Unit -5

Density of state in 2D, 1D and 0D:-

The density of states function describes the no of states that are available in a system and is essential for determining the carrier concentration and energy distributions of carriers within a semiconductor.

In s.c the free motion of carriers is limited to two, one and zero spatial dimensions. when applying s.c statistics to systems of dimensions, the density of states in quantum well (2D), quantum wire (1D) and quantum dots (0D) must be known.

Density of states in 2D:-

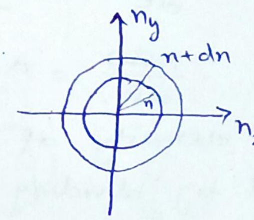
The energy of a particle in a 2D potential well is given by

$$E = \frac{h^2}{8ma^2}(n_x^2 + n_y^2) = \frac{h^2 n^2}{8ma^2} \longrightarrow (1)$$

where $n^2 = n_x^2 + n_y^2$

1. for a 2D case n represents the radius of a circle and only the first quadrant can be considered since the quantum number (i.e n_x, n_y) should be positive.

2. Each state can accommodate two electrons, so the effective no. of states will be



$$N = \frac{1}{4} \times 2 \times \pi n^2$$

$$N = \frac{\pi n^2}{2} \longrightarrow (2)$$

By using eq^n (1), it is possible to calculate the DOS in in terms of energy. So

$$N(E) = \frac{\pi}{2} \cdot \frac{8ma^2 E}{h^2} = \frac{4\pi ma^2 E}{h^2} = \frac{ma^2 E}{\pi \hbar^2} \longrightarrow (3)$$

Thus, density of state per unit energy is then obtained by differentiating eq^n (3) w.r.t E.

$$\frac{dN(E)}{dE} = \frac{ma^2}{\hbar^2 \pi}$$

The density of state per unit area, per unit energy is found by dividing by a^2 (area of the crystal i.e a^2)

$$g(E) = \frac{dN(E)}{dE \cdot V} = \frac{ma^2}{\hbar^2 \pi \cdot a^2}$$

$$\boxed{g(E)_{2D} = \frac{m}{\pi \hbar^2}} \longrightarrow (4)$$

Hence the density of state function is independent of energy.

Density of state in 1D:- The calculation for a 1D solid is similar to the earlier calculations except that there is only one quantum number $(n_x = n)$ and it is represented on a line (instead of circle in 2D)

So $$E = \frac{h^2}{8ma^2} n^2$$

or $$n^2 = \frac{8ma^2 E}{h^2}$$

So the effective no. of states will be

$$N = 2n$$

or

$$N = 2n$$

$$N(E) = 2\sqrt{\frac{8ma^2E}{h^2}}$$

$$N(E) = 2a\sqrt{\frac{8m}{h^2}} \cdot E^{1/2}$$

Thus density of state per unit energy is then obtain by differentiating eq^n (1) w.r.t 'E'

$$\frac{N(E)}{dE} = \frac{2a}{2}\sqrt{\frac{8m}{h^2}} E^{-1/2}$$

$$\frac{N(E)}{dE} = a\sqrt{\frac{8m}{h^2}} E^{-1/2}$$

The density of state per unit line, per unit energy is found by dividing by a

$$g(E) = \frac{N(E)}{dE \cdot a} = \sqrt{\frac{8m}{h^2}} E^{-1/2}$$

$$\boxed{g(E)_{1D} = \sqrt{\frac{8m}{h^2}} \cdot \frac{1}{\sqrt{E}}} = \frac{1}{\hbar\pi}\sqrt{\frac{2m}{E}}$$

So, In 1D solid, the density of states decreases with energy.

Density of state in 0D:-

In 0D materials no free motion is possible because there is no space to filled with electrons and all available states exists only in discrete energies. There fore the density of states for 0D using a delta function is written as

$$\boxed{[g(E)]_{0D} = 2\delta(E-E_c)}$$

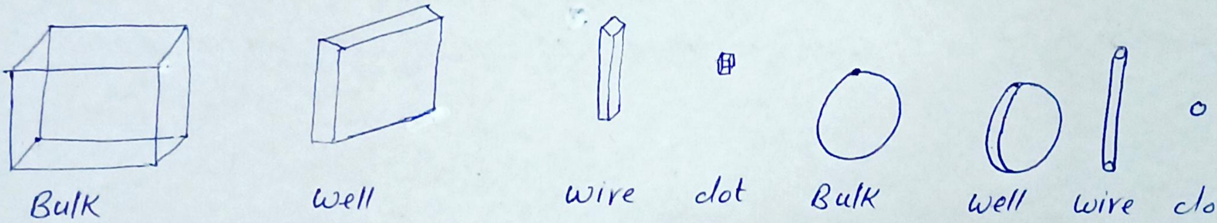
Introduction of low dimensional systems:- when the size or dimension of a material is continuously reduced from a large or macroscopic size such as a meter or centimeter, to a very small size the properties remains the same at first, then small changes begin to occur, until finally when the size drops below 100 nm dramatic changes in properties can occur.

