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New Scheme Based On AICTE Flexible Curricula

Electronics & Communication Engineering, VIII-Semester

EC801- Optical Fibre Communication

PREREQUISITE:-Engineering Physics, Communication Engineering

COURSE OUTCOME:-

Students should be able to:

1. Understand Optical Fiber Communication System and itsparameters.
2. Analyze transmission characteristics of optical fiber
3. Understand the construction and operation of various optical sources anddetectors.
4. Performance analysis of opticalreceivers and study of fiber joints
5. Brief introduction of optical fibernetworks and amplifiers

Unit 1. Introduction to vector nature of light, propagation of light, propagation of light in a cylindrical dielectric rod, Ray model, wave model. Different types of optical fibers, Modal analysis of fiber. Optical fibres : Structure & wave guiding fundamentals, basic optical laws.

Unit 2. Signal degradation in Optical Fibre : Signal degradation on optical fiber due to dispersion and attenuation, intermodal and intramodal dispersion, Fabrication of fibers and measurement techniques like OTDR

Unit 3. Optical sources and detectors: LEDs, LASER diodes, Basic concepts of optical Sourcesvarious laser and LED structures, Optical detectors: basic principle of photo detection, PIN and avalanche photo diode, phototransistor, photo detector noise, detector response time.

Unit 4. Optical transceivers; Direct detection and coherent receivers, noise in detection process, digital receiver performance calculation, BER, System design, power budgeting, rise time budgeting; fibre joints, and splicing techniques, Optical fibre connectors.

Unit 5.Optical networks and amplifiers- Optical networks : Topologies, networks SONET and SDH. Optical amplifiers - EDFA, Raman amplifier, and WDM systemsPassive Optical Networks.

TEXT BOOKS RECOMMENDED:-

1. Senior J.M., Optical Fibre Communications: Principles & Practice, 2nd ed. 2001,PHI.
2. Agrawal Govind P., Fibre Optic Communication Systems, 5th ed. 2001, John Wiley & Sons, studentsed.
3. Black Uyless, Optical Networks and 3rd Genration Transport Systems, 3rd ed. 1998,Pearson.

REFERENCE BOOKS RECOMMENDED:-

1. Keiser G, Optical Fibre Communication, 5th ed. 2006, McGrawHill.
2. Mynbanv and Scheiner, Fibre Optic Communication Technology, 2nd ed 2010, PearsonEdu.
3. Djfar K Mynbaev &Scheiner, Fibre Optic Communication Technology, 5th ed. 2005,Pearson

Unit-1

Overview of Optical Fiber Communications (OFC): Motivation, optical spectral bands, key elements of optical fiber systems.

Optical fibers: Basic optical laws and definitions, optical fiber modes and configurations, mode theory for circular waveguides, single mode fibers, graded-index fiber structure, fiber materials, photonic crystal fibers, fiber fabrication, fiber optic cables.

1.1 Motivation

Advantages of Optical Fibers

1) Long Distance Transmission-Optical Fibers have lower transmission losses compared to copper wires. Consequently data can be sent over long distances, thereby reducing the number of repeaters needed to boost and restore signals in long spans. This reduction in equipment and components decreases system cost and complexity.
2) Large Information Capacity-Optical fibers have wider bandwidth than copper wires, so that more information can be sent over a single physical line. This property decreases the number of physical lines needed for sending a given amount of information.
3) Small Size and Low Weight- Because of low weight and small size optical fibers are used in aircraft, satellites and ships where small light weight cables are advantageous, and in military applications where large amount of cable must be reeled and retrieved rapidly.
4) Immune to Electrical Interference-Optical fibers are made up of a dielectric material, which means it does not conduct electricity. This makes optical fibers immune to electromagnetic effects seen in copper wires, such as inductive pickup from other adjacent signal-carrying wires or coupling of electrical noise into the line from any type of nearby equipment.
5) Enhanced Safety-Optical fibers offer a high degree of operational safety, since they do not have the problems of ground loops, sparks, and potentially high voltages inherent in copper lines.
6) Increased Signal Safety-An optical fiber offers a degree of data security, since the optical signal is well-confined within the fiber and an opaque coating around the fiber absorbs any signal emissions. This feature is in contrast to copper wires where electrical signals potentially could be tapped off easily. Thus fibers are attractive in applications where information security is important, such as financial, legal, government, and military systems.

1.2 Optical Spectral bands

Optical fiber communication uses near infrared spectral band ranging from 770-1675nm.The 770-910nm band is used for shorter-wavelength multimode fiber systems, Thus this region designated as short wavelength Or multimode fiber band. The International Telecommunication Union (ITU) has designed six spectral bands for use in optical fiber communications within the 1260-1675nm region .These long –wavelength band designations arose from attenuation characteristics of optical fibers and the performance behavior of an erbium-doped fiber amplifier (EDFA).Table 1 defines these six spectral bands.

Table: 1 Six spectral bands of optical communication.

Name	Designation	Spectrum(nm)	Origin in name
Original Band	O-band	1260-1360	Original(first) region used for single-mode fiber links
Extended band	E-band	1360-1460	Link use can extend into this region for fibers with low water content
Short band	S-band	1460-1530	Wavelengths are shorter than C band but higher than E-band
Conventional Band	C-band	1530-1565	Wavelength region used by a conventional EDFA
Long band	L-band	1565-1625	Gain decrease steadily to 1
Ultra-long band	U-band	1625-1675	Region beyond the response capability of an EDFA

1.3 Key Elements of Optical Fiber Systems

Basic function of optical fiber link is to transport a signal from communication equipment (e.g. telephone) at one location to corresponding equipment at another location with a high degree of accuracy and reliability. The key sections are transmitter, a cable, and receiver. Additional components include active and passive components. Fig.1 shows the main constituents of optical fiber communication link.

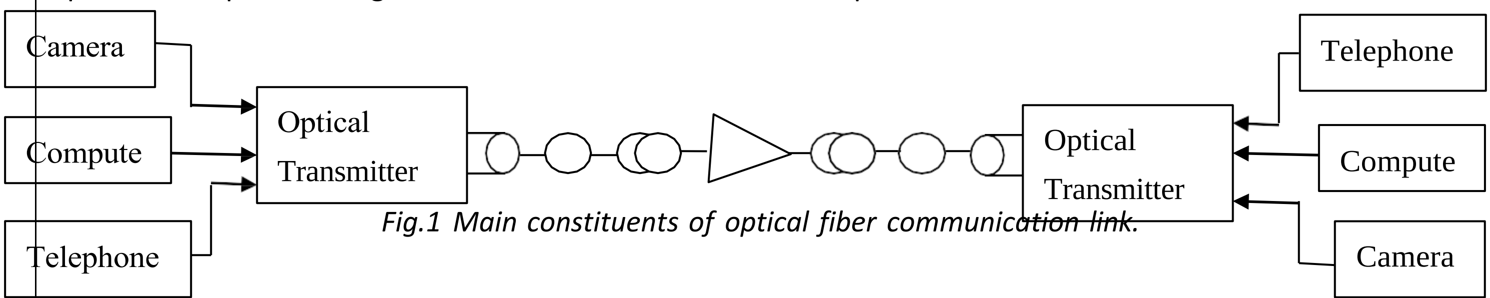

Fig.1 Main constituents of optical fiber communication link.

The Transmitter consist of a light source that is dimensionally compatible with a fiber core and a associated electronic control and modulation circuitry. In the 770-910nm light sources are generally alloys of GaAlAs. At longer , wavelengths 1260-1675nm InGaAsP alloy is the principle optical source material.

Inside the receiver is a photodiode that detects the weakened and distorted optical signal emerging from an end of optical fiber and coverts it to an electrical signal? The receiver also contains electronic amplification devices and circuitry to restore signal fidelity. Silicon photodiodes are used in the 770 -910nm region. The primary material in the 1260-1675nm region is an InGaAs alloy.

Passive devices are optical components that require no electronic control for their operation. Among these are optical filters, optical splitters, optical multiplexers, couplers. Active optical components, which require an electronic control for their operation. These include light signal modulators, tunable optical filters, variable attenuators, and optical switches.

When setting up an optical link engineers formulate a power budget and add amplifiers or repeaters when path loss exceeds available margin. Furthermore, when a link is being installed and tested, operational parameters that should be measured include bit error rate, timing jitter, and signal to noise ratio as indicated by eye pattern.

- Windows and spectral bands

Early applications in the late 1970s made exclusive use of the 770-910nm wavelength band. Where there is a low loss window. Originally this region was referred to as a first window, since around 1000nm there was a large attenuation spike due to absorption by water molecules. As a result of this spike, early fibers exhibited a local minimum in attenuation curve around 850nm.

By reducing the concentration of hydroxyl ions and metallic impurities in the fiber material, in 1980s manufacturers could fabricate optical fibers with very low losses in the 1260-1675 nm region. Since the glass still contained some water molecules, a third order absorption spike remained around 1400nm. This spike defined two-loss windows, these being second window centered at 1310nm and third window centered at 1550nm.

1.4 Basic Optical Laws and Definitions

This includes snell's law, concepts of reflection and refraction.

When a light ray encounters a boundary separating two different media, part of the ray reflected back into the first medium and the remainder is bent (or refracted) as it enters second material. This is shown in Fig.2 $n_2 < n_1$. The relationship at the interface is known as Snell's law and is given by.

$n_1 \sin\varphi_1 = n_2 \sin\varphi_2$

φ_1 =Angle of Incidence between incident ray and normal to the surface.

According to the law of reflection angle θ_1 at which the incident ray strikes the interface is exactly equal to the angle that the reflected ray makes with the same interface. As the angle of incidence φ_1 in an optically denser material becomes larger, the refracted angle approaches $\frac{\pi}{2}$. Beyond this point refraction is possible and light rays becomes totally internally reflected. Or in other words if the angle of incidence φ_1 is greater than the critical angle, the condition for total internal reflection is satisfied; that is light totally reflected back into the glass no light escape from the glass surface .

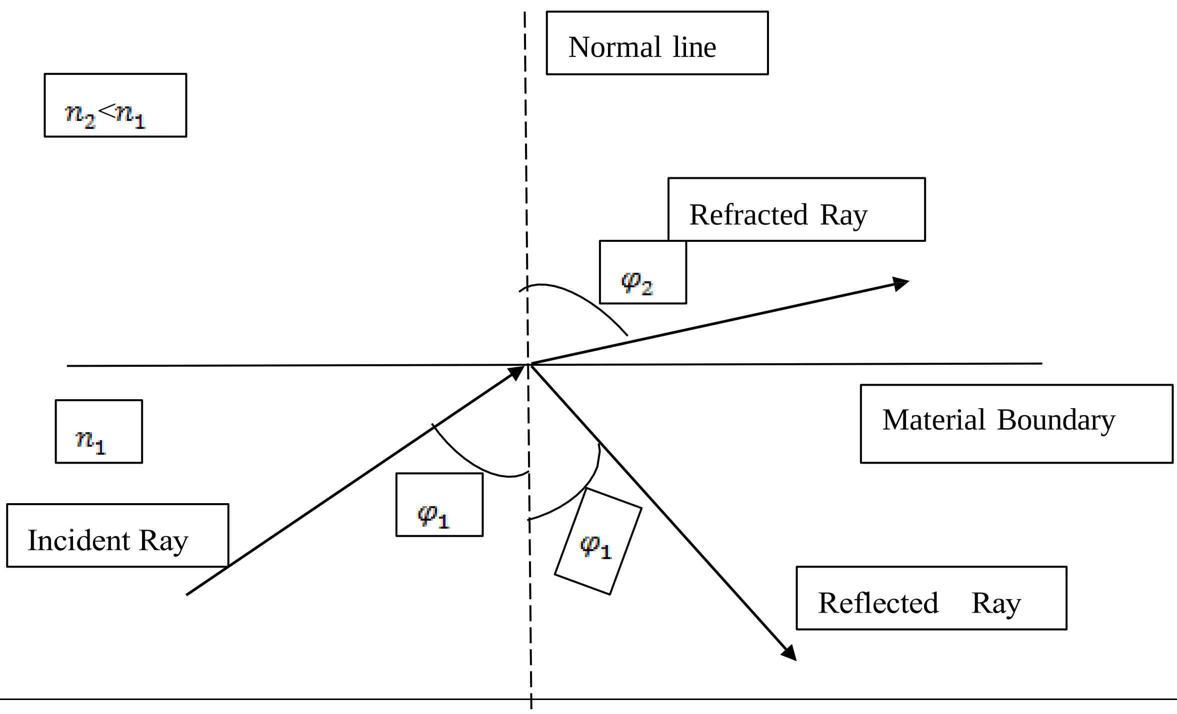

Fig.2 Refraction and reflection of a light ray at a material boundary

Polarization components of light:

An ordinary light consist of many transverse electromagnetic waves that vibrate in a variety of directions and is called un polarized light. Un polarized light can split into separate polarization components either by reflection off of a nonmetallic surface or by refraction when light passes from one material to another. The reflected beam is partially polarized at a specific angle (known as Brewster's angle) the reflected light is completely perpendicularly polarized. The parallel component of the refracted beam is transmitted entirely into the glass whereas perpendicular component is partially refracted.

Polarization characteristics of light are important when examining the behavior of components such as optical isolators and light filters. Three polarization sensitive materials are :Polarizer is a material or device that transmits only one polarization component and blocks the other. Faraday rotator is a device that rotates state of polarization of light passing through by a specific amount. Birefringent material or double refractive crystals splits the light signal entering it into two orthogonally polarized beams. One of the beams is called an ordinary ray or o-ray. The second beam is called the extraordinary ray or e-ray.

1.5 Optical Fiber Modes and Configurations, single mode fibers, graded-index fiber structure:

An optical fiber is a dielectric waveguide that operates at a optical frequencies guides light in a direction parallel to it. Structure of optical fiber as shown in Fig.3.

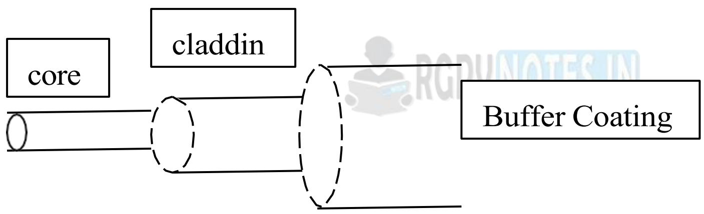

Fig.3 Structure of optical Fiber

Cladding surrounds the core adds mechanical strength to the fiber and protects core from absorbing surface contaminants. On the bases of variation in material composition optical fiber are of two types:

1) Step Index fiber- Refractive index of core is uniform throughout and under goes abrupt changes at the cladding boundary. On the bases of modes of propagation these are further classified as single mode step index and multimode step index fibers. single mode fibers sustains only one mode of propagation as shown in Fig.4. multimode fibers sustains many hundreds of modes of propagation as shown in Fig. 5.

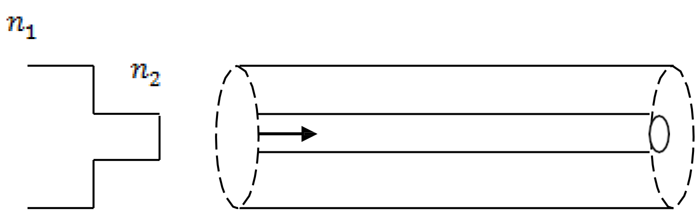

Fig.4 Mono mode step index fiber

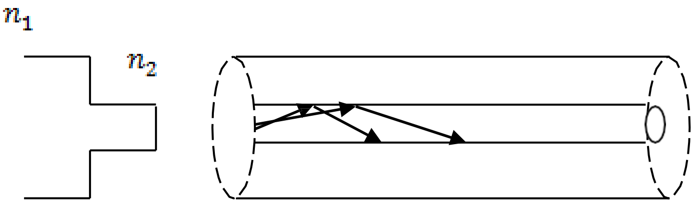

Fig.5 Multimode mode step index fiber

2) Graded Index fibers- Refractive Index is made to vary as function of the radial distance from center of the fiber. Further on the bases of modes of propagation these are classified as two types Mono mode graded index fiber and multimode graded index fiber as shown in Fig.6. Multimode fibers have large core radii due to which larger power can be launched. LED can also be used for launching power in multimode fibers. But multimode fiber suffers from intermodal dispersion.

