USN										

Internal Assessment Test 2 – November 2025

Subject/Code: BEC515D – Satellite and Optical Communication				
Date:	Duration: 90 mins	Max. Marks: 50	Semester: 05	Branch: ECE

Sl.	Answer any FIVE 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

CI CCI HOD

USN										

Internal Assessment Test 2 – November 2025

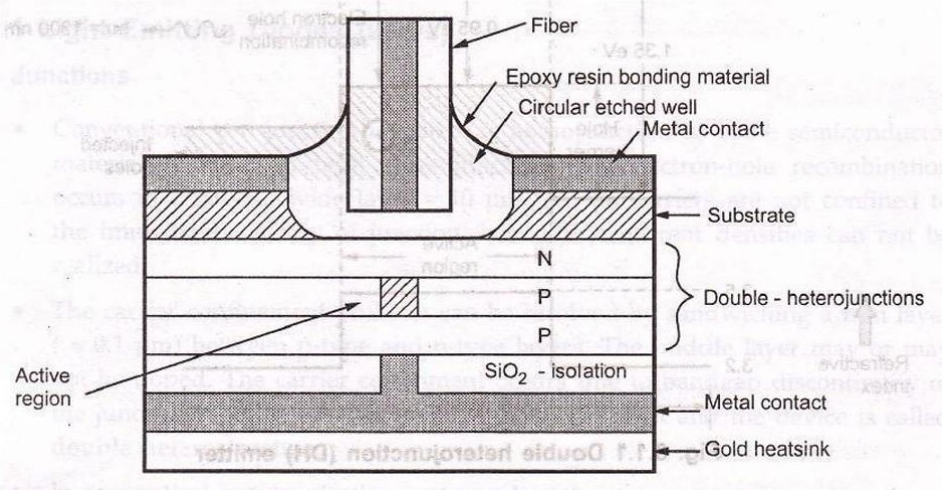
Subject/Code: BEC515D – Satellite and Optical Communication				
Date:	Duration: 90 mins	Max. Marks: 50	Semester: 05	Branch: ECE

Sl.	Answer any FIVE 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

CI CCI HOD

Sl.	Questions with Answers	Marks	CO	RBT
1	**Define numerical aperture (NA) and explain its significance in optical fibers.** **Answer:** Numerical Aperture (NA) is a fundamental parameter of an optical fiber that defines its ability to accept, collect, and guide light into the core. **Significance of NA in Optical Fibers:** ❖ **Light-Gathering Ability**: A higher NA allows the fiber to accept more light from the source, improving coupling efficiency, especially when using LEDs or misaligned connectors. ❖ **Ease of Alignment:** Fibers with large NA are less sensitive to alignment errors, making installation easier and reducing power loss at joints. ❖ **Impact on Bandwidth:** In multimode fibers, high NA supports more propagation modes, which increases modal dispersion and reduces bandwidth. Low-NA fibers offer higher bandwidth suitable for high-speed communication. ❖ **Guidance and Confinement of Light:** NA determines how well light remains confined within the core during propagation. Better confinement reduces leakage and improves overall signal strength. ❖ **Influence on Bending Losses:** Lower NA fibers typically show reduced bending losses, which is critical for long-distance or tightly packed fiber installations. ❖ **System Design Considerations:** NA affects source selection, coupling optics, splicing techniques, and the overall efficiency of optical communication systems. Numerical Aperture is essential for designing, optimizing, and operating optical fiber communication systems. It governs light acceptance, coupling efficiency, signal confinement, and bandwidth performance, making it a crucial parameter in optical fiber technology.	[10]	CO4	L2
2	**Explain the concept of total internal reflection and its application in optical fibers.** **Answer:** Total Internal Reflection (TIR) is an optical phenomenon that occurs when a light ray traveling from a denser medium to a rarer medium strikes the interface at an angle greater than the *critical angle*. Under this condition, instead of refracting out, the light ray is completely reflected back into the denser medium. **TIR requires two conditions:** 1. **Light must travel from a medium of higher refractive index (n_1) to lower refractive index (n_2). 2. The angle of incidence (θ_i) must be greater than the critical angle (θc) **Application in Optical Fibers** Optical fibers work purely based on the principle of Total Internal Reflection. An optical fiber consists of: ❖ Core (higher refractive index) ❖ Cladding (slightly lower refractive index)	[10]	CO4	L2

