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Internal Assessment Test 2 – December 2024

Sub:	**Satellite and Optical Communication**					Sub Code:	**BEC515D**	Branch:	**ECE**
Date:	**14/12/2024**	Duration:	90 Minutes	Max Marks:	50	Sem/Sec:			**OBE**

	Answer Any 5 Questions	MARKS	CO	RBT
1	Define numerical aperture (NA) and explain its significance in optical fibers.	[10]	CO4	L2
2	Explain the concept of total internal reflection and its application in optical fibers.	[10]	CO4	L2
3	Write a short note on macrobending losses and microbending losses in optical fibers.	[10]	CO4	L2
4	Explain the basic structure of a Light Emitting Diode (LED) with a neat diagram.	[10]	CO5	L2
5	Write a short note on the working principle of the pin photodetector.	[10]	CO5	L2
6	What is Wavelength Division Multiplexing (WDM)? Explain its importance in optical communication.	[10]	CO5	L2

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Questions & Solutions

1. Define numerical aperture (NA) and explain its significance in optical fibers.

Answer:

Numerical Aperture (NA) is a dimensionless parameter that measures the light-gathering ability of an optical fiber. It is defined as:

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

where:

- n_1: Refractive index of the core
- n_2: Refractive index of the cladding

Alternatively, it is related to the maximum acceptance angle (θ_a) of the fiber:

$$NA = n_0 \sin \theta_a$$

where n_0 is the refractive index of the surrounding medium, usually air ($n_0 \approx 1$).

Significance of Numerical Aperture in Optical Fibers:

1. **Light-Gathering Capacity:**
NA determines the ability of the fiber to collect and guide light. A higher NA means the fiber can accept light at a larger range of incident angles, making it suitable for applications requiring greater flexibility in light coupling.
2. **Acceptance Angle:**
NA directly relates to the acceptance angle of the fiber, defining the cone of light that can enter the fiber and propagate efficiently.
Larger NA: Wider acceptance angle, easier light coupling.
Smaller NA: Narrower acceptance angle, reduced light losses.
3. **Mode Propagation:**
Fibers with larger NA tend to support multiple modes of propagation (multimode fibers).
Smaller NA typically leads to single-mode operation, reducing modal dispersion for high-speed and long-distance communication.
4. **Efficiency in Signal Transmission:**
A high NA is desirable for short-distance, high-bandwidth applications where more light power is required to ensure strong signals. However, for long distances, lower NA minimizes dispersion, improving signal clarity.
5. **Material and Design Implications:**
The NA of an optical fiber depends on the difference between the core and cladding refractive indices. Engineers optimize this to balance light collection, propagation losses, and dispersion.
6. **Applications:**
High NA fibers are used in medical imaging (endoscopy) and illumination systems where wide-angle light capture is crucial. Low NA fibers are preferred in telecommunications for high-speed data transfer over long distances.
Numerical Aperture (NA) is a critical parameter in optical fiber design and application. It governs the fiber's ability to accept, guide, and transmit light efficiently. By optimizing the NA, engineers can tailor optical fibers for specific requirements, balancing light-gathering capability, signal clarity, and transmission efficiency.

2. Explain the concept of total internal reflection and its application in optical fibers.

Answer:
Concept of Total Internal Reflection:
Total internal reflection (TIR) occurs when a light ray traveling in a medium of higher refractive index (n_1) strikes the boundary with a medium of lower refractive index (n_2) at an angle greater than the critical angle (θ_c). The critical angle is defined as:

$$\theta_c = \arcsin\left(\frac{n_2}{n_1}\right)$$

where n1>n2n_1 > n_2n1>n2.
When the angle of incidence (θi) is greater than θc: No refraction occurs, and all the light is reflected back into the first medium. This reflection is termed "total internal reflection.

Conditions for Total Internal Reflection:

- The light must travel from a medium with a higher refractive index (n1) to one with a lower refractive index (n2).
- The angle of incidence (θi) must be greater than the critical angle (θc).

