



**Solve all the following questions:-**

**Question One (25 mark)**

- Drive an expression for maximum acceptance angle in optical fiber? (3 marks)
- State the main differences between (4 Marks)
  - Avalanche photodiode and LASER diode.
  - Optical fiber Mie and Raman scattering.
- Explain what is meant by the critical bending radius for an optical fiber. A single mode step index fiber has a critical bending radius of 2 mm when illuminated with light at a wavelength of 1.3  $\mu\text{m}$ . Calculate the relative refractive index difference for fiber. (3 Marks)
- A photodiode has a quantum efficiency of 65% when photons of energy  $1.5 \times 10^{-19}$  J are incident upon it. (3 Marks)
  - At what wavelength is the photodiode operating?
  - Calculate the incident optical power required to obtain a photocurrent of 2.5  $\mu\text{A}$  when the photodiode is operating as described above.
- Explain two types of power losses in optical fibers and how to face these factors?
- Calculate the ratio of the stimulated emission rate to the spontaneous emission rate for an incandescent lamp operating at a temperature of 1000 K. It may be assumed that the average operating wavelength is 0.5  $\mu\text{m}$ . (3 Marks)
- What is meaning of LASER, discuss the principle operation for laser diode? (3 Marks)

**Question Two (25 mark)**

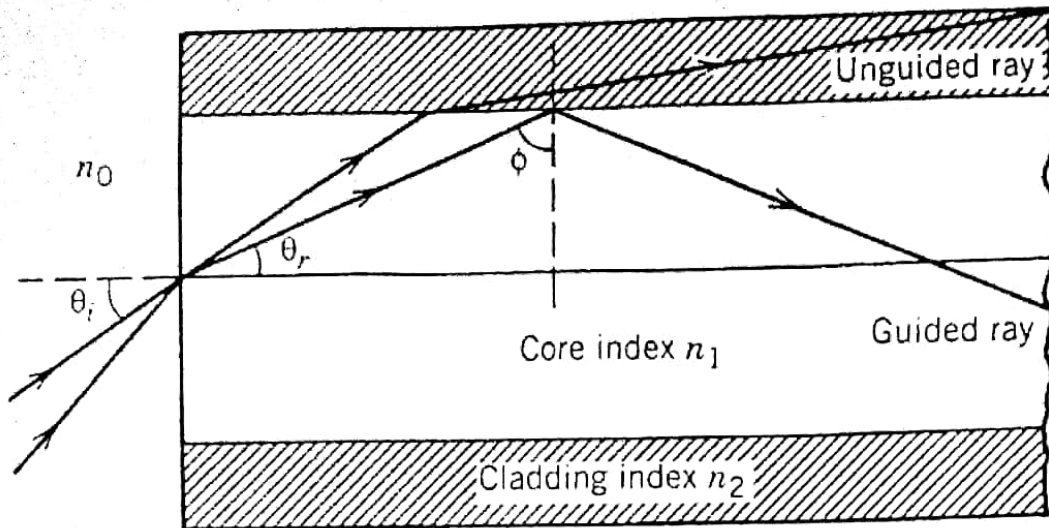
- Define: population inversion- Responsivity – laser oscillation conditions- quantum efficiency of LASER diode and photodetector- stimulated and spontaneous emission of light - PIN photodiodes. (4 Marks)
- A ruby laser contains a crystal of length 4 cm with a refractive index of 1.78. The peak emission wavelength from the device is 0.55  $\mu\text{m}$ . Determine the number of longitudinal modes and their frequency separation. (3 Marks)
- The quantum efficiency of a particular silicon RAPD is 80% for the detection of radiation at a wavelength of 0.9  $\mu\text{m}$ . When the incident optical power is 0.5  $\mu\text{W}$ , the output current from the device (after avalanche gain) is 11  $\mu\text{A}$ . Determine the multiplication factor of the photodiode under these conditions? (4 Marks)

