Parul® University
Vadodara, Gujarat

NAAC GRADE A++

Information and Communication Technology

UNIT- 2
Optoelectronics

Study guide

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1.1 What are optoelectronic devices

Optoelectronic devices are specialized electronic components that either emit, detect, or control light—typically using semiconductor materials. They form a bridge between optics (the study of light) and electronics, enabling conversion between electrical and optical signals. These devices play a crucial role in modern technologies, including communications, displays, sensing, and energy generation.

Types of Optoelectronics devices

Device Category	**Function**
Emitters	**LED, Laser Diode**
Detectors	**Photodiode, Phototransistor**
Transducers	**Solar Cells (photovoltaic conversion**
Modulators	**Electro-optic modulators**
Sensors	**LDR, Imaging devices**

1.1.1 Ordinary Light

Light is a form of electromagnetic radiation that is visible to the human eye.It is a type of energy that travels in the form of waves, and it is part of a broader spectrum of electromagnetic radiation.The electromagnetic spectrum encompasses a wide range of frequencies and wavelengths, with light falling within a specific region of this spectrum.

SPEED: *In a vacuum, light travels at a constant speed (3.00×108 m/s), denoted as c. This speed is one of the fundamental constants in physics.*

ELECTROMAGNETIC SPECTRUM: *Light is just one portion of the electromagnetic spectrum, which includes various types of electromagnetic radiation such as radio waves, microwaves, infrared radiation,* *visible, ultraviolet radiation, X-rays, and gamma rays. Each type of electromagnetic radiation has a specific range of wavelengths and frequencies*

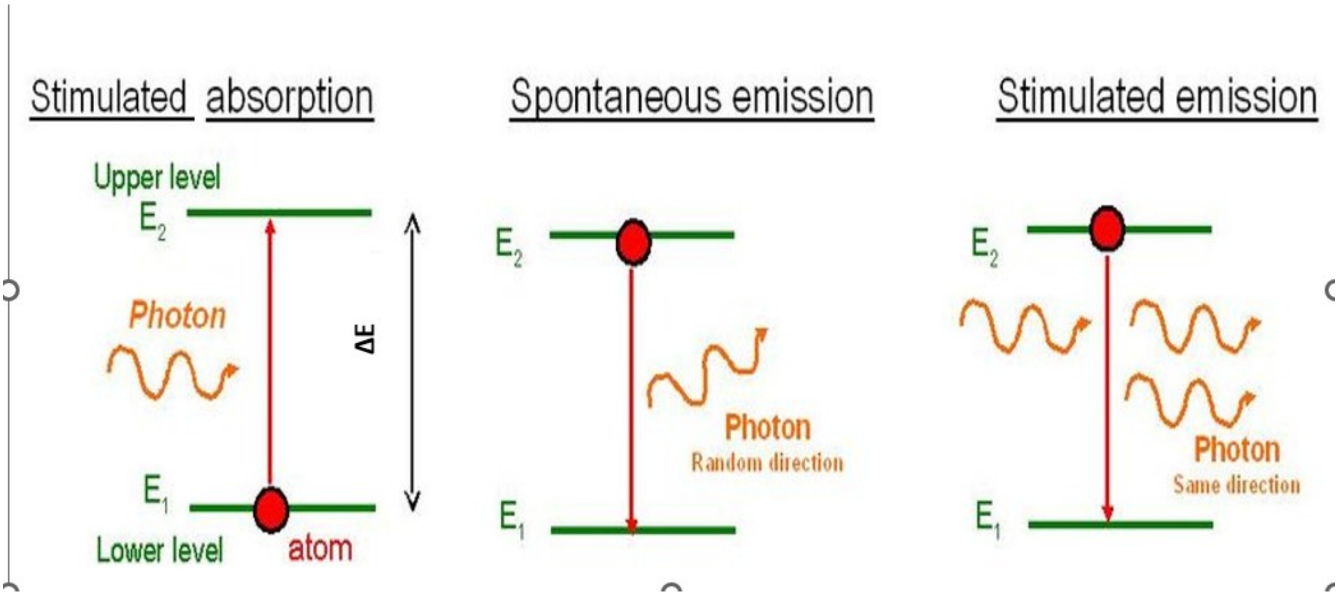
WAVELENGTH AND COLOR: The different colours of light are associated with different wavelengths. In the visible spectrum, shorter wavelengths correspond to colours like violet and blue, while longer wavelengths correspond to colours like red and orange.

ENERGY: The energy of a light wave is directly proportional to its frequency. This relationship is described by the equation $E=h\nu$, where E is the energy, h is Planck's constant, and ν is the frequency of the light wave.

1.2 Interaction of radiation (light) with Matter

Radiation, especially in the form of photons (light), interacts with matter primarily through three main mechanisms:

1.Stimulated Absorption
2.Spontaneous Emission
3. Stimulated Emission



Stimulated Absorption: A photon's energy is taken up by an electron in an atom. This excites the electron to a higher energy state, commonly observed in photoelectric absorption, crucial for devices like photodiodes.

Spontaneous Emission: An excited electron returns to a lower energy state without external prompting, emitting a photon with random phase and direction. (E.g. LED)

Stimulated emission (key to lasers): If an electron in an excited state is struck by a photon of suitable energy, it emits a second, identical photon. This leads to coherent, monochromatic, and directional light—the defining qualities of lasers.

1.3. LASER – Light Amplification by Stimulated Emission of Radiation

A device that stimulates atoms or molecules to emit light at particular wavelength and amplifies that light producing a 1) High Degree Of Coherency

