SRM Institute of Science and Technology
College of Engineering and Technology

SET C

DEPARTMENT OF ECE

SRM Nagar, Kattankulathur – 603203, Chengalpattu District, Tamilnadu

Academic Year: 2024-25 (EVEN)

Test: FT-II | **Date: 27/02/2025**
Course Code & Title: 21ECC304TR- Microwave and Optical communication | **Duration: 12.30-2.15PM**
Year & Sem: III & VI | **Max. Marks: 50**

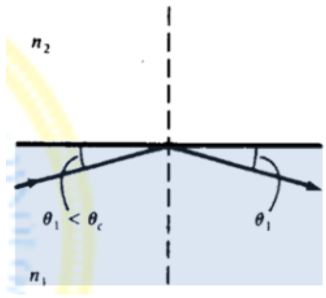
Course Articulation Matrix:

21ECC304TR- Microwave and Optical communication		Program Outcomes (POs)														
		Graduate Attributes												PSO		
COs	Course Outcomes (COs)	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
CO-1:	Familiarize the concept of microwave transmission and generation	3	2	-	-	-	-	-	-	-	-	-	-	3	-	-
CO-2:	Realize systematic methods to design, analyze S-parameters of microwave devices	3	2	-	-	-	-	-	-	-	-	-	-	3	-	-
CO-3:	Identify different measurement techniques for determining various parameters and to gain knowledge on microwave measurements and the techniques with associated equipment	2	-	-	3	-	-	-	-	-	-	-	-	3	-	-
CO-4:	Discover complete information on the fundamentals of light transmission through fiber and their characterization and mechanism	3	2	-	-	-	-	-	-	-	-	-	-	3	-	-
CO-5:	Recognize the link power budget design considerations of optical communication system	3	-	2	-	-	-	-	-	-	-	-	-	-	2	-

Q.No	**PART-A (1*20=20) Answer All questions**	**Marks**	**BL**	**CO**	**PO**
1(a)	(i) When designing an optical fiber for minimal signal loss, which factor plays the most crucial role in maintaining light confinement? (a) Increased core diameter **(b) Higher refractive index difference between core and cladding** (c) Increased fiber length (d) Higher numerical aperture	**1**	**1**	**CO4**	**PO2**
	(ii) A high-speed optical communication system requires a highly coherent light source with narrow spectral width. Which optical source is best suited for this? (a) Light Emitting Diode (LED) (b) Incandescent Lamp **(c) Laser Diode** (d) Optical Coupler	**1**	**1**	**CO4**	**PO2**

1(b)	(iii) Which of the following is an example of a passive device used in optical communication? (a) Semiconductor Optical Amplifier (b) Erbium-Doped Fiber Amplifier **(c) Optical Coupler** (d) Optical Modulator	**1**	**1**	**CO5**	**PO1**
	(iv) An optical fiber system is designed to transmit a signal over 50 km. Despite a high-power laser source, the received signal is much weaker than expected. What is the most likely cause? (a) The fiber optic cable has infinite bandwidth **(b) The signal is experiencing attenuation due to fiber losses and connection points** (c) The receiver is amplifying the signal too much (d) The optical fiber automatically compensates for power loss	**1**	**1**	**CO5**	**PO1**
	(i) A new underground communication system is being developed to provide stable and efficient data transfer. Engineers have noticed that when light enters the transmission medium at certain angles, it fails to propagate effectively. 1. Explain the phenomenon that determines whether light continues or escapes the medium. 2. Discuss the role of the boundary between two different materials in maintaining signal integrity. 3. Explain how an increase or decrease in light entry angle affects overall signal transmission. 4. Analyze why certain rays of light follow a predictable path while others are lost.	**8**	**1**	**CO4**	**PO1**
	Solution: • The continuation or escape of light in a medium is primarily governed by **total internal reflection (TIR)**, which depends on the **critical angle** and the refractive indices of the materials. When light travels from a **higher refractive index medium (n_1)** to a **lower refractive index medium (n_2)**, it bends away from the normal at the interface. If the incidence angle (θ) is greater than the **critical angle ($\theta c = \sin^{-1}(n_2/n_1)$)**, light undergoes total internal reflection, remaining confined within the medium. If $\theta < \theta c$, the light refracts out of the medium, leading to signal loss.	**8**	**3**	**CO5**	**PO1**

