COMBINED FIRST AND SECOND SEMESTER B.TECH (ENGINEERING)

EXAMINATION; EN 14 103 – ENGINEERING PHYSICS

Time: 3 Hours **maximum marks: 100**

PART A: Analytical/problem solving SHORT questions

Answer Eight questions out of Ten (Each Question carries 5 marks)

1. What is the difference between interference and diffraction?
2. What is Rayleigh's criterion for resolving power? How to express resolving power of a grating?
3. Define Brewster's (polarizing) angle?
4. What is mean by double refraction?
5. What are the silent features of F.D. Statistics?
6. Define spontaneous emission and stimulated emission?
7. Define acceptance angle and numerical aperture?
8. What are the properties of nanomaterial?
9. Distinguish between intrinsic and extrinsic semiconductors?
10. Write short note on HTSC? **(8*5 =40marks)**

PART B: Analytical/Problem solving DESCRIPTIVE questions

Answer all questions (Each Question carries 15 marks) **(15*4=60 marks)**

11. i. Derive time dependent Schrodinger wave equation? ii. Explain the physical significance of wave function? **(OR)**
12. i. Explain construction and working of Laurent's half shade polarimeter? ii. Explain the production and detection of elliptically & circularly polarized light?
13. i. Describe the laboratory experiment to determine the velocity of ultrasonic waves in a given liquid by forming an acoustic grating. ii.What is the properties of ultrasonic waves. (**OR**)
14. i. Discuss the theory of Newton's Rings with relevant diagram and derive expression for the wavelength of light using dark and bright rings.
15. i. Explain the principle, construction, working, advantages, disadvantages, and applications of semiconductor laser? **(OR)**
16. i. derive the expression for N.A., in terms of n1(refractive index of core), and Δ (fractional refractive index change) ii. Explain the construction and working of Ruby laser.
17. i. explain type I and type II superconductors with suitable example. ii .write short notes on LED & solar cell. **(OR)**
18. i. Derive expression for Fermi level in extrinsic semiconductors? ii. Explain the construction and working of tunnel diode?

<u>**ANSWERS OF MODEL QUESTION PAPER**</u>

1.

We observe bright and dark fringes both due to interference and diffraction but the fringe patterns differ.

S.No	Interference	Diffraction
1.	Superposition is due to two separate wavefronts originating from two coherent sources.	Superposition is due to secondary wavelets originating from different parts . of the same wavefront
2.	The fringes normally have equal widths.	The width between fringes is never equal.
3.	All the bright fringes have the same intensity.	The intensity of bright fringes usually decreases with increase of order.
4.	All the dark fringes have zero intensity.	The intensity of dark fringes is not zero.

2.

Rayleigh's criterion for resolving power

According to Rayleigh, two nearby images are said to be resolved if the position of the central maximum of one coincides with the first secondary minimum of the other and vice versa.

The method of seeing two close objects as separate using some optical instrument is called resolution. The capacity of the instrument to produce two separate images of very close objects is called resolving power.

Resolving power of a grating

The resolving power of a grating is its ability to show two neighboring lines in a spectrum as separate.

Two lines of wavelengths λ and $\lambda + d\lambda$ are said to be just resolved if the central maxima due to $\lambda + d\lambda$ falls on the first minima of λ (in any order). The resolving power of diffraction grating is given by $\lambda/d\lambda$.

Spectral resolving power $= \lambda/d\lambda = nN$

Thus the resolving power of a grating is directly proportional to (i) the order of spectrum (n) and (ii) the total number of lines on the grating surface (N).

3.

When unpolarized light was reflected at the surface of some transparent medium such as glass, water etc. the reflected light was found to be partially plane polarized. The degree of polarization changed with the angle of incidence. For a particular angle of incidence the reflected light was found to be completely plane polarized. The angle of incidence for which the reflected beam is completely plane polarized is known as polarizing angle or angle of polarization. This angle is also known as Brewster's angle. At this angle, the reflected and transmitted lights are at right angle to each other.

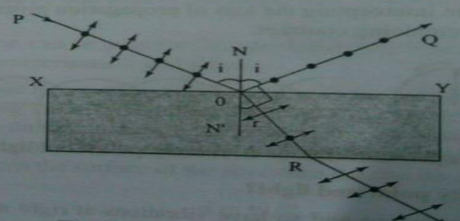


Fig. Polarization by reflection

4.

We know that unpolarized light has two components one vertical and another horizontal. When unpolarized light passes through certain anisotropic crystals such as calcite or quartz, velocity of propagation of these two components vary. This means that the material exhibits two different refractive indices. Since $\mu = (\sin i/\sin r)$, though both the components have the same angle of incidence, they have different angles of refraction. Hence when unpolarized light passes through such crystals, we get two refracted beams and this phenomenon is called double refraction or birefringence.

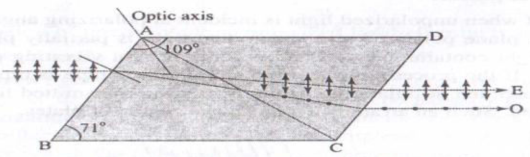


Fig. Double refraction in calcite crystal

5.

Salient features of Fermi-Dirac statistics:

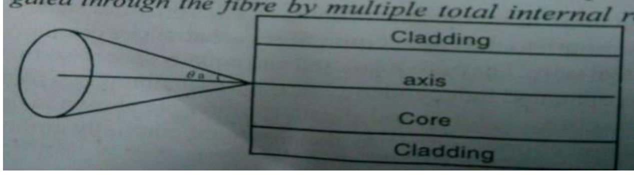
(a) Fermions are identical and indistinguishable.
(b) They obey Paulis' exclusion principle; i.e., there cannot be more than one particle in a single cell in phase space.
(c) Fermions have half integral spin.
(d) Wave function representing Fermions are antisymmetric i.e. $\psi(1,2) = -\psi(2,1)$.
(e) Weak interaction exists between the particles.
(f) Uncertainty principle is applicable.
(g) Energy states are discrete.

6.

	Spontaneous emission		Stimulated emission
1.	An excited atom spontaneously jumps from higher energy level to the lower energy level without the help of any external agency.	1.	An external photon is incident on the excited atom and stimulate it to jump from the higher energy level to the lower energy level. Thus an external photon is necessary for stimulated emission.
2.	During this transition a single photon alone is produced. There is no photon multiplication.	2.	A photon is produced during this transition in addition to the incident photon. Thus there are two photons in the emission. Hence there is photon multiplication.
3.	The energy beam is not coherent.	3.	The emerging beam is highly coherent.
4.	The beam is not monochromatic.	4.	The beam is monochromatic.
5.	The rate of emission depends on the number of atoms or molecules present in the excited state. So the beam is not highly intense.	5.	The rate of emission depends on (a) the number of atoms or molecules present in the excited state and (b) the number of incident photons. Hence the beam is highly intense.
6.	The emission is not due to population inversion.	6.	Emission is due to population inversion and hence it becomes monochromatic.
7.	This is an uncontrolled random process.	7.	This is a controlled regular process.
8.	Travelling in different directions as white light.	8.	Travelling in a particular direction as a narrow beam with definite frequency.
9.	The spectrum is broad and wide.	9.	The spectrum is very narrow and sharp.
10.	There is no common plane of polarization	10.	It has a common plane of polarization.

