# EC 1402 OPTICAL COMMUNICATION

## 2 marks

1. Write the expression for the refractive index in graded index fibers.

   $n(r)= n1[1-2\Delta(r/a)_{\alpha}]_{1/2}$ for 0<=r<=a

   $n1(1-2\Delta)^{1/2} \sim n1(1-\Delta) = n2$ for r>=a

   r    radial distance from fiber axis
   a    core radius
   n1    refractive index at the core
   n2    refractive index at the cladding
   α    shape of the index profile
   Δ    index difference

2. Define Numerical aperture of a step index fiber.

   Numerical aperture (N.A) of the fiber is the light collecting efficiency of the fiber and is the measure of the amount of light rays that can be accepted by the fiber. It is equal to the sine of acceptance.

   $N.A = \sin \Phi_{max} = (n_1 2 - n2^2)_{1/2}$

   where $n_1$ and $n_2$ are the refractive indices of core and cladding respectively.

3. Define Mode-field diameter.

   The fundamental parameter of a single mode fiber is the mode-field diameter. This can be determined from the mode field distribution of the fundamental LPo1 mode.

4. Give the expression for linearly polarized waves.

   The electric or magnetic field of a train of plane polarized waves travelling in a direction k can be represented in the general form

   $A(x,t) = e_i A o \exp[j(wt-k.x)]$

   with $x = xe_x + ye_y + ze_z$ representing a general position vector and $k = k_x e_x + k_y e_y + k_z e_z$ representing the wave propagation vector.

6. What is Snell's law?

   The relationship at the interface is known as Snell's law and is given by

   $n_1 \sin \Phi_1 = n_2 \sin \Phi_2$

7. What is the necessity of cladding for an optical fiber?
   a) To provide proper light guidance inside the core
   b) To avoid leakage of light from the fiber
   c) To avoid mechanical strength for the fiber
   d) To protect the core from scratches and other mechanical damages

8. What are the uses of optical fibers?

      a) To transmit the information which are in the form of coded signals of the telephone communication, computer data, etc.

      b) To transmit the optical images (Example : Endoscopy)

      c) To act as a light source at the inaccessible places.

      d) To act as sensors to do mechanical, electrical and magnetic measurements.

9. What is the principle used in the working of fibers as light guides?

      The phenomenon of total internal reflection is used to guide the light in the optical fiber. To get total internal reflection, the ray should travel from denser to rarer i.e. from core to clad region of the fiber and the angle of incidence in the denser medium should be greater than the critical angle of that medium.

10. what are step index and graded index fibers?

      In the case of graded index fiber, the refractive index of a core is a constant and is larger than the refractive index of the cladding. The light propagation is mainly by meridional rays. In the case of graded index fiber (GRIN fiber) the refractive index of the core varies parabolically from the centre of the core having maximum refractive index to the core-cladding interface having constant minimum refractive index. Here the light propagation is by skew rays.

11. Define acceptance angle.

      The maximum angle '$\Phi_{max}$' with which a ray of light can enter through the entrance end of the fiber and still be totally internally reflected is called acceptance angle of the fiber.

12. Why do we prefer step index single mode fiber for long distance communication?

      Step index single mode fiber has  a)low attenuation due to smaller core diameter b) higher bandwidth and c) very low dispersion.

13. Define relative refractive  index difference.

$$\Delta = \frac{n_1^2 - n_2^2}{2n_1^2} = \frac{n_1 - n_2}{n_1}$$

     Thus relative refractive index difference  is the ratio between the refractive index difference  (of core and cladding) and refractive index of core.

14. What are meridional rays?

      Meridional rays are the rays following Zig Zag  path when they travel through fiber and for every reflection it will cross the fiber axis.

15. What are skew rays?

      Skew rays are the rays following the helical path around the fiber axis when they travel through the fiber and they would not cross the fiber axis at any time.

16. What is V number of fiber or normalized frequency of fiber?

V number of fiber or normalized frequency of fiber is used to find the number of propagating modes through the fiber.

$$V = \frac{2\prod a\ (N.A)}{\lambda}$$

In step index fiber number of modes propagating through the fiber $= \frac{V^2}{2}$

Taking the two possible polarizations, total number of possible modes propagating through the fiber $= \frac{V^2}{2} * 2 = V^2$

17. What are the conditions fro total internal reflection?

a) Light should travel from denser medium to rarer medium.

b) The angle of incidence should be greater than the critical angle of the denser medium.

18. Give the relation between numerical aperture of skew rays and meridional rays.

$(N.A)skew = \cos \gamma (N.A)$ meridional when the fiber is placed in air.

Here $\gamma$ is the half of the angular change in every reflection.

19. State Goos-Haenchen effect.

Goos-Haenchen effect states that there is a lateral shift of the reflected ray at the point of incidence at the core-cladding interface. This lateral shift is called the Goos-Haenchen shift.

20. When do you have phase shift during total internal reflection of light.

When the light ray travels from denser medium to rarer medium, if the angle of incidence is greater than the critical angle of core medium, there is a phase shift for both TE and TM waves.

21. What are hybrid modes? Give two examples.

Hybrid modes are the mixture of TE and TM modes that can be traveled through the optical fiber.

