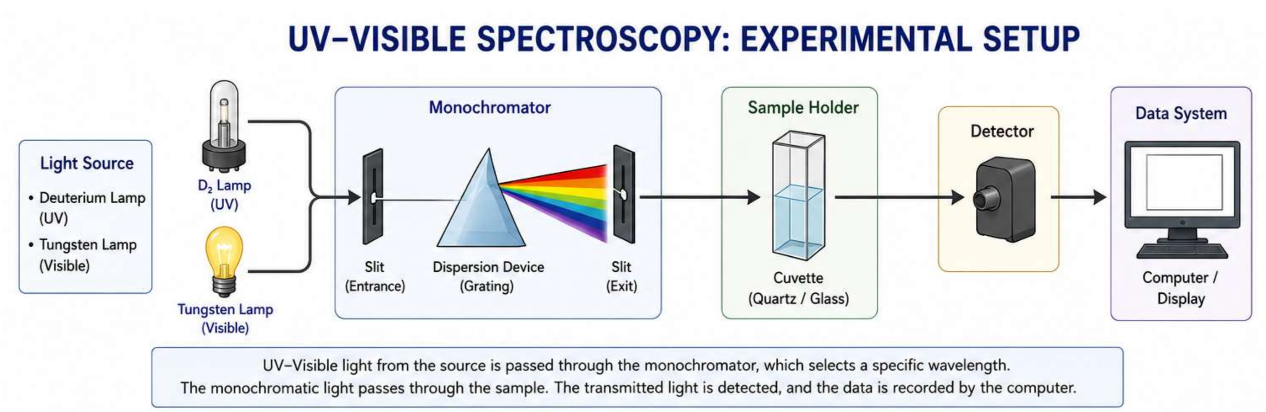

Figure 4.7 Experimental setup of UV-Visible Spectroscopy

Working

1. UV–Visible light is directed onto the sample.
2. The sample absorbs specific wavelengths.
3. The transmitted light reaches the detector.
4. The absorption spectrum is recorded.

Applications

- Nanoparticle characterization

- Band gap determination
- Concentration measurement
- Optical property analysis
- Surface Plasmon Resonance studies

4.7 Photoluminescence (PL) Spectroscopy

Photoluminescence (PL) Spectroscopy is an optical characterization technique used to study the electronic structure, band gap, defects, and recombination processes in materials. It is based on the emission of light from a material after it has absorbed photons.

When a material absorbs light, electrons are excited to higher energy levels. As these electrons return to lower energy states, they release excess energy in the form of light. This emitted light is analyzed to obtain information about the material.

Principle

Light Absorption → Electron Excitation → Electron Relaxation → Light Emission

Working

1. A laser or light source excites the sample.
2. Electrons absorb energy and move to higher energy levels.
3. Electrons return to lower energy levels.
4. Emitted light is collected and analyzed.
5. A PL spectrum is obtained.

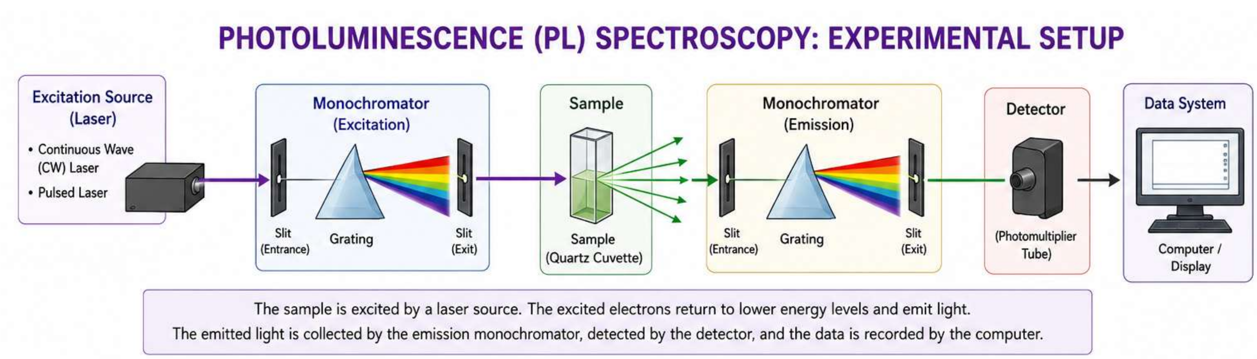

Figure 4.8 *Experimental Setup of Photoluminescence Spectroscopy*

Applications

- Band gap determination
- Defect analysis
- Semiconductor characterization

- Quantum dot studies
- Nanomaterial research

Difference Between UV–Visible and PL Spectroscopy

UV–Visible Spectroscopy	Photoluminescence Spectroscopy
Measures absorbed light	Measures emitted light
Studies absorption properties	Studies emission properties
Determines optical absorption and band gap	Determines band gap and defect states
Output: Absorption spectrum	Output: Emission spectrum

