Unit 5

1. Quantum Well, Quantum Wire, Quantum Dot

Quantum Well:

- A quantum well is a nanostructure where the motion of carriers (electrons or holes) is confined in one dimension but free to move in two dimensions.
- It is created when a thin layer of a semiconductor material (with a small bandgap) is sandwiched between two layers of materials with a larger bandgap.

Key Features:

  - Electrons are confined in the thickness (z-axis) direction.
  - Energy is quantized along the confined direction but continuous along the free directions.
- **Example**: GaAs quantum well between AlGaAs layers.
- **Applications**: Lasers, photodetectors.

Quantum Wire:

- In a quantum wire, the carriers are confined in two dimensions and free to move in only one dimension.
- Fabricated by further reducing the size of a quantum well into a narrow wire-like structure.
- **Key Features**:
  - Electron motion is allowed only along the wire axis (say x-axis).
  - Energy levels are quantized along the y and z axes.
- **Example**: Semiconductor nanowires like InP or GaN nanowires.
- **Applications**: High-speed transistors, nanodevices.

Quantum Dot:

- A quantum dot confines carriers in all three spatial dimensions.
- Often referred to as "artificial atoms" due to their discrete energy levels.

- **Key Features**:
  - Completely quantized energy levels.
  - Size typically 2-10 nm.
- **Example**: Colloidal quantum dots (CdSe nanoparticles).
- **Applications**: Quantum computing, LEDs, solar cells.

2. Density of States (DOS) in 0D, 1D, and 2D Systems

Density of States (DOS) describes the number of available electronic states at a particular energy level.

0D (Quantum Dot):

- In 0D structures, carriers are confined in all directions.
- **DOS**:
  - Represented by delta functions at discrete energy levels.
  - Only specific discrete energies are allowed.
- **Expression**:
  $D(E) \propto \delta(E - E_n)$
- **Graph**: Sharp spikes at allowed energy levels.

1D (Quantum Wire):

- In 1D structures, carriers are free in one direction.
- **DOS**:
  - Increases sharply near the sub-band edges.
  - Follows $D(E) \propto \frac{1}{\sqrt{E - E_n}}$.
- **Graph**: Sharp increase at the start of each sub-band.

2D (Quantum Well):

- In 2D structures, carriers are free to move in two directions.
- **DOS**:
  - Constant for each sub-band.
  - Step-like graph.

- **Expression**:
 D(E)=constant for each energy sub-bandD(E) = \text{constant for each energy sub-band}D(E)=constant for each energy sub-band

3. SEM (Scanning Electron Microscope) and TEM (Transmission Electron Microscope)

Scanning Electron Microscope (SEM):

- SEM scans the surface of a specimen using a focused beam of high-energy electrons.
- The electrons interact with atoms at the surface, producing signals like secondary electrons, backscattered electrons, and characteristic X-rays.
- **Working**:
  - Electron beam is raster-scanned over the sample.
  - Secondary electrons are collected to form an image.
- **Features**:
  - 3D-like surface morphology.
  - Resolution: ~10 nm.
  - Sample preparation is simple (coating with conductive material if non-conductive).
- **Applications**: Surface studies, fracture analysis, material science.

Transmission Electron Microscope (TEM):

- TEM passes a beam of electrons through an ultra-thin specimen.
- The interaction of electrons with the specimen forms an image.
- **Working**:
  Electrons transmitted through the sample are collected and magnified.
- **Features**:
  - High-resolution images revealing internal structures.
  - Resolution: ~0.1 nm (atomic scale).
  - Sample must be very thin (~100 nm or less).
- **Applications**: Crystallography, defect analysis, nanotechnology.

Difference Table:

Property	SEM	TEM
Principle	Scattered electronS	Transmitted electrons
Resolution	~10 nm	~0.1 nm
Image	Surface morphology	Internal structure
Sample preparation	Easier	Harder (ultrathin sections needed)

4. PVD (Physical Vapor Deposition) and CVD (Chemical Vapor Deposition)

Physical Vapor Deposition (PVD):

- A vacuum deposition method where material goes from solid to vapor phase and back to solid as a thin film on the substrate.
- **Types**:
  - Evaporation
  - Sputtering
- **Process**:

  Material is heated/ionized → vaporized → transported → condensed on substrate.

- **Features**:
  - Low pressure environment.
  - Good for metallic coatings.

- **Applications**: Hard coatings, optical coatings, semiconductor device fabrication.

Chemical Vapor Deposition (CVD):

- A chemical process in which gaseous reactants react on or near the heated substrate to form a solid thin film.

- **Types**:

  - Atmospheric Pressure CVD (APCVD)
  - Low Pressure CVD (LPCVD)

- **Process**:

Chemical reactions occur at the substrate → solid material deposits.

- **Features**:
    - Higher temperatures required.
    - Produces conformal, high-purity films.
- **Applications**: Semiconductor industry (SiO_2 layers, TiN coatings), Solar panels.

5. CNT (Carbon Nanotubes)

Introduction:

- Carbon Nanotubes are cylindrical structures composed of carbon atoms arranged in a hexagonal lattice.
- They can be thought of as rolled-up sheets of graphene.

Types:

- **Single-walled Carbon Nanotubes (SWCNT)**:

    One layer of graphene rolled into a cylinder.

- **Multi-walled Carbon Nanotubes (MWCNT)**:

    Multiple layers of graphene cylinders nested inside each other.

Properties:

- Extremely high tensile strength (100x stronger than steel).
- High electrical conductivity (can act as metallic or semiconducting).
- High thermal conductivity.
- Lightweight and flexible.

Synthesis Methods:

- Arc discharge method.
- Laser ablation.
- Chemical Vapor Deposition (CVD).

Applications:

- Nanoelectronics (transistors, diodes).
- Sensors (gas sensors, bio-sensors).
- Energy storage (batteries, supercapacitors).
- Reinforcement in composites (for aerospace, sports goods).
- Drug delivery systems.

SkyTeach

SkyTeach