→ If one dimension is reduced to nanorange, while the other two dimensions remain large, then we obtain a structure known a quantum well.

→ If two dimension are so reduced and one remain large, the resulting structure is reffered to as a quantum wire.

→ The extreme case of this process of size reduction in which all three dimensions reach the low nm range is called a quantum dot.

The word 'quantum' is associated with these three types of nano structure because the charge in properties arise from the quantum - mechanical nature of physics in the domain of ultrasmall.



Introduction of novel low dimensional systems:-

low dimensional systems or materials is the structure of materials with improved properties through controlled synthesis and assembly of the materials at nano scale level. If at least one dimension of ~~the~~ a structured component of a material is less than 100nm then it is called a nanomaterials.

The factors that differentiat nanomaterials from bulk material is the increase in surface area to volume ratio and quantum confinement effects.

These are explained as follows:—

(a) Surface area to volume ratio:-

The nano materials possess large value of surface area to volume ratio as compared to the bulk material. The high surface area can be attained either by fabricating small particles or clusters where the surface to volume ratio of each particle is high.

This unique property of surface to volume ratio leads to greater chemical reactivity of nano materials also enhanced appreciably due to better ordering in microstructure.

(b) Quantum confinement effect:- A/c to the band theory, solid materials have energy bands and isolated atoms possess discrete energy levels. Nanomaterials are in intermediate to the above two cases. for nano materials, if the dimensions of potential well or potential boxes are of the order of de-broglie wave length of electrons or mean free path of electrons, then the energy levels of electrons change, and the electron will remain confined to a small region of the material. This is called quantum confinement, so the quantum effects are dominant in nanoparticles materials.

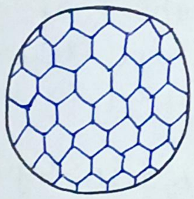
Introduction to Novel low Dimensional systems

1) **Fullerences**:- New allotropy of carbon in which atoms are arranged in closed shell and was discovered in year 1985. It was initially named as Backminister fullerence (as Backminister fuller who designed geodesic domes in 1960).

Different forms of fullerences are C_{60}, C_{70}, C_{76}, C_{84} and most a burdent form is C_{60} having 32 facets (12 pentagons and 20 hexagons) resembles soccer ball. C_{60} are chemically stable and having variety of unusual properties. It can be stretched into rod and tubes. They are having magnetic, super conducting properties and serves as lubricants.

Species of fullerence :- Alkali doped fullerence, fullerence, exohedral fullerence.

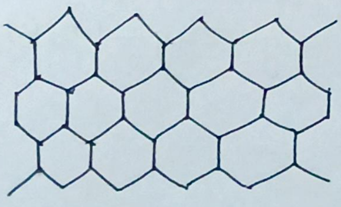
Application of fullerence :- Used for hydrogen or oxygen storage (hydrogenation of fullerence produces hydrides), as catalyst (promotes the conversion of methane into higher hydrocarbons), as sensors (fullerence based capacitors detects ppm of H_2S in N_2), Alloy strengthening / Hardening agent.



structure of fullerence

2) **Graphene** :- Another allotrophy of carbon discovered in 2010. It is a two dimensional building block for carbon-based materials also called as atomic-scale honey comb lattice made of carbon atoms with sp^2 hybridization.

Graphene is million times thinner than paper (0.33) stronger than diamond ($Y = 1.3$ TPa). Better than copper in electrical conduction ($\rho = 10^{-6}\,\Omega m$ & $\mu = 2\times10^{5}\,cm^2 V^{-1} s^{-1}$)



2D Dimensional Graphene

Properties of Graphene

① Perfect thermal conductor ($> 5000\ W/m/K$) & thermal conductivity is isotrophic. This helps to fabricate graphene-based electronic device more cool.

② Harder than diamond (Tensile strength exceeds 1 TPa)

③ Graphene can absorb / deabsorb various atoms and molecules (NO_2, NH_3, K & OH)

④ High conducting nature helps to use Graphene as sensors

⑤ Graphene can be functionalised by several chemical group forming Graphene oxidises fluorinated Graphene.

⑥ Edge of Graphene has more reactivity than surface.

Application of Graphene :- Used to detect single molecule gas, fabrication of low switching time transistors, Transparent conducting electrodes, ultra capacitors, Thermally conductive nano composites, As Reinforcement layer for polymer nanocomposites.