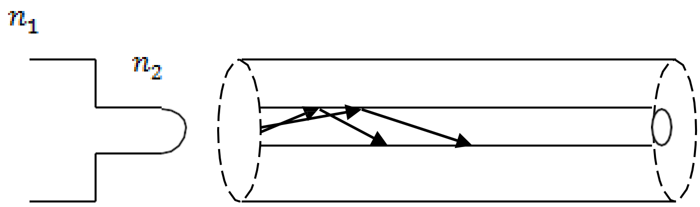

Fig.6 Multimode mode graded index fiber

Intermodal Dispersion: Optical Power in different modes travel with different velocity. Means mode arrive at different times, thus causing pulse to spread out. This can be reduced by graded index fiber. Information capacity of graded index fibers is greater as compared to the step index fibers (data rate transmission).

1.6 Fiber materials

Optical fibers are made from optically transparent glasses of these most common is silica Sio_2 which has refractive index 1.458 at 850nm. To produce two similar materials having slightly different indices of refraction for core and cladding, either fluorine or various oxides such as B_2O_3, Ge_2O_2, or P_2O_5 are added to the silica. P_2O_5 Increase the refractive index where the doping the silica with fluorine or B_2O_3 decreases it.

1.7 Photonic Fibers

Core or cladding contains air holes, which run along the entire length of fiber. They are insensitive to bending. They can deliver high power. These are of two types

1) Index guiding Fibers- Core is solid and cladding region contains air holes running along the length of the fiber as shown in Fig. 7. Core and cladding are made up of same material for example pure silica. Air holes in the cladding region lower the lower refractive index.

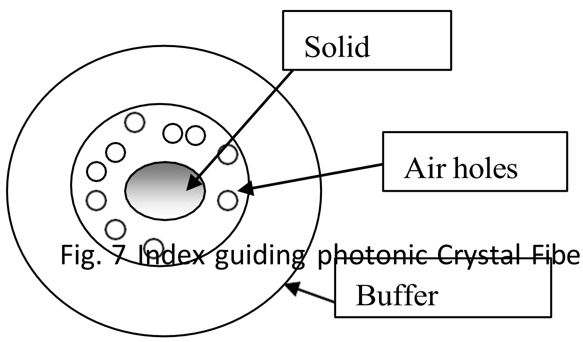

Fig. 7 Index guiding photonic Crystal Fiber

2) Photonic Band Gap Fiber (PBG)- Hollow core, surrounded by cladding region which contains air holes running along the fiber length as shown in Fig.8.

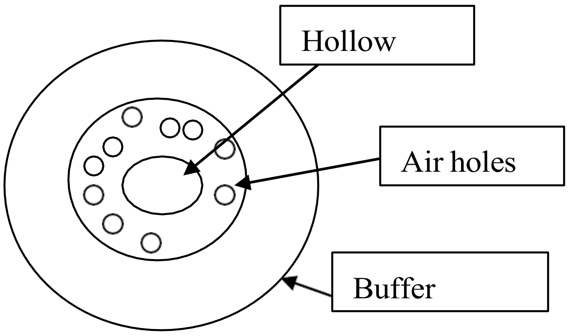

Fig. 8 Photonic Bandgap Fiber

1.8 Fiber Fabrication:

For fabrication two basic techniques are used : Vapor phase oxidation process and direct melt process. In vapor phase oxidation highly pure vapors and metal halides (e.g. $Sicl_4$ and $Gecl_4$) react with oxygen to form white powder of Sio_2 particles. The particles are then collected on the surface of a bulk glass by one of four different commonly used processes and sintered (transformed to a homogeneous glass mass by heating without melting) by one of variety of perform. Preform is a precision fed into a circular heater called the drawing furnace. Four different fiber fabrication process are as follows:

1)Outside Vapor Phase Oxidation(OVPO):Layer of Sio_2 particles called soot is deposited from a burner onto a rotating graphite or ceramic mandrel. The glass soot adheres to this bait rod, layer by layer, a cylindrical porous glass perform is built up. By properly controlling the constituents of metal halides vapor stream during deposition process , the glass composition and dimension desired for core and cladding can be incorporated into the perform.Bait rod rotates and moves back and forth under burner to produce uniform deposition of glass soot particles along the rod.The process is shown through Fig.9

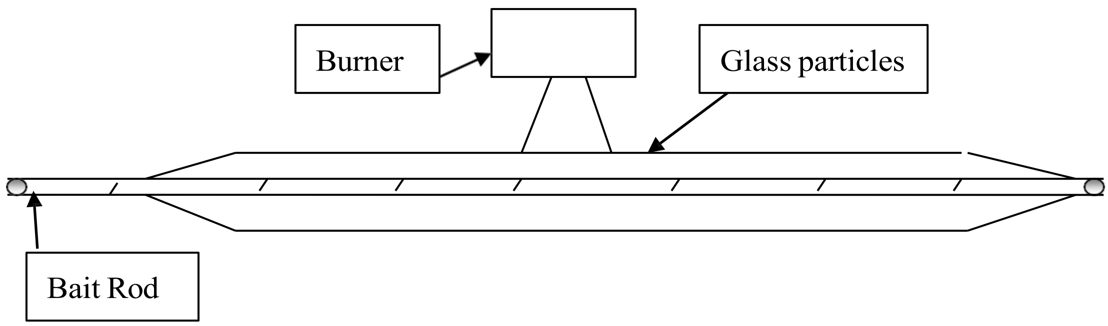

Fig. 9 Outside Vapor Phase Oxidation process of fiber fabrication

3.Modified Chemical Vapor Deposition(MCVD): The glass vapor particles arising from the reaction of the constituent metal halide gases and oxygen flow through inside of a revolving silica tube. As the Sio_2 particles are deposited, they are sintered to a glass layer by oxy hydrogen torch which travels back and forth along the tube as shown in Fig.10.When the desired thickness of glass is has been deposited, the vapor flow is shut off and the tube is heated strongly to cause it to collapse into a solid rod perform. The fiber that is subsequently drawn from this perform rod will have a core that consist of the vapor deposited-material and the cladding consisting of the original silica tube. This method produces low loss graded index fibers.

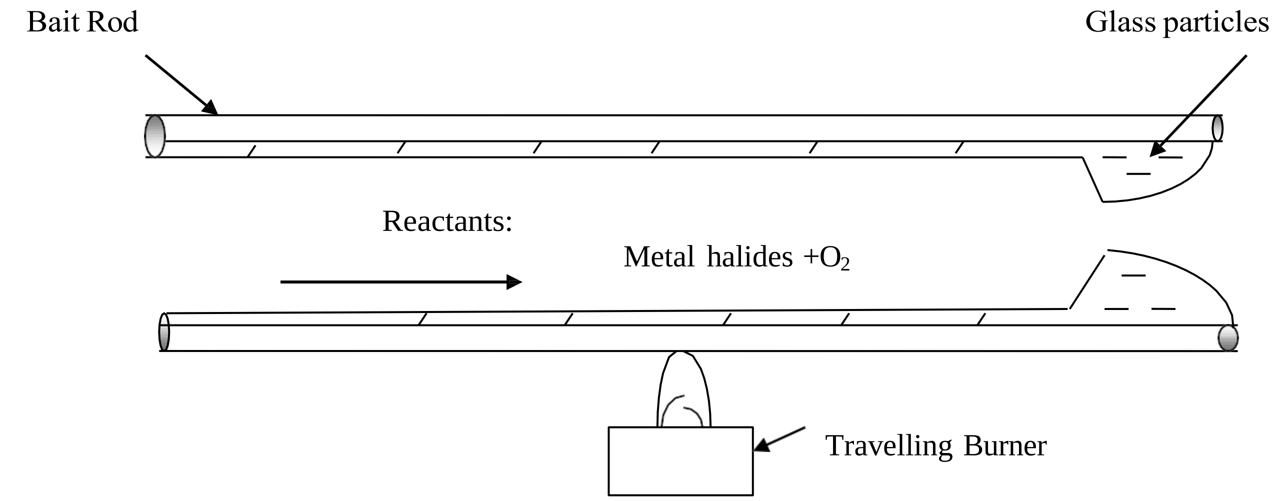

Fig. 10 Modified Chemical Vapor Deposition

3. Plasma Activated Chemical Vapor Deposition (PCVD)

In this method as shown in Fig.11. deposition occurs within the silica tube. However a non isothermal microwave plasma operating at low pressure initiates the reaction with the silica tube held at temperatures in the range of 1000-1200 °C to reduce mechanical stress in the growing glass films, a moving microwave resonator operating at 2.45Ghz generates a plasma inside the to activate chemical reaction. This process deposits clear glass material directly on the tube wall; there is no soot formation. Thus no sintering is required When one has deposited the desired glass thickness, the tube is collapsed into a perform.

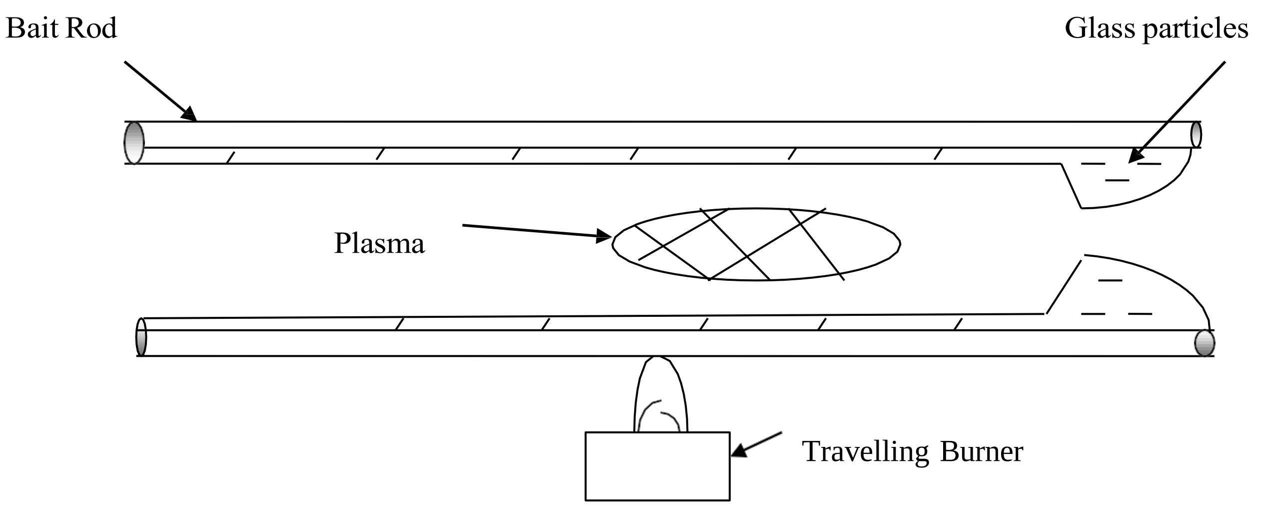

Fig. 11 plasma Activated Chemical Vapor Deposition process

3) Vapor Phase Axial deposition: A porous perform is grown in axial direction by moving rod upward. Fiber can be fabricated in continuous lengths which can affect process cost and product yields. The fact that deposition chamber and the zone melting ring heater are tightly connected to each other in the same encloser allows the achievement of a clean environment.

1.9 Fiber Optic Cables

An **optical fiber cable** is a cable containing one or more optical fibers that are used to carry light. The optical fiber elements are typically individually coated with plastic layers and contained in a protective tube suitable for the environment where the cable will be deployed. Different types of cable are used for different applications, for example long distance telecommunication, or providing a high-speed data connection between different parts of a building. Cables are fragile and are usually placed underground, which makes them difficult and expensive to install. Some fiber-optic cables are installed above ground, but if they break, they often need to be completely replaced, which is not cheap. Several layers of protective sheathing, depending on the application, are added to form the cable as shown in Fig.12. Plastic strength members and high tensile strength synthetic yarns are used to avoid electromagnetic induction.

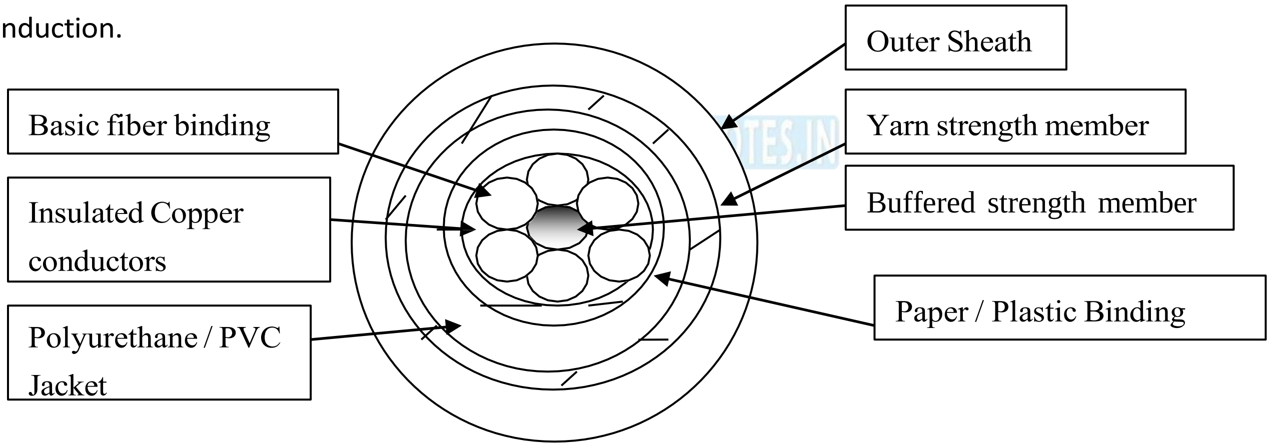

Fig.12 Schematic Structure of a Cable

Individual fibers or modules of bundled fiber groupings and optional copper wires for powering in line equipment are wound loosely around the central buffered strength member. A cable wrapping tape and other strength members such as Kevlar then encapsulate and bind these fibers grouping together. Surrounding these components is tough polymer jacket and provides crush resistance and handles any tensile stress applied to the cable so that the fibers inside are not damaged. Cables are categorized on the bases of their application.

1) Armored Or Underground Cable: For direct burial or underground duct applications has one or more layers of steel wire or steel sheath protective armoring below a layer of polyethylene jacketing. Strength protects from gnawing animals such as squirrels or burrowing rodents often cause damage to underground cables.

2) Underwater cables/Submarine Cables: Other layers are same as in normal cable but it has various water blocking layers, one or more protective inner polyethylene sheaths and heavy outer armor jacket. They are used in river, lakes and ocean environment.

Unit-2

Optical sources: Light emitting diodes (LED): structures, materials, quantum efficiency, LED power, modulation of an LED. Laser diodes: modes, threshold conditions, laser diode rate equations, external quantum efficiency, resonant frequencies, structure and radiation patterns, single mode lasers, modulation of laser diodes.

Power launching and coupling: source to fiber power launching, fiber to fiber joints, LED coupling to single mode fibers, fiber splicing, and optical fiber connectors.

LED (Light Emitting Diode) : To be useful for fiber transmission LED must have high radiance output; a fast response time ; and high quantum efficiency. Its radiance (brightness) is a measure of optical power radiated into unit solid angle per unit area of the emitting surface. The emission response time is the time delay between application of a current pulse and onset of optical emission.

1.1 LED structure

To achieve a high radiance and high quantum efficiency, the LED structure must provide a means of confining the charge carriers and the stimulated emission to the active region of PN junction where radiative recombination takes place. Carrier confinement is used to achieve a high level of radiative recombination in the active region of the device, which yields high quantum efficiency. Optical confinement is of importance for preventing absorption of the emitted radiation by material surrounding the PN junction.

The most effective structure for achieving carrier and optical confinement is double hetero-structure device as shown in Fig.2.1 because of the two different alloy layers on each side of the active region.