	❖ When light enters the core at an appropriate angle, it continuously reflects along the core–cladding boundary without escaping. This enables: ❖ Long-distance transmission of light with very low loss ❖ High-speed data transfer ❖ Immunity to electromagnetic interference Uses of TIR in Optical Fibers ❖ Telecommunication networks (internet, telephone, TV) ❖ Medical endoscopy ❖ Defense and aerospace communication ❖ Sensor systems (temperature, pressure, biochemical) Thus, TIR ensures efficient, reliable, and high-bandwidth optical signal transmission.			
3	**Write a short note on macrobending losses and microbending losses in optical fibers.** **Answer:** Optical fiber performance is affected by bending-related losses that cause attenuation of the optical signal. **A. Macrobending Losses** Macrobending refers to large, visible bends in the fiber cable with a radius greater than a few millimeters. When a fiber is bent sharply: ❖ The angle of incidence reduces below the critical angle. ❖ Light leaks out of the core into the cladding. ❖ This causes radiation loss. Causes: ❖ Improper cable installation ❖ Excessive bending around corners ❖ Tight packing of fibers in trays Impacts: ❖ High signal attenuation ❖ Reduced transmission distance ❖ Possible system failure Prevention: ❖ Maintain minimum bend radius ❖ Use bend-insensitive fibers **B. Microbending Losses** Microbending losses arise from microscopic distortions or irregularities along the fiber axis. These are not visible to the eye. **Causes:** ❖ Manufacturing imperfections ❖ Pressure from cabling ❖ Temperature variations ❖ Mechanical vibrations **Effects:** ❖ Scattering and leakage of guided light ❖ Increased attenuation ❖ Degradation of signal quality **Control:** ❖ Proper fiber coating ❖ Cushioning materials ❖ Controlled cable design	**[10]**	**CO4**	**L2**

	Both macrobending and microbending losses impact signal quality, and minimizing them is critical for efficient optical communication networks.			
4	**Explain the basic structure of a Light Emitting Diode (LED) with a neat diagram.** **Answer:**  **Light Emitting Diodes (LEDs)** **p-n Junction** A conventional p–n junction diode is made using the same semiconductor material on both sides of the junction and is therefore known as a **homojunction**. In a homojunction LED, electron–hole recombination occurs in a relatively thick region (≈10 μm). Since the carriers are not confined to the immediate vicinity of the junction, **high current densities cannot be achieved**, which limits the efficiency of light emission. **2. Need for Carrier Confinement** Carrier confinement is essential to improve radiative recombination efficiency. This is achieved by sandwiching a very thin active layer (≈0.1 μm) between p-type and n-type semiconductor layers. The active layer may be either doped or undoped. Confinement occurs because of the **bandgap discontinuity** at the interfaces, which forces electrons and holes to recombine in the narrow central region. A device based on this concept is called a **heterojunction**, and if both sides are heterojunctions, it forms a **double heterostructure (DH)**. **3. Heterojunctions** A **heterojunction** is an interface between two dissimilar single-crystal semiconductors with different bandgap energies. Heterojunctions are of two types: 1. **Isotype junction:** n–n or p–p 2. **Antisotype junction:** p–n (most commonly used in LED and laser structures) **4. Double Heterojunction (DH) LEDs** To achieve efficient confinement of both carriers and light, a **double heterojunction structure** is used in LED design.	**[10]**	**CO5**	**L2**

Working Principles

- Due to bandgap differences, potential barriers are created on both sides.
- These barriers confine electrons and holes to the active layer.
- Recombination occurs only in the well-defined active region.
- The active region has a higher refractive index than the cladding layers, forming an optical waveguide.
- This waveguide narrows the emitted beam and improves the coupling efficiency to an optical fiber.

