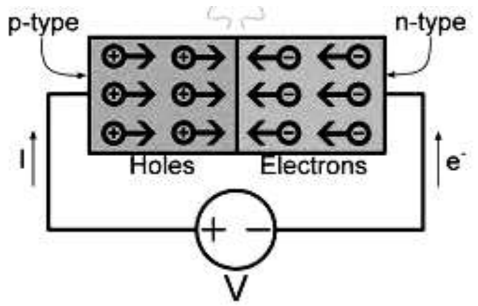
Module V PHOTONICS

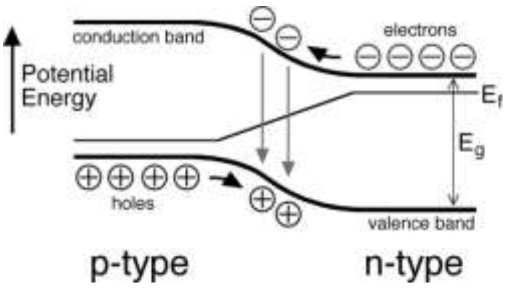
Photonics deals with the production, control and detection of photons. Its applications are in communication, data processing, transportation, medicine, lighting, biotechnology, etc.

Light Emitting Diode (LED)

- LED is a heavily doped pn junction. When current flows across a diode negative electrons and positive holes move in opposite directions
- The holes exist at a lower energy level than the free electrons. Therefore when a free electron recombines with hole, it losses energy.
- This energy is emitted in a form of a photon / light.The color of the light is determined by the energy gap between that of hole and electron.

$\lambda = \frac{hc}{E_g}$; where E_g is the band gap energy

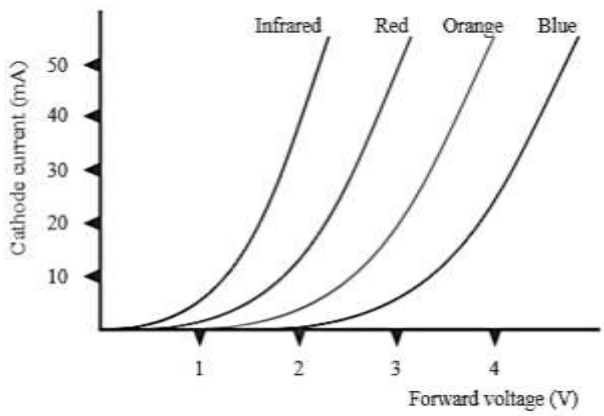




The colour of light emitted depends on band gap energy E_g whereas intensity of light emitted increases with increase of forward current. Generally, LEDs are monochromatic. White light is produced from LEDs by two methods;

i. RGB (Red Green Blue) Mixing: Mixing of light from different LEDs

ii. Phosphor conversion: A phosphor is used to absorb light in blue or near ultraviolet region and to emit white light



V-I Characteristics of LED:

Advantages:

1. Long life, if used in a suitable environment. Saving future maintenance cost.
2. Very high efficiency & lower power consumption compared to incandescent lights.
3. Light weight and miniature size.
4. Lower heat output, conventional incandescent lights waste about 90% of their power on heat output.
5. Typically lower infra-red and ultraviolet output.
6. Faster switching time and less likely to be damaged by on-off cycles.
7. They are usually more rugged. There is normally no glass to break and no filament to damage via vibration.

Disadvantages:

1. High initial price.
2. May fail prematurely in high temperature conditions.
3. Small increase in voltage can cause permanent damage to LED
4. Light output and colour quality can degrade over time period

Applications:

Light-emitting diodes are used in applications as diverse as aviation lighting, automotive headlamps, advertising, general lighting, traffic signals, camera flashes, mobile phones, Televisions and medical devices like OCT and pulse oximeter.

PHOTODETECTOR

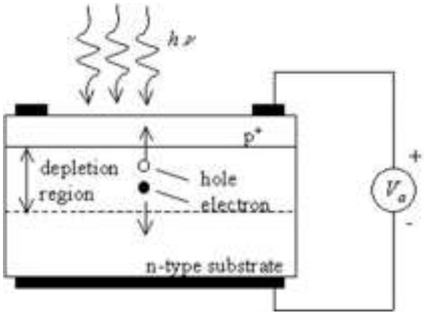
Photodetector is a semiconductor device that converts light into current. The current is generated when photons are absorbed in the detector and electrons are released. Main properties of photodetector are;

i. Sensitive in a spectral region (range of optical wavelengths)
ii. Support a range of optical input power.
iii. Support only a range of frequencies.
iv. Low noise
v. Dark current; the small amount of current that is present when no light is present.