Metal Contacts	N-type GaAs subtrate	N-type GaAlAs Light and Carrier Confinement	N-type GaAlAs Recombination Region	P-type GaAlAs Light and Carrier Confinement	P-type GaAs subtrate	Metal Contacts

Fig. 2.1 GaAlAs Double hetero-structure light emitter

The two basic LED configurations used for fiber optics are:

1) Surface Emitters LED: In the surface emitter the plane of the active light region is oriented perpendicularly to the axis of the fiber, as shown in Fig.2.2. In this configuration a well is etched through the substrate of the device, into which a fiber is then cemented in order to accept the emitted light. The circular active area in practical surface emitters is normally 50µm in diameter and up to 25µm thick. The emission pattern essentially isotropic with 120^0 half power beam width. In this pattern source is equally bright when viewed from any direction, but power decreases as cos θ , where θ is the angle between the viewing direction and normal to the surface. Thus power is down to 50 percent of its peak when $\theta=60^0$, so that the total half power beam width is 120^0 .

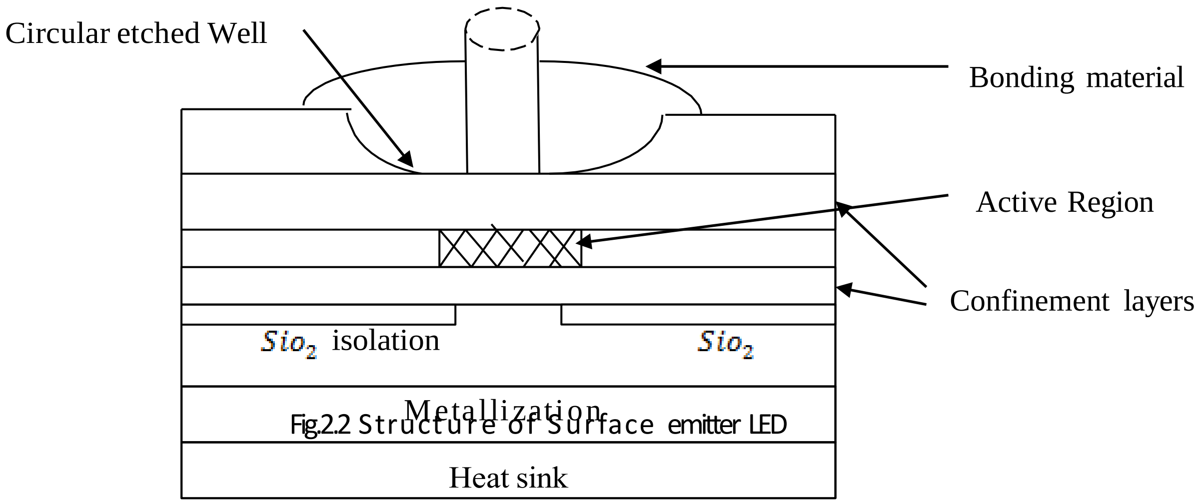

Fig. 2.2 Structure of Surface emitter LED

2) Edge Emitter depicted in Fig.2.3 consist of an active junction region, which is the source of incoherent light, and two guiding layers. The guiding layers both have a refractive index which is lower than that of active region but higher than index of the surrounding material. This structure forms a waveguide channel that directs the optical radiation towards the fiber core. To match the typical core diameters, the contact strips are 50 to 70µm wide. Length of the active regions usually ranges from 100 to 150µm. The emission pattern of edge emitter is more directional than that of surface emitter.

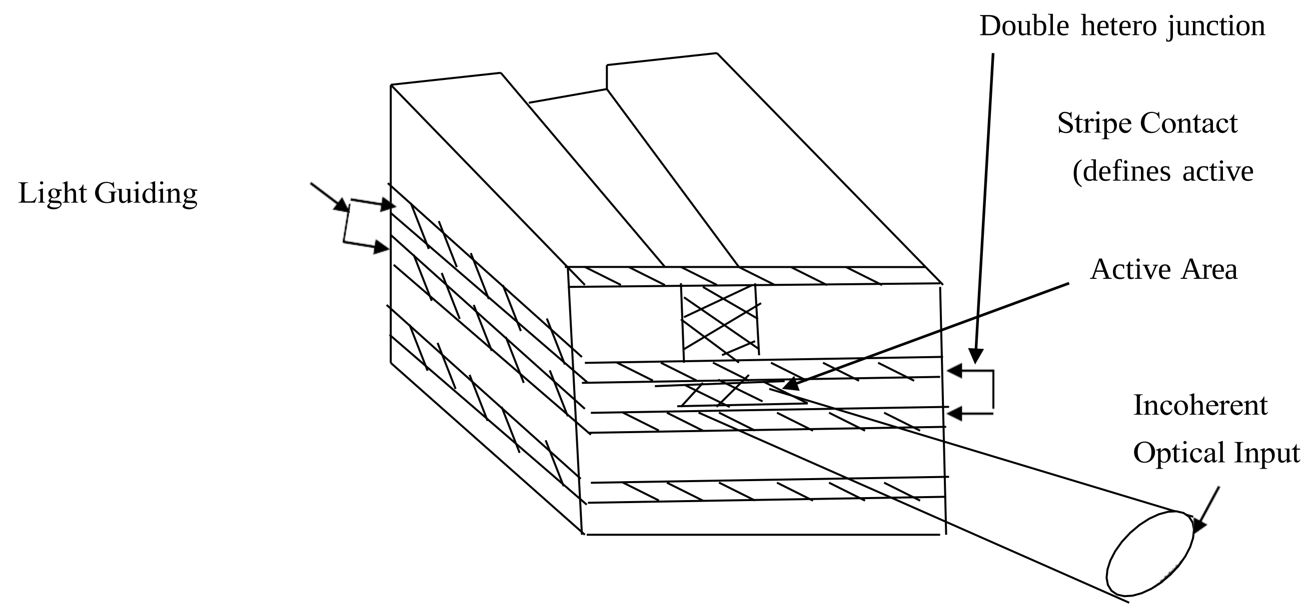

Fig. 2.3 Structure of Edge emitter LED

2.2 Light Source materials

Semiconductor material that is used for the active layer of an optical source must have direct band gap. Only in direct band gap material is the radiative recombination sufficiently high to produce a adequate level of optical emission. Although none of the normal single element semiconductors are direct band-gap materials, many binary compounds are. These are made from compounds of a group III (such as Al, Ga or In) and a group V element (such as P, As or Sb). At longer wavelengths the quaternary alloy $Al_{1-x}Ga_xAs_yP_{1-y}$ is one of the primary material candidates.

2.3 LED Quantum Efficiency and Power

Internal Quantum Efficiency (IQE) is the fraction of electron-hole pairs that recombine radiatively. If Radiative recombination rate per unit volume is R_r the internal quantum efficiency η_{int} is the ratio of radiative recombination rate to the total recombination rate. (IQE - also termed Radiative Efficiency).

For exponential decay of excess carriers, the radiative recombination life time is $\tau_r = \frac{\Delta n}{R_r}$ and non radiative

recombination life time is $\tau_{nr} = \frac{\Delta n}{R_{nr}}$. Thus internal quantum efficiency $\eta_{int} = \frac{\tau}{\tau_r}$.Where

The bulk recombination lifetime is

$$\tau = \frac{\tau_r * \tau_{nr}}{\tau_r + \tau_{nr}}$$

Internal quantum efficiency of homo junction LED is 50% and that of double hetero-junction structure LED is 60-80%. If the current injected into the LED is I then the total number of recombinations per second is

$R_r + R_{nr} = \frac{I}{q}$

From the definition of internal quantum efficiency,

$\eta_{int} = \frac{R_r}{\frac{I}{q}}$ Or $R_r = \frac{I}{q} * \eta_{int}$

R_r is the total number of photons generated per second and each photon has energy hν then optical power generated internally to the LED is

$$P_{int} = \eta_{int} \frac{hcI}{q\lambda}$$

Where, I=current, c=velocity of light, λ=wavelength of emitted light, q=electron charge

Q.1 A double hetero junction InGaAsP LED emitting at peak wavelength of 1310 nm has radiative and non-radiative recombination time 30 ns and 100 ns respectively. For the injected current of 40nA, find bulk recombination lifetime and internal power level yield.

Sol. The bulk recombination lifetime is

$$\tau = \frac{\tau_r * \tau_{nr}}{\tau_r + \tau_{nr}} = \frac{30 * 100}{30 + 100} = 23.1. ns$$

Where,

τ=Bulk recombination time

τ_r =Radiative recombination time

τ_{nr} = Non-Rdiative recombination time

$$\eta_{int} = \frac{\tau}{\tau_r} = \frac{23.1\, ns}{30 ns} = 0.77$$

η_{int} =Internal Efficiency

P_{int} =Internal Power

$$P_{int} = \eta_{int} \frac{hcI}{q\lambda} = 0.77 \frac{(6.62 X 10^{-34} J)(3 X 10^{8}\, m/s)(0.04A)}{(1.602 X 10^{-19}\, C)(1.31 X 10^{-6} m)} = 2.92 \text{ mW}$$

External Quantum Efficiency (EQE)

External Efficiency (also termed Optical Efficiency) once the photons are produced within the semiconductor device, they have to escape from the crystal in order to produce a light-emitting effect. External efficiency is the proportion of photons generated in the active region that escape from the device. The ratio of the number of photons emitted from the LED to the number of electrons passing through the device - in other words, how efficiently the device coverts electrons to photons and allows them to escape.

$$\eta_{ext} \approx \frac{1}{n(n+1)^2}$$

From this it follows that optical power emitted from LED is

P=$\eta_{ext}\, P_{int} = \frac{P_{int}}{n(n+1)^2}$

2.4 Modulation of LED

If the device current is modulated at a frequency w the output power of the device will vary as

P(w)=$P_0[1+(W\tau)^2]^{-1/2}$

P_0 is the power emitted to zero modulation frequency. Modulation bandwidth of LED can be defined as the point where electrical signal power designated P(w) has dropped to half its constant value resulting from the modulated portion of the optical signal. Thus is electrical 3dB point that is the frequency at which the output electrical power is reduced by 3dB with respect to input electrical power which corresponds electrical power attenuation of 6dB.

2.5 LASER Diode Modes and Threshold Conditions

For optical fiber communication systems requiring bandwidths greater than approximately 200Mhz the semiconductor injection LASER diode is preferred over the LED.LASER diodes have response time less then 1ns, can have spectral widths of 2nm or less and are capable of coupling several tens of mille watts of useful luminescent power into optical fibers with small cores and small mode field diameters.

Simulated emission in semiconductor LASERS arises from optical transitions between distributions of energy states in the valence and conduction bands. This differs from gas and solid-state LASERS, in which radiative transitions occur between discrete isolated or molecular levels. The radiation in the laser diode is generated within a Fabri-Parot cavity as in most types of lasers. However this cavity is much smaller being approximately 250 to 500μm, 5 to 15 μm wide and 0.1 to 0.2µm thick. These dimensions are commonly referred as the longitudinal, lateral and transverse dimensions of the cavity, respectively.

In the laser diode Fabry-Parot resonator a pair of flat, partially reflecting mirrors are directed towards each other to enclose the cavity. The mirror facets are constructed by making two parallel cleaves along natural cleavage planes of the semiconductor crystal. The purpose of these mirrors is to provide strong optical feedback in the longitudinal direction, thereby converting the device into an oscillator with a gain mechanism that compensates for optical losses in the cavity. The laser cavity can have many resonant frequencies for which the gain is sufficient to overcome the losses. The sides of the cavity are simply formed by roughening the edges of the device to reduce unwanted emissions in these directions.

In another laser diode type, commonly referred to as distributed feedback (DFB) laser the cleaved facet are not required for optical feedback. The fabrication of this device is similar to the Fabry-Parot types, except that lasing action is obtained from bragg reflectors (gratings) or periodic variations of the refractive index (called distributed feedback corrugations) which are incorporated into a multilayer structure along the length of the diode.

The optical radiations within the resonant cavity of a laser sets up a pattern of electric and magnetic field lines called modes of the cavity. These can conveniently be separated into two independent sets of transverse electric (TE) and transverse magnetic modes. The longitudinal modes are related to the length L of cavity and determine the principal structure of the frequency spectrum emitted optical radiation. Since L is much larger than the lasing wavelength of approximately 1µm, many longitudinal modes can exist.

Lateral modes lie in the plane of pn junction. These modes depend on side wall preparation and width of the cavity. And determine the shape of the lateral profile in the direction perpendicular to the plane of the PN junction.

Lasing is the condition at which light amplification becomes possible in the laser diode. The requirement of the lasing is that a population inversion be achieved. This condition can be understood by considering the fundamental relationship between the optical intensity I , the absorption coefficient α and the gain coefficient g in the fabry-parot cavity. The simulated emission rate into a given mode is proportional to the intensity of radiation in that mode. The radiation intensity at a photon energy hv varies proportional distance z that it transverses along the lasing cavity according to the relationship.

$$I(2L)=I(0)R_1R_2\exp(2L[\Gamma_g(h\nu)-\alpha(h\nu)]) \quad ....(2.1)$$

Where α is the absorption coefficient of the material in the optical path and r is the optical confinement factor (fraction of optical power in active layer).

Optical amplification of selected modes is provided by the feedback mechanism of the optical cavity. In the repeated passes between the partially reflecting mirrors, a portion of radiation associated with those modes having the highest optical gain coefficient is retained and further amplified during each trip through the cavity. Lasing occurs when gain of one Or several guided modes is sufficient to exceed the optical the optical loss during the roundtrip through the cavity, that is for z=2L.During the round only the fractions $R_1 and\ R_2$of the optical radiation are reflected from the two laser ends where $R_1 and\ R_2$ are mirror reflectivities. At the lasing threshold a steady state oscillations take place, and the magnitude of phase of the returned wave must be equal to those of the original wave. This gives condition

$$I(2L)=I(0) \quad ...(2-2)$$

From the above equation condition for reaching lasing threshold optical gain $g_{th}$is the point at which gain g is greater than or equal to total loss α_t in the cavity.

$$rg_{th} \geq \alpha_t=\alpha+\frac{1}{2L}\ln(\frac{1}{R_1R_2}) \quad ...(2-3)$$

The mode that satisfies Eq. (2-3) reaches the threshold first. Theoretically, at the onset of this condition, all additional energy introduced into the laser should augment the growth of this particular mode. A dramatic and sharply defined increase in the power output occurs at the lasing threshold.

2.3 Laser Diode rate Equations

The relationship between optical output power and diode drive currents can be determined by examining the rate equations that govern the interaction of photons and electrons in the active region. Total population is determined by carrier injection, spontaneous recombination and stimulated emission. For a pn junction with carrier confinement region of depth d, the rate equations

$$\frac{d\Phi}{dt}=\text{Cn}\Phi+R_{sp}+\frac{\Phi}{\tau_{ph}} \qquad \text{...(2-4)}$$

=stimulated emission+ spontaneous emission+ photon loss

Which governs the number of photons Φ. And

$$\frac{dn}{dt}=\frac{J}{qd}-\text{Cn}\Phi-\frac{\Phi}{\tau_{sp}} \qquad \text{...(2-4)}$$

=Injection +spontaneous recombination +stimulated emission

This governs the number of electrons n. Here, C is the coefficient describing the strength of the optical absorption and emission interaction, R_{sp} is the of spontaneopus emission into the lasing mode (which is much smaller than the total spontaneous emission rate). τ_{ph} is the photon life time, τ_{sp} is spontaneous recombination lifetime, and J is the injection current density.

2.4 External Quantum Efficiency

External quantum efficiency is defined as the number of photons emitted per radiave-electron hole pair recombination above threshold. Under the assumption that above threshold the gain coefficient the gain coefficient remains fixed at g_{th}, external quantum efficiency is given by.

$$\eta_{ext}=\eta_i \frac{(g_{th-\alpha)}}{g_{th}} \qquad \text{----(2-5)}$$

Here, η_i is the internal quantum efficiency.

