SRM INSTITUTE OF SCIENCE AND TECHNOLOGY
RAMAPURAM

DEPARTMENT OF PHYSICS

PHYSICS: SEMICONDUCTOR PHYSICS (18PYB103J)

CHAPTER - 1

PART - A

1. Which of the following is responsible for electrical conduction in metal?
   a) Electrons
   b) Protons
   c) Neutrons
   d) Positrons

2. The electrons in inner shells are called as
   a) Valence electrons
   b) Core electrons
   c) Conductions electrons
   d) Free electrons

3. Conduction electrons in metal moves in _______
   a) Positive direction
   b) Negative direction
   c) Random direction
   d) Up and down

4. Free electrons move always in
   a) Positive direction
   b) Negative direction
   c) Random direction
   d) Up and down

5. The failures of classical theories were overcome by
   a) Sommerfeld
   b) Drude
   c) Widmann
   d) Lorentz

6. In Quantum theory electrons possess
   a) Particle nature
   b) Wave nature
   c) Liquid nature
   d) Gas nature

7. Free electrons in metals always obey
   a) Fermi Dirac statistics
   b) Wiedemann Franz law
   c) Bose Einstein Statistics
   d) Drude Lorentz theory

8. In real crystal at positive ion site, the potential of electrons will become
- **a) Zero**
- b) 1
- c) 2
- d) 3

9. According to Kronig Penney model, the shape of inner potential of crystal is
- **a) Rectangular**
- b) Triangular
- c) Spherical
- d) Sinusoidal

10. At low temperatures, semiconductors will become
- a) Conductors
- **b) Insulators**
- c) Ferroelectrics
- d) Superconductors

11. In semiconductors at low temperatures, the valence band will be
- **a) Full**
- b) Empty
- c) Partially full
- d) Partially empty

12. The conduction electrons always contribute to
- a) Electricity
- **b) Conductivity**
- c) Thermal effect
- d) Magnetic effect

13. The difference between metals, semiconductors and insulators is based on
- **a) Value of bandgap**
- b) No of electrons in valence band
- c) No of electrons in conduction band
- d) Magnitude of electric field applied

14. The free electron theory of metals was initiated by
- a) Pauli
- b) Sommerfeld
- **c) Lorentz and Drude**
- d) Fermi-Dirac

15. At any temperature T and for $E=E_F$ in metals, the Fermi-distribution function becomes
- a) 0
- b) Infinity
- c) 1
- **d) ½**

16. The value of Fermi-distribution function at absolute zero (T = 0 K) is 1, i.e., F(E)=1, under the condition

a) $E > E_F$
b) $E < E_F$
c) $E = E_F$
d) $E >> E_F$

17. With the increase in temperature, the resistance of a metal

a) Remains constant
b) Increases
c) Decreases
d) Becomes zero

18. A band or range of energy levels that an electron in a crystal is allowed to occupy is known as

a) Allowed energy bands
b) Energy bands
c) Forbidden energy bands
d) Energy Band-gap

19. A band or range of energy levels that an electron in a crystal is not allowed to occupy is known as

a) Allowed energy bands
b) Energy bands
c) Forbidden energy bands
d) Energy Band-gap

20. The principle stating that no two electrons can occupy the same quantum state is known as

a) Heisenberg Uncertainty principle
b) Pauli Exclusion principle
c) De Broglie principle
d) Quantum mechanical principle

21. The complex physical quantity which describes about the particle wave and helps deriving the probability density function is called as

a) Wave equation
b) Wave function
c) Schroedinger equation
d) Probability density function

22. The first Brillouin zone is defined between the region

a) $k = 0$ to π/a
b) $k = -2\pi/a$ to π/a
c) $k = -\pi/a$ to $2\pi/a$
d) $k = -\pi/a$ to π/a

23. The indirect bandgap semiconductors require a change in energy along with change in

a) Momentum
b) Velocity

c) Mass
d) Potential

24. The direct bandgap semiconductors have the requirement of
a) Change in energy & change in momentum
b) No change in energy & change in momentum
c) No change in energy & no change in momentum
d) Change in energy & No change in momentum

25. The position of fermi level E_F in an intrinsic semiconductor is given by
a) $E_F = E_C – E_V$
b) $E_F = E_V – E_C$
c) $E_F = (E_V – E_C) / 2$
d) $E_F = (E_C + E_V) / 2$

26. The donor atoms in extrinsic n-type semiconductors contribute
a) Electrons to conduction band
b) Electrons to valence band
c) Holes to conduction band
d) Holes to valence band

27. The acceptor atoms in extrinsic p-type semiconductor contribute
a) Holes to conduction band
b) Holes to valence band
c) Electrons to conduction band
d) Electrons to valence band

28. The carrier generation is the process by which
a) Electrons are created
b) Holes are created
c) Electrons and holes are created
d) Electrons and holes are annihilated

29. The carrier regeneration is the process by which
a) Electrons and holes are created
b) Electrons and holes are annihilated
c) Electrons are created
d) Holes are created

30. In thermal equilibrium, the concentrations of electrons and holes are
a) Dependent on time
b) Independent of time
c) Dependent on time and energy
d) Independent of time and energy

31. The quantum of energy in elastic wave is known as

a) Photon
b) Phonon
c) Electron
d) Magnon

32. The Phonons are particles that obey

a) Fermi Dirac statistics
b) Wiedemann Franz law
c) Bose Einstein Statistics
d) Drude Lorentz theory

PART – B

1. What are the merits and demerits of Classical free electron theory?
2. What are the merits and demerits of Quantum free electron theory?
3. Write short notes on direct bandgap semiconductors.
4. Write short notes on indirect bandgap semiconductors.
5. Define intrinsic semiconductors using bandgap in energy levels.
6. Explain the concept of phonons
7. Describe in brief about the First Brillouin zone.
8. How does the band theory differentiate the semiconductors and insulators?
9. What is the influence of dopant on n-type semiconductors?
10. What is the influence of dopant on p-type semiconductors?
11. Define Fermi level. Describe the Fermi Distribution function.
12. How does the *E-k* diagram explain the existence of bandgap in materials?
13. Write note on Effective mass.
14. Describe the concept of periodic potential in crystals.
15. Give the band structure diagram of GaAs and Si crystals.
16. Write down the Fermi distribution function. How does the function vary with temperature?
17. Differentiate between semiconductors and insulators based on band theory.

PART – C

1. Describe free electron theory using classical concepts. Also mention its merits and demerits.
2. Describe free electron theory using quantum concepts. Also mention its merits and demerits.
3. Derive the density of states equation for the concentration of charge carriers.
4. Derive the equation for the band structure of energy in solids using the assumptions of Kronig-Penney model.

c18PYB103J-Semiconductor Physics UNIT I

Question Bank

Multiple Choice Questions

1. What does conductivity of metals depend upon?
   a) The nature of the material
   b) Number of free electrons
   c) Resistance of the metal
   d) Number of electrons

2. What happens to the free electrons when electric field is applied?
   a) They move randomly and collide with each other
   b) They move in the direction of the field
   c) They remain stable
   d) They move in the direction opposite to that of the field

3. Outer most shell of atom with highest energy level is known as

   a) 1st shell
   b) 2nd shell
   c) Valence shell
   d) hole shell

4. Which of the following theories cannot be explained by classical theory?
   a) Electron theory
   b) Lorentz theory
   c) Photo-electric effect
   d) Classical free electron theory

5. Which of the following theories can be adopted to rectify the drawbacks of classical theory?
   a) Compton theory
   b) Quantum theory
   c) Band theory
   d) Electron theory

6. How does a semiconductor behave at absolute zero?

a) Conductor
b) Insulator
c) Semiconductor
d) Protection device

7. What are the charge carriers in semiconductors?

a) Electrons and holes
b) Electrons
c) Holes
d) Charges

8. How is charge carriers produced in intrinsic semiconductors?

a) By pure atoms
b) By electrons
c) By impure atoms
d) By holes

9. What type of material is obtained when intrinsic semiconductor is doped with pentavalent impurity?

a) N-type semiconductor
b) Extrinsic semiconductor
c) P-type semiconductor
d) Insulator

10. What type of material is obtained when an intrinsic semiconductor is doped with trivalent impurity?

a) Extrinsic semiconductor
b) Insulator
c) N-type semiconductor
d) P-type semiconductor

11. The motion of electron in periodic potential is explained by

a) Drude Model
b) Lorentz Model
c) Drude – Lorentz Model

d) Kronig Penny Model

12. According band theory of solids, the splitting up of energy levels start from

a) Outermost shell
b) First Shell
c) Second shell
d) Any Shell

13. According band theory of solids, the splitting up of energy levels will be maximum at

a) First Shell
b) Second shell
c) Any Shell
d) Outermost Shell

14. According to classical free electron theory,

1. there is no interaction between conduction electrons
2. the interaction of free electrons with ion cores is negligible
3. the free electrons find uniform electric field of positive ions and that of electrons in metal
4. all

15. Most commonly used semiconductor material is

a. Silicon
b. Germanium
c. Mixture of silicon and germanium
d. Arsenic.

16. Energy band gap size for insulators is in the range _________ eV.

a)1-2
b) 2-3
c) 3-4
d) > 4

17. Fermi energy level for intrinsic semiconductors lies

a) At middle of the band gap
b) Close to conduction band
c) Close to valence band
d) None

18. . In intrinsic semiconductors, number of electrons ___________ number of holes.

a) Equal
b) Greater than

c) Less than

d) Cannot define

19. Energy band gap size for insulators is in the range ________ eV.

a)1-2

b) 2-3

c) 3-4

d) > 4

20. A hole in the semiconductors treated as __________

a) A free electron

b) A incomplete part of electron pair bond

c) A free proton

d) A free neutron

21. The probability that an electron in a metal occupies the Fermi-level, at any temperature (>0 K) is

a) 0

b) 1

c) 0.5

d) 100

22. Consider the following statements: pure germanium and pure silicon are examples of:

1. Direct band-gap semiconductors
2. Indirect band-gap semiconductors
3. Degenerate semiconductors

Of these statements:

a) 1 alone is correct

b) 2 alone is correct

c) 3 alone is correct

d) All are correct

23. What is a Brillouin zone?

a) A region of energy---space that encompasses all of the unique values of energy

b) A region of position---space that the electron is allowed to reside within

c) Another name for the unit cell of the crystal

d) A region of k-space that contains all of the unique solutions of the wave equation

e) A region of k-space where the group velocity is positive

24. When temperature increases, intrinsic concentration increases which results in increase of

a) resistivity
b) conductivity
c) capacitivity
d) all of the above

25. Energy gap is overlapped between Valence band and conduction band in

a) insulators
b) conductors
c) semiconductors
d) super semiconductors

Short Answer Type Questions

1. Write any two success and failures of classical free electron theory
2. Write any two success and failures of quantum free electron theory
3. Write a short note on Band theory of solids.
4. Explain E-K diagram with the help of Kronig-Penney Model (solution only)
5. Discuss Brillouin Zone for 1-D crystal lattice
6. Explain the concept of phonons in the indirect band gap materials using E-K diagram
7. Explain probability of occupation in a given energy level using Fermi-Dirac distribution
8. Write any two differences between n-type and p-type semiconductors
9. Explain direct band gap and indirect band gap in materials with the help of E-K diagram.
10. Write the classification of electronic materials on the basis of band theory

Descriptive Type Questions

1. (a) Explain classical free electron theory with success and failures
   (b) Explain quantum free electron theory with success and failures
2. (a) Derive the expression for effective mass of an electron
   (b) Write short notes non-equilibrium properties of carrier.
3. (a) Explain intrinsic semiconductor on the basis of energy levels.
   (b) Explain the influence of acceptors and donors in semiconductors with energy level diagrams
4. Define and derive the expression for density of states
5. Explain the motion of electron in periodic potential using Kronig-Penney Model

MCQ Questions:

1. Classical free electron theory proposed in……….
a. 1928
b. 1926
c. 1900

d. 1896

2. Quantum free electron theory proposed in…………..

a. 1900
b. 1905
c. 1928
d. 1926

3. …………is defined as time taken by the electron to move from disturbed position to rest position when electric field is switched off.

a. Critical time
b. Relaxation time
c. Mean free time
d. Average time

4. According to quantum free electron theory, …………are having wave motion
a. Electrons
b. Protons
c. Neutrons
d. Photons

5. When two identical atoms are brought closer, the……….of atom overlap and interact.
a. Inner orbit
b. Outermost orbit
c. Nucleus
d. Neutrons

6. For conductors, the energy gap between valance band and conduction band is………….
a. 1 eV
b. 100 eV
c. 10 eV
d. Zero

7. In Kronig-Penney model, the electrons moving in……….potential
a. Constant
b. Zero
c. Periodic
d. Negative

8. …………introduced zone theory
a. Newton
b. Drude
c. Bloch
d. Sommerfield

9. The region between $+\pi/a$ and $-\pi/a$ is called…………..
a. Forbidden gap
b. First Brillouin zone
c. Second Brillouin zone
d. Third Brillouin zone

10. …………… shows characteristics of particular semiconductor material
a. E-K diagram
b. Conventional band diagram
c. Circuit diagram

d. Zone diagram
11. The E-K diagram demonstrate…………..
a. Resistivity
b. Conductivity
c. Electron (or) Hole mobility
d. Thermal conductivity
12. …………..is the example of direct band gap semiconductor
a. GaAS
b. Silicon
c. Germanium
d. Aluminum
13. The probability of a radiative recombination is……….for Indirect band gap semiconductor
a. High
b. Low
c. Zero
d. Infinity
14. A packet of waves can travel throughout the crystal with a definite energy and momentum is called……………..
a. Photons
b. Phonons
c. Mesons
d. Bosons
15. The wave length of phonons is the order of…………………
a. 1 Å
b. 1mm
c. 1 m
d. 1 km
16. The…………….mass takes into account the particle mass and also takes into account the effect of the internal forces.
a. Internal
b. External
c. Effective
d. Critical mass
17. Fermi Energy is the energy of the state at which the probability of electron occupation is…………at any temperature above 0 K.
a. 1
b. 0
c. ½
d. -1
18. The electrical resistivity of copper at 27^{o} C is 1.72 x 10^{-8} Ohm m. and the Lorentz number is 2. 26 x 10^{-8} W Ohm K^{-2} then its thermal conductivity is…………………
a. 394.18 w/m
b. 394.18 w m/m/k
c. 3.9418 w/m/k
d. 3.9418 w/m
19. What is the drift velocity of electron if the current density is 4.976 x 10 power 6 A/m2 and carrier density is 8.46 x 10 power 28 /cubic meter?

a. 367 m/s
b. 0.367 m/s
c. 0.000367 m/s
d. 0.0367 m/s
20. The drift velocity of electron is 0.000367 m/s and carrier density is 8.46 x 10 power 28 /cubic meter then the current density is………………a/m2
a. 4.976 x 10 power 6
b. 4.976 x 10 power -6
c. 4.976 x 10 power -3
d. 4.976 x 10 power 3

Reg. No. | | | | | | | | | | | | | | | |

B.Tech. DEGREE EXAMINATION, NOVEMBER 2019
First / Second Semester

18PYB103J – PHYSICS: SEMICONDUCTOR PHYSICS
(For the candidates admitted during the academic year 2018-2019 onwards)

Note:
(i) **Part - A** should be answered in OMR sheet within first 45 minutes and OMR sheet should be handed over to hall invigilator at the end of 45th minute.
(ii) **Part - B** and **Part - C** should be answered in answer booklet.

Time: Three Hours — Max. Marks: 100

PART – A (20 × 1 = 20 Marks)
Answer ALL Questions

1. The motion of electron in an periodic potential is explained by
   (A) Drude model (B) Lorentz model
   (C) Drude – Lorentz model (D) Kronig Penny Model

2. What type of material is obtained, when an intrinsic semiconductor is doped with trivalent impurity?
   (A) Extrinsic semiconductor (B) Insulator
   (C) N – type semiconductor (D) P – type semiconductor

3. Most commonly used semiconductor material is _____.
   (A) Silicon (B) Copper
   (C) Mixture of silicon and copper (D) Arsenic

4. Energy band gap size for insulators is in the range of ______eV.
   (A) 1 – 2 (B) 2 – 3
   (C) 3 – 4 (D) >4

5. A hole in a semiconductor is defined as ________.
   (A) A free electron (B) The incomplete part of an electron pair bond
   (C) A free proton (D) A free neutron

6. The P-region has a greater concentration of ________ as compared to the n-region in a P-N junction.
   (A) Holes (B) Electrons
   (C) Both holes and electrons (D) Phonons

7. A P-type semiconductor material is doped with ______ impurities whereas N-type semiconductor material is doped with ________ impurities.
   (A) Acceptor, donor (B) Acceptor, acceptor
   (C) Doner, donor (D) Donor, acceptor

8. The forward bias current in a typical Schottky barrier is due to what physical mechanism?
   (A) Drift (B) Diffusion
   (C) Recombination (D) Thermionic emission

9. The absorption of photons in a photodiode is dependent on
(A) Absorption co-efficient (α_0)
(B) Properties of material
(C) Charge carrier at junction
(D) Amount of light

10. The semiconductor material, for which the lowest energy absorption takes place is
(A) GaAs
(B) Silicon
(C) Gash
(D) Germanium

11. Optical processes directly involves ________ absorption and emission.
(A) Electron
(B) Proton
(C) Photon
(D) Neutron

12. ________ statistics can be applied to identical indistinguishable particles of half spin.
(A) Bose-Einstein
(B) Fermi-Dirac
(C) Maxwell-Boltzmann
(D) Bose-Dirac

13. In Four probe technique, the outer two probes are used to apply ________ and inner two probes are used to measure ________.
(A) Voltage, current
(B) Temperature, voltage
(C) Current, voltage
(D) Voltage, Temperature

14. In linear four probe method, the tip of probe diameter is usually ______ than the probe spacing.
(A) Larger
(B) Cooler
(C) Heater
(D) Smaller

15. C-V measurements are capable of yielding information about the ________ and concentration of charge carriers.
(A) Drift potential
(B) Diffusion potential
(C) Bonding
(D) Crystal structure

16. C-V technique uses a metal-semiconductor junction (Schottky barrier) or a p-n junction or a MOSFET to create a ________.
(A) Depletion region
(B) Hole generation
(C) Electron – Hole pairs
(D) Electron generation.

17. An example for O-D material is ________.
(A) Nanowire
(B) Nanorod
(C) Nanosheet
(D) Nanoparticle

18. An ideal monochromator should have an ________ narrow effective bandwidth.
(A) Small
(B) Infinite
(C) Finite
(D) Zero

19. ________ spectroscopy can be used to determine the concentration of the absorbs in a solution.
(A) UV-Vis
(B) IR
(C) Microwave
(D) Gamma

20. The physical parameter that is probed in AFM resulting from different interactions is ______.
(A) Charge
(B) Force
(C) Potential
(D) Current

PART – B (5 × 4 = 20 Marks)
Answer ANY FIVE Questions

21. Explain indirect band gap materials with the help of E-K diagram.
22. Explain nonequilibrium properties of carriers.
23. Write a note on drift current.
24. Write a short note on organic light emitting diodes.
25. Explain optical absorption and recombination process.
26. Explain the working of two point probe technique.
27. Write a note on applications of carbon nanotubes.

PART – C (5 × 12 = 60 Marks)
Answer ALL Questions

28.a.i. Define Density of states. Derive an expression for density of states of a semiconducting material. (9 Marks)
ii. Write any two success and failures of classical free electron theory. (3 Marks)

(OR)

b.i. What is effective mass? Derive an expression for effective mass of an electron. (10 Marks)
ii. Find the temperatures at which there is 1% probability of a state with energy 0.5 eV above Fermi energy. (2 Marks)

29.a.i. Define extrinsic semiconductor. Derive an expression for Fermi energy in N-typ semiconductor. Explain the variation of Fermi level with temperature. (8 Marks
ii. Define P-N junction. Explain the biasing concepts in P-N junction. (4 Marks

(OR)

b.i. What is Light emitting Diode? Describe the principle, construction and working of a LEI (10 Marks
ii. Write any two advantages and disadvantages of LED. (2 Mark

30.a. Explain the absorption and emission process with necessary theory and derive the relati between Einstein's co-efficients.

(OR)

b. Derive an expression for joint density of states and also density of states of photons.

31.a. Describe linear and Vander Pauw's four point probe technique for electrical measurements

(OR)

b. Describe the principle, construction and working of Deep level Transition spectroscopy. (8 Mar
ii. Write a note on I-V characteristics of a junction diode. (4 Mar

32.a.i. Describe the fabrication of Carbon Nanotubes by Physical vapour Deposition (PV technique. (8 Mar
ii. Write a short note on powder XRD technique. (4 Ma

(OR)

b. With a neat sketch, explain the working concept, source and utilization of scanning elec microscope.

* * * * *

b.i. What is a Light Emitting diode (LED)? Describe the principle, construction and working of LED. (8 Marks)

ii. Write a note on diffusion and drift current. (4 Marks)

30. a. Explain the absorption and emissions processes with necessary theory and hence derive the relation between Einsteins coefficients.

(OR)

b.i. Describe the theory of Drudes model and hence derive the expression for electrical conductivity. (10 Marks)

ii. Mention any two applications of photovoltaic effect. (2 Marks)

31. a. Describe the Linear and Vander Pauw Four Point Probe technique for electrical measurements.

(OR)

b. What are the fundamental laws of absorption? Describe the principle, construction and working of UV Visible Spectrophotometer.

32. a.i. What are Carbon nanotubes (CNT)? Mention the properties of CNTs. (4 Marks)

ii ii. Describe the fabrication of CNT's by Physical Vapor Deposition (PVD). (8 Marks)

(OR)

b.i. Describe the principle, construction and working of Scanning Electron Microscope (SEM). (8 Marks)

ii. Write a note on Heterojunctions. (4 Marks)

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(A) (B)

(i) 8+2 (i) 1+8+3

(ii) v_F 8.16 $\times 10^5$ m/s

(i) LED – 8

diff – 4

1) (i) Explain 2+6 = 8

(ii) 4

(i) Drude – 4

$\sigma = \frac{ne^2\tau}{m}$ – 6

(ii) app – 2

a) 4 + 8

(i) 4 + 8

(i) 4 – CNT

(ii) PVD – 8

(i) SEM – 8

(ii) – 4

Dr. ... Saravanan

Reg. No.

B.Tech. DEGREE EXAMINATION, NOVEMBER 2018
First Semester

18PYB103J – PHYSICS: SEMICONDUCTOR PHYSICS
(For the candidates admitted during the academic year 2018-2019)

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Time: Three Hours Max. Marks: 100

PART – A (20 × 1 = 20 Marks)
Answer ALL Questions

1. The average distance travelled by an electron between two successive collisions in the presence of applied field is called ________
(A) Collision time (B) Mean free path
(C) Wave number (D) Drift velocity

2. The band gap is called ________, if the crystal momentum of electrons and holes is the same in both the conduction band and the valence band; an electron can directly emit a photon.
(A) Direct (B) Indirect
(C) Crystalline (D) Noncrystalline

3. ________ is the state at which the probability of electron occupation is ½ at any temperature above 0K.
(A) Valence level (B) Fermi level
(C) Conduction level (D) Density of states

4. When an electron in a periodic potential is accelerated relative to the lattice in an electric field or magnetic field, then the mass of the electron is called the ________
(A) Rest mass (B) Effective mass
(C) Zero mass (D) Accelerated mass

5. ________ is a PN Junction, which is forward biased?
(A) Light Emitting diode (B) Zener diode
(C) Rectifier (D) Transistor

6. When light impinges upon a semiconductor to create electron – hole pairs, some of the carriers are collected at the contact which leads to ________
(A) gain (B) photocurrent
(C) amplification (D) biasing

7. Which type of material is obtained when intrinsic semiconductor is doped with pentavalent impurity?
(A) N-type semiconductor (B) Extrinsic semiconductor
(C) P-type semiconductor (D) Insulator

8. ______________ is the process of radiative recombination of electron-hole pairs created by electron bombardment.
(A) Photoluminescence (B) Cathodoluminescence
(C) Electroluminescence (D) Anodoluminescence

9. The spectral region, where the material changes from being relatively transparent to strongly absorbing is known as ______________
(A) Absorption edge (B) Conduction edge
(C) Valence edge (D) Annihilation edge

10. According to Drudes theory, the velocities of electrons are assumed to have ______________ velocity given by kinetic theory of gases.
(A) Root mean square (B) Drift
(C) Instantaneous (D) Uniform

11. ______________ is the creation of voltage and electric current in a material upon exposure to light and is a physical and chemical phenomenon.
(A) Acousto-optics (B) Photovoltaics
(C) Electrolysis (D) Electrophoresis

12. In stimulated emission, the states at which the life time of atoms is extended is ______________
(A) Metastable state (B) Stable state
(C) ~~Dense state~~ (D) ~~Excited state~~

13. For determining the resistivity of a semiconductor, the diameter of contacts between the probe and the semiconductor should be ______________ the gap between the probes.
(A) Smaller than (B) Greater than
(C) Equal to (D) Double

14. ______________ is a technique for characterizing semiconductor materials and devices, where the applied voltage is varied, and the capacitance is measured and plotted as a function of voltage.
(A) Capactive - voltage profiling (B) Current profiling
(C) Voltage profiling (D) Baising

15. A ______________ is a method of determining quickly whether a semiconductor sample is n (negative) type or p (positive) type.
(A) Electrolysis (B) Hot point probe
(C) Rectification (D) Hydrogenation

16. ______________ law states that, when a beam of monochromatic light passes through an absorbing medium, the rate of decrease in intensity with the thickness of the medium, is proportional to the intensity of light.
(A) Lambert's (B) Beer's
(C) Photoelectric (D) Snell's

17. Nanoparticles are special mainly because of their ______________
(A) Surface area (B) Surface charge
(C) Volume (D) Force

18. In a quantum wire, the material size is reduced ______________
(A) In three directions (B) In two directions
(C) In one direction (D) Infinitely

19. In CVD chamber, the precursors are introduced to the reaction chamber in the ______________ state.
(A) Liquid (B) Solid
(C) Semisolid (D) Gaseous

20. The physical parameter that is probed in AFM resulting from different interactions is ______________
(A) Charge (B) Force
(C) Potential (D) Field

PART – B (5 × 4 = 20 Marks)
Answer ANY FIVE Questions

21. Write a note on Energy bands in solids.
22. Describe the nonequilibrium properties of carriers.
23. What is a PN Junction? Explain the biasing concept in PN Junction.
24. Write a note on organic light emitting diodes.
25. Describe the optical absorption and recombination process.
26. Write a note on I-V characteristics of a diode.
27. Describe the powder method of X-ray diffraction.

PART – C (5 × 12 = 60 Marks)
Answer ALL Questions

28.a.i. What is Density of states? Derive an expression for density of states for a semiconducting material. (10 Marks)

ii. The Fermi level for potassium is 1.9 eV. Calculate the velocity of the electron at the Fermi level. (2 Marks)

(OR)

b. Describe the behavior of electron in a periodic potential and hence explain the Kronig Penny Model in detail with the cases.

29.a.i. What is an extrinsic semiconductor? Describe the variation of Fermi level with carrier concentration and temperature in an N-Type semiconductor. (8 Marks)

ii. Determine the position of the Fermi Level in an instrinsic semiconductor from the centre of forbidden gap at room temperature, if the effective mass of an electron is equal to twice the effective mass of hole. (4 Marks)

(OR)

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DEPARTMENT OF PHYSICS

PHYSICS: SEMICONDUCTOR PHYSICS (18PYB103J)

CHAPTER - 1

PART - A

1. Which of the following is responsible for electrical conduction in metal?
   a) Electrons
   b) Protons
   c) Neutrons
   d) Positrons

2. The electrons in inner shells are called as
   a) Valence electrons
   b) Core electrons
   c) Conductions electrons
   d) Free electrons

3. Conduction electrons in metal moves in _______
   a) Positive direction
   b) Negative direction
   c) Random direction
   d) Up and down

4. Free electrons move always in
   a) Positive direction
   b) Negative direction
   c) Random direction
   d) Up and down

5. The failures of classical theories were overcome by
   a) Sommerfeld
   b) Drude
   c) Widmann
   d) Lorentz

6. In Quantum theory electrons possess
   a) Particle nature
   b) Wave nature
   c) Liquid nature
   d) Gas nature

7. Free electrons in metals always obey
   a) Fermi Dirac statistics
   b) Wiedemann Franz law
   c) Bose Einstein Statistics
   d) Drude Lorentz theory

8. In real crystal at positive ion site, the potential of electrons will become

a) Zero
b) 1
c) 2
d) 3

9. According to Kronig Penney model, the shape of inner potential of crystal is

a) Rectangular
b) Triangular
c) Spherical
d) Sinusoidal

10. At low temperatures, semiconductors will become

a) Conductors
b) Insulators
c) Ferroelectrics
d) Superconductors

11. In semiconductors at low temperatures, the valence band will be

a) Full
b) Empty
c) Partially full
d) Partially empty

12. The conduction electrons always contribute to

a) Electricity
b) Conductivity
c) Thermal effect
d) Magnetic effect

13. The difference between metals, semiconductors and insulators is based on

a) Value of bandgap
b) No of electrons in valence band
c) No of electrons in conduction band
d) Magnitude of electric field applied

14. The free electron theory of metals was initiated by

a) Pauli
b) Sommerfeld
c) Lorentz and Drude
d) Fermi-Dirac

15. At any temperature T and for $E=E_F$ in metals, the Fermi-distribution function becomes

a) 0
b) Infinity
c) 1
d) ½

16. The value of Fermi-distribution function at absolute zero (T = 0 K) is 1, i.e., F(E)=1, under the condition

a) $E > E_F$
b) $E < E_F$
c) $E = E_F$
d) $E >> E_F$

17. With the increase in temperature, the resistance of a metal

a) Remains constant
b) Increases
c) Decreases
d) Becomes zero

18. A band or range of energy levels that an electron in a crystal is allowed to occupy is known as

a) Allowed energy bands
b) Energy bands
c) Forbidden energy bands
d) Energy Band-gap

19. A band or range of energy levels that an electron in a crystal is not allowed to occupy is known as

a) Allowed energy bands
b) Energy bands
c) Forbidden energy bands
d) Energy Band-gap

20. The principle stating that no two electrons can occupy the same quantum state is known as

a) Heisenberg Uncertainty principle
b) Pauli Exclusion principle
c) De Broglie principle
d) Quantum mechanical principle

21. The complex physical quantity which describes about the particle wave and helps deriving the probability density function is called as

a) Wave equation
b) Wave function
c) Schroedinger equation
d) Probability density function

22. The first Brillouin zone is defined between the region

a) $k = 0$ to π/a
b) $k = -2\pi/a$ to π/a
c) $k = -\pi/a$ to $2\pi/a$
d) $k = -\pi/a$ to π/a

23. The indirect bandgap semiconductors require a change in energy along with change in

a) Momentum
b) Velocity

c) Mass
d) Potential

24. The direct bandgap semiconductors have the requirement of
a) Change in energy & change in momentum
b) No change in energy & change in momentum
c) No change in energy & no change in momentum
d) Change in energy & No change in momentum

25. The position of fermi level E_F in an intrinsic semiconductor is given by
a) $E_F = E_C – E_V$
b) $E_F = E_V – E_C$
c) $E_F = (E_V – E_C) / 2$
d) $E_F = (E_C + E_V) / 2$

26. The donor atoms in extrinsic n-type semiconductors contribute
a) Electrons to conduction band
b) Electrons to valence band
c) Holes to conduction band
d) Holes to valence band

27. The acceptor atoms in extrinsic p-type semiconductor contribute
a) Holes to conduction band
b) Holes to valence band
c) Electrons to conduction band
d) Electrons to valence band

28. The carrier generation is the process by which
a) Electrons are created
b) Holes are created
c) Electrons and holes are created
d) Electrons and holes are annihilated

29. The carrier regeneration is the process by which
a) Electrons and holes are created
b) Electrons and holes are annihilated
c) Electrons are created
d) Holes are created

30. In thermal equilibrium, the concentrations of electrons and holes are
a) Dependent on time
b) Independent of time
c) Dependent on time and energy
d) Independent of time and energy

31. The quantum of energy in elastic wave is known as
   a) Photon
   b) Phonon
   c) Electron
   d) Magnon

32. The Phonons are particles that obey
   a) Fermi Dirac statistics
   b) Wiedemann Franz law
   c) Bose Einstein Statistics
   d) Drude Lorentz theory

PART – B

1. What are the merits and demerits of Classical free electron theory?
2. What are the merits and demerits of Quantum free electron theory?
3. Write short notes on direct bandgap semiconductors.
4. Write short notes on indirect bandgap semiconductors.
5. Define intrinsic semiconductors using bandgap in energy levels.
6. Explain the concept of phonons
7. Describe in brief about the First Brillouin zone.
8. How does the band theory differentiate the semiconductors and insulators?
9. What is the influence of dopant on n-type semiconductors?
10. What is the influence of dopant on p-type semiconductors?
11. Define Fermi level. Describe the Fermi Distribution function.
12. How does the *E-k* diagram explain the existence of bandgap in materials?
13. Write note on Effective mass.
14. Describe the concept of periodic potential in crystals.
15. Give the band structure diagram of GaAs and Si crystals.
16. Write down the Fermi distribution function. How does the function vary with temperature?
17. Differentiate between semiconductors and insulators based on band theory.

PART – C

1. Describe free electron theory using classical concepts. Also mention its merits and demerits.
2. Describe free electron theory using quantum concepts. Also mention its merits and demerits.
3. Derive the density of states equation for the concentration of charge carriers.
4. Derive the equation for the band structure of energy in solids using the assumptions of Kronig-Penney model.

DEPARTMENT OF PHYSICS AND NANOTECHNOLOGY
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18PYB103J –Semiconductor Physics

Module 2 Lecture 16

Solving Problems

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1. Determine the wavelength of radiation given out by an LED with an energy of 3 eV, given that h = 6.626 × 10^{-34} m^2 kg / s and C= 3 × 10^8 m/s

We know that

$$E = h\nu = \frac{hc}{\lambda}$$

$$\lambda = \frac{hc}{E} = \frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{3 \times 1.6 \times 10^{-19}}$$

= 414 x 10^{-9} m or 414 nm

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2. Calculate the wavelength of light emission from GaAs whose band gap is 1.44 eV.

We know that

$$E = h\nu = \frac{hc}{\lambda}$$

$$\lambda = \frac{hc}{E_g} = \frac{6.626\times10^{-34}\times3\times10^{8}}{1.44\times1.6\times10^{-19}}$$

= 8628 x 10^{-10} m or 8628 Å

3. Calculate the long wavelength limit of an extrinsic semiconductor if the ionization energy is 0.02 eV.

We know that

$$E = h\nu = \frac{hc}{\lambda}$$

$$\lambda = \frac{hc}{E_g}$$

$= 6.2119 \times 10^{-5}$ m

4. An LED has a peak emission wavelength of 1.55 x 10^{-6} m. Find its band gap in eV.

We know that

$$E_g = h\nu = \frac{hc}{\lambda}$$

5. A cadmium Sulphide (E_g=2.4 eV) photo detector is illuminated with light of wavelength 3000 Å. Find the total energy falling on it and comment whether electron-hole pairs are generated or not?

