14EI704

Hall Ticket Number:

IV/IV B.Tech (Regular / Supplementary) DEGREE EXAMINATION

Jan/Feb , 2021 — **Electronics & Instrumentation Engineering**

Seventh Semester — **Optoelectronics &Laser Instrumentation**

Time: Three Hours — **Maximum :** 60 Marks

Answer ALL Questions from PART-A. (1X12 = 12 Marks)
*Answer **ANY FOUR** questions from PART-B.* (4X12=48 Marks)

Part - A

1 Answer all questions (1X12=12 Marks)

a) What is meant by critical angle?
b) Distinguish between meridional rays and skew-rays?
c) What is the significance of dispersion in optical fibers?
d) What is meant by population inversion?
e) A low power He-Ne laser with optical output ~5mW, operates under a DC voltage source ~2500V and I = 10mA. Estimate the overall power efficiency of the laser.
f) Define mode locking of lasers?
g) List any two bio-medical applications of Lasers?
h) Define internal quantum efficiency of LED?.
i) What is meant by phase modulated fiber optic sensors?
j) What are the desirable characteristics of optical sources?
k) What is the necessity of modulators in optical fibers?.
l) List the applications of polarization maintaining fibers?

Part - B

2 a) Classify basic attenuation mechanisms in an optical fiber? Discuss any two of them in detail. 8M
b) A graded index fiber with a parabolic refractive index profile core has a refractive index at the core axis of 1.5 & a relative index difference of 1%. Estimate the maximum possible core diameter which allows single mode operation at a wavelength of 1.3μm. 4M

3 a) What is dispersion in an optical fiber? How does it affect the communication link? Compare single mode and multi mode fibers in this regard in detail. 8M
b) A 15km optical fiber link uses fiber with a loss of 1.5dB/km. The fiber is jointed every km with connectors which give an attenuation of 0.8dB each. Evaluate the minimum mean optical power which must be launched into the fiber in order to maintain a mean optical power level of 0.3μw at the detector. 4M

4 a) Distinguish between the spontaneous and stimulated emissions. Which one is necessary for laser action and why? 6M
b) Illustrate the principle and operation of laser doppler velocity meter. 6M

5 a) Define holography. Illustrate the holography recording and reconstruction processes. Also mention the applications of holography 8M
b) Outline various industrial applications of lasers? 4M

6 a) With a neat diagram explain the principle and operation of fiber optic sensor used for liquid level measurement 6M
b) Illustrate the operation of Mach-Zehnder interferometric fiber optic sensor used for strain and force measurements 6M

P.T.O.

7	a)	Outline the operation of surface emitter LED and edge emitter LED with neat diagrams	8M
	b)	Explain optical displacement sensor with neat diagram?	4M
8	a)	Compare themerits and demerits of p-i-n and reach through avalanche photo diodes.	6M
	b)	Explain in detail about semiconductor photo diodes without internal gain?	6M
9	a)	Illustrate the operation of Acoustic and magneto optic modulators with neat diagrams	8M
	b)	Discuss about constructional features of various types of polarization maintaining fibers	4M

Optoelectronics &Laser Instrumentation
(14EI704)

Jan/Feb , 2021
Seventh Semester

Scheme

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Scheme
Part-A

1.(a) What is meant by critical angle?

Ans: The angle of incidence beyond which rays of light passing through a denser medium to the surface of a less dense medium are no longer refracted but totally reflected.

.(b) Distinguish between meridional rays and skew-rays?

Ans: A **meridional ray** is a **ray** that passes through the axis of an optical fibre! A **skew ray** is a **ray** that travels in a non planar zig zag path and never crosses the axis of an optical fibre! ... A **meridional ray** is a **ray** that passes through the axis of an optical fiber.

.(c) What is the significance of dispersion in optical fibers?

Ans: In case of travelling long distances, slight differences in speed accumulate. As a result, bit errors will occur. Like attenuation, **dispersion** shortens the distance that signal travels inside **optic fibers**. Unlike attenuation, **dispersion** does not weaken the signal, but it blurs the signal.

.(d) What is meant by population inversion?

Ans: In case of travelling long distances, slight differences in speed accumulate. As a result, bit errors will occur. Like attenuation, **dispersion** shortens the distance that signal travels inside **optic fibers**. Unlike attenuation, **dispersion** does not weaken the signal, but it blurs the signal.

.(e) A low power He-Ne laser with optical output ~5mW, operates under a DC voltage source ~2500V and I = 10mA. Estimate the overall power efficiency of the laser.

$$efficiency = \frac{Output light Power}{Input Electrical Power} = \frac{5X10^{-3}W}{(2500V)(10mA)} = 2x10^{-4}$$

$$\%efficiency = 0.02\%$$

.(f) Define mode locking of lasers?

Ans: **Mode-locking** is a technique in optics by which a **laser** can be made to produce pulses of light of extremely short duration, on the order of picoseconds (10^{-12} s) or femtoseconds (10^{-15} s). A **laser** operated in this way is sometimes referred to as a femtosecond **laser**, for example in modern refractive surgery.

.(g) List any two bio-medical applications of Lasers?

Ans: **Lasers** have long been used in **medicine** for surgery, with **applications** ranging from cauterization of blood vessels to drilling holes through **the** heart. Now, though, **laser**-based diagnostic devices are also proliferating in areas such as **biomedical** imaging and basic **biological** research.

.(h) Define internal quantum efficiency of LED?

Ans: In general, the **internal quantum efficiency** of an **LED** can be on the order of 70%. However, since an **LED** is based on the spontaneous emission and the photon emission is isotropic, its external **efficiency** is usually less than 5%.

.(i) What is meant by phase modulated fiber optic sensors?

Ans: **Phase-modulated fiber optic sensors** typically involve the use of **optical** interferometers to measure the change in **phase** of a single light signal or, more often, the relative **phase** change between two light waves.

.(j) What are the desirable characteristics of optical sources?

Ans: It is desirable that optical sources:

Be compatible in size to low-loss optical fibers by having a small light-emitting area capable of launching light into fiber

Launch sufficient optical power into the optical fiber to overcome fiber attenuation and connection losses allowing for signal detection at the receiver

- Emit light at wavelengths that minimize optical fiber loss and dispersion.
- Optical sources should have a narrow spectral width to minimize dispersion
- Allow for direct modulation of optical output power

.(k) What is the necessity of modulators in optical fibers?.

Ans: Acousto-**optic modulators** are based on the acousto-**optic** effect. They are used for switching or continuously adjusting the amplitude of a laser beam, for shifting its **optical** frequency, or its spatial direction. Electro-**optic modulators** exploit the electro-**optic** effect in a Pockels cell.

.(l) List the applications of polarization maintaining fibers?