2.5 Resonant Frequencies

To examine the resonant frequencies of the laser. The condition to be satisfied is $2\beta L$=2 πm ---(2-6)

Where, m is an integer. Using $\beta = \frac{2\pi n}{\lambda}$ for the propagation constant. From Eq. (2-6).

$$\text{m}=\frac{L}{\lambda/2n} = \frac{2nL\nu}{\lambda} \qquad \text{---(2-7)}$$

Where, c=νλ. This states that cavity resonates when a integer number m of half-wavelength spans in the region between the mirrors. Since in all lasers gain is the function of frequency there will be a range of frequencies for which the Eq. (2-7) holds. Each of these frequencies corresponds to a mode of oscillation of the laser. Depending on the laser structure, any number of frequencies can satisfy Eq. (2-7). Thus some lasers are single mode and some are multimode.

2.6 Laser Diode Structures and Radiation Patterns

Lasers can be made using one of the four fundamental structures. These are:

1) Buried Heterostructure(BH)laser: To make the buried hetero structure laser shown in Fig. 2.4, one etches a narrow mesa stripe (1-2μm wide) in double heterostucture material. The mesa is then embedded in high resistivity lattice matched n-type material. The mesa is then embedded in high resistivity lattice-matched n-type material with an appropriate band gap and low refractive index. This material is GaAlAs in 800-90nm lasers with GaAs active layer, and is InP for 1300-1600nm lasers with an InGaAsP active layer. This configuration thus strongly traps generated light in a lateral waveguide. A number of of this fundamental s been used to fabricate high performing laser diodes.

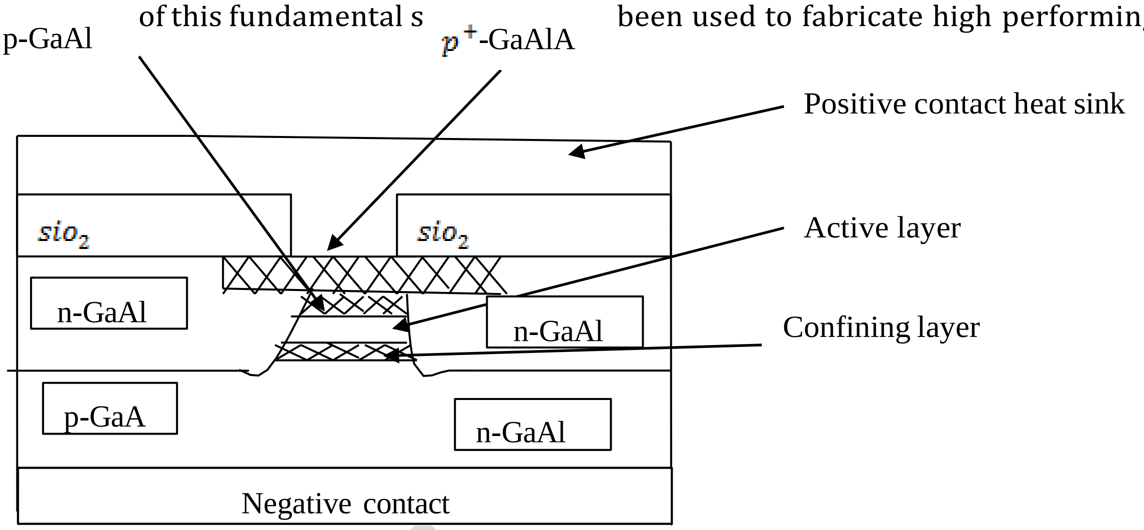

Fig.2.4 InGaAsP Buried Hetero structure laser diode

2) Selectively Diffused Construction: Here, a chemical dopant , such as zinc for GaAlAs lasers and cadmium for InGaAsP lasers, is diffused into the active layer immediately below the metallic contact stripe. The dopant changes the refractive index of the active layer in the form of the lateral waveguide channel. In the varying thickness structure shown in Fig. 2.5, a channel is etched into the substrate. Layers of crystal are then regrown into chnnel using liquid phase-epitaxy. This process fills in the depressions and partially dissolves the protrusions, thereby creating variations in the thickness of the active and confining layers.

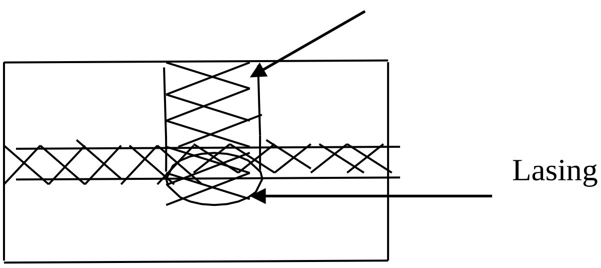

Fig.2.5 selectively diffused structure laser diode

2.7 Fiber Splicing:

Is used to create long optical links or in situations where optical connections and disconnections are needed. splicing techniques are as follows:

1) Fusion Splice: Is normally thermally bonding together prepared fiber ends as shown in Fig. 2.6. In this method fiber ends are first prealigned and butted together. This is done in a groove fiber holder, the butt joint is then heated with an electric arc or laser pulse so that fiber ends are momentarily melted and hence bonded together.

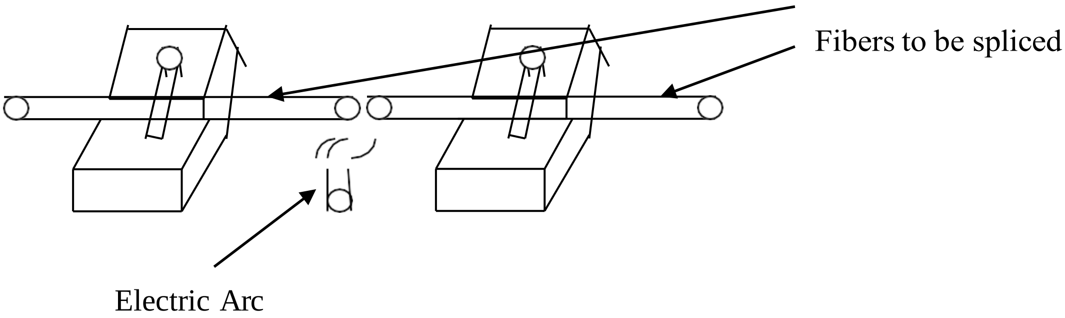

Fig. 2.6 Fusion Splicing of optical fibers.

2) V-Groove Splice: The prepared fiber ends are first butted together in a V shaped groove as shown in Fig. 2.7.They are then bonded together with an adhesive or held in a place by means of cover plate.

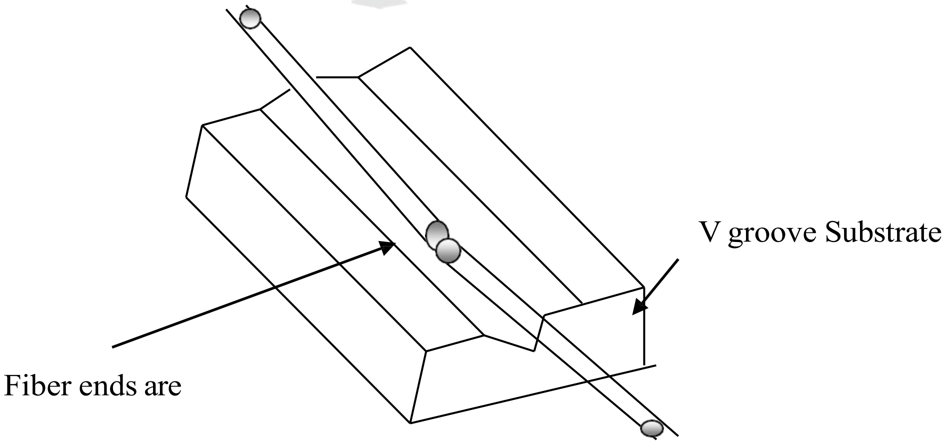

Fig. 2.7 V Groove splice.

Unit: III

Photodetectors: PIN photodetector, avalanche photodiodes, photodetector noise, detector response time, avalanche multiplication noise. Signal degradation in optical fibers: Attenuation: units, absorption, scattering losses, bending losses, core and cladding losses. Signal distortion in fibers: overview of distortion origins, modal delay, factors contributing to delay, group delay, material dispersion, waveguide dispersio n, polarization-mode dispersion. Characteristics of single mode fibers: refractive index profiles, cut-off wavelength, dispersion calculations, mode field diameter, bending loss calculation.

Photo detector-: Is first element sense the luminescent power falling upon it and convert variation of this optical power into a corresponding varying electric current.

Photodiode is almost exclusively for fiber optic systems because of its small size, suitable material, high sensitivity and fast response time. The two types of photodiode used are PIN photo detector and avalanche photodetector (APD).

3.1 PIN PHOTO DIODE

The device structure as shown in Fig. 3.1 consist of P and N regions separated by very lightly N-doped intrinsic I region. In normal operation a sufficiently large reverse bias voltage is applied across the device so that the intrinsic region is fully depleted of carriers. That is in intrinsic region carrier concentration is very small as compared to the P and N regions.

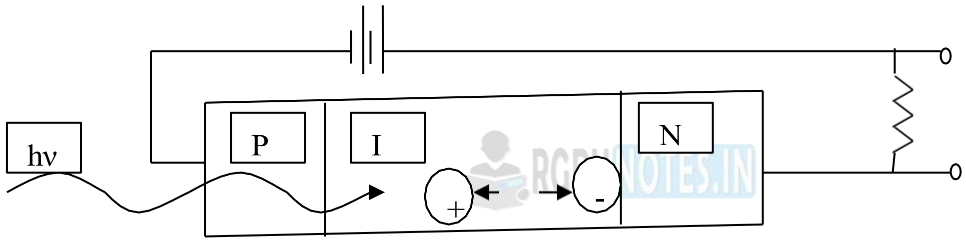

Fig. 3.1 PIN Photodiode

When a incident photon has energy greater than or equal to the band gap energy of the semiconductor material, the photon can give up its energy and excite an electron from the valence band to the conduction band, This process generates mobile electron-hole pairs. The electric field present in the depletion region causes the carriers to separate and be collected across the reverse biased junction. This gives rise to a current flow in an external circuit, with one electrons flowing for every carrier pair generated, This current is known as the Photo current.

The performance of a photodiode is often characterized by the renponsivity R. This related to the quantum efficiency by

$$R=\frac{I_p}{P_{in}}=\frac{\eta q}{h\nu}$$

This parameter is useful, since it specifies the photocurrent generated per unit optical power. Responsivity is a linear function of optical power. That is photocurrent I_p is proportional to the optical power P_{in}

incident upon the photodetector, so that the responsivity R is constant at a given wavelengths (at a given). Note however that the quantum efficiency is not a constant at all wavelengths, since it varies according to photon energy. Consequently, the responsivity is a function of the wavelength and of the photodiode material (since different materials have different band-gap energies). For a given material, as the wavelength of the incident photon becomes longer, the photon energy becomes less than that required to excite an electron from the valence band to conduction band. Responsivity thus falls of rapidly beyond the cutoff wavelength.

3.2 Avalanche Photodiode

Avalanche photodiode (APDs) internally multiply the primary signal photocurrent before it enters the input circuitry of the following amplifier. This increases the receiver sensitivity, since photocurrent is multiplied before encountering the thermal noise associated with the receiver circuit.In order carrier multiplication to take place, the photo generated carriers must traverse a region where a very high electric field is presented. In this high-field region, a photo generated electron or hole can gain enough energy so that it ionizes bound electrons in the valence band upon colliding with them. This carrier multiplication mechanism is known a s Impact Ionization.The newly created carriers are also accelerated by the high electric field, thus gaining enough energy to cause further impact ionization. This phenomenon is called avalanche effect.

A commonly used structure for achieving carrier multiplication with very excess noise is the reach –through construction (RAPD). The reach through avalanche photodiode (RAPD) composed of high resistivity P type material deposited as an epitaxial layer on P+ substrate. Then n+ layer is constructed. This configuration is referred to as P+πpn+ reach through structure. The π layer is basically an intrinsic material. When low reverse bias voltage is applied, most of the potential drop is across pn+ junction. The depletion layer widens with increasing bias until a certain voltage is reached at which peak electric field at the pn+ junction is about 5 -10 percent below needed to cause avalanche breakdown.

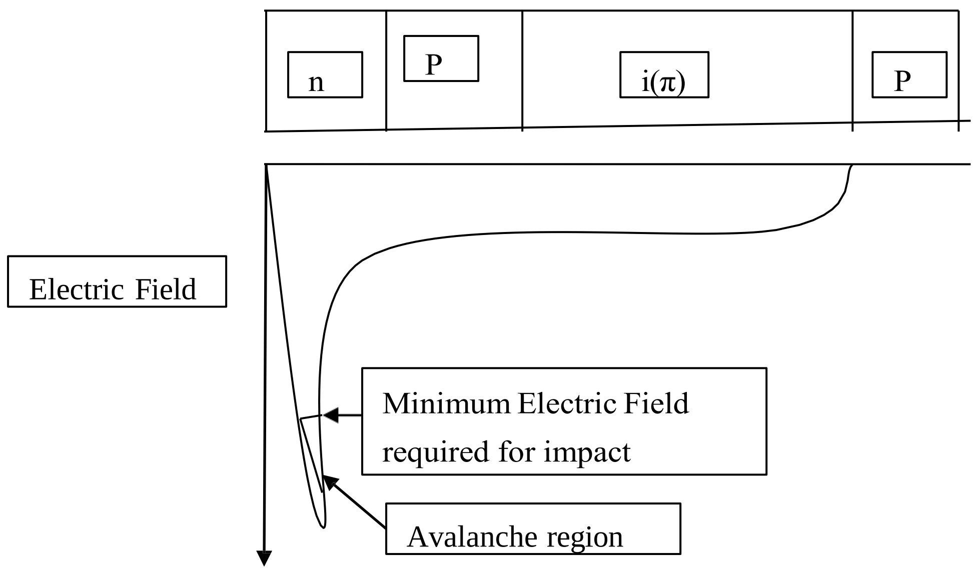

Fig 3.2 Reach through Avalanche structure and the electric fields in the depletion and multiplication region.

Light enters the device through the p+ region and is absorbed in the π material, which act as the collection region for photo generated carriers. Upon being absorbed, photon gives up its energy, thereby creating electron hole pairs which are then separated by electric field in the π region. The photo generated electrons drift through the π region in the pn+ junction, where high electric field exists. It is in this high field region that carrier multiplication takes place. The multiplication M for all carriers generated in the photodiode is defined by

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

Where I_M is the average value of the total multiplied output current I_p is the primary multiplied photocurrent.

3.3 Photo detector Noise

In Fiber optic communication systems, the photodiode is generally required to detect very weak optical signals. Detection of the weakest possible optical signals requires that the photodetector and its following amplification circuitry be optimized so that a given signal to noise ratio is maintained. Signal to noise ratio at output is defined by.

$$\frac{S}{N}=\frac{\text{Signal power from photocurrent}}{\text{Photodetector Noise + amplifier noise power}}$$

Noise Sources

To see different types of noises affecting the signal to noise ratio, let us examine the simple receiver model and its equivalent circuit shown in Fig. 3.3.The photodetector has small resistance R_s a total capacitance C_d consisting of junction capacitance and packaging capacitances and load resistor R_L. The principle noises associated with photodetectors that have no internal gain are quantum noise , dark current noise generated in the bulk material of the photodiode, and surface leakage current noise. The quantum or shot noise arises from statistical nature of the production and collection of the photoelectrons when an optical signal is incident on a photodetector.