We know that, total energy falling on it

$$E_g = h\nu = \frac{hc}{\lambda}$$

SRM INSTITUTE OF SCIENCE AND TECHNOLOGY

DEPARTMENT OF PHYSICS

PHYSICS: SEMICONDUCTOR PHYSICS (18PYB103J)

CHAPTER - 2

PART – A

1. A semiconductor is formed by ____ bonds.

(A) Covalent
(B) Electrovalent
(C) Co-ordinate
(D) Oxidation

2. A semiconductor has _____ temperature coefficient of resistance.

(A) Positive
(B) Zero
(C) Negative
(D) Large

3. When a pure semiconductor is heated, its resistance _____.

(A) Increases
(B) Decreases
(C) Remains the same
(D) Increases then it decreases

4. An n-type semiconductor have ______.

(A) Holes as majority charge carriers
(B) Electrons as majority charge carriers
(C) Equal number of holes and electrons as charge carriers
(D) None of the above

5. A hole in a semiconductor is defined as _____.

(A) A free electron
(B) **The incomplete part of an electron pair bond**
(C) A free proton
(D) A free neutron

6. The random motion of holes and free electrons due to thermal agitation is called_____.

(A) Diffusion
(B) Pressure
(C) Ionization
(D) Drift

7. As the doping to a pure semiconductor increases, the bulk resistance of the semiconductor ______.

(A) Remains the same
(B) Increases
(C) Decreases
(D) Decreases then increases

8. Current flow in a semiconductor depends on the phenomenon of
   (A) Drift
   (B) Diffusion
   (C) Recombination
   (D) All of the above

9. The Fermi level in a p-semiconductor lies close to
   (A) The top of the valence band
   (B) The top of the conduction band
   (C) The bottom of the valence band
   (D) The bottom of the conduction band

10. Electron-hole pairs are produced due to _____.
   (A) Recombination
   (B) Thermal energy
   (C) Ionization
   (D) Doping

11.The p-region has a greater concentration of ______ as compared to the n-region in a P-N junction.
   (A) Holes
   (B) Electrons
   (C) Both holes & electrons
   (D) Phonons

12. A p-type semiconductor material is doped with ____ impurities whereas a n-type semiconductor material is doped with ______ impurities.
   (A) Acceptor, donor
   (B) Acceptor, acceptor
   (C) Donor, donor
   (D) Donor, acceptor

13. The n-region has a greater concentration of _____ as compared to the p-region in a P-N junction diode.
   (A) Holes
   (B) Electrons
   (C) Both holes & electrons
   (D) Phonons

14. Which of the below mentioned statements is false regarding a p-n junction diode?
   (A) Diode are current control devices
   (B) Diodes are rectifying devices
   (C) Diodes are unidirectional devices
   (D) Diodes have three terminals

15. In the p & n regions of the p-n junction the ____ & the ___ are the minority charge carriers respectively.
   (A) holes, holes
   (B) electrons, electrons
   (C) holes, electrons
   (D) Electrons, Holes

16. Let us assume that the doping density in the p-region is 10^{-9} cm^{-3} & in the n-region is $10^{-17} cm^{-3}$ as such the p-n junction so formed would be termed as a

(A) p^{-} n^{-}

(B) p^{+} n^{-}

(C) p^{-} n^{+}

(D) p^{+} n^{+}

17. When a physical contact between a p-region & n-region is established which of the following is most likely to take place?

(A) Electrons from N-region diffuse to P-region

(B) Holes from P-region diffuse to N-region

(C) Both of (A) & (B) statements are True

(D) **Both of (A) & (B) statements are False**

18.Which of the following is true in case of an unbiased p-n junction diode?

(A) Diffusion does not take place

(B) Diffusion of electrons & holes goes on infinitely

(C) There is zero electrical potential across the junctions

(D) Charges establish an electric field across the junction

19. Which of the following is true in case of a forward biased p-n junction diode?

(A) The positive terminal of the battery attract electrons from the p-region

(B) The positive terminal of the battery injects electrons into the p-region

(C) The negative terminal of the battery attract electrons from the p-region

(D) The negative terminal of the battery injects electrons into the p-region

20. What is the forward bias ideality factor of a Schottky barrier diode?

(A) n = 1

(B) n = 2

(C) 1< n < 2

(D) n > 2

21. The amount of radiance in planar type of LED structures is

(A) Low

(B) High

(C) Zero

(D) Negligible

22.In a basic OLED structure, the diamine layer is used as a ______.

(**A) HTL**

(B) ETL

(C) ITL

(D) CCL

23. In a basic OLED structure, the ALQ_3 layer acts as a _____.

(A) HTL

(B**) ETL**

(C) ITL

(D) CCL

24. _______ is the condition for transport of charge carriers in Schottky barrier diode.
(A) $\phi_m = \phi_s$
(B) $\phi_m > \phi_s$
(C) $\phi_m < \phi_s$
(D) $\phi_m = 0$

25. _______ is the condition for transport of charge carriers in Ohmic contact.
(A) $\phi_m = \phi_s$
(B) $\phi_m > \phi_s$
(C) $\phi_m < \phi_s$
(D) $\phi_m = 0$

26. An Ohmic contact is a _____ providing current conduction in both directions.
(A) Low - resistance junction
(B) High - resistance junction
(C) Infinite – resistance junction
(D) Zero - resistance junction

27. In tunneling barrier, the space – charge width is a rectifying metal-semiconductor contact is inversely proportional to square root of ______.
(A) Semiconductor doping
(B) Metal doping
(C) Carrier injection
(D) recombination.

28. LED is a semiconductor p-n junction diode which convert _______ under forward bias.
(A) Light energy into Electrical energy
(B) Electrical energy into Light energy
(C) Thermal energy into electrical energy
(D) Electrical energy into thermal energy

PART –B

1. Write note on intrinsic semiconductor.
2. What is meant by Fermi level in semiconductor? Where does the Fermi level lie in an intrinsic semiconductor?
3. Describe the difference between P-type and N-type semiconductor materials.
4. Explain about carrier generation and recombination.
5. Explain the concept of drift current.
6. Explain the concept of diffusion current.
7. Discuss in detail about the of p-n junction.
8. Write notes on the forward and reverse bias p-n junction.
9. What happens to the bands when a junction is formed between metals and semiconductors?
10. What is a rectifying contact? Explain with diagram.
11. Explain the working concept of Ohmic contact.
12. Write notes on photocurrent in p-n junction.
13. Write a short note on Organic LED.

14. Write a short note on optoelectronic materials and its applications.

PART - C

1. What is intrinsic semiconductor? Explain atomic structure and energy level diagram of intrinsic semiconductor? Where does the Fermi level lie in an intrinsic semiconductor?
2. What is Extrinsic semiconductor? Explain N-type semiconductor and the variation of Fermi level with temperature with the diagram.
3. What is Extrinsic semiconductor? Explain P-type semiconductor and the variation of Fermi level with temperature with the diagram.
4. Explain in detail about the rectifying and non-rectifying contacts using band diagram.
5. Explain in detail (i) Ohmic contacts, and (ii) Schottky contacts.
6. Explain principle, construction, working of LED? Mention its merits, demerits and applications.
7. Explain principle, construction, working of OLED? Mention merits, demerits and applications.
8. Using the concept of carrier drift and diffusion current, derive and explain the concept of continuity equation.

18PYB103J-Semiconductor Physics

Question Bank –Unit II

Multiple Choice Questions.

1. A semiconductor is formed by ……… bonds.
 a. Covalent
 b. Electrovalent
 c. Co-ordinate
 d. None of the above

2. A semiconductor has ………… temperature coefficient of resistance.
 a. Positive
 b. Zero
 c. Negative
 d. None of the above

3. When a pure semiconductor is heated, its resistance …………..
 a. Goes up
 b. Goes down
 c. Remains the same
 d. Can't say

4. An n-type semiconductor is ………
 a. Positively charged
 b. Negatively charged
 c. Electrically neutral
 d. None of the above

5. A hole in a semiconductor is defined as …………….
 a. A free electron
 b. The incomplete part of an electron pair bond
 c. A free proton
 d. A free neutron

6. The random motion of holes and free electrons due to thermal agitation is called ……….
 a. Diffusion
 b. Pressure
 c. Ionisation
 d. None of the above

7. As the doping to a pure semiconductor increases, the bulk resistance of the semiconductor ………..
 a. Remains the same

b. Increases
c. Decreases
d. None of the above

8. Current flow in a semiconductor depends on the phenomenon of
   a. Drift
   b. Diffusion
   c. Recombination
   d. All of the above

9. The Fermi level in a p-semiconductor lies close to
   a. The top of the valence band
   b. The top of the conduction band
   c. The bottom of the valence band
   d. The bottom of the conduction band.

10. Electron-hole pairs are produced by
   a. Recombination
   b. Tthermal energy
   c. Ionization
   d. Doping

11.The p-region has a greater concentration of __________ as compared to the n-region in a P-N junction.
   a. holes
   b. electrons
   c. both holes & electrons
   d. phonons

12. A p-type semiconductor material is doped with ____________ impurities whereas a n-type semiconductor material is doped with __________ impurities
   a. acceptor, donor
   b. acceptor, acceptor
   c. donor, donor
   d. donor, acceptor

13. The n-region has a greater concentration of _________ as compared to the p-region in a P-N junction diode.
   a. holes
   b. electrons
   c. both holes & electrons
   d. phonons

14. Which of the below mentioned statements is false regarding a p-n junction diode?
   a. Diode are uncontrolled devices
   b. Diodes are rectifying devices

c. Diodes are unidirectional devices
d. Diodes have three terminals

15. In the p & n regions of the p-n junction the _________ & the ___________ are the minority charge carriers respectively.
a. holes, holes
b. electrons, electrons
c. holes, electrons
d. electrons, holes

16. Lets assume that the doping density in the p-region is 10^{-9} cm^{-3} & in the n-region is $10^{-17}cm^{-3}$ as such the p-n junction so formed would be termed as a
a. $p^- n^-$
b. $p^+ n^-$
c. $p^- n^+$
d. $p^+ n^+$

17. When a physical contact between a p-region & n-region is established which of the following is most likely to take place?
a. Electrons from N-region diffuse to P-region
b. Holes from P-region diffuse to N-region
c. Both of the above mentioned statements are true
d. Nothing will happen

18.Which of the following is true in case of an unbiased p-n junction diode?
a. Diffusion does not take place
b. Diffusion of electrons & holes goes on infinitely
c. There is zero electrical potential across the junctions
d. Charges establish an electric field across the junction

19. Which of the following is true in case of a forward biased p-n junction diode?
a. The positive terminal of the battery sucks electrons from the p-region
b. The positive terminal of the battery injects electrons into the p-region
c. The negative terminal of the battery sucks electrons from the p-region
d. None of the above mentioned statements are true

20. What is the continuity equation in words?
a. Rate of increase = (inflow – outflow) + drift – diffusion
b. Rate of increase = (inflow – outflow) + generation - recombination
c. Rate of increase = (inflow - outflow)
d. Rate of increase = (inflow + outflow)

21. The forward bias current in a typical Schottky barrier is due to what physical mechanism?
a) Drift

b) Diffusion

c) Recombination

d) Thermionic emission

22. What is the forward bias ideality factor of a Schottky barrier diode?

a) n = 1

b) n = 2

c) 1< n < 2

d) n > 2

23. The amount of radiance in planer type of LED structures is

a) Low

b) High

c) Zero

d) Negligible

24. The overall power conversion efficiency of electrical lens coupled LED is 0.8% and power applied 0.0375 V. Determine optical power launched into fiber

a) 0.03

b) 0.05

c) 0.3

d) 0.01

25. The InGaAsP is emitting LEDs are realized in terms of restricted

a) Length strip geometry

b) Radiance

c) Current spreading

d) Coupled optical power

Short Answer Type Questions

26. Write note on intrinsic semiconductor?

27. What is meant by Fermi level in semiconductor? Where does the Fermi level lie in an intrinsic semiconductor?

28. Describe the difference between P-type and N-type semiconductor materials?

29. Explain about carrier generation and recombination?

30. **Discuss about drift current.**

31. Discuss about diffusion current.

32. Explain concepts of p-n junction.

33. Write note on forward and reverse bias p-n junction.

34. What happens to the bands when we make contact between metals and semiconductors?

35. What is a rectifying contact? explain with diagram.

36. Write note on photocurrent in p-n junction?

37. Explain Organic LED?

Descriptive Type Questions

38. What is intrinsic semiconductor? Explain atomic structure and energy level diagram of intrinsic semiconductor? Where does the Fermi level lie in an intrinsic semiconductor?

39. What is Extrinsic semiconductor? Explain N - type semiconductor with diagram and variation of Fermi level with temperature?

40. What is Extrinsic semiconductor? Explain P - type semiconductor with diagram and variation of Fermi level with temperature?

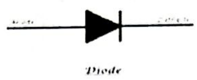
41. Explain principle, construction, working of LED? Mention merits, demerits, applications?

42. Explain principle, construction, working of OLED? Mention merits, demerits, applications?

UNIT-II

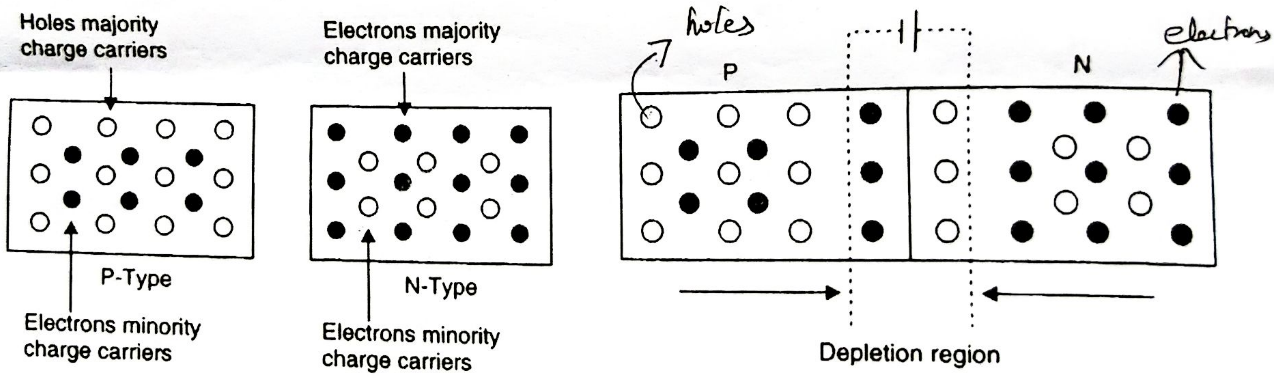
PN junction diode

- A p-n junction Diode is formed by doping one side of a piece of silicon with a p-type dopant (boron) and the other side with a n-type dopant (phosphorus). The *Ge* can be used instead of Silicon.
- It is one of the simplest semiconductor devices as it allows current to flow in only one direction. The symbol of the p-n junction diode is given here.



PN Junction at Equilibrium

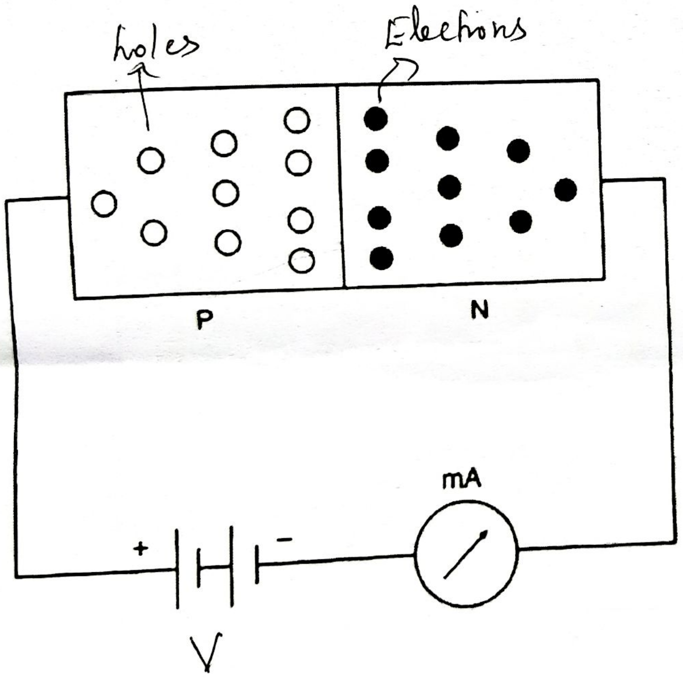
- When two semiconducting materias, p-type and n-type are brought into contact, the majority carrier of each type would diffuse across the junction.
- The diffusion would stop after an electric field is built up sufficiently high to oppose diffusion.
- As the majority carrier such as hole diffuses across the junction, it combines with electron in the n-type side, which creates a net positive charge.

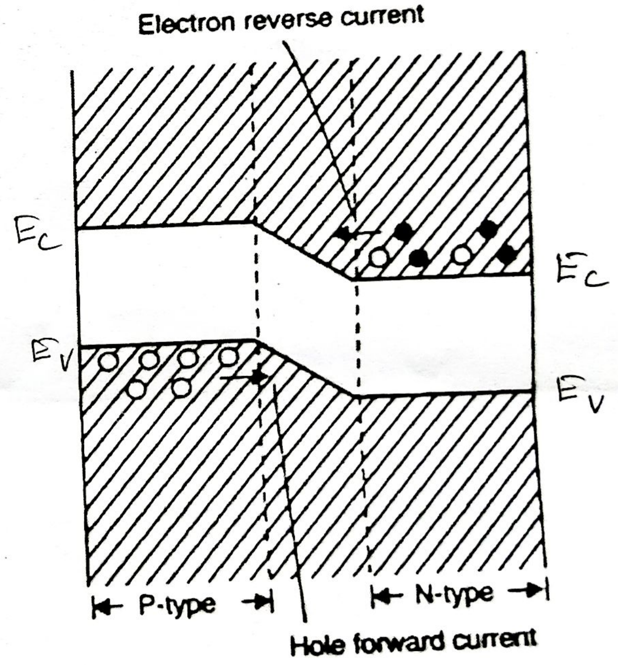


- Likewise, the majority carrier electron from n-type material diffuses across the junction recombines with hole in p-type side creates net negative charge.
- The net charge at each side creates an electric field in the direction, which would oppose further diffusion. This region is called as diffusion region.
- The electric field created would drift the minority carrier in the opposite direction across the junction.
- Thus when equilibrium attained, the drift carriers and diffused carriers should be balanced.

Forward Bias

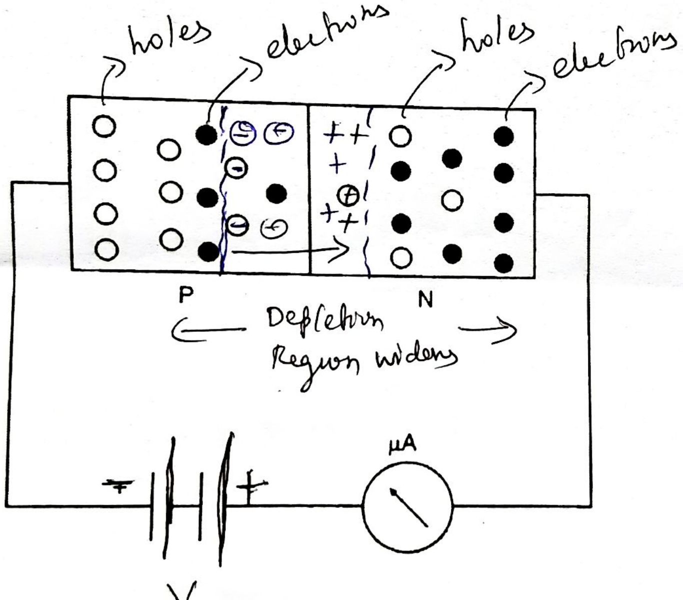
- In the forward bias condition, the negative terminal of the battery is connected to the n-type material and the positive terminal of the battery is connected to the p-type material.
- When the forward bias voltage is increased, the depletion region decreases.
- Now, the electrons from the n-region cross the junction and enter into the p-region. Similarly, the holes from the p-region cross the junction and enter into the n-region.
- Due to the attractive force that is generated in the p-region the electrons are attracted and move towards the positive terminal.
- Simultaneously, the holes are attracted towards the negative terminal of the battery. By the movement of electrons and holes current flows. So, the p-n junction diode conducts electric current in forward bias condition.



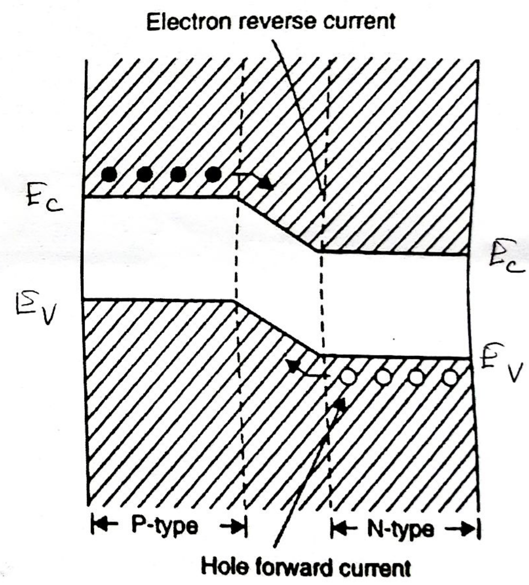


Reverse Bias

- In the reverse bias condition, the negative terminal of the battery is connected to the p-type material and the positive terminal of the battery is connected to the n-type material.
- When the reverse bias voltage is increased, the depletion region widens. So, no majority carriers cross the junction.
- But, the minority charge carriers are crossing the junction i.e. the minority electrons from p-region move into n-region. Simultaneously, minority holes from n-region move into p-region.
- The movement of minority carriers can cause very low current is in the order of micro ampere range. This current is called as reverse saturation current.
- So, the p-n junction diode does not conduct electric current in forward bias condition.



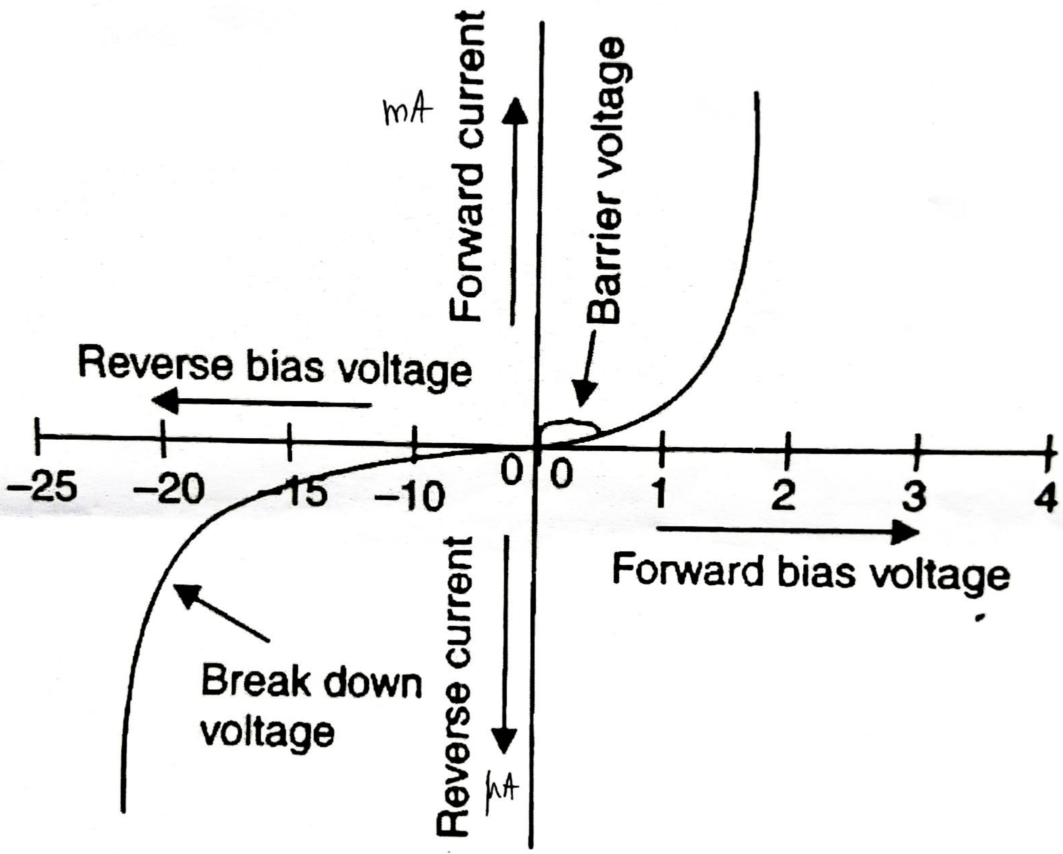
(a)



(b)

V-I Characteristics

- When the p-n junction diode is forward biased, the electrons get enough energy to overcome depletion layer and cross the junction and the same thing happens with the holes as well.
- The amount of energy required by the electrons and holes for crossing the junction is equal to the barrier potential 0.3 V for Ge and 0.7 V for Si. This is also known as Voltage drop.
- The voltage drop across the diode occurs due to internal resistance.
- The V-I characteristics of p-n junction diode is shown in the graph given below.



- When the p-n junction diode is reverse bias, the movement of minority carriers causes less current flow.
- When the reverse voltage is increased beyond the limit, then the reverse current increases drastically.
- This particular voltage that causes the drastic change in reverse current is called reverse breakdown voltage.

Variation of Fermi level (E_F) on carrier-concentration and temperature in an intrinsic semiconductor:

At temperature 0K, the semiconductor behaves like an insulator. When the temperature of the semiconductor slightly increased some covalent bonds are broken and electron - hole pairs are created. For an intrinsic semiconductor, the charge carriers are electrons in conduction band and holes in valence band in equilibrium the electron concentration and hole concentration are equal.

$$Density\ of\ electrons\ in\ conduction\ band\ \ n_e = \int_{E_c}^{\infty} \frac{\pi}{2}\left[\frac{8m_e^*}{h^2}\right]^{\frac{3}{2}} E^{\frac{1}{2}} F(E)\,dE$$

$$n_e = 2\left[\frac{2\pi m_e^* kT}{h^2}\right]^{\frac{3}{2}} \exp\left(\frac{E_F - E_C}{kT}\right) \qquad (1)$$

$$Density\ of\ holes\ in\ valance\ band\ \ n_h = \int_{-\infty}^{E_V} \frac{\pi}{2}\left[\frac{8m_h^*}{h^2}\right]^{\frac{3}{2}} E^{\frac{1}{2}}[1 - F(E)]\,dE$$

$$n_h = 2\left[\frac{2\pi m_h^* kT}{h^2}\right]^{\frac{3}{2}} \exp\left(\frac{E_V - E_F}{kT}\right) \qquad (2)$$

For intrinsic semiconductors, the density of electrons and the density of holes are equal.

$$n_e = n_h$$

$$2\left[\frac{2\pi m_e^* kT}{h^2}\right]^{\frac{3}{2}} \exp\left(\frac{E_F - E_C}{kT}\right) = 2\left[\frac{2\pi m_h^* kT}{h^2}\right]^{\frac{3}{2}} \exp\left(\frac{E_V - E_F}{kT}\right)$$

$$(m_e^*)^{\frac{3}{2}} e^{\left(\frac{E_F}{kT} - \frac{E_C}{kT}\right)} = (m_h^*)^{\frac{3}{2}} e^{\left(\frac{E_V}{kT} - \frac{E_F}{kT}\right)}$$

$$e^{\left(\frac{E_F}{kT} + \frac{E_F}{kT}\right)} = \left(\frac{m_h^*}{m_e^*}\right)^{\frac{3}{2}} e^{\left(\frac{E_V}{kT} + \frac{E_C}{kT}\right)}$$

$$e^{\left(\frac{2E_F}{kT}\right)} = \left(\frac{m_h^*}{m_e^*}\right)^{\frac{3}{2}} e^{\left(\frac{E_V}{kT} + \frac{E_C}{kT}\right)}$$

Taking log on both sides, then we have,

$$Ln\left[e^{\frac{2E_F}{kT}}\right] = Ln\left[\left(\frac{m_h^*}{m_e^*}\right)^{\frac{3}{2}} e^{\left(\frac{E_V}{kT}+\frac{E_C}{kT}\right)}\right]$$

$$\frac{2E_F}{kT} = Ln\left(\frac{m_h^*}{m_e^*}\right)^{\frac{3}{2}} + Ln\left[e^{\left(\frac{E_V}{kT}+\frac{E_C}{kT}\right)}\right]$$

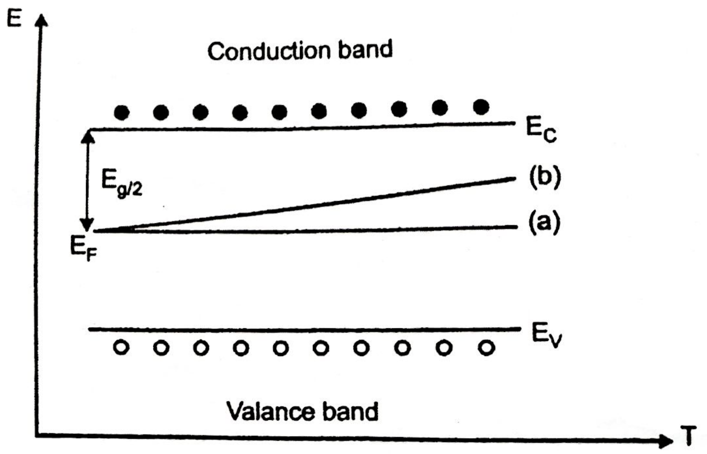
$$E_F = \frac{kT}{2} Ln\left(\frac{m_h^*}{m_e^*}\right)^{\frac{3}{2}} + \frac{kT}{2}\left[\frac{E_V + E_C}{kT}\right]$$

$$E_F = \frac{3kT}{4} Ln\left(\frac{m_h^*}{m_e^*}\right) + \left[\frac{E_V + E_C}{2}\right] \qquad (3)$$

If we assume $m_h^* = m_e^*$, then $Ln\left(\frac{m_h^*}{m_h^*}\right) = Ln1 = 0$

Equation (3) becomes $$E_F = \frac{E_V + E_C}{2} \qquad (4)$$

- From Eq (4), it is noted that the Fermi level E_F is located halfway between the valence and conduction band at lower temperatures.
- If the temperature of the intrinsic semiconductor is slightly increased, then $m_h^* > m_e^*$ and so form just lies above the middle as shown in the figure.



(a) At T = 0 K the Fermi level is in the middle of the forbidden band

(b) AT higher temperatures, the Fermi level shifts upwards.

Variation of Fermi level (E_F) on Temperature and Carrier Concentration in N-type semiconductor:

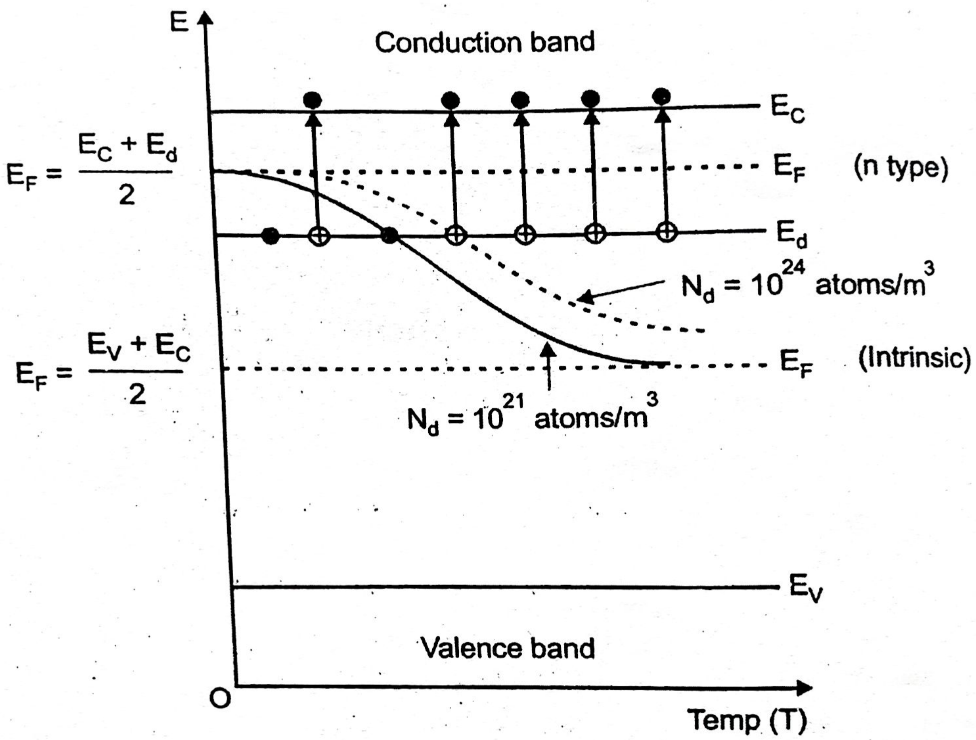
The Fermi level for N-type semiconductor is given by

$$E_F = \frac{E_c + E_d}{2} + \frac{kT}{2} \ln \left[\frac{N_d}{2\left(\frac{2\pi m_e^* kT}{h^2}\right)^{3/2}} \right] \rightarrow (1)$$

When Temperature $T = 0K$, eqn (1) becomes

$$E_F = \frac{E_c + E_d}{2} \rightarrow (2)$$

- At $T = 0K$, The Fermi level lies exactly half way between E_c and E_d.
- When temperature is increased, the donor atoms are ionised and the contribution of electrons from E_d to E_c increases.
- This results the Fermi level E_F shifts down as shown in figure.
- Further increase in temperature results in generation of electron-hole pair due to the breaking of covalent bonds and the material behave like in intrinsic manner.



- When the impurity concentration increases, the extrinsic behaviour is maintained even at high temperature. That is, the Fermi level shifts upwards for $N_d = 10^{24}$ atoms/m^3.

Variation of Fermi leval (E_F) on temperature and carrier concentration in P-type Semiconductor:

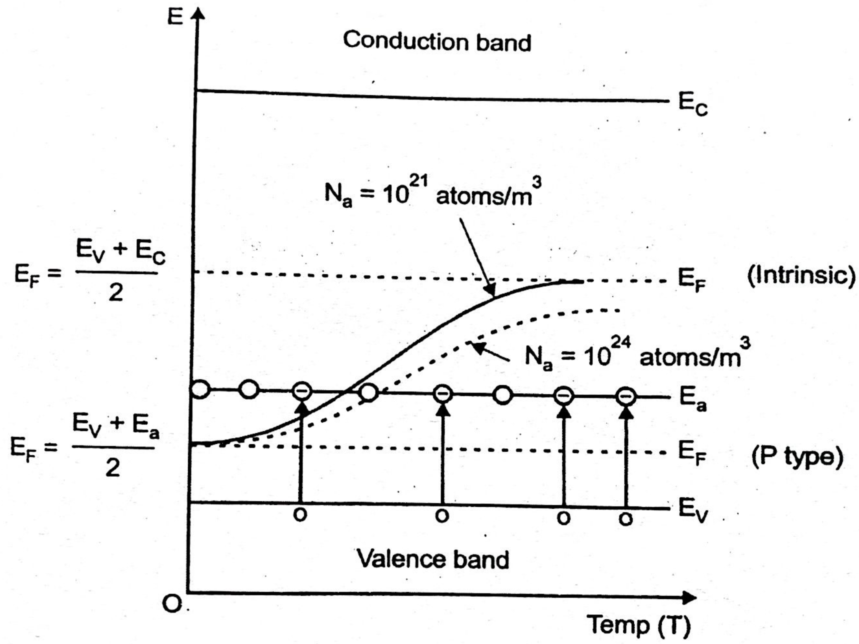
The Fermi level for P-type semiconductor is given by

$$E_F = \frac{E_v + E_a}{2} - \frac{kT}{2} \ln\left[\frac{N_a}{2\left(\frac{2\pi m_h^* kT}{h^2}\right)^{\frac{3}{2}}}\right] \rightarrow (1)$$

When Temperature $T = 0k$, eqn (1) becomes

$$E_F = \frac{E_v + E_a}{2} \rightarrow (2)$$

- At $T = 0k$, the Fermi level lies exactly half way between E_v and E_a.
- When temperature is increased, the acceptor atoms are ionised and the contribution of electrons from E_v to E_a increases.
- This results the Fermi level E_F moves up as shown in figure.
- Further increase in temperature, results in generation of electron-hole pair due to the breaking of covalent bonds and the material behave like Intrinsic manner.