Polarization-maintaining optical **fibers** are used in special **applications**, such as in **fiber** optic sensing, interferometry and quantum key distribution. They are also commonly used in telecommunications for the connection between a source laser and a modulator, since the modulator requires **polarized** light as input.

Part-B

2.(a) Classify basic attenuation mechanisms in an optical fiber? Discuss any two of them in detail. **8M**

Ans:

Material absorption losses in silica glass fibers **4M**

Intrinsic absorption **4M**

A number of mechanisms are responsible for the signal attenuation within optical fibers. These mechanisms are influenced by the material composition, the preparation and purification technique, and the waveguide structure. They may be categorized within several major areas which include material absorption, material scattering (linear and nonlinear scattering), curve and microbending losses, mode coupling radiation losses and losses due to leaky modes.

1.Material absorption losses in silica glass fibers

Material absorption is a loss mechanism related to the material composition and the fabrication process for the fiber, which results in the dissipation of some of the transmitted optical power as heat in the waveguide. The absorption of the light may be intrinsic (caused by the interaction with one or more of the major components of the glass) or extrinsic (caused by impurities within the glass).

2.Intrinsic absorption

An absolutely pure silicate glass has little intrinsic absorption due to its basic material structure in the near-infrared region. However, it does have two major intrinsic absorption mechanisms at optical wavelengths which leave a low intrinsic absorption window over the 0.8 to 1.7 μm wavelength range, as illustrated in Figure 3.1, which shows a possible optical attenuation against wavelength characteristic for absolutely pure glass.

It may be observed that there is a fundamental absorption edge, the peaks of which are centered in the ultraviolet wavelength region. This is due to the stimulation of electron transitions within the glass by higher energy excitations.

The tail of this peak may extend into the window region at the shorter wavelengths, as illustrated in Figure 3.1. Also in the infrared and far infrared, normally at wavelengths above 7 μm, fundamentals of absorption bands from the interaction of photons with molecular vibrations within the glass occur.

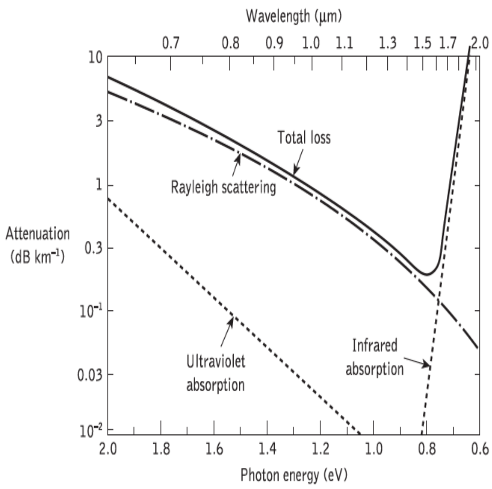


Figure 3.1 The attenuation spectra for the intrinsic loss mechanisms in pure GeO_2–SiO_2 glass [Ref. 5]

2.(b) **A graded index fiber with a parabolic refractive index profile core has a refractive index at the core axis of 1.5 & a relative index difference of 1%. Estimate the maximum possible core diameter which allows single mode operation at a wavelength of 1.3μm.** 4M

Ans:

$$a = \frac{v\lambda}{2\pi n_1 (2\Delta)^{\frac{1}{2}}}$$

$$= \frac{2.4 * 1.3 * 10^{-6}}{2\pi * (1.5)(2 * 0.01)^{\frac{1}{2}}} = 3.525 * 10^{-6} m$$

3.(a) **What is dispersion in an optical fiber? How does it affect the communication link? Compare single mode and multi mode fibers in this regard in detail.** 8M

Ans:

dispersion in an optical fiber 4M

Compare single mode and multi mode fibers 4M

Dispersion

Dispersion of the transmitted optical signal causes distortion for both digital and analog transmission along optical fibers. When considering the major implementation of optical fiber transmission which involves some form of digital modulation, then dispersion mechanisms within the fiber cause broadening of the transmitted light pulses as they travel along the channel. The phenomenon is illustrated in Figure 3.7, where it may be observed that each pulse broadens and overlaps with its neighbors, eventually becoming indistinguishable at the receiver input. The effect is known as intersymbol interference (ISI).

Thus an increasing number of errors may be encountered on the digital optical channel as the ISI becomes more pronounced. The error rate is also a function of the signal attenuation on the link and the subsequent signal-to-noise ratio (SNR) at the receiver. However, signal dispersion alone limits the maximum possible bandwidth attainable with a particular optical fiber to the point where individual symbols can no longer be distinguished. For no overlapping of light pulses down on an optical fiber link the digital bit rate B_T must be less than the reciprocal of the broadened (through dispersion) pulse duration (2τ).

$$B_T \leq \frac{1}{2\tau}$$

This assumes that the pulse broadening due to dispersion on the channel is τ which dictates the input pulse duration which is also τ. Hence Eq. (3.10) gives a conservative estimate of the maximum bit rate that may be obtained on an optical fiber link as 1/2τ. Another more accurate estimate of the maximum bit rate for an optical channel with dispersion may be obtained by considering the light pulses at the output to have a Gaussian shape with an rms width of σ. Unlike the relationship given in Eq. (3.10), this analysis allows for the existence of a certain amount of signal overlap on the channel, while avoiding any SNR penalty which occurs when ISI becomes pronounced. The maximum bit rate is given approximately by :

$$B_T(\text{max}) \simeq \frac{0.2}{\sigma} \text{ bit s}^{-1}$$

Where σ is STANDARD DEVIATION (or STANDARD ERROR,)

It must be noted that certain sources give the constant term in the numerator of Eq. (3.11) as 0.25. However, we take the slightly more conservative estimate given, following Olshansky and Gambling *et al. Equation (3.11) gives a* reasonably good approximation for other pulse shapes which may occur on the channel resulting from the various dispersive mechanisms within the fiber. Also, σ may be assumed to represent the rms impulse response for the channel. assumed to represent the rms impulse response for the channel. The conversion of bit rate to bandwidth in hertz depends on the digital coding format used. For metallic conductors when a nonreturn-to-zero code is employed, the binary 1 level is held for the whole bit period τ. In this case there are two bit periods in one wavelength (i.e. 2 bits per second per hertz), as illustrated in Figure 3.8(a). Hence the maximum bandwidth *B is one-half the maximum data rate or:*

$$B_T(\max) = 2B$$

However, when a return-to-zero code is considered, as shown in Figure 3.8(b), the binary 1 level is held for only part (usually half) of the bit period. For this signaling scheme the data rate is equal to the bandwidth in hertz (i.e. 1 bit per second per hertz) and thus $B_T = B$.