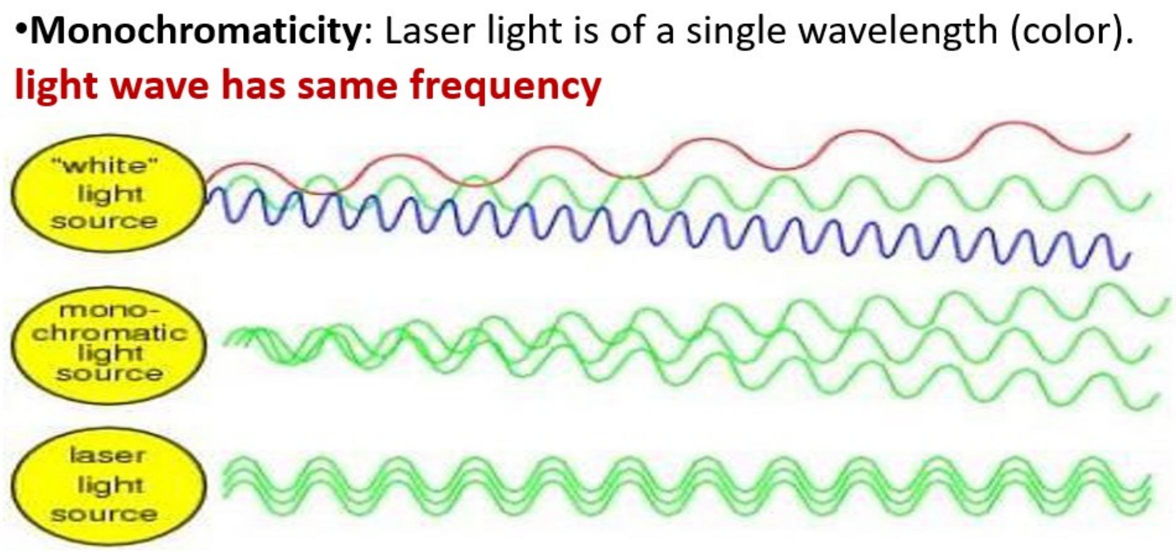
(2) Highly Monochromatic

(3) Highly Directional

(4) Highly Intense

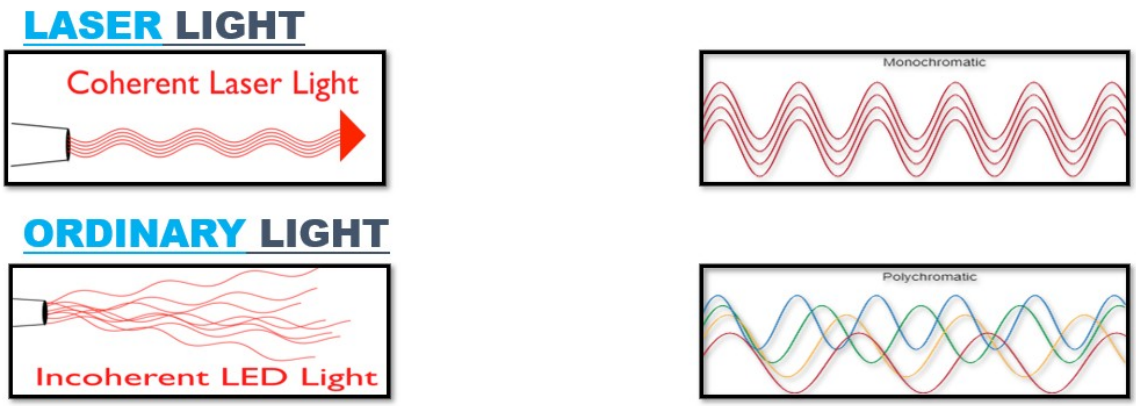
1.3.1. Characteristics/Properties of LASER light

a) **Monochromaticity**



b) **Coherence**

•**High coherence**: Photons are in phase spatially and temporally, resulting in highly ordered waves.



High directionality: The laser beam is extremely narrow and can travel long distances with minimal spread.

High intensity: Laser light is vastly more intense than ordinary sources due to the concentration of energy

1.3.2 Population inversion

Definition : Population Inversion is an artificial non-equilibrium process/condition of the material that is established by generation of large numbers of atoms in the higher energy state (N2) than ground state (N1), i.e N2 .>> N1.

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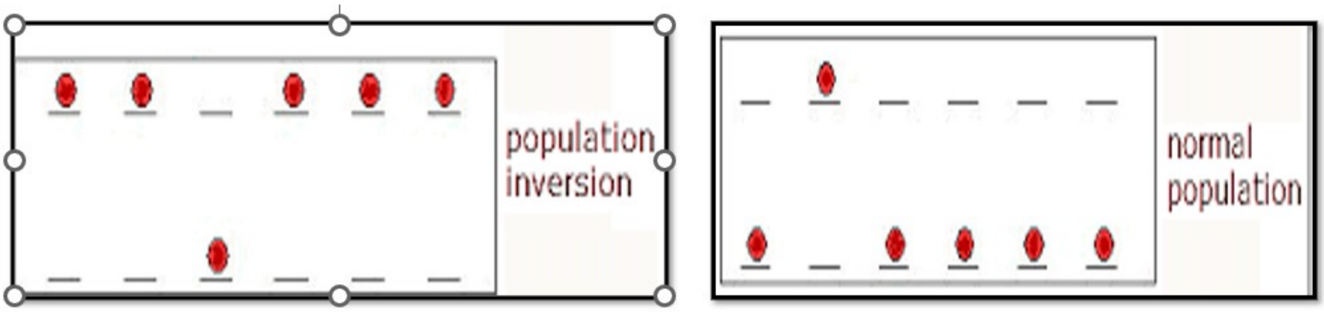
[At ordinary conditions N1 > N2, i.e., the population in the ground or lower state is always greater than the population in the excited or higher states.]

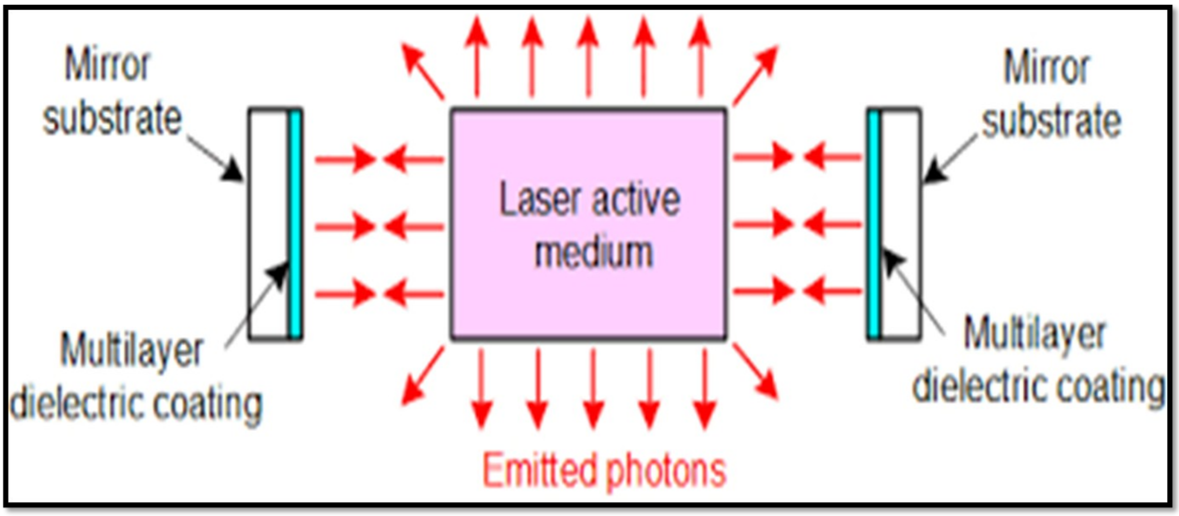


1.3.3 Components of LASER

Laser requires three Components: 1) Active Medium/Gain Medium

2) Pumping scheme

3) Optical Cavity/Resonator



1) Active Medium:

The fundamental component of laser is material medium which is known as an Active/Gain Medium. Types:

Solid (e.g., Ruby, Nd:YAG crystals)

Liquid (e.g., dye solutions)

Gas (e.g., He-Ne, CO_2)

Semiconductor (e.g., GaAs in laser diodes)

The choice of active medium determines the laser's wavelength (color) and properties.