7.

All the light rays which are incident at the end of the core are not accepted and allowed to propagate through the fibre. The light rays which are incident within a particular angle with the axis of core alone are allowed to propagate through the fibre by multiple total internal reflections. The maximum of this particular angle is called acceptance angle θ_a. *The acceptance angle θ_a of an optic fibre is that maximum angle with the axis of the core so that all the rays which are incident within this angle will be accepted and propagated through the fibre by multiple total internal reflections.* It



Numerical Aperture (NA)

Numerical aperture NA of an optic fibre is the sine of acceptance angle θa .

NA = Sin θa .

NA depends on the acceptance angle. If θa is larger, NA will also be higher. Numerical aperture is also the light gathering power of the fibre and it measures the amount of the light accepted by the fibre. Hence NA represents the sensibility or figure of merit of the fibre. Numerical aperture is between 0.13 and 0.50. If NA is larger, fibre can accept more light from the source. NA depends on the refractive indices of core and cladding.

$$NA = \sqrt{n_1^2 - n_2^2}$$

where n_1 is refractive index of core and n_2 is that of cladding.

8.

Table 1 Properties of nanomaterials

Properties	Examples
Catalytic	Better catalytic efficiency through higher surface-to-volume ratio
Electrical	Increased electrical conductivity in ceramics and magnetic nanocomposites, increased electric resistance in metals
Magnetic	Increased magnetic coercivity up to a critical grain size, superparamagnetic behaviour
Mechanical	Improved hardness and toughness of metals and alloys, ductility and superplasticity of ceramic
Optical	Spectral shift of optical absorbtion and fluorescence properties, increased quantum efficiency of semiconductor crystals
Biological	Increased permeability through biological barriers (membranes, blood-brain barrier, etc.), improved biocompatibility

.

9.

Intrinsic semiconductor	Extrinsic semiconductor
It is a pure semiconducting material without any impurity atoms	Impurity atoms are added to the pure semiconductors by doping.
The number of free electrons in conduction band and number of holes in valence band are exactly equal.	The number of free electrons and number of holes are never equal. N-type semiconductors have excess of electrons and p-type semiconductors have excess of holes.
Electrical conductivity depends on temperature.	Electrical conductivity depends on both the temperature and the quantity of impurity atoms
Electrical conductivity is small	Electrical conductivity is high
Germanium and silicon crystals are examples.	Germanium and silicon crystals with impurity atoms like arsenic, antimony, phosphorus boron, aluminium etc. are examples.

10.

High temperature Superconductors – HTSC

The discovery of a new type of superconductor is one of the most important scientific events in our century. Scientists made a lot of research works to produce superconductor with high T_c. In 1977 a high transition temperature 23K was achieved using metallic compound of niobium and germanium. But in 1986 Bednorz and Muller discovered La - Ba – CuO system of ceramic superconductors with a T_c of 34K for which they were awarded with the Nobel prize. Such superconductors with high critical temperature are called High Temperature Superconductors. *High Temperature Superconductors are ceramic superconductors with a high transition temperature greater than 40K.*

In low temperature superconductors, it is very difficult and expensive to maintain a low temperature for a long period. For example it is very difficult to maintain the liquid helium temperature(4.2K) for a very long period. Nowadays it is possible to replace the expensive liquid He with cheaper and more efficient coolant liquid nitrogen. It is discovered that the transition temperature can be raised by microwave and laser radiations.

11.i.

SCHRODINGER'S WAVE EQUATION FOR A FREE PARTICLE AND TIME DEPENDENT EQUATION

Schrodinger's equation is the basic expression used in quantum mechanics. This cannot be derived from elementary rules. We can derive it by considering the plane wave equation and combining with Einstein's equation for quantum of energy and de Broglies' expression for wavelength.

A particle in motion is associated with a wavefunction that contains the information about the motion. A plane progressive wave that propagates along X-direction is given by

$$\Psi = Ae^{i(kx-\omega t)} \quad \text{.....................(1)}$$

where k is the wave vector given by $\frac{2\pi}{\lambda}$ and ω is the angular frequency.

Einstein's formula for photon energy is

$$E = h\upsilon = \frac{h\omega}{2\pi} = \hbar\omega; \text{ where } \hbar = \frac{h}{2\pi}$$

de-Broglie's expression for matter wavelength is $\lambda = \frac{h}{p}$

$$\therefore p = \frac{h}{\lambda} = \frac{h}{2\pi}\cdot\frac{2\pi}{\lambda} = \hbar k$$

Using the above expression, equation (1) becomes

$$\Psi = Ae^{\frac{i}{\hbar}(\hbar kx - \hbar\omega t)}$$

ie $\Psi = Ae^{\frac{i}{\hbar}(px - Et)}$

On partial differentiation of ψ with respect to x, twice, we get

$$\frac{\partial^2\Psi}{\partial x^2} = \frac{-p^2}{\hbar^2}\Psi \quad \text{.............................(2)} \quad \text{and}$$

Differentiating with respect to time,

$$\frac{\partial\Psi}{\partial t} = \frac{-iE}{\hbar}\Psi \quad \text{.....................(3)}$$

These are equivalent to

$$p^2\Psi = -\hbar^2\frac{\partial^2\Psi}{\partial x^2} \quad \text{.....................(4)}$$

$$= i\hbar\frac{\delta}{\delta x}\left(-i\hbar\frac{\delta}{\delta x}\right)\psi \quad \text{............ (4a)}$$

From 3 and 4, $p = -i\hbar\frac{\delta}{\delta x}$

This is called space operator.

$$E\Psi = i\hbar\frac{\partial\Psi}{\partial t} \quad \text{.....................(5)}$$

$$\therefore E = i\hbar\frac{\partial}{\partial t} \quad \text{.....................(5a)}$$

This energy is called time operator.