Figure 3.9 shows the three common optical fiber structures, namely multimode step index, multimode graded index and single-mode step index, while diagrammatically illustrating the respective pulse broadening associated with each fiber type. It may be observed that the multimode step index fiber exhibits the greatest dispersion of a transmitted light pulse and the multimode graded index fiber gives a considerably improved performance. Finally, the single-mode fiber gives the minimum pulse broadening and thus is capable of the greatest transmission bandwidths which are currently in the gigahertz range, whereas transmission via multimode step index fiber is usually limited to bandwidths of a few tens of megahertz. However, the amount of pulse broadening is dependent upon the distance the pulse travels within the fiber, and hence for a given optical fiber link the restriction on usable bandwidth is dictated by the distance between regenerative repeaters .

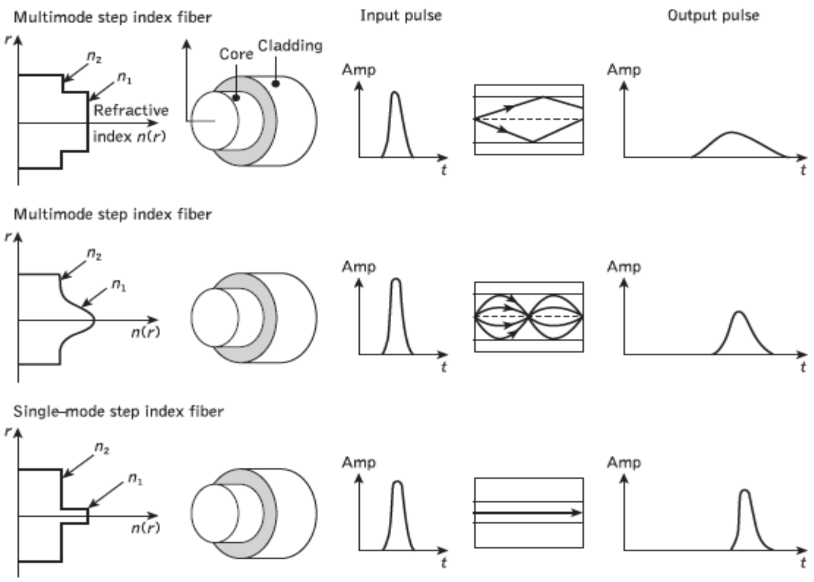


Figure 3.9 Schematic diagram showing a multimode step index fiber, multimode graded index fiber and single-mode step index fiber, and illustrating the pulse broadening due to intermodal dispersion in each fiber type

The distance the light pulse travels before it is reconstituted). Thus the measurement of the dispersive properties of a particular fiber is usually stated as the pulse broadening in time over a unit length of the fiber (i.e. ns km−1). Hence, the number of optical signal pulses which may be transmitted in a given period, and therefore the information-carrying capacity of the fiber, is restricted by the amount of pulse dispersion per unit length. In the absence of mode coupling or filtering, the pulse broadening increases linearly with fiber length and thus the bandwidth is inversely proportional to distance. This leads to the adoption of a more useful parameter for the information-carrying capacity of an optical fiber which is known as the bandwidth–length product (i.e. $B_{opt} \times L$).

$$\delta f_{D_o} = \left| \frac{2v}{\lambda} n \sin\frac{\theta}{2} \right|$$

3.(b) **A 15km optical fiber link uses fiber with a loss of 1.5dB/km. The fiber is jointed every km with connectors which give an attenuation of 0.8dB each. Evaluate the minimum mean optical power which must be launched into the fiber in order to maintain a mean optical power level of 0.3μw at the detector.** **4M**

Ans:

Solution: (*i*) Connector loss = 0.8 dB/km

∴ Connector loss for 15 km length = 0.8 × 15 = 12 dB.

(*ii*) Fibre loss = 1.5 dB/km

∴ Fibre loss for 15 km = 1.5 × 15 = 22.5 dB

Total loss = 12 dB + 22.5 dB = 34.5 dB

Optical power level at detector $P_2 = 0.3\ \mu W$

Optical power at launch position $= P_1$

Now we have the relation $\alpha = 10 \log \frac{P_1}{P_2}$

$$34.5 = 10 \log \frac{P_1}{0.3\mu W} \text{ or } \log \frac{P_1}{0.3\mu W} = 3.45$$

Taking antilogs on both sides

$$\frac{P_1}{0.3\mu W} = 2818.3$$

$$\therefore \quad P_1 = 8.455 \times 10^{-4} \text{ W}$$

$$= \mathbf{0.846\ mW.}$$

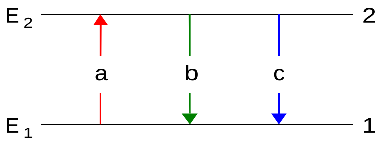
4.(a) **Distinguish between the spontaneous and stimulated emissions. Which one is necessary for laser action and why?** **6M**

Ans:

spontaneous emissions **3M**

stimulated emissions **3M**

Absorption and emission processes



a absorption

b spontaneous emission

c stimulated emission

Absorption

Molecule absorbs a quantum of radiation (a photon) and is excited from 1 to 2. $M + h\upsilon \rightarrow M^*$ (state 1) (state 2)

Spontaneous emission

M^* (in state 2) spontaneously emits a photon of radiation. $M^* \rightarrow M + h\upsilon$

Stimulated emission

A quantum of radiation is required to stimulate M^* to go from 2 to 1. $M^* + h\upsilon \rightarrow M + 2h\upsilon$

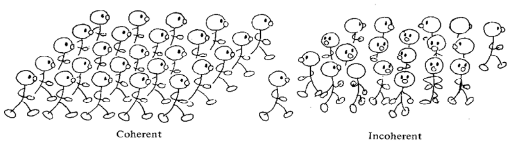
Stimulated and spontaneous emission

Spontaneous emission

- Photons emitted in all directions and on a random time scale.
- The emitted photons are INCOHERENT

Stimulated emission

- Emitted and stimulating photons have the same :
  - Frequency
  - Direction
  - Phase
- The emitted and incident photons are COHERENT



4.(b) **Illustrate the principle and operation of laser doppler velocity meter?.** **6M**

Ans:

laser doppler velocity meter **2M**

Operation **4M**

Excentrinsic single mode fiber sensors has been developed to provide noninvasive measurement for several physical measurands (e.g. velocity ,fluid surface velocity and vibration).In particular ,the all-fiber laser Doppler velocimetr (LDV) illustrated in figure 14.25 allows the measurement of velocity in gases and fluids as well as the velocity of objects , to be taken .