4.8 Key Words

Term	Meaning
Characterization	Process of analyzing the properties and structure of materials.
AFM	Atomic Force Microscopy used for surface topography analysis.
SEM	Scanning Electron Microscopy used for studying surface morphology.
TEM	Transmission Electron Microscopy used for examining internal structure at high resolution.
XRD	X-Ray Diffraction technique used to determine crystal structure and grain size.
Bragg's Law	Fundamental law governing X-ray diffraction in crystals.
Crystallite Size	Average size of coherent crystalline domains in a material.
UV–Visible Spectroscopy	Technique used to study absorption of UV and visible light.
Photoluminescence (PL)	Emission of light from a material after excitation.
Band Gap	Energy difference between the valence band and conduction band.

4.9 Chapter Summary

- Characterization techniques are used to determine the structural, morphological, and optical properties of nanomaterials.
- **AFM** provides three-dimensional surface images by measuring forces between a sharp tip and the sample surface.
- **SEM** uses a focused electron beam to obtain detailed images of surface morphology and particle shape.
- **TEM** transmits electrons through a thin sample to reveal internal structure and atomic-scale details.
- **XRD** is used to identify crystal structure, phase composition, and crystallite size.
- Bragg's Law explains the diffraction of X-rays from crystal planes.
- Grain size can be estimated using the Debye–Scherrer equation from XRD peak broadening.
- **UV–Visible Spectroscopy** measures light absorption and is useful for studying optical properties and band gap energy.
- **Photoluminescence Spectroscopy** analyzes light emitted by a material after excitation and provides information about electronic structure and defects.
- These characterization techniques are essential for understanding and optimizing nanomaterials for various applications.

4.10 Objective Questions

1. Which technique is used to obtain a three-dimensional surface image of a nanomaterial?

A) XRD
B) AFM
C) UV–Visible Spectroscopy
D) PL Spectroscopy

2. In Atomic Force Microscopy (AFM), the surface is scanned using a

A) Laser beam
B) X-ray beam
C) Sharp probe tip
D) Magnetic field

3. Scanning Electron Microscopy (SEM) uses

A) Light waves
B) X-rays

C) Sound waves
D) Electron beams

4. Which characterization technique provides information about the internal structure of nanomaterials?

A) SEM
B) AFM
C) TEM
D) UV–Visible Spectroscopy

5. X-Ray Diffraction (XRD) is mainly used to determine

A) Crystal structure
B) Colour of material
C) Density only
D) Temperature

6. The grain size of nanoparticles can be estimated using

A) Beer-Lambert Equation
B) Debye–Scherrer Equation
C) Einstein Equation
D) Arrhenius Equation

7. Which law forms the basis of X-Ray Diffraction?

A) Ohm's Law
B) Hooke's Law
C) Bragg's Law
D) Faraday's Law

Answers

1. B) AFM
2. C) Sharp probe tip
3. D) Electron beams
4. C) TEM
5. A) Crystal structure
6. B) Debye–Scherrer Equation
7. C) Bragg's Law

4.11 Review Questions

Short Answer Questions

1. What is meant by characterization of nanomaterials?
2. Explain the principle of Atomic Force Microscopy (AFM).
3. What is the working principle of Scanning Electron Microscopy (SEM)?
4. How does Transmission Electron Microscopy (TEM) differ from SEM?
5. State Bragg's Law used in X-ray diffraction.
6. How is grain size determined using XRD?
7. What is the principle of UV–Visible Spectroscopy?
8. Explain the principle of Photoluminescence (PL) Spectroscopy.

Long Answer Questions

1. Explain the construction, working, and applications of Atomic Force Microscopy (AFM).
2. Describe the principle, instrumentation, and applications of Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM).
3. Explain Powder X-Ray Diffraction (XRD) and discuss its role in crystal structure determination and grain size analysis.
4. Describe the principle, instrumentation, and applications of UV–Visible Spectroscopy.
5. Explain Photoluminescence Spectroscopy and compare it with UV–Visible Spectroscopy in the characterization of nanomaterials.