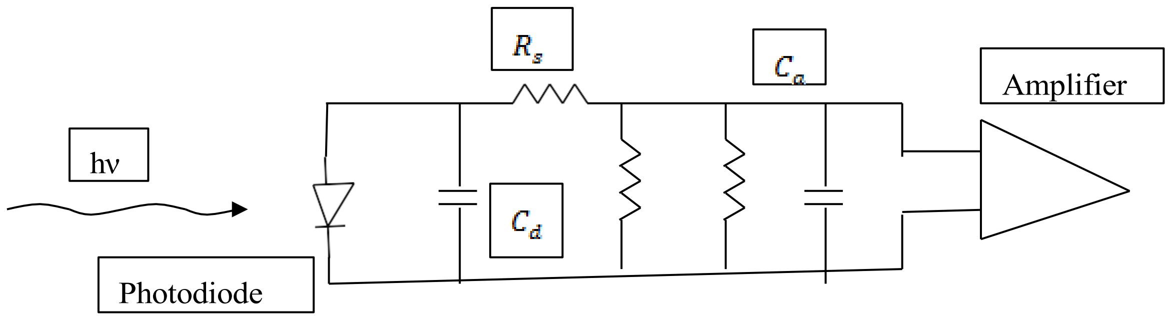

Fig. 3.3 Photo detector Equivalent Circuit

The shot noise current has a mean square value in receiver bandwidth B_e which is proportional to the average value of photocurrent I_p.

$i_{shot}^2=2qI_pB_eM^2F(M)$--------(1)

Where F(M) is a noise figure associated with the random nature of the avalanche process.

Photocurrent dark current is the current that continues to flow through the bias circuit of the bulk dark current i_{DB} arises from the electrons or holes which are thermally generated in the pn junction of photodiode.

i_{DB}^2 =2q$I_D B_e M^2$F(M) -------- (2)

Where $I_D$is the primary detector bulk dark current .

Surface dark current is also referred as surface leakage current or simply leakage current. It is dependent on surface defects, cleanliness, bias voltage and surface area. An effective way of reducing surface dark current is through the use of a guard ring structure which shunts surface leakage currents away from the load resistor. The mean square value of surface dark current is given by

i_{DS}^2 =2q$I_L B_e$ ----(3)

Where $I_L$is the surface leakage current.

To simplify the analysis of receiver circuitry, we shall assume here that the amplifier input impedance is much greater than the load resistance, so that its thermal noise is much smaller than that of R_L. The photodetector load resistor contribute a mean square thermal (Johnson) noise current.

$i_T^2 = \frac{4 K_B T B_e}{R_L}$ ---(4)

Where K_B is Boltazmann's constant and T is absolute temperature. This noise is reduced by using a load resistor which is large but still consistent with the receiver requirement.

3.4 Response Time

The response time of a photodiode together with output circuit depends on the following factors:

The transit time of the photo carriers in the depletion region

The diffusion of the photocarriers generated outside the depletion region.

The RC Time constant of the photodiode and its associated circuit.

3.5 Attenuation

Signal attenuation also known as fiber loss or signal loss. The basic attenuation mechanisms in a fiber are absorption, scattering and radiative losses of the optical energy.

Absorption: Absorption is caused by three different mechanisms:

Absorption by atomic defects in glass composition.

1. Extrinsic absorption by impurity atoms in the glass material.
2. Intrinsic absorption by the basic constituent atoms of the fiber material.

Atomic defects are imperfections in the atomic structure of the fiber material. Examples are missing molecules, high density clusters of atom groups , oxygen defects in the glass structure.

The dominant absorption factor in silica fibers is the presence of minute quantities of impurities in the fiber material. These impurities include OH- (water) ions that are dissolved in the glass and transition metal ions such as iron, copper, chromium and vanadium.

Intrinsic absorption occurs when the material is in a perfect state with no density variations, impurities , material inhomogeneties and so on. Intrinsic absorption results from electronic absorption bands in the ultraviolet region and from atomic vibration band in the near infrared region.

Scattering Losses:

Scattering losses in glass arises from microscopic variations in the material density, from compositional fluctuations and from structural inhomogeneties or defects occurring during fiber manufacture.Due to variation in the refractive index occurring within the glass over distances that are small compared with the wavelength.these index variations cause a Rayleigh type scattering in the light.

Bending losses:

Radiative losses occur whenever an optical fiber undergoes a bend of finite radius of curvature. Fibers can subject to two types of bends.

i) Macroscopic bends having radii that are large compared to the fiber diameter as shown in Fig. 3.4 ,also known as macrobending losses or simply bending losses. As radius of curvature decreases loss increases exponentially.

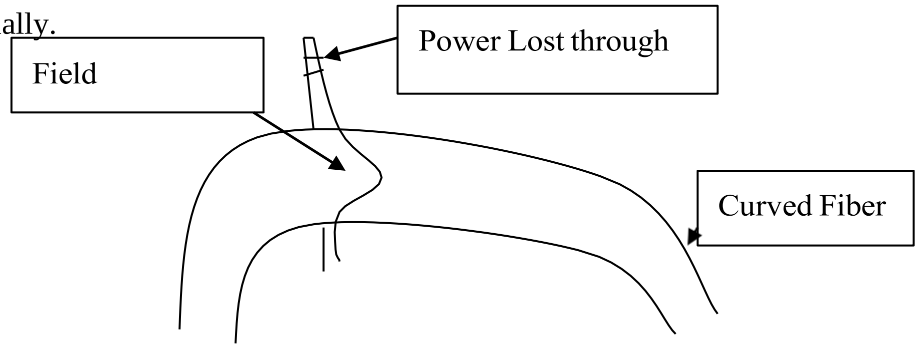

Fig. 3.4 Sketch of Fundamental mode field in curved optical waveguide

ii) Microbends are repetitive small scale fluctuations in the radius of the curvature of the fiber axis. They are caused either by non uniformities in the manufacturing of the fiber or by non uniform lateral pressure created during the cabling of the fiber.

One method of minimizing microbending losses is by extruding a compressible jacket over the fiber. When external forces are applied to this configuration, the jacket will be deformed but fiber will tend to stay relatively straight.

3.6 Signal Distortion

An optical signal weakens from attenuation mechanisms and broadens due to distortion effects as it travels along a fiber as shown in Fig.3.5. Signal distortion is consequence of factors such as intermodal delay, intramodal delay, polarization mode dispersion and higher order dispersion effects.

a) Intramodal Dispersion:

Is pulse spreading takes place within a single mode. This spreading arises from the finite spectral emission width of an optical source. This phenomenon is known as group velocity dispersion, since dispersion is a result of the group velocity being a function of the wavelength.

b) Intermodal Dispersion: Appears only in multimode fibers, modal delay is the result of each mode having a different value of group velocity at a single frequency.

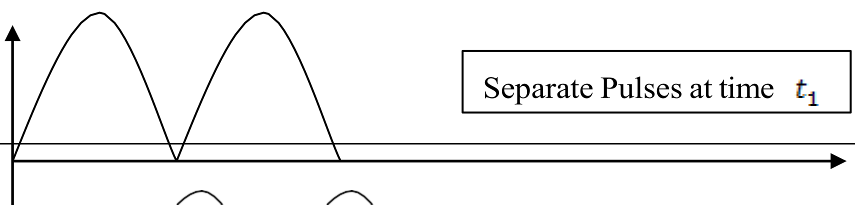

Fig. 3.5 Broadening and attenuation of two adjacent pulses as they travel along the fiber

Material Dispersion: Arises due to the variations of the refractive index of the core material as a function of wavelength.

Waveguide Dispersion: Causes pulse spreading only part of the optical power propagating along the fiber is confined in the core . Dispersion arises because of the fraction of light power propagating in the cladding travels faster than the light confined in the core, since the index is lower in the cladding.

Polarization Mode dispersion: results from the fact that light signal energy at a given wavelength in a single mode fiber actually occupies two orthogonal polarization state or modes. At the start of the fiber the two polarization states are aligned. However since fiber material is not perfectly uniform throughout its length, each polarization mode will encounter slightly different refractive index.

3.7 Characteristics of Single Mode Fibers

These characteristics include index profile configurations used to produce different types of fibers, the concept of cut off wavelength, signal dispersion designations and calculations.

Refractive Index Profile: It is possible to modify the waveguide dispersion by changing from a simple step-index design to more complex index profiles for the cladding, thereby creating different chromatic-dispersion characteristics in single mode fibers. The four refractive index profiles for fiber design are 1310nm optimized fibers, dispersion shifted fibers, dispersion flattened fibers and large effective core three dimensional profiles for several different types of single mode fibers.

1310nm optimized single mode fibers are either the matched cladding or depressed cladding. Matched cladding fibers have uniform refractive index throughout the cladding. In depressed cladding fibers the cladding material next to the core has lower index than outer cladding region. By creating fiber with large negative waveguide dispersion and assuming the same values for material dispersion can then shift the zero dispersion point to longer wavelengths. The resulting optical fiber is known as Dispersion shifted fiber.To reduce the effects of fiber nonlinearities, fiber designers developed the non zero dispersion shifted fibers (NZDSF). The large core areas in these fibers reduce the effects of fiber nonlinearities.

An alternative fiber design concept is to distribute the dispersion minimum over a wider spectral range. This approach is known as dispersion flattening.

3.8 Cutoff Wavelength

The cutoff wavelength of first higher mode is an important transmission parameter for single mode fibers, since it separates the single mode from multimode regions . Single mode operation occurs above the theoretical cut off wavelength given by.

$\lambda_{c;th}=\frac{2\pi a}{V}\,(n_1^2 - n_2^2)^{1/2}$

With V=2.405 for step index fibers.

3.9 Dispersion Calculation

The total chromatic dispersion in single mode fibers consists mainly of material and waveguide dispersions. The resultant intramodal or chromatic dispersion is given by

$$D(\lambda) = \frac{d\tau}{L d\lambda}$$

Where τ is a group delay. The dispersion is commonly expressed in ps/(nm.km). The broadening σ of an optical pulse over a fiber of length L is given by

$\sigma = D(\lambda) L\, \sigma$

Where σ is the half power spectral width of the optical source. To measure the dispersion, one examines the pulse delay over a desired wavelength range.

3.10 Bending Loss

Macro bending and micro bending losses are important in the design of single mode fibers. These fibers are principally evident in 1550nm region, and show up a rapid increase in attenuation when fiber is bent smaller than a certain bend radius. The lower the cutoff wavelength relative to the operating wavelength, the more susceptible single mode fibers are for bending. The bending losses are primarily a function of the mode field diameter , the smaller the bending loss. This is true for both match-clad and depressed clad fibers.

Unit IV

Optical receivers: Fundamental receiver operation, digital receiver performance, eye diagrams, coherent detection: homodyne and heterodyne, burst mode receiver, analog receivers.

Digital links: Point to point links, link power budget, rise time budget, power penalties.

Analog links: Overview of analog links, carrier to noise ratio, multichannel transmission techniques.

An optical receiver consists of photo detector, an amplifier and signal processing circuitry. The receiver has the task of first converting the optical energy from the end of a fiber into an electric signal, and then amplifying this signal to a large enough level so that it can be processed by the electronics following the receiver amplifier.

4.1 Fundamental Receiver Operation

A receiver must be able to detect weak, distorted signals and make decisions on what type of data was sent based on an amplified and reshaped version of this distorted signal. Figure 4.1 illustrate the shape of a digital signal at different points along the optical link. The transmitter signal is a two level binary data stream consisting of either 0 or a 1 at a time slot of duration T_b. This time slot is referred to as a bit period. One of the simplest techniques for sending binary data is amplitude shift keying (ASK) or on-off keying (OOK), wherein a voltage level is switched between two values which are usually on or off. The resultant signal wave thus consists of a voltage pulse of amplitude V relative to the zero voltage level when a binary 1 occurs and a zero voltage level space when a binary zero occurs.

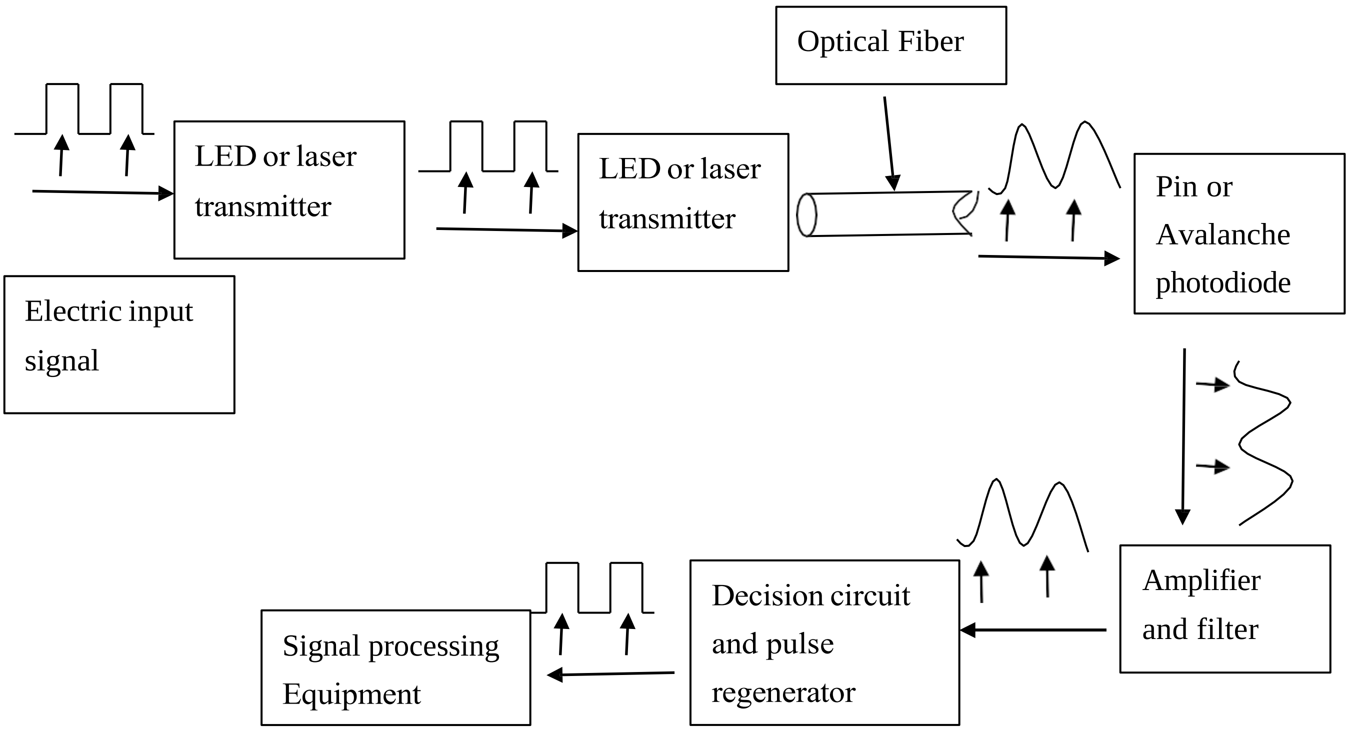

Fig. 4.1 Signal path through an optical data Link

The function of optical transmitter is to convert the electric signal to an optical signal. One way of doing this is by directly modulating the light source drive current with the information stream to produce a varying optical output power p(t). The optical signal that is coupled from the light source to the fiber becomes attenuated and distorted as it propagates along the fiber waveguide. Upon arriving at the end of the fiber, a receiver converts the optical signal back to an electrical format.

Figure 4.2 shows basic components of an optical receiver. The first element is either pin or an avalanche photodiode, which produces an electric current that is proportional to the received power level. Since this electric current is very weak, a front end amplifier boost it to a level that can be used by the following electronics. After the electric signal produced by the photodiode is amplified, it passes through a low pass filter to reduce the noise that is outside of the signal bandwidth.

This filter thus defines the receiver bandwidth. In addition, to minimize the effects of inter symbol interference (ISI) the filter can reshape the pulses that have become distort as they travelled through the fiber. This function is called equalization since it equalizes or cancels pulse-spreading effects. In the final optical receiver module shown in Fig. 4.2, a decision circuit samples the signal level at the midpoint of each time slot and compares it with the certain reference voltage known as the threshold level. If the received signal level is greater than the threshold level,1 is said to have been received. If the voltage is below the threshold level, 0 is assumed to have been received. To accomplish this bit interpretation the receiver must know where the bit boundaries are. This is done with the assistance of the periodic waveform called clock, which has a periodicity equal to the bit interval. Thus this function is called clock recovery or timing recovery.