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- d. A multimode graded index fiber exhibits total pulse broadening of  $0.1 \mu\text{s}$  over a distance of 15 km. Estimate: (3 marks)
- (i) the maximum possible bandwidth on the link assuming no Intersymbol interference;
  - (ii) the pulse dispersion per unit length;
  - (iii) the bandwidth-length product for the fiber.
- e. An injection laser has an active cavity with losses of  $30 \text{ cm}^{-1}$  and the reflectivity of the each cleaved laser facet is 30%. Determine the laser gain coefficient for the cavity when it has a length of  $600 \mu\text{m}$ . (3 marks)
- f. Draw the block diagram of Endoscopy instrument and explain the different components? (5 marks)
- g. What are the main characteristics of flexible Endoscopes? (3 marks)

Best wishes of success  
Dr. Bedir yousif

## Answer Model

Q1-a



refraction at the fiber–air interface, the ray bends toward the normal.

The angle  $\theta_r$  of the refracted ray is given by Snell's law  $n_0 \sin \theta_i = n_1 \sin \theta_r$

The critical angle  $\phi_c$ , at core-clad interface defined by

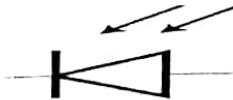

$$\sin \phi_c = n_2 / n_1.$$

reflections occur throughout the fiber length, all rays with  $\phi > \phi_c$  remain confined to the fiber core. This is the basic mechanism behind light . Now, noting that  $\theta_r = \frac{\pi}{2} - \phi_c$  For such a ray , we obtain  $n_0 \sin \theta_i = n_1 \sin \phi_c = (n_1^2 - n_2^2)^{1/2}$

At  $\phi = \phi_c$ , then  $\theta_i = \theta_{0max}$ , (acceptance angle)  $n_0 \sin \theta_{0max} = \sqrt{n_1^2 - n_2^2} = N_A$

**b- State the main differences between**

Avalanche photodiode and LASER diode

Avalanche photodiode	LASER diode
Optical detector device	Optical source device
Connected in reverse bias	Connected in forward bias
Convert light signal into electrical signal	Convert electrical signal into light signal
	

ii- Optical fiber Mie and Raman scattering

Optical fiber Mie	Raman scattering
Linear scattering	Nonlinear scattering
Causes due to inhomogeneities of atoms in fiber	Causes due to a high power of optical signal
There is no frequency shift	There is s frequency shift occurs in a signal

Q1-c: Explain what is meant by the critical bending radius for an optical fiber. A single mode step index fiber has a critical bending radius of 2 mm when illuminated with light at a wavelength of 1.3  $\mu\text{m}$ . Calculate the relative refractive index difference for fiber

ans.

Critical bending radius for optical fiber is the maximum radius of curvature fiber allowed during installing the fiber after this radius the power will go out the fiber

$$R_c \cong \frac{3n_1^2 \lambda}{4\pi(n_1^2 - n_2^2)^{3/2}}$$

$$2 \times 10^{-3} = 3n_1^2(1.3 \times 10^{-6}) / [4\pi \text{NA}^3]$$

$$\text{NA}^3 = 0.1552 \times 10^{-3} n_1^2 \text{----- (1)}$$

This is the design problem it is required the fiber parameters ( $n_1, n_2, \Delta, a$ ) to meet the system requirements ( $R_c = 2 \text{ mm}, \lambda = 1.3 \mu\text{m}$ ) Here, may be assume any value of a single mode step index fiber radius from 1  $\mu\text{m}$  to 3  $\mu\text{m}$  in order to in safe region but the best assume  $n_1$  any value from 1.45 to 1.8 (glass material refractive index)

Then let  $n_1 = 1.45$  as a result  $\text{NA} = 0.069$

The relative refractive index difference

$$\Delta = \text{NA}^2 / (2n_1^2) = (0.069)^2 / (2 \times (1.45)^2) = 0.00113 = 0.11\%$$

The maximum core radius =  $V_c * \lambda / (2\pi \text{NA}) =$

$$2.405 \times 1.3 \mu\text{m} / (6.28 \times 0.069) = 7.2 \mu\text{m}$$

Note that avoid maximum core radius in the design because the mode travel at the interface between core- cladding

Q1-d: A photodiode has a quantum efficiency of 65% when photons of energy  $1.5 \times 10^{-19} \text{ J}$  are incident upon it.