For a free particle total energy is given by

$$E = \frac{p^2}{2m}, \text{ since } V = 0$$

$$\text{ie} \quad E\Psi = \frac{p^2}{2m}\Psi \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Using equation (4) and (5), Equation (6) becomes

$$\frac{-\hbar^2}{2m}\frac{\partial^2 \Psi}{\partial x^2} = i\hbar \frac{\partial \Psi}{\partial t} \quad \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

This is Schrodinger's equation for a free particle in one dim

In three dimension it becomes for a free particle, as

$$\frac{-\hbar^2}{2m}\nabla^2\Psi = i\hbar\frac{\partial \Psi}{\partial t} \quad \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

$$\text{where } \nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$$

is called *Lapalcian operator*

If the particle is moving under a potential V(r,t) then eq (8) becomes

$$\left[\frac{-\hbar^2}{2m}\nabla^2 + V_{(r,t)}\right]\Psi = i\hbar\frac{\partial \Psi}{\partial t}$$

This is Schrodinger's time dependent equation

ii.

PHYSICAL CONCEPT OF WAVE FUNCTION

The quantity with which quantum mechanics is concerned is the wave function ψ of a particle. The quantity that undergoes periodic changes of a body is called wave function ψ. It is in general a complex valued function and itself has no physical interpretation. The square of the absolute magnitude $|\psi|^2$ or $\psi\ \psi^*$ dxdydz is proportional to the probability of finding the particle in the small volume element dxdydz about the point x,y,z. We can obtain all the physical properties of the system if we know the wave function.

The wavefunction should fulfil certain requirements.

Since $\psi\ \psi^*$ dxdydz is proportional to the probability of finding the particle with in the volume element, the integral $\int \Psi\Psi^*$dxdydz must be finite if the particle is somewhere there. If $\int \Psi\Psi^*$ dxdydz is zero, the particle does'nt exist and if it is infinity, the particle is everywhere simultaneously.

Since the probability of finding the particle in the volume element is a surety, then $\int_{-\infty}^{+\infty} \Psi\Psi^*$ dxdydz must be equal to 1. The wave function satisfying above condition is called normalised wavefunction.

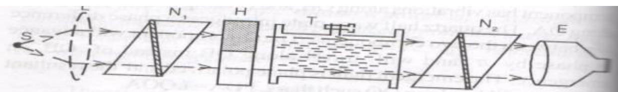
The requirements of wave function

12.i

LAURENT'S HALF SHADE POLARIMETER

Polarimeter is a device used to measure the angle of rotation of plane polarised light, produced by a liquid or solution and hence to determine the specific rotation.

S is a source of monochromatic light. L is convex lens to produce parallel beam of light. N_1 is a nicol prism (polarizer) to produce a beam of plane polarised light. H is Laurent's half shade plate. T is a



hollow glass tube. N_2 is another nicol prism used as analyser. E is an eye-piece to observe the image. The polarizer N_1 is fixed. The analyser N_2 can be rotated. The angle of rotation can be measured on a circular scale attached to it.

The glass tube T is initially filled with pure water, which is not optically active. Looking through the eye-piece E, the analyser N_2 is rotated until the two halves of the field of view appear equally bright. The reading of the circular scale is noted. The glass tube T is then filled with the given solution. Looking through the eye-piece, the analyser N_2 is rotated until the two halves of the field of view again appear equally bright. The reading of the circular scale is noted. The difference in the two readings gives θ, the angle of rotation of the plane polarised light.

The length 'l' of the tube T is measured in cms and the concentration 'c' of the solution is found in gm/cc. Then the specific rotation of the substance in solution is calculated using the formula.

$$s = \frac{10\,\theta}{l\,c} \quad \text{degrees/decimeter/unit concentration.}$$

The specific rotation s is a constant for a substance.

2. CIRCULARLY POLARISED LIGHT

a) Production

A beam of plane polarised light is made to fall normally on a quarter wave plate perpendicular to the optic axis, with vibrations inclined at 45° with the principal section. The beam splits up into ordinary and extra-ordinary components of equal amplitudes. The quarter wave plate introduces a phase difference of $\frac{\pi}{2}$ between the two components. When they come out, they recombine to produce circularly polarised light.

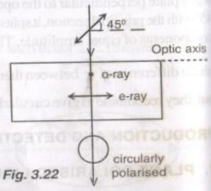


Fig. 3.22

EXPERIMENT

A parallel beam of monochromatic light is allowed to fall on a nicol prism N_1. The beam emerging from N_1 is plane polarised. The nicol N_2 is crossed and hence the field of view will be dark. The quarter wave plate P is mounted on a tube A in between N_1 and N_2 as in figure. The tube A can be rotated coaxially inside an outer fixed tube B. The angle of rotation of the tube A can be noted from a circular scale. There is a fixed mark M on the plate P.

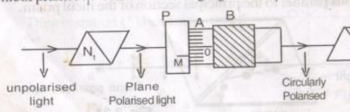


Fig. 3.23

The plane polarised light from N_1 falls normally on the quarter wave plate P. The field of view may be bright. Now the plate P alone is rotated so that the field of view becomes dark. Keeping P fixed, the tube A is rotated until the fixed mark M coincides with zero mark on A. Now the quarter wave plate P alone is rotated exactly through 45°. (The mark M is against 45°). This is the required position. The plane polarised light is incident on P with its vibrations at an angle 45° with optic axis. So the plane polarised light splits up into ordinary and extraordinary components with equal amplitudes. On emerging, they recombine to form circularly polarised light.

(b) Detection

The given beam of light is passed through a rotating nicol prism. If the intensity of the light coming out remains unchanged, the given beam of light is circularly polarised. The same effect is exhibited by ordinary unpolarised light also.

The given beam of light is then passed through a quarter wave plate. If the beam is circularly polarised, it splits up into ordinary and extra-ordinary components of equal amplitudes and with a phase difference of $\frac{\pi}{2}$. The quarter wave plate introduces an additional phase difference of $\frac{\pi}{2}$ between them. Then the total phase difference between the two components will be either π or zero according as the phase difference is introduced on one component or the other. When they come out, they recombine to form plane polarised light. This beam of light is then passed through a rotating nicol prism. If the intensity of the emergent light varies between maximum and zero, the given beam of light is circularly polarised. If the intensity still remains unchanged, the given beam of light is ordinary unpolarised light.

3. ELLIPTICALLY POLARISED LIGHT

a) Production

Plane polarised light is made to fall normally on a quarter wave plate perpendicular to the optic axis, with vibrations inclined at an angle other than 45° with the principal section. The beam splits up into ordinary and extra-ordinary components of unequal amplitudes. The quarter wave plate introduces a path difference of $\frac{\lambda}{4}$ or a phase difference of $\frac{\pi}{2}$ between them. Hence, when they come out of the plate, they recombine to produce elliptically polarised light.

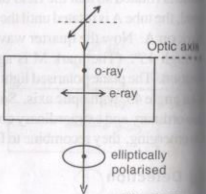


Fig. 3.24

EXPERIMENT

A parallel beam of monochromatic light is allowed to fall on a nicol prism N_1. The beam emerging from N_1 is plane polarised. The nicol N_2 is crossed and hence the field of view will be dark. The quarter wave plate P is mounted on a tube A in between N_1 and N_2 as in figure. The tube A can be rotated coaxially inside an outer fixed tube B. The angle of rotation of the tube A can be noted from a circular scale. There is a fixed mark M on the plate P.