Carbon Nanotubes (CNT)

CNT was discovered in 1991 by Japanese electron microscopist Samio Iijma. while studying the material deposited on the cathode through arc evaporation synthesis of fallerences found that central force of core of cathode deposited contained a variety of closed graphite structure called carbon Nano Tube (CNT).

CNT are sheet of graphite rolled in cylindrical form ( ) constructed from hexagonal rings of covalently bonded carbon layer.

CNT are constructed with one or multiple graphene layer. If CNT is observed with one graphene layer it is called single walled CNT and observed with more than one graphene layer (or) multiple graphene layer, it is called multiwalled CNT.

CNT's are also having three unique geometry (or) structure. They are

① Armchair - (n, n) Tube ② zig-zag - (n, 0) tube

③ chiral - (n, m) Tube.

These geometries can be classified by how the carbon sheet is wrapped into a tube & method prescribed is called Hamada method.

Properties of CNT :-

1) Chemical Reactivity :- The chemical reactivity of CNT is compared with graphene sheet, enhanced as a direct result of the curvature of CNT surfaces. Reactivity is directly related to the Pi-orbital mismatch caused by an increased curvature. Therefore, side walled and end caps are having different reactivity. Also covalent chemical modification on side walls / end caps gives different solubility limit for CNT in solvents.

2) Electrical conductivity :- Depending on geometry, CNT with smaller diameter are either semi-conducting or metallic. Their difference in conducting property are caused by the molecular structure. That results in different band structure and thus a different (E_g).

3) Mechanical strength :- CNT have a very large youngs modulus in their axial direction. The Young modulus is over 1 TPa & estimated tensile strength is 200 GPa. These properties are ideal for reinforced composites.

4) Optical activity :- Theoretical studies have revealed that the optical activity of chiral nanotubes (n,m-tubes) disappears if the nanotubes becomes layer. It is expected that other properties are influenced by these parameters too.

Other's unique properties of CNT are :-

High electrical conductivity, highly flexible, very elastic, high thermal conductivity, low thermal expansion coefficient, highly absorbent, Good field emission of electrons.

Synthesis of CNT :- There are commonly used methods are considered.

1) **Laser ablation** :- A high power laser is rastered across a carbon target. In the plasma plume created with appropriate conditions, SWNT are formed downstream from the plasma plume. On a cold substrate usually graphite is used as carbon source and atmospheric condition is maintained with Argon / Helium.

2) **Arc- discharge method** :- CNT are synthesized by using a fairly low voltage power supply to strike an electric arc between two carbon electrodes. The carbon anode is enriched with particles of a transition metal in a order to aid synthesis. This method provides copy of multiwalled CNT.

3) **Chemical vapour deposition** :- This method uses carbon species in the gas phase and an energy source such as plasma (or) a resistively heated coil, to import energy to a gaseous carbon molecule. commonly used carbon source in CVD method are methane, carbon monoxide & acetylane. The energy source is used to crack the molecule into a reactive radical species. These reactive species than diffuse down to the substrate which is heated and already coated with catalyst (transition metals - Ni, Fe, Co).

Application of CNT

1) **Hydrogen storage** :- Hydrogen is a combustion product in water and can be easily regenerated. for this reason, a suitable hydrogen storage system is necessary for energy extraction. The hydrogen storage can be done either in gas phase and electrochemical adsorption. It has been predicted that carbon nanotubes can store gas liquid in their inner cores through capillary effect because of cylindrical geometry and nanometre scale diameter.

2) **Lithium Intercalation** :- The basic principle of rechargable lithium batteries is electrochemical intercalation and deintercalation of lithium in both ~~bag~~ electrodes.

single walled CNT shown to possess both highly reversible / irreversible capacities. But highly observed voltage hysteresis still limits the use of CNT for battery applications.

3) Transistors :- FET a three terminal switching devices - can be constructed of only one semiconducting SWNT. By applying voltage to the gate electrode, the nanotype can be switched from a conducting to an insulating state. such CWT can be coupled together, working as a logical switch which is the basic component of computer.

4) Field emitting devices :- An ideal emitter is required to have a nanometer size diameter, a structural integrity, a high electrical conductivity, a small energy spread and large chemical stability. CNT possess all these properties if the fabrication process and synthesis conditions are optimized.

5) Sensors :- single walled nanotubes may be used as miniaturised chemical sensor. On exposure to environments which contain NO_2, NH_3 (or) O_2, the electrical resistance charges.

6) Nanoprobes :- It can be used in scanning probe instruments. Multiwalled Nanotubes are conducting, they can be used in STM and AFM instruments. Advantages are the improved resolution in comparison with conventional Si (or) Metal tips.