Photovoltaic Effect:

It is the phenomenon of production of an emf across junction of two dissimilar materials by incidence of light.

Junction Photodiode



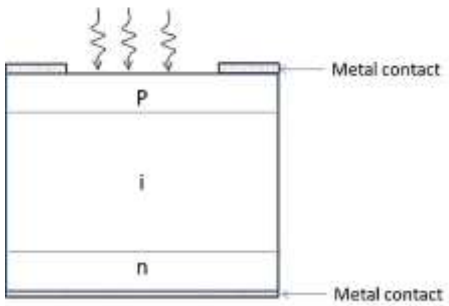
It is a pn junction, with a heavily doped thin p-layer on thicker n-type material layer. Light enters the junction through transparent p-layer.

It works on the basis of photovoltaic effect. When light is incident on photodiode, it gets absorbed mainly at the depletion region and electrons are released from valance band and it goes into conduction band. This creates holes in valance band. So a large number of electron-hole pairs are created which results in current called photocurrent.

Applications:

Barcode scanners, security systems, optical communication

PIN Photodiode



In PIN photodiode, a wide intrinsic semiconductor is placed between heavily doped p type and n-type regions. The depletion region of a PIN structure extends across the intrinsic region, deep into the device. This wider depletion width enables more absorption of light and more electron-hole pair generation deep within the device. This increases the efficiency of the diode.

The advantage of using a PIN photodiode over junction photodiode is the better long wavelength response and increased quantum efficiency.

Photodiode operation modes

Photovoltaic mode

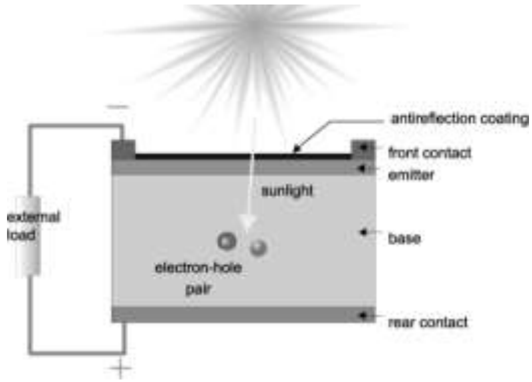
- ✓ In the photovoltaic mode, the photodiode is unbiased. In other words, no external voltage is applied to the photodiode under photovoltaic mode.
- ✓ Dark current is very low, but have low response speed.
- ✓ Sensitivity is low and hence generally used for detecting low light levels

Photoconductive mode

- ✓ In photoconductive mode, an external reverse bias voltage is applied to the photodiode.

- ✓ Applying a reverse bias voltage increases the width of depletion region and reduces the junction capacitance which results in increased response speed. But this this increases the dark current.
- ✓ Photodiodes operated in photoconductive for obtaining high dynamic range.

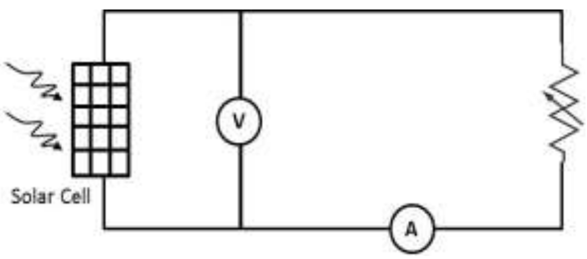
SOLAR CELL

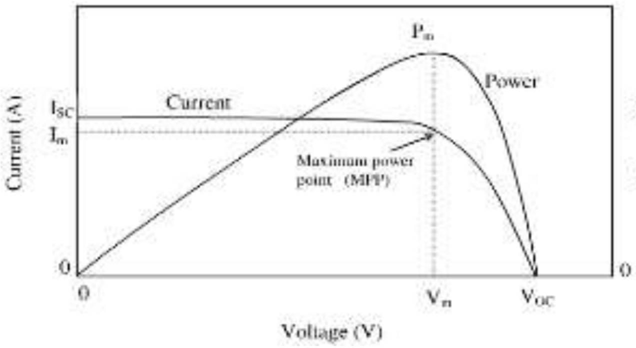


- Solar cell is a device which converts sunlight into electricity.
- It consists of an array of large area junction photodiodes and works on the principle of photovoltaic effect.
- Sunlight is absorbed at the p-n interface and electron-hole pairs are produced. The electric field at the junction pulls electrons towards n-region and holes towards p-type region. As a result a current flows from p-terminal to n-terminal.
- In a solar panel, array of photodiodes connected in series to increase output voltage then in parallel to increase output current.