Advantages of DH LEDs

- Enhanced carrier confinement
- Higher radiative recombination efficiency
- Better optical confinement
- Narrower emission angle (improved coupling efficiency)
- Reduced threshold currents (in lasers)

5. When are LEDs Used in Optical Communication?

LEDs are preferred in optical fiber communication systems when:

1. **Bit rate requirements** are in the range of 100–200 Mb/s
2. Required **optical output power** is in the range of tens of microwatts

LEDs are advantageous because they are economical, highly reliable, and easier to couple to multimode fibers.

6. LED Structures

Presently, two major LED configurations are used in optical fiber communication:

A. Surface-Emitting LED (SLED)

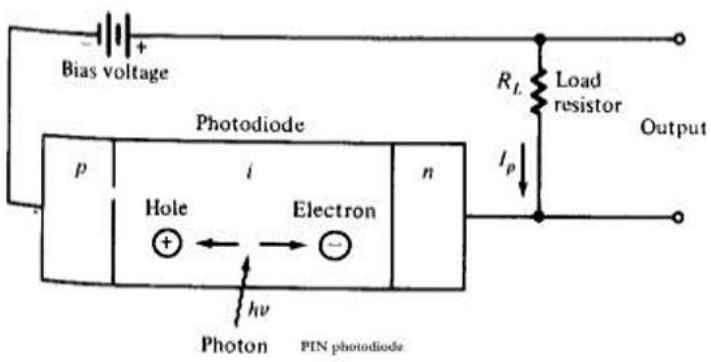
- Emits light perpendicular to the junction surface
- Wider emission pattern
- Easy to fabricate and couple to multimode fibers

B. Edge-Emitting LED (ELED)

- Emits light from the edge of the active layer
- Provides a narrower beam
- Better coupling efficiency and higher bandwidth
- Often used in systems requiring higher data rates

Both types employ **double heterojunctions** for efficient carrier and light confinement.

5	**Write a short note on the working principle of the pin photodetector.** **Answer:**	**[10]**	**CO5**	**L2**



A PIN photodetector is a semiconductor-based optical detector widely used in optical communication systems due to its high sensitivity, fast response, and ability to operate at high data rates. The device consists of a p-type,

intrinsic (i-type), and n-type semiconductor layer arranged in a p–i–n structure. The intrinsic region plays a crucial role in achieving high quantum efficiency and fast carrier transit.

Structure of the PIN Photodetector

- The device is composed of p-type and n-type semiconductor regions separated by a lightly doped intrinsic region.
- During operation, a reverse bias voltage is applied across the diode.
- The reverse bias widens the depletion region so that no free charge carriers exist in the intrinsic region.
- When an incident photon with energy equal to or greater than the bandgap of the semiconductor strikes the device, it generates an electron–hole pair in the intrinsic region.

Working Principle

When the PIN diode is reverse biased:

1. The intrinsic layer becomes fully depleted of charge carriers.
2. Photons entering the intrinsic region generate electron–hole pairs (photocarriers).
3. A strong electric field across the i-region sweeps the photocarriers apart:
   - Electrons move toward the n-region.
   - Holes move toward the p-region.
4. The separation and collection of these carriers through the external circuit results in a measurable photocurrent.

Photo Carriers

- When photons are absorbed, they produce free mobile charge carriers.
- These generated electron–hole pairs are known as photocarriers.
- Only photons with sufficient energy (hν≥Egh\nu \geq E_ghν≥Eg) can induce the transition of electrons from the valence band to the conduction band.

Photocurrent

- The movement of photocarriers under the influence of the electric field produces a current in the external circuit, called the photocurrent.
- The magnitude of photocurrent is proportional to:
  - Incident optical power,
  - Quantum efficiency,
  - Absorption characteristics of the material.

Energy Band Diagram

The energy band diagram of a PIN photodiode shows:

- A wide depletion region across the intrinsic layer.
- Photons with energy ≥ bandgap create electron–hole pairs.
- Carrier movement occurs because of the built-in electric field and applied reverse bias.

Photons with energy below bandgap (longer wavelengths) do not get absorbed → upper wavelength cutoff.