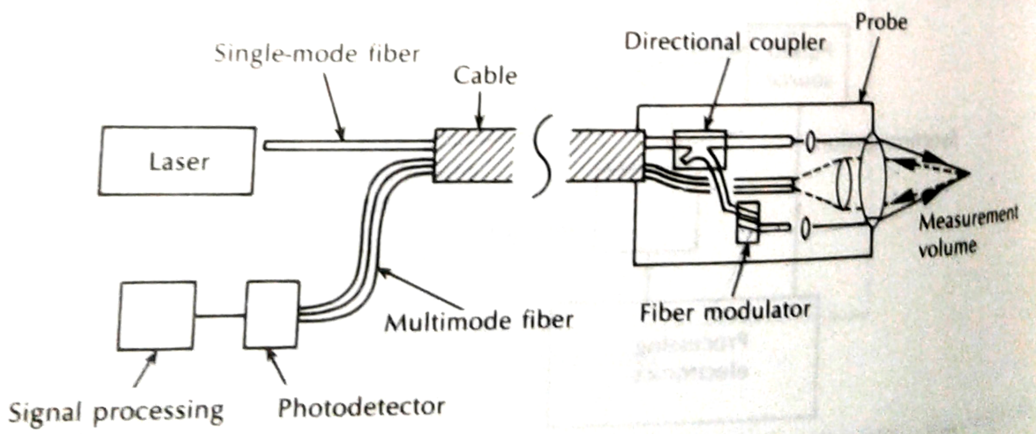


Figure 14.25 Optical fiber laser Doppler velocimeter.

Where is the wavelength of the laser source ,n is the refractive index of the measurement volume and is the angle of convergence between the two input beams. It may be noted that ,an ambiguity in the direction of the velocity which may introduce serous errors .

This problem can be resolved however ,through the introduction of a frequency shift Into one of the transmitted beams . Hence the fiber modulator shown in figure14.25 produces the required frequency shift .With such a fiber LDV system , velocity can be measured with high precision in a short period of time .

In addition ,arrangements based on the classical The arrangement shown in figure 14.25 employs two single mode fibers to guide the transmitted beams to and from the probe . A fiber directional coupler is used at the probe to obtain two beams from the single incoming beam . The measurement volume is formed by the region of intersection of these two coherent optical beams which are independently scattered and Doppler shifted , a Doppler difference technique is then employed because the frequency shift is different for each beam as they are travelling in different directions .The two frequency shifts beat together to produce a frequency which is proportional to the component of component of the scattering particle v particular to the mean direction of the incident beam and in their plane ,so that

$$\delta f_{D_o} = \left| \frac{2v}{\lambda} n \sin\frac{\theta}{2} \right|$$

5.(a) **Define holography. Illustrate the holography recording and reconstruction processes. Also mention the applications of holography ?** **8M**

Ans:

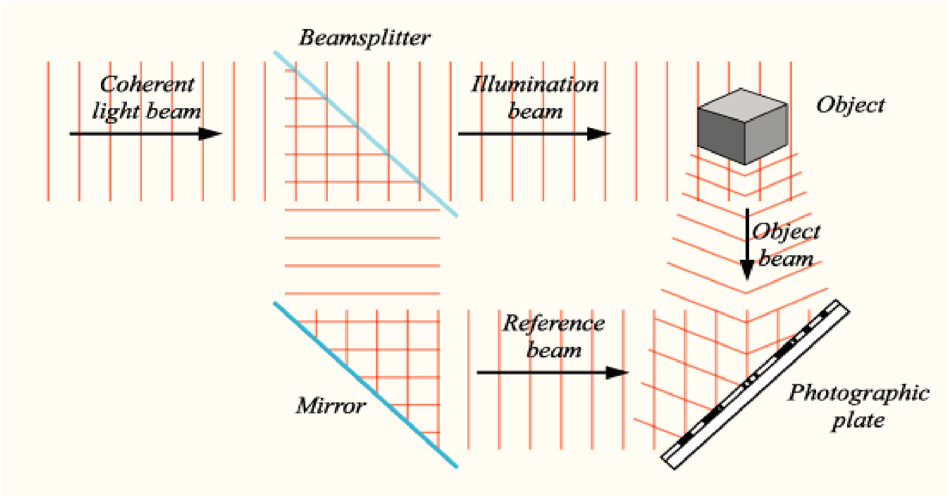
Holography construction **4M**

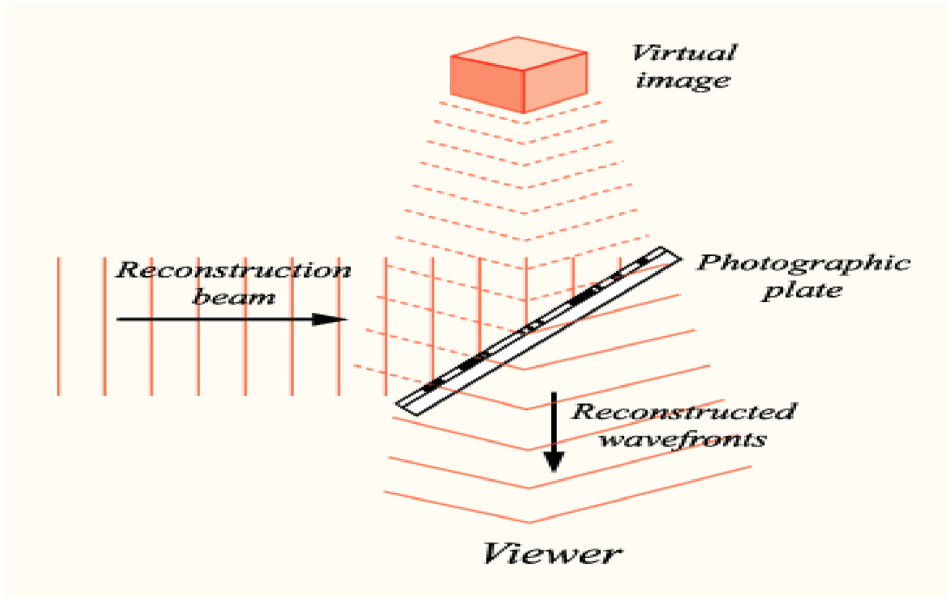
Explanation **4M**

Hologram construction

- Laser : Red lasers, usually helium-neon (HeNe) lasers, are common in holography .
- Beam splitter: This is a device that uses mirrors and prisms to split one beam of light into two beams.
- Mirrors: These direct the beams of light to the correct locations.

- Holographic film: Holographic film can record light at a very high resolution, which is necessary for creating a hologram. It's a layer of light-sensitive compounds on a transparent surface, like photographic film.





Holography is a technique that enables a light field, which is generally the product of a light source scattered off objects, to be recorded and later reconstructed when the original light field is no longer present, due to the absence of the original objects . Holography can be thought of as somewhat similar to sound recording, whereby a sound field created by vibrating matter like musical instruments or vocal cords, is encoded in such a way that it can be reproduced later, without the presence of the original vibrating matter.

Laser

Holograms are recorded using a flash of light that illuminates a scene and then imprints on a recording medium, much in the way a photograph is recorded. In addition, however, part of the light beam must be shone directly onto the recording medium - this second light beam is known as the reference beam. A hologram requires a laser as the sole light source. Lasers can be precisely controlled and have a fixed wavelength, unlike sunlight or light from conventional sources, which contain many different wavelengths. To prevent external light from interfering, holograms are usually taken in darkness, or in low level light of a different color from the laser light used in making the hologram. Holography requires a specific exposure time (just like photography), which can be controlled using a shutter, or by electronically timing the laser.