Characteristics of Solar Cell

Experimental setup to study I-V characteristics of solar cell is shown in figure. Typical I-V characteristics are shown in second figure.





Short circuit current (I_{sc}) is the current through solar cell when the voltage across is zero. V_{oc} is the open circuit voltage across solar cell when the current is zero.

Maximum Power Point (MPP) is the condition under which solar cell generates its maximum power output($P_{max} = I_{max} \times V_{max}$)

Fill Factor - $FF = \frac{V_{max} \times I_{max}}{V_{oc} \times I_{sc}}$

Conversion Efficiency, $\eta = FF \times \frac{V_{oc} \times I_{sc}}{EA}$

Where E-input irradiance and A-Area of solar Cell

Applications

1. In artificial satellites
2. As electrical power generator in solar street lighting systems, inverters etc.
3. Used in pocket calculators, watches, etc.

Advantages of Solar Cell

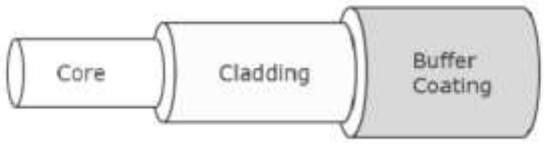
1. Solar energy is clean, renewable and sustainable, and virtually free after the initial investment.
2. Solar systems have no moving mechanical parts.
3. Solar systems are silent.

Disadvantages of Solar Cell

1. Solar power depends on daylight in order to generate electricity. Best results require solar panels to be placed at an angle that directly faces the incoming sunlight.
2. The maximum efficiency of solar panels is only just over 20%.
3. Solar systems require significant initial investment.

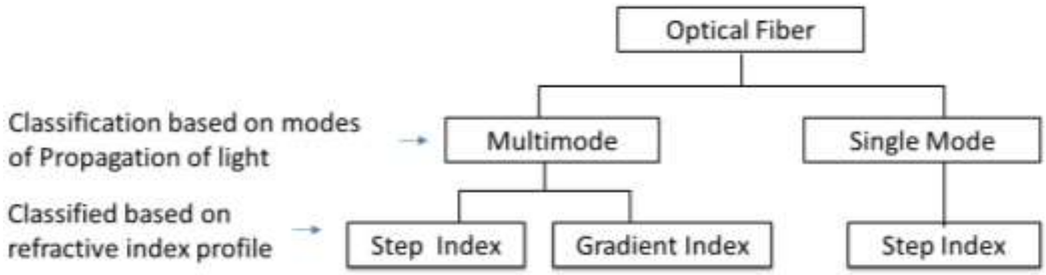
OPTICAL FIBER

- ✓ Optical fibers are circular dielectric wave-guides that can transport optical energy and information.
- ✓ They have a central core surrounded by a concentric cladding with slightly lower (by ≈ 1%) refractive index.
- ✓ Optical fibers are made of glass and plastic. Plastic fibers are more flexible. But due to higher attenuation/power loss, plastic fibers are not used for long haul transmission.
- ✓ Optical fiber transmits light along its axis, by the process of total internal reflection.



Parts of an Optical fiber

Types of optical fiber



1. Multimode Step index fiber

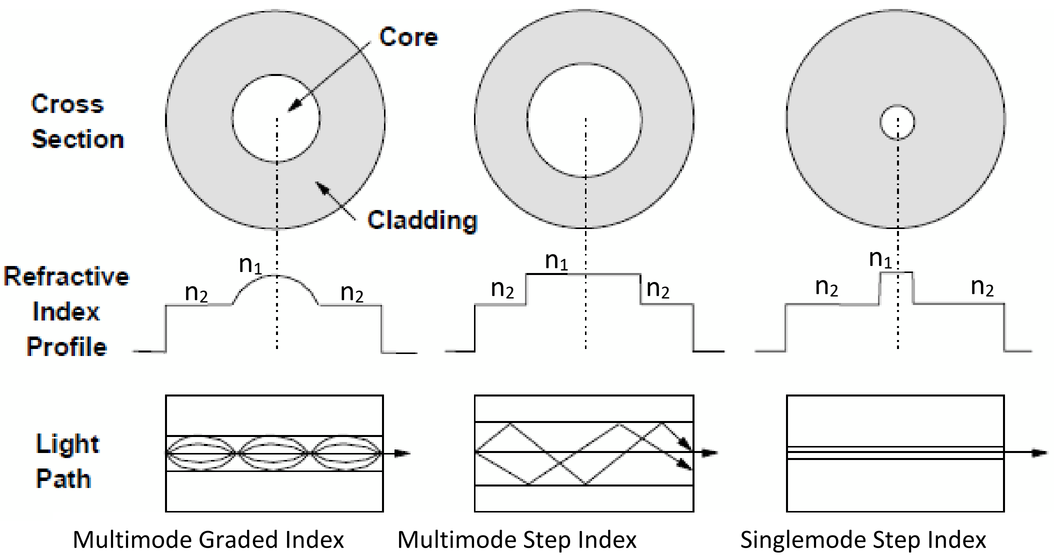
- Core refractive index is constant.
- Refractive index reduces abruptly at core-cladding boundary
- Supports multiple modes of propagation of light