UNIT:5

Applications of Nano-Materials

5.1 Introduction

Nanomaterials possess unique physical, chemical, electrical, optical, and mechanical properties due to their extremely small size and large surface-to-volume ratio. These special characteristics make them useful in a wide range of applications including medicine, electronics, energy, environmental protection, and industrial manufacturing.

Nanotechnology has revolutionized many fields by enabling the development of materials and devices with improved performance, higher efficiency, and enhanced functionality.

5.2 Applications in Medicine: Drug Delivery and Photodynamic Therapy

Nanomaterials have revolutionized modern medicine by enabling **targeted drug delivery** and advanced treatment techniques such as **Photodynamic Therapy (PDT)**. Their small size, large surface area, and ability to carry therapeutic agents make them highly effective for biomedical applications.

5.2.1 Drug Delivery

Drug delivery is the process of transporting a therapeutic drug to a specific site in the body. Nanoparticles can act as carriers that deliver drugs directly to diseased tissues, reducing side effects and improving treatment efficiency. Nanocarriers such as liposomes, polymeric nanoparticles, gold nanoparticles, and magnetic nanoparticles can protect drugs from degradation and provide controlled release.

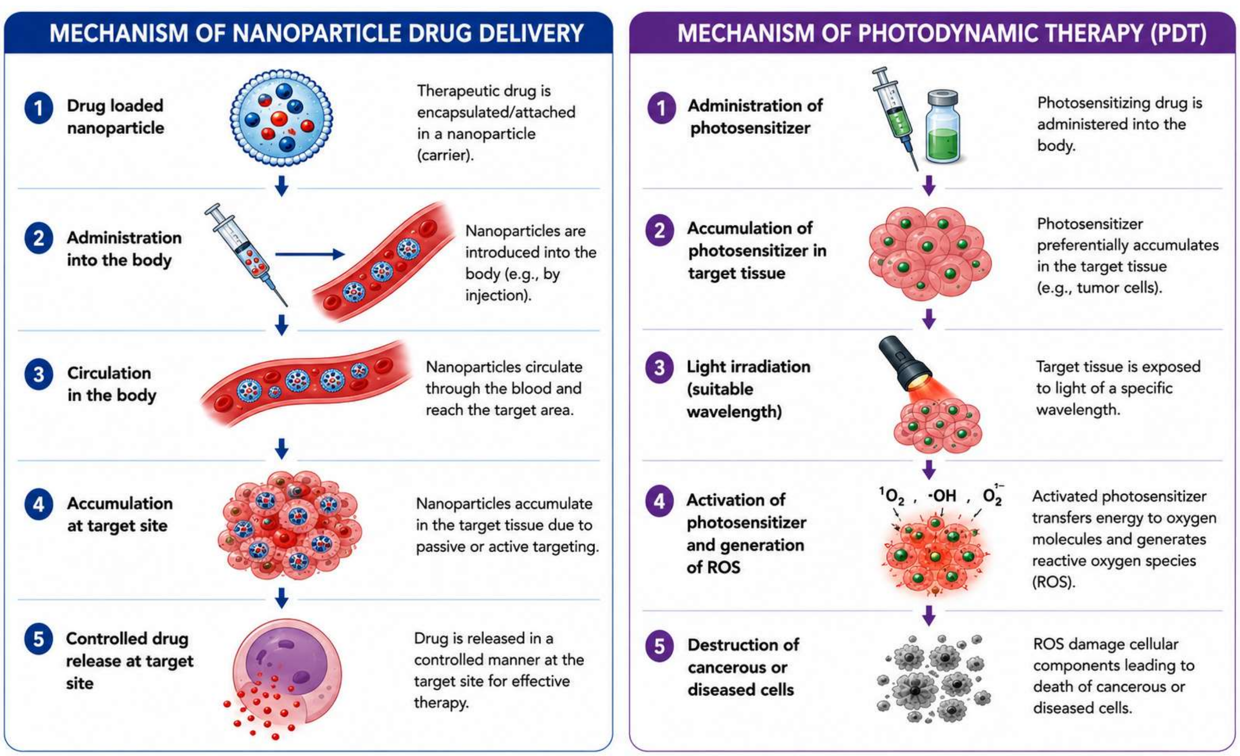

Figure 5.1 *Mechanisms of Nanoparticle Drug Delivery and PDT*

Advantages

- Targeted delivery to diseased cells
- Reduced side effects
- Improved drug stability
- Controlled drug release
- Enhanced therapeutic efficiency

5.2.2 Photodynamic Therapy (PDT)

Photodynamic Therapy is a treatment method that uses a **photosensitizer**, **light**, and **oxygen** to destroy diseased cells. The photosensitizing drug accumulates in the target tissue and is activated by light of a specific wavelength. The activated drug reacts with oxygen to generate reactive oxygen species (ROS), which destroy cancer cells or harmful microorganisms.