Total Internal Reflection

- 

Role of Boundary in Maintaining Signal Integrity
The boundary between two materials with different refractive indices, such as the **core and cladding of an optical fiber**, ensures light confinement through total internal reflection. The refractive index difference (Δn) between the core and cladding helps define the **numerical aperture (NA = sinθ_max)**, which determines the range of acceptable entry angles for efficient transmission. Any **irregularities, impurities, or roughness** at the boundary can cause scattering, reflection losses, or mode conversion, degrading signal integrity.

- **Effect of Light Entry Angle on Signal Transmission**

The **angle at which light enters** an optical fiber affects how efficiently it propagates.

- If the entry angle is **too large**, light may not be confined within the core, leading to **refraction and signal loss** into the cladding.
- If the entry angle is **optimal (within the acceptance cone determined by the numerical aperture, NA)**, light undergoes total internal reflection, ensuring efficient transmission.
- A smaller entry angle improves confinement but may result in increased **modal dispersion**, affecting data transmission over long distances.

- **Predictability of Light Paths and Loss of Certain Rays**

Some rays of light follow a **predictable path** due to total internal reflection, dictated by Snell's Law and the refractive index contrast between the core and cladding. These guided modes maintain their trajectory and remain within the fiber.
Other rays are **lost** due to:

- **Refraction** at the boundary when the incident angle is below the critical angle.
- **Scattering** caused by imperfections in the fiber material.
- **Absorption** within the fiber due to impurities or material properties.
- **Bending losses** when the fiber is sharply curved, forcing some light to escape.

(ii) A data center is upgrading its fiber-optic backbone from 2.5 Gbps to 10 Gbps to accommodate increased traffic demand. The system has the following rise-time components:

- Transmitter rise time = 80 ps
- Fiber dispersion rise time = 100 ps
- Receiver rise time = 60 ps

(a) Explain the concept of rise-time budget analysis in high-speed digital transmission.
(b) Calculate the total system rise time using the given values.
(c) Compare the total rise time with the maximum allowable rise time for 10 Gbps using the equation:

$$t_{max} = \frac{0.7}{\text{Bit Rate}}$$

Solution:

(a) Concept of Rise-Time Budget Analysis in High-Speed Digital Transmission

Rise-time budget analysis is used to evaluate the overall response speed of a high-speed digital transmission system. It ensures that the combined rise times of various components (transmitter, fiber, and receiver) do not exceed the system's maximum allowable rise time, which is determined by the bit rate.

Key components affecting rise time in fiber-optic systems:

1. **Transmitter Rise Time (t_T)** – The time required for the optical transmitter (e.g., laser or LED) to transition from low to high intensity.
2. **Fiber Dispersion Rise Time (t_D)** – The time broadening caused by chromatic and modal dispersion as the signal propagates through the optical fiber.
3. **Receiver Rise Time (t_R)** – The response time of the photodetector and associated electronics in converting the optical signal back to an electrical signal.

The **total system rise time** must be less than the **maximum allowable rise time** ($t_{\max}$) to avoid inter-symbol interference (ISI), which can degrade signal quality.