(i) At what wavelength is the photodiode operating?

(ii) Calculate the incident optical power required to obtain a photocurrent of 2.5  $\mu\text{A}$  when the photodiode is operating as described above.

Ans. The photon energy  $E = hf = hc/\lambda$ . Therefore:

$$\lambda = \frac{hc}{E} = \frac{6.626 \times 10^{-34} \times 2.998 \times 10^8}{1.5 \times 10^{-19}} = 1.32 \mu\text{m}$$

The photodiode is operating at a wavelength of 1.32  $\mu\text{m}$ .

$$R = \frac{\eta e}{hf} = \frac{0.65 \times 1.602 \times 10^{-19}}{1.5 \times 10^{-19}} = 0.694 \text{ A W}^{-1}$$

$$R = \frac{I_p}{P_o}$$

$$P_o = \frac{2.5 \times 10^{-6}}{0.694} = 3.6 \mu\text{W}$$

The incident optical power required is 3.60  $\mu\text{W}$

Q1-e Explain two types of power losses in optical fibers and how to face these factors?

material absorption losses divided into two phases

The absorption of the light may be intrinsic (caused by the interaction with one or more of the major components of the glass) or extrinsic (caused by impurities within the glass)

**Intrinsic absorption:** causes a power losses in UV region, near IR region

The strong absorption bands occur due to oscillations of structural units such as Si-O (9.2  $\mu\text{m}$ ), P-O (8.1  $\mu\text{m}$ ), B-O (7.2  $\mu\text{m}$ ) and Ge-O (11.0  $\mu\text{m}$ ) within the glass.

**Extrinsic absorption**

from transition metal element impurities. Some of the more common metallic impurities found in glasses are shown in the Table 3.1, together with the absorption losses caused by one part in  $10^9$

### Linear scattering Losses

This process tends to result in attenuation of the transmitted light as the transfer may be to a leaky or radiation mode which does not continue to propagate within the fiber core, but is radiated from the fiber

Overcoming or reducing power losses

- 1- Reducing the absorption lossess due to atomic defects via of making the material without crystalline defects
- 2- Reducing the absorption lossess due to intrinsic losses via of using the optical fiber with light interaction in range from 800nm to 1550nm
- 3- Reducing the absorption lossess due to extrinsic losses via decreasing the impurities in fiber.
- 4- Avoid the scattering losses by making the fiber more homogeneous medium and the geometry perfect cylinder.

Q1-f Calculate the ratio of the stimulated emission rate to the spontaneous emission rate for an incandescent lamp operating at a temperature of 1000 K. It may be assumed that the average operating wavelength is 0.5  $\mu\text{m}$ .

Ans.

The average operating frequency is given by  $f = \frac{c}{\lambda} = \frac{3 \times 10^8}{0.5 \times 10^{-6}} = 6 \times 10^{14} \text{ Hz}$

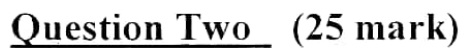
Using Eq. he ratio is:  $\frac{\text{stimulated emission rate}}{\text{spontaneous emission rate}} = \frac{B_{21}\rho_f}{A_{21}} = \frac{1}{\exp\left(\frac{hf}{KT}\right) - 1}$

$$= \frac{1}{\exp\left(\frac{6.626 \times 10^{-34} \times 6 \times 10^{14}}{1.381 \times 10^{-23} \times 1000}\right) - 1} = 3.1 \times 10^{-13}$$