Nanoparticles are often used to deliver photosensitizers more efficiently to tumors, improving treatment effectiveness and reducing damage to healthy tissues.

Principle

Photosensitizer + Light + Oxygen → Reactive Oxygen Species (ROS) → Cell Destruction

Applications

- Cancer treatment
- Skin disorders
- Antibacterial therapy
- Tumor-targeted therapy

5.3 Energy Applications of Nanomaterials

5.3.1 Fuel Cells

A **fuel cell** is an electrochemical device that converts the chemical energy of a fuel (such as hydrogen) directly into electrical energy. Nanomaterials are used as catalysts and electrode materials to improve efficiency, increase reaction rates, and reduce the amount of expensive catalyst required.

Role of Nanomaterials

- Platinum nanoparticles as catalysts
- Increased surface area for reactions
- Faster electron transfer
- Improved efficiency and durability

5.3.2 Rechargeable Batteries

Rechargeable batteries store electrical energy in chemical form and can be charged and discharged repeatedly. Nanomaterials improve battery performance by increasing electrode surface area and enhancing ion transport.

Role of Nanomaterials

- Faster charging
- Higher energy density
- Longer battery life
- Improved conductivity

Examples

- $LiFePO_4$ nanoparticles
- Graphene
- Carbon nanotubes (CNTs)

