OPTICAL SOURCES

By: Irfan Latif Khan

Optical Sources

- There are two types of light sources used in fiber optic:
  - Light Emitting diode (LED)
  - LASER diodes (LD's)

- LED's may have two types of source:
  - Surface-emitting LED
  - Edge-emitting LED

Optical Sources

- LASER diodes are:
  - Fabry- Perot
  - Distributed feed back (DFB)
  - Vertical cavity surface-emitting Laser (VCSEL)

- All light emitters are complex semiconductors that convert an electrical current in to light.

Optical Sources

- The conversion process in fairly efficient as it creates very little heat compared to the heat generated by incandescent lights.

Optical Sources

- LED's and Laser diodes are of interest for fiber optic because of five inherent characteristics.

  - Small size
  - High radiance
    (Emit a lot of light in a small area)
  - Small emitting area
    (Area is comparable to the dimension of optical fiber cores)

Optical Sources

- Very long life
  (offer high reliability)
- Can be modulated at high speed

- LED's are used as visible indicator in most electronics equipment.
- LASER diodes are most widely used in compact disk players.

Optical Sources

- The LED's used in fiber optic differ from the more common indicator LED's in two ways.
  - The wavelength in generally in the near infrared because the optical loss of fiber is the lowest at these wavelengths.
  - The LED emitting area is generally much smaller to allow the highest possible modulation bandwidth and improve the coupling efficiency with small core optical fibers.

Optical Sources

Optical Sources Performance Characteristics

- Peak wavelength
- Spectral width
- Emission pattern
- Power
- Speed

Cost/Performance trade off

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How Light is Generated

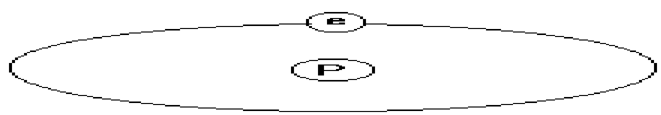
- Atoms contain two specific types of energy:
  - Binding energy of nucleus.
  - Electron energy.
- Electrons have different specific energy levels in which they move around the nucleus.

How Light is Generated

- Forbidden zone between each energy level is known as **“Energy gap”**.
- For an electron to move from one energy level to another, it must gain or lose the exact energy difference between the two levels.

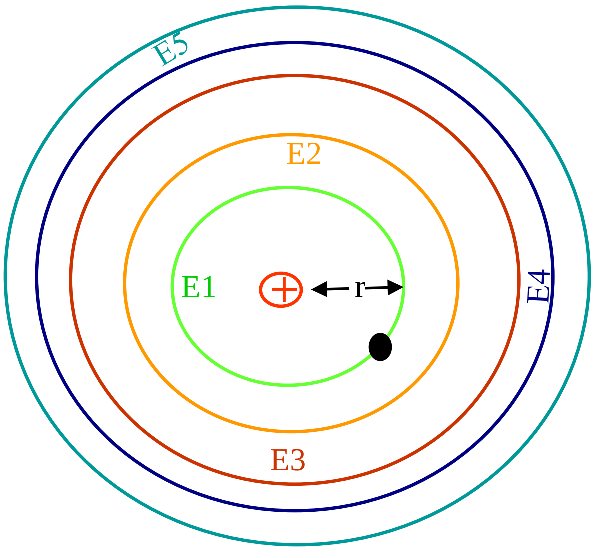
How Light is Generated

- When the electron is orbiting in the nucleus at its lower energy level E_1, it is said to be in its unexcited or ground state.