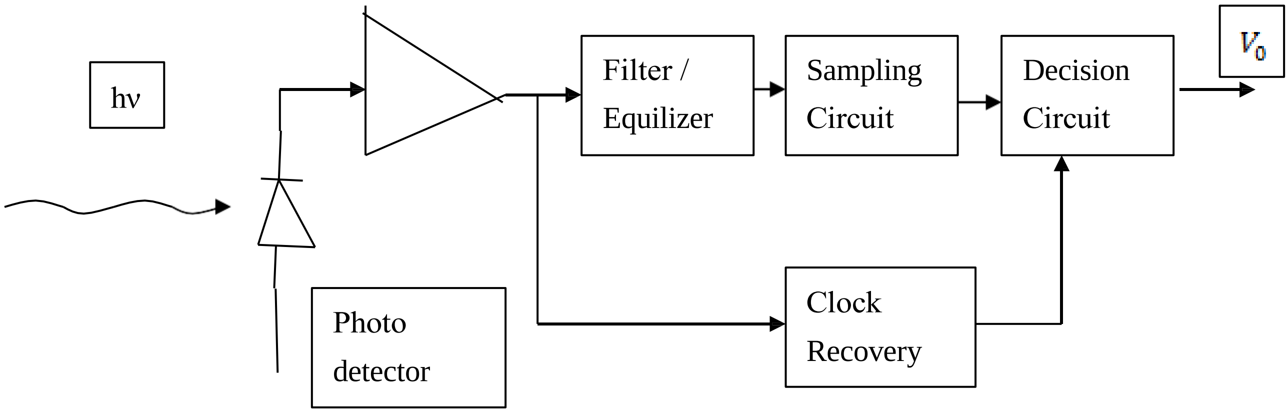

Fig. 4.2 The basic sections of an optical Receiver

There are many noises which affect the receiver operation such as shot noise arises from discrete nature of current flow in the device. Thermal noise arises from random motion of electrons in a conductor. Thermal noise arising from the detector load resistor and from amplifier electronics tend to dominate in application with low signal to noise ratio when pin photodiode is used.

4.2 Digital Receiver Performance Calculation

In digital receiver the amplified and filtered signal emerging from the equalizer is compared with a threshold level once per time slot to determine whether or not a pulse present at a photo detector in that time slot. In practice there are several standard ways of measuring the rate error occurrence in digital data stream. One common approach is to divide N_e of errors occurring over interval t by the number N_t of pulses (ones and zeros) transmitted during this interval. This is called either bit error rate Or the bit error rate, which is commonly abbreviated BER. Thus we have.

BER=$\frac{N_e}{N_t}$

To compute the bit error rate at the receiver, we have to know the probability distribution of the signal at the equalizer output.

p_1(v)=$\int_{-\infty}^{v} p\left(\frac{y}{1}\right) dy$

Which is the probability that equalizer output voltage is less than v when 1 pulse was sent, and

p_0(v)=$\int_{-\infty}^{v} p\left(\frac{y}{0}\right) dy$

Which is the probability that output voltage exceeds v when a 0 was transmitted. The functions $p\left(\frac{y}{1}\right)$ and $p\left(\frac{y}{0}\right)$.

Are the conditional probability distribution functions that is $p\left(\frac{y}{x}\right)$ is the probability that the output voltage is y, given then an x was transmitted. If the threshold voltage is v_{th} then the error probability P_e is defined as

$P_e = aP_1(v_{th}) + aP_0(v_{th})$

The weighting factors a and b determined by the a priori distribution of the data. That is a and b are probabilities that are either a 1 or 0occurs, respectively.

4.3 Eye Diagrams

The eye diagram is powerful measurement tool for assessing the data handling ability of a digital transmission system. The method has been used extensively for evaluating the performance of wire line systems and also applies to optical fiber data links.

Eye Pattern Features:

The eye patterns measurements are made in the time domain and allow the effects of waveform distortion to be shown immediately on the display screen of the standard BER test equipment. Figure 4.3 shows a typical display pattern, which is known as an eye pattern or an eye diagram. The basic upper and lower bounds are determined by logic one and zero levels shown by b_{on} and b_{off}, respectively.

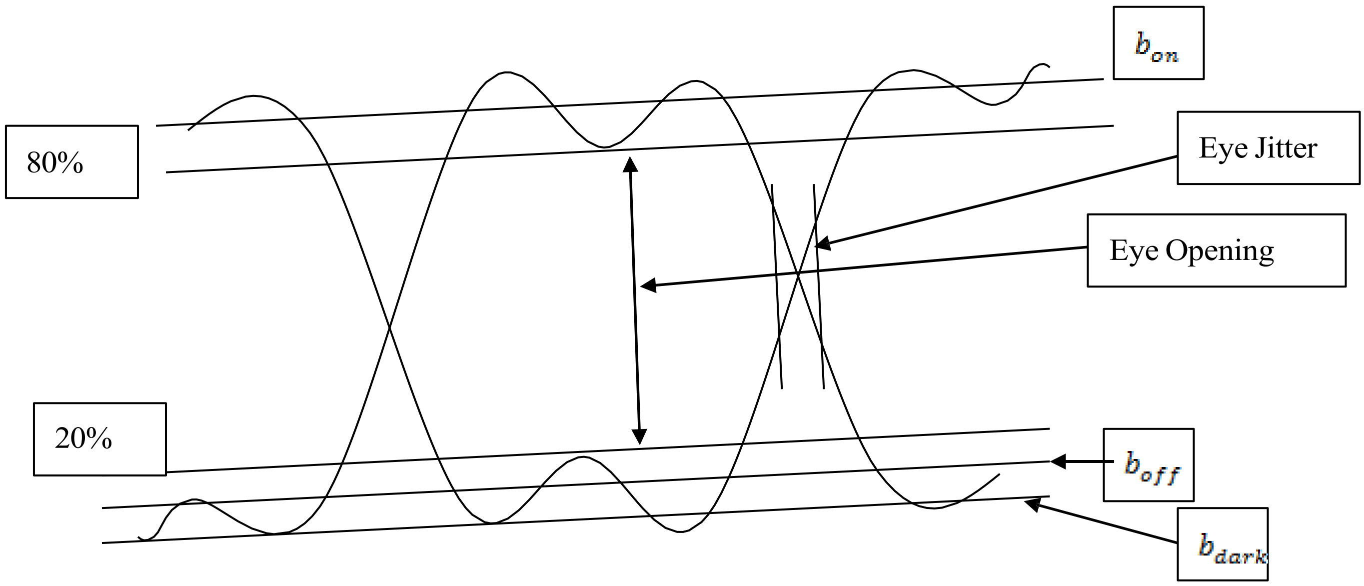

Fig.4.3 General Configuration of an eye diagram

The width of the eye opening defines the time interval over which the received signal can be sampled without error due to interference from adjacent pulses (Known as intersymbol interference).The best time to sample the received waveform is when the height of the eye opening is largest. This height is reduced as a result of amplitude distortion in the data signal. The vertical distance between top of the eye opening and the maximum signal level gives the degree of distortion .The more eye closes, the more difficult is to distinguish between ones and zeros in the digital signal.

The Timing jitter in an optical fiber system arises from noise in the receiver and pulse distortion in the optical fiber. Excessive jitter can result in bit errors, since jitter can produce uncertainties in clock timing. I f the signal sampled in the middle of time interval (i.e. midway between the times when signal crosses the threshold level) then amount of distortion ΔT at the threshold level indicates the amount of jitter.

Timing Jitter=$\frac{\Delta T}{T_b}$X100 percent.

4.4 Coherent Detection

Optical communication systems which use homodyne or heterodyne detection are called coherent optical systems since their implementation depends on phase coherence of the optical carrier. The key principle of the coherent detection technique is to provide gain to the incoming optical signal by coming or mixing it with locally generated continuous wave optical field. Let's us consider the electric field of the transmitted optical signal to be plane wave having the form

E_s=$A_s$cos[w_s t+Φ_s(t)]

Where $A_s$is the amplitude of the optical signal field, w_s is the optical signal carrier frequency and Φ_s(t) is the phase of optical signal. The mixing of information and local-oscillator signals is done on the surface of photodetector. If the local oscillator (LO) field has the form

E_{LO}=$A_s$cos[w_{LO} t+Φ_{LO}(t)]

Where A_{LO} is the amplitude of local oscillator field, w_{LO} is local oscillator frequency and Φ_s(t) is the phase of oscillator frequency.

Then the detected current is proportional to the square of the total electric field of the signal falling on the photodetector. That is intensity

I_{ch}(t)=$(E_{LO} + E_s)^2$

Optical power is proportional to the intensity, at the photodetector.

Homodyne Detection

When the signal carrier and local oscillator frequencies are equal that is, w_{IF}=0 ($w_{IF} = w_s - w_{LO}$), we have the special case of homodyne detection. Homodyne detection brings the signal directly to the baseband frequency, so that no further electrical demodulation required. Homodyne detection yields most sensitive coherent systems.

Heterodyne Detection

When the signal carrier and local oscillator frequencies are not equal that is, w_{IF} c 0 ($w_{IF} = w_s - w_{LO}$), and optical phase locked loop is not needed, we have the special case of heterodyne detection. Heterodyne receiver are much easier to implement.

4.5 Burst Mode Receivers

For passive optical Networks (PON) applications, at the central office of the operational characteristics of an optical receiver differ significantly from those used in conventional point to point links. This arises from the fact that amplitude and phase information packets received in successive time slots from differ ent network user locations can vary widely from packet to packet. Type of data pattern can be that there is no amplitude variation in the received logic ones, size of the packet may differ there amplitude is same. Or Signal amplitude can change from packet to packet depending on how far away each ONT is from central office. Fig. 4.4 shows received data pattern in conventional point to point links.

Since a conventional optical receiver is not capable of instantaneously handling rapidly changing differences in the signal amplitude and clock phase alignment, a specially designed Burst mode receiver is needed. These receivers can rapidly extract the decision threshold and determines the signal phase from a set of overhead bits placed at the beginning of each packet burst.

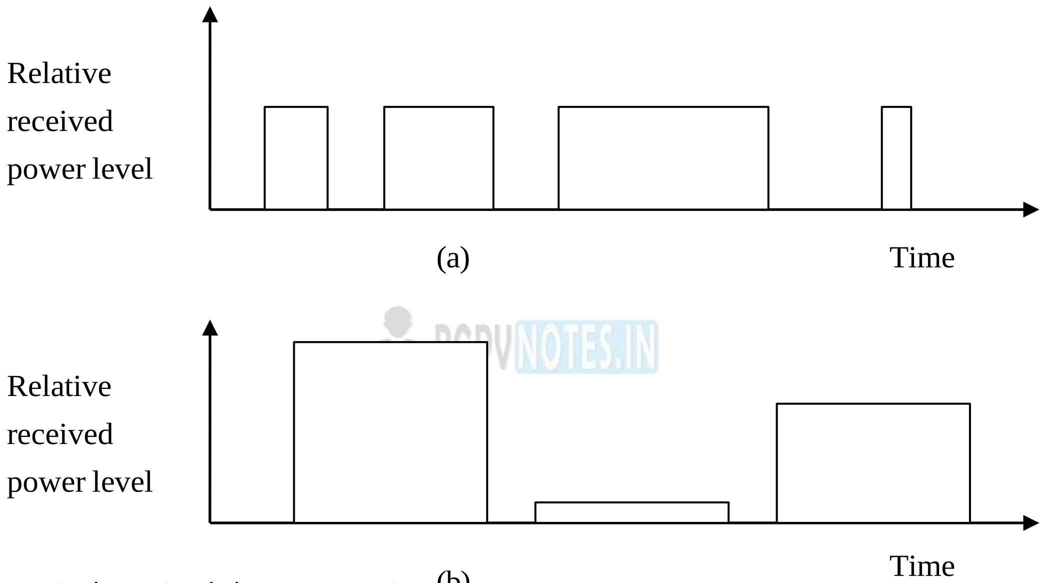

Fig.4.4 (a) Typical received data pattern in conventional point to point links; (b) Optical signal level variations in pulses that may arrive at OLT

4.6 Analog Receivers

In addition to wide usage of the fiber optics for transmission of digital signals, there are many potential applications for analog links. The simplest analog technique is to use amplitude modulation of the source. In this scheme, a time varying electrical signal s(t) is used to modulate an optical source directly about some bias point defined by bias current I_B. The transmitted optical power is thus of the form.

P(t)=P_t[1+ms(t)]. Where P_t is the average transmitted power, s(t)] is analog modulation signal and m is the modulation signal index defined by $m=\frac{\Delta I}{I_B}$. Here, ΔI is the variation in current about the bias point.

4.7 Point to point Links

The simplest transmission link is a point-point link that has transmitter on one end and a receiver on other end. The following key system requirements are needed in analyzing a link:

1) The desired or possible transmission distance
2) The data rate or channel bandwidth
3) The bit error rate(BER)

To fulfill these requirements designer has a choice of the following components and their associated characteristics:

1) Multimode or Single mode fibers
2) LED or LASER diode optical source
3) PIN or Avalanche photodiode

4.8 Link Power Budget

In the link power budget analysis one first determines the power margin between the optical Transmitter output and the minimum receiver sensitivity needed to establish a specified BER. This margin can then be allocated to connector. Splice and fiber losses, plus any additional margins required for the other components. If the choice of components did not allow the desired transmission distance to be achieved, the components might have to be changed or amplifiers might have to be incorporated in the link.

The link loss budget is derived from the sequential loss contributions of each element in the link. Each of these elements are is expressed in decibels(dB) as

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

Where aP_{in} and P_{out} are optical power entering and leaving the loss element.

4.9 Rise Time Budget

Rise time budget is done to ensure that the desired overall system performance has been met. A rise time budget analysis is a convenient method for determining the dispersion limitation of an optical fiber link. In this approach, the total rise time t_{sys} of the link is the root mean square of the rise times from each contributor or t_i to the pulse rise time degradation:

$t_{sys}=(\sum_{i=1}^{N} t_i^2)^{1/2}$

The four basic elements that may significantly limit system speed are transmitter rise time, the group velocity dispersion rise time, the modal dispersion rise time and receiver rise time.

4.10 Power Penalties

The reduction in SNR is known as power penalty for that effect which degrade the link performance and generally is expressed in decibels. Thus if SNR_{ideal} and SNR_{impair} are signal to noise ratios for ideal and impaired cases, respectively, then power penalty PP_x for impairment x is given by

PP_x=-10 log $\frac{SNR_{impair}}{SNR_{ideal}}$

4.11 Overview of Analog Links

Figure 4.4 shows basic elements of analog link Transmitter contains either an LED or an Laser diode optical

optical source. One must take into account the frequency dependence of the amplitude, phase and group delay in the fiber. Thus the should have the flat amplitude and group delay response within the pass band required to send the signal free of linear distortion.

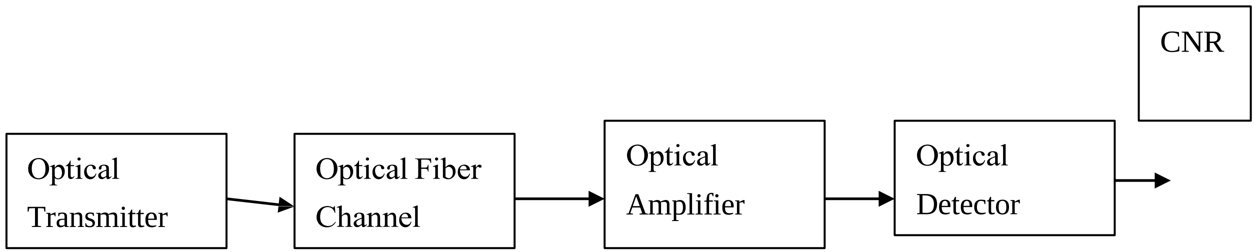

Fig. 4.4 Basic Elements of Analog Link

4.12 Carrier to Noise Ratio

In analyzing performance of analog systems, one usually calculates the ratio of rms carrier power to the rms noise power at the input of RF receiver following the photo detection process. This is known as carrier to noise ratio (CNR).