Examples:
1. $HE_{1m}$ modes in which $|E_z|>|H_z|$
2. $EH_{1m}$ modes in which $|H_z|>|E_z|$

22. Define cutoff wavelength of the fiber.

The cutoff wavelength is defined as the minimum value of wavelength that can be transmitted through the fiber. The wavelengths greater than the cutoff wavelength can be transmitted.

$$\lambda_{cutoff} = \frac{2\prod a\ (N.A)}{V}$$

23. Mention the rule distinguishing 'mode' and 'order'.

The rule states that the smaller the modes propagating angle, the lower the order of the mode. Hus the mode traveling precisely along the fiber's central axis is zero mode.

24. What is fiber birefringence?

Imperfections in the fiber are common such as asymmetrical lateral stress, non circular imperfect variations of refractive index profile. These imperfections break the circular symmetry of ideal fiber and mode propagate with different phase velocity and the difference between their refractive index is called fiber birefringence.

$$B=ko(n_y-n_x)$$

25. Give the expression for numerical aperture in graded index fibers.

$$N.A(r)=N.A.(0) \ (1-(r/a)_{\alpha})1/2 \ \text{for } r<=a$$

where N.A(0) = axial numerical aperture = $(n_{12}-n2^2)1/2$

a is core radius and $\alpha$ is the refractive index profile.

26. What is Intra Modal Dispersion?

Intra Modal dispersion is pulse spreading that occurs with in a single mode. The spreading arises from finite spectral emission width of an optical source. This phenomenon is also called as group velocity dispersion.

27. What are the causes of intra modal dispersion?

There is two main causes of intra modal dispersion. They are:
- Material dispersion
- Wave guide dispersion

28. What is material dispersion?

Material dispersion arises from the variation of the refractive index of the core material as a function of wavelength. Material dispersion is also referred to as chromatic dispersion. This causes a wavelength dependence of group velocity of given mode. So it occurs because the index of refraction varies as a function of optical wavelength. Material dispersion is an intra modal dispersion effect and is for particular importance for single ode wave-guide.

29. What is waveguide dispersion?

Wave guide dispersion which occurs because of a single mode fiber confines only about 80% of optical power to the core. Dispersion this arises since 20% of light propagates in cladding travels faster than the light confined to the core. Amount of wave-guide dispersion depends on fiber design. Other factor for pulse spreading is inter modal delay

30. What is group velocity?

If L is the distance traveled by the pulse, ® is the propagation constant along axis then the group velocity in the velocity at which energy is a pulse travels along the fiber.

$$Vg = C. \ (d® \ / \ dk)$$

31. What is group delay?

In an optical fiber there are various modes present. Then the optical input, which is propagated along the fiber, will travel in various modes. Because of these modes the velocity of the signal will vary also there may be a delay in the optical signal of these various modes. This is called as the ' Group Delay'.

32.What is polarization?

It is a fundamental property of an optical signal .It refers to the electric field orientation of a light signal which can vary significantly along the length of a fibre.

33.What is pulse Broadening?

Dispertion induced signal distortion is that a light pulse will broaden as it travels along the fibre.This pulse broadening causes a pulse to overlap with neighbouring pulses.After a time 't',the adjacent pulses can no longer be individually distinguished at the receiver and error will occur.

34.What is polarization Mode Dispersion(PMD)?

The difference in propagation times between the two orthogonal polarization modes will result in pulse spreading.This is called as polarization Mode Dispersion.

35.What is Mode Coupling?

It is another type of pulse distorsion which is common in potical links.The pulse distortion will increase less rapidly after a certain initial length of fibre due to this mode coupling and differential mode losses.In initial length coupling of energy from one mode to another arises because of structural irregularities,fibre dia. etc.

36.What is Profile Dispersion?

A fibre with a given index profile(alpha) will exhibit different pulse spreading according to the sourse wavelength used.This is called as Profile Dispersion.

37.What is M-C fiber?

Fibers that have a uniform refractive index throughout the claddind is called as M-C fiber or Matched-cladding fiber.

38.What is D-C fiber?

In   depressed cladding fiber the cladding portion next to the core has a lower index than the outer cladding region.

39.Define depression shifted fiber

by  creating a fiber with large negative waveguide dispersion & assuming the same values for material dispersion as in a standard  single mode fiber the addition of waveguide & material dispersion can then shifted to zero dispersion point to long wavelenth. The resulting optical fiber are known as dispersioin shifted fiber.

40.Define dispersion flattening?

The reduction of  fiber dispersion by spreading the dispersion minimum out over a widen range .this approach is known asd dispersion flattering.

41.What is effective cut-off  wavelenth?

It is defined as the largest wavelenth at which the higher order LP11 mode power relative to the fundamental LP01 mode power is redued to 0.1db. 2.what is intramodal dispersion?

The intramodal dispersion depends on wavelength and its effect on signal distortion increases with the spectral width of the optical source.(It is a band of wavelength over which the source emits light

42. Write a note on scattering losses.

Scattering losses in glass arise from microscopic variation in the material density from compositional fluctuation and from structural in homogeneities or defects occurring during fiber manufacture

43.What is Rayleigh scattering?