7) composite Materials :- Theoretically single walled CNT's could have Young's Modulus of 1TPa. Multiwalled CNT's are weaker because the individual cylinders slide with respect to each other. Single walled CNT's are highly flexible and sustain large straine in tension without fracture. Therefore used as reinforcement material for composites.

Fabrication Technique for Low dimensional systems

1) chemical vapour deposition (CVD)

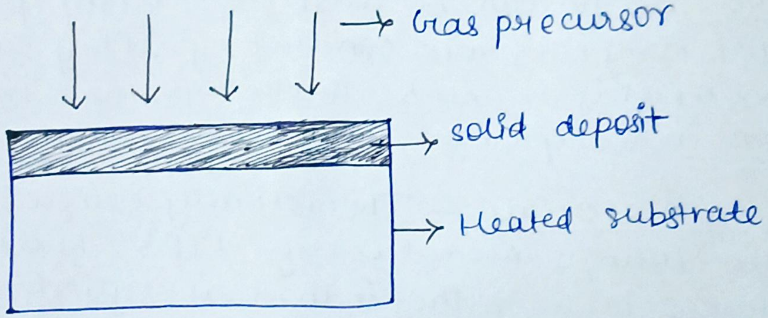
Involves depositing a solid material from a gaseous phase. Micro fabrication processes widely uses CVD to deposit materials in monocrystalline / polycrystalline / Amorphous / Epitaxial form.

Working concept :- Results from the chemical reaction of gaseous precursor (source) at a heated substrate to yield a fully dense deposit. Thermodynamics and kinetics drive both precursor generation and decomposition. (le) control through temperature, Pressure & concentration yields the desire deposit.

- for Metal deposition Metal halide (gas) → Metal (solid) + by product (gas)
- for ceremic decomposition Metal halide (gas) + $O_2/C_2/N_2/B_2$ (gas) → ceramic (solid) + by product (gas)

Steps involved in CVD system for material process / deposition

1) A predefined mix of reactant gas ~~and~~ diluent inert gas are introduced at a specified flow rate into the reaction chamber.
2) Gas species move to the substrate.
3) Reactants undergo chemical reaction with substrate to form the film.
4) Gaseous by-product of reaction are desorbed and evacuated from the reaction chamber.
5) Reactants get absorbed on the surface of the substrate.



During deposition process, the reactant gases undergoes two types of reaction.

Homogenous Reaction :- Reaction that takes place in gas phase which results low density films with lot of defects.

Heterogenous Reaction :- Reaction that takes place at the substrate surface thereby helps to create good Quality of films.

- In short heterogenous reaction are much more desirable than homogenous reaction during CVD.

Types of CVD

1) Based on chemical reaction and processing condition classified as hot walled and cold wall reactor.
2) Based on operating pressure classified as Atmospheric pressure CVD, Low pressure CVD, plasma Enhanced CVD.

Advantages of CVD :- It is used to coat wide range of metals/ceremics, coating free standing structures to fabricate complex shapes, controllable thickness and morphology, coats multiple components and pocoders.

Applications :- wide range of industrial components like aircraft and Land gas turbine blades, chemical implant items, parts of automotive industry. Apart from this

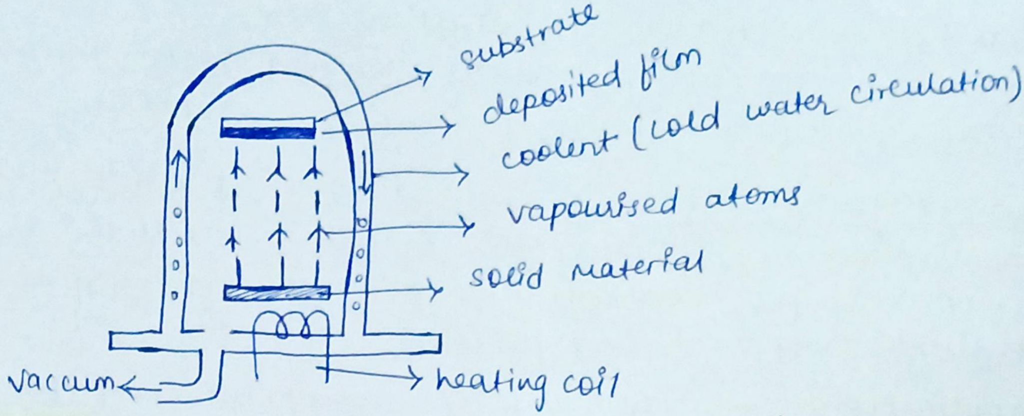
a) used to do surface modification to prevent adhesion
b) Photoresist adhesion for semiconductor water.
c) coppe copping and Anti corrosive coatings.
d) Promote biocomptability between natural and synthetic materials.