Application of TIR in Optical Fibers:

Optical fibers rely on total internal reflection to transmit light over long distances with minimal loss. The structure of an optical fiber comprises:
Core: High refractive index material where light propagates.
Cladding: Lower refractive index material surrounding the core.
Light Propagation in the Core:

- When light enters the fiber within its acceptance angle, it undergoes continuous total internal reflection at the core-cladding interface.
- This ensures the light remains confined within the core, even over bends and long distances.

Efficient Signal Transmission:
TIR enables optical fibers to transmit signals with low attenuation and high efficiency, as very little light escapes through the cladding.

Key Applications in Optical Fibers:

Telecommunications: Optical fibers use TIR to transmit data as light pulses over vast distances at high speeds with minimal loss, enabling internet, telephone, and cable TV services.
Medical Applications: In endoscopy, optical fibers guide light into the human body and transmit images back for diagnostic purposes.
Industrial Applications: Used in sensors and illumination systems where precise light guidance is required.
Networking: Backbone for high-speed networks due to their ability to handle large bandwidths and transmit data over long distances without significant loss.

Advantages of TIR in Optical Fibers:

Low Losses: Light remains confined within the core, minimizing power loss.
High Bandwidth: Enables transmission of large volumes of data.
Flexibility: Fibers can bend without significant loss due to TIR.

3. Write a short note on macrobending losses and microbending losses in optical fibers.

Answer:

Optical fibers are highly efficient in guiding light, but certain bending or deformation can cause losses in the transmitted signal. These losses are broadly classified as macrobending losses and microbending losses:

1. Macrobending Losses:
Macrobending losses occur when the optical fiber is bent with a large radius of curvature, usually in the order of millimeters or centimetres.

Mechanism:

- When the fiber is bent sharply, the light rays traveling close to the critical angle may refract out of the core into the cladding or escape entirely.
- This results in signal attenuation due to loss of light energy.

Key Characteristics:

- Depends on the radius of the bend: smaller bending radii result in higher losses.
- Wavelength-dependent: longer wavelengths are more affected.
- Typically occurs due to improper handling, tight installation spaces, or fiber coiling.

Mitigation:

- Use of bend-insensitive optical fibers.
- Avoiding sharp bends during fiber installation.

2. Microbending Losses:

Microbending losses are caused by small-scale, localized deformations of the fiber, usually on the microscopic level. These can result from manufacturing imperfections, mechanical stress, or external pressure.

Mechanism:

- Microbends alter the internal geometry of the core-cladding boundary, causing scattering and leakage of light.
- Even slight deformations disrupt the total internal reflection of light within the fiber.

Key Characteristics:

- Independent of wavelength but sensitive to external forces and environmental factors.
- Commonly caused by cable sheathing, external pressure, or thermal stress.

Mitigation:

- Proper fiber coating and cushioning.
- Avoiding external pressures during installation.

4. Explain the basic structure of a Light Emitting Diode (LED) with a neat diagram

Answer:

Light Emitting Diodes (LEDs)

p-n Junction

Conventional p-n junction is called as homojunction as same semiconductor material is sued on both sides' junction. The electron-hole recombination occurs in relatively layer = 10 μm. As the carriers are not confined to the immediate vicinity of junction, hence high current densities cannot be realized. The carrier confinement problem can be resolved by sandwiching a thin layer (= 0.1 μm) between p-type and n-type layers. The middle layer may or may not be doped. The carrier confinement occurs due to bandgap discontinuity of the junction. Such a junction is called heterojunction and the device is called double heterostructure. In any optical communication system when the requirements is 1. Bit rate f 100-2—Mb/sec. 2. Optical power in tens of micro watts, LEDs are best suitable optical source.