The index variation causes a Rayleigh type of scattering of light. Rayleigh scattering in glass in the same phenomenon that scatters light from sun in the atmosphere, giving rise to blue sky.
The expression for Rayleigh scattering loss is given by

$$\langle_{scat} =(8\square^3/3\lambda^2)(n^2-1)^2 k_B T_f \circledR_T$$

n = refractive index
$k_B$ = boltzman constant
$\circledR_T$ = isothermal compressibility
$T_f$ = fictive temperature
$\lambda$ = operative wavelength

44.What is intermodal dispersion?

Intermodal dispersion is a pulse spreading that occurs with in a single mode. the spreading arises from finite spectral emission width of an optical source. it is called group velocity dispersion or intermodal dispersion

45.what is intramodal delay?

The other factor giving rise to pulse spreading is intramodal delay which is a result of each mode having a different value of
Group velocity at a single frequency.

46.what is the measure of information capacity in optical wave guide?
It is usually specified by bandwidth distance product in MHz.For a step index fiber the various distortion effects tend to limit the bandwidth distance product to 20MHz.

47.Mention the losses responsible for attenuation in optical fibers.

Absorption losses, Scattering losses and bending losses

48.What do you meant by Extrinsic absorption ?

Absorption phenomena due to impurity atoms present in the fiber.

49. Define microscopic bending?

Fiber losses occur due to small bending arise while the fiber is inserted into a cable.

50. Define macroscopic bending?

If any bending present in the fiber while cabling , the optical power get radiated

51. What are the advantages of optical communication?

1. Low transmission loss.

2 Small size and weight.

3. No electromagnetic interference.

4. Electrical isolation.

52. Define direct band gap materials and indirect band gap materials.

In direct band gap materials direct transition is possible from valence band to conduction band.e.g.GaAs,InP,InGaAs

In indirect band gap materials direct transition is not possible from valence band to conduction.e.g.silicon,germanium.

53. What are the advantages of LED?

1. LEDs are less complex circuits than Laser diodes.

2. Fabrication is easier.

3. They have long life.

53. What are the two types of confinement used in LEDs?

1. optical confinement.

2. carrier confinement.

54. What are the two types of LED configurations?

1. homo junction

2. Single and double hetero junction.

55. What are the three requirements of Laser action?

1. Absorption

2. Spontaneous emission

3. stimulated emission.

56. What are the three types of Laser diode structures?

1. Gain indexed guide

2. Positive indexed guide

3. Negative indexed guide

57. What are the fundamental structures of Index guided lasers?

1. buried hetero structure.

2. Selectively diffused construction

3. Varying thickness structure

4. Bent layer configuration.

58. What are the three basic methods of current confinement?

1. Preferential dopant diffusion.

2. Proton implantation

3. Inner strip confinement

4. Re growth of back biased PN junction.

59. Define modulation.

The process of imposing information on a light stream is called modulation. This can be achieved by varying the laser drive current.

60. Define external quantum efficiency.

The external quantum efficiency is defined as the number of photons emitted per radiative electron-hole pair recombination above threshold.

61. Define threshold current.

The threshold current is conventionally defined by extrapolation of the lasing region of the power-versus-current curve. At high power outputs, the slope of the curve decreases because of junction heating.

62. Define longitudinal modes.

Longitudinal modes are associated with the length of the cavity and determine the typical spectrum of the emitted radiation.

63. Define lateral modes.

These modes lie in the plane of the pn junction. They depend on the sidewall preparation and the width of the cavity.

It determines the shape of the lateral profile of the laser beam.

64. Define transverse modes.

Transverse modes are associated with the electromagnetic field and beam profile in the direction perpendicular to the plane of the pn junction. They determine the laser characteristics as the radiation pattern and the threshold current density.

65. Define population inversion.

Stimulated emission will exceed absorption only if the population of the excited states is greater than that of the ground state. This condition is called as population inversion

66. Define internal quantum efficiency.

The internal quantum efficiency is the fraction of the electron-hole pairs that recombine radiatively.If the radiative recombination rate is R and the non radiative recombination rateis Rnr, then the internal quantum efficiency is the ratio of the ratio of the radiative recombination rate to the total recombination rate.

67. Differentiate LEDs and Laserdiodes.

| S.No. | LED | Laser diode |
|-------|-----|-------------|
| 1., | The output obtained is incoherent. | The output obtained is coherent. |
| 2. | Less expensive and less complex | More expensive and more complex. |
| 3. | Long lifetime. | Less lifetime. |

68. What is mass action law?

Pn=ni*ni

Where p-- concentration of holes.

n concentration of electrons.

Ni intrinsic concentration.

69. What is an intrinsic and extrinsic semiconductor material?

Intrinsic semiconductors have no impurities.

Extrinsic semiconductors contain impurities like boron and phosphorus.

70. Define responsivity

The performance of an avalanche photodiode is characterized by its responsivity

$R_{APD=} \eta qM = R_0 M$
hv

where $R_0$ is the unity gain responsivity.

71. Define long wavelength cut off related to photodiode.

The upper wavelength cutoff ($\lambda c$) is determined by the band gap energy Eg of the material. If Eg is expressed in units of electron volts(eV),then $\lambda c$ is given in units of micrometers (μm) by

$\lambda c(\mu m) = \dfrac{hc}{Eg} = \dfrac{1.24}{Eg(eV)}$

72. A given APD has a quantum efficiency of 65% at a wavelength of 900 nm. If 0.5 μW of optical power produces a multiplied photocurrent of 10μA, find the multiplication M.