(b) Calculation of Total System Rise Time

The total system rise time (t_{sys}) is determined using the **root sum square (RSS) method**:

$$t_{sys} = \sqrt{t_T^2 + t_D^2 + t_R^2}$$

Given values:

- $t_T = 80$ ps
- $t_D = 100$ ps
- $t_R = 60$ ps

$$t_{sys} = \sqrt{(80)^2 + (100)^2 + (60)^2}$$

$$t_{sys} = \sqrt{6400 + 10000 + 3600}$$

$$t_{sys} = \sqrt{20000}$$

$$t_{sys} = 141.42 \text{ ps}$$

(c) Comparison with Maximum Allowable Rise Time

The **maximum allowable rise time** (t_{max}) is given by:

$$t_{\max} = \frac{0.7}{\text{Bit Rate}}$$

For a **10 Gbps** system:

$$t_{\max} = \frac{0.7}{10 \times 10^9}$$

$$t_{\max} = 70 \text{ ps}$$

Comparison:

- The calculated **total rise time** is **141.42 ps**, which is **greater than** the allowable limit of **70 ps** for a **10 Gbps system.**
- This indicates that **the current system may not support 10 Gbps transmission without significant signal degradation** due to insufficient bandwidth and dispersion-related broadening.

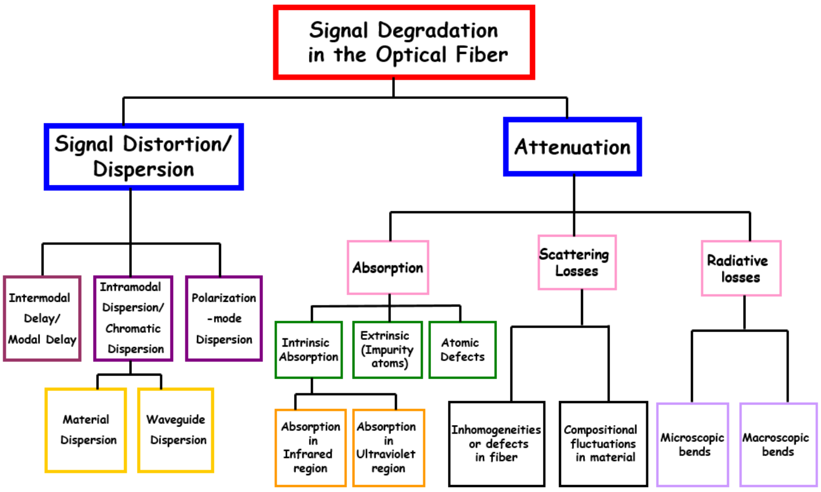
PART-B (2*15=30)

Answer Any Two Questions

2(a)	A long-distance data transmission system is experiencing a gradual decrease in signal intensity as information travels through the network. A team of engineers is investigating the reasons behind this degradation and considering possible solution. What may be the underlying reasons when the signals might weaken over long distances? Analyze the different physical and material-based factors that contribute to signal degradation.	**7**	**2**	**CO4**	**PO1**
		8	**3**	**CO4**	**PO2**

Solution:

Students need explain



(b) An optical receiver needs to detect very weak signals in a high-speed communication system. Which type of devices should be used, and what challenges might arise with your choice?

Solution:

To detect very weak signals in a high-speed optical communication system, the following types of optical detectors are commonly used:

Avalanche Photodiode (APD)

Why APD?

APDs provide internal gain through avalanche multiplication, which amplifies weak optical signals before conversion to electrical form.

They have high sensitivity, making them suitable for detecting weak signals in long-distance or low-power applications.

APDs operate efficiently in high-speed communication systems, such as long-haul fiber-optic networks and free-space optical communication.

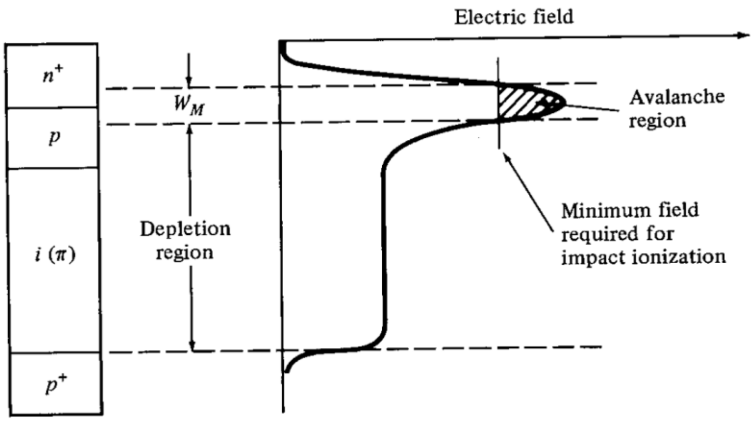
Avalanche Photodiodes

- When a p-n junction diode is applied with high reverse bias, breakdown can occur by two separate mechanisms.