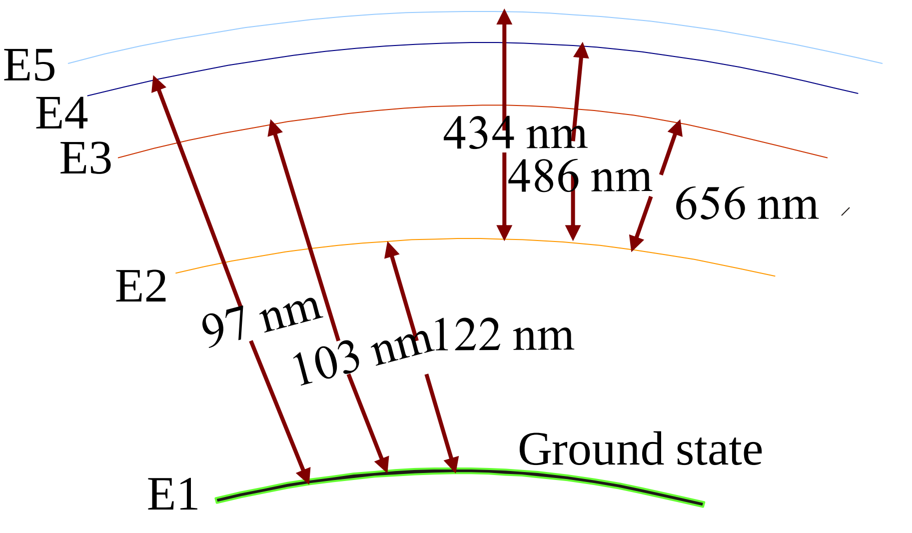


Bohr model of the hydrogen atom

How Light is Generated



Bohr model of the hydrogen atom showing permissible electron energy levels.



Energy level diagram of the hydrogen atom.

How Light is Generated

Direct Transition.

- When the stimulated electron drops directly back to its ground state, its called direct transition.

Indirect Transition.

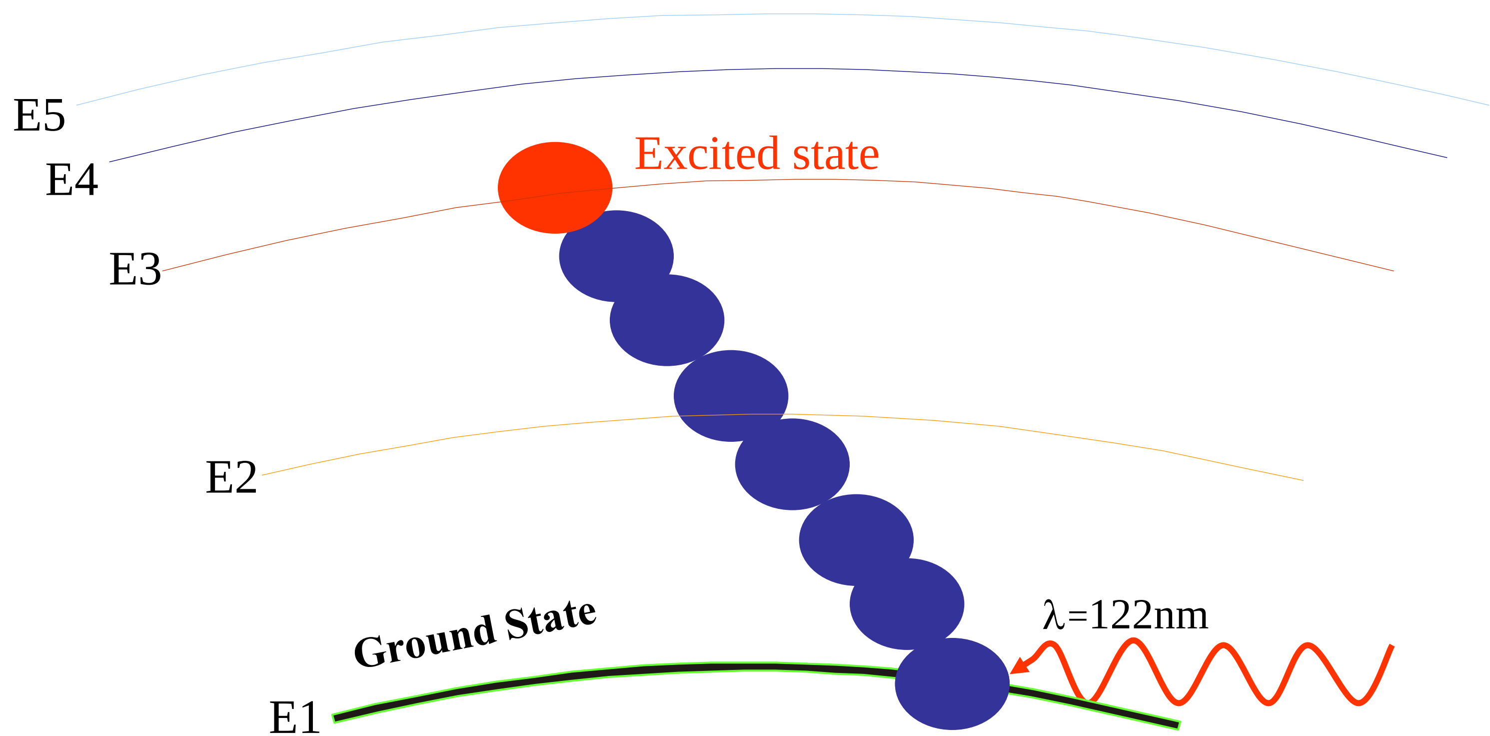
- When the electron returns to its ground state in two or more steps, its called indirect transition.