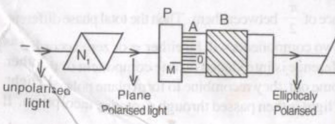


Fig. 3.25

The plane polarised light from N_1 falls normally on the quarter wave plate P. The field of view may be bright. The beam coming out of the plate P is elliptically polarized light (care must be taken so that the vibrations of the plane polarised light must not make 45° with the optic axis).

b) Detection

The given beam of light is passed through a nicol prism which is slowly rotated about the direction of light. If the intensity of the emergent light varies between maximum and minimum, the given beam of light is either elliptically polarised or a mixture of plane polarised light and ordinary light.

The given beam of light is then passed through a quarter wave plate. If the beam of light is elliptically polarised, it splits up into ordinary and extra-ordinary components of unequal amplitudes, with a phase difference of $\frac{\pi}{2}$. The quarter wave plate introduces an additional phase difference of $\frac{\pi}{2}$ between them. Then the total phase difference between the two components is either π or zero according as the phase difference is introduced on one component or the other. When they come out, they recombine to form plane polarised light. This beam of light is then passed through a rotating nicol prism. If the intensity of the emergent light varies between maximum and zero, the original beam of light is elliptically polarised. If the intensity still varies between maximum and minimum, the original beam of light is a mixture of plane polarised light and ordinary unpolarised light.

13. i.

In a glass cell liquid under study is taken. Ultrasonic transducer is fixed at one side wall inside the cell and ultrasonic waves are generated. The waves travelling inside the liquid get reflected from the reflector in the opposite wall. Due to the interference of incident and reflected waves standing wave pattern called acoustic grating is formed.

Applying the theory of diffraction, if 'd' is the distance between two adjacent nodal or antinodal planes, 'd' will be the grating element.

Hence the general formula

$$\sin\theta = nN\lambda$$

can be written as $\sin\theta = n(1/d)\lambda$ since $(1/d) = N$ is the number of lines per unit length.

i.e.

$$d \sin \theta_n = n\lambda \tag{1}$$

where n is the order of diffraction, λ is the wavelength of light and θ_n is the angle of diffraction for n^{th} diffracted order.

If λ_a is the wavelength of ultrasonic waves

$$d = \lambda_a/2 \tag{2}$$

Substituting Eq.(2) in Eq.(1),

$$(\lambda_a/2) \sin \theta_n = n\lambda \quad \text{or} \quad \lambda_a = 2n\lambda/\sin\theta \tag{3}$$

Knowing the wavelength of laser λ, and measuring θ_n, λ_a can be calculated. If f is the frequency of the ultrasonic waves (as given by oscillator) and v its velocity in the liquid, then

$$v = f\lambda_a = 2fn\lambda/\sin\theta \tag{4}$$

ii.

GENERAL PROPERTIES OF ULTRASONICS

1. Ultrasonic waves are acoustic waves with a frequency greater than 20 kHz. They travel through any medium like solid liquid and gas. But they cannot travel through vacuum.
2. They are high energetic waves
3. **Speed**

   The speed of ultrasonic waves in a thin rod or crystal is given by $V = \sqrt{\frac{Y}{\rho}}$ where Y is the Young's modulus of the material and ρ its density.

   Its speed in a liquid is given by $V = \sqrt{\frac{K}{\rho}}$ where K is the bulk modulus of liquid and ρ is its density. Its speed in a gas is given by $V = \sqrt{\frac{\gamma P}{\rho}}$ where P is the pressure of gas, ρ its density and γ is the ratio of specific heats of gas $\left(\gamma = \frac{Cp}{Cv}\right)$.
4. Their speed depends on frequency. Greater the frequency, higher the velocity

14.i.

THEORY OF NEWTON'S RINGS BY REFLECTION

A plano-convex lens L is placed on a plane glass plate G. Let R be the radius of curvature of the lens. A thin film of air of varying thickness is formed between the lens and the glass plate.

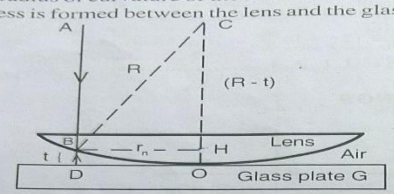


Fig . 1. 11

Consider a beam of monochromatic light, AB of wavelength λ incident normally on the lens. The light rays reflected from the top surface of the air film, at B and the top surface of the glass plate at D interfere. Since the thickness of air film is the same along a circle, alternate dark and bright rings are formed, with O as the centre.

Since n = 0, a dark spot is obtained at the centre.

To find the radius of the n^{th} dark ring

Let C be the centre of curvature of the curved surface of the lens and R be its radius of curvature. Let the n^{th} dark ring be formed through B where the thickness of the air film is 't'. Let r_n be the radius of this dark ring. ie, $BH = r_n$

The condition for the formation of the n^{th} dark ring at D is,

$2 \mu t \cos r = n\lambda$ ....(1)

where n = 0, 1. 2, 3 ....

Since the light is incident normally, $r = 0$ or $\cos r = 1$.

Also $\mu = 1$ for air.

$\therefore 2t = n\lambda$ ....(2)

From the right angled triangle CBH,

$CB^2 = CH^2 + BH^2$

ie, $R^2 = (R - t)^2 + r_n^2$

$= R^2 + t^2 - 2Rt + r_n^2$.

Since t is very small t^2 is negligible.

$\therefore R^2 = R^2 - 2Rt + r_n^2$

or $r_n^2 = 2Rt$ ....(3)

$2t = n\lambda$ from (2).

$\therefore r_n^2 = Rn\lambda$ ....(4)

or $r_n = \sqrt{Rn\lambda}$ ....(5)

i.e., radius of the ring, $r \propto \sqrt{n}$, square root of natural numbers.

As n increases, the distance between the rings decreases. That is, the rings come closer as we move away from the centre.

Radius of the n^{th} bright ring

If the n^{th} bright ring is formed at B where the thickness of the air film is t, the condition for brightness is

$2\mu t \cos r + \frac{\lambda}{2} = n\lambda$................(6)

$2\mu t + \frac{\lambda}{2} = n\lambda$.

$\mu = 1$ for air, $\cos r = 1$ for normal incidence.

$2\mu t = (2n-1)\frac{\lambda}{2}$

$\therefore 2t = (2n-1)\frac{\lambda}{2}$.........................(7)

From equation (3), $r_n^2 = 2Rt$.

$\therefore 2t = \frac{r_n^2}{R}$

Substituting, $r_n^2 = R(2n-1)\frac{\lambda}{2}$

or $r_n = \sqrt{R(2n-1)\frac{\lambda}{2}}$...............(8)

This is the radius of the n^{th} bright ring.