1. Direct ionization of the lattice atoms → Zener breakdown
2. **High voltage carriers causing Impact Ionization of the lattice atoms → Avalanche breakdown.**

APDs uses the avalanche breakdown phenomenon for its operation. The APD has its internal gain which increases its responsivity.

Avalanche Photodiodes



Reach-through avalanche photodiode structure and the electric fields in the depletion and multiplication regions.

Avalanche Photodiodes

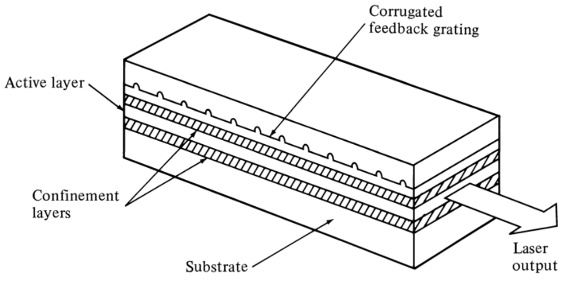
- The fig. shows the schematic structure of an APD. By virtue of the doping concentration and physical construction of the n^+ p junction, the electric field is high enough to cause impact ionization.
- Under normal operating bias, the I-layer is completely depleted.
- This is known as reach through condition, hence APDs are also known as Reach through APDs or RAPDs.

	Avalanche Photodiodes **Impact Ionization:** The photo generated carriers traverse a region where a very high electric field is present. These carriers can gain enough energy under high electric field and excite new electron-hole pairs. This phenomenon is called Impact Ionization **Avalanche Effect:** During Ionization new generated carriers also accelerated by high electric field and gain enough energy to cause further impact ionization. This phenomenon is called avalanche effect. **Avalanche Photodiodes** **Avalanche Multiplication:** • The multiplication M for all carriers generated in the photodiode is defined by $M = I_M / I_p$ where I_M is the average value of the total multiplied output current and I_p is the primary unmultiplied photocurrent. **Responsivity:** • The performance of an APD is characterized by the responsivity given by $R_{APD} = (hq/hn)M = R_o M$ where R_o is the unity gain responsivity.				
3(a)	A telecom company needs a cost-effective optical source for a short-distance fiber link and a high-speed, long-distance source for a national backbone network. Which optical sources would you recommend for each case, and why? **Solution:** Long-Distance, High-Speed Backbone Network DFB Laser or ECL Why? DFB Lasers provide a narrow spectral linewidth (~0.1 nm), reducing chromatic dispersion in long-haul transmission. ECLs offer even better stability and spectral purity, making them ideal for ultra-long-distance networks. Operate efficiently in Dense Wavelength Division Multiplexing (DWDM) systems, enabling multiple channels over the same fiber. Suitable for single-mode fibers (SMF) used in national backbone and high-speed optical networks.	**8** **7**	**2** **3**	**CO4** **CO5**	**PO1** **PO3**

Explain about the laser:

DFB(Distributed FeedBack) Lasers

- In DFB lasers, the optical resonator structure is due to the incorporation of Bragg grating or periodic variations of the refractive index into multilayer structure along the length of the diode.