How Light is Generated

- The result of direct transition is emission of radiations of a single wavelength.

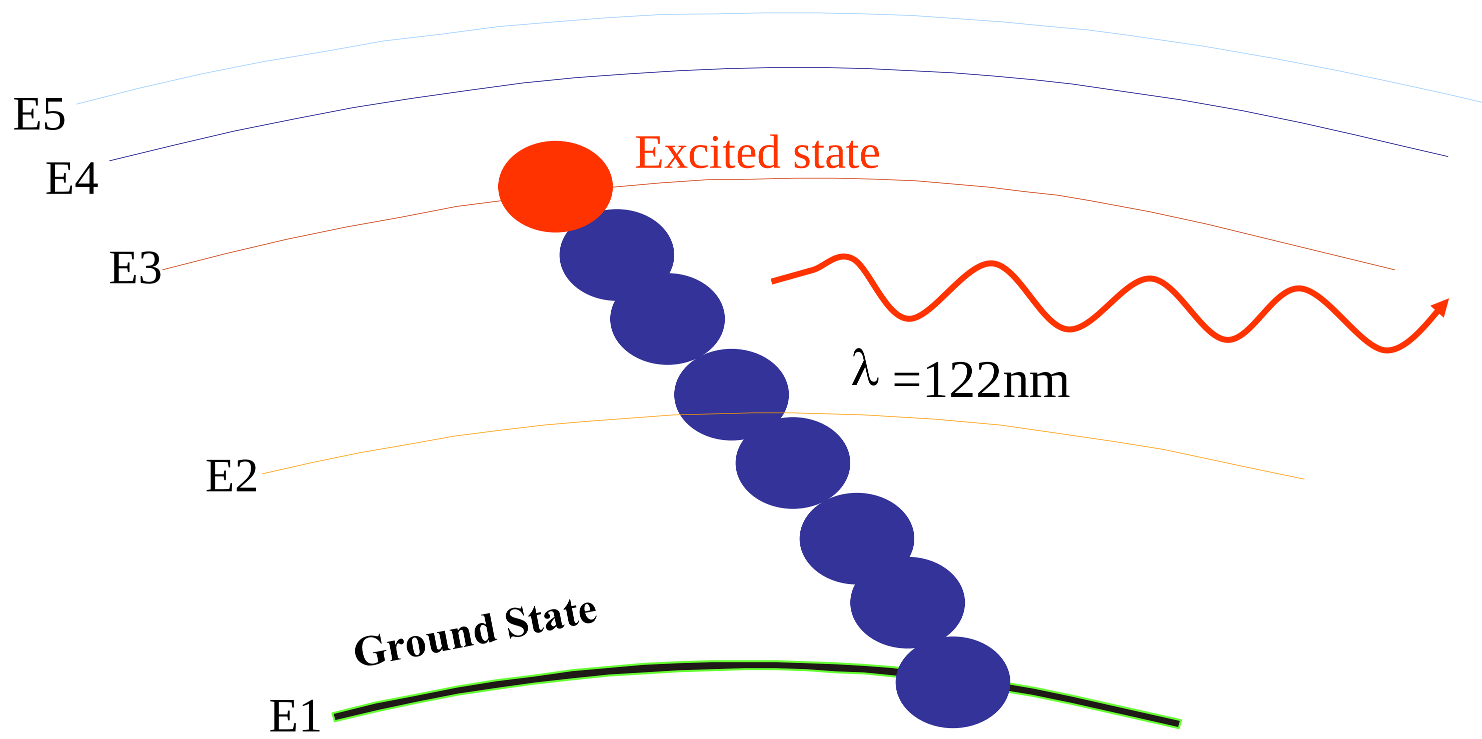
- The result of indirect transition is the emission of radiations of two or more wavelengths.