Here radius of the ring, $r_n \propto \sqrt{(2n-1)}$

Since (2n-1) is an odd number, $r_n \propto$ square root of odd numbers

To find the wavelength of light, λ

The radius of the n^{th} dark ring is

$r_n = \sqrt{Rn\lambda}$

ie $r_n^2 = Rn\lambda$

If D_n is the diameter of the n^{th} dark ring,

$r_n = \frac{D_n}{2}$

or $r_n^2 = \frac{D_n^2}{4} = Rn\lambda$

or $D_n^2 = 4Rn\lambda$..............(9)

If D_{n+k} is the diameter of the $(n+k)^{th}$ dark ring,

$D_{n+k}^2 = 4R(n+k)\lambda$.............(10)

Then $D_{n+k}^2 - D_n^2 = 4Rk\lambda$.

or $\lambda = \frac{D_{n+k}^2 - D_n^2}{4kR}$ ....(11)

Thus, measuring D_{n+k}, D_n, and R, the wavelength λ can be calculated.

Similarly, the radius of the n^{th} bright ring, r_n, is given by

$r_n^2 = R(2n-1)\frac{\lambda}{2}$

Then $r_n = \frac{D_n}{2}$

or $r_n^2 = \frac{D_n^2}{4} = R(2n-1)\frac{\lambda}{2}$

or $D_n^2 = 4R(2n-1)\frac{\lambda}{2}$..............................(12)

$D_{n+k}^2 = 4R[2(n+k)-1]\frac{\lambda}{2}$.........................(13)

$$D_{n+k}^2 - D_n^2 = 4Rk\lambda$$

$$\text{or} \quad \lambda = \frac{D_{n+k}^2 - D_n^2}{4\,k\,R} \quad \text{.......................(14)}$$

Thus, measuring D_{n+k}, D_n and R for the bright rings, λ can be calculated.

15.i

4. SEMICONDUCTOR LASER

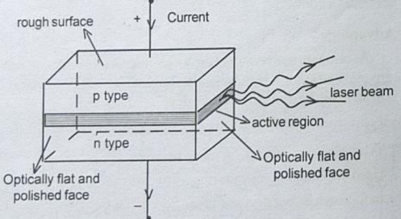
Semiconductor laser is a solid state laser.

Principle

The light emitted by a LED is incoherent.It can be made coherent by using suitable material and proper biasing.When a particular value of current is passed through a highly doped pn junction stimulated emission takes place producing laser light.When a pn junction is forward biased electrons and holes are injected into the depletion layer.Now electrons recombine with holes producing laser beams.

A semiconductor laser is a pn junction diode formed by two heavily doped semiconductors.Generally there are two kinds of semiconductor lasers. (1)Homojunction laser in which pn junction is formed on the same material by proper doping.(2)Heterojunction laser in which the junction is made between two dissimilar semiconductors.

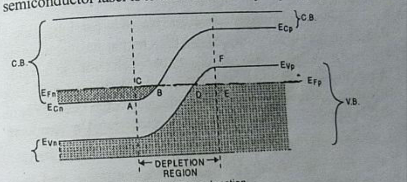
Construction



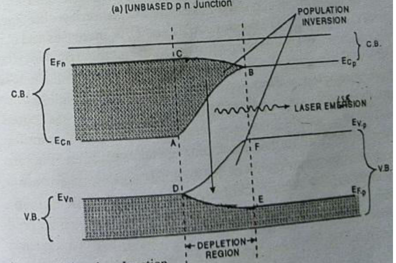
Diode laser is very small in size in the order of nearly 1mm.The end faces are parallel and perpendicular to the plane of junction.The region between p type and n type behaves as an active medium and it is very thin in the order of 1μm.The top and bottom faces have metal coatings with current leads so as to pass a current through it.A pair of opposite faces is polished well so that they behave like reflecting surfaces of resonant cavity.(left and right faces).The other pair of opposite faces is made rough to prevent laser action in that direction (front and rear faces).

Working

A simple way of achieving population inversion in a semiconductor laser is to use it as a heavily doped pn junction and



(a) [UNBIASED p n Junction



For ward biased pn Junction

hence to make it forward biased.The energy band diagram of a heavily doped pn junction diode is as in figure.A part of conduction bands and complete part of valence band of n region are filled with electrons.The Fermi-energy level E_{F_n} is within the conduction band.In P region there are holes in the valence band and Fermi level E_{F_p} lies within the valence band. At thermal equilibrium the Fermi level is uniform across the junction(the same horizontal level as in fig.).The small portion ABC in the depletion region is filled electrons in n side.Similarly small region DEF in the depletion layer is filled with holes in p side.

When the pn junction is forward biased by passing a current through it, electrons are injected into the n region and electrons are removed away from p region. i.e. Number of electrons in n region gets increased and Fermi level splits up and rises in the n region(fig b).Similarly number of holes in p region gets increased and Fermi level falls down(as in fig b).Fermi levels are separarted by an amount $\Delta E = eV$ where e is the charge of electron and V is the forward bias voltage.As a result the electron concentration and hole concentration in depletion layer increase and depletion layer becomes very thin.So the size of regions ABC and DEF increases and at a particular stage DEF becomes just below the region ABC.Now the current flowing through diode is called 'threshold current'.There is high population of electrons in the upper region of depletion layer and thus population inversion takes place due to injection of electrons and holes.Forward biasing (current) behaves as a pumping agent.Now electron-hole recombination takes place and photons with energy h υ are produced due to spontaneous emission.Now it behaves as LED.When current increases the intensity of emission also increases.When the current becomes equal to the threshold current, photons emitted stimulate the electrons to jump to the valence band resulting stimulated emission.Light amplification is maintained by shuttling between the polished faces and coherent emission is released from the active medium through the polished face.

The frequency of laser beam is given by $\nu = \frac{\Delta E}{h} = \frac{eV}{h}$ where V is the bias voltage and h is Planck's constant.Only a very small voltage(1.5 volts) is enough to produce highly efficient laser beam.GaAs(Gallium Arsenide) is the most commonly used laser to produce a laser beam wavelength 9000Å in IR region. GaAsP laser can produce laser of 6500Å in the visible region.PbS, PbSe, PbTe, InP, InAs, InSb etc. are also used as semiconductor lasers.

Advantages

(1) It is miniature in size.
(2) It is highly efficient.
(3) Very easy to handle and operate.
(4) It is very simple and portable.
(5) It requires only a low power to operate.
(6) Laser output can be easily modulated by controlling the junction current.

Disadvantages

(1) Output is generally in the form of a wide beam.
(2) Purity and monochromaticity are poorer than other types of solid state laser.