5.(b) Outline various industrial applications of lasers?

Ans:

Applications of holographic interferometry	
Field	Field
Aerospace	Defects in honeycomb plates Testing of construction materials, Testing of welding methods Inspection of rocket bodies Flow visualization in wind tunnels Vibration modes of turbine blades
Automobiles	Testing of oil pressure sections Testing of welding methods Research in construction of automobile bodies Construction of engines
Machine tools and precision instruments	Measurement of deformations of machine parts, jigs and tools Measurement inside cylinders Measurements of stiffness (heat, static or dynamic) Analysis of construction of instruments and tools
Electrical and electronic industries	Vibration modes of turbine blades, motors, transformers, loudspeakers Testing of welding and adhesion Testing of circuit parts Analysis of audio equipments Leak test of batteries
Civil Engineering	Analysis of constructions Design of pipes Research in concrete
Chemical industry	Measurement of mixed fluids. Tyre, rubber and NDT of tyres, plastics Testing of molded products Measurement of adhesion defects
Medicine	Measurement on living bodies Chest deformation due to inhalation Measurement on teeth and bones Testing materials for dental surgery Testing of urinary track Measurement on eyes, ears, etc.
Musical instruments	Measurement of vibration modes
Cultural articles and paintings	NDT and restoration.

6.(a) With a neat diagram explain the principle and operation of fiber optic sensor used for liquid level measurement? **6M**

Ans:

principle ,diagram of liquid level measurement **3M**
operation of fiber optic sensor used for liquid level measurement **3M**

Numerous extrinsic fiber sensor mechanisms have been proposed and investigated ,but to date relatively few practical commercial devices have emerged . A technique which have been realized as a commercial product is illustrated in figure14.21.

This shows the operation of a simple optical fluid level switch .When the fluid ,which has a refractive index grater than the glass forming the optical dipstick , reaches the chamfered end , total internal reflection ceases and the light is transmitted in to the fluid . Hence an indication of the fluid level is obtained at the optical detector . Although this system is somewhat crude and will not provide a continuous measurement of a fluid level ,it is simple and safe for use with flammable liquids

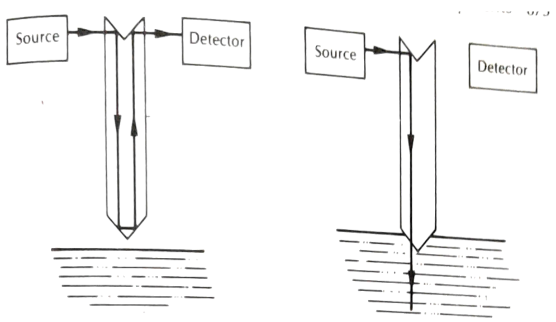


Figure 14.21 Optical fluid level detector.

..Intensity modulation of the transmitted light beam is utilized in the extrinsic refractive or fotonical optical sensor shown in figure 14.22(a) to give a measurement of displacement.Light reflected from the target is collected is collected by a return Fiber(s) and is a function of the distance between the fiber ends and the target .Hence the position or displacement of the target may be registered at the optical detector .

6.(b) **Illustrate the operation of Mach-Zehnder interferometric fiber optic sensor used for strain and force measurements?** **6M**

Ans:

Diagram of Mach-Zehnder interferometric fiber optic sensor **3M**
operation of Mach-Zehnder interferometric fiber **3M**

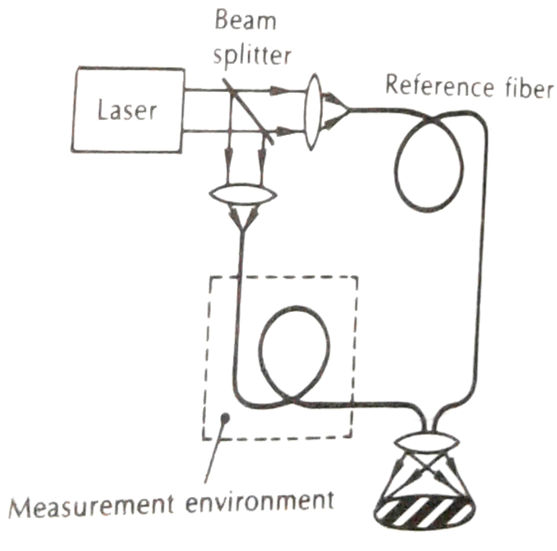
Phase and polarization fiber sensors

These devices cause interference of coherent monochromatic light propagating in a strained or temperature varying fiber with light either directly from the laser source (as shown in fig 14.17(a))or guided by a reference fiber isolated from external influence.

Figure 14.17.single-mode fiber interferometric sensors (a) a two arm interferometer (March-Zehnder);

The effects of strain ,pressure or temperature change give rise to differential optical paths by changing the fiber length , core diameter or refractive index with respect to reference fiber.

This provides a phase difference between the two fibers , the light emitted from two fibers giving interference patterns . For example , using fused silica in such a two arm Fiber interferometer ,it can be shown that the temperature sensitivity is about 107 rad^{o}C^{-1}

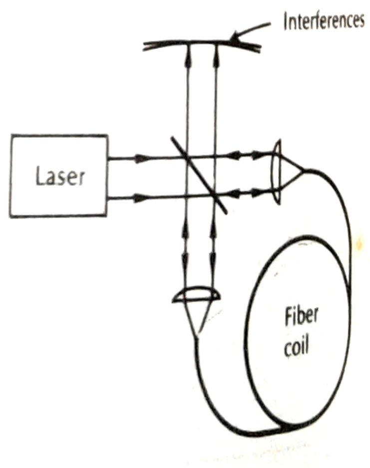


(a)

Another common single mode fiber inteferometric sensor which is finding wide scale application is the fiber gyroscope. This device is based on the classical Sagnac ring interferometer , a fiber version of which is illustrated in fig 4.17(b).

In this device light entering the multiturn fiber coil is divided in to two counter propagating waves which will return in phase after traveling along the same path in opposite directions when the fiber coil is rotating about an axis perpendicular to the plane of the coil , however then the path lengths between the counter propagating waves differ . This difference produces a phase shift which in turn can be measured by interferometric techniques in order to obtain the rotation.

A further interferometric sensor used to measure acoustic pressure which has attracted significant attention is the fiber hydro phone.