The optical feedback is provided by fiber Bragg Gratings

€ Only one wavelength get positive feedback

Modes of the cavity

- Optical radiation within the resonance cavity of a laser diode sets up a pattern of electric and magnetic field lines called as modes of cavity
- Longitudinal modes- related to length of cavity
  -Determine principal structure of frequency spectrum of emitted optical radiation
- Lateral modes – lie in the plane of pn junction
  - depends on side wall preparation and width of cavity
  - determine shape of lateral profile of laser beam
- Transverse modes- associated with EMF and beam profile in direction perpendicular to the plane of pn
  - determine radiation pattern and threshold current density

THRESHOLD GAIN & CURRENT DENSITY

$$\Gamma g_{th} = \bar{\alpha} + \frac{1}{2L}\ln\left(\frac{1}{R_1 R_2}\right)$$

LASER starts to Lase only if g>gth

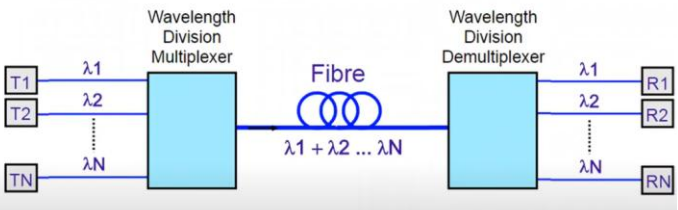
For laser structure with strong carrier confinement, the threshold current Density for stimulated emission can be well approximated by:

$$g_{th} = \beta J_{th}$$

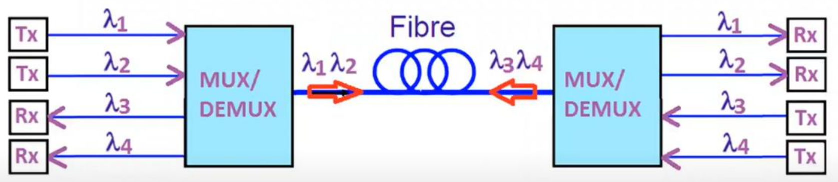
β : constant depends on specific device construction

(b) An optical fiber system has a 60 km link with fiber attenuation of 0.22 dB/km. The system includes 4 splices (0.15 dB each) and 2 connectors (0.9 dB each). If the transmitter power is 10 dBm, will the receiver (with a sensitivity of -20 dBm) receive a strong enough signal?

Solution:

	Optical Fiber Link Budget Calculation Step 1: Calculate Fiber Attenuation Fiber Loss = 0.22 dB/km * 60 km = 13.2 dB Step 2: Calculate Splice Loss 4 Splices * 0.15 dB = 0.6 dB Step 3: Calculate Connector Loss 2 Connectors * 0.9 dB = 1.8 dB Step 4: Total Link Loss Total Loss = 13.2 dB + 0.6 dB + 1.8 dB = 15.6 dB Step 5: Calculate Received Power Received Power = 10 dBm - 15.6 dB = -5.6 dBm Step 6: Compare with Receiver Sensitivity Required Sensitivity = -20 dBm Since -5.6 dBm > -20 dBm, the signal is strong enough. Conclusion: Yes, the receiver gets sufficient power with a margin of: (-5.6 dBm) - (-20 dBm) = 14.4 dB (Safe margin)				
4(a)	A telecommunication company is facing an exponential increase in data demand. The existing optical fiber infrastructure is becoming insufficient to meet bandwidth requirements. While increasing the number of fiber cables is an option, network engineers suggest an alternative solution that does not require laying additional fibers. • What technology could be implemented to maximize bandwidth utilization and efficiently manage multiple data streams without physically expanding the fiber network?	**7**	**2**	**CO5**	**PO1**
	Solution: Wavelength Division Multiplexing (WDM) Technology To handle the exponential increase in data demand without laying additional optical fibers, the telecommunication company can implement Wavelength Division Multiplexing (WDM). Why WDM? WDM is an optical multiplexing technology that transmits multiple data streams simultaneously over a single fiber by assigning each data stream a different wavelength (color) of light. This allows network engineers to maximize bandwidth utilization and manage multiple data channels efficiently. **Basics of WDM** ❖ It is Wavelength Division Multiplexing ❖ WDM is used to increase capacity of single standard fiber ❖ Here, a number of light sources are used with different wavelength. ❖ Using Multiplexer, all signals are transmitted by single fiber. ❖ At receiver side, Demultiplexer separates different wavelength and gives it to different receiver. **WDM Architecture** 	**8**	**3**	**CO5**	**PO1**