Applications

(1) Used in optical communication system.
(2) Used as a barcode reader and in UPC scanners.
(3) It is widely used to read the digitized data that is encoded on CD, DVD and Blue-Ray Discs(BD).
(4) As a range finding instrument.

16.i.

Numerical Aperture (NA)

Numerical aperture NA of an optic fibre is the sine of acceptance angle θa.

$$NA = \sin \theta a.$$

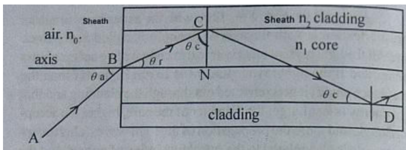
NA depends on the acceptance angle. If θa is larger, NA will also be higher.Numerical aperture is also the light gathering power of the fibre and it measures the amount of the light accepted by the fibre.Hence NA represents the sensibility or figure of merit of the fibre.Numerical aperture is between 0.13 and 0.50.If NA is larger, fibre can accept more light from the source.NA depends on the refractive indices of core and cladding.

$$NA = \sqrt{n_1^2 - n_2^2}$$

where n_1 is refractive index of core and n_2 is that of cladding.

Proof:

Consider a light ray AB incident at B at the edge of the core of an optic fibre from air.It is incident at an angle θa with the axis of the core.This maximum angle is called acceptance angle. Since it travels from air to the core, it is refracted along BC at an angle



θr called the critical propagation angle.This refracted ray is now incident at C at the core-cladding interface with an angle slightly greater than the critical angle θc Hence the ray is undergoing total internal reflection and it is travelling along CD.At D it is incident at an angle slightly greater than critical angle and again undergoes total internal reflection.Thus the ray is propagated through the fibre by multiple total internal reflections.

At C, CN is drawn normal to the axis.The angle at C is taken as the limiting angle θc, the critical angle.Let n_0 be the refractive index of air, n_1 that of core and n_2 that of cladding.

By Snell's law, at B , Sin $= \frac{n_1}{n_0}$ ——>(1)

i.e. $n_0 \sin \theta a = n_1 \sin \theta r$ ——(2)

(n_0 for air = 1)

But, NA is $\sin \theta a$

ie $NA = n_1 \sin \theta r$ ——>(3)

In triangle BCN, $\frac{BN}{BC} = \cos \theta r$

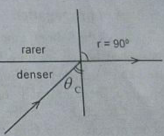
But $\frac{BN}{BC} = \sin \theta c$

$\therefore \cos\theta_r = \sin\theta c$ ——>(4)

But $\cos^2\theta_r + \sin^2\theta_r = 1$

At critical angle, considering the refraction from core to the cladding $\frac{\sin \theta c}{\sin 90} = \frac{n_2}{n_1}$

$\sin \theta c = \frac{n_2}{n_1}$ ——>(5)



Substituting for $\sin \theta_c$ in eqn (5),

$$\sin^2 \theta r = 1 - \frac{n_2^2}{n_1^2}$$

$$\sin^2 \theta r = \frac{n_1^2 - n_2^2}{n_1^2}$$

i.e. $n_1^2 \sin^2 \theta r = n_1^2 - n_2^2$ ——>(6)

$NA^2 = n_1^2 - n_2^2$ from eqn (3)

$\therefore$ Numerical Aperture $NA = \sqrt{n_1^2 - n_2^2}$ ——>(7)

This represents numerical aperture of the fibre in terms of n_1 and n_2.

$$NA = \sqrt{n_1^2 - n_2^2}$$

V-Number or normalized frequency V

V-number is an important parameter of optic fibre.It is also called the normalized frequency.V number is given by,

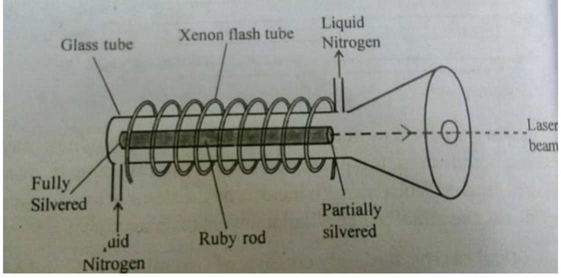
$V = \frac{2 \pi a}{\lambda} NA$ where a=radius of the core

$\therefore V = \frac{\pi d}{\lambda} NA$ where d is the core-diameter, λ is the

ii.

1. RUBY LASER

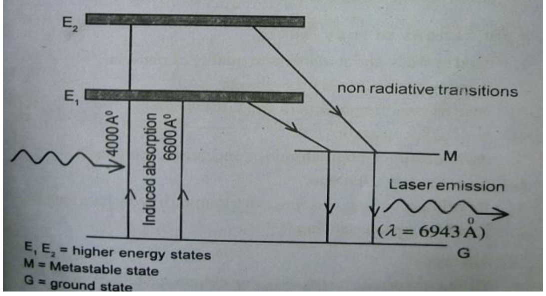
Ruby laser is a three level solid state laser. The first ruby laser was fabricated by Maimann in 1960. Ruby is aluminium oxide crystal



(Al_2O_3). Here ruby crystal consists of aluminium oxide with some of aluminium atoms replaced by chromium ie Aluminium oxide (Al_2O_3) is doped with .05% chromium oxides (Cr_2O_3). C_r^{3+} ions are active while aluminium and oxygen atoms remain inert.

Ruby laser consists of a ruby crystal cut into a cylindrical rod with several cms in length and several mms in diameter. The end faces of this cylinder are made exactly flat and polished with silvering. They act as optical cavity. One end face is fully silvered so that it is 100% reflecting while the other face is partially silvered so that it is partially reflecting and partially transparent. Laser beam is finally emerging through this side. Ruby cylinder is enclosed in a cylindrical glass tube surrounded with xenon flash tube as in fig. Xenon flash tube provides enough energy for optical pumping. Elliptical reflectors are used for increasing the intensity of light. When light radiations are incident, the chromium ions absorb this energy and get excited to higher energy states E_1 and E_2.

The higher energy states E_1 and E_2 are broad and hence they

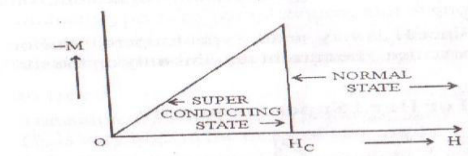


accept a large range of wavelengths. The transitions to E_1 and E_2 are caused by 6600 Å and 4000 Å respectively. These energy state E_1 and E_2 have a very short life time in the order of 10^{-9} seconds. Hence the chromium ions suddenly jump to the metastable state M making non radiative transition. The metastable state M has a large life time of 10^{-3} secs and hence the number of chromium ions gets increased at M and finally population inversion is achieved. At this stage the photons produced are shuttling between the end faces thereby compelling for lasing action. Stimulated emission takes place from M to the ground state G. As a result an intense coherent and monochromatic laser beam of $\lambda = 6943$ Å is emerging through the partially silvered face. The laser beam is in the form of pulses. This is because when the threshold state is reached, all the ions are lasing to the ground state during a flash light leaving the metastable state vacant. During the next flash of the lamp the process is continued again.