- When the Impurity concentration increases, the extrinsic behaviour is maintained even at high temperature. So, the Fermi level shifts downwards for $N_a = 10^{24}$ atoms/m^3.

Drift and diffusion transport:

The net current flow in a semiconductor is due to

1. Drift current
2. Diffusion current.

Drift current:

In general, the movement of a charge carrier will be like a wave model rather than a particle model in a defect free crystal. i.e. the electron moves freely in a defect free crystal.

In the absence of electric field, the random motion of charge carriers will not contribut current.

In the presence of electric field E, then the electrons are drifted towards the positive terminal and the holes are drifted to the negative terminal. This net movement of charge carriers are called as drift transport.

The drift velocity of electrons $v_d = \mu_e E \rightarrow (1)$

The current density due to electron drift is $\Big\}$ $J_e = n e v_d \rightarrow (2)$

Using (1) in (2) $\quad J_e = n e \mu_e E \rightarrow (3)$

For holes $\quad J_p = p e \mu_p E \rightarrow (4)$

Total drift current density $J = J_e + J_p \rightarrow (5)$

Using eqn (1) and (2) in (3)

$$\boxed{J = n e \mu_e E + p e \mu_p E}$$

Diffusion current:

In addition to the drift current, the diffusion current is set up in the semiconductor due to the diffusion of charge carriers. The excess charge carriers are introduced within a semiconductor, either by causing carrier generation by heating or incident radiation or by injecting carriers into material. This results a non uniform distribution of charge within the material.

The excess charges in the region of higher density will move to region of lower density tending to produce uniform distribution. This current is called as diffusion current.

The diffusion current density for electrons $\Big\}$ $J_n = eD_n \frac{dn}{dx} \rightarrow (1)$

where $D_n \rightarrow$ diffusion coefficient for electrons.

The diffusion current density for holes $\Big\}$ $J_p = -eD_p \frac{dp}{dx} \rightarrow (2)$

Total current in semiconductor = drift current + diffusion current

For electrons, N-type

$$J_n = ne\mu_n E + eD_n \frac{dn}{dx}$$

For P-type

$$J_p = pe\mu_p E - eD_p \frac{dp}{dx}.$$

Carrier generation and Recombination

Carrier generation

Carrier generation is a process where electron-hole pairs are created by exciting an electron from the valence band of the semiconductor to the conduction band, thereby creating a hole in the valence band.

The product of the electron and for densities is constant at equilibrium.

$$n_0 p_0 = n_i^2$$

When there is a surplus of carriers i.e. $np > n_i^2$, the rate of recombination becomes greater than the rate of generation driving the system back towards equilibrium.

Carrier Recombination

Recombination is the reverse process where electrons and holes from the conduction respectively valence band recombine and are annihilated.

When there is a deficit of carriers i.e. $np < n_i^2$ the rate of generation becomes greater than the rate of recombination driving the system back towards equilibrium.

As an electron moves from one energy band to another, the energy and momentum that it has loss or gain must go to or come from the other particles (Photons, electrons and vibrating lattice atoms) involved in the process.

There are two types of recombination namely,

1. Direct recombination
2. Indirect recombination

Direct recombination

- The direct transition of an electron from the conduction band to the valence band is unlikely, however, since the free electron and a hole will only be combined if momentum is conserved in the system.
- That is if the electron and hole initially have nearly equal and opposite momenta.
- The probability for this in Germanium and silicon is low and another recombination mechanism must be invoked.

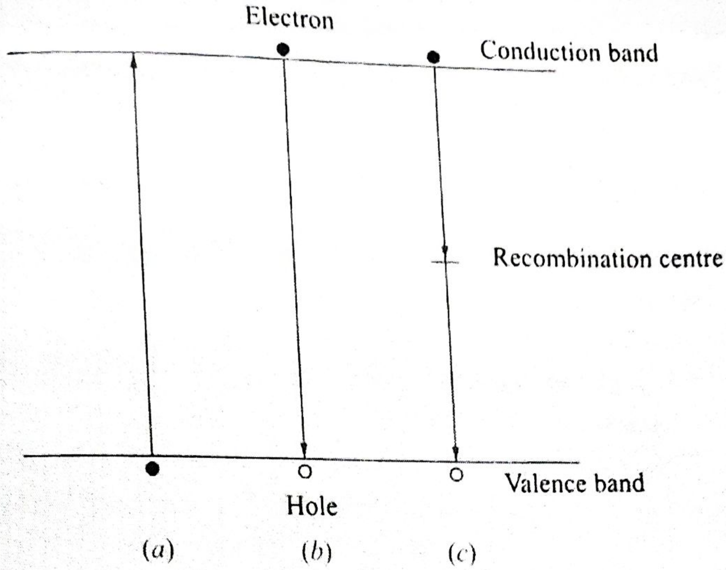


Fig. 10.30 (*a*) Generation of an electron-hole pair (*b*) Direct recombination of an electron and a hole (*c*) Recombination through a recombination centre

Indirect recombination

- The majority of recombination events are found to take place at the site of an impurity atom or a lattice defect in the crystal.
- Such a location acts as a trap or recombination centre.
- This can satisfy the momentum requirements in the electron hole position. The electron move from conduction band into the trap level and remains there for short time before passing down in the valence band.
- The electron is in trap is not free to move and does not contribute to the conductivity.

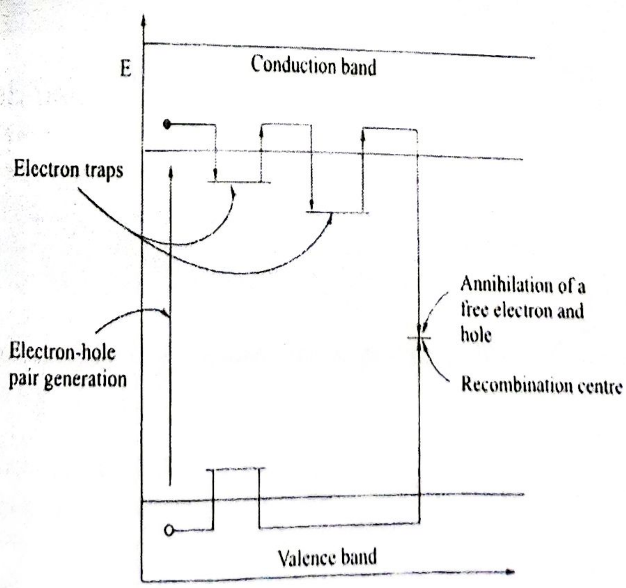


Fig. 10.31 Band model representation of generation and recombination in a semiconductor

- Non-uniformity occurs at an interface between two crystals results termination of regular array of atoms.
- These disturbances in the electric field create levels which have a high probability of capturing an electron, hole or both types of carriers.
- Such levels corresponding to energies near conduction band are called electron traps as they have high probability of capturing free electrons, wild those having energies near valence band levels are called whole traps having a high probability of capturing a hole.
- During recombination process the electrons and holes can be trapped at these levels. The average time that an electron or hole remains free after generation is known as lifetime (τ).

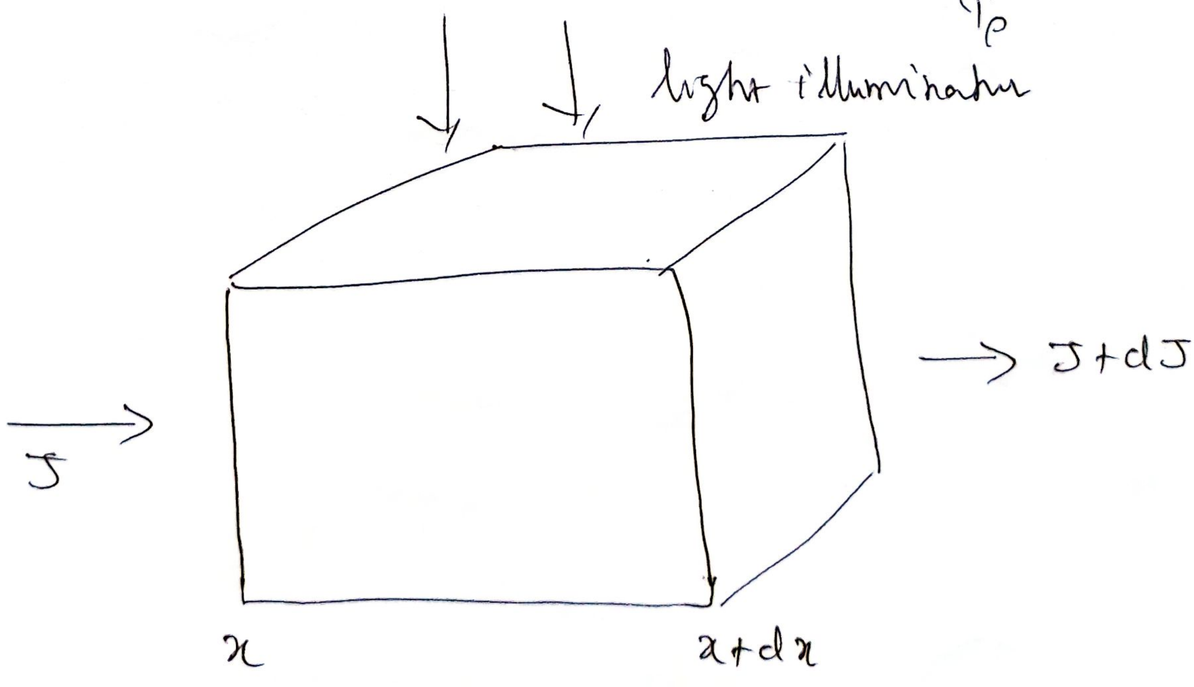
Continuity equation:

Since the action of semiconductor devices like the diodes and the transistor depend on the generation and transport of excess minority carriers, it is necessary to have an equation governing their motion in a semiconducting crystal. This equation is known as continuity equation.

Let P be the concentration of charge carriers at the instant time 't'. The electrons and holes are generated by thermal processes. So the generation of generation and recombination of electrons and holes must be considered.

The carrier generation rate $g = \frac{P_0}{\tau_p} \rightarrow (1)$

The carrier recombination rate $r = \frac{P}{\tau_p} \rightarrow (2)$



The rate of carrier concentration $\frac{dP}{dt} = \frac{P_0 - P}{\tau_P} \rightarrow (3)$

The sum of drift and diffusion current $\Big\}$ $J = eE\mu_P P - eD_P \frac{dP}{dx} \rightarrow (4)$

Differentiate eqn. (4) w.r.t 'x'

$$\frac{dJ}{dx} = eE\mu_P \frac{dP}{dx} - eD_P \frac{d^2P}{dx^2} \rightarrow (5)$$

The change in current density in the element 'dx' $\Big\}$ $dJ = -e\left(\frac{dP}{dt}\right)dx \rightarrow (6)$

From eqn (6) $\frac{dP}{dt} = -\frac{1}{e}\frac{dJ}{dx} \rightarrow (7)$

Sub. eqn (5) in eqn (7)

$$\frac{dP}{dt} = -\frac{1}{e}\left[eE\mu_P \frac{dP}{dx} - eD_P \frac{d^2P}{dx^2}\right]$$

$$\frac{dP}{dt} = -E\mu_P \frac{dP}{dx} + D_P \frac{d^2P}{dx^2} \rightarrow (8)$$

The complete continuity equation by combining eqns (3) and (8)

$$\frac{dP}{dt} = \frac{P_0 - P}{\tau_P} - E\mu_P \frac{dP}{dx} + D_P \frac{d^2P}{dx^2}$$

For electrons,

$$\boxed{\frac{dn}{dt} = \frac{n_0 - n}{\tau_n} + E\mu_n \frac{dP}{dx} + D_n \frac{d^2n}{dx^2}}$$

Photo Current in PN junction diode

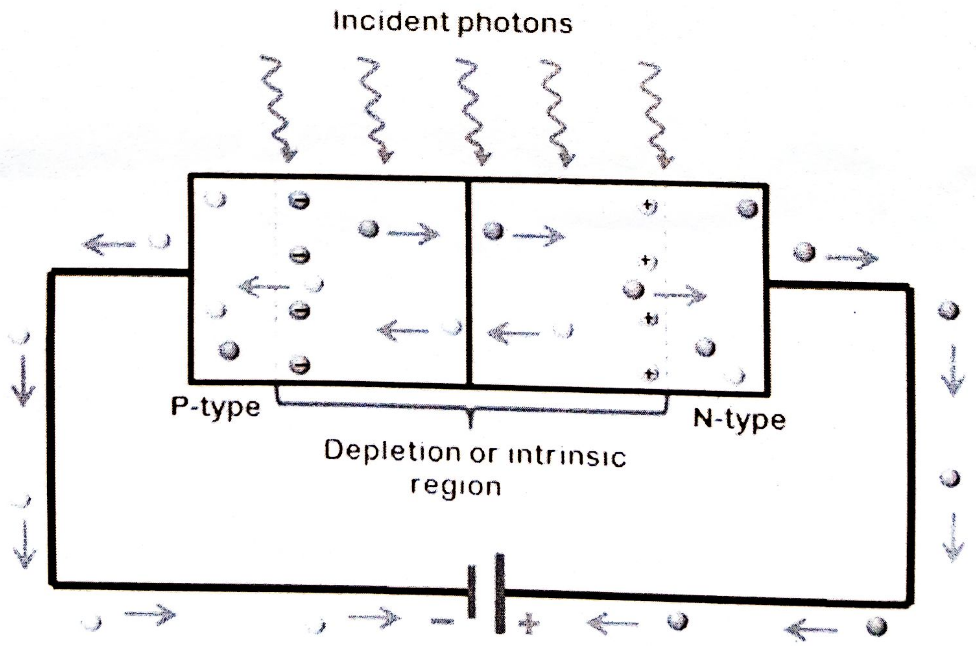
A photodiode is a p-n junction diode that consumes light energy to produce electric current. Sometimes it is also called as photo-detector, a light detector, and photo-sensor. These diodes are particularly designed to work in reverse bias condition.

The required materials to make a photodiode and the range of electromagnetic spectrum wavelength range include the following:

- For silicon material, the electromagnetic spectrum wavelength range will be (190-1100) nm.
- For Germanium material, the electromagnetic spectrum wavelength range will be (400-1700) nm.
- The Si-based photodiodes produce lower noise than Ge-based photodiodes.

Working of Photodiode

- Let us consider a p-n junction diode in which excess charge carriers are generated uniformly at the rate G_L and the depletion layer of width W is formed near the junction.



- When a photon of energy greater than the depletion width strikes the diode, it makes the electron to move towards n region and holes move towards p region.

- The photo current through the diode arising due to the absorption of light is given by,

$$I_L = \int_0^W AeG_L \, dx$$

$$I_L = AeG_L w$$

Where $A \rightarrow$ Area of the diode, $e \rightarrow$ Charge, $w \rightarrow$ width of depletion layer,

$G_L \rightarrow$ Carrier generation rate.

- In addition to the carriers generated in the depletion region, the electron – hole pairs are generated in the neutral n and p regions.
- So, the photo current produced in the diode is due to all the carriers in depletion region, p and n region.

Light Emitting Diode [LED]

The Light Emitting Diode (LED) is a semiconductor p-n junction diode which converts electrical energy into light energy under forward bias. It emits light in both visible and Infra Red (IR) region.

There are two types of LED

(1) Surface emitting LED

(2) Dome shaped LED.

LED Symbol

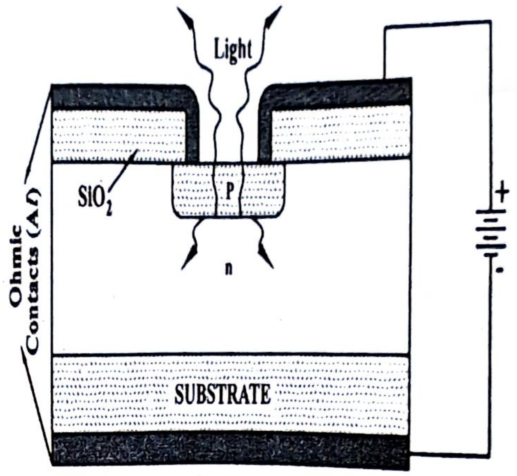
Let us discuss about surface emitting LED.

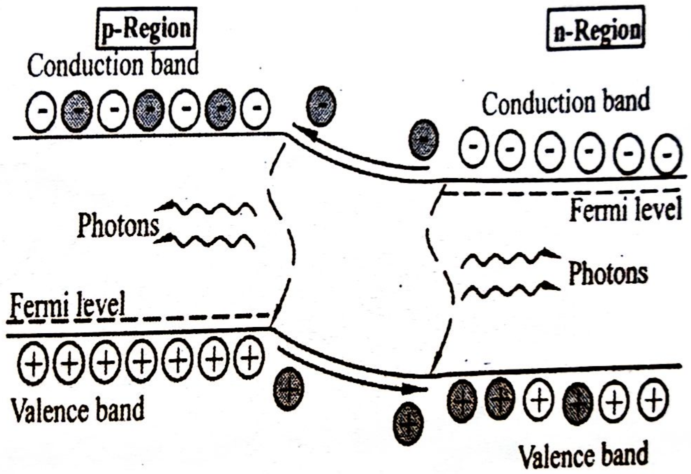
Principle:

When the LED is forward biased, the majority charge carriers moves from 'p' region to 'n' region and vice versa. The recombination of excess minority electrons in 'p' region with majority holes in valence band produce light.

Construction:

* The p-n junction is formed by doping Si with GaAs.
* To increase the rate of recombination, the thickness of 'n' type is made larger than that of 'p' type as shown in figure.
* Ohmic contacts are made with the help of metal Al in the top and bottom for the proper biasing.
* A small gap is left uncovered in the top for the emission of light.
* The entire p-n junction is surrounded by plastic material to avoid losses due to reflection.





Working:

* When the diode is forward biased, the majority carriers from 'n' and 'p' regions cross the junction and become minority in the other region.
* The electrons in 'n'-region cross the junction ~~and move~~ ~~in to~~ get into 'p'-region and become minority carriers in 'p' region
* Similarly, holes in p-region move to n-region and become minority carrier in 'n' region.
* This phenomenon is called minority carrier injection.
* When the voltage increased further, the excess minority carriers diffuse away from junction and directly recombine with holes in p region.
* This electron-hole recombination occur more and more and thereby light photons are emitted through the top layer of the 'p' material which is left uncovered.

* The number of recombination is proportional to the carrier injection rate and the total current flowing through LED.

Total current $I = I_0 \left[\exp\left(\frac{eV}{\beta kT}\right) - 1 \right]$

where $I_0 \rightarrow$ Saturation current, $V \rightarrow$ forward bias voltage

$\beta \rightarrow$ Varies from 1 to 2 ; $k \rightarrow$ Boltzmann Const

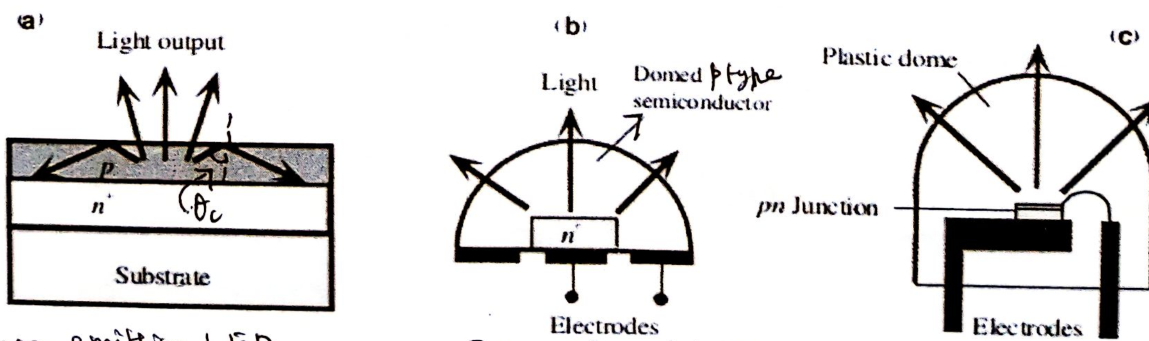
* The energy of photon $h\nu = E_g$

$$E_g = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{hc}{E_g}$$

$\boxed{\because \nu = \frac{c}{\lambda}}$

Dome Shaped LED:

The loss of light due to internal reflection can be minimised by making 'p' type material in the shape of a hemispherical dome as shown in figure.



Surface emitting LED

Dome shaped LED

(a) Some light suffers total internal reflection and cannot escape. (b) Internal reflections can be reduced and hence more light can be collected by shaping the semiconductor into a dome so that the angles of incidence at the semiconductor-air surface are smaller than the critical angle. (c) An economic method of allowing more light to escape from the LED is to encapsulate it in a transparent plastic dome.

The rays of light incident on the interface at an angle greater than the critical angle θ_c will suffer total internal reflection. So most of the light rays reflected back within the device. This will reduce the effeciency of LED.

To minimise the loss, the p-type material of the LED is made in the form of dome structure. Another method to increase efficiency is to cover the p-n junction by a plastic medium of higher refractive index in the shape of hemispherical dome.

Organic Light Emitting Diode (OLED)

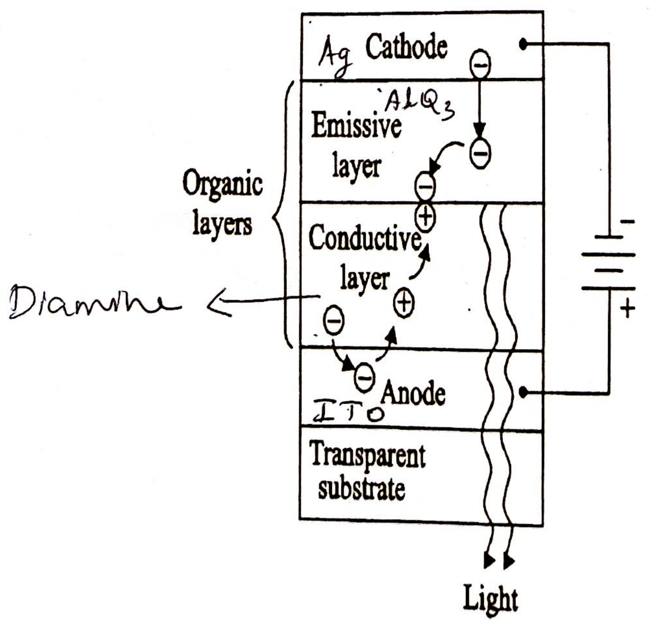
Principle:

An electron moves from the cathode to emissive layer and the hole moves from the anode to conductive layer and the recombine to produce photons.

Organic Light Emitting Diode (OLED) is commonly known, as a new class of materials where the emissive layer is an organic compound sandwiched between two electrodes. The structure of an OLED device is shown in figure.

Construction:

- A simple OLED is made up of many layers. On the top and bottom there are layers of protective glass or plastic.
- The cathode is usually a reflective material, like a metal film (Ag, Mg etc) having thickness of 200nm, and is deposited on the substrate.
- The anode is a transparent material like Indium Tin oxide (ITO), so that the light emitted can be extracted out of the device.
- In between the anode and cathode are two layers made from organic molecules called the emissive layer and the conductive layer.
- The emissive layer is made from organic material AlQ_3 Tris (8-hydroxy quinolinato) aluminum and conductive layer is made from aromatic diamine.
- To light up the OLED, The anode and cathode are connected to the source to provide potential difference.



Working:

- The working principle of OLED is similar to that of solid state LED.
- For organic molecules, instead of valence and conduction bands, there are discrete electron energy states called HOMO (highest occupied molecular orbital) and LUMO (lowest unoccupied molecular orbital) and recombination occurs across these levels.
- The color of the radiation depends on the energy gap between these two levels.
- Due to the applied voltage, the cathode emits electrons to the emissive layer.
- The anode withdraws an electron from the conductive layer and creates a hole in that layer. The aromatic Nitrogen in diamine structure (emissive) layer has a lone electron pair which is easily ionized to accept holes
- Now, the emissive layer becomes rich in electron and the conductive layer becomes rich in holes.
- Due to the recombination of electron and hole produces light is emitted through the transparent substrate as shown in figure.

Advantages of OLEDs

- They can be used to form flexible displays by depositing on suitable substrates.
- The devices are light weight, have wider viewing angles, and a faster response time.

Disadvantages of OLEDs

- They are costly, and have a short lifespan due to degradation of the organic layer.
- The color balance, especially in the blue region, is not good.
- They are susceptible to water damage and consume more power than solid state LEDs.

Metal-semiconductor junctions

- Formation of electronic devices requires putting together two or more dissimilar materials (semiconductors, metals, insulators).
- The interface between these materials becomes crucial because it affects the electrical properties (transport) of the devices. This interface is called as junction.
- An ideal junction is one in which no defects is formed at the interface.
- Forming ideal junctions is challenging and most real materials have defects at the interface which can affect the electronic properties.
- When a metal and semiconductor are brought into contact, there are two types of junctions formed depending on the work function of the semiconductor and its relation with the metal.

1. Schottky junction (Rectifying) - $\phi_m > \phi_s$
2. Ohmic junction (Non-Rectifying) - $\phi_m < \phi_s$

Where ϕ_m and ϕ_s are the work function of the metal and semiconductor respectively.

Schottky junctions:

- Consider a metal and n-type semiconductor. Before contact, the Fermi level of the semiconductor is higher than that of the metal.
- When the metal and semiconductor are in contact, the electrons are moving from n-type semiconductor to the empty energy states above Fermi Energy level of metal due to the low charge density.
- This leaves a positive charge on the semiconductor side and due to the excess electrons, a negative charge on the metal side.
- So, a positive contact potential V_0 is formed on the semiconductor side and the Fermi levels of both metal and semiconductor line up at equilibrium as shown in figure.

  This leads to the formation of the Schottky junction between the metal and semiconductor.

  The difference of the work function $eV_0 = \phi_m - \phi_s$

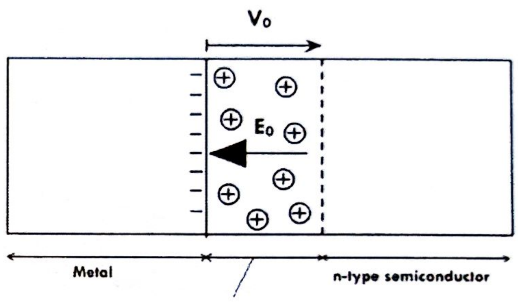
- The work function of the metal is a constant while the semiconductor work function depends on the dopant concentration.

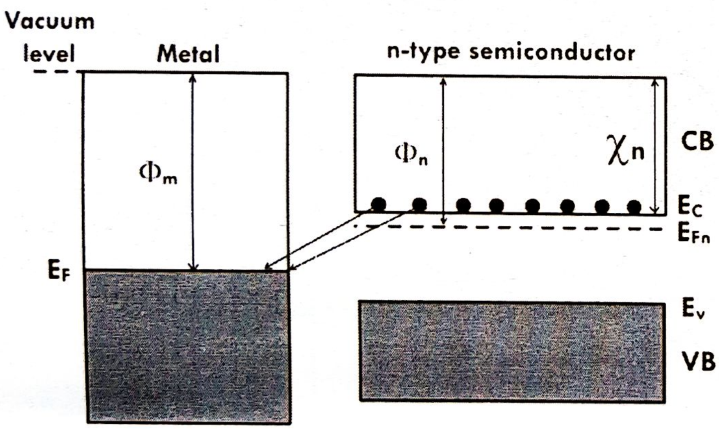
- The contact potential V_0 thus formed prevents further motion of the electrons to the metal. There is also a barrier for electrons to move from metal to semiconductor. This is called the Schottky barrier ϕ_B and denoted by

$$\phi_B = \phi_m - \chi_n.$$

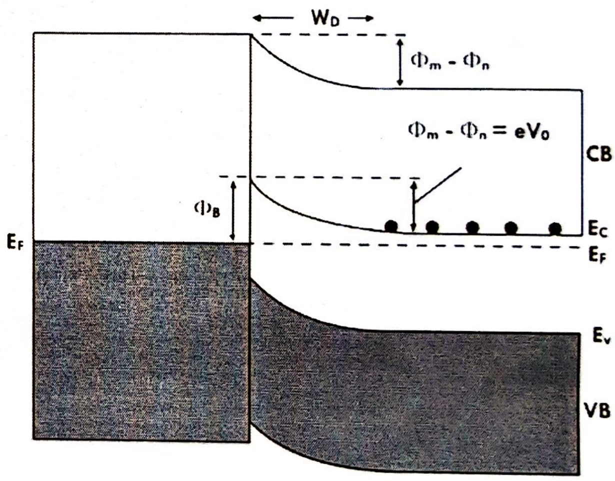
Where χ_n is the electron affinity for n-type semiconductor.

- At equilibrium, the motion of electrons from the semiconductor to metal is balanced by the contact potential V_0 so that there is no net current.





Before contact



After contact

The Schottky junction can be biased by application of an external potential. There are two types of bias viz.

- **Forward bias** - metal is connected to positive terminal and n-type semiconductor connected to negative terminal.
- **Reverse bias** - metal is connected to negative terminal and n-type semiconductor connected to positive terminal.

Forward bias

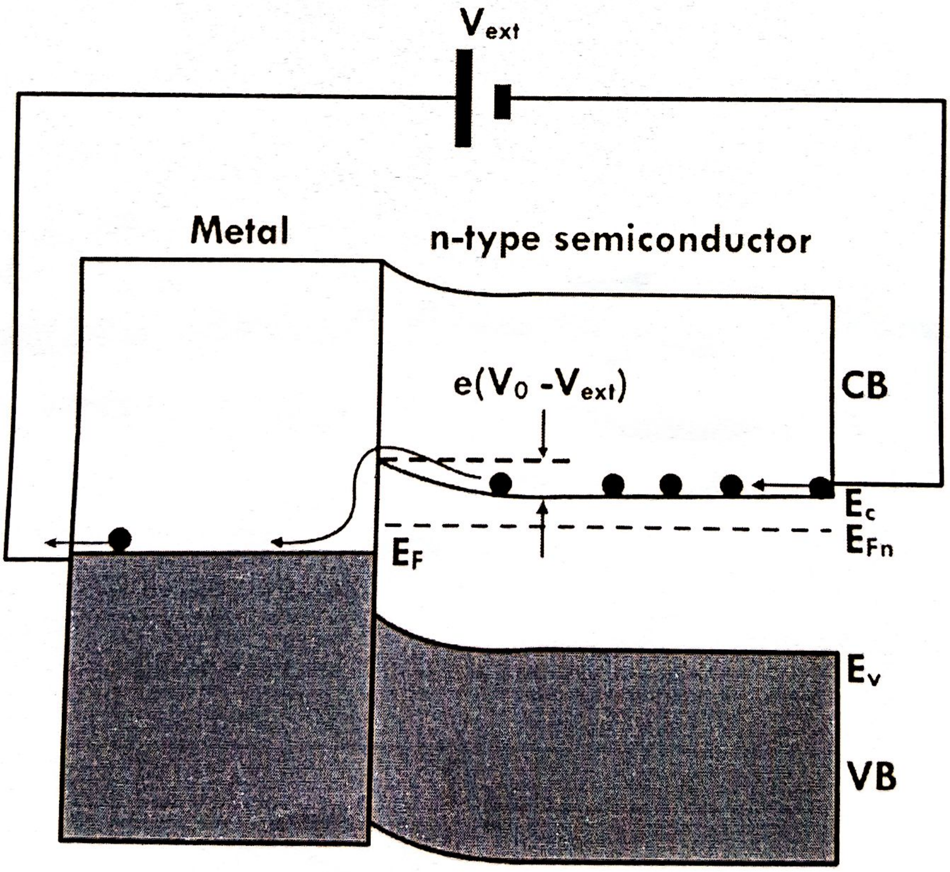
- When Schottky junction is forward biased, the external potential is applied to opposes the contact potential V_0.
- Under forward bias, the Fermi levels no longer line up, but they are shifted with respect to one another and the magnitude of the shift depends on the applied voltage.
- Hence, the electrons injected from the semiconductor to metal.
- This leads to a current in the circuit which increases with increasing external potential.

Now, the current in a Schottky diode under forward bias is given by

$$J = J_0\left[exp\left(\frac{eV}{kT}\right) - 1\right]$$

Where J is the current density for an applied potential of V.