$R = \dfrac{\eta e \lambda}{hc}$

$Ip = PoR$

$M = \dfrac{I}{Ip}$

73. Give some types of photodetectors.
   - Photomultipliers
   - Pyroelectric detectors
   - Semiconductor- based detectors
   - Phototransistors
   - Photodiodes

74. What are the advantages of photodiodes?
   a. Small size
   b. Suitable material
   c. High sensitivity
   d. Fast response time

75. What are the types of photodiodes?
   - PIN photodetector
   - Avalanche photodiode(APD)

76. Define photocurrent.

The high electric field present in the depletion region causes the carriers to separate and be collected across the reverse-biased junction. This gives to a current flow in the external circuit, with one electron flowing for every carrier pair generated. This current flow is known as photocurrent.

77. Define quantum efficiency.

It is defined as the number of the electron – hole pairs generated per incident photon of energy hv and is given by

$$\underline{n = \text{No. of electron-hole pairs generated}}$$
$$\text{No. of incident photons}$$

## 78. Define impact ionization.

In order for carrier multiplication to take place, the photogenerated carriers must traverse a region where a very high electric field is present. In this high field region, a photo generated electron or hole can gain energy so that it ionizes bound electrons in the valence band upon colliding with them. This carrier multiplication mechanism is known as impact ionization.

## 79. Define avalanche effect.

The newly created carriers are accelerated by the high electric field, thus gaining enough energy to cause further impact ionization. This phenomenon is called avalanche effect.

## 80. What is p+ ∏ p n+ reach- through structure?

The reach –through avalanche photodiode (RAPD) is composed of a high resistivity p-type material deposited as an epitaxial layer on a p+ substrate. A p-type diffusion is then made in the high resistivity material, followed by the construction of an n+ layer. The configuration is called p+ ∏ p n+ reach- through structure.

## 81. Define ionization rate.

The avg. no. of electron hole pairs created by a carrier per unit distance traveled is called ionization rate.

## 82. What are the conditions to be met for a high signal- to- noise ratio in a photodetector?

- The photodetector must have a high quantum efficiency to generate a large sign al power
- The p and amplifier noises should be kept as low as possible.

## 83. Define minimum detectable optical power.

It is defined as the optical power necessare to produce a photocurrent of the same magnitude as the root mean square of the total current.

## 84. Define quantum noise.

It is not possible to predict exactly how many electron-hole pairs are generated by a known optical power incident on the detector is the origin of the type of short noise called quantum noise.

## 85. What is meant by error rate?

An approach is to divide the number Ne of errors occurring over a certain time interval t by the number Nt of pulses transmitted during this interval. This is called either the error rate or the bit error rate.

$$\text{Bit error rate} \quad BER = \frac{Ne}{Nt} = \frac{Ne}{Bt}$$

$$\text{Where } B = \frac{1}{Tb}$$

86. Define quantum limit

It is possible to find the minimum received optical power required for a specific bit error rate performance in a digital system. This minimum received power level is known as quantum limit.

87. Give the classifications of preamplifiers.
- Low impedence(LZ) preamplifier
- High impedence(HZ) preamplifier
- Transimpedence  preamplifier

88. What is meant by excess noise factor?

The ratio of the actual noise generated in an avalanche photodiode to the noise that would exist if all carrier pairs were multiplied by exactly m is called the excess noise factor (F).

$$F = \frac{(m^2)}{(m)^2} = \frac{(m^2)}{m^2}$$

89. What is meant by inter symbol interference(ISI) ?

ISI results from pulse spreading in the optical fibre. The presence of this energy in adjacent time slots results in an interfering signal. Hence it is called ISI.

90. Give the advantages of  Pin photodiodes.
- Very low reverse bias is necessary
- High quantum efficiency
- Large bandwidth
- Low noise level

91. What do you mean by thermal noise?

Thermal noise is due to the random motion of electrons in a conductor. Thermal noise arising from the detector load resistor and from the amplifier electronics tend to dominate in applications with low signal to noise ratio.

92. Give the equation for mean square shot noise.

The mean square shot noise is given by

$\langle i_{n2} \rangle = 2qI_B$

$I_B$ average output current

B    bandwidth of the amplifier

93. Define multiplication  M.

The multiplication M for all carriers generated in  the photodiode is defined by

$$M = \frac{I_M}{I_P}$$

$I_M$ average value of the total multiplied output current

$I_P$ primary unmultiplied photocurrent

94. What is current mode of operation  of photodiode?

In photoconducting mode, the photocurrent is slightly dependent on the reverse bias. For a constant reverse bias, the current is linear. This is called current mode of operation of the photodiode.