Overheating is avoided by cooling the system using a coolent like liquid nitrogen which is circulated around the rod.

17.i.

1)Type - I or Soft Superconductors



When a superconductor is placed in a magnetic field H, the intensity of magnetization M is induced in it. When H increases, M also increases. The variation of M with H is shown graphically. The intensity of magnetization increases linearly with H so that M = H.(slope = 1). The magnetic lines of force are expelled from the material due to the repulsive force. But when the applied field reaches the critical Hc($H = H_c$), M suddenly falls to zero indicating that the material has lost its superconducting property and changed into its normal state. Upto Hc, it behaves like a diamgnet and strictly obeys Meissner law. At Hc, magnetic lines of force are penetrating through it since there is no repulsive force. The value of critical field Hc is very small in the order of 0.1T and 0.2T. *Such type of superconductors for which M becomes zero abruptly when $H = H_c$ are called Type–I superconductors*. Since H_c is small, very low magnetic field can destroy the superconducting property.So they are called soft superconductors.

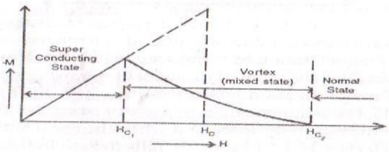
Properties

(1) Transition to normal state is very abrupt.
(2) H_c is very small in the order of 0.1T.
(3) Superconductivity can be easily destroyed.
(4) At H_c the transition is reversible.If the field is reduced below H_c, the superconducting property is reinstated.

Examples : Lead, tin,Hg, aluminium, magnesium.Almost all pure metals belong to this group

Uses : Since H_c is very small, Type–I superconductors have no physical importance.The current remains only on the surface of the materials.

(2)Type - II or Hard Superconductors



When external magnetic field H increases, intensity of magnetization M also increases linearly as in the case of Type-I .This is continued upto H_{c1} called lower critical field where M begins to decrease.Upto H_{c1} repulsive force expels all the magnetic lines and it is diamagnetic. i.e. It strictly obeys Meissner law upto H_{c1} Beyond H_{c1}, magnetic lines of force begin to penetrate through the material slowly and material loses diamagnetic property correspondingly.This is continued upto H_{c2} called upper critical field where the material loses diamagnetic property completely and all the lines of force are penetrating exclusively through the material.Upto H_{c2} the material behaves as a superconductor. H_{c2} is very high.Beyond H_{c2} it reaches to its normal state.The material is in a mixed state in the region between H_{c1} and H_{c2} It behaves partially conducting as well as partially superconducting in this region and the region is called *vortex.* It does not strictly obey Meissner law in this region. Here the transition from superconducting state to normal state is very slow and gradual.The upper critical H_{c2} field is very high in the order of 10T to 20T and hence a very strong magnetic field is needed to destroy superconducting property completely.

Both Type-I and Type-II obey Meissner law upto the lower critical field and hence both are ideal superconductors upto that limit.

Properties

(1) Transition to normal state is gradual.
(2) H_{c2} is very high in the order of 10T to 20T.
(3) Very strong magnetic field is required to destroy superconducting property.
(4) The transition is irreversible since there is hysteresis loss.

Examples : Niobium, Germanium, niobium–tin, niobium–zirconium, niobium–titanium etc.

Uses : (1) very strong magnetic field can be produced using Type-II superconductors.Such huge magnetic field is very essential in particle accelerators, plasma-production, fusion reactors etc.

(2) This strong magnetic field is used for magnetic levitation(maglev).

(3) Used in power generators.

ii.

5. **Write a note on bipolar junction transistors.**

When a third doped element is added to a crystal diode in such a way that in two *PN* junctions are formed, the resulting device is known as a transistor.

A transistor consists of two *PN* junctions formed by sandwiching either *p*-type or *n*-type semiconductor between a pair of opposite types. Accordingly, there are two types of transistors namely

1. *n-p-n* transistor   2. *p-n-p* transistor.

An *n-p-n* transistor is composed of two *n*-type semiconductors separated by a thin section of *p*-type as shown in Fig.(a). However a *p-n-p* transistors is formed by two *p*-types separated by a thin section of *n*-type as shown in Fig.(b).

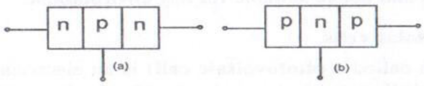


Fig. Bipolar junction transistor (a) n-p-n type and (b) p-n-p type

(a) These are two *PN* junctions. Therefore, a transistor may be regarded as a combination of two diodes connected back to back.
(b) There are three terminals taken from each type of semiconductor.
(c) The middle section is a very thin layer. This is the most important factor in the function of a transistor.

A **solar cell** (also called a **photovoltaic cell**) is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect. It is a form of **photo-electric cell** which, when exposed to light, can generate and support an electric current without being attached to any external voltage source. Solar cells generate electricity from sunlight. Cells can be described as photovoltaic even when the light source is not necessarily sunlight (lamplight, artificial light, etc.,).

The solar cell works in three steps:

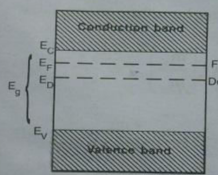
(a) Photons in sunlight fall on the solar panel and are absorbed by semiconducting materials, such as silicon.
(b) Electrons (negatively charged) are knocked loose from their atoms, causing an electric potential difference. Current starts flowing through the material to cancel the potential and this electricity is captured. Due to the special composition of solar cells, the electrons are only allowed to move in a single direction.

18.i.

(1) Fermi level in N-type extrinsic semiconductor

When donor impurities are added to the intrinsic semiconductor electrons are supplied and it becomes N type extrinsic semiconductor (pentavalent impurities donate electrons) Addition of these electrons creates new energy levels and as a result a new energy level E_D called donor level is formed just below the conduction band.