Bidirectional WDM Architecture



Components of WDM

❖ Important components of WDM Network is as follows:

- ❑ Optical Line Terminals OLT
- ❑ Optical Add/Drop Multiplexer
- ❑ Optical Cross Connect

1. **Optical Line Terminals (OLT)**
   - OLT is a crucial network element that connects optical fiber networks to the core network. It manages the WDM signals, controls data transmission, and interfaces with end-user devices.
2. **Optical Add/Drop Multiplexer (OADM)**
   - OADM allows selective addition or removal of specific wavelength channels from a WDM signal while letting other wavelengths pass through. It is commonly used in metro and long-haul optical networks.
3. **Optical Cross Connect (OXC)**
   - OXC is a network switching device that dynamically routes optical signals based on their wavelengths. It helps manage and optimize traffic flow in large-scale optical networks.

Technologies of WDM

- ❖ Thin Film Filter
- ❖ Fused Fiber Coupler
- ❖ Arrayed Waveguide grating
- ❖ Interleaver

1. **Thin Film Filter (TFF)**
   - A multilayer optical filter that selectively transmits or reflects specific wavelengths. Used in WDM systems for wavelength multiplexing and demultiplexing.
2. **Fused Fiber Coupler**
   - A passive optical device that splits or combines optical signals by fusing two or more optical fibers together. It enables efficient signal distribution in WDM networks.
3. **Arrayed Waveguide Grating (AWG)**
   - A photonic device that uses multiple waveguides to separate or combine different wavelengths. It is widely used in dense WDM (DWDM) systems for high-capacity signal routing.
4. **Interleaver**
   - A device that improves spectral efficiency by separating or combining adjacent WDM channels with specific spacing. It enhances performance in high-channel-count WDM systems.

Important feature of WDM

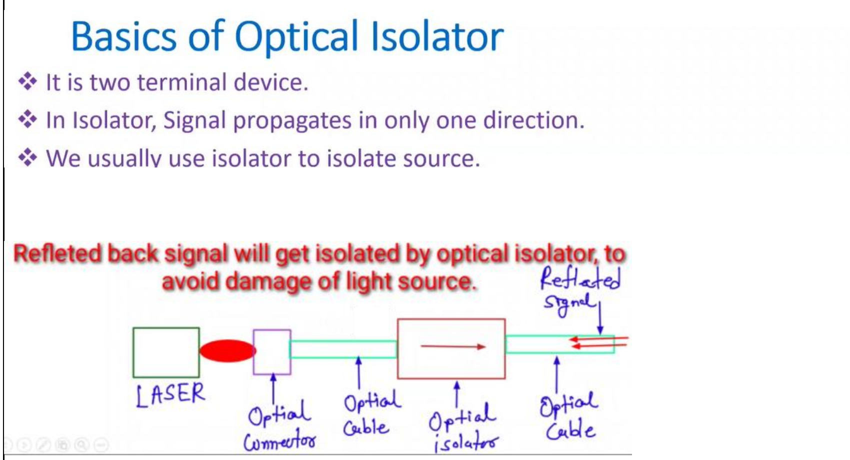
- ❖ Wavelength reuse
- ❖ Wavelength conversion
- ❖ Transparency
- ❖ Circuit switching
- ❖ Survivability

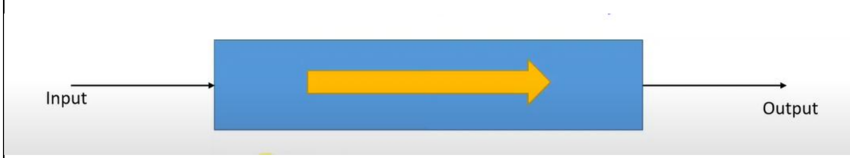
(b) A fiber-optic transmitter in a high-speed WDM system is experiencing performance instability due to unwanted reflections. Engineers suspect that back-reflected light is interfering with the laser source, affecting signal quality.