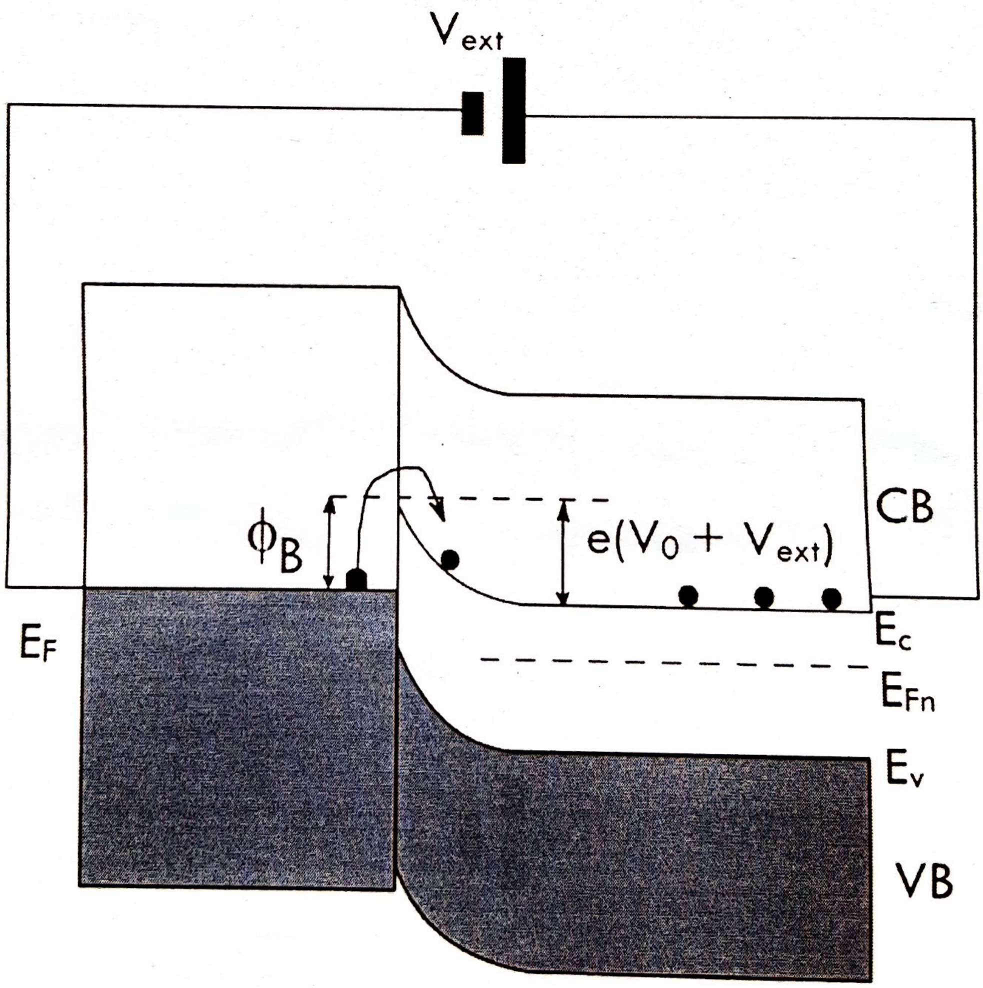
J_0 is constant and depends on the Schottky barrier ϕ_B. $J_0 = AT^2 exp\left(\frac{-\varphi_B}{kT}\right)$



Forward bias of Schottky junction

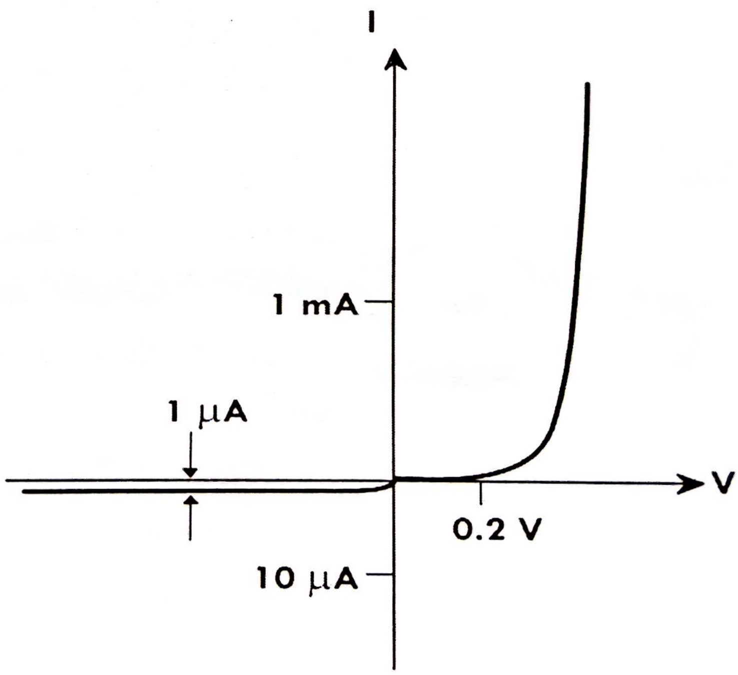
Reverse bias

- In the case of a reverse bias, once again the Fermi levels no longer line up but the barrier for electron motion from the n-type semiconductor to metal becomes higher.
- The electron flow is now from the metal to the semiconductor and the barrier for this is given by the Schottky barrier.
- So there is a constant current in reverse bias, whose magnitude is equal to J_0.
- In Schottky junction, the current in the forward bias is orders of magnitude higher than the current in reverse bias.
- So, the Schottky junction acts as a rectifier i.e. it conducts in forward bias but not in reverse bias.



The *I* -*V* characteristics of Schottky junction:

- The forward voltage drop of the Schottky barrier ranges from 0.2 volts to 0.5 volts and is very low compared to a p- n junction diode.
- The curve increases exponentially as the forward voltage increases.
- When a reverse bias voltage is applied, the depletion width increases. As a result, the electric current stops flowing.
- However, a small leakage current flows due to the thermally excited electrons in the metal.
- If the reverse bias voltage is increased, a sudden rise in electric current takes place.
- The V-I characteristics of a Schottky barrier diode are very steeper compared to the V-I characteristics of normal PN junction diode due to the high concentration of current carriers.



$I - V$ characteristics of a Schottky junction :

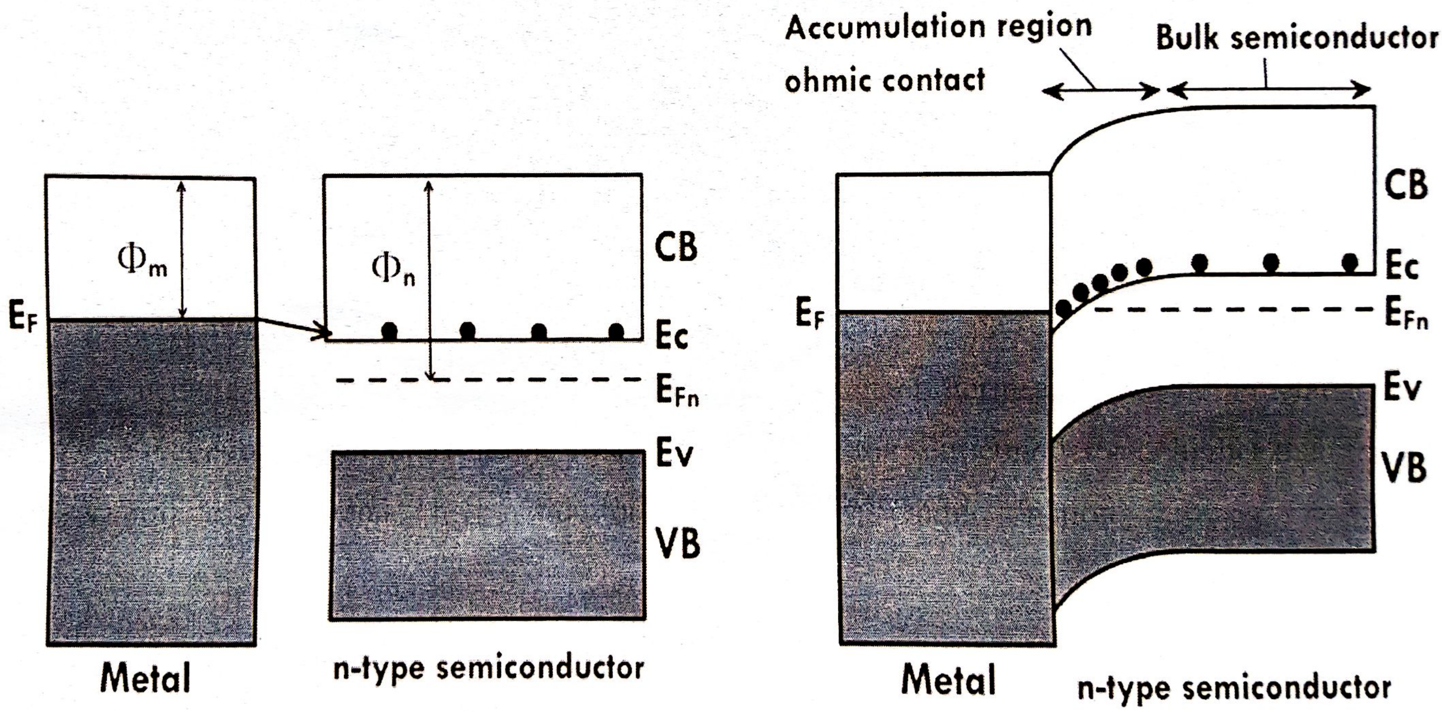
Ohmic contact/ junction

- The Ohmic contact is a low resistance junction (non-rectifying) provides current conduction from metal to semiconductor and vice versa.
- Ideally the current through the Ohmic contact is a linear function with the applied voltage with an immediate response.

- There are two types of the Ohmic contact:
  1. Ideal non-rectifying barrier.
  2. Tunneling barrier.

Ideal non-rectifying barrier

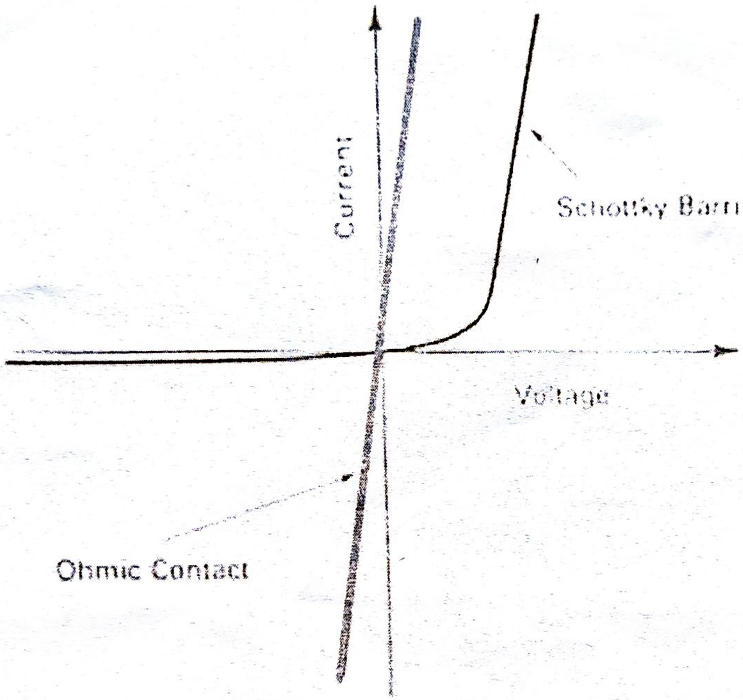
- Consider an ideal metal – n type semiconductor contact.
- Before contact, the Fermi energy level for metal is higher than that of the semiconductor.
- So, the work function of the metal is less than that of the n type semiconductor.
- When the metal and semiconductor contact are in contact, Fermi levels of both metal and semiconductor line up. But, the conduction band of the semiconductor is higher than the Fermi level of metal. The junction formed is called the Ohmic junction.



(a) Before contact (b) After contact

- When the positive potential is given to metal and negative potential given to n-type semiconductor, then the electrons are flowing from n-type semiconductor into metal.
- When the positive potential is given to n-type semiconductor and negative potential give to metal, then the electrons are flowing from metal into n-type semiconductor.
- Thus, an Ohmic junction behaves as a resistor and conducting in both forward and reverse bias.

- For Ohmic junction, depending on the direction of current flow (forward or reverse bias), heat can be generated or absorbed. This is observed in Peltier effect.
- The comparision of I - V characteristics of Ohmic contact with Scottky junction is shown in figure.

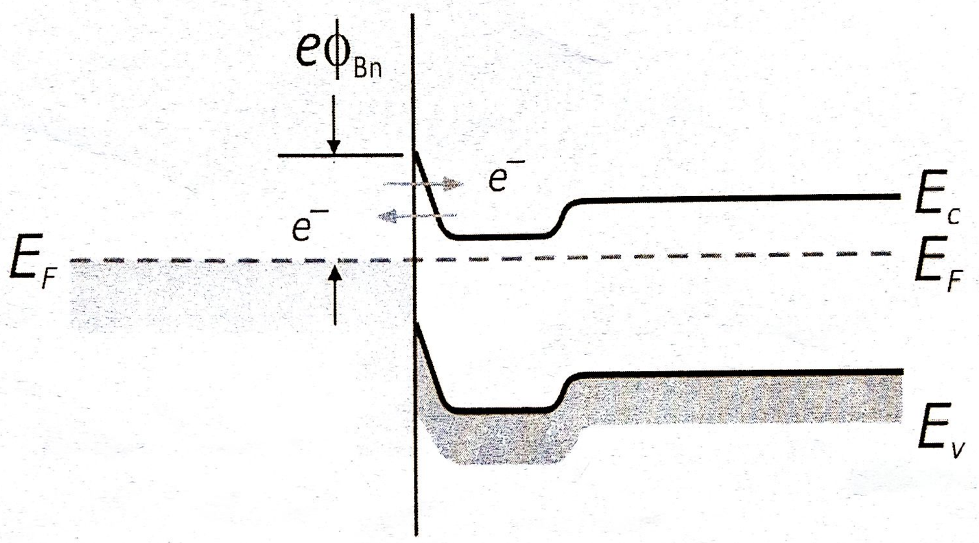


Tunneling barrier

- The space-charge width in a metal-semiconductor contact is inversely proportional to the square root of semiconductor doping.

$$The\ width\ of\ depletion\ region\ W \propto \frac{1}{\sqrt{Doping\ Concentration}}$$

- Thus, as doping concentration increases, the probability of tunneling through the barrier increases. So, in a heavily doped semiconductor, the depletion width is in the order of A^0.



SRM INSTITUTE OF SCIENCE AND TECHNOLOGY

DEPARTMENT OF PHYSICS

PHYSICS: SEMICONDUCTOR PHYSICS (18PYB103J)

CHAPTER - 3

PART – A

1. An absorbed photon can result in transition between a donor (or acceptor) level and a band in a doped semiconductor called ____.

(A) Band to band transition
(B) Impurity to band transition
(C) Free carrier Transition
(D) Photonic transition

2. The direct band to band absorption and emission can take place only at frequencies for which photon energy ______.

(A) $h\gamma > E_g$
(B) $h\gamma < E_g$
(C) $h\gamma = E_g$
(D) $h\gamma = 0$

3. ________ is the process where the energy due to recombination is dissipated as photons.

(A) Radiative transition
(B) Non-radiative transition
(C) Absorption
(D) Radiation

4. The _______ process is in which the electron-hole pairs are created and recombined radiatively.

(A) Luminescence
(B) Photon emission
(C) Phonon emission
(D) Radiation.

5. The average velocity acquired by the electrons in a particular direction during the presence of electric field is called _______.

(A) Relaxation time
(B) Drift velocity
(C) Collision time
(D) Diffusion current

6. The maximum voltage generated across the terminals of solar cell when they are kept open is called _______.

(A) Short circuit voltage
(B) Open circuit voltage
(C) Fill factor
(D) Drift Voltage.

7. The photons of energy value ____ that of the band gap values do not get absorbed in photovoltaic cell.
   (A) Greater than
   (B) Less than
   (C) Nearly equal than
   (D) Zero

8. An absorbed photon can result in upward transition of electron from valence band to conduction band is called _______.
   (A) Band to band transition
   (B) Impurity to band transition
   (C) Free carrier Transition
   (D) Photonic transition

9. The direct band to band absorption and emission can take place only at wave length for which photon energy ________.
   (A) $\lambda_g = \lambda$
   (B) $\lambda_g < \lambda$
   (C) $\lambda_g > \lambda$
   (D) $\lambda_g = 0$

10. _____ is the process where the excess energy due to recombination is usually imported to phonons and dissipated as heat.
   (A) Radiative transition
   (B) Non-radiative transition
   (C) absorption
   (D) Radiation.

11. The radiative recombination of electron-hole pair created by injection of photons is called ________.
   (A) Photoluminescence
   (B) Photon emission
   (C) Phonon emission
   (D) Radiation

12. The maximum current flows in solar cell when its P-side & N-side terminal are shorted, such a current is called _____.
   (A) Drift current
   (B) Diffuse current
   (C) Short-circuit current
   (D) Alternative current

13. The ratio between E_g and charge of electron in photovoltaic cell is called _____.
   (A) Current loss
   (B) Voltage loss
   (C) loss due to metal
   (D) Optical loss.

14. _____ is the process of radiative recombination of electron–hole pairs created by electron bombardment.
   (A) Photoluminescence

(B) photon emission
(C) Phonon emission
(D) Cathodoluminescence

15. The band to band transition (inter-band transition) occurs in ________.
(A) Direct band gap semiconductors
(B) Indirect band gap semiconductors
(C) Metal – semiconductors
(D) Superconductors

16. The impurity to band transition occurs in --------.
(A) Direct band gap semiconductors
(B) Indirect band gap semiconductors
(C) Metal - semiconductors
(D) Superconductors

17. The ______ does not require any external energy for process to take place.
(A) Stimulated emission
(B) Spontaneous emission
(C) Stimulated absorption
(D) Stimulated radiation.

18. The process where upper energy level is more populated than lower energy level is called ________.
(A) Stimulated emission
(B) Spontaneous emission
(C) Population inversion
(D) Temperature inversion.

19. The light amplification is achieved by _____ from an atomic or molecular system.
(A) Spontaneous emission
(B) Stimulated emission
(C) Time inversion
(D) Temperature inversion

20. The sun light can be converted to electricity due to the _________.
(A) Photovoltaic effect
(B) Compton effect
(C) Raman effect
(D) Zeeman Effect.

21. The ratio of the maximum power that can be extracted from a solar cell to the ideal power is called ___.
(A) Short circuit voltage
(B) Open circuit voltage
(C) Fill factor
(D) Drift Voltage.

22. The open circuit voltage of a solar cell increases with _______.
(A) Increase in bandgap
(B) Decrease in band gap

(C) Increase of in holes
(D) Decrease in holes

23. The current density is directly proportional to the _________.
(A) Rest mass of electron
(B) Applied electric field
(C) density of core electron
(D) Collision time.

24. The ratio between spontaneous and stimulated emission coefficients is called ________.
(A) Lorenz number
(B) Lorentz coefficient
(C) Absorption coefficient
(D) Einstein's coefficient

PART –B

1. Discuss how does photon interactions affect the bulk semiconductors.
2. Describe about the optical recombination process.
3. Explain the optical absorption and emission process in semiconductors using band diagram.
4. Distinguish between spontaneous emission and stimulated emission.
5. Write notes on optical loss.
6. Write notes on optical gain.
7. What happens to the bands when we illuminate a light on PN junction diode under forward bias?
8. Write notes on losses occurring in a Photovoltaic cell.
9. Discuss about the parameters affecting efficiency of a Photovoltaic cell.
10. Derive the expression for electrical conductivity of metals based on Drude-Lorentz model.
11. Write about the basic assumptions of Drude and Lorentz model.

PART – C

1. Derive an expression for the Einstein's coefficient for absorption and emission of radiation.
2. Explain about the Fermi's Golden rule for the transition rates in optical process.
3. Explain about the joint density of states in a optical materials. Also discuss about the density of states of photons.
4. Define Photovoltaic effect. Discuss about the application of photovoltaic effect. Write notes on the efficiency of Photovoltaic cell.
5. Explain Drude-Lorentz model of free electrons and its application to the conductivity.
6. Explain the basic principle of Photovoltaic Cell and the losses occurring in a Photovoltaic cell.
7. Write about the basic assumptions of Drude and Lorentz model, also give the merits and demerits. Derive the expression for electrical conductivity of metals based on the model.

DEPARTMENT OF PHYSICS AND NANOTECHNOLOGY
SRM INSTITUTE OF SCIENCE AND TECHNOLOGY

18PY103J – Physics: Semiconductor Physics
Module-III, Lecture-16

Numerical based on Solar Cell & Electrical Conductivity

Numerical based on Solar Cell & Electrical Conductivity

Solved Numerical:

1. Determine the Open-Circuit Voltage V_{oc} of the solar cell, if Saturation Current (I_s) = $1x10^{-10}$ A, Light Generated Current(I_L) = 0.5 A, Ideality Factor (n) =1, and Temperature (T) = 300 K

Solution:

Open-Circuit Voltage $V_{OC} = \frac{nkT}{q} \ln(1 + \frac{I_L}{I_S})$

$$= \frac{1x1.38x10^{-23}x300}{1.61x10^{-19}} \ln(1 + \frac{0.5}{1x10^{-10}})$$

$$= 0.57V$$

Numerical based on Solar Cell & Electrical Conductivity

2. Determine the Fill Factor FF of the solar cell, if Short-Circuit Current (I_{sc}) = 2.75 A, Open-Circuit Voltage (V_{oc}) = 0.6V, Current at Maximum Power (I_m) = 2 A and Voltage at Maximum Power (V_m) = 0.5V

Solution:

Fill Factor $FF = \frac{I_m V_m}{I_{sc} V_{oc}} \quad = \frac{2x0.5}{2.75x0.6}$

$= 0.606$

Numerical based on Solar Cell & Electrical Conductivity

3. Determine the Conversion Efficiency η of the solar cell, if Short-Circuit Current (I_{sc}) = 3.5A, Open-Circuit Voltage (V_{oc}) = 0.6V, Fill Factor (FF) = 0.7 and Input Power (P_{in}) = 10W

Solution:

$$\text{Efficiency } \eta = \frac{I_{sc}V_{oc}FF}{P_{in}} \text{ x } 100\%$$

$$= \frac{3.5x0.6x0.7}{10} \text{ x } 100\%$$

$$= 14.7\%$$

Numerical based on Solar Cell & Electrical Conductivity

4. Determine the Conductivity (σ) of the Intrinsic Semiconductor. The given parameters are: μ_e = 0.145 m^2/V-s; μ_h= 0.055 m^2 /V-s; n_i= 1.5625×10^{16}/m^3 ; q = 1.602×10^{-19} C.

Solution:

Conductivity $\sigma = ne[\mu_h + \mu_h]$

$$= 1.5625x10^{16}x1.602x10^{-19}[0.145 + 0.055]$$

$$= 5.0x10^{-4}mhos/m$$

Numerical based on Solar Cell & Electrical Conductivity

5. The resistivity of intrinsic germanium at 300 K is 0.47 Ωm. If the electron and hole mobilities are 0.38 m^2/V-s and 0.18 m^2/V-s, then calculate the Intrinsic carrier density (n) at 300 K.

Solution:

Conductivity $\sigma = ne[\mu_h + \mu_h]$

$$n = \frac{\sigma}{e[\mu_h + \mu_h]}$$

$$= \frac{1/0.47}{1.602x10^{-19}[0.38 + 0.18]}$$

$$= 2.3x10^{19}m^3$$

Numerical based on Solar Cell & Electrical Conductivity

Unsolved Problems:

1. Determine the Open-Circuit Voltage V_{oc} of the solar cell, if Saturation Current (I_s) = 0.75×10^{-10} A, Light Generated Current(I_L) = 0.65 A, Ideality Factor (n) = 0.9, and Temperature (T) = 310K. [Ans: V_{oc} = 0.55V]

2. Determine the Fill Factor FF of the solar cell, if Short-Circuit Current (I_{sc}) = 2.25 A, Open-Circuit Voltage (V_{oc}) = 0.75V, Current at Maximum Power (I_m) = 1.5 A and Voltage at Maximum Power (V_m) = 0.85V. [Ans: FF = 0.7556]

3. Determine the Conversion Efficiency η of the solar cell, if Short-Circuit Current (I_{sc}) = 2.8A, Open-Circuit Voltage (V_{oc}) = 0.55V, Fill Factor (FF) = 0.8 and Input Power (P_{in}) = 10W. [Ans: η = 12%]

4. The following data are given for an intrinsic semiconductor at 27°C; n_i = $2.4\times10^{19} m^{-3}$, μ_e = 0.39 m^2/V-s and μ_h = 0.19 m^2/V-s. Calculate the conductivity of the intrinsic semiconductor. [Ans: σ = 2.22 $\Omega^{-1}m^{-1}$]

Unit -4

Part – A

1. In a ---- the electrons are ejected from a photoemissive surface and are amplified within the cell.
   (A) Photomultiplier tube (B) Bolometer (C) Electrode (D) Photodiode

2. Alkali metals and their oxides are best ------ materials.
   (A) Photoemissive (B) Conductig (C) Insulating (D)Semiconducting

3 .The crystallie solids absorbs energy and re-emits it the visible region of the spectrum is called -----.
   (A) Luminescence (B) Photon emission (C) Phonon emission (D) Radiation.

4. Find out the hall coefficient of an n type semiconductor having carrier concentration of 5 x 10^{15} cm^{-3}
   (A) 1150 (B). 1250 (C). 1350 (D) 1450

5. ------- Spectroscopy can be used to determine the concentration of absorbs in a solution.
   (A) UV Vis (B) IR (C) Microwave (D) Gamma

6. An ideal monochromator should have an ------ narrow effective bandwidth.
   (A) Infinitely (B) Small (C) Zero (D) finite

7. ------ is an instrumentation used for determine the concentration of impurities of a sample.
   (A) DLTS (B) TGA (C) DTA (D) IR

8. ------ is used for separating source radiation wavelengths.
   (A) Monochromator (B) Antenna (C) Detector (D) Display device.

9. The ------- method is generally employed in the system where crystals are not easily obtained.
   (A) Rotating crystal (B) Oscillating **(C) Powder Crystal** (D) Fixed Crystal

10. the method which provides information on bond length and angles I the molecule which helps I structure determination -------.
    (A) Thermal method **(B) X-ray diffraction method** (C) potentiometric method
    (D) Ammperometric method

11. The path difference is an integral multiple of wavelength is called --------.
    (A) Bragg law (B) Biotsavart's Law (C) Ohms Law (D) Lambert's law

Unit – 5

Part – A

1. In a quantum wire the material size is reduced-----.

   (A) 3 directions (B). **2 directions** (C). 1 directions (D). 0 directions

2. Tensile strength of CNT exceeds----.

   (A) 1KPa (B) 1 MPa **(C) 150 GPa** (D) 1TPa

3. Carbon nanotube reactivity is related to -----.

   (A) volume (B) length (C) **diameter** (D) Width

4. In CVD chamber the precursors are introduced to the reaction chamber in the ….. state.

   (A) Liquid (B) Solid (C) Gaseous (D) colloidal

5. Nano structures have dimensions in between ……

   (A) 1 to 100 Å (B) **1- 100 nm** (C) 100-1000 nm (D) 100- 1000 Å

6. AFM tip should have a radius of curvature of-----.

   (A) **greater than 20-50 nm** (B) lesser than 20-50 nm (C) around 100 nm
   (D) more than 100 nm

7. In a quantum dot the material size is reduced -------.

(A) **3 directions** (B) 2 directions (C) 1 directions (D) 0 directions

8. Electrons are caused by the de-energization of the specimen after a secondary electron is produced -----.

(A) **Auger** (B) Bragg (C) Lorenz (D) Kakuchi

9. The physical parameter that is propped in AFM resulting from different interaction is ----.

(A) Charge (B) **Force** (C) potential (D) temperature

10. In PVD chamber the precursors are introduced to the reaction chamber in the ….. state

    (A) Liquid (B) **Solid** (C) Gaseous (D) semisolid

11. In CVD Chamber, the precursors are introduced to the reaction chamber in the ____ state.

    (A) Liquid (B) Solid (C) **Gaseous** (D) semisolid

12. Nanoparticles are special mainly because of their ____

(A) **Surface area** (B)surface charge (C) volume (D) force

13. Exciton can move freely in two directions only in

    (A) **Quantum well** (B) quantum wire (C) quantum dot (D) bulk

14. Bands of alternating light and dark lines that are formed by inelastic scattering interactions that are related to atomic spacings in the specimen are called ____.

(A) Auger bands (B) Bragg bands (C) Lorentz bands (D) **Kakuchi bands**

15. Nanotechnology deals with ___ of nanostructures into useful nanoscale devices such as electronic circuits and mechanical devices at the molecular level
(A) the design (B) manufacturing (C) applications (D) **engineering**

1.What do you mean by Density of states?
• The density of states function describes the number of energy states that are available in a system and is essential for determine the carrier concentrations and energy distributions of carriers within a semiconductor.
• In semiconductors, the free motion of carriers is limited to two, one and zero spatial dimensions. When applying semiconductor statistics to systems of these dimensions, the density of states in quantum well (2D), quantum wires (1D) and quantum dots (0D) must be known.
2. What are low dimensional systems?
•A low-dimensional system, also called confined system, is any way quantum system in which the carriers are free to move in two, one, or zero dimensions in these systems, the spatial dimensions are of the order of De Broglie wavelength of the carriers and therefore the carrier energy states and density of states become quantized. As a result, the electronic, electrical, and optical behaviour of the carriers are governed by quantum mechanical principles or mechanisms
• A low-dimensional system is one where the motion of microscopic degrees-of-freedom, such as electrons, phonons or photons, is restricted from exploring the full three dimensions of the present world.
• In the low dimensional quantum systems such as Quantum well, Quantum wire and Quantum dot, the charge carriers are free to move in two, one and zero dimensions respectively.
• The main advantages of these low dimensional semiconductor systems are in the realizations of important devices, like the double heterostructure lasers with low threshold at room temperature, high effective LEDs, bipolar transistors, p-n-p-n switching devices, high electron mobility transistors (HEMT) and many other optoelectronic devices.
3. Brief the DOS in low dimensional systems?
• A low-dimensional system is one where the motion of microscopic degrees-of-freedom, such as electrons, phonons or photons, is restricted from exploring the full three dimensions of the present world.
• In the low dimensional quantum systems such as Quantum well, Quantum wire and Quantum dot, the charge carriers are free to move in two, one and zero dimensions respectively.
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4. Compare the DOS in OD,1D and 2D systems. ************
in zero-dimensional (0D) nanomaterials all the dimensions are measured within the nanoscale (no dimensions are larger than 100 nm). Most commonly, 0D nanomaterials are nanoparticles.
In one-dimensional nanomaterials (1D), one dimension is outside the nanoscale. This class includes nanotubes, nanorods, and nanowires.
In two-dimensional nanomaterials (2D), two dimensions are outside the nanoscale. This class exhibits plate-like shapes and includes graphene, nanofilms, nanolayers, and nano coatings.
5. Discuss about quantum well, quantum wire and quantum dot.
<u>Quantum well: -</u>
•If one dimension is reduced to the nano-range while the other dimensions remain large, then we obtain a structure known as quantum well. In these systems the particles are confined in one direction and are free to move in two directions.

•The conduction electrons are confined in a narrow dimension and such a configuration is referred as quantum well.

Quantum wire: -

•If two dimensions are reduced the nano-range and one remain large, the resulting structure is referred to as a quantum wire. In these systems the particles are confined in two directions and are free to move in one direction

•A quantum wire is a structure such as a copper wire that is long in one dimension, but has a nano-meter size as its diameter. In this case, the electrons move freely along the wire but are confined in the transverse directions.

Quantum dot: -

•The extreme case of this process of size reduction in which all three dimensions reach the low nano-meter range is called a quantum dot. In these systems the particles are confined in all three directions and can not move freely in any spatial direction.

•The quantum dot may have the shape of a tiny cube, a short cylinder or a sphere with low nanometre dimensions.

6. What are the different allotropes of carbon?

•Diamond, graphite and fullerenes (substances that include nanotubes and 'buckyballs', such as buckminsterfullerene) are three allotropes of pure carbon.

7. Write the properties of CNT.

CNT exhibits extraordinary mechanical properties:

•The Young's modulus is over 1 Tera Pascal. It is stiff as diamond.

•The estimated tensile strength is 200 GPa. These properties are ideal for reinforced composites, Nano electromechanical systems (NEMS)

•Apart from remarkable tensile strength, CNT nanotubes exhibit varying electrical properties (depending on the way the graphite structure spirals around the tube, and other factors, such as doping), and can be superconducting, insulating, semiconducting or conducting (metallic)

•CNT Nanotubes can be either electrically conductive or semi conductive, depending on their helicity (shape), leading to nanoscale wires and electrical components.

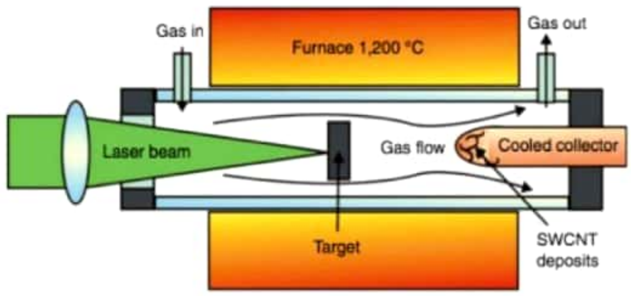
Chemical reactivity:

•The chemical reactivity of a CNT is very high as compared with a graphene sheet because of its curved surface.

•A Nanotube with smaller diameter results in increased reactivity.

8. How will you synthesize CNT by Laser ablation?

Process: -



Process: -

•Vaporizes graphite at 1200 0C with Helium or argon gas

• A hot vapor plume forms and expands and cools rapidly

• Carbon molecules condense to form large clusters

• Yield of up to 70%

9. Give any 3 Applications of CNT.

•Carbon Nanotube can be used as a conducting channel in Field emission Transistor
•Because of their flexibility, Nanotubes can also be used in scanning probe instruments.
•High Strength Composites
•Conductive Composites
•Medical Applications

10. Brief on the working of CVD

A basic CVD process consists of the following steps: -

•A predefined mix of reactant gases and diluent inert gases are introduced at a specified flow rate into the reaction chamber;
•The gas species move to the substrate;
•The reactants get adsorbed on the surface of the substrate;
•The reactants undergo chemical reactions with the substrate to form the film; and
•The gaseous by-products of the reactions are desorbed and evacuated from the reaction chamber.

11. Differentiate heterogenous and homogenous reactions in CVD

s.no	Homogeneous reactions	Heterogeneous reactions
1	Reactions that take place in the gas phase are known as homogeneous reactions	Reactions that take place at the substrate surface are known as heterogeneous reactions
2	selectively occur on the heated surface of the wafer where they create good-quality films.	Homogeneous reactions form gas phase aggregates of the depositing material, which adhere to the surface poorly and at the same time form low-density films with lots of defects.

•heterogeneous reactions are much more desirable than homogeneous reactions during chemical vapor deposition.

12. Differentiate Hot wall reactor and cold wall reactor in CVD

s.no	Hot wall reactor	cold wall reactor
1	a reactor is said to be 'hot-wall' if it uses a heating system that heats up not only the wafer	In cold wall reactors, the substrate itself is heated
2	In hot-wall reactors, films are deposited on the walls in much the same way as they are deposited on wafers.	'Cold-wall' reactors use heating systems that minimize the heating up of the reactor walls while the wafer is being heated up
3	Example: - radiant heating from resistance-heated coils.	Example: - of which is heating via IR lamps inside the reactor.

13. Classify CVD based on the operating pressure

•These are classified into 3 types based it on the range of their operating pressure.

1) Atmospheric pressure CVD

•Reactors operate at atmospheric pressure, and are therefore the simplest in design.

2) Low-pressure CVD

•reactors operate at medium vacuum (30-250 Pa) and higher temperature than APCVD reactors.

3) Plasma Enhanced CVD

•reactors also operate under low pressure, but do not depend completely on thermal energy to accelerate the reaction processes.

14. Brief on the working of PVD.

• Physical vapour deposition (PVD) is fundamentally a vaporisation coating technique, involving transfer of material on an atomic level. It is an alternative process to electroplating

• The process is similar to chemical vapour deposition (CVD) except that the raw materials/precursors, i.e. the material that is going to be deposited starts out in solid form, whereas in CVD, the precursors are introduced to the reaction chamber in the gaseous state.

15. What are the four 4 processes in PVD?

• PVD processes are carried out under vacuum conditions. The process involved four steps:

1.Evaporation
2.Transportation
3.Reaction
4.Deposition

Evaporation

During this stage, a target, consisting of the material to be deposited is bombarded by a high energy source such as a beam of electrons or ions. This dislodges atoms from the surface of the target, 'vaporising' them.

Transport

This process simply consists of the movement of 'vaporised' atoms from the target to the substrate to be coated and will generally be a straight-line affair.

Reaction

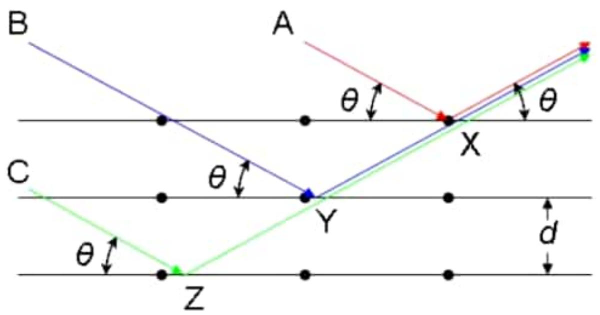
The atoms of metal will then react with the appropriate gas during the transport stage.

Deposition

This is the process of coating build up on the substrate surface. Depending on the actual process, some reactions between target materials and the reactive gases may also take place at the substrate surface simultaneously with the deposition process.

16. State Bragg's law?

Bragg's law: - The law states that when the x-ray is incident onto a **crystal** surface, its angle of incidence 'θ', will reflect back with a same angle of scattering 'θ'. And, when the path difference, d is equal to a whole number, n, of wavelength, a constructive interference will occur.