4.13 Multichannel Transmission Techniques

For sending multiple signal over the fiber one can employ multiplexing technique where a number of baseband signals are superimposed electronically on a set of N subcarriers that have different frequencies $f_1, f_2, f_3 \ldots f_n$. These modulated subcarriers are then combined electrically through frequency division multiplexing (FDM) to form composite signal that directly modulates a signal optical source

Unit: 05

Optical technologies: Wavelength division multiplexing (WDM) concepts: Operational principles of WDM, passive optical star coupler, isolators, circulators, and Active optical components: MEMS technology, variable optical attenuators, tunable optical filters, dynamic gain equalizers, polarization controller, and chromatic dispersion compensators. Optical amplifiers: Basic applications and types of optical amplifiers, Erbium Doped Fiber Amplifiers (EDFA): amplification mechanism, architecture, power conversion efficiency and gain. Amplifier noise, Optical SNR, System applications. Performance Measurement and monitoring: Measurement standards, basic test equipment, optical power measurements, optical fiber characterization, eye diagram tests, optical time-domain Reflectometer, optical performance monitoring.

5.1 Operational Principles of WDM

The technology of combining a number of independent information carrying wavelengths onto the same fiber is known as Wavelength Division Multiplexing or (WDM).A characteristic of WDM is that discrete wavelengths form an orthogonal set of carriers which can be separated, routed and switched without interfering with each other. This isolation between channels holds as long as the total optical power intensity is kept sufficiently low to prevent nonlinear effects such as stimulated brillouin scattering and four wave mixing processes from degrading the link performance.

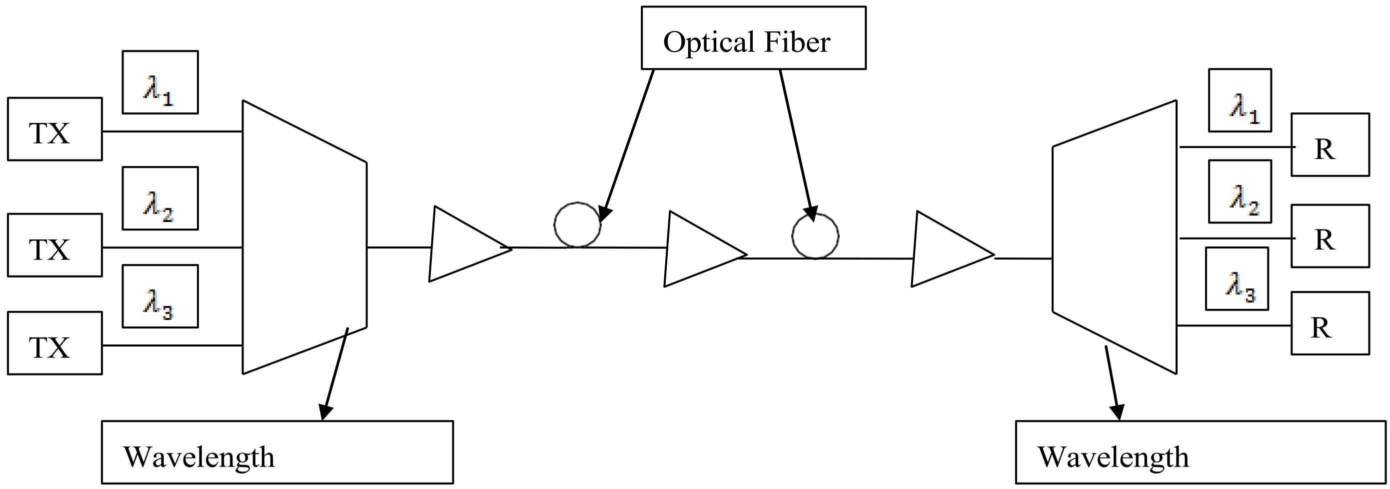

Fig.5.1 Implementation of a typical WDM Network containing various types of optical Amplifiers

Figure 5.1 shows the implementation of active and passive components in a typical WDM link containing various types of amplifiers. At the transmitting end there are several independently modulated light sources, each emitting signals at a unique wavelength. Here a multiplexer is needed to combine these optical outputs into a continuous spectrum of signals and couple them onto a single fiber. At the receiving end a demultiplexer is required to separate the optical signals into appropriate detection channels for signal processing.

5.2 Passive Optical Star Coupler

Star coupler combines the light streams from two or more input fibers and divide them among several output fibers. In general splitting is done uniformly for all wavelengths, so that each of each of N outputs receives 1/N of the power entering the device as shown in Figure 5.2.It is a device with two inputs and two outputs hence called 2X2 coupler. In general NXM coupler has N inputs and m outputs. The techniques for creating star couplers include fused fibers, gratings, micro-optic technologies, and intergrated optic schemes.

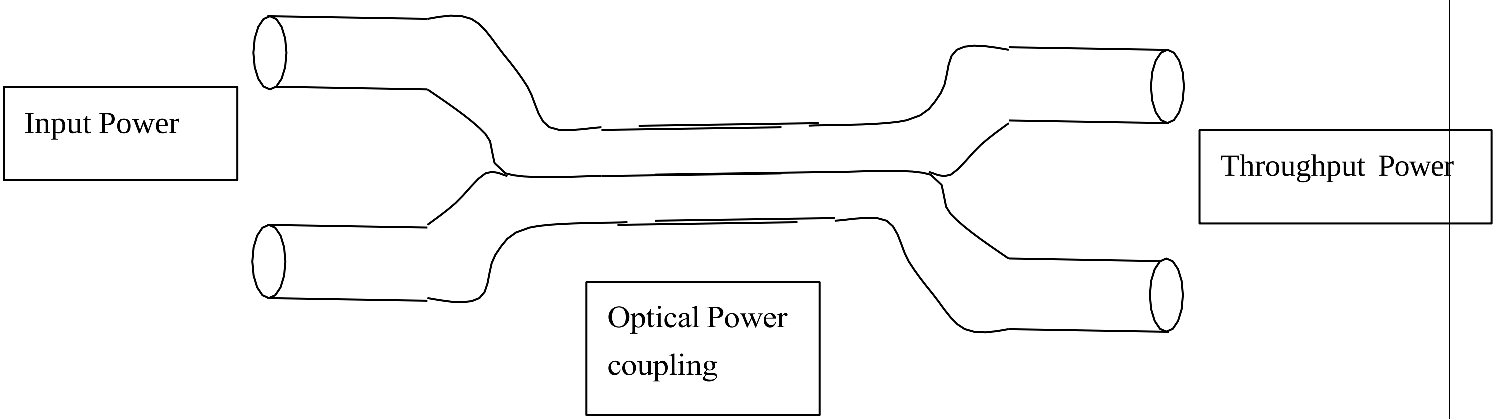

Fig 5.2 Cross-sectional view of fiber coupler

5.3 Isolators and Circulars

In number of applications it is desirable to have a passive optical device that is nonreciprocal, that is, it works differently when inputs and outputs are reversed. Two examples of such devices are isolators and circulators. Optical Isolator: Are devices that allow light to pass through them only in one direction as shown in Fig. 5.3. This is important in a number of instances to prevent scattered or reflected light from travelling in the reverse direction. Simple design configuration of isolator depends on the state of polarization of the input light. However, such a design results in 3dB loss when un polarized light is passed is passed through the device.

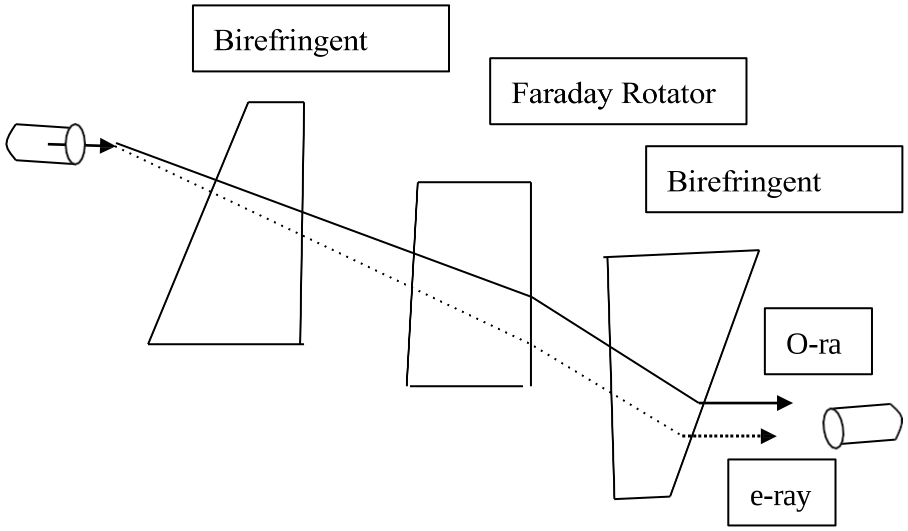

Fig. 5.3 Design of Polarization independent Isolator

Optical Circulator: An optical circulator is a non-reciprocal multiport passive device that directs light sequentially from port to port in only one direction. This device is used in optical amplifiers, add / drop multiplexes, and dispersion compensation modules. The operation of circulators is similar to that of an isolator except its construction is more complex. Typically it consist of number of walk-off polarizers, half wave plates and faraday rotator and has three or four ports. Here an input port 1 is sent out out on port2, an input port2 is sent out on port 3 and input port 3 is sent out on port 1.

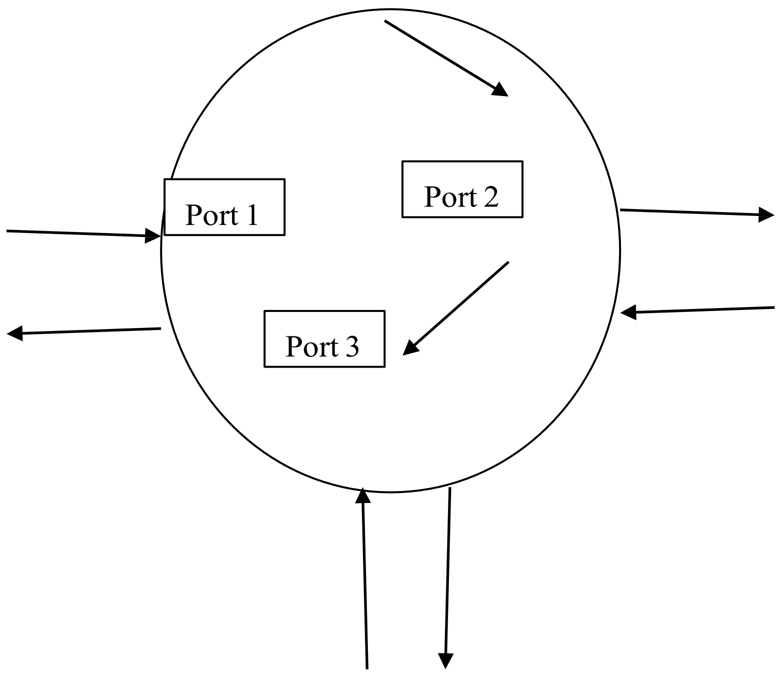

Fig. 5.4 Operational Concept of three port circulator

5.4 MEMS Technology

MEMS is the acronym for micro electro-mechanical systems. These are miniature devices that can combine mechanical, electrical and optical components to provide sensation and actuation functions. MEMS devices are fabricated using integrated circuit compatible batch-processing techniques and range in size from micrometers to millimetres. To control the actuation of a MEMS device is done through electrical, thermal or magnetic means such as micro gears or movable levers, shutters or mirrors. The devices are used widely in automobile air-bag deployment systems, in ink-jet printer heads, for monitoring mechanical shock and vibration during transportation of sensitive goods, for monitoring the condition of moving machinery for preventative maintenance. And in biomedical applications for patient activity monitoring and pacemakers. MEMS technology are also finding applications in light wave systems for variable optical attenuators, tunable optical filters, tunable lasers, optical add-drop multiplexers etc.

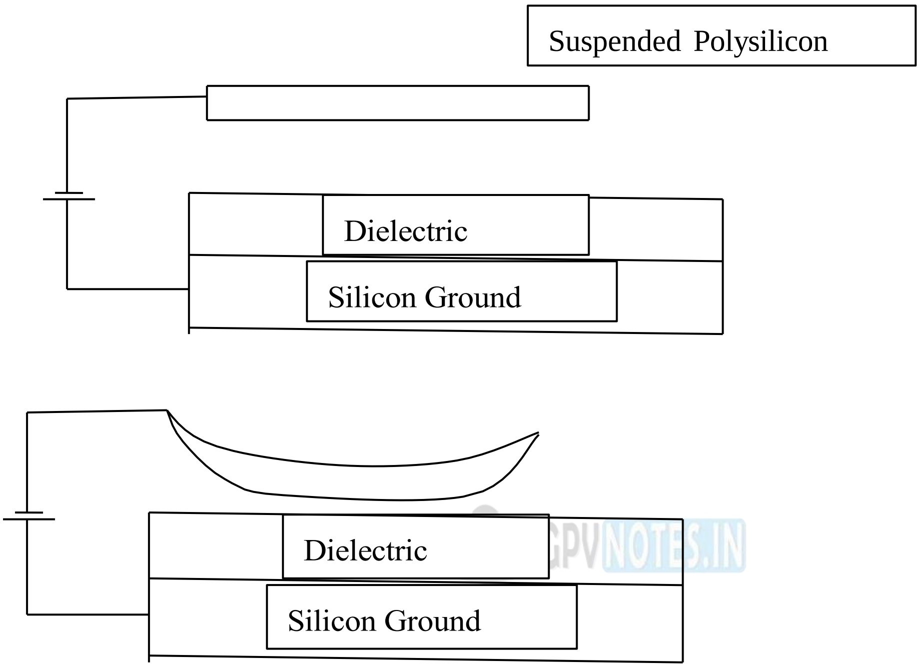

Fig.5.5 MEMS actuation method. The top shows an “off “position and bottom shows an “on” position

Figure 5.5 shows a simple example of a MEMS actuation method. At the top of the device there is thin suspended polysilicon beam that has typical length of 80μm, 10μm and 0.5μm respectively. At the bottom there is silicon ground plane which is covered by an insulator material. There is a gap of nominally 0.6μm between the beam and the insulator. When a voltage is applied between the silicon ground plane and polysilicon beam, electric force pulls the beam down so that it makes contact with lower structure. Current MEMS devices are made with highly compliant polymeric materials that are as much as six orders of magnitude less stiff than silicon.

5.5 Variable Optical Attenuators

A Variable optical attenuator (VOA) offers dynamic signal level control. This device attenuates optical power by various means to control signal levels precisely without disturbing the properties of a light signal. That means they should be polarization independent, attenuate light independent of wavelength, and have low insertion loss. The control methods include mechanical, thermo-optic, MEMS, or electro-optic techniques. The mechanical methods are reliable but have a low dynamic range.

5.6 Tunable Optical Filters

The key technologies to make a tunable filter are MEMS- based and bragg –grating based devices. MEMS actuated filters have the advantageous characteristics of a wide tunning range and design flexibility. The MEMS based devices consists of two sets of epitaxially grown semiconductor layers that form a single fabry perot cavity. The device operation is based on allowing one of the two mirrors to be moved precisely by an actuator. This enables the change in the distance between the two cavity mirrors, there by resulting in the selection of different wavelengths to be filtered.

5.7 Dynamic Gain Equalizers

A dynamic gain equalizer (DGE) is used to reduce the attenuation of the individual wavelengths within a spectral band. These devices are also called dynamic channel equalizers (DCE) or dynamic spectral equalizers. The function of DGE is equivalent to filtering out individual wavelengths and equalizing them on a channel by channel bases. Their applications include flattening the non linear gain profile of an optical amplifier (such as EDFA or raman amplfier), compensation for variation in transmission losses on individual channels across the given spectral band within a link, and attenuating , adding or dropping selective wavelengths.