2) Physical vapour Deposition (PVD)

It is a vapourisation coating technique involving transfer of material on an atomic level. It is an alternative process of electroplating. Here the starting material is taken in solid form where as in CVD, the starting material is in gaseous state.

Working concept :- Process is carried out water vacuum condition which involves four steps :-

1) **Evaporation** :- Target Material to be deposited is vapourised by high energy source using electron beam (or) beam of ions.
2) **Transport** :- The vapourised atoms are moved from target material to the substrate in straight line affair.
3) **Reaction** :- In some cases like metal oxide, nitrides, carbides coating, the vapourised atoms are reacted with appropriate gas during transport stage.
4) **Deposition** :- Here the vapourised atom reacts on surface rod and built up thin films on substrate.



Types of PVD (in the order of increasing novalty)

1. Evaporation Deposition
2. Electron beam PVD
3. Sputter deposition
4. Cathodic arc deposition
5. Pulsed Laser deposition

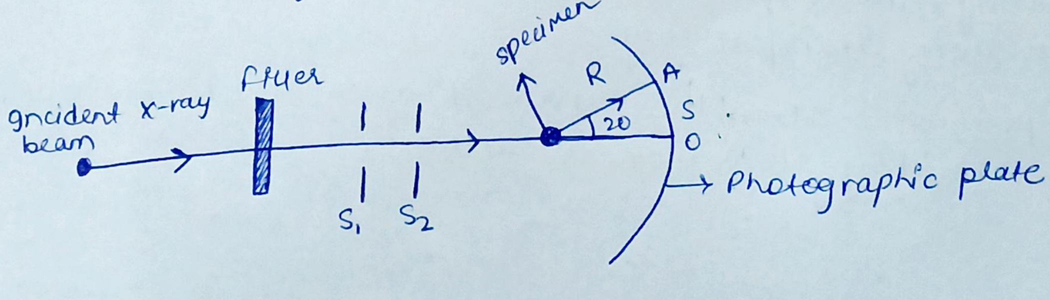
Advantages :- Improved properties can be achieved, Any type of inorganic and organic material coating, process is environmentally friendly than electroplating used to improve oxidation / wear resistance.

Applications :- coating used in Aerospace, Automotive medical, cutting tools, Die and mould industries.

Disadvantages :- High capital cost, operates at high vaccums, requires large heat and appropriate cooling systems.

Characterisation techniques for Locodimensional material

1) Power X-ray diffraction techniques :- This method employs powdered samples in which the crystals are oriented in all directions so that some of the crystals will be properly oriented for all observable reflections.



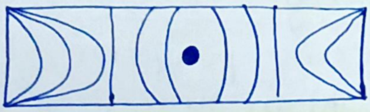
In this method, finally powdered specimen in thin walled glass capsule, X-ray from sources are made approximately monochromatic by filter 'F' (usually zirconium oxide). The narrow beam of monochromatic x-rays is suitably collimated by the two lead sheets S1 and S2. Then the beam is made to fall on specimen (powdered form) which is suspended vertically on the axis of a cylindrical camera is fitted with photographic plate.

The film covers nearly the whole circumferance in order to record the beams diffraction upto 180°.

For a given wavelength and given value of d, these can be only one 'θ' value which satisfies the equation.

$$2d \sin\theta = n\lambda \quad \text{where } n = 1 \quad \text{(Braggs law)}$$

Such reflected beam emerges out from the specimen in all direction inclined at an angle 2θ with the direction of the incident beam. Therefore there will be a cone for each set of diffracted x-rays. These cones produce a series of concentric ares of the photographic plate.



Structure determination of crystal:

Let 's' be the distances between the symmetrical lines on a stretched photograph and 'R' be the radius of cylindrical film then

$$2\theta = \frac{S}{R} \text{ radian} \quad \text{i.e., } 2\theta = \frac{S}{R} \times \frac{180}{\pi} \text{ degree}$$

Then using Bragg's law condition, 'd' is calculated and crystal structure is identified.

Applications:- Employed to study microcrystaline substance like metals, alloys, carbons and other forms where single crystal are not available.

Electron Microscopes Techniques

A scientific instrument that use a beam of highly energetic electrons to examines objects on a very fine scale. The main advantage is unusual short wavelength of electron beam for light wave. The wavelength of about

The examination following informations

① Topography – surface feature of specimen
② – shape and size of particle making up object
③ composition – Elements and compounds that the object is composed.
④ crystallographic information – Atomic arrangement, d-spacing etc.