2) Pumping scheme : Supplies external energy to excite the atoms of the active medium, creating a population inversion (more atoms in an excited state than in the ground state).

Methods:

Electrical current (in diode lasers)

Light from flash lamps or other lasers (optical pumping)

Electrical discharge (in gas lasers)

Chemical reactions (in chemical lasers)

3) Optical Resonator (Cavity) :Traps photons and amplifies light via multiple reflections between two mirrors placed parallel to each other around the active medium.

Components: Two Mirrors:

One fully reflective mirror (100%)

One partially reflective mirror (output coupler, allows some light to escape as the laser beam)

Purpose: Ensures that photons move back and forth to sustain stimulated emission, building up the laser beam's intensity

1.3.2 Semiconductor Laser: Construction

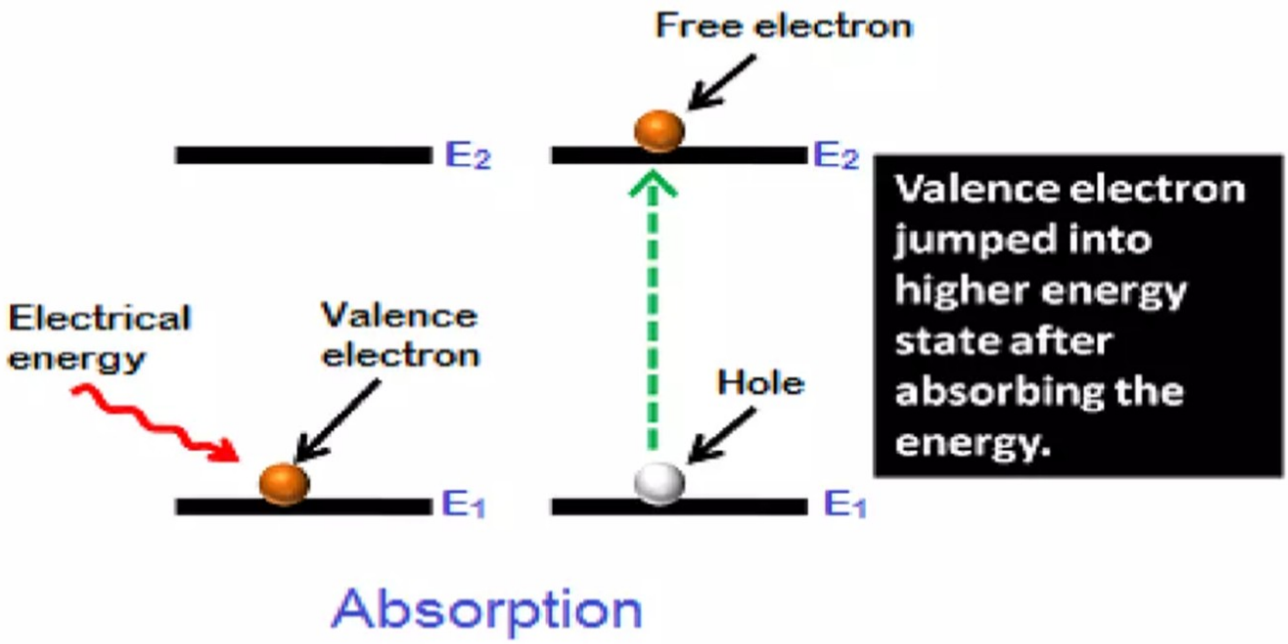
A diode laser is a semiconductor device that generates coherent light through stimulated emission at a p-n junction. Its main structural elements include:

Absorption of energy: Absorption of energy is the process of absorbing energy from the external energy sources.

In laser diodes, electrical energy or DC voltage is used as the external energy source. When the DC voltage or electrical energy supplies enough energy to the valence electrons or valence band electrons, they break bonding with the parent atom and jumps into the higher energy level (conduction band). The electrons in the conduction band are known as free electrons.

When the valence electron leaves the valence shell, an empty space is created at the point from which electron left. This empty space in the valence shell is called a hole.

Thus, both free electrons and holes are generated as a pair because of the absorption of energy from the external DC source.



Spontaneous emission:

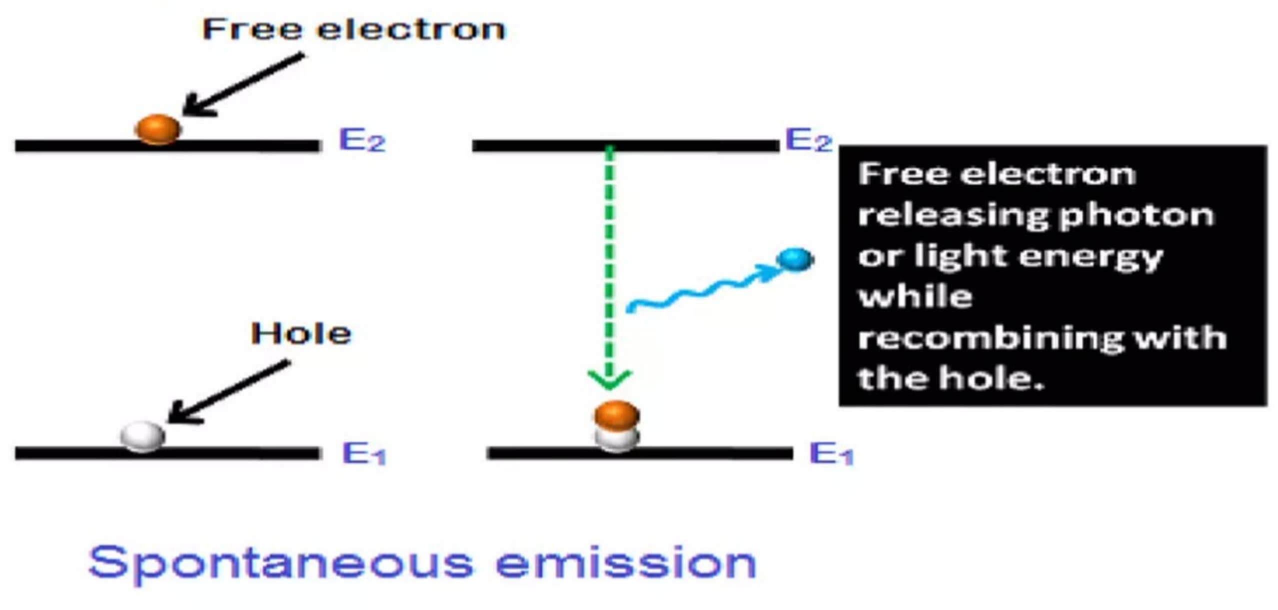
Spontaneous emission is the process of emitting light or photons naturally while electrons falling to the lower energy state.

In laser diodes, the valence band electrons or valence electrons are in the lower energy state. Therefore, the holes generated after the valence electrons left are also in the lower energy state.

On the other hand, the conduction band electrons or free electrons are in the higher energy state. In simple words, free electrons have more energy than holes.