95. What are the system requirements?

The following are the key system requirements.
- The desired or possible transmission distance
- The data rate or channel bandwidth
- Bit error rate(BER)

96. What are splices? What are the requirements of splices?

The splices are generally permanent fiber joints, whereas connectors are temporary fiber joints. Splicing is a sort of soldering. The requirements of splices are:
- Should cause low attenuation
- Should be strong & light in weight
- Should have minimum power loss
- Should be easy to install

97. What are the methods of fiber splicing?

There are 3 methods of fiber splicing. They are:
- Electric arc fusion splicing or fusion splicing
- Mechanical splicing
- V-groove splicing or loose tube splicing

98. What are connectors? What are the types of connectors?

The connectors are used to join the optical sources as well as detectors to the optical fiber temporarily. They are also used to join two optical fibers. The 2 major types of connectors are:
- Lensed type expanded beam connector
- Ferrule type connector

99. What are the requirements of a good connector?

The requirements of a good connector are as follows:
- Low loss
- Repeatability
- Predictability
- Ease of assembly and use
- Low cost & reliability
- compatibility

100. Give the 2 analysis that are used to ensure system performance?

The 2 analysis that are used to ensure system performance are:
- link power budget analysis
- rise time budget analysis

101. Explain briefly about link power budget analysis?

In the optical power loss model for a pt-to-pt link, the optical power rxed at the photo detector depends on the amount of light coupled into the fiber & losses occurring in the fiber at the connectors & splices. The link loss budget is derived from the sequential loss contribution of each element in the link.

$$Loss = 10 \log \frac{(P_{out})}{(P_{in})}$$

The total optical power loss is, $P_T = P_S - P_R$

102. Give the range of system margin in link power budget?

The system margin is usually (6-8) dB. A positive system margin ensures proper operation of the circuit. A negative value indicates that insufficient power will reach the detector to achieve the required bit error rate, BER.

103. The specifications of the light sources are converted to equivalent rise time in rise time budget. Why?

A rise time budget is a convenient method to determine the dispersion limitation of an optical link. This is particularly useful for digital systems. For this purpose, the specifications of the light sources (both the fiber & the photo detector) are converted to equivalent rise time. The overall system rise time is given in terms of the light source rise time, fiber dispersion time & the photo detector rise time.

104. What are the system components of system rise time?

The 4 basic system components that contribute to the system rise time are:
- transmitter (source) rise time
- receiver rise time
- material dispersion time of the fiber
- modal dispersion time of the fiber link

All these 4 basic elements may significantly limit system speed.

105. Why the attenuation limit curve slopes downwards to the right?

As the minimum optical power required at the rxer for a given BER becomes higher for increasing data rates, the attenuation limit curve slopes downward to the right.

106. What are the noise effects on system performance?

The main penalties are modal noise, wavelength chirp, spectral broadening, mode- partition noise.

107. Define modal noise?

It arises when the light from a coherent laser is coupled in to a multimode fiber operating at 400Mbps and higher. It mainly occurs due to mechanical vibrations and fluctuations in the frequency of the optical source.

108. What are the measures to avoid modal noise?

The measures are
- use LEDs
- use LASER having more longitudinal modes
- use a fiber with large numerical aperture
- use a single mode fiber

109. Define mode partition noise?

The mode partition noise is associated with intensity fluctuations in the longitudinal modes of a laser diode. It becomes more pronounced for the higher bit rates.

110. What is meant by chirping?

It means that the dynamic line broadening (line broadening is a frequency chirp) in the laser which oscillates in the single longitudinal mode under CW operation when the injection current is intensity modulated.

111. What is the best way to minimize the chirping?

It is to choose the laser emission wavelength close to the zero-dispersion of the wavelength of the fiber.

112. What is reflection noise?

It is the optical power that gets reflected at the refractive index discontinuities such as in splices, couplers and filters, or connectors. The reflected signals can degrade both the transmitter and receiver performance.

113. What are the effects of reflection noise in high speed systems?

They cause optical feedback which leads to optical instabilities that may lead to intersymbol interference and intensity noise.

114. What are the techniques to reduce optical feedback?

Fiber end faces with a curved surface to the laser emitting facet.
Index matching oil or gel at air glass interfaces.
PC connectors
Optical isolators within the transmitter module.

115. What are the basic performances of the WDM?

- Insertion loss
- Channel width
- Cross talk

116. What is WDM? Define.

WDM is wavelength division multiplexing. The optical beam consists of different wavelengths and several channel information is transmitted over a single channel.

117. What is meant as bidirectional WDM?

A single WDM which operates as both multiplexing and demultiplexing Devices is said as the bidirectional WDM.

118. Define Radiance.

Radiance (or brightness) is a measure, in Watts, of the optical power radiated into a unit solid angle per unit area of the emitting surface.

119. What is meant by 'population inversion'?

In thermal equilibrium, the density of excited electrons is very small. Most photons incident on the system will therefore be absorbed, so that stimulated emission is essentially negligible. Stimulated emission will exceed absorption only if the population of the excited states is greater than that of the ground state. This condition is known as population inversion.

120. What are the factors to be considered in link power budget?

The factors to be considered in link power budget are:

- transmission speed
- optical sources & detectors
- optical fiber

121. What are the causes of absorption?

Normally, the system is in the ground state. When a photon of energy $h\gamma_{12}$ impinges on the system, an electron in state $E_1$ can absorb the photon energy & be excited to state $E_2$.