Two types of electron microscopy technique

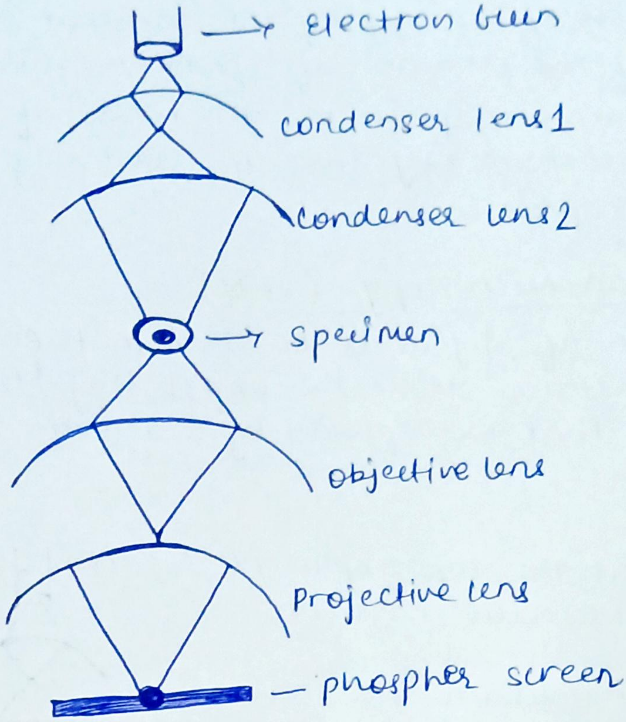
① Transmission Electron microscopy (TEM)
② scanning Electron Microscopy (SEM)

1) Transmission Electron Microscopy (TEM)

working concept :- much like slide projector, TEM shine a beam of electrons (like the light in slide projectors) through the specimen and transmitted beam is projected on phosphor screen for analyse.

Construction :-

1) The virtual source at the top represents the electron gun, producing a stream of monochromatic electron.
2) This stream is focused to a small, thin coherant beam by condenser lens 1 and 2. first one decides the size and second one decides the brightness.
3) The beams strikes the specimen and parts are transmitted. The transmitted parts (portion) is focussed by objective lens into a image.
4) The image is passed down the column through the projector lenses being enlarged and finally strikes the phosphor screen where light is generated, allowing the user to see image.



Specimen interaction with electron beam & uses

① Unscattered electrons :- Incident electrons which are transmitted through the thin specimen without any interaction occuring inside the specimen.

Use :- unscattered electrons is inversely proportional to specimen thickness

(i.e.,) for thicker specimen – fewer unscattered e^- appears (dark)
for thinner specimen – more unscattered e^- appears (bright)

② Elastically scattered electrons :- Incident electrons that are scattered by atoms in the specimen in an elastic fashion without energy loss.

Uses :- All incident electron that are scattered by the same ~~angles~~ atomic spacing will be scattered by the same angle when recorded, each spots on photographic plates represent atomic spacing and crystal phase.

③ Inelastically scattered electrons :- Incident electrons that interact with each specimen atom inelastic fashion, loosing energy during interaction and transmitted.

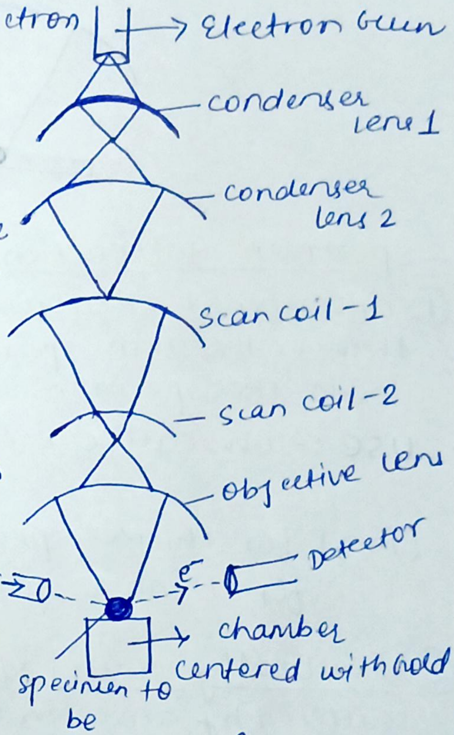
Uses:- Inelastic loss of energy by the incident electrones is characteristics of the elements of specimen, thus given composition of elements in specimen. Also bonds of alternating bright and dark lines formed by inelastic scattering relates the atomic spacing in specimen.

2) Scanning Electron Microscopy (SEM)

SEM allows surface of objects to be seen in their natural state without staining. As electron strikes the object they knock loose showers of electrons that are captured by a detector to form the image.

construction

1) The virtual source at the top represents electron gun producing monochromatic electrons.



2) The beam strikes condenser lens 1 & 2 colour size and brightness is controlled. The beam falls on scan coils (1 & 2) then which sweeps the beam dwelling on points for a period of time.