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

where:

- λ is the wavelength of the x-ray,
- d is the spacing of the crystal layers (path difference),
- θ is the incident angle (the angle between incident ray and the scatter plane), and
- n is an integer

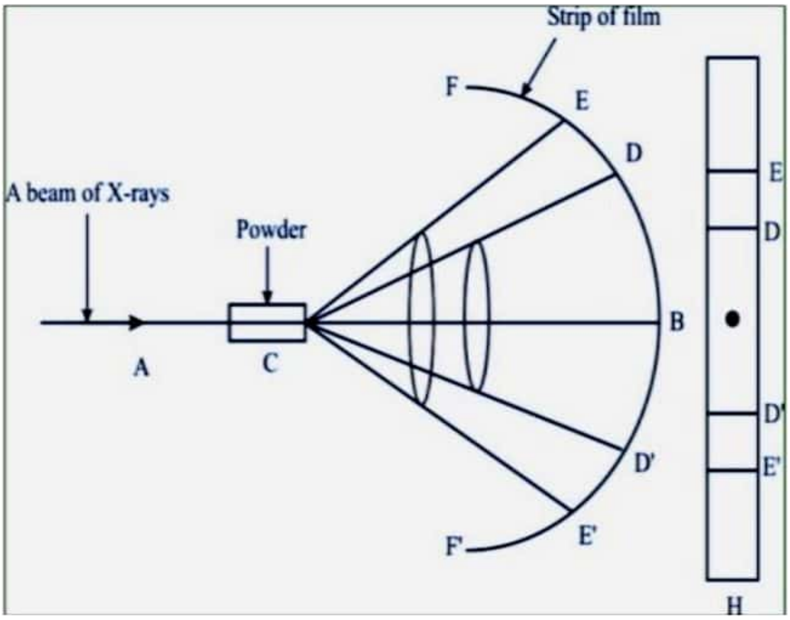
17. What is the method of Powder XRD?

The powder method:

•A narrow beam of monochromatic X-rays fall on the finely powdered specimen to be examined, and the diffracted rays are passed on to a strip of film which almost completely surrounds the specimen.

•The random orientation of crystals produces diffraction rings. This method is commonly used for identification purposes by comparing the data with the standard files available.

•For a cubic crystal the identification of lines in the powder photograph is simple compared to other types.



18. What is the principle of SEM?

• Scanning electron microscopes (SEMs) use an electron beam to image samples with a resolution down to the nano-meter scale. The electrons are emitted from a filament and collimated into a beam in the electron source. The beam is then focused on the sample surface by a set of lenses in the electron column.

• "Scanning Electron Microscopy", or SEM analysis, provides high-resolution imaging useful for evaluating various materials for surface fractures, flaws, contaminants or corrosion

19. How are backscattered, secondary and Auger electrons utilised in SEM?

Backscattered Electrons: -

•The production of backscattered electrons varies directly with the specimen's atomic number.

•This differing production rates causes higher atomic number elements to appear brighter than lower atomic number elements.

•This interaction is utilized to differentiate parts of the specimen that have different average atomic number.

Secondary Electrons: -

• Production of secondary electrons is very topography related.
• Due to their low energy, 5eV, only secondaries that are very near the surface (<10nm,) can exit the sample and be examined.
• Any changes in topography in the sample that are larger than this sampling depth will change the yield of secondaries due to collection efficiencies.
• Collection of these electrons is aided by using a "collector" in conjunction with the secondary electron detector.

Auger Electrons: -
• Auger Electrons have a characteristic energy, unique to each element from which it was emitted from.
• These electrons are collected and sorted according to energy to give compositional information about the specimen

20. What is the principle of TEM?

•TEM Principle: -The TEM operates on the same basic principles as the light microscope but uses

electros instead of light. ... Because the wavelength of electrons is much smaller than that of light, the

optimal resolution attainable for TEM images is many orders of magnitude better than that from a light

microscope

21. How does unshattered, elastically scattered and inelastically scattered electrons provide information in TEM?

•When a specimen is a crystal, elastically scattered electrons become diffracted waves that travel in specific directions given by the Bragg condition. ... As a specimen is thinner, the intensity of a TEM image or a diffraction pattern is explained by elastically scattered electrons.

22. What is the principle of AFM?

•AFM Principle: -

•Surface Sensing: -

an AFM uses a cantilever with a very sharp tip to scan over a sample surface. As the tip approaches the surface, the close-range, attractive force between the surface and the tip cause the cantilever to deflect towards the surface. However, as the cantilever is brought even closer to the surface, such that the tip makes contact with it, increasingly repulsive force takes over and causes the cantilever to deflect away from the surface.

• Detection Method: -

A laser beam is used to detect cantilever deflections towards or away from the surface. By reflecting an incident beam off the flat top of the cantilever, any cantilever deflection will cause slight changes in the direction of the reflected beam. A position-sensitive photo diode (PSPD) can be used to track these changes. Thus, if an AFM tip passes over a raised surface feature, the resulting cantilever deflection (and the subsequent change in direction of reflected beam) is recorded by the PSPD.

•Imaging: -

An AFM images the topography of a sample surface by scanning the cantilever over a region of interest. The raised and lowered features on the sample surface influence the deflection of the cantilever, which is monitored by the PSPD. By using a feedback loop to control the height of the tip above the surface— thus maintaining constant laser position—the AFM can generate an accurate topographic map of the surface features.

23. Comment on the working concept of AFM.

•The Atomic Force Microscope works on the principle measuring intermolecular forces and sees atoms by using probed surfaces of the specimen in nanoscale. ... The Atomic Force Microscope (AFM) takes the image of the surface topography of the sample by force by scanning the cantilever over a section of interest.

24. Define Diffusion.

•Diffusion is the process of movement of molecules under a concentration gradient. It is an important process occurring in all living beings. Diffusion helps in the movement of substances in and out of the cells. The molecules move from a region of higher concentration to a region of lower concentration until the concentration becomes equal throughout.

25. Define ion implantation.

•Ion implantation is a low-temperature process by which ions of one element are accelerated into a solid target, thereby changing the physical, chemical, or electrical properties of the target. Ion implantation is used in semiconductor device fabrication and in metal finishing, as well as in materials science research. The ions can alter the elemental composition of the target (if the ions differ in composition from the target) if they stop and remain in the target. Ion implantation also causes chemical and physical changes when the ions impinge on the target at high energy. The crystal structure of the target can be damaged or even destroyed by the energetic collision cascades, and ions of sufficiently high energy (10s of MeV) can cause nuclear transmutation.

26. Define epitaxial growth

•Epitaxial growth is broadly defined as the condensation of gas precursors to form a film on a substrate. Liquid precursors are also used, although the vapor phase from molecular beams is more in use.

27. Shortly discuss the band diagrams of dissimilar single layer p-n junction.

28. Shortly discuss the band diagrams of dissimilar double layer p-n junction.

Module-IV

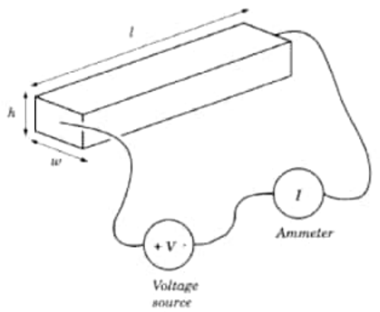
1. Explain resistivity of a given material determined using two probe method.

ANS:

Two-probe method:

Let us consider a rectangular bar of length l, height h and width w as shown in figure. copper wire are attached both ends of the bar.

The resistivity of the bar can be measured by measuring voltage drop across the wire due to passage of known current supplied by the battery *E* through the probes 1 and 2. The potential difference *(V)* between the two contacts at the ends of the bar can be measured by a voltmeter. Therefore, the resistivity of the wire is, i.e.,



$$\rho \equiv \frac{Rwh}{l}$$

2. Mention any three advantages of Four Point Probe over two point probe method.

ANS:

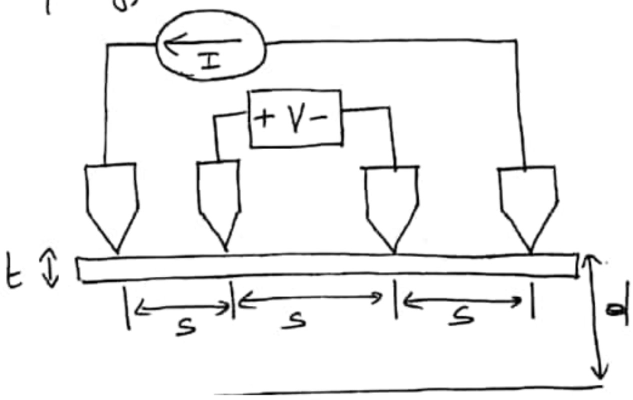
Advantage of four probe method over two probe method

Four point probe is preferred than two-point probe as the contact and spreading resistances in two point probe are large and the true resistivity cannot be actually separated from measured resistivity. In the four probe method, contact and spreading resistances are very low with voltage probes and hence accuracy in measurement is usually very high. To measure very low resistance values, four probe method is used. The resistance of probe will be not be added to that of sample being tested. It uses two wires to inject current in the resistance and another two wires to measure the drop against the resistance.

3. Explain how the sample is connected to the probes in Four Point Probe method.

ANS:

→ The four-point probe method, has four equally spaced in-line probes with probe tip diameters small compared to the probe spacing, "s".



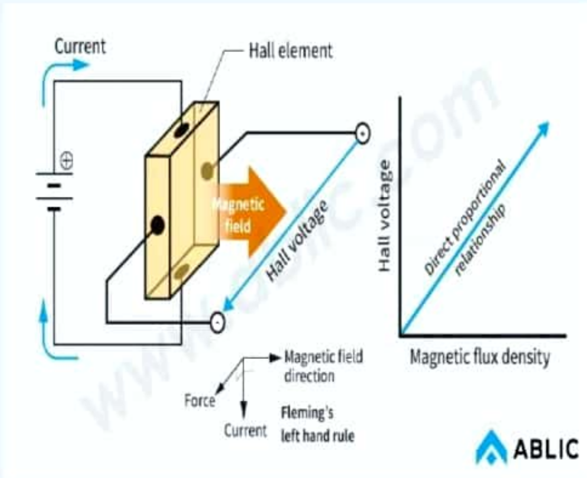
In-line four-point probe measurement of a conductive film of thickness t, uses a known current source, high-impedance voltmeter, spring loaded sharp probes.

4. State Hall Effect with diagram.

ANS:

Definition

When a piece of conductor (metal or Semiconductor) carrying current is placed in a transverse magnetic field, an electric field is produced inside the conductor in a direction normal to both the current and the magnetic field. This phenomenon is known as the Hall Effect and the generated voltage is called the Hall voltage.



5. Derive the expression for the Hall coefficient of n type semiconductor

ANS;

At equilibrium , $eE_H = Bev$ (or) $E_H = Bv$ (1)

If J is the current density, then , $J= -nev$ (2)

Where 'n ' is the concentration of current carriers,

From equ. (2)

$v= J/-ne$ (3)

Substituting the value of v in equ. (1) we get,

$E_H = BJ/-ne$ (4) .

- The Hall Effect is described by means of the Hall coefficient 'R_H ' in terms of current density ' J' by the relation,

$E_H = R_H BJ$

(or) $R_H = E_H / BJ$ (5)

By substituting the value of E_H from equ. (4) we get,

$R_H = BJ/ -neBJ = - 1/ne$ (6)

- Since all the three quantities E_H, J and B are measurable , the Hall coefficient R_H and hence the carrier density 'n' can be found out.

6. Write any three applications of Hall Effect.

ANS:

Applications of Hall effect:

(1) Determination of type of semiconductor

For a N-type semiconductor, the Hall coefficient is negative whereas for a P-type semiconductor, it is positive. Thus from the direction of the Hall voltage developed, one can find out the type of semiconductor.

(2) Calculation of carrier concentration

Once Hall coefficient R_H is measured, the carrier concentration can be obtained from,

$n = 1/eR_H$ or $p = 1/eR_H$

(3). Determination of mobility

We know that, conductivity, $\sigma_n = ne\mu_e$ (or) $\mu_e = \sigma_n /ne = - \sigma_n R_H$

Also $\sigma_p = pe\mu_h$ or $\mu_h = \sigma_p /pe = \sigma_p R_H$. Thus by measuring σ and R_H, μ can be calculated.

(4) Measurement of magnetic flux density:

Using a semiconductor sample of known 'R_H' the magnetic flux density can be deduced from $R_H = V_H t/ BI$ or $B = V_H t / R_H I$

7. A silicon plate of thickness 1 mm, breath 10mm and length 10mm is placed in a magnetic field of 0.5 Wb/m^2 acting perpendicular to its thickness. If 1×10^{-3}A current flows along its length, calculate the Hall voltage developed if the Hall coefficient is 3.66x 10^{-4} m^3/C.

ANS:

4. A silicon plate of thickness 1 mm, breath 10mm and length 100mm is placed in a magnetic field of 0.5 Wb/m^2 acting perpendicular to its thickness. If 10^{-2} A current flows along its length, calculate the Hall voltage developed if the Hall coefficient is 3.66x 10^{-4} m^3 / coulomb.

Given Data:

t= 1mm; w= 10mm ; L = 100 mm ; B = 0.5 Wb/m^2 ; I = 10^{-2} A ; R_H = 3.66x 10^{-4} m^3 / coulomb.

Solution:

Hall coefficient $R = V_H t / IB$

$V_H = R_H IB/t$

$= 3.66\times 10^{-4} \times 10^{-2} \times 0.5 / 1\times10^{-3}$

$= 1.83\times 10^{-3}$ V = 1.83 mV

8. An n-type semiconductor has Hall coefficient = 4.16 x10^{-4} m^3C^{-1}. The conductivity is 10^8 $ohm^{-1}m^{-1}$. Calculate its charge carrier density and electron mobility at room temperature.

ANS:

i) Carrier density(n) $= \frac{1}{R_H q}$ cm^{-3}

R_H = Hall coefficient
q = Charge of the e^- or hole (C)

$= \frac{1}{4.16\times10^{-4}\times1.6\times10^{-19}}$

Carrier density(n) $= 1.502\times10^{22} m^{-3}$, ~~$\mu_d = 4.16\times10^{4} m$~~

ii) Carrier mobility (μ) $= R_H\, \sigma\ cm^2 V^{-1} s^{-1}$

R_H = Hall coefficient
σ = conductivity ($C V^{-1} S^{-1} cm^{-1}$)

$= 4.16\times10^{-4}\times10^{8}$

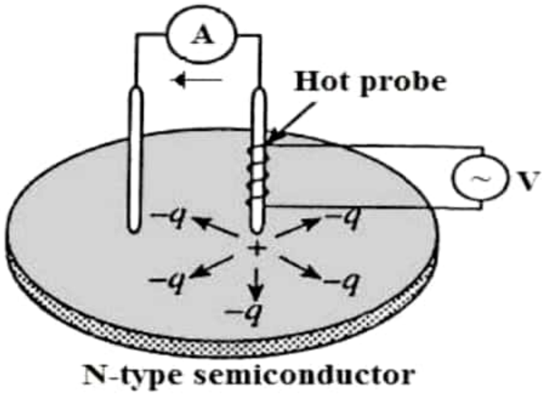
$= 4.16\times10^{4}\ m^2V^{-1}s^{-1}$

9. Explain the working principle of hot point probe method.

ANS:

Principle:

•A conventional Hot-Probe experiment enables a simple and efficient way to distinguish between n-type and p-type semiconductors using a hot probe and a standard multi- meter.



While applying the cold and hot probes to an n-type semiconductor, positive voltage readout is obtained in the meter, whereas for a p- type semiconductor, negative voltage is obtained.

10. Explain the principle of capacitance-voltage measurement method.

ANS:

Principle:

- The capacitance at an p-n or metal –semiconductor junctions depends on the properties of the charge- depletion layer formed at the junction
- The depletion regions is the vicinity of the PN junction and is " depleted" of free carriers due to the drift field required to maintain charge neutrality.

Capacitance-Voltage measurements

- Hillibrand and Gold (1960) first described the use of capacitance –voltage (C-V) methods to determine the majority carrier concentration in semiconductors.
- C-V measurements are capable of yielding quantitative information about the diffusion potential and doping concentration in semiconductor materials.
- The technique employs PN-junctions, metal- semiconductor junctions (Schottky barriers), electrolyte –semiconductor junction MIS field effect semiconductors.
- C-V measurements yield accurate information about the doping concentrations of majority carriers as a function of distance (depth) from the junction.

11. How does the capacitance of p-n junction diode vary in forward bias and reverse bias.

ANS:

Deep-level transient spectroscopy(DLTS)

DLTS Principle:

- Emission of trapped charge carriers change the depletion capacitance of a PN-junction or Schottky diode. The transient measurement provides information on the defect levels in the band gap.

- Deep-level transient spectroscopy is a method of determining the concentration and thermal emission rate of semiconductor deep levels by measuring capacitance transients as a function of temperature.

- A Schottky or p-n diode is first forward biased to fill the traps, then the capacitance transient caused by carrier emission from filled traps in the depletion region is measured at the quiescent reverse bias.

- A DLTS peak is generated when the thermal emission rate of the trap is the same as that of the rate window. Because of the strong temperature dependence of the trap emission rates, it is possible to resolve the emission from different traps using an appropriate emission rate window.

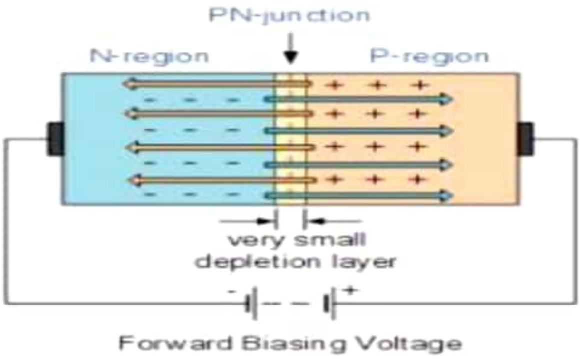
- When voltage across a p-n junction is changed, there is a corresponding change in the depletion region width. This change in width causes a change in the number of free charge carriers on both sides of the junction, resulting in a change in the capacitance.

- This change has two contributions; a) the contribution due to change in depletion width known as the junction capacitance and b) the contribution due to change in minority carrier concentration called the diffusion capacitance.

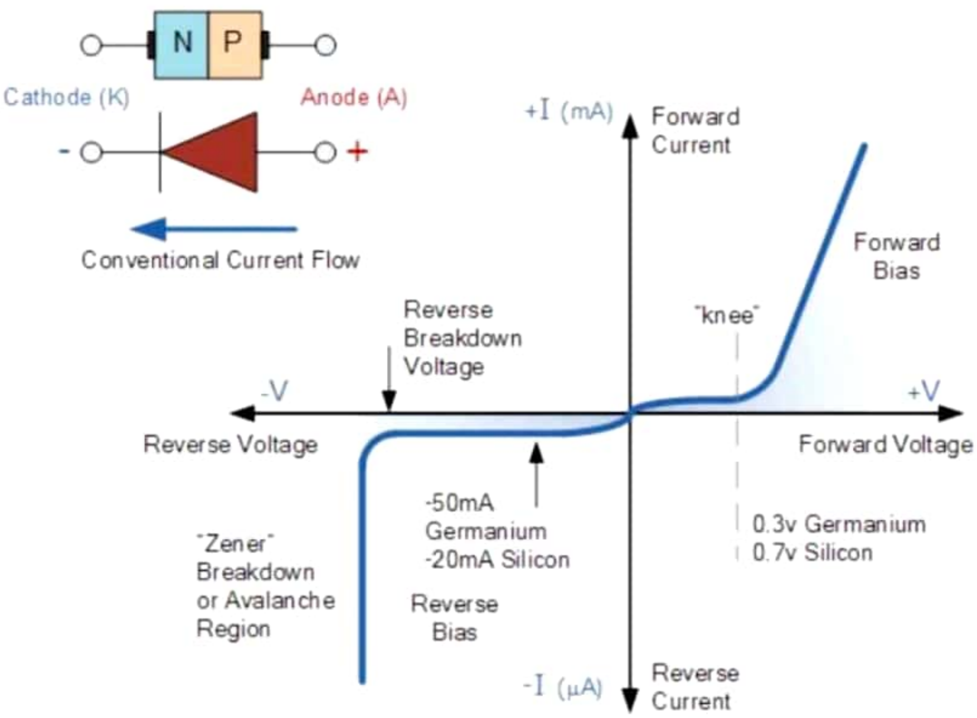
- Junction capacitance is dominant under reverse biased conditions while diffusion capacitance is dominant under forward biased conditions.

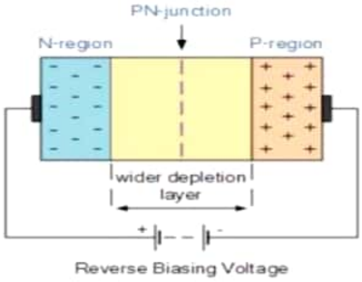
12. Explain forward biasing and reverse biasing of p-n junction diode.

ANS;



➢When a diode is connected in a **Forward Bias** condition, a negative voltage is applied to the N-type material and a positive voltage is applied to the P-type material. If this external voltage becomes greater than the value of the potential barrier, approx. 0.7 volts for silicon and 0.3 volts for germanium, the potential barriers opposition will be overcome and current will start to flow.





- When a diode is connected in a **Reverse Bias** condition, a positive voltage is applied to the N-type material and a negative voltage is applied to the P-type material.

- The net result is that the depletion layer grows wider due to a lack of electrons and holes and presents a high impedance path, almost an insulator. The result is that a high potential barrier is created thus preventing current from flowing through the semiconductor material.

- This condition represents a high resistance value to the PN junction and practically zero current flows through the junction diode with an increase in bias voltage. However, a very small **leakage current** does flow through the junction which can be measured in micro-amperes, (μA).

13. Write a short note on I-V characteristics of p-n junction diode in reverse bias.

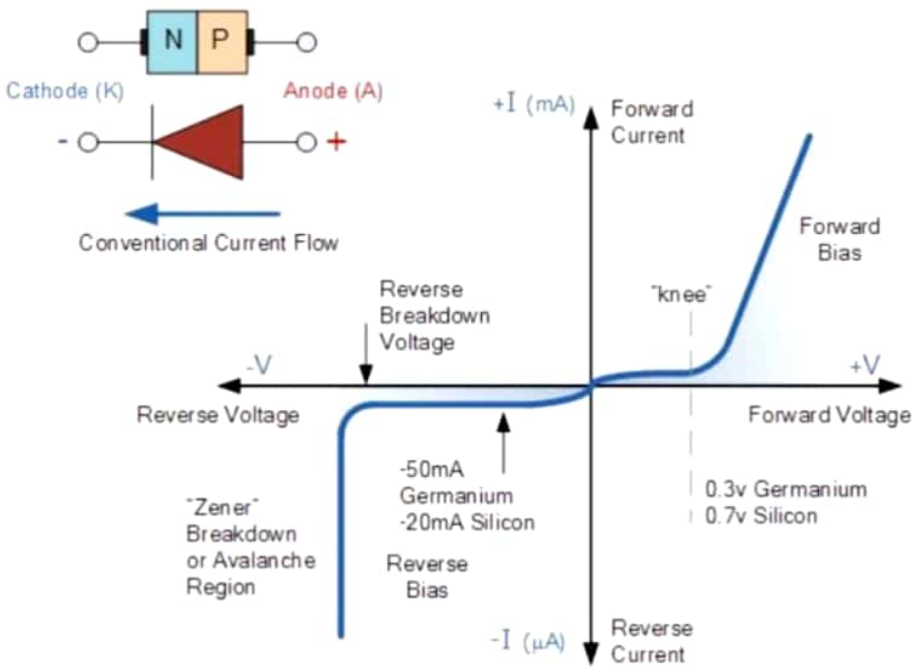
ANS:

I-V Characteristics in a Diode

- A *PN Junction Diode* is one of the simplest semiconductor devices around, and which has the characteristic of passing current in only one direction only. However, unlike a resistor, a diode does not behave linearly with respect to the applied voltage as the diode has an exponential current-voltage (I-V) relationship and therefore we can not described its operation by simply using an equation such as Ohm's law.

- If a suitable positive voltage (forward bias) is applied between the two ends of the PN junction, it can supply free electrons and holes with the extra energy they require to cross the junction as the width of the depletion layer around the PN junction is decreased.

- By applying a negative voltage (reverse bias) results in the free charges being pulled away from the junction resulting in the depletion layer width being increased. This has the effect of increasing or decreasing the effective resistance of the junction itself allowing or blocking current flow through the diode.

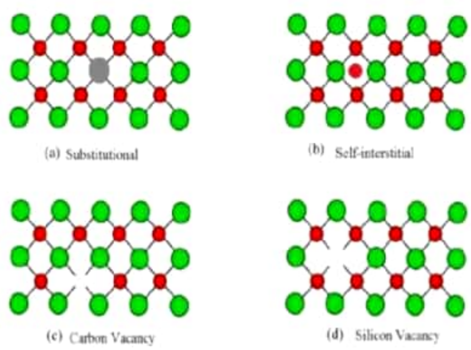


14. What are Shallow Level Traps and Deep Level Traps?

ANS;

Introduce energy level in the band structure

- **Shallow level**
  - –Close to the edges of the bandgap
  - –Use mainly as a dopant
- **Deep level**
  - –Close to the middle of the bandgap
  - –Act as generation/recombination or trap center.



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15. State combined Beer Lambert Law.

ANS;

The **Beer-Lambert law** is the linear relationship between **absorbance** and concentration of an **absorbing** species. The **Beer-Lambert law** implies that both the type and the concentration of the molecules are important in the process of radiation **absorption**.

- When the light beams are passed through a dilute sample, the absorption will be less since there is only less number of absorbing particles presented.
- The light beam was passed through a concentrated sample.
- The intensity of the transmitted beam was considerably low, which leads to violation of Beer Lambert's law.
- The law thus states that for a dilute solution, A = Kcl

  Where,

  A – absorbance

  K – molar absorbance coefficient

  c– molar concentration

  l - Path length

16. Write any three applications of U-V spectroscopic technique.

ANS:

Applications of UV Spectroscopy

SRM

- UV absorption spectroscopy can characterize those types of compounds which absorbs UV radiation thus used in qualitative determination of compounds. Identification is done by comparing the absorption spectrum with the spectra of known compounds.
- This technique is used to detect the presence or absence of functional group in the compound. Absence of a band at particular wavelength regarded as an evidence for absence of particular group.
- Kinetics of reaction can also be studied using UV spectroscopy. The UV radiation is passed through the reaction cell and the absorbance changes can be observed.

17. What is Photoluminescence? And how it is classified in to?

ANS:

• Luminescence is an electromagnetic (EM) radiation phenomenon due to excessive thermal radiation or incandescence in physical system.

• With regard to luminescent semiconductors, when energy of incident photon is equal or beyond the energy band gap, it will excite the electron of valence band into conduction band through band gap.

Luminescence of semiconductors can divide two types:

(1) Radiative transition

When an electron drops to lower energy state from higher energy state, it will probably occur radiative transition regardless of intrinsic state or energy state formed by impurities. Therefore, the system is not a balanceable condition and we assume that excited phenomena will generate electron-hole pairs in semiconductors. Firstly, we consider some basic transitions:

(a)Band-to-band transition:

Band-to-band transition is the relationship of free-electrons and holes. Those transitions usually occur in direct band gap materials such as Ⅲ-Ⅴ compounds where the electron-hole pairs will generate radiation recombination effectively between conduction band and valence band.

(b)Free exciton transition

If the material is very pure, an electron and a hole will attract each other to form exciton. Then, they will recombine to generate a very narrow spectrum. In Ⅲ-Ⅴ compounds, free exciton energy state usually describes Wannier-Mott approximation. The energy of free exciton can be expressed as Equation 1.

$$E_n = 2\pi^2 m^* e^4 / h^2 \varepsilon^2 n^2 \qquad (1)$$

In this equation, m* is effective mass, h is Planck constant, ε is dielectric constant, and n is quantum number.
However, there are probably several mechanisms to result in non-radiative transition. Those transitions will compete with radiative transition to result in lower luminescence.

(c)Free-to-bound transition

The transition is free-to-bound transition between energy bands of materials and impurity energy level. This transition is between the impurity and one of energy bands such as from conduction band to acceptor or from donor to valence band. The energy of radiative photon is E_g-E_b and E_b is bound energy of shallow impurity energy level.

(d)Donor-acceptor pair recombination

The transition is between donor and acceptor. After optical pumping, the electrons and holes will be bounded at D+ and A- locations to generate neutral D_0 and A_0 centers. Some neutral donor electrons will recombine with neutral acceptor holes radiatively.

Non-radiative transition

Some opportunities which cause non-radiative transition will compete with radiative recombination transition and influence luminescent efficiency negatively. They can describe as below:

a) Because of thermal oscillation to generate phonons;

a) Recombination on the surface state includes two dimensional dislocation, and agglomerative boundary et al. through step-wise transition which causes loss energy. It also calls cascade process;

a) Impurity locations are often not radiative recombination centers;

a) Loss energy of trapped carriers will excite other carriers in the lattice and emit non-radiative loss energy by Auger process.

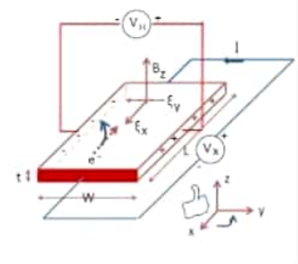
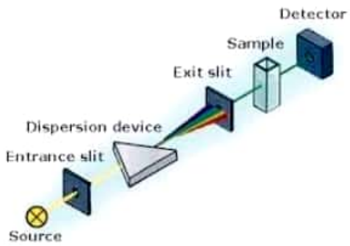
UNIT 4

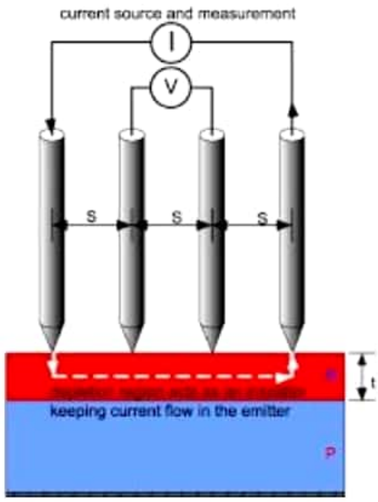
PART A-ONE MARK QUESTIONS

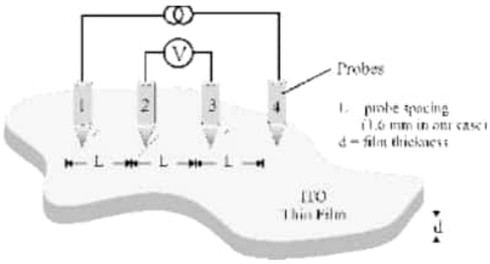
QUESTION NO.	QUESTIONS
1	In a …………., the electrons are ejected from photosensitive surface and are amplified within the cell. (A) Photodiode (B) Bolometer (C) Electrode (D) **photomultiplier tube**
2	Alkali metals and their oxides are best ………… materials. **(A) Photo emissive** **(B)** Conducting **(C)** Insulating **(D)** Semiconducting

3	The crystalline solids absorbs energy and re-emits it in the visible region of the spectrum is called ……………… (A) **Luminescence** (B) Photon emission nn (C) Phonon emission (D) Radiation
4	……………….. Spectroscopy can be used to determine the concentration of absorbs in a solution. (A) Gamma (B) IR (C) Microwave (D) **UV Vis**
5	An ideal monochromator should have an ……….. narrow effective bandwidth. **(A) infinitely** **(B)** Small **(C)** Zero **(D)** finite
6	……………….. is an instrumentation used to determine the traps in semiconductors (a) TGA **(B) DLTS** **(C)** DTA **(D)** IR

7	…………. is used for separating source radiation wavelengths. (A) Detector (B) Antenna (C) **Monochromator** (D) Display device
8	In ……………. the conductivity increases with increasing temperature (A) IR (B) DTA (C) Phonos (D) **Semiconductors**
9	In ………………. semiconductor, the Hall coefficient is negative (A) P-type (B) Dilute (C) **N-type** (D) Magnetic

10	The given diagram represents ……………… effect  **(A) Hall effect** **(B)** Thermoelectric effect **(C)** Faradays effect **(D)** Photoelectric effect
11	The given diagram represents instrumentation of …………… spectroscopy  (A) IR (B) NMR (C) Gamma ray (D) **UV**

12	The given diagram represents experimer ………………  **(A) Four probe** **(B)** Hall effect **(C)** Two probe **(D)** DMS

13	………………… law states that, when a beam of monochromatic light passes through an absorbing medium, the rate of decrease in intensity with the thickness of the medium, is proportional to the intensity of light. (A) Snell's (B) Beer's (C) **Lambert's** (D) Photoelectric
14	A ………………. is a method of determining quickly whether a semiconductor sample is n (negative) type or p (positive) type (A) Electrolysis (B) **Hot probe method** (C) Hydrogenation (D) Rectification
15	The ……………….. method is used to measure the resistance (A) Hydrogenation (B) Rectification (C) **Vander Pauw** (D) Electolysis
16	The energy gap in a semiconductor is also called as …………. **(A) Forbidden gap** **(B)** Large gap **(C)** Narrow gap **(D)** Electrical gap
17	The ……………… is the ratio of the voltage measured across the sample to the current driven through the sample (A) Capacitance (B) **resistance** (C) Inductance (D) capacitor
18	 The given diagram represents …………… method **(A) Vander Pauw** **(B)** Electolysis **(C)** Hydrogenation **(D)** Rectification

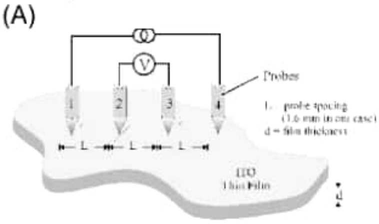
19	For determining the resistivity of a semiconductor, the diameter of contacts between the probe and the semiconductor should be ………………………. the gap between the probes. **(A) Smaller Than** **(B)** Greater than **(C)** Equal to **(D)** Double
20	……………….. is a technique for characterizing semiconductor materials and device, where the applied voltage is varied, and the capacitance is measured and plotted as a function of voltage. **(A) Capacitive – voltage profiling** **(B)** Current profiling **(C)** Voltage profiling **(D)** Baising

QUESTION NO.	QUESTIONS

21

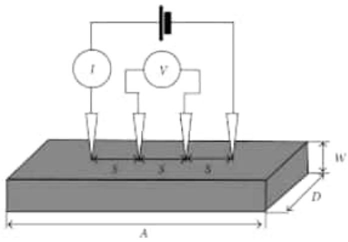
Identify the resistivity measurement by four probe linear method

(A)



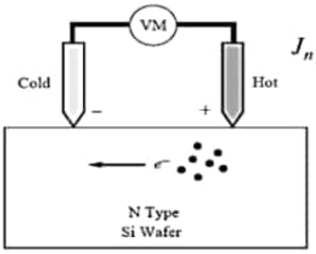
This technique is commonly used to measure the resistivity and the Hall coefficient of a sample

(B)



This technique involves using four equally-spaced,known as a four-point probe to make electrical contact with the material.

(C)



The method of determining quickly whether a semiconductor sample is n type or p type. A voltmeter or ammeter is attached to the sample, and a heat source, such as a soldering iron, is placed on one of the leads.