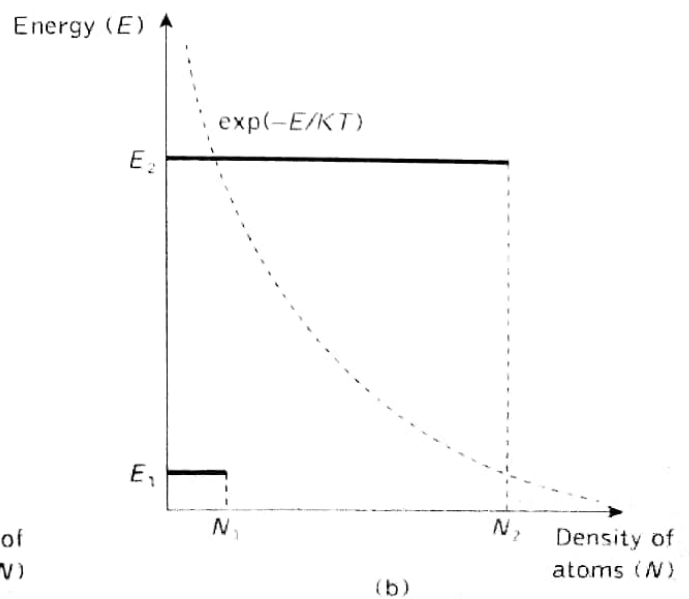
Q1-g: What is meaning of LASER, discuss the principle operation for laser diode

Ans.

When connect the laser diode in forward bias with enough voltage, the electrons in valance band absorbed the energy and transfers to the conduction band. After this operation the emission process starts to cause the electron moving from conduction band C.B to valance band V.B and emits a photon, this photon reflected twice with set of mirrors to C.B and transfer another electron from C.B to V.B and emits another photon with the same wavelength, phase, direction so the process is called stimulated and so on repeated this process to finished at the output of the device.



Ans.  
population inversion: it is necessary to create a nonequilibrium distribution of atoms such that the population of the upper energy level is greater than that of the lower energy level (i.e.  $N_2 > N_1$ ).





Responsivity:  $R$  is often of more use when characterizing the performance of a photodetector. It is defined as:

$$R = \frac{I_p}{P_o} \quad (Aw^{-1})$$

Quantum efficiency  $\eta$  : is defined as the fraction of incident photons which are absorbed by the photodetector and generate electrons which are collected at the detector terminals:

$$\eta = \frac{\text{number of electrons collected}}{\text{number of incident photons}} = \frac{r_e}{r_p}$$

Laser oscillation conditions: 1- population inversion must be satisfied to make the amplification. And resonance condition along the axis of the cavity is  $L = \frac{\lambda q}{2n}$

1- the gain in the amplifying medium exactly balances the total losses  
*high threshold gain per unit length is required in order to balance the losses from the cavity.*

$$\bar{g}_{th} = \bar{\alpha} - \frac{1}{2L} \ln \frac{1}{r_1 r_2}$$

**Spontaneous emission:** the transfer of electron from conduction band to valance band emits only one photon with wavelength depends on the energy gap.

**Stimulated emission:** the transfer of electron from conduction band to valance band emits more than photon with wavelength depends on the energy gap.

**Q2-b:** A ruby laser contains a crystal of length 4 cm with a refractive index of 1.78. The peak emission wavelength from the device is 0.55  $\mu\text{m}$ . Determine the number of longitudinal modes and their frequency separation

Ans.  
 The number of longitudinal modes supported within the structure may be obtained from

$$q = \frac{2nL}{\lambda} = \frac{2 \times 1.78 \times 0.04}{0.55 \times 10^{-6}} = 2.6 \times 10^5$$

the frequency separation of the modes is:

$$\delta f = \frac{3 \times 10^8}{2 \times 1.78 \times 0.04} = 2.1 \text{ GHz}$$

**Q2-c:** The quantum efficiency of a particular silicon RAPD is 80% for the detection of radiation at a wavelength of 0.9  $\mu\text{m}$ . When the incident optical power is 0.5  $\mu\text{W}$ , the output current from the device (after avalanche gain) is 11  $\mu\text{A}$ . Determine the multiplication factor of the photodiode under these conditions?