The free electrons in the conduction band need to lose their extra energy in order to recombine with the holes in the valence band.

The free electrons in the conduction band will not stay for long period. After a short period, the free electrons recombine with the lower energy holes by releasing energy in the form of photons.

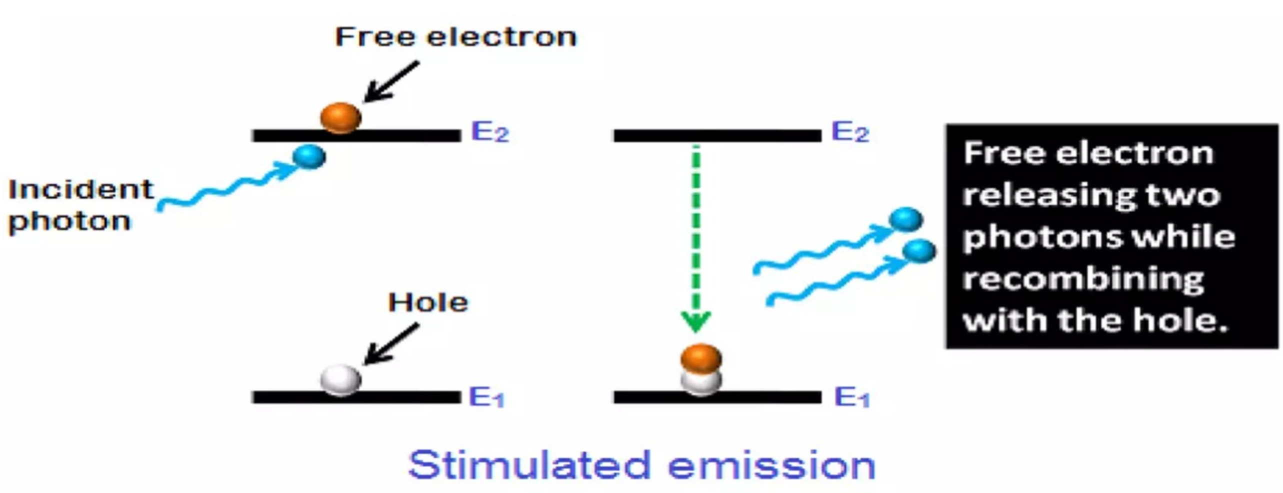


Stimulated emission:

Stimulated emission is the process by which excited electrons or free electrons are stimulated to fall into the lower energy state by releasing energy in the form of light. The stimulated emission is an artificial process.

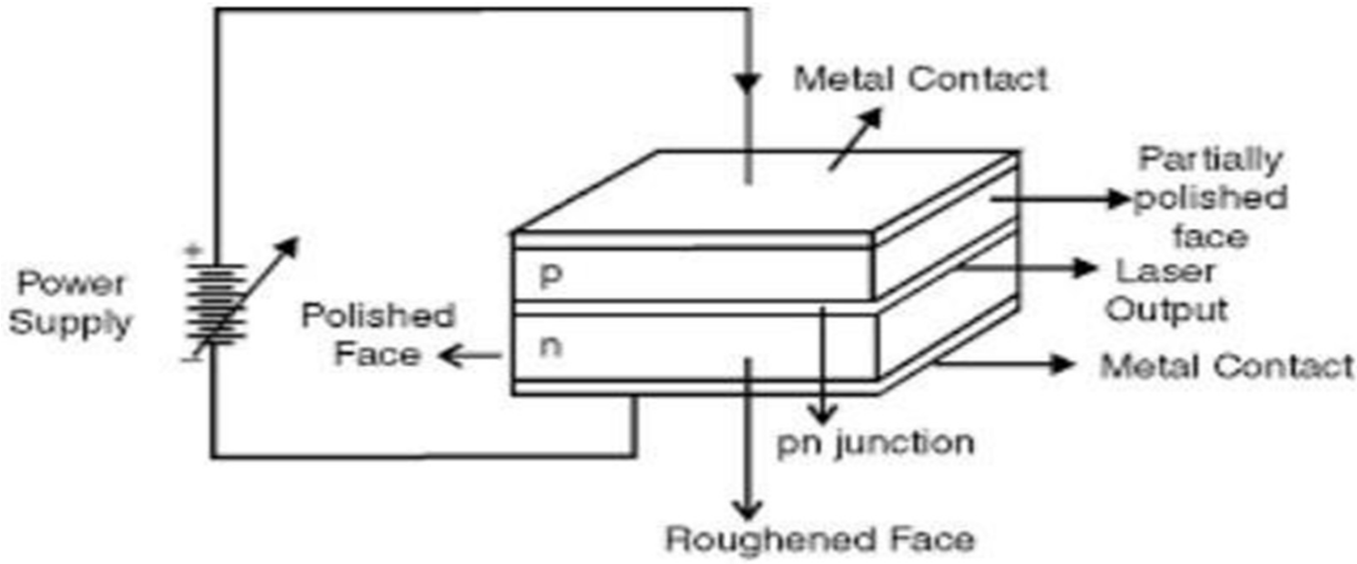
In stimulated emission, the excited electrons or free electrons need not wait for the completion of their lifetime. Before the completion of their lifetime, the incident or external photons will force the free electrons to recombine with the holes. In stimulated emission, each incident photon will generate two photons.

All the photons generated due to the stimulated emission will travel in the same direction. As a result, a narrow beam of high-intensity laser light is produced.



1.4 Construction: Semiconductor Laser

Construction: Semiconductor laser



In diode laser P-type & N-type Layers made from semiconductor materials like gallium arsenide (GaAs), doped to create p-type (positive) and n-type (negative) regions.

Active Region (Intrinsic Layer): A thin undoped (intrinsic) layer of GaAs or similar material is sandwiched between the p- and n-layers. Photon generation through electron-hole recombination occurs here.

Optical Cavity: The faces of the diode (created by cleaving or polishing) act as mirrors, one highly reflective and the other partially reflective to trap and amplify light within the device.

Metal Contacts: Enable external voltage to be applied across the junction, forward-biasing the diode.

Working of a semiconductor LASER

Forward Biasing: An external voltage is applied so that electrons (from n-type) and holes (from p-type) are injected into the active region.

Carrier Recombination: Electrons and holes recombine in the active region, releasing energy as photons.

Stimulated Emission: Initial photons stimulate further recombination events, producing more photons of exactly the same phase, direction, and energy.

Optical Resonance: The photons reflect back and forth between the two end mirrors, stimulating even more emissions.

Laser Output: When the rate of stimulated emission exceeds loss, intense, coherent, and monochromatic light is emitted from the partially reflective end.

1.4.1 Uses of Semiconductor Laser

Diode lasers are widely used due to their compact size, low power requirement, and efficiency:

Telecommunications: As the light source for fiber-optic data transmission and multiplexing.

Consumer Electronics: In CD/DVD/Blu-ray players and recorders.

Printing & Scanning: In laser printers, barcode, and QR code scanners.