(b)

Fig.14.17.(b). Ring interferometer with multiturn fiber coil (Sagnac)

7.(a) **Out line the operation of surface emitter LED and edge emitter LED with neat diagrams?** **8M**

Ans:

Surface emitter LED **4M**
Edge emitter LED **4M**

A method for obtaining high radiance is to restrict the emission to a small active region within the device. The technique pioneered by Burrus and Dawson with homostructure devices was to use an etched well in a GaAs substrate in order to prevent heavy absorption of the emitted radiation, and physically to accommodate the fiber. These structures have a low thermal impedance in the active region allowing high current densities and giving high-radiance emission into the optical fiber. Furthermore, considerable advantage may be obtained by employing DH structures giving increased efficiency from electrical and optical confinement as well as less absorption of the emitted radiation. This type of surface emitter LED (SLED) has been widely employed within optical fiber communications.

The structure of a high-radiance etched well DH surface emitter for the 0.8 to 0.9 μm wavelength band is shown in Figure 7.5 .

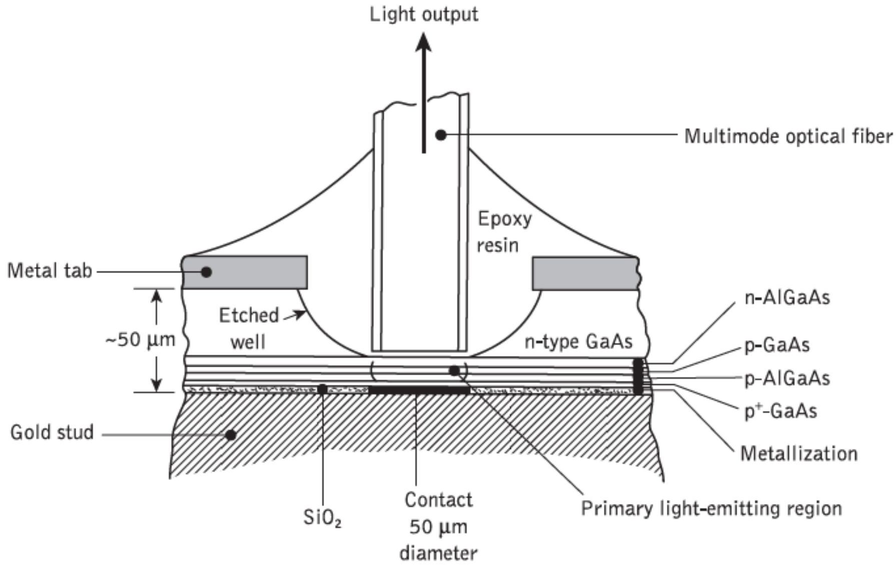


Figure 7.5 The structure of an AlGaAs DH surface-emitting LED (Burrus type). Reprinted from Ref. 11 with permission from Elsevier

The internal absorption in this device is very low due to the larger bandgap-confining layers, and the reflection coefficient at the back crystal face is high giving good forward radiance. The emission from the active layer is essentially isotropic, although the external emission distribution may be considered Lambertian with a beam width of 120° due to refraction from a high to a low refractive index at the GaAs–fiber interface. The power coupled P_c into a multimode step index fiber may be estimated from the relationship.

$$P_c = \pi (1 - r) A R_D (NA)^2$$

where r is the Fresnel reflection coefficient at the fiber surface, A is the smaller of the fiber core cross-section or the emission area of the source and RD is the radiance of the source.

However, the power coupled into the fiber is also dependent on many other factors including the distance and alignment between the emission area and the fiber, the SLED emission pattern and the medium between the emitting area and the fiber. For instance, the addition of epoxy resin in the etched well tends to reduce the refractive index mismatch and increase the external power efficiency of the device.

Hence, DH surface emitters often give more coupled optical power than predicted by Eq. (7.22). Nevertheless Eq. (7.22) may be used to gain an estimate of the power coupled, although accurate results may only be obtained through measurement.

Edge emitter LEDs

Another basic high-radiance structure currently used in optical communications is the stripe geometry DH edge emitter LED (ELED). This device has a similar geometry to a conventional contact stripe injection laser, as shown in Figure 7.7 .

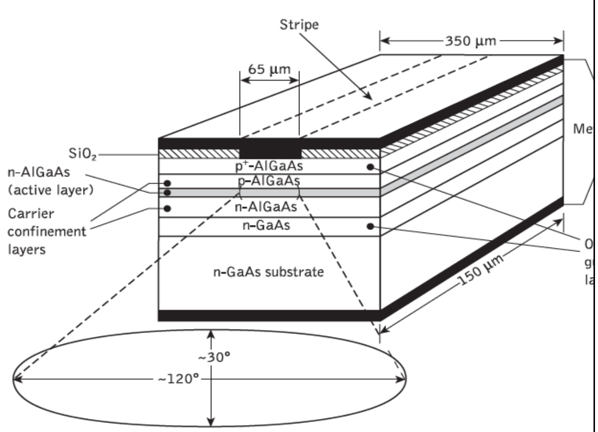


Figure 7.7 Schematic illustration of the structure of a stripe geometry DH edge-emitting LED

It takes advantage of transparent guiding layers with a very thin active layer (50 to 100 μm) in order that the light produced in the active layer spreads into the transparent guiding layers, reducing self-absorption in the active layer. The consequent waveguiding narrows the beam divergence to a half-power width of around 30° in the plane perpendicular to the junction. However, the lack of waveguiding in the plane of the junction gives a Lambertian output with a half-power width of around 120°, as illustrated in Figure 7.7.

Most of the propagating light is emitted at one end face only due to a reflector on the other end face and an antireflection coating on the emitting end face. The effective radiance at the emitting end face can be very high giving an increased coupling efficiency into small-*NA fiber compared with the surface emitter.*

However, surface emitters generally radiate more power into air (2.5 to 3 times) than edge emitters since the emitted light is less affected by reabsorption and interfacial recombination. Comparisons have shown that edge emitters couple more optical power into low *NA (less than 0.3) than* surface emitters, whereas the opposite is true for large *NA (greater than 0.3).*

The enhanced waveguiding of the edge emitter enables it in theory to couple 7.5 times more power into low-*NA fiber than a comparable surface emitter. However, in* practice the increased coupling efficiency has been found to be slightly less than this (3.5 to 6 times) . Similar coupling efficiencies may be achieved into low-*NA fiber* with surface emitters by the use of a lens. Furthermore, it has been found that lens coupling with edge emitters may increase the coupling efficiencies by comparable factors (around five times).

The stripe geometry of the edge emitter allows very high carrier injection densities for given drive currents. Thus it is possible to couple approaching a milliwatt of optical power into low-*NA (0.14) multimode step index fiber with edge-emitting LEDs operating at high* drive currents (500 mA).

Edge emitters have also been found to have a substantially better modulation bandwidth of the order of hundreds of megahertz than comparable surface-emitting structures with the same drive level .

In general it is possible to construct edge-emitting LEDs with a narrower linewidth than surface emitters, but there are manufacturing problems with the more complicated structure (including difficult heat-sinking geometry) which moderate the benefits of these devices.