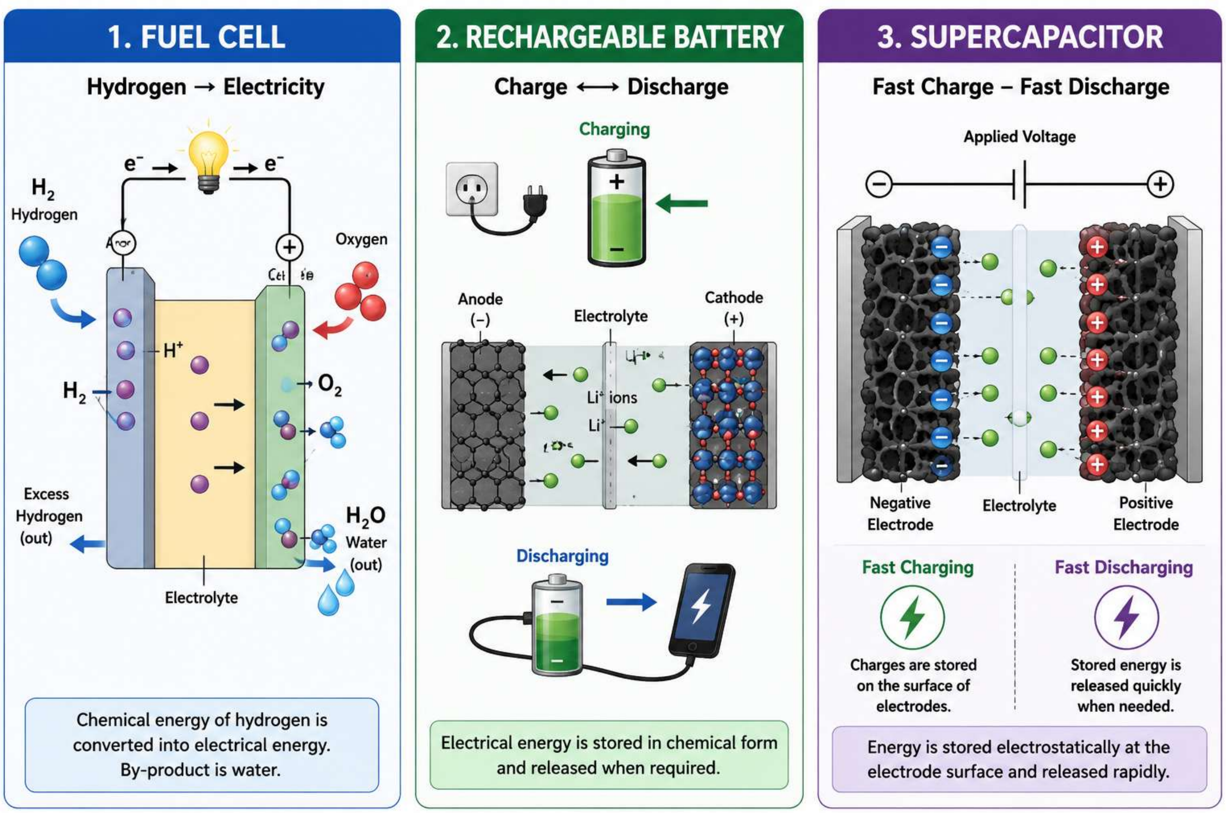

Figure 5.2 *Internal Mechanisms in Fuel cell, Rechargeable Batteries and Supercapacitor*

5.3.3 Supercapacitors

Supercapacitors are energy storage devices that can store and release energy much faster than conventional batteries. Nanomaterials provide extremely large surface areas for charge storage.

Role of Nanomaterials

- High power density
- Rapid charging and discharging
- Long cycle life
- High electrical conductivity

Examples

- Graphene
- Carbon nanotubes
- Activated carbon nanomaterials

5.4 Optical Nanosensors

Optical nanosensors operate by detecting changes in the interaction of light with nanomaterials. When the target analyte interacts with the sensor surface, optical properties such as absorption, fluorescence, photoluminescence, or surface plasmon resonance change.

Principle

Target Molecule → Change in Optical Property → Optical Signal

Optical Properties Used

- Absorption
- Fluorescence
- Photoluminescence
- Surface Plasmon Resonance (SPR)