Laser Pointers: Compact and energy-efficient sources for pointing and classroom demonstrations.
Medical Field: For eye and dental surgery, hair removal, skin therapy, photodynamic treatments, and soft tissue surgery.

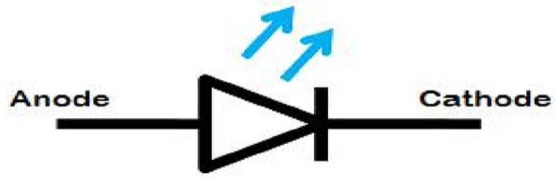
Industrial Applications: Material processing including cutting, engraving, welding, laser marking.

Scientific Research: Spectroscopy, microscopy, material analysis.

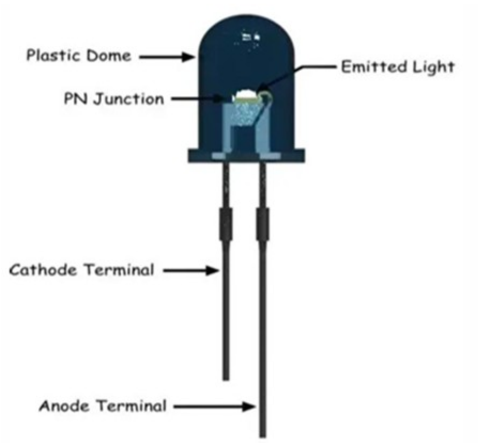
Sensing and Measurement: For distance measurement (lidar), range finding, and optical metrology

1.5 Light Emitting DIODE

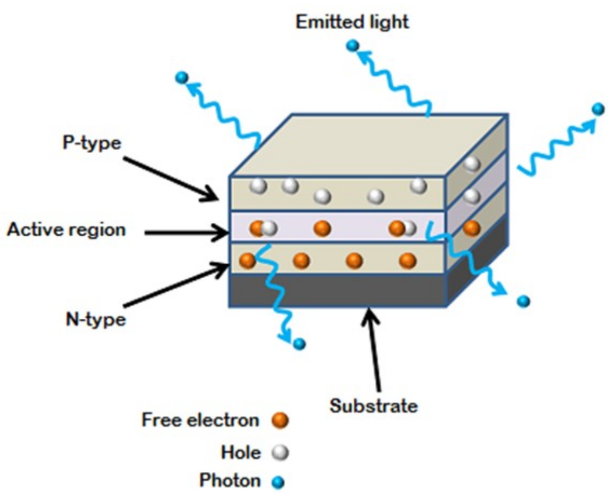
LED (Light Emitting Diode) is an optoelectronic device which works on the principle of electro-luminance. Electro-luminance is the property of the material to convert electrical energy into light energy. It is specially doped p-n junction diode made up of specific type of semiconductors. When the light emitting diode light is forward biased, then it emits light either invisible region or infra red region.



LED symbol



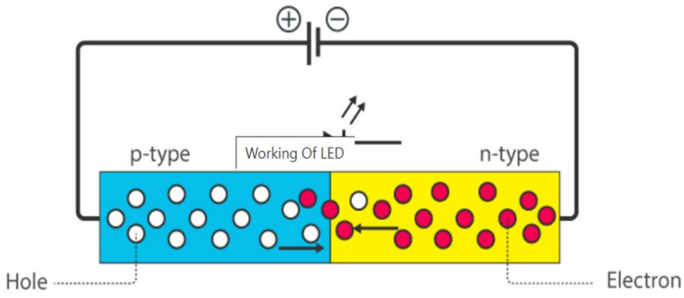
The methods used to construct LED are to deposit three semiconductor layers on the substrate.
The three semiconductor layers deposited on the substrate are n-type semiconductor, p-type semiconductor and active region.
Active region is present in between the n-type and p-type semiconductor layers.
When LED is forward biased, free electrons from n-type semiconductor and holes from p-type semiconductor are pushed towards the active region

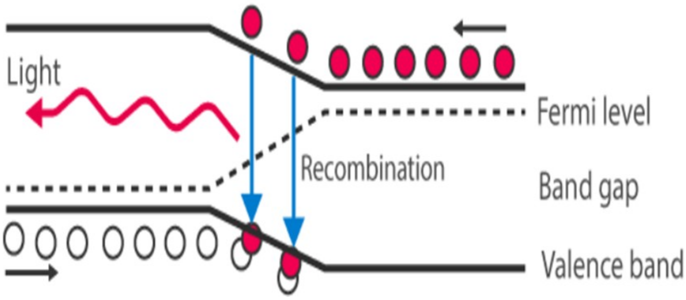


Construction of LED

1.5.1 Working of LED

The light emitting diode works like a normal PN-junction diode. When the diode is forward biased, then the current flows through the diode. The flow of current in the semiconductors is caused by the both flow of holes in the opposite direction of current and flow of electrons in the direction of the current. Hence there will be recombination due to the flow of these charge carriers.





The recombination indicates that the electrons in the conduction band jump down to the valence band. When the electrons jump from one band to another band, the electrons will emit the electromagnetic energy in the form of photons and the photon energy is equal to the energy band gap (Eg)

1.5.2. Advantages of LED

Light emitting diodes consume low energy.
LEDs are very cheap and readily available.
LEDs are light in weight.
Smaller size.
LEDs have longer lifetime.
LEDs operates very fast.

1.5.3. Applications of LED

LED is used as a bulb in the homes and industries
Burglar alarms systems
Calculators
Picture phones
Traffic signals
Digital computers

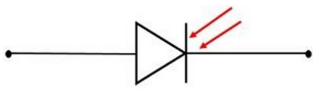
Multimeters
Microprocessors
Digital watches

1.5.4. Some common materials used for LED

Some commonly used LEDs and material are used in LED’s mentioned below:
Gallium Arsenide (GaAs) – infra-red
Gallium Arsenide Phosphide (GaAsP) – red to infra-red, orange
Aluminium Gallium Arsenide Phosphide (AlGaAsP) – high-brightness red, orange-red, orange, and yellow
Gallium Phosphide (GaP) – red, yellow and green
Aluminium Gallium Phosphide (AlGaP) – green
Gallium Nitride (GaN) – green, emerald green
Gallium Indium Nitride (GaInN) – near ultraviolet, bluish-green and blue
Silicon Carbide (SiC) – blue as a substrate
Zinc Selenide (ZnSe) – blue Aluminium Gallium Nitride (AlGaN) – ultraviolet

1.6 Photodiode

A photodiode is a semiconductor device that converts light (photons) into an electrical current. Designed primarily as a light detector, it operates in reverse bias and produces a current proportional to the intensity of incident light. Photodiodes are widely used in applications such as optical communication, light sensing, medical equipment, and many electronic devices.