7.(b) Explain optical displacement sensor with neat diagram? **4M**

Ans:

Diagram of optical displacement sensor **2M**

Operation **2M**

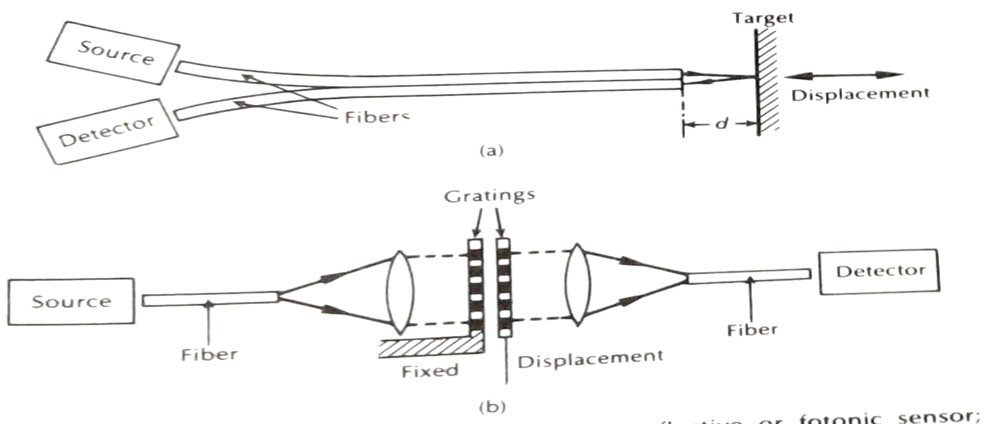


Figure 14.22 Optical displacement sensors: (a) reflective or fotonic sensor; (b) Moiré fringe modulation sensor.

Intensity modulation of the transmitted light beam is utilized in the extrinsic refractive or fotonical optical sensor shown in figure 14.22(a) to give a measurement of displacement.Light reflected from the target is collected is collected by a return Fiber(s) and is a function of the distance between the fiber ends and the target .Hence the position or displacement of the target may be registered at the optical detector .

A method of overcoming the above draw back with optical fiber intensity modulation sensors is due to use a digital measurement technique . Such a technique is shown in figure 14.22(b) where by measurement of displacement is obtained using Morie fringe modulator. In this case the opaque lined gratings produce dark Morie fringes. Transverse movement of one grating with respect to other causes the fringes to move up or down .Thus a count of fringes as the gratings are moved provides a measurement of displacement .The fringe counting is independent of instabilities with in the system components which affect the measurement accuracy and prove difficult to eradicate . Also there are problems involved with loss of count if ,for any reason ,optical power to the sensor is interrupted.

8.(a) Compare merits and demerits of p-i-n and reach through avalanche photodiodes. **6M**

Ans:

11. Comparison between PIN and AVALANCHE photo detector. [AUC MAY 2010]

Comparison of PIN and APD:

S.No	Parameters	PIN	APD
1	Sensitivity	Less sensitive (0- 12 dB)	More sensitive (5-15 dB)
2	Biasing	Low reverse biased voltage (5 to 10 V)	High reverse biased voltage (20- 400 volts)
3	Wavelength region	300- 1100 nm	400 -1000 nm
4	Gain	No Internal gain	Internal gain
5	S/N ratio	Poor	Better
6	Detector circuit	Simple	More complex
7	Conversion efficiency	0.5 to 1 Amps/ watt	0.5 to 100 Amps/ watt
8	Cost	Cheaper	More expensive

8.(b) Explain in detail about semicounductor photo diodes without internal gain ? **6M**

Ans:

PN photo diode **3M**

PIN photo diode **3M**

Semiconductor photodiodes without internal gain generate a single electron–hole pair per absorbed photon. This mechanism was outlined in Section 8.3, and in order to understand the development of this type of photodiode it is now necessary to elaborate upon it. 8.8.1 The *p–n photodiode* Figure 8.4 shows a reverse-biased *p–n photodiode with both the depletion and diffusion* regions. The depletion region is formed by immobile positively charged donor atoms in the *n-type semiconductor material and immobile negatively charged acceptor atoms in* the *p-type material, when the mobile carriers are swept to their majority sides under the* influence of the electric field. The width of the depletion region is therefore dependent upon the doping concentrations for a given applied reverse bias (i.e. the lower the doping, the wider the depletion region).

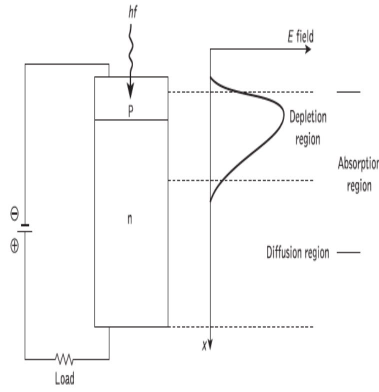


Figure 8.4 The *p–n* photodiode showing depletion and diffusion regions

Photons may be absorbed in both the depletion and diffusion regions, as indicated by the absorption region in Figure 8.4. The absorption region's position and width depend upon the energy of the incident photons and on the material from which the photodiode is fabricated. Thus in the case of the weak absorption of photons, the absorption region may extend completely throughout the device. Electron–hole pairs are therefore generated in both the depletion and diffusion regions. In the depletion region the carrier pairs separate and drift under the influence of the electric field, whereas outside this region the hole diffuses towards the depletion region in order to be collected. The diffusion process is very slow compared with drift and thus limits the response of the photodiode .

It is therefore important that the photons are absorbed in the depletion region. Thus it is made as long as possible by decreasing the doping in the *n-type material. The depletion* region width in a *p–n photodiode is normally 1 to 3 μm and is optimized for the efficient* detection of light at a given wavelength. For silicon devices this is in the visible spectrum (0.4 to 0.7 μm) and for germanium in the near infrared (0.7 to 0.9 μm). Typical output characteristics for the reverse-biased *p–n photodiode are illustrated in* Figure 8.5. The different operating conditions may be noted moving from no light input to a high light level.

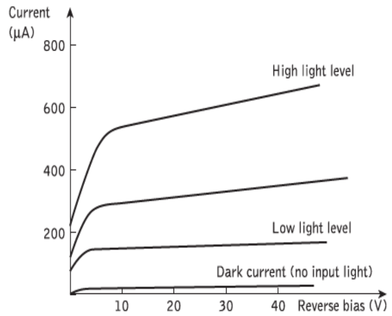


Figure 8.5 Typical *p–n* photodiode output characteristics

2 The *p–i–n photodiode*

In order to allow operation at longer wavelengths where the light penetrates more deeply into the semiconductor material, a wider depletion region is necessary. To achieve this the *n-type material is doped so lightly that it can be considered intrinsic, and to make a low resistance* contact a highly doped *n-type (n+) layer is added. This creates a p–i–n (or PIN)* structure, as may be seen in Figure 8.6 where all the absorption takes place in the depletion region.