2. Multimode graded index fiber

- Refractive index of core gradually reduces as the distance increases from the centre
- Supports multiple modes of propagation of light

3. Single mode Step index fiber

- Core refractive index is constant.
- Refractive index reduces abruptly at core-cladding boundary
- Supports only single mode of propagation of light



Advantages of Optical Fiber

1. Low transmission loss. Typical attenuation of a Single mode fiber is 0.15dB/km. This reduces the requirement for repeaters (or amplifiers)
2. Optical fibers used in communication are made of silica glass and have a diameter of 100to 250μm only. This results in low volume and weight making it easy to handle
3. Immune to electromagnetic interference hence eliminates cross talk.
4. Can be used in hazardous environments including high voltage environments.
5. Made of silica glass, which is abundant in nature and very cheap
6. High Bandwidth Over Long Distances (presently available networks support upto 100GbPs)
7. Non-flammable: Because no electricity is passed through optical fibers, there is no fire hazard.

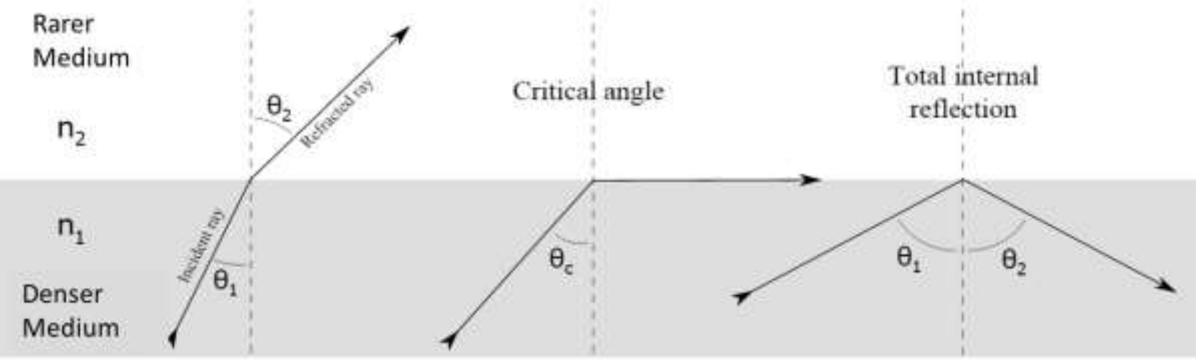
Working Principle of Optic fiber

If the angle of incidence in the denser medium is greater than the critical angle, the incident ray is reflected back to the same medium totally. This phenomenon is called total internal reflection and this is the basicworking principle of optic fiber.

Conditions for TIR

i. Light must travel from optically denser to optically rarer medium.

ii. The angle of incidence in the denser medium must be greater than the critical angle.

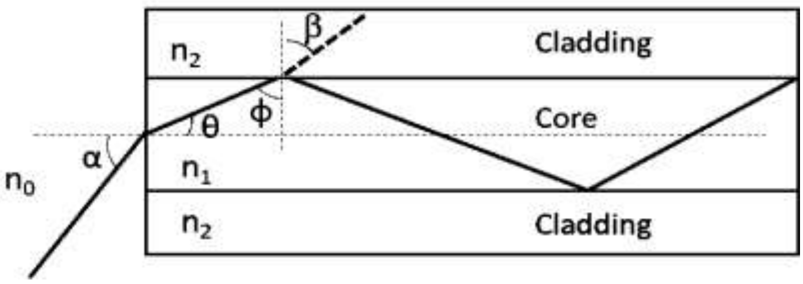


Numerical aperture (NA) of Fiber

Numerical Aperture (NA) of a fiber is a measure of light gathering capacity of fiber. NA is the measure of angle over which light is accepted in the fiber. Light entering fiber within the acceptance angle will transmit through it.

$$NA = \sin \alpha_m \qquad \text{where } \alpha_m \text{ is the acceptance angle}$$

Numerical Aperture (NA) of Step Index Fiber



Consider a step index fiber with core of refractive index n1 and cladding of refractive index n2. From figure;

i) α is the angle that incident ray makes with axis of the fiber

ii) θ is the propagation angle that incident ray makes with axis of the fiber, inside the fiber and

i) ϕ is the internal reflection angle that ray makes at core –cladding boundary.