When donor impurity is completely ionized, all the electrons try to occupy this donor level E_D. Hence it is very difficult for the electrons of the valence band to cross the band gap energy and reach the conduction band. As a result, the number of holes in the valence band gets decreased. *So the Fermilevel E_F will be just below the bottom level of conduction band in N type semiconductor.*



The energy required to transfer an electron from the donor level E_D to the conduction band is in the order of .01 eV for germanium. Even at ordinary temperature .02 eV energy is available and hence almost all the electrons are easily transferred to the conduction band so electron density in the conduction band will be nearly equal to the density of donor atoms:

Let 'n' be the electron concentration in the conduction band N_d be the density of donor atoms.

$$\therefore \quad N_d = n = 2\left(\frac{m_n kT}{2\pi\hbar^2}\right)^{3/2} e^{\left(\frac{E_F - E_g}{kT}\right)}$$

Since $E_c = E_g$

$$N_d = 2\left[\frac{m_n kT}{2\pi\hbar^2}\right]^{3/2} e^{\left(\frac{E_F - E_c}{kT}\right)} \text{...............(1)}$$

$$\text{ie } N_d = N_c \; e^{\left(\frac{E_F - E_c}{kT}\right)} \text{...............(2)}$$

where $N_c = 2\left[\dfrac{m_n kT}{2\pi\hbar^2}\right]^{3/2}$ = a constant

$$\therefore \quad \frac{N_c}{N_d} = e^{-\left(\frac{E_F - E_c}{kT}\right)} \text{...............(3)}$$

Taking logarithm,

$$\log_e \frac{N_c}{N_d} = -\left(\frac{E_F - E_c}{kT}\right)$$

$$\therefore \quad kT \log_e \frac{N_c}{N_d} = -(E_F - E_c) = -E_F + E_c$$

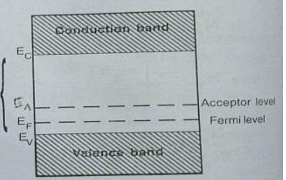
$$\therefore \quad E_F = E_c - kT \log_e \frac{N_c}{N_d} \text{...............(4)}$$

This shows that in an N type extrinsic semiconductor, Fermilevel

E_F is just below the bottom level of conduction band. When temperature rises, Fermilevel E_F gets lowerd and at very high temperature it approaches the middle level and the conductor behaves like intrinsic semiconductor.

(2) Fermi level in P type extrinsic semiconductor

When acceptor impurities are added to the intrinsic semiconductor, vacancies for electrons (ie holes) are created in the valence band and it becomes P type extrinsic semiconductor. Addition of such acceptor impurities increases the number of holes in the valence band and as a result a new energy level called acceptor level E_A is formed above the top of valence band.



When the acceptor atoms are completely ionised there is a corresponding increase in the number of holes in the valence band. Hence hole concentration p is nearly equal to the density of acceptor impurities N_a. Holes have maximum energy near the valence band. In a P type semiconductor, hole concentration in valence band is greater than electron concentration in conduction band. *As a result the Fermi level E_F is just above the top level of valence band as in figure. E_F will be in between E_A and E_V*

Since $P = N_a$

$$N_a = 2\left[\frac{m_p kT}{2\pi\hbar^2}\right]^{3/2} e^{\left(\frac{E_V - E_F}{kT}\right)} \text{...............(1)}$$

ie $N_a = N_v \; e^{\left(\frac{E_V - E_F}{kT}\right)}$ ....(2) where

$$N_V = 2\left[\frac{m_p kT}{2\pi\hbar^2}\right]^{3/2} = \text{a constant}$$

$$\therefore \; \frac{N_V}{N_a} = e^{-\left(\frac{E_v - E_F}{kT}\right)} \quad ....(3)$$

Taking logarithm,

$$\log_e \frac{N_v}{N_a} = -\left(\frac{E_v - E_F}{kT}\right)$$

$$kT \log_e \frac{N_v}{N_a} = -E_v + E_F$$

$$\therefore \; E_F = E_v + kT \log_e \frac{N_v}{N_a} \quad ......(4)$$

This reavels that Fermi level E_F in P type extrinsic semiconductor is just above the top level of valence band. The position of Fermi level depends on concentration of impurities and temperature. If we add more and more acceptor impurities, Fermilevel E_F will be lowered. At a very high concentration of acceptor impurities, it may be in the valence band.

On otherhand if the temperature is increased, Fermi level E_F gets raised. At a very high temperature, more and more electrons in the valence band get excited and reached the conduction band. Now the Fermi level E_F approaches the middle of the forbidden band gap energy and the conductor behaves like intrinsic semiconductor.

ii.

A tunnel diode is a special type of p-n junction between two heavily doped semiconductors which operate in a region of incremental negative resistance of its $I - V$ characteristic. The quantum mechanical tunneling of electrons takes place through the finite potential barrier of the junction.

In a tunnel diode concentration of impurity atoms is very large (about 10^{18} to 10^{19} cm^{-3}) in both p-and n-region, the barrier width being very small(in the order of 100°A). Because of heavy doping, the donor level widens and overlaps the edge of the conduction band.

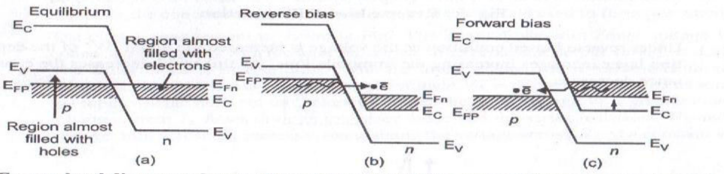


Fig. Energy level diagram of zener diode (a) unbiased (b) reverse biased and (c) forward biased

(a) **Zero bias (Equilibrium condition)**

Under equilibrium condition of a p-n junction no current flows.

(b) **Reverse bias**

When a small reverse bias is applied , filled states in the valence band on the p-side and the empty states in the conduction band on the n-side are separated by a narrow layer of depletion region. Because of high doping concentration and there is a large electric field at the junction which is quite sharp thus creating suitable condition for tunneling. There is, therefore, a tunneling of electrons from the filled valence band states on p-side to the empty conduction band states on n-side. As the reverse bias is increased the number of electrons tunneling from $p \rightarrow n$ also increases. This is equivalent to an increasing conventional current from n to p. This is shown by the portion OA of the $I - V$ characteristic (Fig.d).

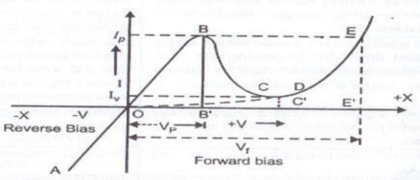


Fig. (d) I-V characteristics of a tunnel diode

(c) **Small forward bias**

When a small forward bias is applied electron tunneling takes place from n to p with resulting conventional current from p to n. This forward tunneling current continues to increase with increasing bias. This is shown by the portion OB of the I-V curve (Fig.d). With further increase in forward bias the number of empty states in conduction band opposite to the filled states in valence band decreases resulting in a decrease in tunneling and corresponding decrease in current as shown by the portion BC of the I-V curve.

(d) **Large forward bias**

If the forward bias is increase beyond OC', the current begins to increase again forming a valley in the I-V graph because as the bands pass each other, the behavior becomes similar to that of a conventional diode. The forward current in now dominated by the electrons diffusing from n to p up the potential barrier and the holes diffusing from p to n. This is shown by the portion DE.