(D)

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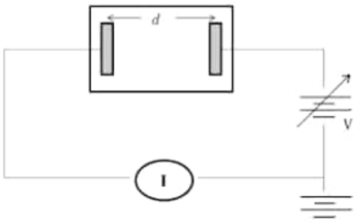
<tr><td></td><td>

This Method is one of the standard and most commonly used method for the measurement of resistivity of very high resistivity samples like sheets/films of polymers</td></tr>
<tr><td>22</td><td>Illustrate the properties of Photoluminescence ………………

(I) The Principle of this method is based on the absorption of ultraviolet light or visible light by chemical compounds, which results in the production of distinct spectra. Spectroscopy is based on the interaction between light and matter.
(II) It is a process in which a molecule absorbs a photon in the visible region, exciting one of its electrons to a higher electronic excited state, and then radiates a photon as the electron returns to a lower energy state.
(III) This method is routinely used in analytical chemistry for the quantitative determination of different analytes, such as transition metal ions, highly conjugated organic compounds, and biological macromolecules.
(IV) It is the spontaneous emission of light from a material following optical excitation. It is a powerful technique to probe discrete energy levels and to extract valuable information about semiconductor sample composition, quantum well thickness or quantum dot sample mono dispersity.
(A) All the four Incorrect
(B) Both II and III correct
(C) Both III and I correct
(D) Both II and IV correct</td></tr>
<tr><td>23</td><td>Analyse the device Photoemissive cell

I) This cell is commonly known as a phototube, makes use of the photoelectric effect, the phenomenon whereby light-sensitive surfaces give off electrons when struck by light. These cells are sometimes called photocells or electric eyes.
(II) This is is an electrical device that converts the energy of light directly into electricity by the photovoltaic</td></tr>
</table>

	effect, which is a physical and chemical phenomenon. (III) In this cell the photons passed their energy in fixed quantities to atoms inside the metal, knocking some of their electrons out of them, so producing an electric current. The photons need a minimum threshold frequency to free electrons and produce an effect, known as the work function. (IV) These are the class of vacuum tubes, and more specifically vacuum phototubes, are extremely sensitive detectors of light in the ultraviolet, visible, and near-infrared ranges of the electromagnetic spectrum. These detectors multiply the current produced by incident light by as much as 100 million times or 108 (i.e., 160 dB)[1], in multiple dynode stages (A) Both I and II correct (B) **Both I and III correct** (C) Both II and IV correct (D) Both I and II correct
24	Point out the applications of Uv- Vis Spectroscopy. (I) Quantitative and not Qualitative analysis. (II) Determination of molecular weight. (III) Determination of molar absorbance coefficient. (IV) Determination of known compound. (V) Detection of non-functional group. (VI) Detection of isomers and geometrical isomers. (VII) Detection of impurities. (a) The statements I, II, VII and V are correct (b) The statements I, II, VI and V are correct (c) The statements II, III,VI and VII are correct (d) The statements I, V, VI and VII are correct
25	If the drift velocity of holes under a field gradient of 100v/m is 5m/s, the mobility is **A. 0.05** **B.** 0.55 **C.** 500 **D.** 50

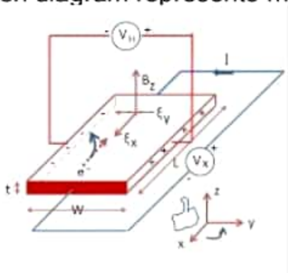
26	A silicon sample is uniformly doped with 10^{16} phosphorus atoms/cm^3 and 2×10^{16} boron atoms/cm^3. If all the dopants are fully ionized, the material is: A. n-type with carrier concentration of $3 \times 10^{16}/cm^3$ B. **p-type with carrier concentration of** **$10^{16}/cm^3$** C. p-type with carrier concentration of $4 \times$ $10^{16}/cm^3$ D. Intrinsic
27. 28.	In Photoluminescence process, electrons change energy states by either resonantly gaining energy from absorption of a …………… or losing energy by emitting ………………. A. Mesons B. Phonons C. Baryons D. **Photons** In hot probe technique, ……………….. probe is connected to the positive terminal of the meter while the …………………. probe is connected to the negative terminal. A. Cold, Hot B. Thick, Thin C. Thin, Thick D. **Hot, Cold**
29 30	Vis. The wavelength range used in UV – Spectrophotometer is …………………………. **A. 200 nm to 2500 nm** **B.** 200 nm to 3500 nm **C.** 200 nm to 4000 nm **D.** 400 nm to 700 nm The Lambert law and Beer law may be combined i single relationship which shows the effect of t ……………….. and ……………of absorbing substance A. Composition, Refractive Index B. **Thickness, Concentration** C. Elasticity, Plasticity D. Hardness, Isotropy

31.	What is the unit of absorbance which can be derived from Beer Lambert's law? A. $Lmol^{-1}cm^{-1}$ B. $gm^{-1}cm^{-1}$ C. cm D. **No unit**
32. 33. 34. 35.	In conventional DLTS the capacitance transients are investigated by using a …………………………… A. Hartley oscillator B. Cathode Ray Oscilloscope C. **Lock-in- Amplifier** D. Intermediate frequency amplifier The temperature range of the most of the semiconductors to characterize in DLTS is ……………….. **A. 77 K to 380 K** **B.** 87 K to 380 K **C.** 77 K to 383 K **D.** 77 K to 400 K The DLTS is used to characterize …………………. A. Conductors B. **Semiconductors** C. Insulators D. Superconductors To characterize the material in DLTS, it is necessary to form …………………… A. Thin film B. Nano particles C. **PN junction** D. Solution of the material
36.	……………….. is not taking part in CV measurement A. Accumulation B. Depletion C. Inversion D. **Emission**

37.	The leakage current occurs in ……………………… A. Forward Bias B. **Reverse Bias** C. Both forward and reverse bias D. LDR
38.	C-V measurements are capable of yielding information about the ………………………. and concentration of charge carriers A. Drift potential B. **Diffusion potential** C. Bonding D. Crystal structure
39.	The exponential ………………….. in current steeps as the diode current becomes limited by the resistance of undepleted region of diode A. Increase B. Decrease C. Zero D.equals
40.	In linear four probe method the tip of probe diameter is usually ………………….. than the probe spacing A. Larger B. Cooler C. Hotter D. **Smaller**
41.	Van der Pauw technique measures the resistivity and ………………. of the sample A. Coefficient of Friction B. Absorption C. **Hall coefficient** D. Emission
42.	To identify the nature of semiconductor (p-type or

	n–type) ……………. methods will be used, A. Two-point method B. Linear four-point method C. Van der Pauw four-point method D. **Hall effect**
43.	The leakage current occurs in ……………………… A. Forward Bias B. **Reverse Bias** C. Both forward and reverse bias D. LDR

QUESTION NO.	QUESTIONS
44	Hall Effect is defined as (I) The production of a voltage difference across an electrical conductor, transverse to an electric current in the conductor and to an applied magnetic field perpendicular to the current. (II) The production of a magnetic field across an electrical conductor, transverse to an electric current in the conductor and to the applied voltage perpendicular to the current. (III) The production of a current across an electrical conductor, transverse to voltage in the conductor and to an applied magnetic field perpendicular to the current. (IV) The production of a potential difference across an electrical conductor when a magnetic field is applied in a direction perpendicular to that of the flow of current.. (a) Both I and III correct (b) All the four Incorrect (c) Both II and III correct (d) **Both I and IV correct**
45.	The Hall coefficient of sample (A) of a semiconductor is measured at room temperature. The hall coefficient of (A) at room temperature is $4x10^{-4}$ m^3 $coulomb^{-1}$ .The carrier concentration in sample A at room temperature is A. ~ 10^{21} m^{-3}

	B. ~ 10^{20} m^{-3} C. **~ 10^{22} m^{-3}** D. ~ 10^{23} m^{-3}
46.	Applications of Hall effect (I) The probes are often used as magnetometers, i.e. to measure magnetic fields, or inspect materials (such as tubing or pipelines) using the principles of magnetic flux leakage. These devices produce a very low signal level and thus require amplification. (II) This converts mechanical energy into electrical energy, which is why it's useful during a power outage. This is when a current flows through a coil on a stovetop, which produces a magnetic field. (III) These sensors are used to time the speed of wheels and shafts. These are used to detect the position of permanent magnet in brushless electric DC motors. The sensors are embedded in digital electronic devices along with linear transducers. (IV) This can be used to solve complex electrostatic problems involving unique symmetries like cylindrical, spherical or planar symmetry. This can be used to simplify evaluation of electric field. (A) Both III and IV are correct (B) **Both I and III are correct** (C) All the four correct (D) Both II and III are correct
47.	The given diagram represents ……………… effect  **(a)** **Hall effect** **(b)** Thermoelectric effect **(c)** Faradays effect **(d)** Photoelectric effect

48.	Hot probe method (I) This method is routinely used in analytical chemistry for the quantitative determination of different analytes, such as transition metal ions, highly conjugated organic compounds, and biological macromolecules. (II) This method of determining quickly whether a semiconductor sample is n (negative) type or p (positive) type. A voltmeter or ammeter is attached to the sample, and a heat source, such as a soldering iron, is placed on one of the leads. (III) This technique is commonly used to measure the resistivity and the Hall coefficient of a sample (IV) The conventional characterization method enables only the definition of a semiconductor type, P or N, by identifying the majority of the charged carriers **(A) Both II and IV correct** **(B)** Both III and IV correct **(C)** Both I and IV correct **(D)** All the four correct
49.	Vander paw method. (I) This Method is a technique not commonly used to measure the resistivity and the Hall coefficient of a sample. (II) The doping type i.e. whether it is a P-type or N-type material (III) The sheet carrier density of the majority carrier cannot be determined. (IV) The charge density and doping level can be found (V) The mobility of the majority carrier can be found (VI) This method involves applying a current and measuring voltage using four small contacts on the circumference of a flat, arbitrarily shaped sample of uniform thickness. (VII) This method is particularly useful for measuring very small samples because geometric spacing of the contacts is unimportant. (A) All are correct (B) All are Incorrect (C) **II,IV,V,VI and VII are correct** (D) I, II, III, VI and VII are correct

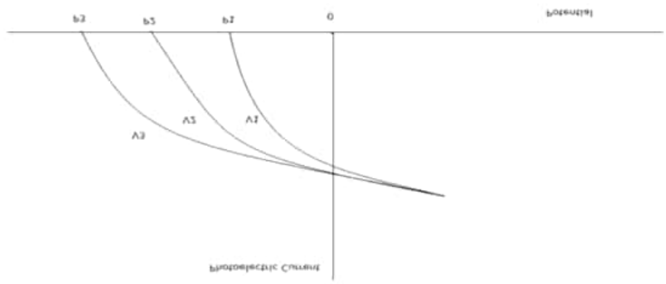
50.	Two probe method (I) This converts mechanical energy into electrical energy, which is why it's useful during a power outage. This is when a current flows through a coil on a stovetop, which produces a magnetic field. (II) The production of a voltage difference across an electrical conductor, transverse to an electric current in the conductor and to an applied magnetic field perpendicular to the current. (III) This method is one of the standard and most commonly used method for the measurement of resistivity of very high resistivity samples like sheets/films of polymers. (IV) 1. Remote sensing areas. 2. Resistance thermometer. 3. Induction hardening processes. 4. Precise estimation of geometrical factors. 5. Characterization of fuel cells bipolar plates (A) Both II and IV correct (B) **Both III and IV correct** (C) Both I and IV correct (D) All the four correct
51. 52.	The basic components of UV-Vis Spectrometer. (A) They have three basic parts: (1) a large magnet, which is responsible for the static magnetic field H0, (2) a transmitter, which provides the alternating field H1, and (3) a receiver. (B) This consists of three basic components: radiation source, monochromator, and detector.The common radiation source for the spectrometer is an inert solid heated electrically to 1000 to 1800 °C. (C) **They have five main components: the light source, monochromator, sample holder, detector, and interpreter. The standard light source consists of a deuterium arc (190–330 nm) and a tungsten filament lamp (330–800 nm), which together generates a light beam across the 190–800 nm spectral range.** (D) A LASER source is needed to excite the target species. A filter collects the scattered light (Stokes) and filters out the Raleigh and Anti Stokes light. What is the unit of molar absorptivity or absorptivity which is used to determine absorbance A in Beer Lambert's

	formula? **i) L mol^{-1} cm^{-1}** ii) L gm^{-1} cm^{-1} iii) Cm iv) No unit
53.	Transmittance is given as T = P/Po. If Po is the power incident on the sample, what does P represent? **i) Radiant power transmitted by the sample** ii) Radiant power absorbed by the sample iii) Sum of powers absorbed and scattered iv) Sum of powers transmitted and reflected
54.	Which of the following is not true about Absorption spectroscopy? i) It involves transmission ii) Scattering is kept minimum **iii) Reflection is kept maximum** iv) Intensity of radiation leaving the substance is an indication of concentration

55.	The representation of Beer Lambert's law is given as A = abc. If 'b' represents distance, 'c' represents concentration and 'A' represents absorption, what does 'a' represent? a) Intensity b) Transmittance c) **Absorptivity** d) Admittance Which of the following is not a limitation of Beer Lambert's law, which gives the relation between absorption, thickness, and concentration? a) Concentration must be lower b) **Radiation must have higher bandwidth** c) Radiation source must be monochromatic d) Does not consider factors other than thickness and concentration that affect absorbance In which of the following ways, absorption is related to transmittance? a) Absorption is the logarithm of transmittance b) Absorption is the reciprocal of transmittance c) **Absorption is the negative logarithm of transmittance** d) Absorption is a multiple of transmittance Beer Lambert's law gives the relation between which of the following? a) Reflected radiation and concentration b) Scattered radiation and concentration c) **Energy absorption and concentration** d) Energy absorption and reflected radiation
56.	
57.	
58.	
59.	In photo emissive transducers, electrons are attracted by ………………… a) Cathode

	b) Anode **c)** Grid **d)** Body
60.	During Einstein's Photoelectric Experiment, what changes are observed when the frequency of the incident radiation is increased? a) The value of saturation current increases b) No effect c) **The value of stopping potential increases** d) The value of stopping potential decreases
61.	What is the time lag between the incidence of photons and the ejection of photoelectrons? a) Greater than 10^{-5} s b) Between 10^{-5} s and 10^{-9} s c) **Less than 10^{-9} s** d) 1 second
62.	How does the intensity affect the photoelectric current? **a) As intensity increases, the photoelectric effect increases** **b)** As the intensity increases, the photoelectric effect decreases **c)** As the intensity decreases, the photoelectric effect becomes twice **d)** No effect

63. Identify the correct order of frequencies.



a) $v_1 > v_2 > v_3$

b) $v_2 > v_3 > v_1$

c) $\mathbf{v_3 > v_2 > v_1}$

d) $v_1 > v_3 > v_2$

64. The work function of lithium is 2.5 eV. The maximum wavelength of light that can cause the photoelectric effect in lithium is ………………..

a) 3980 Å

b) **4980** Å

c) 5980 Å

d) 6980 Å

65. Light of wavelength 3500 Å is incident on two metals A and B. Which metal will yield more photoelectrons if their work functions are 5 eV and 2 eV respectively? a) A

b) B

c) A & B

d) C

66. The Kinetic energy of a photoelectron emitted on shining a light of wavelength 6.2×10^{-6} m on a metal surface of work function 0.1 eV is ………………..

a) 0.01 eV

b) 0.02 eV

c) **0.1 eV**

d) 1 eV

Concept of Electrical Measurements

→ Electrical and electronic measurements of materials are among the most powerful techniques available for materials characterization.

→ The information that can be derived from these measurements are conductivity (resistivity), carrier concentration, mobility, bandgap and other details about material transport properties.

Conductivity Measurement.

→ A material's conductivity, σ, relates its ability to conduct electricity.

→ In metals, conduction of electricity is based on conduction of electrons whose density and scattering are important.

→ In semiconductors, conductivity is determined by the numbers of available charge carriers and carrier mobilities

→ Since the mechanisms for conductivity are different, its dependence on temperature are also different.

→ Conductivity increases with increasing temperature for semi-conductors (more carriers are generated) and it decreases with increasing temperature for metals (more scattering by the lattice).

→ The conductivity is also dependent on the physical structure, crystal type, orientation, crystallites (grains).

→ The ~~Ex~~ accurate determination of a material's conductivity can be critical for understanding material composition.

→ The method used to determine conductivity depends on whether the material is a bulk sample or a thin film.

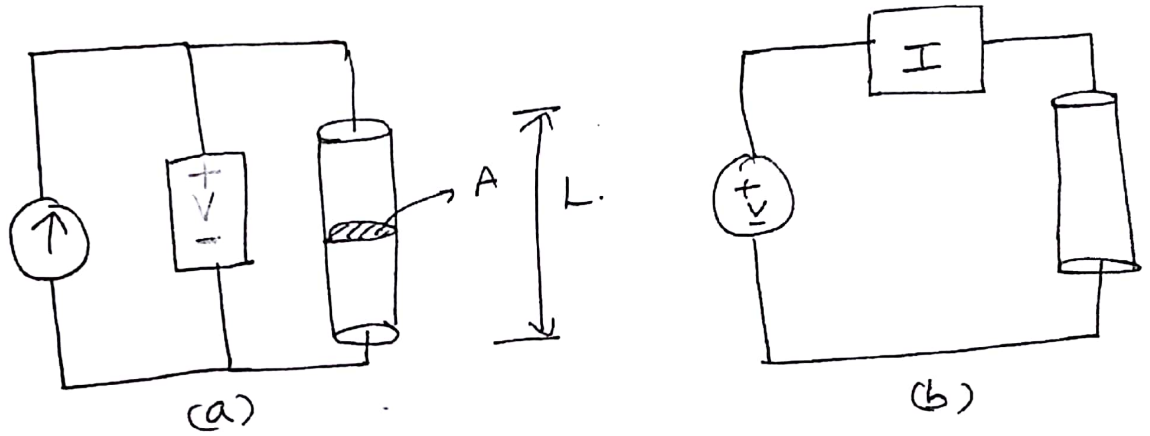
Two Point Probe Technique.

Principle

→ The Conductivity or resistivity of a bulk Sample is based on accurate measurement of both resistance and the sample dimensions.

→ The resistance is the ratio of the voltage measured across the Sample to the current driven through the Sample (or) of the Voltage applied across the Sample to the measured Current.

Experiment.



Two-point measurement of a resistive bar of length L and Cross Sectional area, A using (a) an ideal voltmeter in parallel with an ideal Current Source and (b) an ideal ammeter in Series with an ideal voltage Source

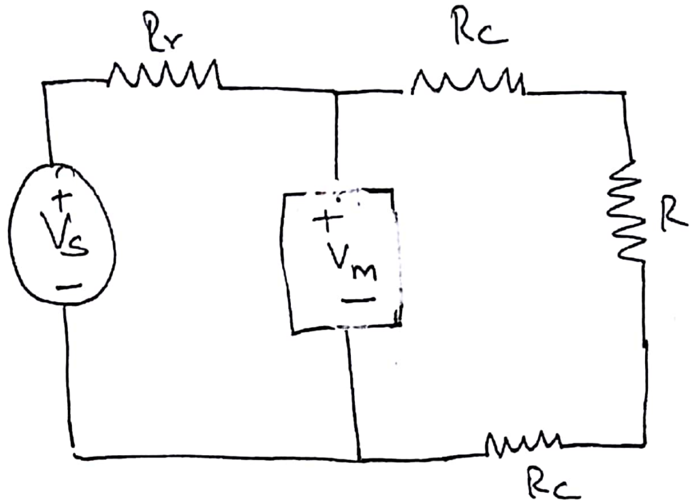
→ For a homogenous bar of length L, and uniform Crossection A the resistance R, is related to the resistivity, ρ by.

$$R = \frac{\rho L}{A}$$

→ The rod is connected in a "two-point" arrangement. The measurement apparatus is connected to the bar at the two end points.

→ The measurement apparatus is represented by an ideal Current Source in parallel with a high-impedance voltmeter.

The apparatus can also be realised using an ideal voltage source in series with a low-impedance ammeter.



Two-point ohmmeter measurement circuit, which includes contact and cable resistance, Rc

→ This approach is a more realistic one.

→ A voltage source and a variable range resistance (R_r) supply the current, where R_r is adjusted to provide a convenient voltage across the voltmeter.

→ Typical values of R_r from 100 to 10,000 Ω.

→ R_c represents series resistance in cable and the wire to sample contact resistance.

→ The resistance in the bar is calculated as.

$$R = \frac{(R_r V_m / V_s)}{[1 - (V_m/V_s)]} - 2R_c$$

→ A long bar of resistive material is desirable to minimize the effect of extra resistance in the measurement system or inaccurate length measurement.

→ The two-point approach is most accurate for high-resistance measurements where usually small R_c term can be ignored.

Four Point Probe Technique - Linear Method. (1)

→ One of the most common approaches for measuring Sheet or Surface Conductivity is the four-point probe method.

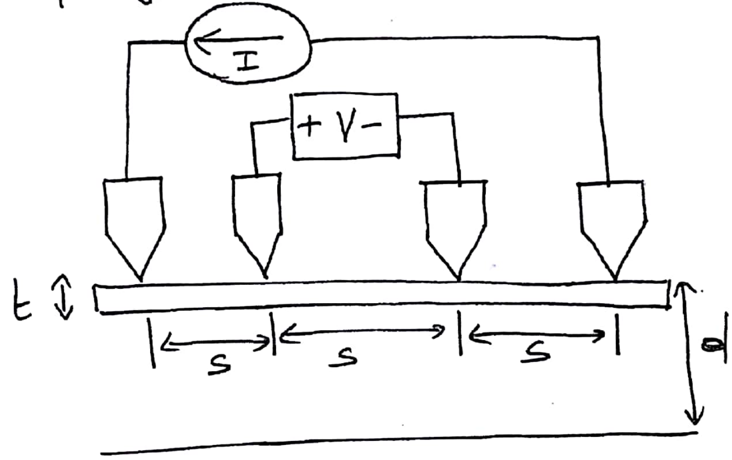
Principle

→ The Current is driven between a pair of probes or Connections and the voltage is measured across the other two.

→ The four-point probe method is most often realised by Contacting a flat film surface with four equally Spaced in-line probes.

Experiment.

→ The four-point probe method, has four equally spaced in-line probes with probe tip diameters Small Compared to the probe Spacing, "s".



In-line four-point probe measurement of a Conductive film of thickness t, uses a known Current Source, high-impedance Voltmeter, Spring loaded Sharp probes.

→ An Ohmic Contact is assumed between the probe tip and the Sample.

→ Current is most Commonly passed between the outer two probes and the voltage difference is measured between the two inner probes.

→ Resistivity in a four-point probe measurement is given

$$\rho = \frac{2\pi s F V}{I}$$

where, F → is a correction factor.

→ For placement of probes near the center of a medium of area large relative to the probe spacing, and of a semi-infinite thickness, the correction factor F is unity.

→ The correction factor F is dependent on the thickness of conducting layer, sample thickness, lateral dimensions of the sample (square, round, etc) and the conducting or semi-conducting nature of samples.

→ Locating the probes closer than four probe spacings from the wafer edge can also result in measurement error.

→ Separation of the current source from the high-impedance voltage meter avoids errors associated with contact resistance

→ At times of semiconductor measurements, sufficient separation between the current and voltage probes is required so that minority carriers injected near the current probes recombine before their presence can be felt the voltage probes.

Four Point Probe Method – Van der Pauw Method

→ One of the most common approaches for measuring sheet or surface conductivity is the Van der Pauw method.

Principle.

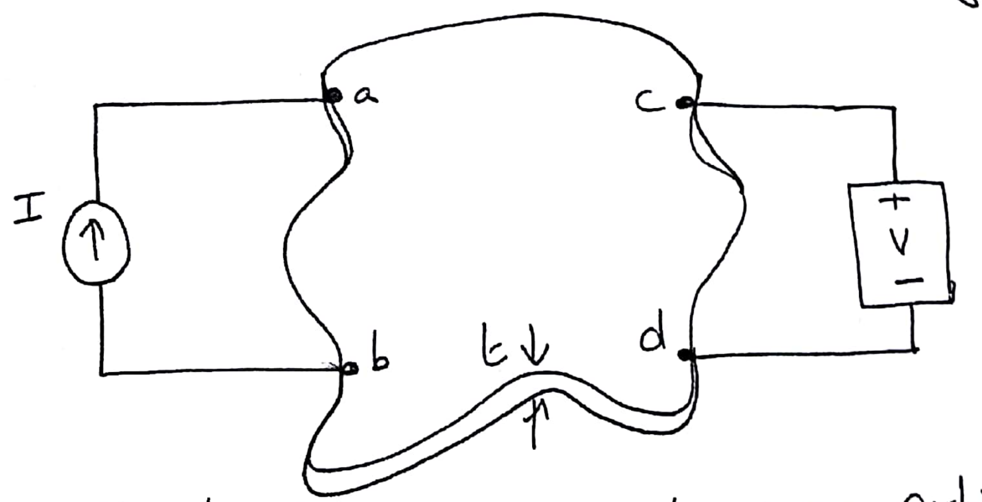
→ The current is driven between a pair of probes or connections and the voltage is measured across the two.

→ The Van der Pauw method can measure resistivity of small, arbitrarily shaped layers where the four contacts are typically placed around the ~~pt~~ periphery of the sample.

Experiment

→ The Van der Pauw method can determine the resistivity of small, arbitrarily shaped layers and generally requires less surface area than the four point probe method.

→ It is often used in integrated circuit processing.



Van der Pauw measurement of an arbitrarily shaped sample uses a known current and a high-impedance voltmeter.

→ The method considers four small contacts placed on the periphery of a homogenous, uniform thickness "t" sample,

→ The resistance $R_{ab,cd}$ is determined by driving a current from point "a" to "b" and measuring the voltage from point "c" to "d"

$$R_{ab,cd} = \frac{|V_c - V_d|}{|I_{ab}|}$$

→ The resistivity is given as,

$$\rho = \frac{\pi t}{\ln 2} \frac{R_{ab,cd} + R_{bc,da}}{2} F$$

→ for the case of a material with a uniform thickness, homogenous film with identical contacts, F=1, then

$$\rho = \frac{\pi t}{\ln 2} R_{ab,cd} = 4.532\, t\, R_{ab,cd}$$

→ In Van der Pauw measurements, it is common to calculate resistivity from two sets of measurements ($R_{ab,cd}$ and $R_{bc,da}$). for uniform samples with good contacts, the same results should be measured.

Hot Probe Method for Semiconductor Thin films

→ Physical properties of thin films significantly differ from those of bulk materials.

→ There are various parameters such as thickness, crystal structure, composition and defects, which characterize a semiconductor film.

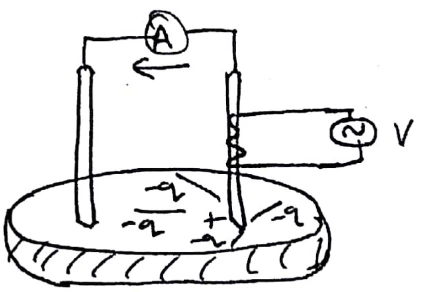
→ The parameters of charge carriers like

(a) type of semiconductor
(b) impurities concentration
(c) Mobility of charged carriers.
(d) Diffusion coefficient

define the possibility to apply material for various electronic devices.

Principle

→ A conventional hot-point probe experiment enables a simple and efficient way to distinguish between p-type and n-type semiconductors using a hot probe and a stand multimeter.



N- type semiconductor.

→ While applying the cold and hot probes to an n-type semiconductor, positive voltage readout is obtained in meter, whereas for a p-type semiconductor, negative voltage readout is obtained.

Experiment-

→ A couple of a cold probe and a hot probe are attach to the semiconductor film surface.

This is

→ The hot probe is connected to the positive terminal of the multimeter while the cold probe is connected to the negative terminal.

→ The thermally excited majority free charged carriers are translated within the semiconductor from the hot probe to the cold probe.

→ Mechanism for this motion within the semiconductor is of a diffusion type since the material is uniformly doped due to the constant heating in the hot probe contact.

→ These translated majority charged carriers define the electrical potential sign of the measured current in multimeter.

→ The hot-probe measurement may be describe as a three-step process:

1. the heated probe excites additional free charged carriers of two types.

2. The hot majority carriers begin to leave the heated part of semiconductor surface by a diffusion mechanism. Simultaneously, a built-in electrical field is created between the electrodes and the second (cold) electrode is warmed as well. This warming and the built-in electrical field tend to prevent the diffusion process up to a halt at a steady state. This steady state condition exists untill the heated source is switched off.

3. This third process is actually a recombination of excited additional charged carriers.

This three-step process may be described, in general, by the Continuity and Poisson's equation,

$$\nabla J + \frac{\partial Q}{\partial t} = 0$$

$$\nabla E = \frac{Q}{\varepsilon_0 \varepsilon_r}$$

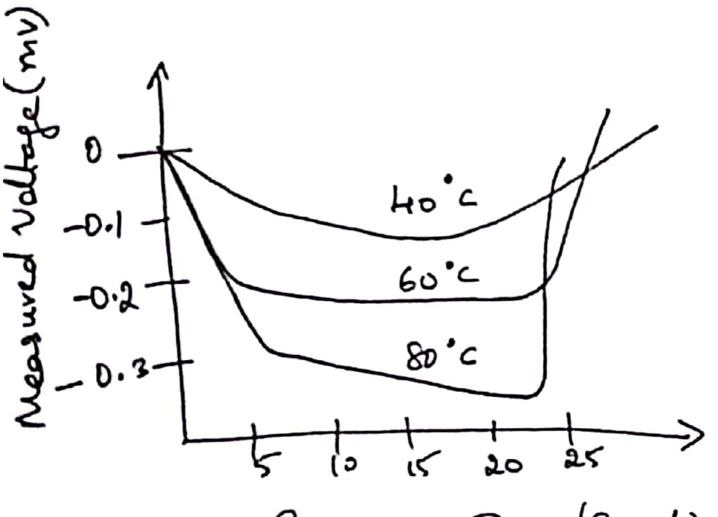
where, $Q \rightarrow$ uncompensated charge density excited by the heated electrode.

$J \rightarrow$ Current density.

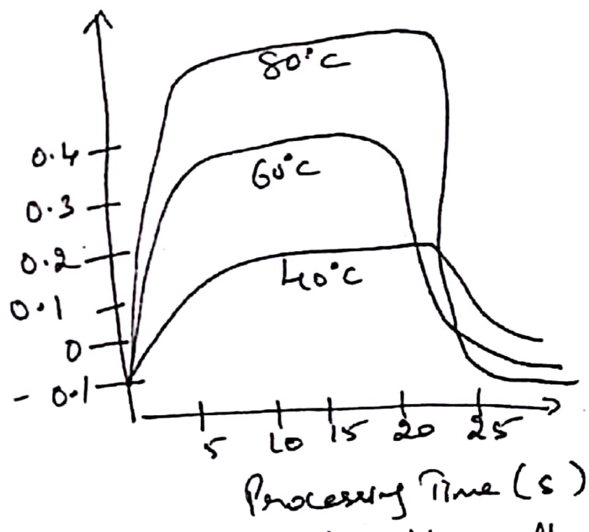
$\varepsilon_0 \rightarrow$ absolute permittivity.

$\varepsilon_r \rightarrow$ relative permittivity.

$E \rightarrow$ built-in electrical field.



(a) as deposited film of p-type



(b) thermally treated film of N-type

Hot Probe characteristics for Vanadium Oxide thin films deposited on oxidised Silicon Surface by thermal evaporation.

Capacitance - Voltage Measurements

→ Hillibrand and Gold (1960) first described the use of Capacitance - voltage (C-V) methods to determine the majority carrier concentration in semiconductors.

→ C-V measurements are capable of yielding quantitative information about the diffusion potential and doping concentration in semiconductor materials.

→ The technique employs pn-junctions, metal-semiconductor junctions (Schottky barriers), electrolyte-semiconductor junction metal-insulator-semiconductor junctions capacitors, and MIS field effect transistors.

→ C-V measurements yield accurate information about the doping concentrations of majority carriers as a function of distance (depth) from the junction.

Principle

→ The capacitance at an p-n or metal-semiconductor junction depends on the properties of the charge-depletion layer formed at the junction.

→ The depletion region is in the viscinity of the pn junction and is "depleted" of free carriers due to the drift field required to maintain charge neutrality.

Experiment.

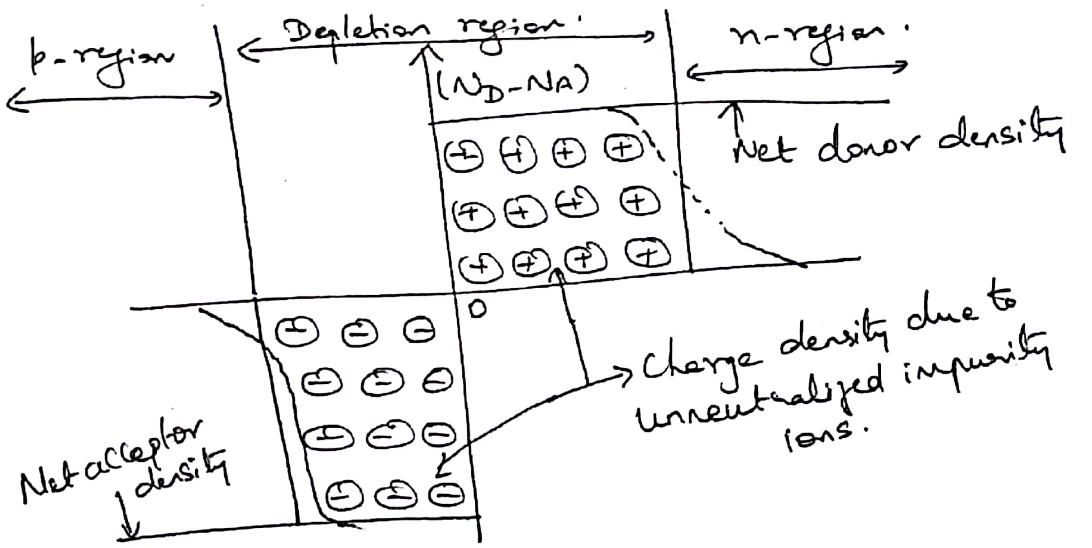
→ As shown in figure, an abrupt pn junction is considered.

→ The bandgap of the semiconductor $E_G = E_C - E_V$ is defined by the difference between the conduction band energy E_C and the valence band energy, E_V

→ The fermi energy E_F defines the equilibrium condition for charge neutrality.

The difference in energy between the conduction band as one crosses the pn junction is called the diffusion potential, V_{bi} (built-in potential).