3) Then objective lens towards focusses the scanned beam onto the part of specimen. When electrons interacts with specimen and are detected by detectors (1 & 2). The process is repeated to scan entire area. (Entire pattern is scanned 30 times per second).

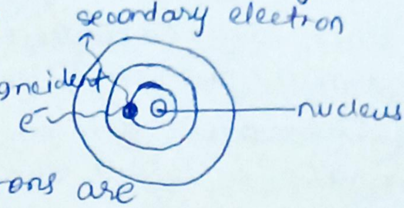
Specimen Interaction with electronbeam and its uses

1) **Backscattered electrons :-** Incident electrons colliding with an atom in specimen is then scattered backward 180°.

Uses:- Backscatterd electrons varies with specimen atomic nos. Different backscattering causes higher atomic number elements to appear bright for lower atomic number elements. Thus interaction in different parts helps to find average atomic number.

2) **secondary electrons :-** Incident electrons passing near the atom imparts energy to lower K-shell electrons of atom. Thus ionised electron then leaves the atom with small kinetic energy as is termed as secondary electrons.

Uses:- Secondary electron rate relates the topography. Any change in surface depth changes the secondary electron collection rate.



3) **Auger electron:-** caused by degeneration of the specimen atom after the secondary electrons are produced. To fill the vacancy higher energy electron from the same atom can fall to lower energy filling the vacancy, thus create energy surplus to release from atom called Auger electron.

Uses:- Auger electron energy have a characteristic energy, unique to each element from which it was emitter from and this gives compositional formation about specimen.

Atomic force Microscopy (AFM)

It is also called as scanning force microscope (SFM). AFM faster scan a sharp probe over the surface of a sample and measure the changes in the force between the probe tip and the sample.

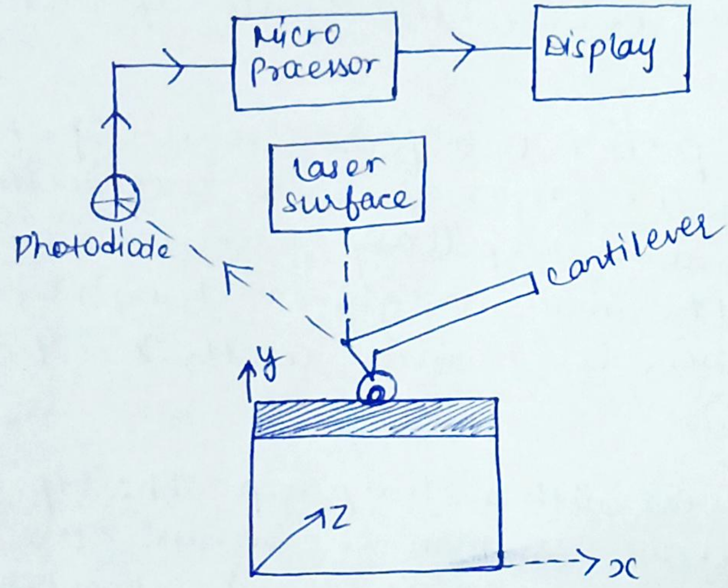
Working concept

The physical parameter probed is a force resulting from different interactions. The origin of these interactions can be ionic repulsion, vander wals, capillary, electrostatic and magnetic force. The AFM image is generated by recording the force changes as the probe is scanned in the X & Y directions.

Constructions :-

AFM consist of cantilever with a sharp tip. The tip small should have radius of curvature less than 20-50nm. The movement of the tip (or) sample in X, Y & Z direction is controlled by a Piezoelectric tube scanner. The typical scanner range is 80 in X-Y plane and 5 m in Z-direction. The force that are exerted between tip and sample are measured by the amount of bending of the cantilevel.

Working → The sample is mounted on a piezoelectric scanner, which ensures three dimensional positioning with high resolution. The force is monitered by attaching the probe to a pliable cantilever, which acts as spring and measuring the bending (or) deflection of the cantilever. Larger the deflection, higher the force experienced by the probe. The deflection is measured by focussing laser beam on the free end of cantilever. The reflected beam is detected by photo diode which given electric signals to microprocessor to form surface image.



Applications :- Useful to obtain three dimensional topographic information of insulating & conducting structures with lateral resolution down to 1.5 mm and vertical resolution to 0.05 nm.

To study Powder Catalyst :- aggregate structural determinations.

Metal → fooling studies, roughness, corrosion etc.

Advantages :- It provides 3D surface image, No special treatment for sample is required, works in ambient air (or) liquid environment tests biological macromolecules and living organism

Disadvantages:- AFM scanning depth is less (μm) and scanning area is ($150 \times 150 \mu m$). Quality of image is limited by radius of curvature of probe. scanning time is slow compared to SEM.