How Light is Generated



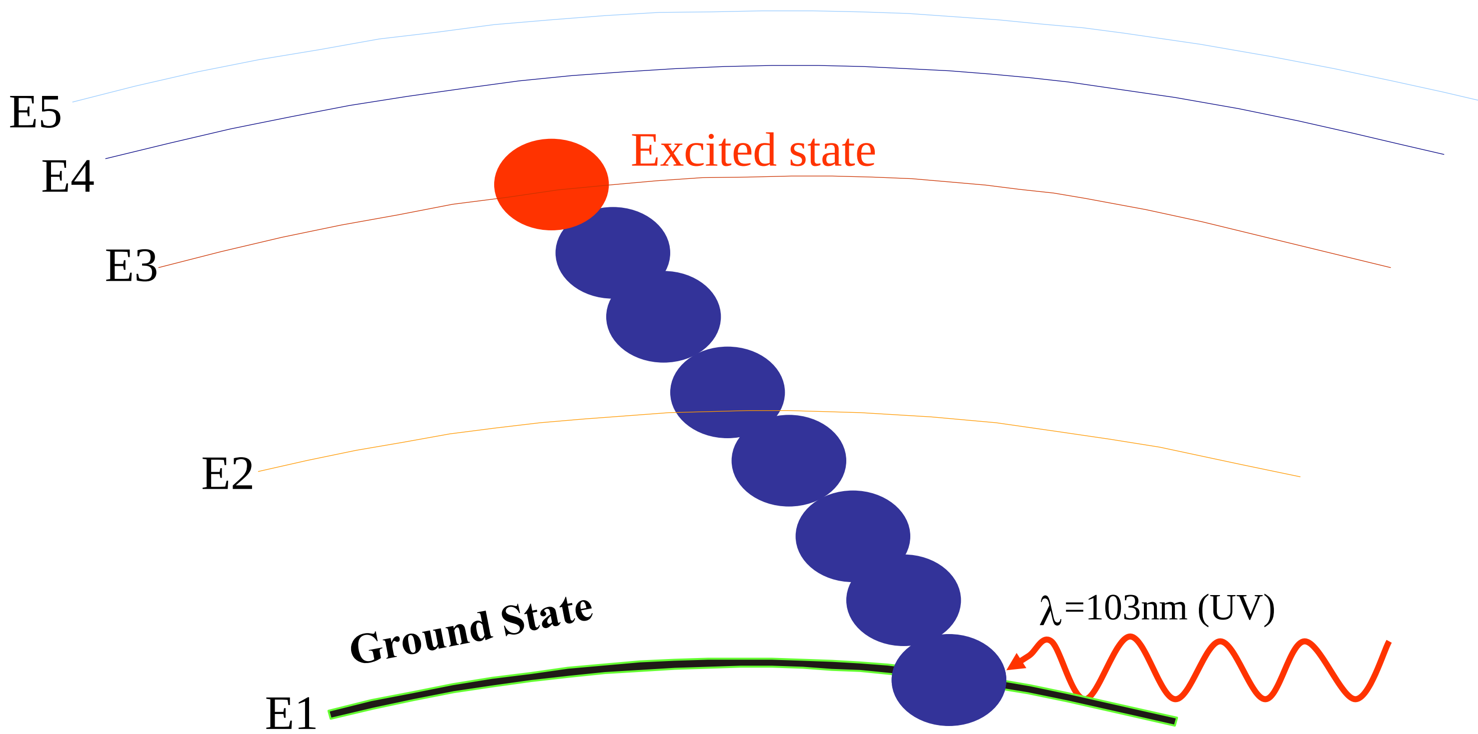
Electron Energy Absorption

How Light is Generated



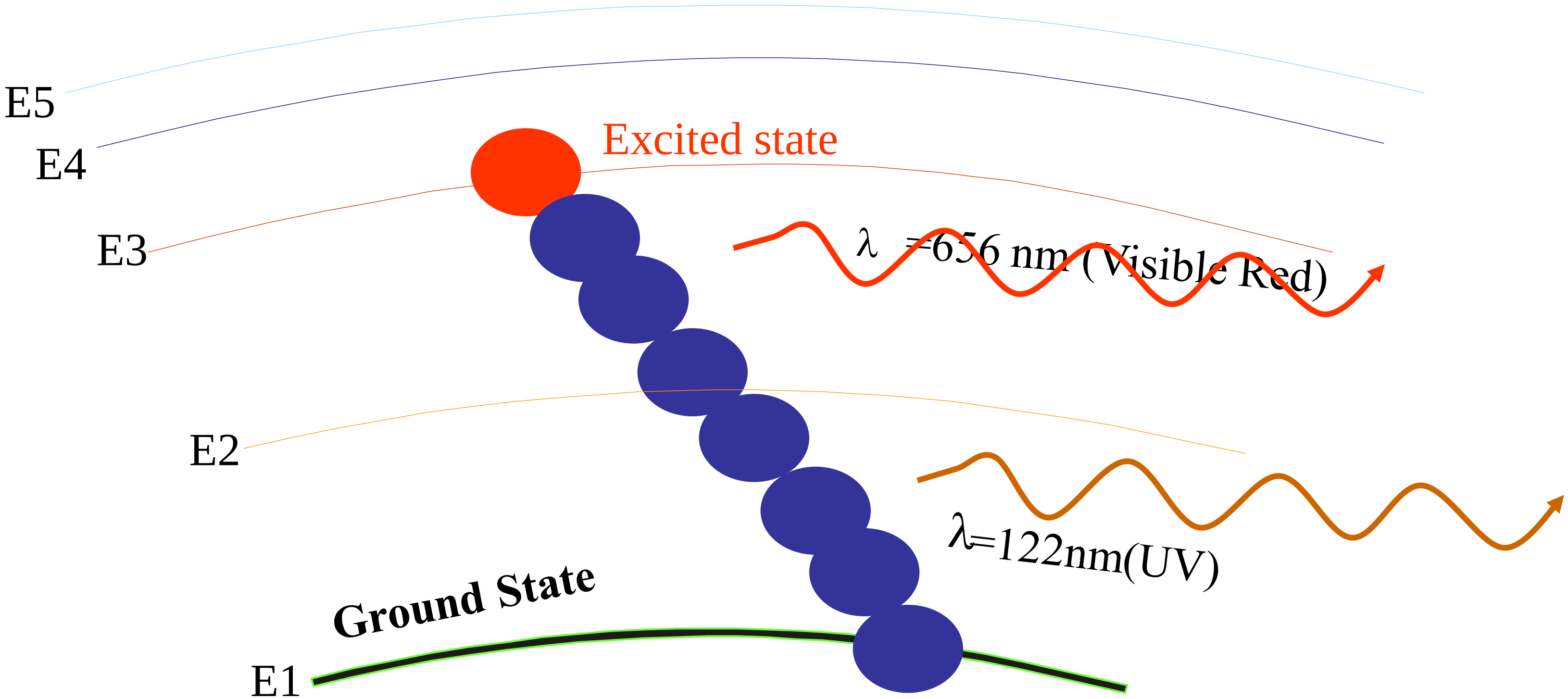
Direct transition

How Light is Generated



Indirect transition.

How Light is Generated



Indirect transition

How Light is Generated

How an atom can be stimulated ?

- Atom is stimulated by using light energy.
- Energy can also be imparted to an atom by heat, Electrical force or by collision with other particles.

Semiconductor Material

- **Semiconductors**
  - Conduction properties lie between conductor and insulator
  - Conduction properties can be described by Energy Bands
  - At low temperature conduction band is completely empty
  - By raising the temperature, electron exited across the band gap.