Examples

- Gold nanoparticle sensors
- Quantum dot sensors
- Fluorescent biosensors

Applications

- Medical diagnostics
- Glucose monitoring

- Environmental monitoring
- Pathogen detection

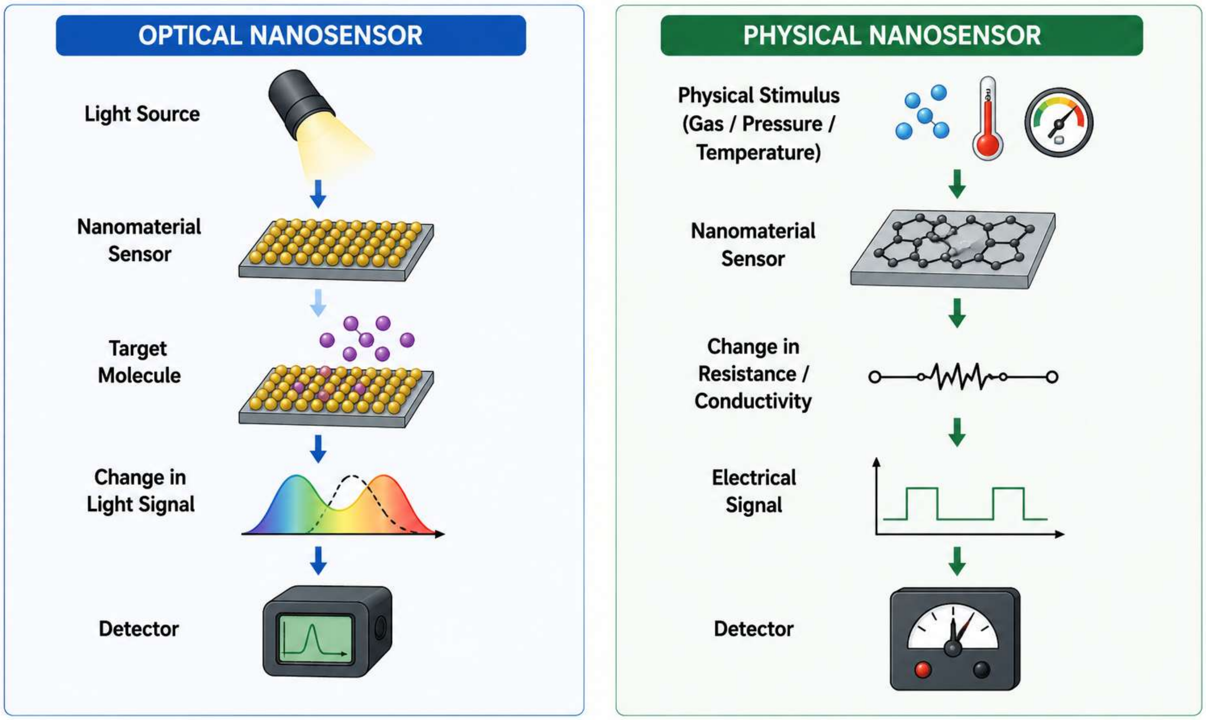

Figure 5.3 Processes involved in Optical and Physical Nanosensors

2. Physical Nanosensors

Physical nanosensors detect changes in physical properties such as electrical resistance, conductivity, pressure, temperature, force, or magnetic field. Nanomaterials are highly sensitive to small physical changes because of their nanoscale dimensions.

Principle

Physical Stimulus → Change in Physical Property → Electrical Signal

Physical Properties Used

- Electrical conductivity
- Resistance
- Temperature
- Pressure
- Magnetic field

Examples

- CNT-based sensors

- Graphene sensors
- Nanowire sensors
- Magnetic nanoparticle sensors

Applications

- Pressure sensors
- Temperature sensors
- Gas sensors
- Motion detectors
- Biomedical devices

Difference Between Optical and Physical Nanosensors

Optical Nanosensors	Physical Nanosensors
Detect changes in light properties	Detect changes in physical properties
Based on absorption, fluorescence, SPR	Based on resistance, conductivity, pressure, temperature
High optical sensitivity	High electrical sensitivity
Used in biosensing and diagnostics	Used in electronic and environmental sensing

Nanoelectronics

Nanoelectronics is a branch of nanotechnology that deals with the application of nanomaterials and nanoscale devices in electronic systems. Nanomaterials such as carbon nanotubes, graphene, quantum dots, and magnetic nanostructures are used to develop faster, smaller, and more energy-efficient electronic devices.

1. Carbon Nanotube Field Effect Transistor (CNTFET)

A **Carbon Nanotube Field Effect Transistor (CNTFET)** is a transistor in which a carbon nanotube acts as the conducting channel instead of silicon. Due to their excellent electrical conductivity, high carrier mobility, and nanoscale dimensions, CNTFETs can operate faster and consume less power than conventional silicon transistors.

Advantages

- High electron mobility
- Low power consumption
- High switching speed

- Miniaturization of electronic devices

Applications

- Nanoelectronic circuits
- High-speed processors
- Memory devices
- Flexible electronics

2. Display Screens

Nanomaterials are widely used in modern display technologies to improve brightness, color quality, contrast, and energy efficiency.

Role of Nanomaterials

- Quantum dots produce highly pure colors.
- CNTs can be used as electron emitters in displays.
- Nanostructured materials improve display efficiency.