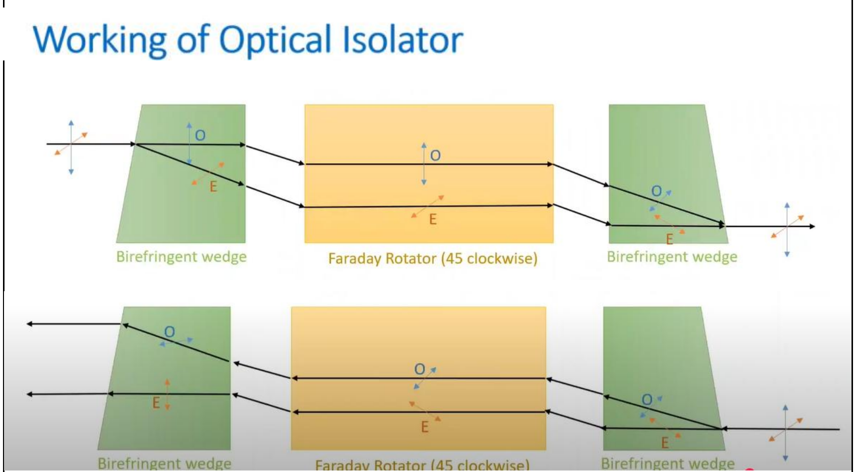
- Which passive optical device can be used to allow light to travel in only one direction, preventing back-reflection into the laser? and Also, which passive optical device is used to filter out specific wavelengths from a multi-wavelength WDM system?

Solution:

Optical Isolator – This passive optical device allows light to travel in only one direction and prevents back-reflection into the laser. It is commonly used in optical communication systems to protect laser sources from unwanted reflections that could cause instability or damage.







Optical Filter (e.g., Thin-Film Filter or Fiber Bragg Grating) – This passive optical device is used to filter out specific wavelengths from a multi-wavelength Wavelength Division Multiplexing (WDM) system. Thin-film filters selectively transmit or block certain wavelengths, while Fiber Bragg Gratings (FBG) reflect specific wavelengths and allow others to pass through.

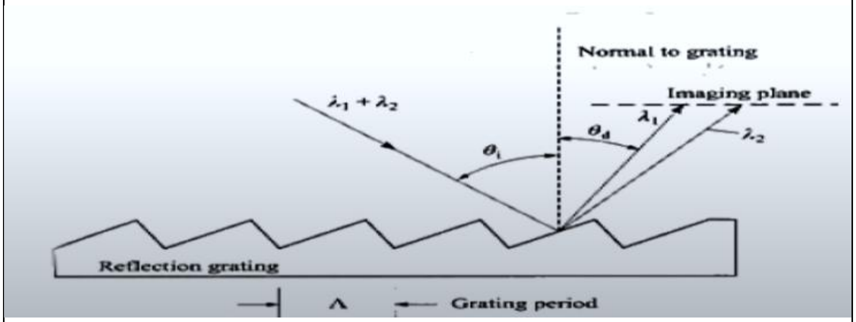
Fiber Grating Filters

- Important element in WDM systems for combining and separating individual wavelengths.
- Grating is a periodic structure or perturbation in a material. This variation in the material has the property of reflecting or transmitting light in a direction depending on the wavelength.

Fiber Grating Filters

Grating Basics:

- Θ1 is the incident angle of the light, θd is the diffracted angle and ᴧ is the period of the grating
- In a transmission grating consisting of a series of equally spaced slits, the spacing between 2 adjacent slits is called the pitch of the grating.