122. What is meant by hetero junction?

In hetero junction, two different alloy layers are on each side of the active region. Because of the sandwich structure of differently composed alloy layers, both the carriers & optical field are confined in the central active layer.

123. What is meant by indirect band gap semiconductor material?

For indirect band gap materials, the conduction-band minimum & the valence-band maximum energy levels occur at different values of momentum. Here, band-to-band recombination must involve a third particle to conserve momentum, since the photon momentum is very small. Phonons serve this purpose.

124. What is meant by 'modal noise'?

It arises when light from a laser is coupled into the multimode fiber.

125. What is the necessity of cladding for an optical fiber?
   a) To provide proper light guidance inside the core
   b) To avoid leakage of light from the fiber
   c) To avoid mechanical strength for the fiber
   d) To protect the core from scratches and other mechanical damages

# 16 MARKS :

1. Discuss the mode theory of circular waveguides.
   - Overview of modes
       Electric field distributions for lower-order guided modes
   - Key modal concepts
   - Maxwell's Equations
   - Waveguide equations
   - Waveguide equations for Step-Index Fibers
   - Modal equation
   - Modes in Step-Index Fibers
   - Linearly polarised modes
   - Power flow in Step-Index Fibers

2. Explain in detail about fiber materials.
   - Requirements of optical fibers
   - Glass fibers
   - Halide Glass fibers
   - Active Glass fibers
   - Chalgenide Glass fibers
   - Plastic optical fibers

3. Explain in detail about single-mode fiber.
   - Dimensions of core diameter
   - Mode-field diameter
     Distribution of light in a single-mode fiber above its cutoff wavelength
   - Propagation modes
     i. Fiber birefringence
     ii. Fiber beat length

4. Discuss the structure and numerical aperture of graded index fiber.
   - Power law relationship
   - Index difference
   - Numerical aperture
   - Number of bound modes

5. Explain in detail about fiber fabrication.
   - Outside vapour- phase oxidation
   - vapour- phase axial deposition
   - modified chemical vapor deposition
   - plasma activated chemical vapor deposition
   - Double crucible method

6. What is waveguide dispersion? Derive expression
   Wave-guide dispersion, which occurs because a single mode fiber confines only 80% of the optical power to the core. Dispersion thus arises since the 20% of the light propagating in the cladding travels faster than the light confined to the core. The amount of wave-guide dispersion depends on the fiber design, since the modal dispersion constant ® is a fn of $(a / \lambda)$

7. What is material dispersion ? Derive Expression
   Material dispersion occurs because the index of refraction varies as a function of the optical wavelength.

8. Explain –design optimization of single mode fibers
   refractive index profile:
1. For achieving a maximum transmission distance of a high-capacity link, the dispersion null should be at the wavelength of minimum attenuation.
2. Four main categories
   a. 1300 nm optimised fibers
   b. dispersion-shifted fibers
   c. dispersion-flattened fibers
   d. large-effective core area fibers.
3. matched cladding fibers have a uniform refractive index throughout the cladding.

4.typical mode field diameters are 9.5 micro meter and core-to-cladding index differences are around o.37%.

5.material dispersion depends only on the composition of the material.

6.an alternative is to reduce fiber dispersion by spreading the dispersion minimum out over a wide range. This approach is known as dispersion flattening.

9.What is Pulse Broadening?Derive the expression for the same in Graded index Waveguides.

Dispertion induced signal distortion is that a light pulse will broaden as it travels along the fibre.This pulse broadening causes a pulse to overlap with neighbouring pulses.After a time 't',the adjacent pulses can no longer be individually distinguished at the receiver and error will occur.

10.Signal distortion in optical waveguide-Explain
Distortion due to
1.Intramodal dispersion
2.Intermodal delay effects.
The distortion effects are explained by examining the behaviour of the group velocities of the guided mode..

11.Signal distortion in optical waveguide- explain

1.optical signal gets distorted as it travels along a fiber

2.distortion is due to intramodal dispertion  and  intermodal delay

3.it is explained by examining the behaviour of the group velocities of the guided mode.

4.intramodal dispersion depends on wavelenth   and its effect on signal distortion increases with a spectrum width of the optical source

5.waveguide dispersion occurs because a single mode fiber cofines only 80% of  the optical power to the core.

6.the other factor giving rise to pulse spreading   having a different value of group velocity at a single frequency.

7.among the 3 waveguide dispersion  can be ignored in multimode fibers but it is significant in single mode fiber.

8.there are 3 distortion can be mitigated by
a)optical power launching conditions
b)non uniform mode attenuation
c)mode mixing in the fiber and splices
d)by statistical variation
e)non ideal index profile

12.Give an account on the direct and indirect band gap materials.

Direct band gap materials:

In direct band gap materials direct transition is possible from valence band to conduction

band.e.g.GaAs,InP,InGaAs

The electron and the hole have the same momentum value.

Indirect band gap materials:

In indirect band gap materials direct transition is not possible from valence band to conduction.e.g.silicon,germanium.

The electron and the hole have the different momentum value.

13.Give an account on LED structures.

Surface emitters:

Also called as burrus or front emitters.

The plane of the active light-emitting region is oriented perpendicularly to the axis of the fiber.

The emission pattern is isotropic with a 120 half-power beam width.