5.8 Polarization Controllers

Polarization controllers offers high speed real time polarization control in a closed loop system that includes a polarization sensor and control logic. These devices dynamically adjust any incoming state of polarization to an arbitrary output state of polarization. For example, the output could be a fixed, linearly polarized state. Normally, this is done through electronic control voltages and are applied independently to adjustable polarization-retardation plates. Application of polarization controllers include polarization mode dispersion (PMD) compensation, polarization scrambling, and polarization multiplexing.

5.8 Chromatic Dispersion Compensators

A critical factor in optical links operating above2.5Gb/s is compensating for chromatic dispersion effects. This phenomenon causes pulse broadening which leads to increased bit error rates. The device for compensating is referred to as Dispersion compensating Module (DCM).This module can be tuned manually, remotely, or dynamically, Manual tuning is done by a network technician prior to or after installation of module in telecommunications racks. Dynamic tuning is done by the module itself without any human intervention.

One method of achieving dynamic chromatic dispersion is through the use of chirped fiber bragg grating (FBG). Here the grating spacing varies linearly over the length of the grating, which creates what is known as chirped grating. The relative delays induced by the grating on different frequency components of the pulse are the opposite of the delays caused by the fiber. This results in dispersion compensation, since it compresses the pulse.

5.9 Basic applications and types of amplifiers

To amplify an optical signal with conventional repeater, one performs photon-to-electron conversion, electrical amplification, retiming , pulse shaping and then electron to photon conversion. Three fundamental amplifier types Are semiconductor optical amplifiers (SOAs), Doped fiber amplifiers (DFAs), and Raman amplifiers. All optical amplifiers increase the power level of incident light through a stimulated emission or an optical power transfer process. SOAs and DFAs does not have optical feedback mechanism.

An in-line optical amplifier can be used to compensate for transmission loss and increase the distance between regenerative repeaters.

Preamplifier is used as front end amplifier for an optical receiver. There by, a weak optical signal is amplified before photodetection so that signal to noise ratio degradation caused by thermal noise in the receiver electronics can be suppressed.

Power amplifier of booster amplifier applications include placing the device immediately after an optical transmitter to boost the transmitted power.

5.10 Erbium Doped Fiber Amplifiers

The active medium in an optical fiber amplifier consists of a nominally 10 t0 30 m length of optical fiber that has been lightly doped with a rare earth element, such as erbium (Er), ytterbium (Yb), thulium (Tm), praseodymium (Pr), the most fiber material can be standard silica, a fluoride- based glass, or tellurite glass. The operating regions of these devices depend on the host material and doping elements. A popular material for long haul telecommunication applications is silica fiber doped with erbium, which is known as erbium-doped fiber amplifier or EDFA. In some cases Yb is added to increase the pumping efficiency and amplifier gain. The operation of standard EDFA normally is limited to 1530 to 1560nm region. Actually the EDFA operated in this region of the C-band

5.11 Amplification Mechanism of EDFA

Whereas semiconductor optical amplifiers use external current injection to excite electrons to excite electrons to higher energy levels, optical amplifiers use optical pumping. In this process, one uses photons to directly raise electrons into excited states. The optical pumping process requires three or more energy levels. The top energy level to which electron is elevated initially must quickly lie energetically above the desired final emission level. After reaching initial excited state, the electron must release some of its energy and drop to a slightly lower energy level. A signal photon can then trigger the excited electron sitting in this new lower level into stimulated emission, whereby the electron releases its remaining energy in the form of a new photon with wavelength identical to that of signal photon. Since pumping photon must have a higher energy than signal photon, the pump wavelength is shorter than signal wavelength.

To get understanding how an EDFA works, we need to look at the energy level structure of erbium as shown in figure 5.6 . The erbium atoms in silica are Er^{3+} ions, which are erbium atoms that have lost three of their outer electrons. The two principal levels for telecommunication applications are metastable level and pump level. The term metastable means that the life times for transitions from this state to the ground state are very long compared with the life times of the states that led to this level. In normal operation a pump laser emitting 980nm photons is used to excite ions from the ground sate to the pump level. These excited ions decay very quickly from pump band to metastable band . Within the metastable band, the electrons of the excited ions tend to populate the lower end of the band. Some of the ions sitting at the metastable level can decay back to the ground state in the absence of an externally stimulating photon flux as shown in transition process 5. This decay phenomenon is known as spontaneous emission and adds to the amplifier noise. Two more types of transitions occur when a flux of signal photons that have energies corresponding to the band gap energy between ground state and metastable level passes through the device. First, a small portion of external photons will be absorbed by the ions in the ground state, which raises these ions to metastable level as shown by transition process 6. Second, in the stimulated emission process (transition process 7) a signal photons triggers an excited ion to drop to the ground state, thereby emitting a new photon of same energy, wavevector, and polarization as incoming signal photon.

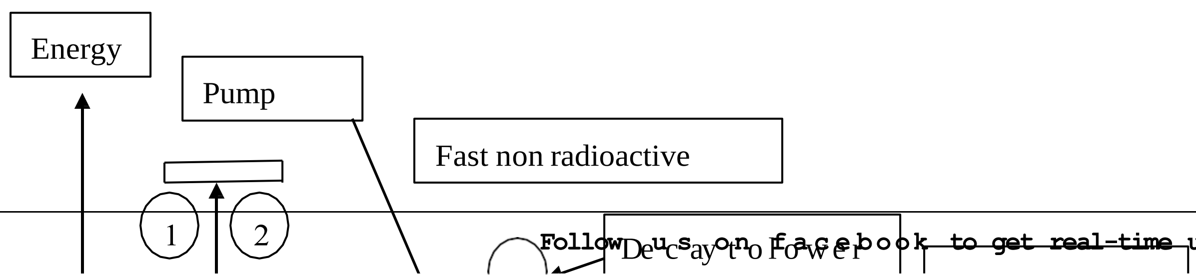

Fig. 5.6 Energy level Diagrams and various transition process of Er^{3+} ions

5.12 EDFA Architecture

An optical amplifier consist of a doped fiber, one or more pumped lasers, a passive wavelength coupler, optical isolators and tap couplers. The diachronic (two-wavelength) coupler handles either 980/1550nm or 1480/1550nm wavelength combinations to couple both pump and signal optical powers efficiently into the fiber amplifier. The pump light is usually injected from the same direction as the signal flow. This is known as co directional pumping. It is also possible to inject the pump power in the opposite direction to the signal flow, which is known as counter directional pumping.

5.12 EDFA Power Conversion efficiency and Gain

As is the case with any amplifier, as the magnitude of any output signal from an EDFA increase, the amplifier gain eventually starts to saturate. The reduction in gain in an EDFA occurs when the population inversion is reduced significantly by large signal thereby yielding the typical gain-versus power performance curve. The input and output powers of an EDFA can be expressed in terms of principle of energy conservation.

$$P_{s,out} \leq P_{s,in} + \frac{\lambda_p}{\lambda_s} P_{p,in}$$

Where $P_{p,in}$ is the input power and λ_p and λ_s are the pump and signal wavelengths, respectively. The power conversion efficiency is defined as

PCE= $\frac{P_{s,out} - P_{s,in}}{P_{p,in}}$ is less than unity. The maximum theoretical value of PCE is $\frac{\lambda_p}{\lambda_s}$. For absolute reference purposes, it is useful to use the quantum conversion efficiency (QCE), which is wavelength independent and is defined by.

QCE=$\frac{\lambda_p}{\lambda_s} PCE$

5.13 Amplifier Noise

The dominant noise generated in an optical amplifier is called amplified spontaneous emission (ASE) noise. The origin of this noise is spontaneous recombination of electrons and holes in the amplifier medium.This recombination occurs over a wide range of electron-hole energy differences and thus give rise to broad spectral background of noise photons that get amplified along with the optical signal as they travel through the EDFA.

5.14 Optical SNR

When analyzing a transmission link that has a series of optical amplifiers in it, an important point is that the light signal entering the optical receiver may contain a significant level of ASE noise that has been added to the cascade of optical amplifiers. In this case one has to evaluate the optical signal to noise Ratio (OSNR). This parameter is defined as the ratio of EDFA optical signal ouput power P_{out} to the unpolarized ASE optical noise power P_{ASE} In decibel OSNR is

OSNR (dB)=10 log$\frac{P_{out}}{P_{ASE}}$

In practice OSNR can be measured with an Optical spectrum analyzer (OSA).

5.15 System Applications

For Power amplifiers, the input power is high, since the device immediately follows an optical transmitter. High pump powers are required for this application. In-Line Amplifiers are used for long distance transmission, they are needed to periodically restore the power level after it has decreased due to attenuation in the fiber.

5.16 Measurement Standards

Three basic classes of standards exist for fiber optics are primary, component testing and system standards. Primary standards referred to measuring and characterizing fundamental physical parameters such as attenuation, bandwidth, mode- field diameter for single mode fibers and optical power. In united states the main group involved in primary standards is the national Institute of Standards and technology (NIST). Other national organizations include the National Physical laboratory (NPL) in united kingdom and PHysikalisch-Technische Bundesanstalt (PTB) in germany.

Several International organizations are involved in formulating component and system testing standards. The measure organizations that deal with measurement methods for links and networks are the Institute of Electricals and Electronics engineers (IEEE) and the telecommunication union (ITU-T). Component testing standards define relevant test for fiber optic component performance, and they establish equipment-calibration procedure. A key organization for component testing is the Telecommunication industry association (TIA) in association with electronic Industries Alliance (EIA).

System standards refers to measurement methods for links and networks. The major organizations involved here are American National Standards Institute (ANSI), IEEE and ITU-T.

5.17 Basic Test Equipment

As optical signals pass through the various parts of an optical link, they need to be measured and characterized in terms of the three fundamental areas of optical power, polarization and spectral content. The basic instruments for carrying out such measurements on optical fiber components and systems include optical power meters, attenuators, tunable laser sources, spectrum analyzers and optical time domain reflectometers.

5.18 optical power Measurements

Optical power measures rate at photons arrive at a detector. Thus it is measure of energy transfer per unit time. Since the rate of energy transfer varies with time, the optical power is function of time , It is measured in watts or joules per second (J/s). radiance (or brightness) is measure, in watts, of how much optical power radiates into a solid angle per unit solid angle per unit emitting surface. The two standard classes of power measurements are 1) peak power is a maximum power level in a pulse. 2)Average power is a measure of power level averaged over relatively long time period compared to the duration of individual pulse. Optical power meters are used for power measurement, they measure power in terms of dBm (where 0dBm=1mW).

5.19 optical Fiber Characterization

Various types of equipment for factory use have been developed to characterize the physical and performance parameters of these fibers. These parameters include mode field diameter, attenuation, cut-off wavelength, refractive index profile, effective area, geometric properties of core and cladding diameters. Two basic measurement methods used by this specialized equipment are the refracted near field techniques which determines refractive index profile and transmitted near field techniques which measures mode field diameters. Mode field diameter is important since it describes the radial optical field distribution across the fiber core. Detailed information of MFD enables one to calculate characteristics such as source to fiber coupling efficiency, splice and joint losses, micro bending loss and dispersion.

5.20 optical Time- Domain Reflectometer

An Optical time reflectometer is a versatile portable instrument that is used widely to evaluate the characteristics of an installed optical fiber link. In addition to identifying and locating faults or anomalies within a link, this instrument measures parameters such as attenuation, length, optical connector and splice losses and light reflectance. OTDR operates by periodically launching narrow laser pulses into one end of a fiber under test by using either a directional coupler or a circulator. The properties of optical fiber link then are determined by analyzing the amplitude and temporal characteristics of the waveform of the reflected and back scattered light. A typical OTDR consist of a light source and receiver, data acquisition and processing modules, an information storage unit for retaining data either in the internal memory or in an external disk , and a display. Figure 5.7 shows principle of an OTDR using an optical circulator. The backscattered waveform has four distinct features:

1) A large initial pulse resulting from Fresnel reflection at the input end of the fiber.
2) A long decaying tail resulting from Rayleigh scattering in the reverse direction as input pulse travels along the fiber.
3) Abrupt shift in the curve caused by optical loss at joints or connectors in the fiber line.
4) Positive spikes arising from Fresnel reflection at far end of the fiber, at fiber joints and at fiber imperfections

Fresnel reflection occurs when light enters in a medium having a different index of refraction. For a glass- air interface, when light of power P_o is incident perpendicular to the interface, the reflected power is P_{ref} is

$$P_{ref} = P_o \left(\frac{n_{fiber} - n_{air}}{n_{fiber} + n_{air}}\right)^2$$

Where n_{fiber} and $n_{n_{air}}$ are the refractive indices of core and air, respectively. Two important performance parameters of an OTDR are dynamic range and measurement range. Dynamic range is defined as the difference between the initial back scatter level at the front connector and the noise level peak at the far end of the fiber. It is expressed in decibels of one way fiber loss. Dynamic range provides information on the maximum fiber loss that can be measured and denotes the time required to measure a given fiber loss. Measurement range deals with how far away an OTDR can identify events in the link, such as splice points, connection points, or fiber breaks. The maximum range R_{max} depends on the fiber attenuation α and the pulse width, that is on the dynamic range D_{OTDR}.

$$R_{max} = \frac{D_{OTDR}}{\alpha}$$

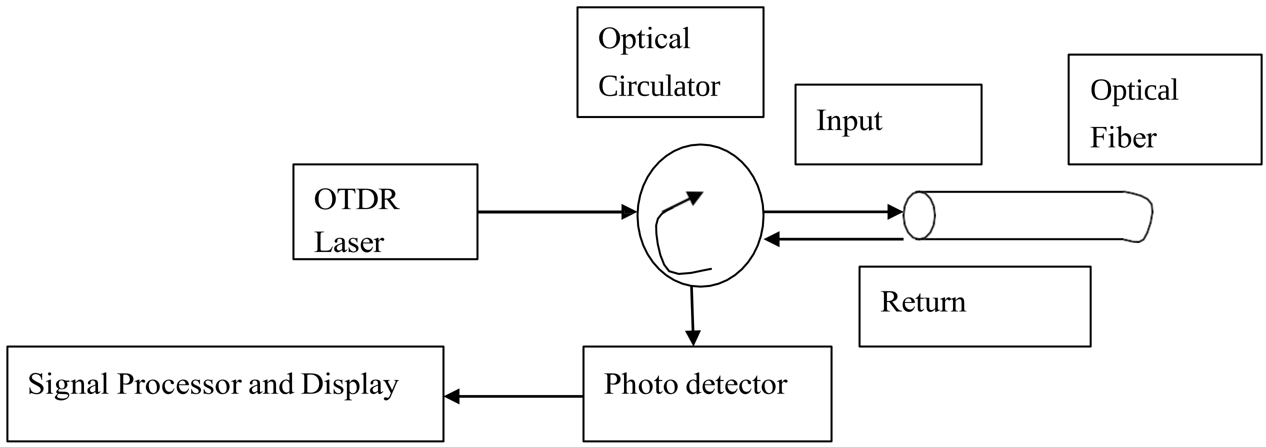

Fig.5.7 Operational principle of OTDR using optical Circulators

5.21 optical Performance Monitoring

To offer services with an extremely high degree of reliability, operators need to have a means to monitor the health and status of all parts of their network continuously. Basically network health is assessed by means of a continuous in-line-BER measurement. In addition another standard network management function is fault monitoring, which checks to see where and why a network failure has occurred or is about to take place. The network management console is a specialized workstation that serves as the interface for the human network manager. Management software modules, called agents, residing in a microprocessor within the elements continuously gather and compile information on the status and performance of managed devices. The agent stores this information in a management information base(MIB), and then provide data to the management entities within a network management system (NMS) that resides in the management workstation. The information transfer from the MIB to the MNS is done by a network management protocol such as the widely used simple network management protocol (SNMP).When agent notices problems in the element they are monitoring (for example link or component faults, wavelength drifts, reduction in the optical power levels, or excessive bit error rates), they send alerts to the management entities. Upon receiving an alert, management entities can initiate one or more action such as operator notification, event logging, system shutdown, or automatic attempts at fault isolation or repair.