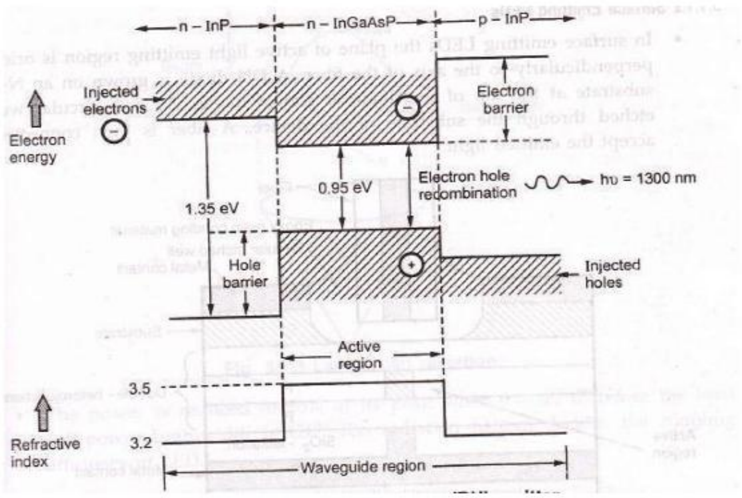
LED Structures

Heterojunctions:

A heterojunction is an interface between two adjoining single crystal semiconductors with different bandgap. Heterojunctions are of two types, Isotype (n-n or p-p) or Antisotype (p-n).

Double Heterojunctions (DH):

In order to achieve efficient confinement of emitted radiation double heterojunctions are used in LED structure. A heterojunction is a junction formed by dissimilar semiconductors. Double heterojunction (DH) is formed by two different semiconductors on each side of active region. The below shows double heterojunction (DH) light emitter.



The crosshatched regions represent the energy levels of free charge. Recombination occurs only in active In GaAsP layer. The two materials have different band gap energies and different refractive indices. The changes in band gap energies create potential barrier for both holes and electrons. The free charges can recombine only in narrow, well defined active layer side. A double heterojunction (DH) structure will confine both hole and electrons to a narrow active layer. Under forward bias, there will be a large number of carriers injected into active region where they are efficiently confined. Carrier recombination occurs in small active region so leading to an efficient device. Another advantage DH structure is that the active region has a higher refractive index than the materials on either side, hence light emission occurs in an optical waveguide, which serves to narrow the output beam.

LED configurations

At present there are two main types of LED used in optical fiber links Surface emitting LED and Edge emitting LED. Both devices used a DH structure to constrain the carriers and the light to an active layer.

5. Write a short note on the working principle of the pin photodetector.

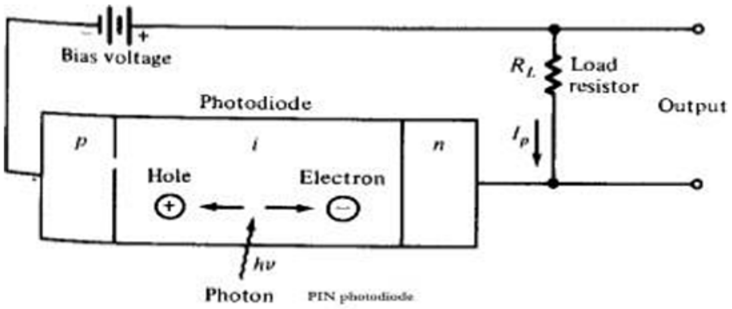
Answer:

A PIN photodetector is a type of photodiode designed to convert incident light into an electrical current. The "PIN" stands for the three layers of the device:

- P-region (positive, heavily doped)
- Intrinsic region (undoped or lightly doped)
- N-region (negative, heavily doped)

PIN diode

- A simple way to increase the depletion-region width is to insert a layer of undoped (or lightly doped) semiconductor material between the p–n junction.
- Since the middle layer consists of nearly intrinsic material, such a structure is referred to as the p–i–n photodiode.



➢ When photon enters photodetector, the low band gap absorption layer absorbs the photon, and an electron-hole pair is generated. This electron hole pair is called photocarrier.
➢ These photocarriers, under the influence of a strong electric field generated by a reverse bias potential difference across the device as shown in figure produce photocurrent proportional to number of incident photons.