Edge emitter:

Consists of an active junction region, which is the source of the incoherent light, and the two guiding layers.

The refractive index of the guiding layers is less than the active region.

The emission pattern of the edge emitter is more directional than that of the surface emitter.

14. Give an account on the Laser diode modes.

Fabry-Perot resonator:

It consists of partially reflecting mirrors that are directed toward each other to enclose the cavity.

The purpose of these mirrors is to provide strong optical feedback in the longitudinal section.

The device will oscillate at the resonant frequencies.

Distributed feedback configurations:

In this case lasing action is achieved by Bragg reflectors.

A pattern of electric and magnetic field lines are set up which are called the modes of the cavity.

The different modes are longitudinal, transverse, and lateral.

Longitudinal modes are associated with the length of the cavity and determine the typical spectrum of the emitted radiation.

These modes lie in the plane of the pn junction. They depend on the sidewall preparation and the width of the cavity.

Transverse modes are associated with the electromagnetic field and beam profile in the direction perpendicular to the plane of the pn junction. They determine the laser characteristics as the radiation pattern and the threshold current density determines the shape of the lateral profile of the laser beam

15. Give an account on the optical confinement of lasers.

 1. Gain indexed guide
2. Positive indexed guide
3. Negative indexed guide

Indexed lasers have the following structures.

1. buried hetero structure.

2. Selectively diffused construction

3. Varying thickness structure

4. Bent layer configuration.

16. Give an account on single mode lasers and modulation of laser diodes.

Single mode lasers:

It is used for long-distance communication.

It consists of a single longitudinal mode and single transverse mode.

The spectral width is low.

Alternative devices developed are

1. Vertical cavity surface emitting lasers

2. Structures that have a built-in frequency-selective grating.

3. Tunable lasers.


Modulation:

The process of imposing information on a light stream is called modulation. This can

be achieved by varying the laser drive current

Pulse modulation is used.


17. Discuss the receiver operation with neat block diagram.
      Digital signal transmission
        Fig) Signal path through an optical data link
      Error sources
        Fig)Noise sources and disturbances in the optical pulse detection
      mechanism
      Receiver configuration
        Fig) Schematic diagram of a typical optical receiver
      Fourier transform representation


18. Write in detail about avalanche photodiodes and explain briefly about photodetector noise and SNR.

    Avalanche photodiodes
      a. Impact ionization
      b. Avalanche effect
      c. Reach-through construction
      d. p+ $\prod$ p n+ reach- through structure
      e. Principle of reach through
      f. Ionization rate

    Photodetector noise
      SNR at output of an optical receiver
      Condition to achieve a high SNR

    SNR

$$\frac{S}{N} = \frac{(i_p^2)M^2}{2q(I_p+I_D)M^2F(M)+2qI_LB+4K_BT_B/R_L}$$

19. An InGaas pin photodiode has the following parameters to wavelength of 1300nm: $I_D = 4$ nA, $\eta = 0.9$, $R_L = 1000\Omega$ and the surface leakage current is negligible. The incident optical power is 300nW (-35 dBm), and the receiver bandwidth is 20 MHz. Find the various noise terms of the receiver.

$$\text{Shot noise} = \frac{\eta P_o e}{hf}$$
$$\text{Total shot noise} = 2eB(I_D + I_p)$$

$$\text{Thermal noise} = \frac{4KT_B}{R_L}$$

20. Discuss the performance of digital receiver by defining the probability of error.

    Bit error rate
    Probability distributions
     Fig)Probability distributions for received 0 and 1 signal
  pulses
    Mean - square noise voltage
     Fig)Gaussian noise characteristics of a binary signal
    Error function
     Fig) Plot of the BER(Pe) versus the factor Q.

21. Explain the error sources of fundamental receiver operations.

    Errors due to noises and disturbances in the signal detection system
    Definition of noise
    Types of noises
     i.  Internal noise
     ii.  External noise
   Other types
     i.  shot noise
     ii.  thermal noise
    Fig) Noise sources and disturbances in the optical pulse detection
    mechanism
    Photocurrent
    Inter symbol interference(ISI)
    Fig)Pulse spreading in an optical signal that leads to ISI.

22. Explain in detail about the system considerations?
- The 3 system considerations
- Transmitting distance: decide wavelength-choose components-txion distance is not long, operate in (800-900) nm region-txion distance is long; operate in (1300-1550) nm region.
- Optical source & detectors:
  - Choose photo detector & optical source, compute characteristics of fiber
  - Detect the amount of light falling on detector to satisfy BER.
  - Pin photodiode rxer is simpler, stable, less expensive, need low bias vge (<50V) than avalanche photodiode.
  - Signal dispersion, data rate, txion distance & cost decides source (LED & LASER).
  - In laser, spectral width is narrow, couple (10-15) db more optical power, greater repeated, less txion, but complex circuitry.
- Optical fiber:
  - Select single-mode or multimode either a step-index or graded-index core.
  - Multi-mode fibers used with LEDs, LASERs use single-mode or multi-mode fibers.

- o   Optical power coupled depends on core-cladding index difference & thus numerical aperture.
  - o   Single-mode fiber provides ultimate bit-rate distance products of about 30 Gbps/km.
- Disadvantages of single-mode fiber
- When choosing the attenuation characteristics of a cabled fiber, the extra losses from cabling process must be added to the fiber attenuation.