Symbolic representation of Photodiode

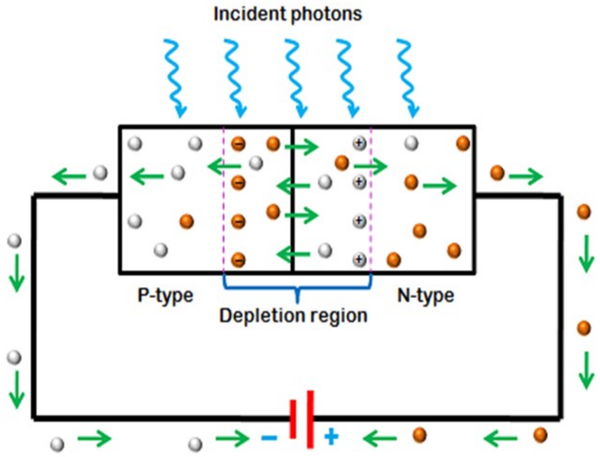
1.6.1 Principle of Photodiode

When photons with sufficient energy strike the active region (typically the depletion layer) of a photodiode, they generate electron-hole pairs. These charge carriers are quickly separated by the built-in electric field, resulting in a flow of current, known as photocurrent. The photocurrent is directly proportional to the light intensity falling on the photodiode. Most photodiodes are operated in reverse bias to maximize sensitivity and speed.

Types of Photodiodes
PN Junction Photodiode
PIN Photodiode
Avalanche Photodiode (APD)

1.6.2 Construction

Made from a piece of semiconductor material, usually silicon.
Has two regions: p-type and n-type, forming a p-n junction.
The junction creates a depletion region, which is sensitive to light.
Metal contacts are attached to both sides to connect the device to a circuit.
The top is covered with a transparent window or casing to let light reach the depletion region.
Sometimes, an extra undoped (intrinsic) layer is added for better sensitivity.
Overall, the photodiode is designed to absorb light and quickly generate an electrical current.



1.6.3 Working

The photodiode is typically operated in reverse bias (the p-side is connected to negative, n-side to positive). When photons with sufficient energy enter the depletion region, they are absorbed, creating electron-hole pairs. The built-in electric field across the depletion region quickly separates these pairs: electrons are swept to the n-side, holes to the p-side, creating a photocurrent that flows through the external circuit. The magnitude of this current is proportional to the intensity of incident light. Photodiodes can detect rapid changes in light and respond to a wide range of intensities.

1.6.4 Application

Optical Communication: Used in fiber-optic receivers to convert light signals into data.
Light Measurement: Photometers, light meters, and exposure meters in cameras.
Safety and Security: Smoke detectors, intrusion sensors, and fire alarms.
Medical Devices: Pulse oximeters, medical imaging, and scintillation detectors.
Bar Code & QR Code Scanners: Detect reflected light patterns.

Consumer Electronics: Remote-control receivers, CD/DVD players.
Industrial Automation: Position sensors, object counters, and robotics.

1.6.5 Disadvantages of PN junction photodiode

Low Sensitivity: The depletion region (where light is absorbed and charge carriers are generated) is thin, so fewer electron-hole pairs are created per incident photon.
Slow Response Time: Narrow depletion region means slower collection of carriers; hence it is not ideal for high-speed applications.
High Capacitance: Small depletion region leads to high junction capacitance, further limiting speed.
Lower Quantum Efficiency: Less light is absorbed in the thin depletion region.

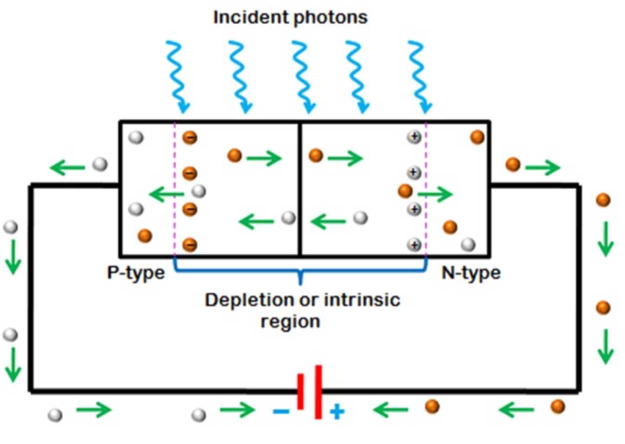
1.7 PIN Photodiode

The weakness of the simple PN photodiode in speed and sensitivity led to the invention of the PIN photodiode, which improved both by expanding the depletion region for better light absorption and faster response

1.7.1 construction

A PIN photodiode is a semiconductor device built with three key layers:

P-type layer: This is the positively doped region where holes (positive charge carriers) dominate.
Intrinsic (I) layer: Sandwiched between the P and N layers, this region is undoped (pure semiconductor), significantly increasing the width of the depletion region. This wide intrinsic section is crucial for enhancing light absorption and the generation of electron-hole pairs.



PIN photodiode

Structure:
The stack follows a P–I–N sequence. Metal contacts are attached to the P and N regions to connect the photodiode to an external circuit. The top is usually encapsulated with a transparent window, allowing light to effectively reach the intrinsic region. N-type layer: The negatively doped region where electrons (negative charge carriers) are the majority carriers.

1.7.2 Working

The PIN photodiode is typically operated with Reverse Bias Operation. This bias increase the width of the depletion region across the intrinsic layer and enabling efficient light absorption.

When light photons enter the intrinsic region, they are absorbed and producing electron-hole pairs (EHP) within this zone.
The EHP built-in electric field across the wide intrinsic region rapidly drives electrons towards the N-side and holes towards the P-side.
The movement of these charge carriers creates a current through the external circuit. This current is called photocurrent and is directly proportional to the intensity of incident light.

1.7.3 Applications

Optical communication systems: Detecting light signals in fiber optic links.
Photodetectors: Employed in imaging devices, medical instruments, and scientific measurement equipment.
Remote control receivers: Used in TVs, set-top boxes, and other consumer electronics.
Environmental and safety monitoring: Used in smoke detectors, radiation detectors, and light sensors.
Industrial & automotive: Light detection in automation, barcode scanners, and safety systems.
High-energy physics and nuclear instrumentation: For detecting X-rays, gamma rays, and other forms of ionizing radiation

1.8 Avalanche Photodiode

Limitation of PIN: Fails in ultra-low-light or long-distance systems where weak signals must be reliably detected.

Even with these improvements, PIN diodes couldn't efficiently detect very low light levels without further amplification. The development of the APD introduced internal gain, allowing detection of very weak signals—at the cost of higher voltage, added noise, and system complexity

An Avalanche Photodiode (APD) is a type of photodiode specially designed to provide high sensitivity by internally amplifying the photocurrent through avalanche multiplication. Its construction is somewhat similar to a PIN photodiode but has additional structural features for avalanche action:

It consists of a p+ - i - p - n+ layered structure:
p+ and n+ layers: Heavily doped regions that serve as the anode and cathode contacts.
Intrinsic (i) layer: Undoped or lightly doped region where most of the photon absorption and electron-hole generation takes place

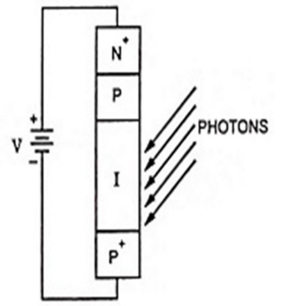


Fig. 25.27 *Structure of Avalanche Photodiode*

1.8.1 Construction

Lightly doped p-region: Positioned near the multiplication region, this high-resistivity layer helps to create a high electric field in a narrow depletion region known as the multiplication region.