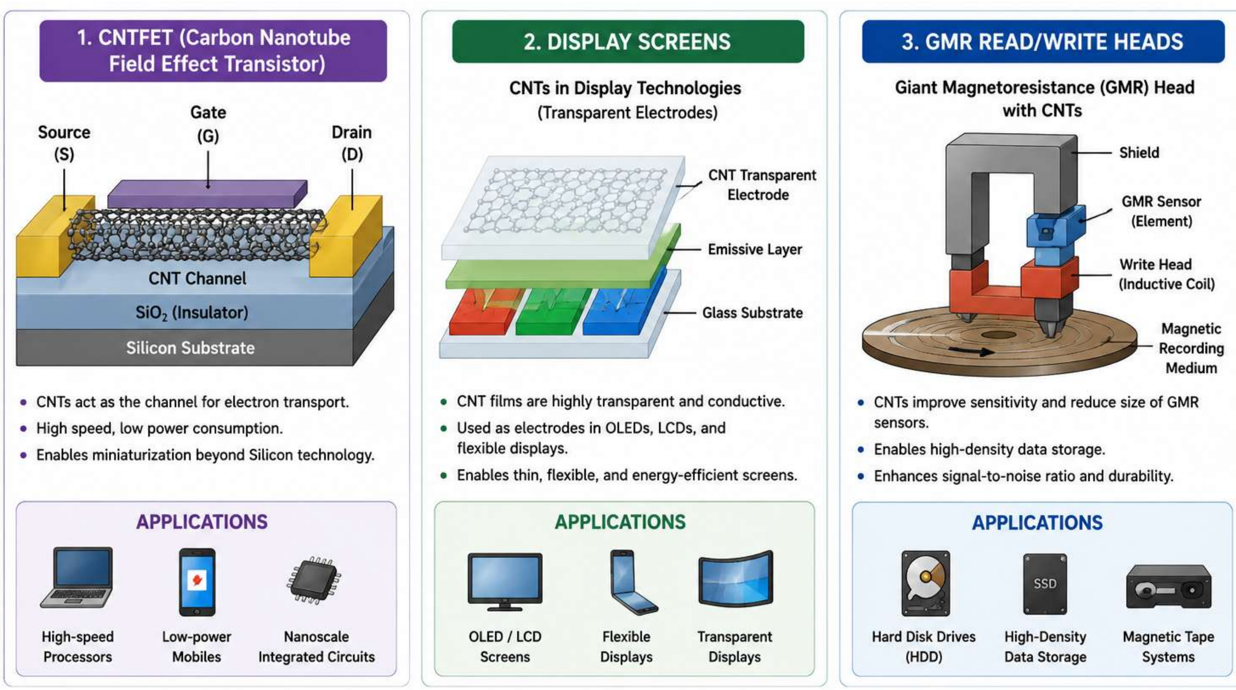

Figure 5.4 Applications of CNTs in Nano-Electronics

Applications

- LED displays
- QLED televisions
- Smartphone screens

- Computer monitors
- Flexible displays

3. GMR Read/Write Heads

Giant Magnetoresistance (GMR) is a phenomenon in which the electrical resistance of a material changes significantly in the presence of a magnetic field. GMR technology uses nanometer-thick magnetic layers and is widely used in hard disk drive read/write heads.

When the magnetic field from a stored bit on a hard disk changes, the resistance of the GMR sensor changes, allowing the data to be read accurately.

Advantages

- High sensitivity to magnetic fields
- Increased storage density
- Fast data reading
- Improved signal detection

Applications

- Hard disk drives
- Magnetic sensors
- Data storage devices
- Magnetic recording systems