Using Snell's law at air - core interface

$n_o \sin\alpha = n_1 \sin\theta$

$\theta = 90 - \phi$

$n_o \sin\alpha = n_1 \cos\phi$ ---(1)   { Sin(90- θ) = Cos ϕ }

Using Snell's law at core - cladding interface

$n_1 \sin\varphi = n_2 \text{S}\sin\beta$ ---(2)

Light starts reflecting back to the core for angles $\phi \geq \phi_c$,critical angle.

when $\phi = \phi_c$, we have $\beta = 90$, $\alpha = \alpha_m$ and $\theta = \theta_m$

From eqn (2), $n_1 \sin\phi_c = n_2$

$$\sin\phi_c = \frac{n_2}{n_1} \quad \text{-------------------------(3)}$$

$$\cos\phi_c = \sqrt{1 - \sin^2\phi_c} = \frac{\sqrt{n_1^2 - n_2^2}}{n_1} \text{----------------(4)}$$

When $\phi = \phi_c$ we have $\alpha = \alpha_m$, maximum angle of incidence (acceptance angle).Using eqn(4) in eqn(1)

$\sin\alpha_m = n_1 \cos\phi_c$

$$n_o \sin\alpha_m = n_1 \frac{\sqrt{n_1^2 - n_2^2}}{n_1}$$

$$\mathbf{NA = \sin\alpha_m = \frac{\sqrt{n_1^2 - n_2^2}}{n_0}}$$

For Air $n_o = 1$

$NA = \text{Sin}\,\alpha_m = \sqrt{n_1^2 - n_2^2}$

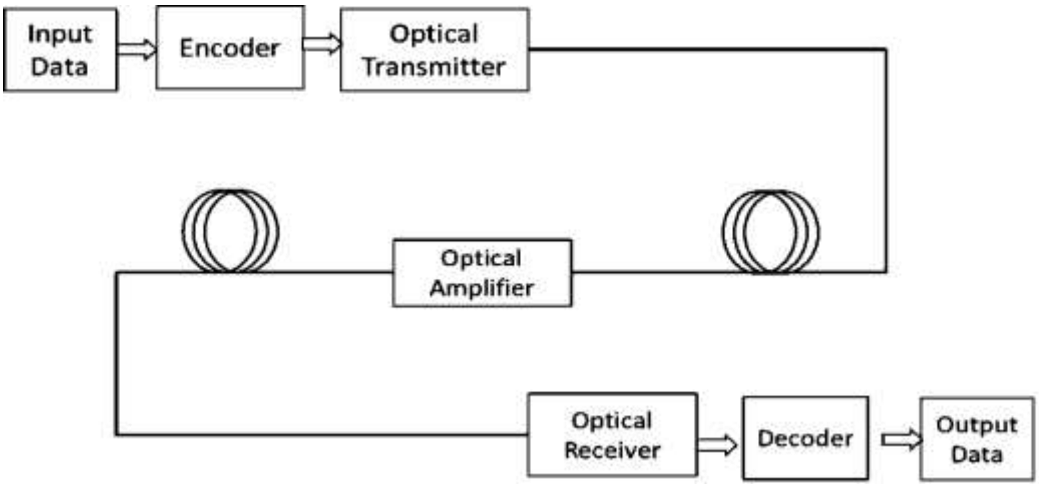
Note : NA in terms of fractional refractive index change

Fractional refractive index change is $\Delta = \frac{n_1 - n_2}{n_1}$

$$NA = n_1\sqrt{2\Delta}$$

OPTICAL FIBER COMMUNICATION SYSTEM

Communicatioan system which carries information through a guided optical fiber is called fiber optic communication system. The main parts of an optical fiber communication system are Encoder, Optical Transmitter, Optical fiber, Optical amplifier,Optical reciever and decoder.



Input Data: Electrical signals containing the information to be transmitted. Non electrical signals are converted into electrical signal.