A



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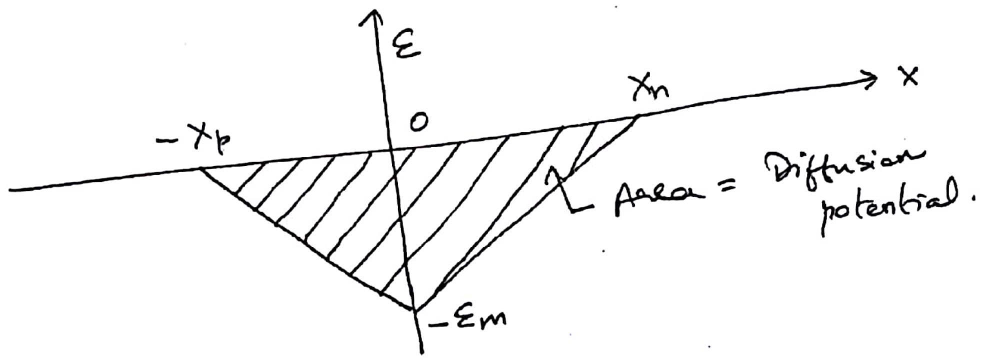
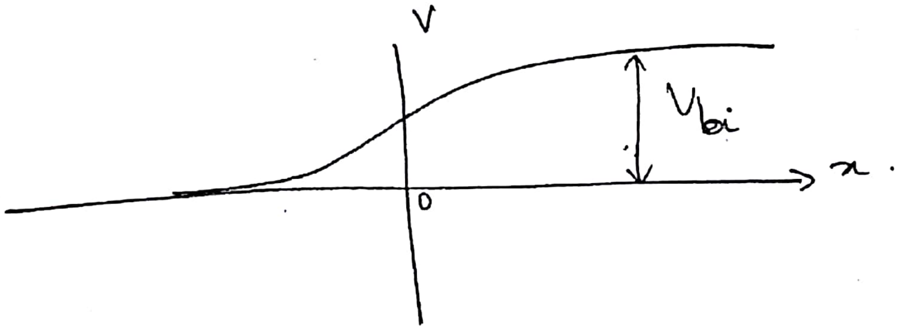


C



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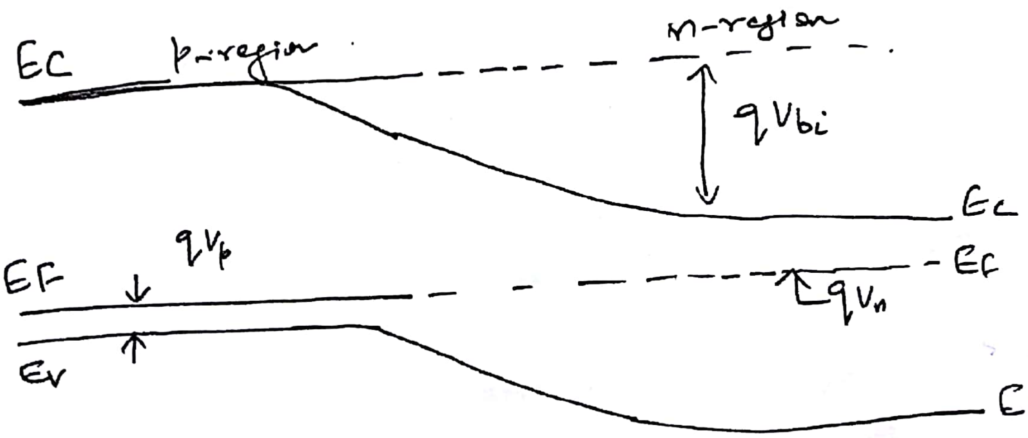

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Diagram Explanation:

Abrupt pn junction in thermal equilibrium (no bias).

A. Space charge distribution in the depletion approximation. The dashed lines indicate the majority carrier distribution tails.

B. Electric field accross the depletion region.

C. Potential distribution due to the electric field where V_{bi} is the (built-in) diffusion potential.

D. Energy band diagram.

→ Consider the pn junction, where the regions denoted by ⊕ and ⊖ indicate the junction region depleted of free carriers, leaving behind ionized donors and acceptors.

→ In this region, from Poisson's equation

$$-\frac{\partial^2 V}{\partial x^2} = \frac{\partial E}{\partial x} = \frac{\rho(x)}{\varepsilon} = \frac{q}{\varepsilon}\left[p(x) - n(x) + N_D^+(x) - N_A^-(x)\right]$$

→ For predominantly doped p-type

$$-\frac{\partial^2 V}{\partial x^2} \approx \frac{q}{\varepsilon} N_D^+ \quad \text{for } 0 < x \leq x_n$$

→ and for n-type

$$-\frac{\partial^2 V}{\partial x^2} \approx \frac{q}{\varepsilon} N_A^- \quad \text{for } (-x_p \leq x < 0)$$

where, V → voltage, E → electric field.
q → electronic charge,
$p(x)$ & $n(x)$ → the hole and electron concentrations (electric potential) comprising the mobile carriers.

Deep-Level Transient Spectroscopy. (DLTS)

→ Defects are responsible for many characteristic properties of a SemiConductor. They play a Crucial role in determining the viability of a given material for device applications.

→ The performance and reliability of devices can be significantly affected by only minute concentrations of undersirable defects.

→ Deep-level transient Spectroscopy (DLTS) probes the temperature dependance of the charge carriers escaping from trapping centers formed by the point defects in the material.

Principle.

→ Deep-level transient Spectroscopy was first introduced in 1974, by Lang.

→ The basis of this method is the dependence of the Capacitance of a Space-charge region on the occupancy of the traps within the space-charge region in a Semiconductor.

→ Under a non-equilibrium Condition such as that existing in a Space-charge region, a trapped Carrier can escape from a trapping center by thermal excitation to the nearest energy band.

Experiment.

→ To characterize a Semiconductor, it is neccessary to fabricate a junction diode such as pn- or Schottky barrier diode on material of interest.

→ A Space-Charge region is formed by reverse biasing the p-n or schottky diode. The diode is initially ... reverse biased to empty the traps.

→ When the bias across the junction is reduced (or even forward biased), the width of the space-charge region is reduced.

→ An equilibrium condition is established in the neutralized region with the majority carriers populating the traps.

→ When the reverse bias is restored, the space-charge region is again created as before, with only difference being that there are trapped carriers now residing in the defect centers within the space-charge region.

→ The non-equilibrium condition thus created causes the trapped carriers to be thermally re-emitted to the relevant energy band.

→ The rate of thermal emission, or "detrapping", of a carrier is temperature dependent.

→ The change of occupancy of these trapping centers is reflected in the capacitance of the junction producing a capacitance transient.

→ Minority-carrier injection can also occur when the junction is forward biased during the bias pulse.

→ Since both the majority and minority charge carriers are involved, which makes this method all more effective because emission of each type of carrier can be detected by monitoring the capacitance transients.

→ The activation energy of the trap, or the depth of the trapping level from the nearest energy band edge, and the capture cross-section can be determined from the temperature dependance of emission rate.

→ The trap concentration can be determined from the intensity of the capacitance peak, and the polarity of the carriers can be found from the sign of the capacitance change.

Instrumentation:

→ As the trapped electrons are emitted into the conduction band following the termination of the bias pulse, the capacitance of the junction will decay exponentially with a time constant τ_n according to the equation

$$C(t) = C(0)\, e^{-t/\tau_n}$$

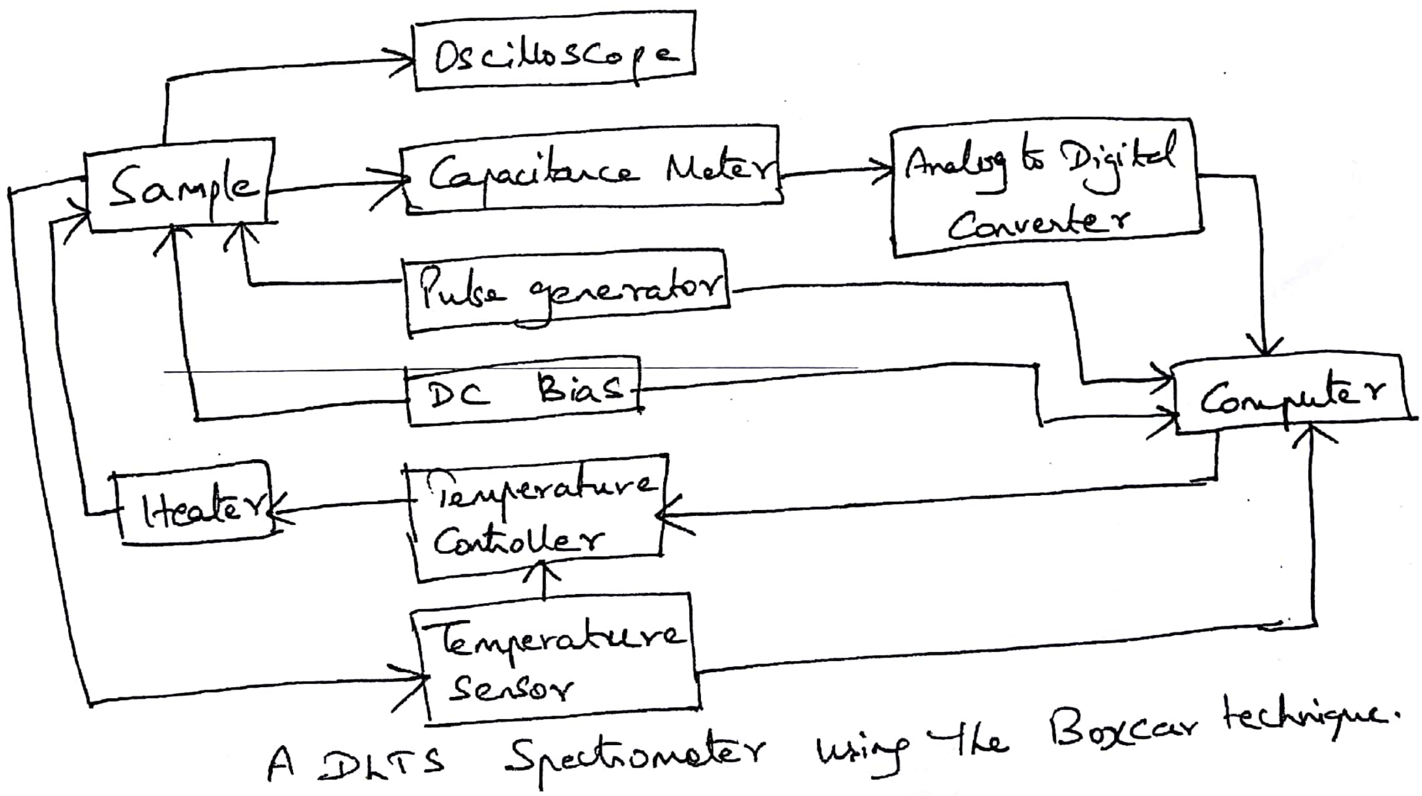
→ But $e_n = \frac{1}{\tau_n}$

then, $$C(t) = C(0)\, e^{-e_n t}$$

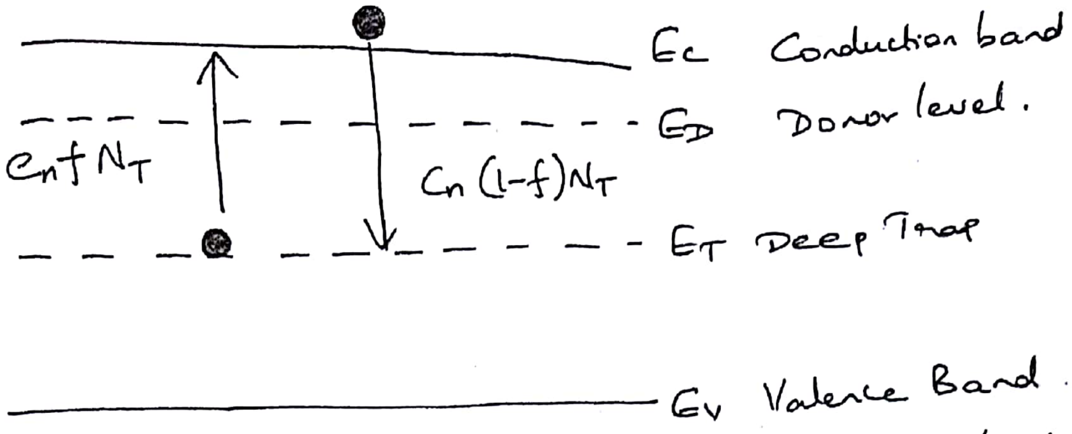
→ If the decaying capacitance transient is measured at two different time delays t_1 and t_2 from the termination of the bias pulse, then the difference in the capacitances will be given by

$$S = \Delta C = C(t_1) - C(t_2) = C(0)\left(e^{-e_n t_1} - e^{e_n t_2}\right)$$

→ The capacitance difference S is the DLTS signal.



A DLTS Spectrometer using the Boxcar technique.



Electron transitions between the trapping level and the conduction band.

→ The rate of electron Capture

$$\frac{dc_n}{dt} = n\, V_{th}\, \sigma_n\, (1-f)\, N_T$$

Where, C_n → Capture probability.
σ_n → electron Capture Cross-section
V_{th} → thermal Velocity.
n → electron Concentration.
$(1-f)$ → probability that a trap is vacant.
f → fermi-Dirac probability factor (a fraction of total Concentration of traps N_T is filled)

→ The electron detrapping rate

$$\frac{de_n}{dt} = e_n N_T^- = e_n f N_T$$

Where, e_n → electron emission rate
N_T^- → Concentration of occupied traps N_T^-

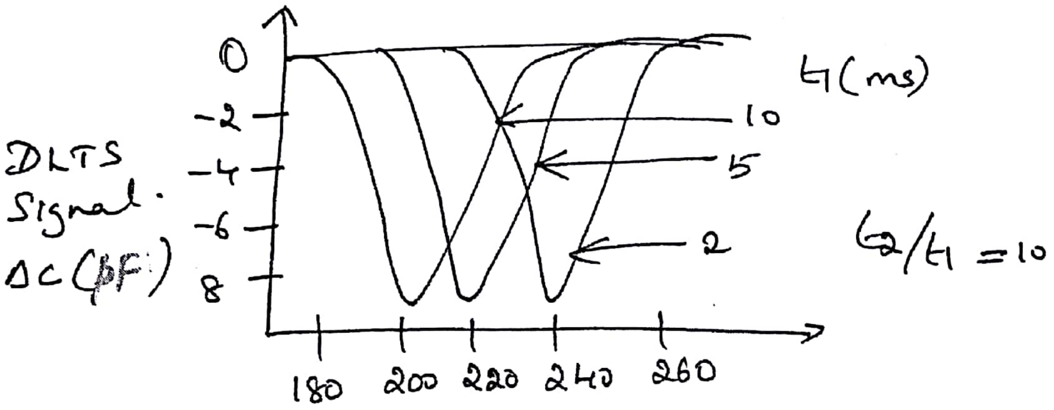
By monitoring the DLTS Signal s, as a function of temperature, it is observed that at low temperatures ($T \ll T_m$) and at high temperatures ($T \gg T_m$), the signal is very small.

→ However, at an intermediate temperature T_m, the signal will go through a maximum value. At this temperature,

$$\frac{ds}{dT} = \frac{ds}{de_n} \times \frac{de_n}{dT} = 0$$

Therefore, $\frac{ds}{de_n} = -t_1 e^{-e_n t_1} + t_2 e^{-e_n t_2} = 0$

which gives, $e_n = \frac{\ln (t_2/t_1)}{t_2 - t_1}$



→ By varying t_2 and t_1, but keeping the ratio t_2/t_1 constant (thus changing to different value of e_n) and repeating the temperature scan, a different curve will be obtained, with signal S peaking at different temperatures T_m.

Scanned by CamScanner

$N_D(x)$ & $N_A(x)$ → the donor and acceptor doping concentrations.

$\varepsilon = K_s \varepsilon_0$ → the permittivity with dielectric coefficient K_s

→ The spatial dependence, x, is measured relative to the physical location of the p-n junction.

→ The solution of these equations in a form useful for C-V measurement is

$$V(x) = V_{bi}\left[2\left(\frac{x}{W}\right) - \left(\frac{x}{W}\right)^2\right]$$

where, $$V_{bi} = \frac{kT}{q}\ln\left(\frac{N_A N_D}{n_i^2}\right)$$

Photoluminescence

→ When a Crystalline Solid absorbs energy (usually in the form of radiation) and re-emits it in the visible (or nearly visible) region of the Spectrum, this phenomenon is Called as luminescence

→ It is a two step process:
(i) excitation of electrons from a lower energy state to a higher energy state as a result of absorption of energy.
(ii) emission of light radiation when the electrons fall back to a lower energy State

→ When the luminescence is produced by the bombardment of photons of an electromagnetic radiation lying in the range from infrared to X-rays, it is Called photoluminsecence

→ The time during which the luminescence is observed, depends on the time interval between the acts of excitation and emission.

→ If the emission takes place within 10^{-8} seconds of excitation or if the emission takes place as long as the excitation is maintained, the phenomenon is Called ~~floor~~ fluorescence.

→ If the luminescent emission Continues for Some time even after the excitation has been removed, it is known as phosphorescence or afterglow.

Module - 5

Density of States in 2D, 1D & 0D Systems

Density of states gives the number of allowed energy state for electron/hole in the given Energy (E) per unit volume of given system

We know that density of states in 3D system = $\boxed{\frac{8\pi\sqrt{2}}{h^3}(m)^{3/2}\sqrt{E}}$

But most of the semiconductors device today were based on 2D, 1D & 0D systems

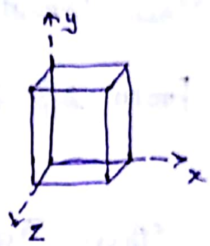
Example for 2D system = Quantum well were electrons are confined in 1 Dimensions

Example for 1D system = Quantum wire were electrons are confined in 2 Dimensions

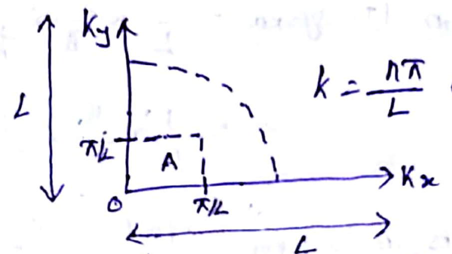
Example for 0D system = Quantum dot were electrons are confined in 3 Dimensions

(1) Density of States in 2D

Consider a 2D system of Quantum well.



Let the k-spacing for 2D system is given by



$k = \frac{n\pi}{L}$ where $n = 1, 2, 3 \ldots$

In k space diagram - Each Energy state occurs at π/L

Then Area $= (\pi/L)^2$

Let us first find the number of states in k space by considering circle with radius 'k' then

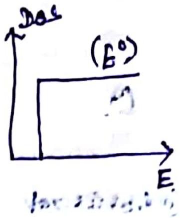
$$N = \frac{\left[\frac{1}{4}^{th}\text{ Area of circle}\right] \times \text{Electron spin}}{\text{Area of Energy State}}$$

$$N = \frac{1}{4}\pi k^2 \times \left(\frac{L}{\pi}\right)^2 \times 2$$

Diff w.r.to. k $\quad \frac{dN}{dk} = \frac{L^2}{\pi} k$

Then Density of States in 2D Systems $= \frac{dN/dE}{A} = \frac{1}{A} \cdot \frac{dN}{dk} \cdot \frac{dk}{dE}$

To find dk/dE we know that $E = \frac{\hbar^2 k^2}{2m}$



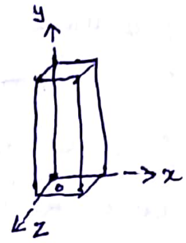
$$\frac{dE}{dk} = \frac{\hbar^2 k}{m} \Rightarrow \frac{dk}{dE} = \frac{m}{\hbar^2 k}$$

$\therefore$ Density of State in 2D System $= \frac{1}{L^2} \times \frac{L^2 k}{\pi} \times \frac{m}{\hbar^2 k} = \frac{m}{\hbar^2 \pi}$

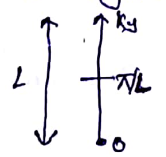
Density of States in 2D System $= \frac{4\pi^2 m}{h^2 \pi} = \boxed{\frac{4\pi m}{h^2}}$ $\left[\because \hbar^2 = \frac{h^2}{4\pi^2}\right]$

(ii) Density of States in 1D Systems

Consider 1D system of Quantum wire.



Let the k-spacing for 1D system is given by



Number of energy states is given by $(N) = 2 \times k \times \left(\frac{L}{\pi}\right)$

Diff. w.r. to dk $\left(\frac{dN}{dk}\right) = \frac{2L}{\pi}$

Then Density of States in 1D Systems $= \frac{dN/dE}{A} = \frac{1}{A} \cdot \frac{dN}{dk} \cdot \frac{dk}{dE}$

From 2D systems we know $\frac{dk}{dE} = \frac{m}{\hbar^2 k}$ where $k = \frac{\sqrt{2mE}}{\hbar}$

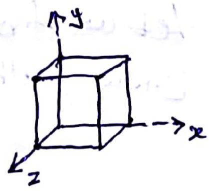
Then Density of States in 1D system $= \frac{1}{L} \times \frac{2L}{\pi} \times \frac{m}{\hbar^2 \left[\frac{\sqrt{2mE}}{\hbar}\right]}$

$$= \frac{1}{L} \times \frac{2L}{\pi} \times \frac{m \times 2\pi}{h\sqrt{2mE}}$$

Density of States in 1D system $= \boxed{\frac{2\sqrt{2}\,(m)^{1/2}\,(E)^{-1/2}}{h}}$

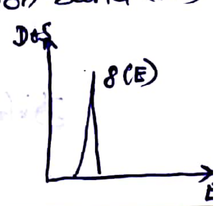
(iii) Density of States in 0D Systems

Consider 0D systems of Quantum dot.



We cannot plot k-spacing for 0D as all three dimensions are reduced. Hence energy states cannot be determined excatly

But considering a δ function, Energy of Conduction band (E_c) and the total energy of system as (E) we write



Density of States in 0D Systems $= \boxed{2 \times \delta(E - E_c)}$

Introduction to Low dimensional systems

Refers to development and Production of Components at small Scale (1 - 100 nm). It refers one billionth of something or 1 nm = 10^{-9} m. The technology used to manipulate matters at atomic level to produce low dimensional systems to achieve some properties is called Nanotechnology

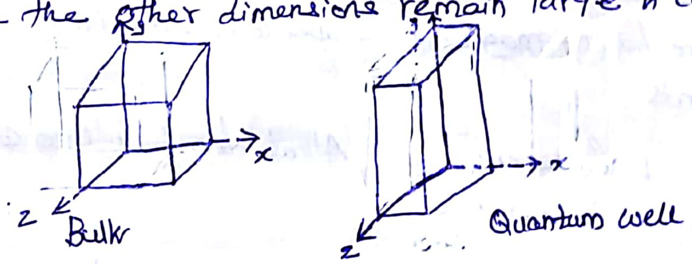
When Surface to volume ratio increases for low dimensional systems it results better chemical, electronic, magnetic, catalytic, Optical & mechanical properties

(Eg) For bulk matter - Gold - melting Point is 1064°c
For nano meter → (2nm) Gold particle - melting point is 680°c
For bulk cdse Crystal - Eg is 2.52 eV
For 4.4 cdse crystal - Eg is 2.14 eV

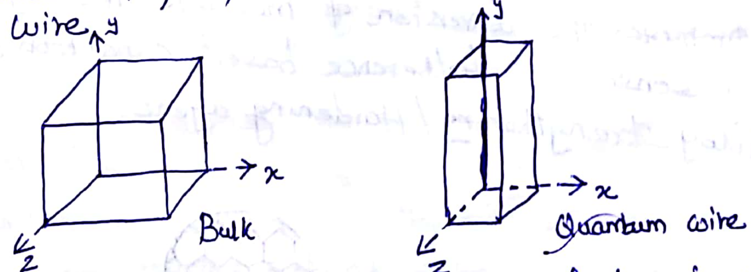
Types of low dimension systems

classified as Quantum Well, Quantum wire and Quantum dot

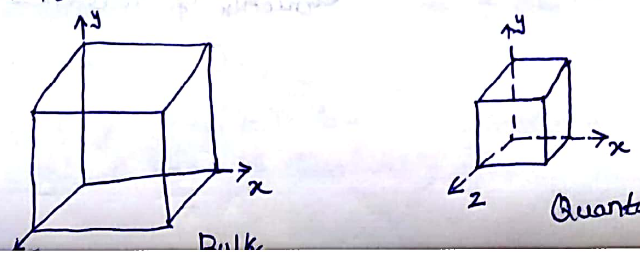
1) Quantum well - If one dimension is reduced to nanometer range while the other dimensions remain large it called Quantum well.



2) Quantum wire - If two dimensions are so reduced and one dimension remains large, the resulting structure is referred as quantum wire.



3) Quantum dot - The process in which size reduction in which all three dimensions reach the low nanometer range is called Quantum dot.



In Quantum well, exciton can move freely in 2-dimension. In Quantum wire the exciton can move freely in 1-dimension & in Quantum dot exciton cannot move freely in any direction

Two common approaches to synthesis Low dimensional systems

Top down approach – Large scale object in which atoms are vaporized and are coated on substrate

Bottom up approach – The individual atoms and molecules are collected through controlled chemical reactions and structures are formed.

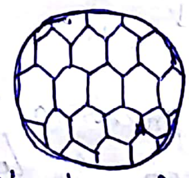
Introduction to Novel low dimensional systems

I) Fullerences – New allotropy of carbon in which atoms are arranged in closed shell and was discovered in year 1985. It was initially named as Buckminister fullerence (as Buckminister fuller who designed geodesic domes in 1960)

Different forms of fullerenes are C_{60}, C_{70}, C_{76}, C_{84} and most abundant 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, endohedral fullerence, Exohedral fullerence

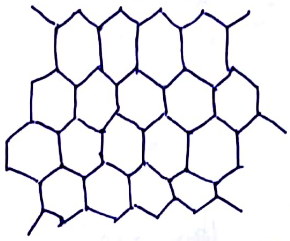
Applications of fullerence – Used for hydrogen or oxygen storage (hydrogenation of fullerence produces hydrides), as catalyst (promotes the conversion of methane into higher hydrocarbons), as sensors (fullerence based capacitor detects ppm of H_2S in N_2) Alloy strengthening / Hardening agent.



Structure of fullerences.

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 (0.33~0.36nm) Stronger than diamond ($Y = 1.3 TPa$). Better than Copper in electrical Conduction ($\rho = 10^{-6} \Omega m$ & $\mu = 2 \times 10^5 cm^2 V^{-1} s^{-1}$)



2D Dimensional Graphene

Properties of Graphene

1) Perfect thermal Conductor (> 5000 W/m/k) & thermal Conductivity is isotropic. 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 functionalized by several Chemical group forming Graphene Oxide & Fluorinated Graphene

5) Edge of Graphene has more reactivity than surface

Applications 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 Nano tubes (CNT)

CNT was discovered in 1991 by Japanese Electron microscopist Sumio Iijima. While studing the matrial deposited on the Cathode through arc-evaporation synthesis of fullerenes, found that central Core of cathode deposite Contained a variety of Closed graphite Structure called Carbon Nano Tube (CNT).

CNT are sheet of graphite rolled in Cylindrical form (or) Constructed from hexagonal rings of Covalently bonded Carbon / graphene 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) Arm chair-(n,n) Tube, (2) Zig-Zag-(n,0) tube and (3) Chiral-(n,m) Tube. These geometries can be classified by how the carbon sheets 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 surface. Reactivity is directly related to the pi-orbital mismatch caused by an increased curvature. Therefore side walls 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. The 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 Young's modulus in their axial direction. The Young's 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 large. It is expected that other properties are influenced by these parameters too.

Other 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 three 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 & 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 order to aid synthesis. This method provides ropy & multiwalled CNT.

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

Applications 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 rechargeable lithium batteries is electrochemical intercalation and deintercalation of lithium in both electrodes. Single walled CNT shown to posses 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 device – can be constructed of only one semiconducting SWNT. By applying voltage to the gate electrode, the nanotube can be switched from a conducting to an insulating state. Such CNT 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 posses all these properties if the fabrication process and synthesis conditions are optimized.

5) Nanoprobes – Nanotubes 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.

6) 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 changes.

7) Composite materials – Theoretically single walled CNT's could have Young's modulus of 1TPa. Multiwalled CNTs are weaker because the individual cylinders slide with respect to each other. Single walled CNTs are highly flexible & sustain large strains 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. Microfabrication processes widely uses CVD to deposit materials in monocrystalline / polycrystalline / Amorphous / Epitaxial form.

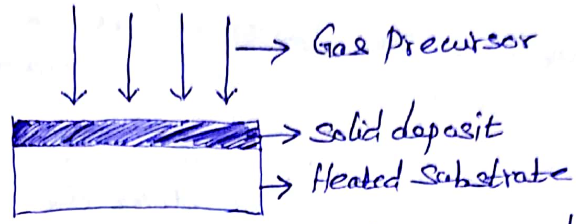
Working concept – results from the chemical reaction of gaseous precursor (source) at a heated substrate to yield a fully dense deposit. Thermodynamics and kinetics drive both precursor generation and decomposition. (ie) Control through temperature, pressure & concentration yields the desire deposit.

For Metal deposition Metal halide (gas) → metal (solid) + byproduct (gas)

For Ceramic deposition Metal halide (gas) + O_2/C_2/N_2/B_2 (gas) → Ceramic (solid) + byproduct (gas)

Steps involved in CVD System for material process /deposition

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



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

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

Hetrogeneous Reaction - Reaction that takes place at the substrate surface thereby helps to creat good-quality films.

In short hetrogeneous reaction are much more desirable than homogeneous reaction during CVD.

Types of CVD - reaction & processing condition classified as

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

Advantages of CVD - Used to coat wide range of metals/ceramics, to fabricate complex shapes, coating free standing structures, controllable thickness & morphology, Coats multiple components & Powders.

Applications — wide range of industrial components like aircraft & land gas turbine blades, chemical implant items, parts of atomotive industry. Apart from this

1) Used to do surface modification to prevent adhesion
2) Photoresist adhesion for semiconductor wafer
3) Coppe Copping & Anti corrosive coatings
4) Promote biocompatibility between natural and synthetic materials

2) Physical Vapour deposition - (PVD)

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

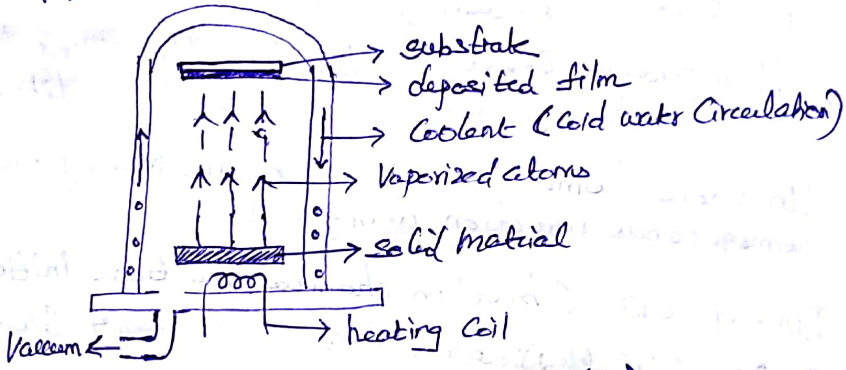
Working concept - Process is carried out under vacuum condition which involves four steps

1) Evaporation - Target matrial to be deposited is vaporized by high energy source using electron beam (or) beam of ions.

2) Transport - The vaporized atoms are moved from target matrial to the substrate in straight line affair.

3) Reaction - In some cases like metal oxide, nitrides, carbides coating, the vaporized atoms are reacted with appropriate gas during transport stage.

4) Deposition - Here the vaporized atom reacts on surface and builds up thin films on substrate.



Types of PVD (in the order of increasing novelty)

1) Evaporation Deposition
2) Electron beam PVD
3) Sputter deposition
4) Cathodic Arc deposition
5) Pulsed Laser deposition

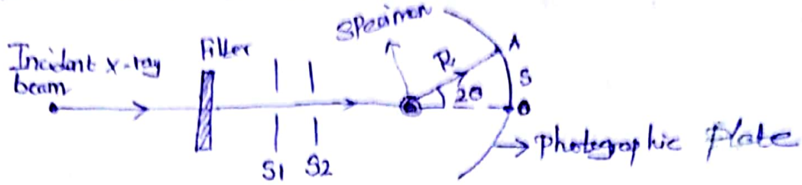
Advantages - Improved properties can be achieved, Any type of inorganic and organic matrial coating, process is environmentally friendly than electroplating, used to improve oxidation/wear resistance

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

Disadvantages - High capital cost, operates at high vacuums, requires large heat & appropriate cooling systems.

Characterization techniques for low dimensional materials

1) Powder X-ray diffraction technique - 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.

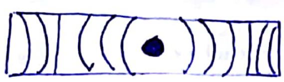


In this method, finely powdered specimen in thin walled glass capsule, X-ray from from Source are made approximately monochromatic by filter 'F' (usually Zirconium oxide). The narrow beam of monochromatic X-rays is suitably collimated by the two lead sheets S_1 & S_2. Then the beam is made to fall on 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 circumference in order to record the beams diffraction upto 180°.

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

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

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 arcs of the photographic plate.


→ Trace on photographic plate

Structure determination of crystal:

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

$$2\theta = \frac{S}{R} \text{ radian (ie) } 2\theta = \left(\frac{S}{R}\right) \times \left(\frac{180}{\pi}\right) \text{ degree}$$

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

Applications: employed to study microcrystalline substance like metals, Alloys, Carbons and other forms where single crystals are not available.

2. Electron Microscopy technique

An Scientific instrument that use a beam of highly energetic electrons to examine objects on a very fine scale. The main advantage is unusual short wavelength of electron beam substituted for light wave. The wavelength of about 0.005 nm increases the resolving power of instruments to fractions of a nanometer.

The examination yields following informations

1) Topography - Surface feature of specimen
2) Morphology - 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.

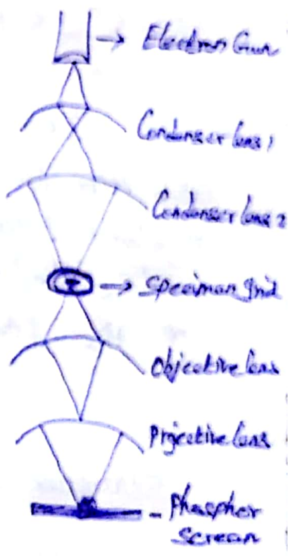
Two types of Electron microscopy technique

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 projector) 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 focussed to a small, thin coherent beam by condenser lens 1 & 2. First one decides the size & second one decides the brightness

3) The beam strikes the specimen & parts are transmitted. The transmitted 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

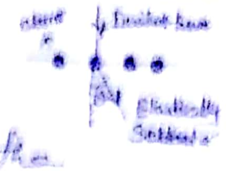
Specimen Interaction with electron beam & uses

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

(c) For thicker specimen - fewer unscattered electrons appears (dark)
For thinner specimen - more unscattered electrons 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 atomic spacing will be scattered by the same angle. When recorded, each spot on photographic plates represents atomic spacing & crystal phase

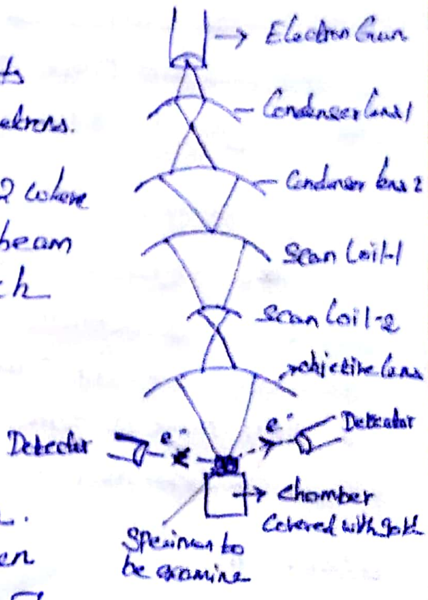
3) Inelastically scattered electrons - Incident electron that interacts with specimen atom in inelastic fashion, loosing energy during interaction & transmitted

Uses : Inelastic loss of energy by the incident electrons is characteristics of the elements of specimen, thus gives compositions of elements in specimen. Also bands of alternately bright and dark lines formed by inelastic scattering relates the atomic spacing in specimen.

2) Scanning Electron microscopy (SEM)

SEM allows surfaces 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 where 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.