23. Explain in detail about the methods of fiber splicing?
- The 3 methods of fiber splicing
- Electric arc fusion splicing or fusion splicing
  - Figure
  - Broken fiber edges aligned, pressure is applied; heat is applied
  - Unite as a single fiber
  - Plastic jacket made of epoxy resin to cover the splice
  - Loss of (0.25-0.1)db is achieved
- Mechanical splicing or elastic tube splicing
  - Figure
  - Broken fiber edges aligned, locked in position with positioning devices & optical cement
  - Edges polished, splicing compound added
  - Central hole diameter of precision tube is similar than fiber
  - Insert fiber, expands hole diameter
  - A symmetrical force allows accurate or automatic alignment of the axis of two joined fibers
- V-groove splicing or loose tube splicing
  - o   Figure
  - o   Fiber ends are fixed in v-shaped groove
  - o   Grooved silicon, plastic ceramic or metal substrate
  - o   Splice loss dependent on metal size

24. Explain about the two types of connectors?
- The 2 types of connectors.
- Lensed type/ Expanded beam connectors
  - Figure
  - Two lenses: Collimator lens & pre focusing lens
  - Adjust the two lenses, optical signal from one fiber is connected to other.
- Ferrule type connector
  - o   Figure
  - o   Fibers placed in ferrule, fixed by an adhesive material
  - o   Brought together under cylindrical sleeves.

25. Explain in detail about link power budget & rise time budget?
- Link power budget: In the optical power loss model for a pt-to-pt link, the optical power rxed at the photo detector depends on the amount of light coupled into the fiber & losses occurring in the fiber at the connectors & splices. The link loss budget is derived from the sequential loss contribution of each element

in the link.
- Figure
- Formula
- System margin is usually (6-8) db.
- Rise time budget: It is a convenient method to determine the dispersion limitation of an optical link. This is particularly useful for digital systems. For this purpose, the specifications of the light sources are converted to equivalent rise time. The overall system rise time is given in terms of the light source rise time, fiber dispersion time & the photo detector rise time.
- Formula
- Basic system components

26. Discuss the operational principles of WDM and its key features?

An optical beam consists of different wavelengths. Several channel information are transmitted over a single channel and increases the information carrying capacity.
The three basic performance of WDM are:

     o   Insertion loss: amount of power loss arises from the fiber optic link by the addition of WDM coupling devices. Also the loss occurs at the junction of the fiber optic link to the WDM device.

     o   Channel width: wavelength range allocated to a particular source. For lasers, channel width is several 10s of nm required for no interference.

     o   Cross talk: problem at the receiver caused by the mixing of two or more channels. It depends on the application. Tolerable level is above -30 dB.

27. Describe the noise effects on the system performance?

It is assumed that the optical power falling on the photo detector is a clearly defined function of time within the statistical nature of the quantum detection process but in reality various interactions between spectral imperfections in the propagating optical power and the dispersive waveguide give rise to the variations in the optical power level falling on the photo detector. The main penalties are modal noise, wavelength chirp, spectral broadening, mode- partition noise.

Modal noise: It arises when the light from a coherent laser is coupled in to a multimode fiber operating at 400Mbps and higher. It mainly occurs due to mechanical vibrations and fluctuations in the frequency of the optical source. The measures to avoid are:
                 use LEDs
                 use LASER having more longitudinal modes
                 use a fiber with large numerical aperture
                 use a single mode fiber

Mode partition noise: The mode partition noise is associated with intensity fluctuations in the longitudinal modes of a laser diode. It becomes more pronounced for the higher bit rates.

Chirping: It means that the dynamic line broadening (line broadening is a frequency chirp) in the laser which oscillates in the single longitudinal mode under CW operation when the injection current is intensity modulated. They cause optical feedback which leads to optical instabilities that may lead to inter symbol interference and intensity noise.

Reflection noise: It is the optical power that gets reflected at the refractive index discontinuities such as in splices, couplers and filters, or connectors. The reflected

signals can degrade both the transmitter and receiver performance. They cause optical feedback which leads to optical instabilities that may lead to inter symbol interference and intensity noise.

28. (a)(i) Discuss the operational principles of WDM.

(ii) Describe the key features of WDM.

An optical beam consists of different wavelengths. Several channel information are transmitted over a single channel and increases the information carrying capacity.

The three basic performance of WDM are:

o Insertion loss: amount of power loss arises from the fiber optic link by the addition of WDM coupling devices. Also the loss occurs at the junction of the fiber optic link to the WDM device.

o Channel width: wavelength range allocated to a particular source. For lasers, channel width is several 10s of nm required for no interference.

o Cross talk: problem at the receiver caused by the mixing of two or more channels. It depends on the application. Tolerable level is above -30 dB.

(b) Explain the rise-time budget of a fiber-optic point-to-point link.

- Rise time budget: It is a convenient method to determine the dispersion limitation of an optical link. This is particularly useful for digital systems. For this purpose, the specifications of the light sources are converted to equivalent rise time. The overall system rise time is given in terms of the light source rise time, fiber dispersion time & the photo detector rise time.
- Formula
- Basic system components