Ans. the responsivity:

$$R = \frac{\eta e \lambda}{hc} = \frac{0.8 \times 1.602 \times 10^{-19} \times 0.9 \times 10^{-6}}{6.626 \times 10^{-34} \times 3 \times 10^8} = 0.581 \text{ Aw}^{-1}$$

Also, from Eq. (5.4), the photocurrent:

$$I_p = P_o R = 0.5 \times 10^{-6} \times 0.581 = 0.291 \mu A$$

Finally, using Eq. (5.15):

$$M = \frac{I}{I_p} = \frac{11 \times 10^{-6}}{0.291 \times 10^{-6}} = 37.8$$

The multiplication factor of the photodiode is approximately 38.

Q2-d: A multimode graded index fiber exhibits total pulse broadening of  $0.1 \mu s$  over a distance of 15 km. Estimate:

- (i) the maximum possible bandwidth on the link assuming no Intersymbol interference;
- (ii) the pulse dispersion per unit length;
- (iii) the bandwidth-length product for the fiber.

The maximum possible optical bandwidth which is equivalent to the maximum possible bit rate (for return to zero pulses) assuming no ISI may be obtained from Eq. (3.10), where:

$$B_{opt} = BT = \frac{1}{2\tau} = \frac{1}{0.2 \times 10^{-6}} = 5 \text{ MHz}$$

(b) The dispersion per unit length may be acquired simply by dividing the total dispersion by the total length of the fiber:

$$\text{Dispersion} = \frac{0.1 \times 10^{-6}}{15} = 6.67 \text{ ns km}^{-1}$$

(c) The bandwidth-length product may be obtained in two ways. Firstly by simply multiplying the maximum bandwidth for the fiber link by its length. Hence:

$$B_{opt} L = 5 \text{ MHz} \times 15 \text{ km} = 75 \text{ MHz km}$$

Alternatively, it may be obtained from the dispersion per unit length using Eq. (3.10) where:

$$B_{opt} L = \frac{1}{2 \times 6.67 \times 10^{-6}} = 75 \text{ MHz km}$$

Q2-e: An injection laser has an active cavity with losses of  $30 \text{ cm}^{-1}$  and the reflectivity of the each cleaved laser facet is 30%. Determine the laser gain coefficient for the cavity when it has a length of  $600 \mu m$ .