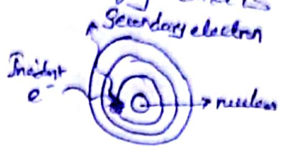
3) Then objective lens focuses the scanned beam onto the part of specimen. When electrons interact with specimen and are detected by detectors (1 & 2). The process is repeated to scan entire area. (Entire pattern is scanned 30 times per second)

Specimen interaction with electron beam and uses

1) Backscattered electrons – Incident electron colliding with an atom in specimen is then scattered backward 180°

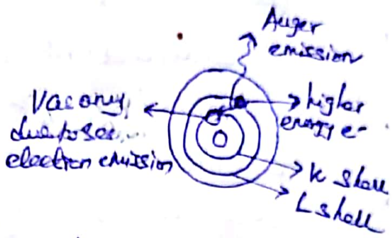
Uses : Backscattered electron varies with specimens atomic number. Different backscattering causes higher atomic number elements to appear bright than lower atomic number elements. These interaction in different parts helps to find average atomic number

2) Secondary electrons – Incident electron passing near the atom imparts energy to lower k-shell electrons of atom. These ionized electron then leaves the atom with small kinetic energy and 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 electrons – Caused by de-energization 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 electrons.



Uses : Auger electron energy have a characteristic energy, unique to each element from which it was emitted from and thus gives compositional information about specimen.

Atomic Force microscopy (AFM)

Also called scanning force microscope (SFM). AFM raster scans a sharp probe over the surface of a sample and measure the changes in force between the probe tip and the sample.

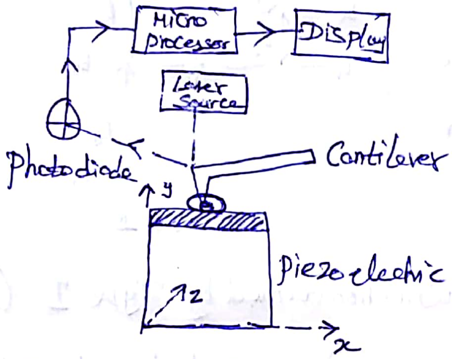
Working Concept

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

Construction

AFM consist of cantilever with a sharp tip. The tip should have radius of curvature less than 20-50 nm. The movement of the tip (or) sample in x, y & z direction is controlled by a piezo electric tube scanner. The typical scanner range is 80μm x 80μm in x-y plane & 5μ in z-direction. The force that are exerted between tip and sample are measured by the amount of bending of the cantilever.

Working – The sample is mounted on a piezoelectric scanner, which ensures three-dimensional positioning with high resolution. The force is monitored by attaching the probe to a pliable cantilever, which acts as spring & 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 gives 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 nm and vertical resolution to 0.05 nm.
To study powder catalysts; aggregate structural determinations
Metal – tooling studies, roughness, corrosions etc,

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

Disadvantages – AFM scanning depth is less (μm) and scanning area is (150x150 μm). Quality of image is limited by radius of curvature of probe. Scanning time is slow compared to SEM.

Hetro Junctions – defined as junctions of two (or) more semi-conductor materials, each with a different bandgap. In homo junction both sides of the junctions are made of same material

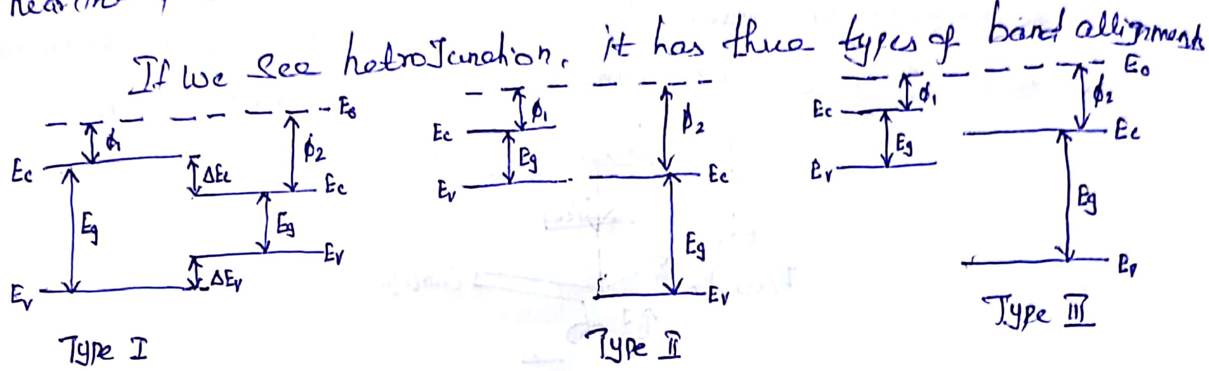
Commonly used hetro junctions are nP, Pn, Nn, PP hetro junctions. Here (n, p) refers semiconductors with a relatively narrow forbidden band and (N, P) refers semiconductors with a wider forbidden gap
nP & Pn → Anisotype hetro junction
Nn & pP → Isotype hetro junction

HetroJunction 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 hetroJunction

In normal pn Junction after placing the P-type & 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.

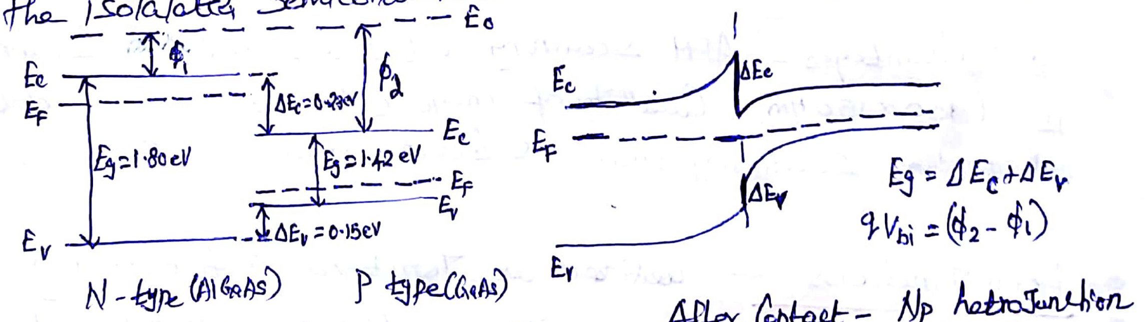
If we see hetroJunction, it has three types of band allignment



If we consider hetroJunction formed by Type I (Np or nP)

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

For Example, if energy band diagram of Np HetroJunction [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 workfunction of the isolated semiconductors.



Befor Contact (Np type material)

After Contact – Np hetroJunction
Np denotes E_g of $(N > P)$ semiconductor
Example – AlGaAs : GaAs

Similarly band diagram for pN, nN, Pp HetroJunctions are drawn.

0 SRM INSTITUTE OF SCIENCE AND TECHNOLOGY, RAMAPURAM CAMPUS, CHENNAI

DEPARTMENT OF PHYSICS

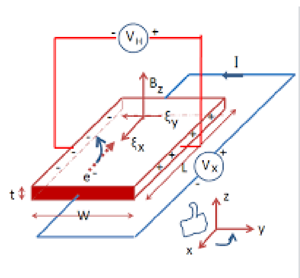
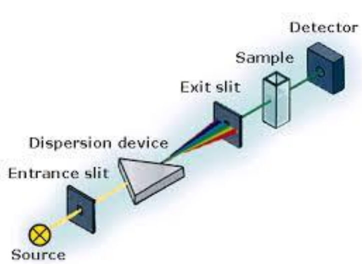
QUESTION BANK

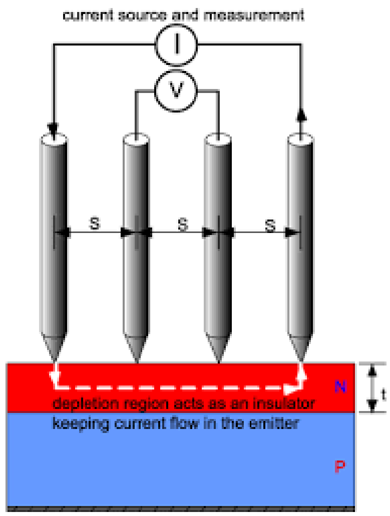
18PYB103J- SEMICONDUCTOR PHYSICS

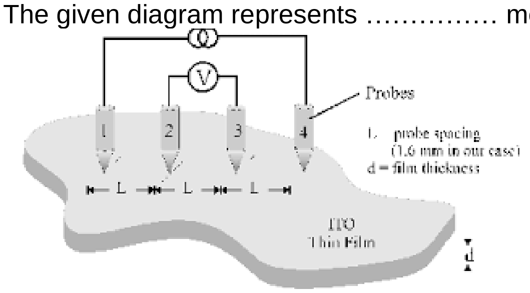
UNIT 4

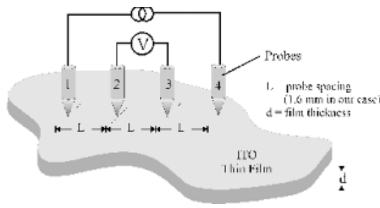
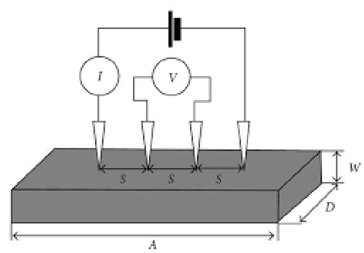
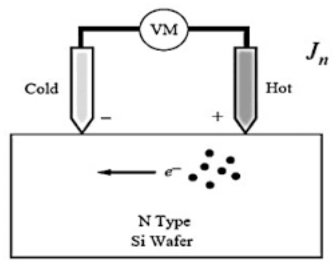
PART A-ONE MARK QUESTIONS

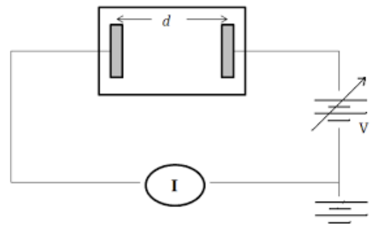
QUESTION NO.	QUESTIONS
1	In a …………., the electrons are ejected from photosensitive surface and are amplified within the cell. (A) Photodiode (B) Bolometer (C) Electrode **(D) photomultiplier tube**
2	Alkali metals and their oxides are best ………… materials. **(A) Photo emissive** (B) Conducting (C) Insulating (D) Semiconducting
3	The crystalline solids absorbs energy and re-emits it in the visible region of the spectrum is called ……………... (**A) Luminescence** (B) Photon emission nn (C) Phonon emission (D) Radiation
4	……………….. Spectroscopy can be used to determine the concentration of absorbs in a solution. (A) Gamma (B) IR (C) Microwave **(D) UV Vis**
5	An ideal monochromator should have an ………… narrow effective bandwidth. **(A) infinitely** (B) Small (C) Zero (D) finite
6	……………….. is an instrumentation used to determine the traps in semiconductors (a) TGA **(B) DLTS** (C) DTA (D) IR

7	………… is used for separating source radiation wavelengths. (A) Detector (B) Antenna **(C) Monochromator** (D) Display device
8	In ……………. the conductivity increases with increasing temperature (A) IR (B) DTA (C) Phonos **(D) Semiconductors**
9	In ……………… semiconductor, the Hall coefficient is negative (A) P-type (B) Dilute **(C) N-type** (D) Magnetic
10	The given diagram represents …………….. effect  **(A) Hall effect** (B) Thermoelectric effect (C) Faradays effect (D) Photoelectric effect
11	The given diagram represents instrumentation of ………….. spectroscopy  (A) IR (B) NMR (C) Gamma ray **(D) UV**
12	The given diagram represents …………….. experiment

	 **(A) Four probe** (B) Hall effect (C) Two probe (D) DMS
13	………………… law states that, when a beam of monochromatic light passes through an absorbing medium, the rate of decrease in intensity with the thickness of the medium, is proportional to the intensity of light. (A) Snell's (B) Beer's **(C) Lambert's** (D) Photoelectric
14	A ……………….. is a method of determining quickly whether a semiconductor sample is n (negative) type or p (positive) type (A) Electrolysis **(B) Hot probe method** (C) Hydrogenation (D) Rectification
15	The ……………….. method is used to measure the resistance (A) Hydrogenation (B) Rectification **(C) Vander Pauw** (D) Electolysis
16	The energy gap in a semiconductor is also called as ………… **(A) Forbidden gap** (B) Large gap (C) Narrow gap (D) Electrical gap

17	The ……………… is the ratio of the voltage measured across the sample to the current driven through the sample (A) Capacitance **(B) resistance** (C) Inductance (D) capacitor
18	The given diagram represents …………… method  **(A) Vander Pauw** (B) Electolysis (C) Hydrogenation (D) Rectification
19	For determining the resistivity of a semiconductor, the diameter of contacts between the probe and the semiconductor should be ………………………. the gap between the probes. **(A) Smaller Than** (B) Greater than (C) Equal to (D) Double
20	……………….. is a technique for characterizing semiconductor materials and device, where the applied voltage is varied, and the capacitance is measured and plotted as a function of voltage. **(A) Capacitive – voltage profiling** (B) Current profiling (C) Voltage profiling (D) Baising

QUESTION NO.	QUESTIONS
21	Identify the resistivity measurement by four probe linear method (A)  This technique is commonly used to measure the resistivity and the Hall coefficient of a sample **(B)**  **This technique involves using four equally-spaced,known as a four-point probe to make electrical contact with the material.** (C)  The method of determining quickly whether a semiconductor sample is n type or p type. A voltmeter or ammeter is attached to the sample, and a heat source, such as a soldering iron, is placed on one of the leads. (D)

	 This Method is one of the standard and most commonly used method for the measurement of resistivity of very high resistivity samples like sheets/films of polymers
22	Illustrate the properties of Photoluminescence …………….. (I) The Principle of this method is based on the absorption of ultraviolet light or visible light by chemical compounds, which results in the production of distinct spectra. Spectroscopy is based on the interaction between light and matter. (II) It is a process in which a molecule absorbs a photon in the visible region, exciting one of its electrons to a higher electronic excited state, and then radiates a photon as the electron returns to a lower energy state. (III) This method is routinely used in analytical chemistry for the quantitative determination of different analytes, such as transition metal ions, highly conjugated organic compounds, and biological macromolecules. (IV) It is the spontaneous emission of light from a material following optical excitation. It is a powerful technique to probe discrete energy levels and to extract valuable information about semiconductor sample composition, quantum well thickness or quantum dot sample mono dispersity. (A) All the four Incorrect (B) Both II and III correct (C) Both III and I correct **(D) Both II and IV correct**
23	Analyse the device Photoemissive cell I) This cell is commonly known as a phototube, makes use of the photoelectric effect, the phenomenon whereby light-sensitive surfaces give off electrons when struck by light. These cells are sometimes called photocells or electric eyes. (II) This is is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect, which is a physical and chemical phenomenon.

	(III) In this cell the photons passed their energy in fixed quantities to atoms inside the metal, knocking some of their electrons out of them, so producing an electric current. The photons need a minimum threshold frequency to free electrons and produce an effect, known as the work function. (IV) These are the class of vacuum tubes, and more specifically vacuum phototubes, are extremely sensitive detectors of light in the ultraviolet, visible, and near-infrared ranges of the electromagnetic spectrum. These detectors multiply the current produced by incident light by as much as 100 million times or 108 (i.e., 160 dB)[1], in multiple dynode stages (A) Both I and II correct **(B) Both I and III correct** (C) Both II and IV correct (D) Both I and II correct
24	Point out the applications of Uv- Vis Spectroscopy. (I) Quantitative and not Qualitative analysis. (II) Determination of molecular weight. (III) Determination of molar absorbance coefficient. (IV) Determination of known compound. (V) Detection of non-functional group. (VI) Detection of isomers and geometrical isomers. (VII) Detection of impurities. (a) The statements I, II, VII and V are correct (b) The statements I, II, VI and V are correct (c) The statements II, III,VI and VII are correct (d) The statements I, V, VI and VII are correct
25 26	If the drift velocity of holes under a field gradient of 100v/m is 5m/s, the mobility is **A. 0.05** B. 0.55 C. 500 D. 50

	A silicon sample is uniformly doped with 10^{16} phosphorus atoms/cm^3 and 2×10^{16} boron atoms/cm^3. If all the dopants are fully ionized, the material is: A. n-type with carrier concentration of $3 \times 10^{16}/cm^3$ **B. p-type with carrier concentration of $10^{16}/cm^3$** C. p-type with carrier concentration of $4 \times 10^{16}/cm^3$ D. Intrinsic
27. 28.	In Photoluminescence process, electrons change energy states by either resonantly gaining energy from absorption of a ……………. or losing energy by emitting ………………. A. Mesons B. Phonons C. Baryons **D. Photons** In hot probe technique, ……………….. probe is connected to the positive terminal of the meter while the …………………. probe is connected to the negative terminal. A. Cold, Hot B. Thick, Thin C. Thin, Thick **D. Hot, Cold**
29 30	The wavelength range used in UV – Vis. Spectrophotometer is …………………………. **A. 200 nm to 2500 nm** B. 200 nm to 3500 nm C. 200 nm to 4000 nm D. 400 nm to 700 nm The Lambert law and Beer law may be combined into single relationship which shows the effect of both ……………….. and ……………of absorbing substance. A. Composition, Refractive Index **B. Thickness, Concentration** C. Elasticity, Plasticity D. Hardness, Isotropy

31.	What is the unit of absorbance which can be derived from Beer Lambert's law? A. $Lmol^{-1}cm^{-1}$ B. $gm^{-1}cm^{-1}$ C. cm **D. No unit**
32. 33. 34. 35.	In conventional DLTS the capacitance transients are investigated by using a …………………………… A. Hartley oscillator B. Cathode Ray Oscilloscope **C. Lock-in- Amplifier** D. Intermediate frequency amplifier The temperature range of the most of the semiconductors to characterize in DLTS is ……………….. **A. 77 K to 380 K** B. 87 K to 380 K C. 77 K to 383 K D. 77 K to 400 K The DLTS is used to characterize …………………. A. Conductors **B. Semiconductors** C. Insulators D. Superconductors To characterize the material in DLTS, it is necessary to form …………………… A. Thin film B. Nano particles **C. PN junction** D. Solution of the material
36.	……………….. is not taking part in CV measurement A. Accumulation B. Depletion C. Inversion **D. Emission**

37.	The leakage current occurs in ………………………. A. Forward Bias **B. Reverse Bias** C. Both forward and reverse bias D. LDR
38.	C-V measurements are capable of yielding information about the ………………………. and concentration of charge carriers A. Drift potential **B. Diffusion potential** C. Bonding D. Crystal structure
39.	The exponential ………………….. in current steeps as the diode current becomes limited by the resistance of undepleted region of diode A. Increase B. Decrease C. Zero D.equals
40.	In linear four probe method the tip of probe diameter is usually ………………….. than the probe spacing A. Larger B. Cooler C. Hotter **D. Smaller**
41.	Van der Pauw technique measures the resistivity and ………………. of the sample A. Coefficient of Friction B. Absorption **C. Hall coefficient** D. Emission
42.	

43.	To identify the nature of semiconductor (p-type or n–type) …………….. methods will be used, A. Two-point method B. Linear four-point method C. Van der Pauw four-point method **D. Hall effect** The leakage current occurs in ……………………… A. Forward Bias **B. Reverse Bias** C. Both forward and reverse bias D. LDR

QUESTION NO.	QUESTIONS
44	Hall Effect is defined as (I) The production of a voltage difference across an electrical conductor, transverse to an electric current in the conductor and to an applied magnetic field perpendicular to the current. (II) The production of a magnetic field across an electrical conductor, transverse to an electric current in the conductor and to the applied voltage perpendicular to the current. (III) The production of a current across an electrical conductor, transverse to voltage in the conductor and to an applied magnetic field perpendicular to the current. (IV) The production of a potential difference across an electrical conductor when a magnetic field is applied in a direction perpendicular to that of the flow of current.. (a) Both I and III correct (b) All the four Incorrect (c) Both II and III correct **(d) Both I and IV correct**
45.	The Hall coefficient of sample (A) of a semiconductor is measured at room temperature. The hall coefficient of (A) at room temperature is $4x10^{-4}$ m^3 $coulomb^{-1}$ .The carrier concentration in sample A at room temperature is A. ~ 10^{21} m^{-3} B. ~ 10^{20} m^{-3}

C. ~ 10^{22} m^{-3}

D. ~ 10^{23} m^{-3}

Applications of Hall effect

46. (I) The probes are often used as magnetometers, i.e. to measure magnetic fields, or inspect materials (such as tubing or pipelines) using the principles of magnetic flux leakage. These devices produce a very low signal level and thus require amplification.

(II) This converts mechanical energy into electrical energy, which is why it's useful during a power outage. This is when a current flows through a coil on a stovetop, which produces a magnetic field.

(III) These sensors are used to time the speed of wheels and shafts. These are used to detect the position of permanent magnet in brushless electric DC motors. The sensors are embedded in digital electronic devices along with linear transducers.

(IV) This can be used to solve complex electrostatic problems involving unique symmetries like cylindrical, spherical or planar symmetry. This can be used to simplify evaluation of electric field.

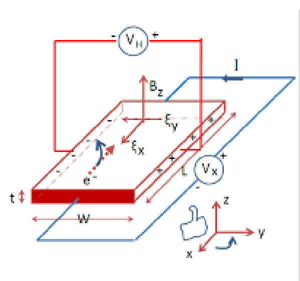
(A) Both III and IV are correct

(B) Both I and III are correct

(C) All the four correct

(D) Both II and III are correct

47. The given diagram represents ……………… effect



(a) Hall effect

(b) Thermoelectric effect

(c) Faradays effect

(d) Photoelectric effect

48. Hot probe method

	(I) This method is routinely used in analytical chemistry for the quantitative determination of different analytes, such as transition metal ions, highly conjugated organic compounds, and biological macromolecules. (II) This method of determining quickly whether a semiconductor sample is n (negative) type or p (positive) type. A voltmeter or ammeter is attached to the sample, and a heat source, such as a soldering iron, is placed on one of the leads. (III) This technique is commonly used to measure the resistivity and the Hall coefficient of a sample (IV) The conventional characterization method enables only the definition of a semiconductor type, P or N, by identifying the majority of the charged carriers **(A) Both II and IV correct** (B) Both III and IV correct (C) Both I and IV correct (D) All the four correct
49.	Vander paw method. (I) This Method is a technique not commonly used to measure the resistivity and the Hall coefficient of a sample. (II) The doping type i.e. whether it is a P-type or N-type material (III) The sheet carrier density of the majority carrier cannot be determined. (IV) The charge density and doping level can be found (V) The mobility of the majority carrier can be found (VI) This method involves applying a current and measuring voltage using four small contacts on the circumference of a flat, arbitrarily shaped sample of uniform thickness. (VII) This method is particularly useful for measuring very small samples because geometric spacing of the contacts is unimportant. (A) All are correct (B) All are Incorrect **(C) II,IV,V,VI and VII are correct** (D) I, II, III, VI and VII are correct
50.	Two probe method (I) This converts mechanical energy into electrical energy, which is why it's useful during a power outage. This is

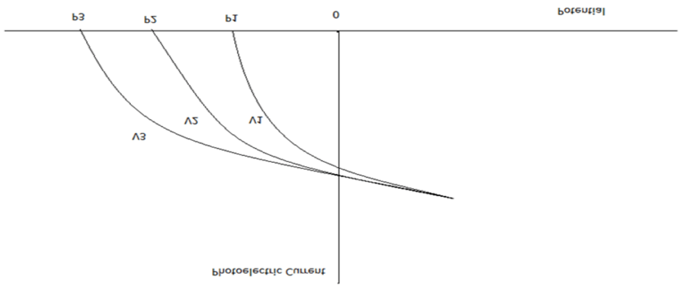
	when a current flows through a coil on a stovetop, which produces a magnetic field. (II) The production of a voltage difference across an electrical conductor, transverse to an electric current in the conductor and to an applied magnetic field perpendicular to the current. (III) This method is one of the standard and most commonly used method for the measurement of resistivity of very high resistivity samples like sheets/films of polymers. (IV) 1. Remote sensing areas. 2. Resistance thermometer. 3. Induction hardening processes. 4. Precise estimation of geometrical factors. 5. Characterization of fuel cells bipolar plates (A) Both II and IV correct **(B) Both III and IV correct** (C) Both I and IV correct (D) All the four correct
51. 52.	The basic components of UV-Vis Spectrometer. (A) They have three basic parts: (1) a large magnet, which is responsible for the static magnetic field H0, (2) a transmitter, which provides the alternating field H1, and (3) a receiver. (B) This consists of three basic components: radiation source, monochromator, and detector.The common radiation source for the spectrometer is an inert solid heated electrically to 1000 to 1800 °C. **(C) They have five main components: the light source, monochromator, sample holder, detector, and interpreter. The standard light source consists of a deuterium arc (190–330 nm) and a tungsten filament lamp (330–800 nm), which together generates a light beam across the 190–800 nm spectral range.** (D) A LASER source is needed to excite the target species. A filter collects the scattered light (Stokes) and filters out the Raleigh and Anti Stokes light. What is the unit of molar absorptivity or absorptivity which is used to determine absorbance A in Beer Lambert's formula? **i) L mol^{-1} cm^{-1}** ii) L gm^{-1} cm^{-1}

	iii) Cm iv) No unit
53.	Transmittance is given as T = P/Po. If Po is the power incident on the sample, what does P represent? **i) Radiant power transmitted by the sample** ii) Radiant power absorbed by the sample iii) Sum of powers absorbed and scattered iv) Sum of powers transmitted and reflected
54.	Which of the following is not true about Absorption spectroscopy? i) It involves transmission ii) Scattering is kept minimum **iii) Reflection is kept maximum** iv) Intensity of radiation leaving the substance is an indication of concentration

55.	The representation of Beer Lambert's law is given as A = abc. If 'b' represents distance, 'c' represents concentration and 'A' represents absorption, what does 'a' represent? a) Intensity b) Transmittance **c) Absorptivity** d) Admittance
56.	Which of the following is not a limitation of Beer Lambert's law, which gives the relation between absorption, thickness, and concentration? a) Concentration must be lower **b) Radiation must have higher bandwidth** c) Radiation source must be monochromatic d) Does not consider factors other than thickness and concentration that affect absorbance
57.	In which of the following ways, absorption is related to transmittance? a) Absorption is the logarithm of transmittance b) Absorption is the reciprocal of transmittance **c) Absorption is the negative logarithm of transmittance** d) Absorption is a multiple of transmittance
58.	Beer Lambert's law gives the relation between which of the following? a) Reflected radiation and concentration b) Scattered radiation and concentration **c) Energy absorption and concentration** d) Energy absorption and reflected radiation
59.	In photo emissive transducers, electrons are attracted by ………………… a) Cathode **b) Anode**

	c) Grid d) Body
60.	During Einstein's Photoelectric Experiment, what changes are observed when the frequency of the incident radiation is increased? a) The value of saturation current increases b) No effect **c) The value of stopping potential increases** d) The value of stopping potential decreases
61.	What is the time lag between the incidence of photons and the ejection of photoelectrons? a) Greater than 10^{-5} s b) Between 10^{-5} s and 10^{-9} s **c) Less than 10^{-9} s** d) 1 second
62.	How does the intensity affect the photoelectric current? **a) As intensity increases, the photoelectric effect increases** b) As the intensity increases, the photoelectric effect decreases c) As the intensity decreases, the photoelectric effect becomes twice d) No effect

63. Identify the correct order of frequencies.



a) $v_1 > v_2 > v_3$

b) $v_2 > v_3 > v_1$

c) $v_3 > v_2 > v_1$

d) $v_1 > v_3 > v_2$

64. The work function of lithium is 2.5 eV. The maximum wavelength of light that can cause the photoelectric effect in lithium is ………………..

a) 3980 Å

b) 4980 Å

c) 5980 Å

d) 6980 Å

65. Light of wavelength 3500 Å is incident on two metals A and B. Which metal will yield more photoelectrons if their work functions are 5 eV and 2 eV respectively?

a) A

b) B

c) A & B

d) C

66. The Kinetic energy of a photoelectron emitted on shining a light of wavelength 6.2 X 10^{-6} m on a metal surface of work function 0.1 eV is ………………..

a) 0.01 eV

b) 0.02 eV

c) 0.1 eV

d) 1 eV

SRM INSTITUTE OF SCIENCE AND TECHNOLOGY, RAMAPURAM CAMPUS, CHENNAI

DEPARTMENT OF PHYSICS

QUESTION BANK

18PYB103J- SEMICONDUCTOR PHYSICS

UNIT 5

PART A-ONE MARK QUESTIONS

QUESTION NO.	QUESTIONS
1	Nano structures have size in between……. A. 1 and 100 A^0 **B. 1 and 100 nm** C. 100 and 1000 nm D. 100 and 1000A^0
2	The probe of scanning tunneling microscope is as sharp as…………… **A. An atom at the tip** B. Many atoms at the tip C. A needle D. Knife
3	Nano particles are special mainly because of their……. **A. Surface area** B. Surface charge C. Volume D. Force
4	The colour of the nano gold particle is…….. A. Yellow B. Orange C. Red **D. Variable**
5	In a quantum wire, the material size is reduced……………………. A. In three directions **B. In two directions** C. In one directions D. In zero directions
6	Carbon nanotube reactivity is related to……………… A. Volume B. Length **C. Diameter** D. Area

7	Carbon nano tubes are the………………… form of graphite A. Cylinder B. Cube C. Embeded **D. Sheet**
8	In how many methods the CNT can be prepared? A. 1 B. 2 C. 3 **D. 4**
9	In CVD chamber, the precursors are introduced to the reaction chamber in the ………….. state A. Liquid B. Solid **C. Gaseous** D. Semi solid
10	X-ray Diffraction methods are not used to identify the physical properties of which of the following? A. Metals **B. Liquids** C. Polymeric materials D. Solids ANSWER: B
11	Which of the following is used in electron microscope? A. Electron beams B. Magnetic fields C. Light waves **D. Electron beams and magnetic fields**
12	Which among the following helps us in getting a 3D picture of the specimen? A. TEM **B. SEM** C. Compound microscope D. Simple microscope
13	The secondary electrons radiated back in scanning microscope is collected by? A. Specimen **B. Anode** C. Vacuum chamber D. Cathode
14	The resolving power of TEM is derived from………. **A. Electrons** B. Specimens C. Power D. Ocular system

15	AFM stands for……… A. Auto focusing microscope B. Antenna focusing microscope **C. Atomic force microscope** D. Atomic focusing microscope
16	The physical parameter that is probed in AFM resulting from different interactions is ----------- A. Charge **B. Force** C. Potential D. Field
17	A…………………….. is an interface that occurs between two layers or regions of dissimilar semiconductors **A. Hetero junction** B. Homo junction C. PN junction D. Barrier
18	………. is then example for hetero junction materials. A. Ge B. Ga C. Si **D. GaAlAs**
19	Exciton can move freely in two directions only. **A. Quantum well** B. Quantum wire C. Quantum dot D. Quantum spin
20	Tensile strength of grapheme exceeds…… **A. 1TPa** B. 2TPa C. 5TPa D. 0.5TPa

QUESTION NO.	QUESTIONS
21	Carbon nano tubes are the sheet form of graphite about….. A. 0.1 nm B. 0.2 nm C. 0.3 nm **D. 0.4 nm**
22	To grow single rather than multi walled nanotubes……………. A. Require semi metal catalyst B. Require non metal catalyst **C. Require metal catalyst** D. Does not require any catalyst
23	In PVD chamber, the precursors are introduced to the reaction chamber in the ………….. state A. Liquid **B. Solid** C. Gaseous D. Semi solid
24	X-Ray diffraction techniques provide …………. information about the compounds present in a solid sample A. Quantitative B. Qualitative **C. Quantitative and Qualitative** D. Either quantitative or qualitative
25	Bands of alternating light and dark lines that are formed by inelastic scattering interactions that are related to atomic spacing in the specimen are called ………….. A. Auger bands B. Bragg bands C. Lorentz bands **D. Kakuchi bands**
26.	Electrons are caused by the de-energization of the specimen atom after a secondary electron is produced……….. **A. Auger** B. Bragg

	C. Lorentz D. Kakuchi
27.	The resolving power of a …………………….. electron microscope derived from the electrons that pass through the specimen. **A. TEM** B. SEM C. AFM D. XRD
28.	AFM tip should have a radius of curvature of…………….. A. > 20-50 nm **B. < 20-50 nm** C. 100 nm D. 100 mm-150 mm
29.	The properties like dispersibility, conductivity, etc changes on varying the ……… A. Size B. Composition **C. Surface properties** D. Electric field
30.	Which of the following is an example of top-down approach for the preparation of nanomaterials? A. Gas phase agglomeration B. Molecular self - assembly **C. Mechanical grinding** D. Molecular beam epitaxy

QUESTION NO.	QUESTIONS
31	The four types of artificial nanomaterials are …. A. Carbon – based, non – metallic, composites and ceramics B. Carbon – based, metallic, composites and ceramics C. Carbon – based, non – metallic, composites and dendrimers **D. Carbon – based, metallic, composites and dendrimers**
32.	A nanometer sized conductive island is connected between two contacts via tunnel barriers, in the presence of a third gate electrode. Such a device is often called a single electron transistor, This is because at low bias voltage, A. It can be deliver only a single electron of current/second B. It can deliver an electron flow defined with a precision better than 1 electron **C. The Charge on the islands is defined with a precision better than 1electron** D. The charge on the island is exactly 1 electron
33	The kinetic energy of electrons in monolayer graphene is proportional to….. **A. The value of wavevector, k** B. The square value of wavevector, k2 C. The value of electron effective mass, m* D. The reciprocal value of electron effective mass, 1/m*
34.	CNTs process a very high Young's modulus, due to A. 4 valence electronic bonds of carbon atoms that equally share stress in any directions B. A perfect construction in tubular form **C. Covalent sp2 bonds formed between the individual carbon atoms** D. Delocalized π- electrons that travel across several carbon atoms to increase strength

	ANSWER: C
35.	A plasma assisted CVD process **A. Is made at lower temperature than a CVD process** B. Is made at higher temperature than a CVD process C. Is based on the sputtering of a target D. Is based on the decomposition of gaseous precursors
36.	When Scanning tunneling microscopy reveals periodic structures with atomic dimensions, what is exactly seen? A. The atomic lattice **B. Electronic density of states modulations associated to the atomic lattice** C. Fermi level modulations associated to the atomic lattice D. The electron diffraction pattern associated to the atomic lattice

PART – B

1. Discuss about quantum well, quantum wire and quantum dot.
2. Write the applications of AFM.
3. Write any four Applications of Powder X-ray diffraction method.
4. Write the applications of SEM and TEM.
5. Write a short note on CNT.
6. Write the properties of CNT.
7. Write any four Applications of CNT.

PART -C

1. Explain the working principle of Scanning Electron Microscopy(SEM).
2. Explain the working principle of Transmission Electron Microscopy(TEM).

3. Write the principle of Atomic Force Microscopy (AFM). Explain the basic components and working of AFM. Write the merits, demerits and Applications of AFM.

4. What is Carbon Nano tube (CNT)? Explain the structure, Type, properties, synthesis methods and applications of CNT.

5. Explain the Physical Vapour Deposition (PVD) method of material synthesis.

6. Explain the Chemical Vapour Deposition (CVD) method of material synthesis.

7. What is Nano structured materials (Quantum well, Quantum Dot, and Quantum wire)?

8. Explain the synthesis methods for Nano structured materials. Explain density of state of zero dimension.

9. Explain Powder X-Ray diffraction method and write the applications of Powder XRD?