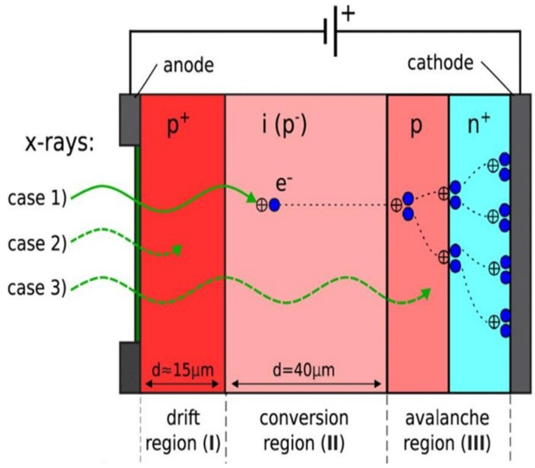
The APD is designed to operate under a high reverse bias voltage, close to its breakdown voltage, to create a strong electric field in the multiplication region.
The depletion region in APD is narrower compared to a PIN photodiode but experiences much higher electric fields

1.8.2 Working

When photons enter the APD, they are absorbed primarily in the intrinsic region, creating electron-hole pairs, similar to a regular photodiode.

Under the applied high reverse bias voltage, these carriers (electrons and holes) gain high kinetic energy as they move through the multiplication region.

The energetic carriers collide with the lattice atoms, causing impact ionization, which generates additional electron-hole pairs



This process creates an avalanche multiplication of charge carriers, greatly amplifying the photocurrent. The gain (multiplication factor) depends strongly on the reverse bias voltage; higher voltages create stronger electric fields and thus higher multiplication, but also increase noise.
This internal gain allows APDs to detect very weak light signals with high sensitivity, making them suitable for low-light or high-speed applications.

1.8.3 Applications

Fiber-optic communication: For receiving and detecting low-level opticalsignals over long distances.

Laser rangefinders and LIDAR: Detect faint reflected laser pulses to measure distance.

Medical instrumentation: Positron emission tomography (PET) scanners and other imaging equipment.

Scientific research: High-energy physics detectors and photon counting.

Military and aerospace: Low-light detection and imaging systems.

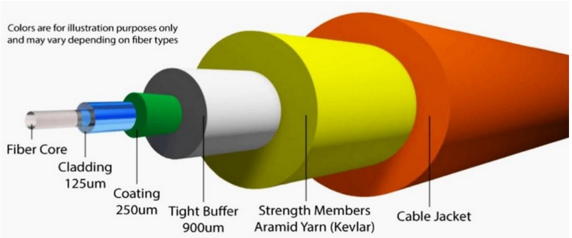
Optical sensors: Smoke detectors and environmental monitoring with weak light signals.

1.9 Optical Fibre

Optical fiber technology is fundamentally used in modern telecommunication, medical devices, and networking, because of its capacity for high-speed, high-volume data transmission.

It is a technology in which electrical signals are converted into optical signals, transmitted through a thin glass fiber and reconverted into electrical signals.

Optical fibers are resilient to electromagnetic interference, atmospheric wear and tear, etc.



1.9.1 Structure of an optical fibre

Core: This is the innermost and central region where the light actually travels. It's made of high-purity glass or plastic and has a higher refractive index than the surrounding materials. The core diameter is typically 9–10 microns for single-mode fibers and 50–62.5 microns for multimode fibers.

Cladding: This layer surrounds the core and has a slightly lower refractive index. Its primary job is to keep the light confined within the core by causing total internal reflection at the core-cladding interface.

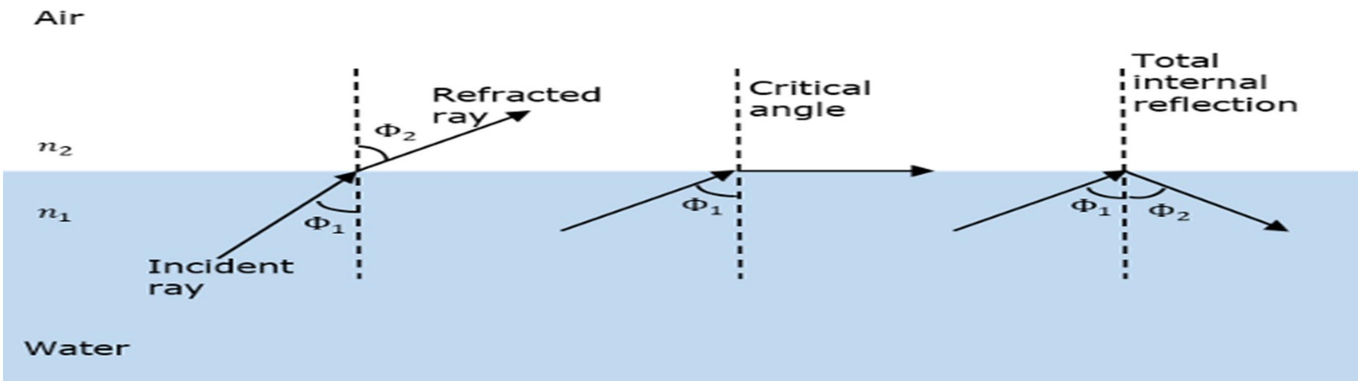
Coating (Buffer Coating): The cladding is covered by a protective coating, usually a polymer layer (or two layers: "soft" for cushioning and "hard" for abrasion resistance). The coating protects the delicate glass fiber from physical damage and moisture.
Additional Components in Fiber Optic Cable Construction

Strengthening Fibers: Materials like aramid yarn (Kevlar) are used to add mechanical strength and protect the fiber from tension and stress during installation.

Cable Jacket (Outer Sheath): This is the external plastic covering that shields the cable from the environment, mechanical damage, and provides overall durability.

1.9.2 Principle of an optical fibre

When a light ray travels from denser to rarer medium, the ray bends away from the normal.
If the incident angle goes on increasing, the refracted ray further moves away from the normal and at a certain angle called critical angle (C) the refracted ray travels parallel to the interface.
Now if the incident angle becomes more than critical angle (C), then the ray is completely reflected back in the same medium. This is called Total Internal Reflection (TIR).



- Consider light traveling from a denser medium with refractive index n_1 to a rarer medium with refractive index n_2, where $n_1 > n_2$. Let the angle of incidence be i and the angle of refraction be *r*.

- Applying Snell's Law: The relationship between these angles and refractive indices is given

$$n_1 \sin i = n_2 \sin r$$

- When the angle of refraction $r = 90^o$, the refracted ray grazes along the boundary. The angle of incidence corresponding to this situation is called the critical angle, θ_c.