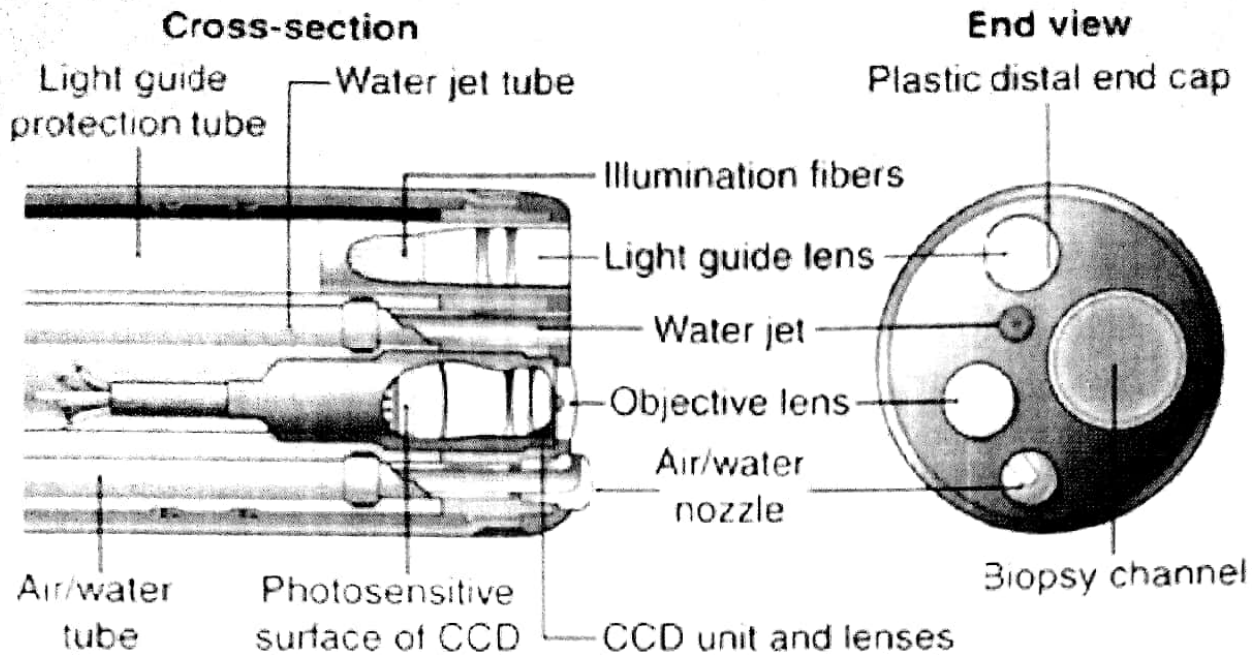
The threshold gain per unit length where  $r_1 = r_2 = r$  is given by

$$\bar{g}_{th} = \bar{\alpha} - \frac{1}{2L} \ln \frac{1}{r_1 r_2} = 30 + \frac{1}{0.06} \ln \frac{1}{0.3} = 50 \text{ cm}^{-1}$$

The threshold gain per unit length is equivalent to the laser gain coefficient for the active cavity, which is  $50 \text{ cm}^{-1}$



Q2-f: Draw the block diagram of Endoscopy instrument and explain the different components?



Q2-g: What are the main characteristics of flexible Endoscopes?

Flexible endoscopy provided a quantum leap in the area of diagnosis and therapy of the aerodigestive tract.

1. **Optical properties.** Two types of flexible endoscope are currently in use, and they **transmit the image differently**.

a. **Fiber optic endoscopes** are based upon fiber **optic light transmission technology**.

i. Each individual fiber is clad in a wrapping of greater optical density, creating a reflective layer that causes light to bounce back and forth within the fiber with little loss of light.

ii. Thousands of fibers are packed tightly together in a bundle, each carrying a small parcel of light to or from a portion of the viewing area.

iii. One bundle of fibers carries light into the examined organ, and a second bundle transmits the image from the organ interior to the viewing optic.

iv. The latter bundle must have all the fibers arranged in a "coherent bundle" (i.e., in the same spatial arrangement at both ends of the fiber, causing the portion of the total image that each carried to be in its proper position).

v. Major disadvantages with flexible fiber optic endoscopes include fragility. When individual fibers break, light transmission is decreased and the visual image develops dark spots (corresponding to the broken fibers).

vi. These endoscopes are generally direct-viewing endoscopes; therefore the endoscopist looks directly into an eyepiece. **An optical beam splitter** allows a second observer to view the image. Alternatively, a small video camera may be placed on the end of the endoscope and the image viewed on a video screen. The addition of side arms and external video screens introduces optical interference, which reduces visual clarity.

**b. Video endoscopy applies video technology to endoscopy.**

An increasing number of the endoscopes in use today are video endoscopes.

- i. Light is transmitted to the tip of the endoscope through a fiber optic bundle, as in the endoscopes described earlier.
- ii. However, the viewing fiber optic bundle is replaced with a charge-coupled device (CCD) chip camera, placed at the tip of the endoscope. This chip carries a digital image back to a video processor, which displays an image on a color monitor.
- iii. The CCD chip camera uses a dense grid of photocell receptors, each of which generates a single pixel on the monitor.