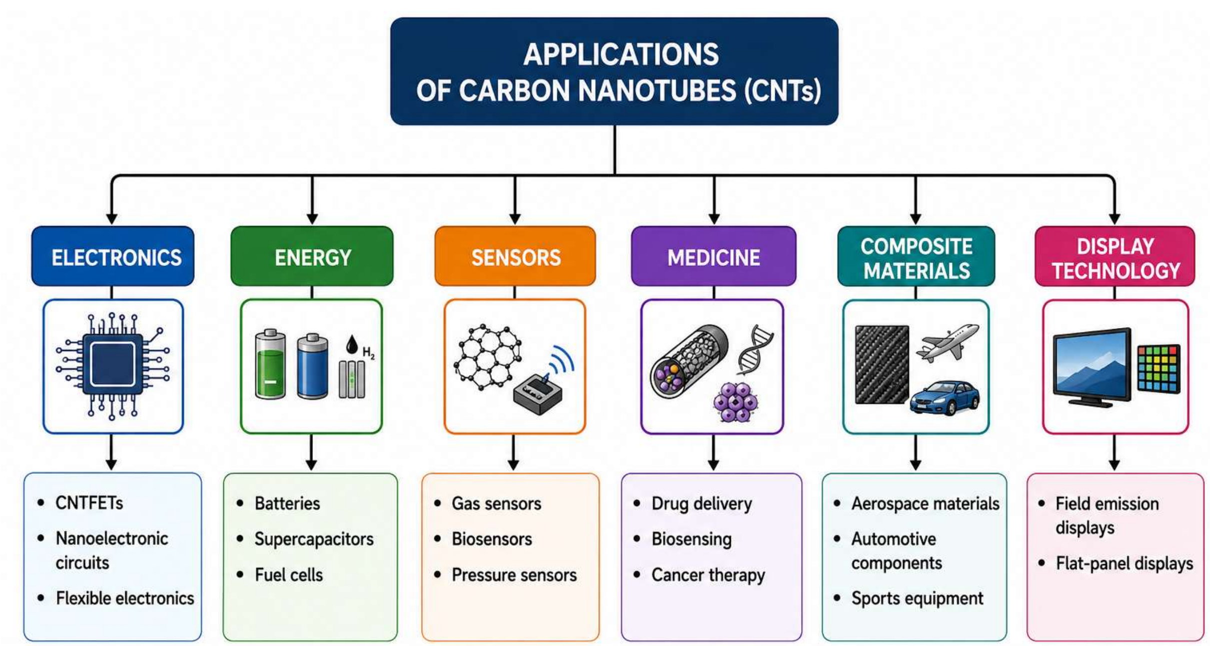

Figure 5.5 *Applications of Carbon Nanotubes (CNTs)*

5.10 Key Terms

Term	Meaning
Drug Delivery	Targeted transport of drugs to specific tissues using nanocarriers.
Photodynamic Therapy (PDT)	Treatment using light-activated drugs to destroy diseased cells.
CNTFET	Carbon Nanotube Field Effect Transistor used in nanoelectronics.
Fuel Cell	Device that converts chemical energy directly into electrical energy.
Rechargeable Battery	Energy storage device that can be charged and discharged repeatedly.
Supercapacitor	High-power energy storage device with rapid charging and discharging capability.
Optical Nanosensor	Sensor that detects changes in optical properties such as absorption or fluorescence.
Physical Nanosensor	Sensor that detects changes in physical properties such as resistance or pressure.
GMR	Giant Magnetoresistance effect used in magnetic read/write heads.
Nanocomposite	Material consisting of a matrix reinforced with nanoscale fillers.

5.11 Chapter Summary

- Nanomaterials have diverse applications in medicine, electronics, energy, sensing, and advanced materials.
- In medicine, nanoparticles enable targeted drug delivery and photodynamic therapy.
- CNTFETs are important nanoelectronic devices that provide high-speed and low-power operation.
- Nanomaterials improve display technologies by enhancing brightness, efficiency, and flexibility.
- GMR technology enables high-density magnetic data storage.
- Nanomaterials enhance the performance of fuel cells, rechargeable batteries, and supercapacitors.

- Optical nanosensors detect changes in light-related properties, while physical nanosensors detect changes in electrical, thermal, or mechanical properties.
- Carbon nanotubes are widely used in electronics, energy devices, sensors, medicine, composites, and display technologies.
- Nanocomposites improve the mechanical strength and durability of engineering materials.
- Nanotechnology continues to play a key role in next-generation devices and advanced technologies.

Objective Questions

1. Nanoparticles are used in medicine mainly for

A) Welding
B) Drug Delivery
C) Casting
D) Milling

2. Photodynamic Therapy uses

A) Heat and Pressure
B) Light, Photosensitizer and Oxygen
C) Electric Current only
D) Magnetic Field only

3. CNTFET stands for

A) Carbon Nanotube Field Effect Transistor
B) Carbon Nano Thin Film Transistor
C) Ceramic Nano Field Transistor
D) Carbon Nanotube Frequency Transistor

4. GMR stands for

A) Giant Magnetic Resistance
B) General Magnetic Response
C) Giant Magnetoresistance
D) Graphene Magnetic Resistance

5. Which energy device stores charge electrostatically?

A) Fuel Cell
B) Battery
C) Supercapacitor
D) Solar Cell

6. Optical nanosensors detect changes in

A) Pressure
B) Resistance
C) Light Properties
D) Temperature

7. Carbon nanotubes are widely used in

A) Electronics and Sensors
B) Wood Processing
C) Pottery Industry
D) Glass Manufacturing

Answers

1. B) Drug Delivery
2. B) Light, Photosensitizer and Oxygen
3. A) Carbon Nanotube Field Effect Transistor
4. C) Giant Magnetoresistance
5. C) Supercapacitor
6. C) Light Properties
7. A) Electronics and Sensors

5.12 Review Questions

Short Answer Questions

1. What are the major applications of nanomaterials?
2. Explain the role of nanomaterials in drug delivery.
3. What is Photodynamic Therapy (PDT)?
4. What is a CNTFET?
5. How are nanomaterials used in display technologies?
6. Explain the working principle of GMR read/write heads.
7. Differentiate between optical and physical nanosensors.
8. Mention the applications of carbon nanotubes (CNTs).

Long Answer Questions

1. Discuss the applications of nanomaterials in medicine with reference to drug delivery and photodynamic therapy.
2. Explain the role of nanomaterials in nanoelectronics, including CNTFETs, display screens, and GMR read/write heads.
3. Describe the applications of nanomaterials in energy devices such as fuel cells, rechargeable batteries, and supercapacitors.
4. Explain optical nanosensors and physical nanosensors with suitable examples and applications.
5. Discuss the applications of carbon nanotubes (CNTs) in electronics, energy, sensors, medicine, composite materials, and display technology.

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