Advantages of PIN Structure:

❖ Wide Intrinsic Region: Enhances the efficiency of photon absorption and increases the response time.
❖ Reduced Capacitance: The intrinsic layer reduces junction capacitance, allowing for faster operation in high-speed communication.
❖ High Sensitivity: Capable of detecting weak light signals over a broad range of wavelengths.

Applications:

❖ Optical communication systems, including fiber-optic receivers.
❖ LIDAR and optical sensing.
❖ Medical imaging and spectrometry.
❖ High-speed photodetectors in data networks.

6. What is Wavelength Division Multiplexing (WDM)? Explain its importance in optical communication.

Answer:

Wavelength Division Multiplexing (WDM)

- Optical signals of different wavelength (1300-1600 nm) can propagate without interfering with each other. The scheme of combining a number of wavelengths over a single fiber is called wavelength division multiplexing (WDM).
- Each input is generated by a separate optical source with a unique wavelength. An optical multiplexer couples light from individual sources to the transmitting fiber. At the receiving station, an optical demultiplexer is required to separate the different carriers before photodetection of individual signals. Fig. 7.1.1 shows simple SDM scheme.

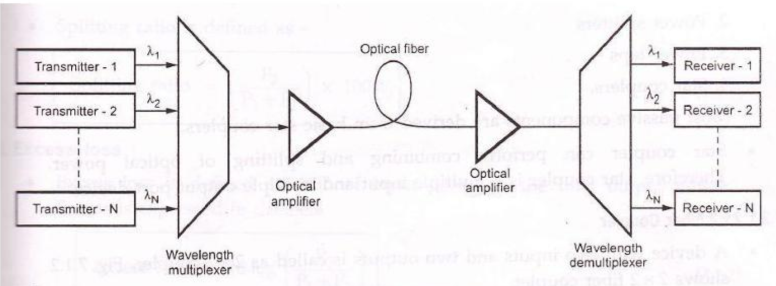


Fig. 7.1.1 WDM scheme

- To prevent spurious signals to enter into receiving channel, the demultiplexer must have narrow spectral operation with sharp wavelength cut-offs. The acceptable limit of crosstalk is – 30 dB.

Features of WDM

- Important advantages or features of WDM are as mentioned below –
  1. Capacity upgrade : Since each wavelength supports independent data rate in Gbps.
  2. Transparency : WDM can carry fast asynchronous, slow synchronous, synchronous analog and digital data.
  3. Wavelength routing : Link capacity and flexibility can be increased by using multiple wavelength.
  4. Wavelength switching : WDM can add or drop multiplexers, cross connects and wavelength converters.

Passive Components

- For implementing WDM various passive and active components are required to combine, distribute, isolate and to amplify optical power at different wavelength.

- Passive components are mainly used to split or combine optical signals. These components operates in optical domains. Passive components don't need external control for their operation. Passive components are fabricated by using optical fibers by planar optical waveguides. Commonly required passive components are –
  1. N x N couplers
  2. Power splitters
  3. Power taps
  4. Star couplers.

  Most passive components are derived from basic stat couplers.

- Stat coupler can person combining and splitting of optical power. Therefore, star coupler is a multiple input and multiple output port device.

<u>Importance in Optical Communication:</u>

1. Efficient Utilization of Fiber Bandwidth: Optical fibers have a very high bandwidth capacity. WDM maximizes this potential by enabling multiple signals to coexist on the same fiber.
2. Increased Data Transmission Rates: By using multiple wavelengths, the total data transmission rate is significantly increased, enabling high-speed communication.
3. Cost-Effectiveness: Eliminates the need for deploying additional optical fibers by making better use of existing infrastructure.
4. Scalability: WDM systems are scalable; new wavelengths can be added without disrupting existing traffic, making them ideal for growing network demands.
5. Support for Different Signal Formats: Different types of data (voice, video, internet) can be transmitted simultaneously on separate wavelengths without interference.
6. Long-Distance Communication: WDM reduces the need for electrical repeaters by leveraging optical amplifiers like Erbium-Doped Fiber Amplifiers (EDFAs) that amplify all wavelengths simultaneously.