Ex: cameras (audio and video). ,Telephone -audio

Encoder: Converts the electrical signals into proper encrypted format. This is for keeping data secure and to sperate different data from each other.

Optical Transmitter: A laser diode (LD) or a light emitting diode (LED) is used. They provide stable, single frequency waves with sufficient power for long distance propagation.

Optical Receiver: A photodetector that convert the optical signal into electrical signal**.**

Decoder: It removes the encryption and separates the data from the carrier signal.

Output Data: Electrical signal that is given to devices which will be converted into desired format. Ex: Loud speaker, TV ,computer

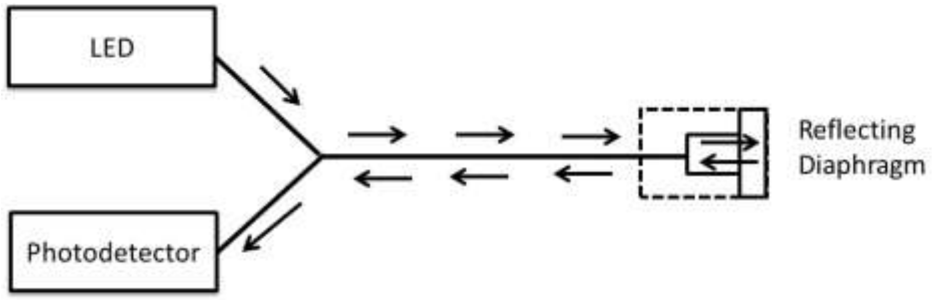
FIBER OPTIC SENSORS

An optical fiber sensor, in general consists of a light source, photodetector, and optical fiber to carry light to the material under test and back to detector.

1. Intensity Modulated Sensor

Intensity Modulated sensors measure change in intensity, thereby measuring the cause of the change.

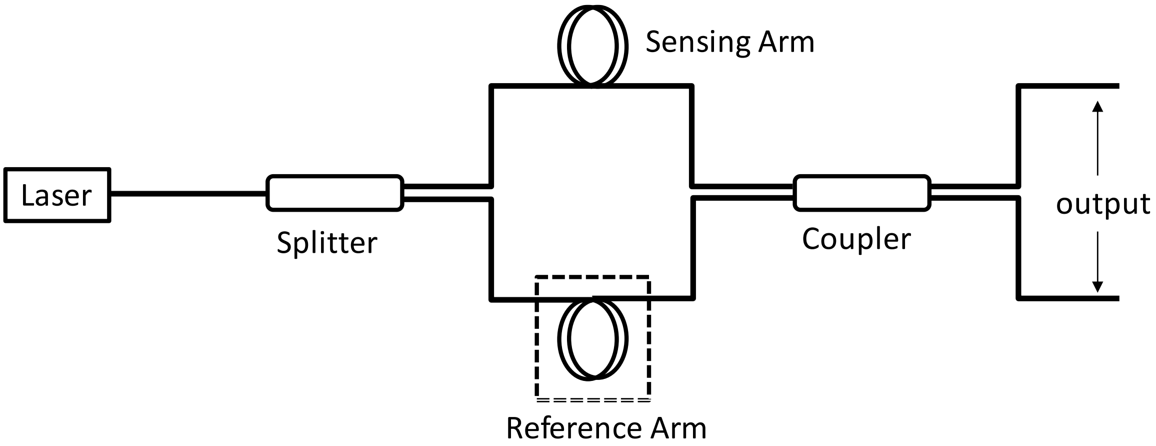
Input light is transmitted to the measuring end through a fiber. Light reflected from diaphragm is transmitted to the Photodetector. Diaphragm will change shape and move based on change in pressure. This will result in variation in intensity of reflected light. Hence the variation in pressure can be observed as a change in electrical output of photodetector. This can be used to measure pressure upto 6 Mega Pascal



2. Phase Modulated Sensor

Phase Modulated sensors measure change in phase of the light, thereby measuring the cause of the change.

Input light is split into two equal parts; one part travels through reference arm and reaches coupler unaltered while second part of light passes through sensing arm and will get affected by the measureand (ex; temperature, vibration). These two rays interfere inside the coupler. The output across the coupler will vary based on the phase change.



Applications of Optical fiber

1. In LAN and other telecommunication.
2. Sensor applications
3. Medical applications: OCT, Blood analysers
4. Computer applications where high speed data transfer is required.
5. Remote sensing
6. High accuracy gyroscopes
7. Security systems