Detector Response Time

The overall speed of the photodiode is limited by:

1. Transit time of carriers across the depletion region
   - Shorter depletion widths → faster transit.
2. Diffusion time of carriers generated outside the depletion region
   - Slow and unwanted → reduces bandwidth.

	3. RC time constant ❖ τRC=RC\tau_{RC} = RCτRC=RC ❖ Lower capacitance and resistance → higher speed. Fast photodiodes minimize all three to achieve high bandwidth. A PIN photodetector is a widely used optoelectronic device due to: ❖ High sensitivity ❖ High quantum efficiency ❖ Fast response time ❖ Wide operating wavelength region Its intrinsic layer enhances photon absorption and carrier separation, making it ideal for high-speed optical communication, sensing, and fiber-optic networks.			
6	**What is Wavelength Division Multiplexing (WDM)? Explain its importance in optical communication.** **Answer:** Wavelength Division Multiplexing (WDM) is an advanced multiplexing technique used in optical communication systems in which multiple optical signals of different wavelengths (colors of light) are transmitted simultaneously through a single optical fiber. Each wavelength carries independent data, similar to how multiple radio stations operate at different frequencies without interfering with one another. In WDM, the optical spectrum of a fiber is divided into several distinct wavelength channels (λ1, λ2, λ3, …). Each channel can modulate an independent data stream using sources such as LEDs or laser diodes. A multiplexer (MUX) combines these wavelengths at the transmitter end into one fiber, and a demultiplexer (DEMUX) separates them back into individual channels at the receiver end. **Operating Principle** ❖ Different wavelengths of light propagate through the same optical fiber without affecting each other. ❖ Dense WDM (DWDM) typically uses wavelength spacing as small as 0.8 nm with 40, 80, or even 160 channels. ❖ Coarse WDM (CWDM) uses wider spacing (20 nm) and fewer channels but is more cost-effective. **Importance of WDM in Optical Communication** 1. Tremendous Increase in Transmission Capacity WDM allows dozens or even hundreds of channels to coexist on one fiber. For example, if each channel carries 10 Gbps, 80-channel DWDM can provide: 80 × 10 Gbps = 800 Gbps on a single fiber. This dramatically increases bandwidth without laying additional fibers. 2. Efficient Utilization of Existing Fiber Infrastructure Installing new optical fibers is costly and difficult, especially undersea or inter-city. WDM upgrades network capacity using existing fibers, reducing cost and deployment time. 3. Supports Long-Distance Communication Combined with EDFA (Erbium-Doped Fiber Amplifiers), WDM enables ultra-long-haul transmission because:	**[10]**	**CO5**	**L2**

	❖ EDFAs amplify multiple wavelengths simultaneously. ❖ No need to convert optical signals back to electrical form. This makes WDM essential for submarine cables and international communication networks. 4. Enables Simultaneous Multi-Service Transmission Different wavelengths can be allocated for different types of data: ❖ Internet data ❖ Telecommunication signals ❖ VoIP ❖ Cable TV ❖ Sensor networks Thus, WDM supports convergence of multiple services on a common platform. 5. Flexible and Scalable Network Architecture WDM supports various topologies: ❖ Point-to-point links ❖ Metropolitan rings ❖ Mesh networks As bandwidth demands grow, new wavelengths can be added without disrupting the existing system—making WDM highly scalable. 6. Reduced Crosstalk and High Security Since each wavelength acts like an independent optical channel: ❖ Crosstalk is minimal ❖ Signals are harder to tap or intercept, improving data security This is crucial for banking networks, defense communication, and cloud-based data centers. 7. Supports High-Speed Future Technologies WDM can handle advanced modulation formats and very high bit rates (100 Gbps, 400 Gbps, and above). It is also compatible with: ❖ Optical add-drop multiplexers (OADM) ❖ Reconfigurable optical add-drop multiplexers (ROADM) ❖ 5G/6G backbone networks ❖ High-performance computing (HPC) networks These ensure WDM will remain fundamental for next-generation optical communication systems.			