$n_1\, sin\, \theta_c = n_2\, sin\, \theta_2$

Since, $\theta_2 = 90^o \Rightarrow \; sin\, 90^o = 1$

$\therefore\, n_1 \sin \theta_c = n_2$

$\therefore\, \sin \theta_c = \frac{n_2}{n_1}$

Condition for Total Internal Reflection:

- The light must travel from a denser to a rarer medium ($n_1 > n_2$).

- The angle of incidence must be greater than the critical angle, i.e., $i > \theta_c$.

→ When $i > \theta_c$, no refraction occurs; instead, the light is totally reflected inside the denser medium—this is total internal reflection.

1.9.3 Acceptance angle and numerical aperture

The Acceptance Angle of an optical fiber is the maximum angle at which light can enter the fiber core and still be guided through the fiber by total internal reflection.

In other words, it is the largest angle between the incident light ray and the fiber axis for which the light will stay confined within the core and propagate along the fiber without escaping into the cladding.

At the entrance of light : From Snell's law,

- $n_0 \sin i = n_1 \sin \theta$
- $n_0 \sin i = n_1 \sin(90 - \phi)$ (from fig : $\theta + \phi = 90$)
- $n_0 \sin i = n_1 \cos \phi$

At $i = i_A\,;\phi = \phi_c\ (cricle\ angle)$

Thus,

$$n_0 \sin i_A = n_1 \cos \phi_c$$

$$\therefore\ n_0 \sin i_A = n_1\sqrt{1 - \sin^2 \phi_c}$$

$$\therefore n_0\ \sin i_A = n_1 \sqrt{1 - \left(\frac{n_2}{n_1}\right)^2}$$

$$\therefore n_0\ \sin i_A = \sqrt{{n_1}^2\ - {n_2}^2}$$

$$\therefore \mathrm{NA} = \sin i_A = \sqrt{{n_1}^2\ - {n_2}^2}$$

1.9.4 classification of optical fibre

Based on Refractive Index

Step-index fibers

In step-index fibers the refractive index of the core is constant along the radial direction and abruptly falls to a lower value at the cladding and core boundary.

Graded-index (GRIN) fibers

In the case of GRIN fibers, the refractive index of the core varies smoothly over the diameter of the core. It has a maximum value at the center and decreases gradually towards the edge of the core.

<u>Based on modes</u>

Single Mode Step-INDEX fibers

Core Diameter: Very small, typically around 8 to 10 micrometers (μm).

Structure: The core has a uniform refractive index, and there is an abrupt change (step) to a lower refractive index in the cladding.

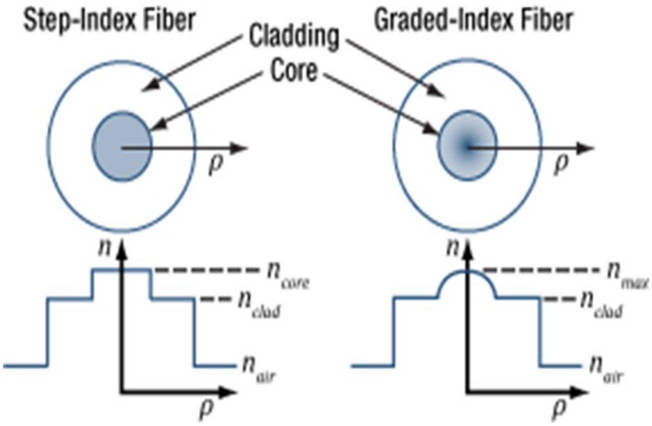
Mode of Propagation: Supports only one light mode (the fundamental mode) because of the small core diameter and refractive index profile.

Light Behavior: Light travels straight along the fiber axis without much reflection or dispersion since only one mode is guided

Advantages:

Very low modal dispersion, resulting in high bandwidth.

Suitable for long-distance communications such as telecommunications and internet backbones.



2. Multimode Step-Index Fibers

Core Diameter: Larger, typically between 50 and 62.5 µm.
Structure: The core has a uniform refractive index, and the cladding's refractive index abruptly steps down.
Mode of Propagation: Supports multiple propagation modes (light rays travel through different paths).
Light Behavior: Light rays reflect sharply at the core-cladding interface, traveling different lengths and times.
Disadvantages: Modal dispersion occurs because different light modes take different paths, causing pulse broadening and limiting bandwidth and distance.
Applications: Suitable for short-distance communication such as within buildings or local area networks (LANs).
3. Graded-Index (GRIN) Fibers

Core Diameter: Typically, similar to multimode fibers (e.g., 50 to 62.5 µm).
Structure: The core refractive index decreases gradually from the center to the outer edge, forming a parabolic or graded profile instead of an abrupt step.
Mode of Propagation: Supports multiple modes like multimode step-index fibers.
Light Behavior: The gradual change in refractive index causes light rays to bend smoothly instead of reflecting sharply, which equalizes the travel time of different modes.
Advantages:
Reduces modal dispersion compared to step-index multimode fibers.
Improves bandwidth and allows longer transmission distances than multimode step-index fibers.
Applications: Used in medium-distance communication systems requiring better performance than multimode step-index fibers.

As a light signal propagates through a fiber it suffers loss of amplitude and changes in shape. The loss of amplitude is referred to as attenuation and the change in shape as distortion.

1.9.4 Losses in optical Fibre

Attenuation: When an optical signal propagates through a fiber, power of the signal decreases exponentially with distance. The loss of optical power as light travels down a fiber is known as Attenuation.
The attenuation of optical signal is defined as the ratio of the optical output power from a fiber of length L to the input optical power.

If P_i is the optical power launched at the input end of the fiber, then the power P_o at a distance L down the fiber is given by,

$$\alpha = \frac{L}{10}\log_{10}\frac{P_i}{P_o}$$

where,
α= fiber attenuation coefficient

In case of an ideal fiber, P_0 = P_i and the attenuation would be zero.

The unit of measurement of attenuation is **decibel/kilometer (dB/km)**.

1.9.5 Applications of optical Fibre

Security: It is difficult to tap optical fibers without detection, enhancing data security.

Low Signal Loss: Optical fibers have low attenuation, resulting in less signal loss during transmission.

Resistance to Corrosion and Harsh Environments: Optical fibers are not affected by moisture or chemicals, making them durable in harsh environments.

Military and Aerospace

Fibers are used in military communication and aerospace for secure, lightweight, and high-capacity communication lines that are resistant to electromagnetic interference.

Lighting and Decorations

Due to their ability to transmit light efficiently, they are used for decorative lighting, Christmas lights, and architectural lighting.

Safety: Optical fibers do not conduct electricity, reducing risk of electrical hazards.

Data Networks

They serve as the main medium for local area networks (LANs), wide area networks (WANs), and data centers due to their high speed and bandwidth capabilities.

Sensing and Imaging

Optical fibers are used in sensors to monitor temperature, pressure, and other physical parameters in environments difficult to access or harsh conditions. They are also used in industrial imaging to inspect small or intricate areas.

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