Heterojunctions:- Defined as junctions of two (or) more semi-conductor materials each with a different bandgap. In homo junction both sides of the junction are made of same material.

Commonly used heterojunctions are nP, Pn, Nn, pP heterojunctions. Here (n,p) refers semiconductors with a relatively narrow forbidden band and (N,P) refers semiconductors with a wider forbidden gap

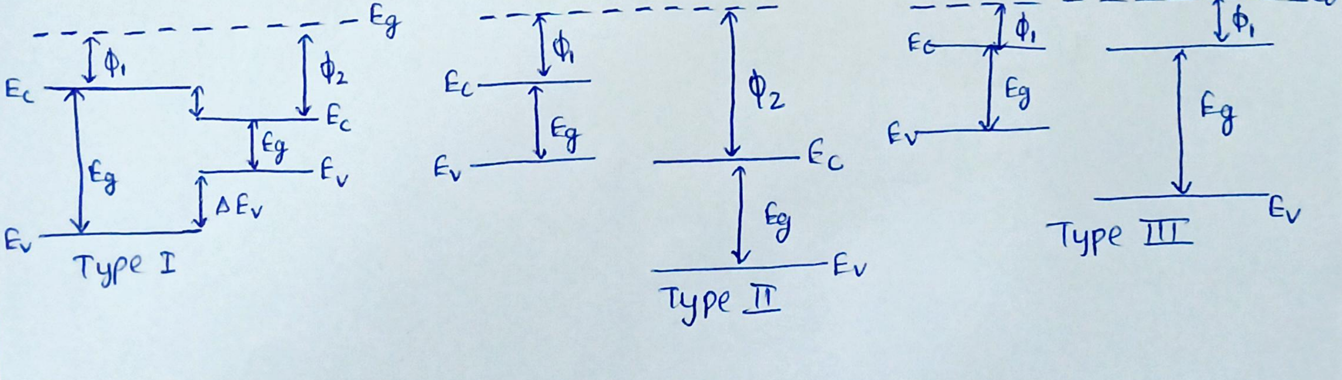
nP & Pn → Anis D type heterojunction
Nn & pP → Isotype heterojunction

Heterojunction can be formed based on Availability of substrate and proper lattice matching. Most available substrates are GaAs, InP, GaSb as they provides relatively low cost and good lattice matching.

Band diagram for heterojunction

In normal Pn junction after placing the p-type and n-type material in contact, electron flow from region of higher fermi level to region of lower fermi level. As a result, a built in potential is created near the potential barrier region.

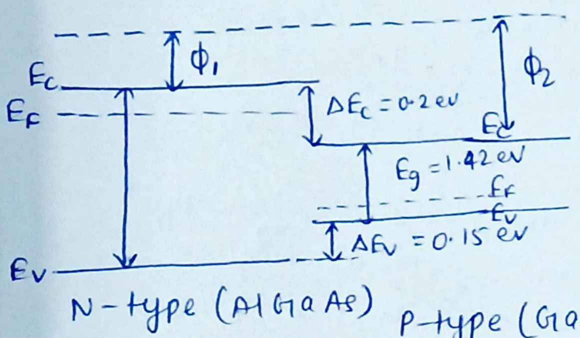
If we see hetrojunction, it has three types of band alignments.



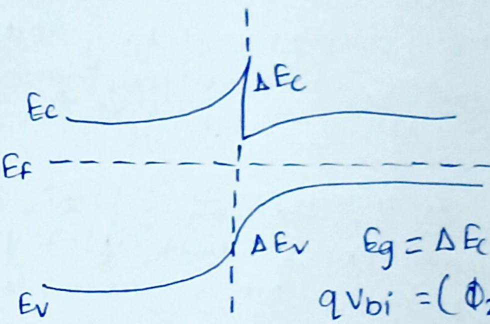
If we considered hetrojunction formed by Type I (Np (or) nP)

The band diagram ignore electrostatic potential due to re-arrangement of mobile carriers which occurs near the compositional junction after the semiconductors are placed in contact.

for example, if energy band diagram of Np Heterojunction [AlGaAs : GaAs] having the energy gap ($N-E_g > P-E_g$).
when the two materials are kept in contact, electrons moves from the semiconductor with higher fermi level to the other and an electric field is produced to balance this transfer. The build in potential is simply the difference in workfunctions of the isolated semiconductors.



Before contact (N-P type material)



$E_g = \Delta E_c + \Delta E_v$

$qV_{bi} = (\phi_2 - \phi_1)$

After contact - Np hetrojunction
Np denotes $\cdot$ Eg of (N > P) semiconductors
Example - AlGaAs : GaAs

Simply band diagram for PN, nN, Pp electrojunction are drawn.