Figure 8.7 shows the structures of two types of silicon *p–i–n photodiode for operation* in the shorter wavelength band below 1.09 μm. The front-illuminated photodiode, when operating in the 0.8 to 0.9 μm band (Figure 8.7(a)), requires a depletion region of between 20 and 50 μm in order to attain high quantum efficiency (typically 85%) together with fast response (less than 1 ns) and low dark current (1 nA). Dark current arises from surface leakage currents as well as generation–recombination currents in the depletion region in the absence of illumination.

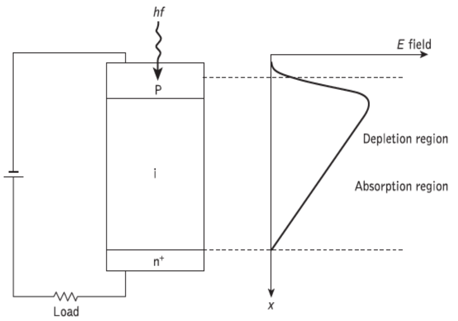


Figure 8.6 The *p–i–n* photodiode showing the combined absorption and depletion region

The side-illuminated structure (Figure 8.7(b)), where light is injected parallel to the junction plane, exhibits a large absorption width (500 μm) and hence is particularly sensitive at wavelengths close to the bandgap limit (1.09 μm) where the absorption coefficient is relatively small Germanium *p–i–n photodiodes which span the entire wavelength range of interest are* also commercially available, but as mentioned previously the relatively high dark currents are a problem (typically 100 nA at 20 °C increasing to 1 μA at 40 °C).

9.(a) **Illustrate the operation of Acoustic and magneto optic modulators with neat diagrams** **8M**

Ans:

operation of Acoustic optic modulators **4M**

magneto optic modulators **4M**

5.3 Acousto-optic Modulation

Acousto-optic effect

The refractive index of an optical medium is altered by the presence of sound. Sound therefore modifies the effect of the medium on light; i.e., sound can control light (Fig. 5.10)

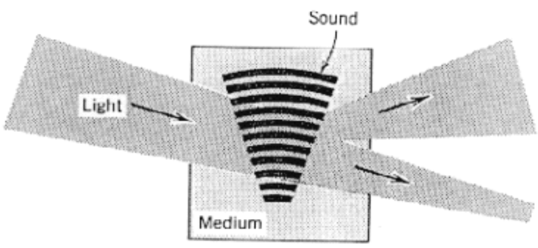


Fig. 5.10: Sound modifies the effect of an optical medium on light

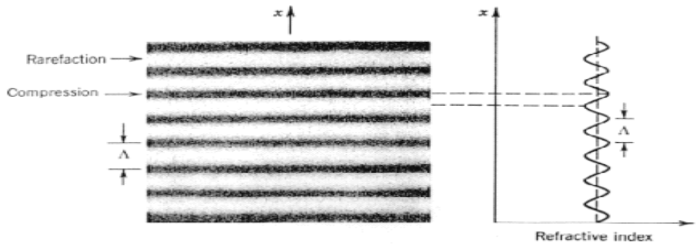


Fig. 5.11: Variation of the refractive index accompanying a harmonic sound wave. The pattern has a period Λ, the wavelength of sound, and travels with the velocity of sound.

- The variations of the refractive index in a medium perturbed by sound are usually very slow in comparison with an optical period.
- The material can be regarded as quasi-stationary, and acousto-optics becomes the optics of an inhomogeneous medium (usually periodic) that is controlled by sound.

5.2 Magneto-optic Modulation

Faraday Effect

$$\rho = VB \qquad (5\text{-}16)$$

V is known as the **Verdet constant.**

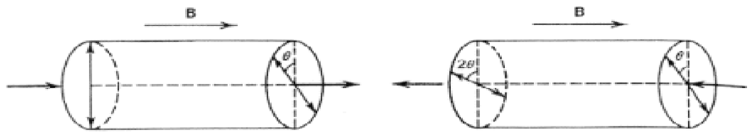


Fig. 5.8: Polarization rotation in a medium exhibiting the Faraday effect. The sense rotation is invariant to the direction of travel of the wave

The sense of rotation is governed by the direction of the magnetic field: only and does not reverse with the reversal of the direction of propagation of the wave (Fig. 5.8). The Verdet constant is a function of the wavelength λ_0.

Materials that exhibit the Faraday effect include glasses, yttrium-iron-garnet (YIG), terbium-gallium-garnet (TGG), and terbium-aluminum –garnet (TbAIG).

A polarization rotator rotates the plane of polarization of linearly polarized light by a fixed angle, maintaining its linearly polarized nature. Materials exhibiting the Faraday effect acts as polarization rotators.

9.(b) Discuss about constructional features of various types of polarization maintaining fibers. 4M

Ans:

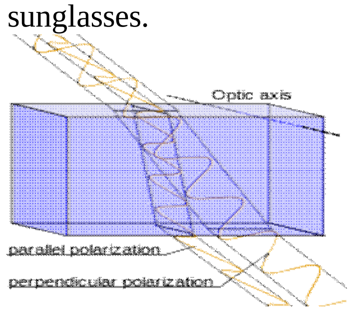
Diagram of polarization-maintaining optical fiber 2M

Explanation 2M

Polarization-maintaining optical fiber

The ability of waves to oscillate in more than one direction; in particular polarization of light, responsible for example for the glare-reducing effect of polarized sunglasses.

In fiber optics , polarization-maintaining optical fiber (PMF or PM fiber) is a single-mode optical fiber in which linearly polarized light, if properly launched into the fiber, maintains a linear polarization during propagation , exiting the fiber in a specific linear polarization state; there is little or no cross-coupling of optical power between the two polarization modes. Such fiber is used in special applications where preserving polarization is essential.



Birefringence is the optical property of a material having a refractive index that depends on the polarization and propagation direction of light. These optically anisotropic materials are said to be birefringent (or birefractive).

Polarization crosstalk

In an ordinary (non-polarization-maintaining) fiber, two polarization modes (say vertical and horizontal polarization) have the same nominal phase velocity due to the fiber's circular symmetry. However tiny amounts of random birefringence in such a fiber, or bending in the fiber, will cause a tiny amount of crosstalk from the vertical to the horizontal polarization mode. And since even a short portion of fiber, over which a tiny coupling coefficient may apply, is many thousands of wavelengths long, even that small coupling between the two polarization modes, applied coherently, can lead to a large power transfer to the horizontal mode, completely changing the wave's net state of polarization. Since that coupling coefficient was unintended and a result of arbitrary stress or bending applied to fiber, the output state of polarization will itself be random, and will vary as those stresses or bends vary; it will also vary with wavelength.