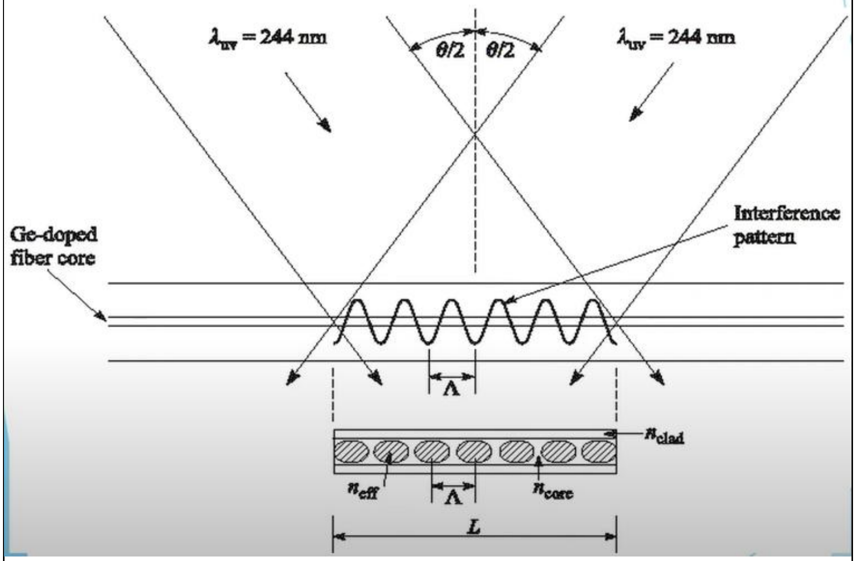


Fiber Bragg Grating (FBG)

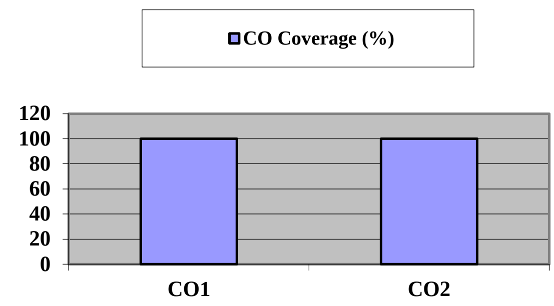
- The technique is based on the observation that GE- doped silica fiber exhibits high photosensitivity to ultra violet light
- This can induce a change in the refractive index of the core by exposing it to ultraviolet radiation such as 244nm
- Several methods can be used to create a fiber phase-grating is called external – writing technique

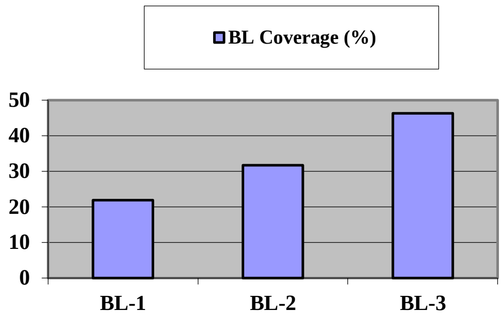
Fiber Bragg Grating (FBG)

- The grating fabrication is accomplished by 2 UV beams transversely irradiating the fiber to produce an interference pattern in the core .
- Here the regions of high intensity cause an increase in the local refractive index of the photosensitive is thus written into the core
- When a multi wavelength signals encounters the grating whose wavelength are phase-matched to the bragg reflection condition are not transmitted

	Bragg Grating formation 				

Course Outcome (CO) and Bloom's level (BL) Coverage in Questions





Evaluation Sheet

Name of the Student: **Register No.:**

Part- A (1*20 = 20 Marks)					
Q. No	CO	PO	Max. Marks	Mark Obtained	Total
1a(i)	4	2	1		
(ii)	4	2	1		
(iii)	5	1	1		
(iv)	5	1	1		
1b(i)	4	1	8		
(ii)	5	1	8		
Part- B (2*15= 30 Marks)					
2a	4	1	7		
2b	4	2	8		
3a	4	1	8		
3b	5	3	7		
4a	5	3	7		
4b	5	1	8		

Consolidated Marks:

CO	Max.Marks	Mark Obtained
CO4	33	
CO5	32	
Total	65	

PO	Max.Marks	Mark Obtained
PO1	41	
PO2	10	
PO3	14	
Total	65	

Signature of the Course Teacher