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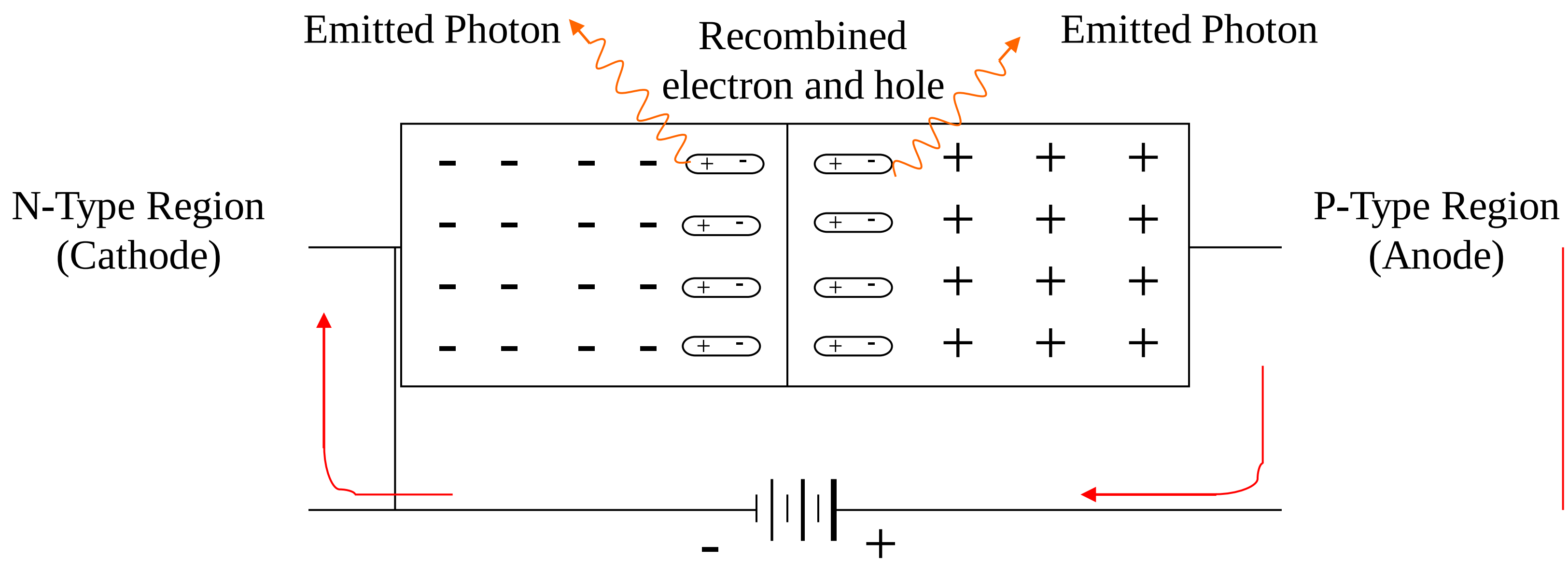
Light-Emitting Diodes (LEDs)

- Best Light source for bit rates less than approx 100 – 200 Mb/s and multimode fiber.
- LED is a solid-state component and has nearly unlimited life expectancy.
- It is physically more sturdy than its glass-encapsulated predecessors and requires far less operating power.

LED Operation

- LED is a PN junction diode that emits light through the recombination of electrons and holes when current is forced through its junction.

LED Operation



Basic operation of a light emitting diode

LED Driver Circuits

- The optical output of LED is approximately proportional to the drive current.
- LEDs are usually driven with either a digital signal or an analog signal.
- The key concern is driving the LED so that maximum speed is achieved.

LED Structures

- LED for optical used should have
  - High radiance out put
  - Fast emission response time
  - High quantum efficiency
  - High confinement of the charge carrier to the active region of PN junction
  - For this double hetrostructure configuration is used

LED Structures

- Two different alloy layers on each side of the active region
- Recombination region is maximum confined to 0.3 um.
- Two LED configuration
  - Surface emitter
  - Edge emitter

LED Structures

Radiance or brightness:

It is a measure ,in watts, of the optical power radiated into a unit solid angle per unit area of emitting surface

Emission response time:

It is the time delay between the application of a current pulse and the onset of optical emission.

Quantum efficiency:

It is related to fraction of injected electron-hole pairs that recombine radiatively.

LED Structures

Charge carrier confinement:

It is used to achieve a high level of radiative recombination in the active region of the device.

Optical confinement:

It is used to prevent absorption of the emitted radiation by the material surrounding the pn junction

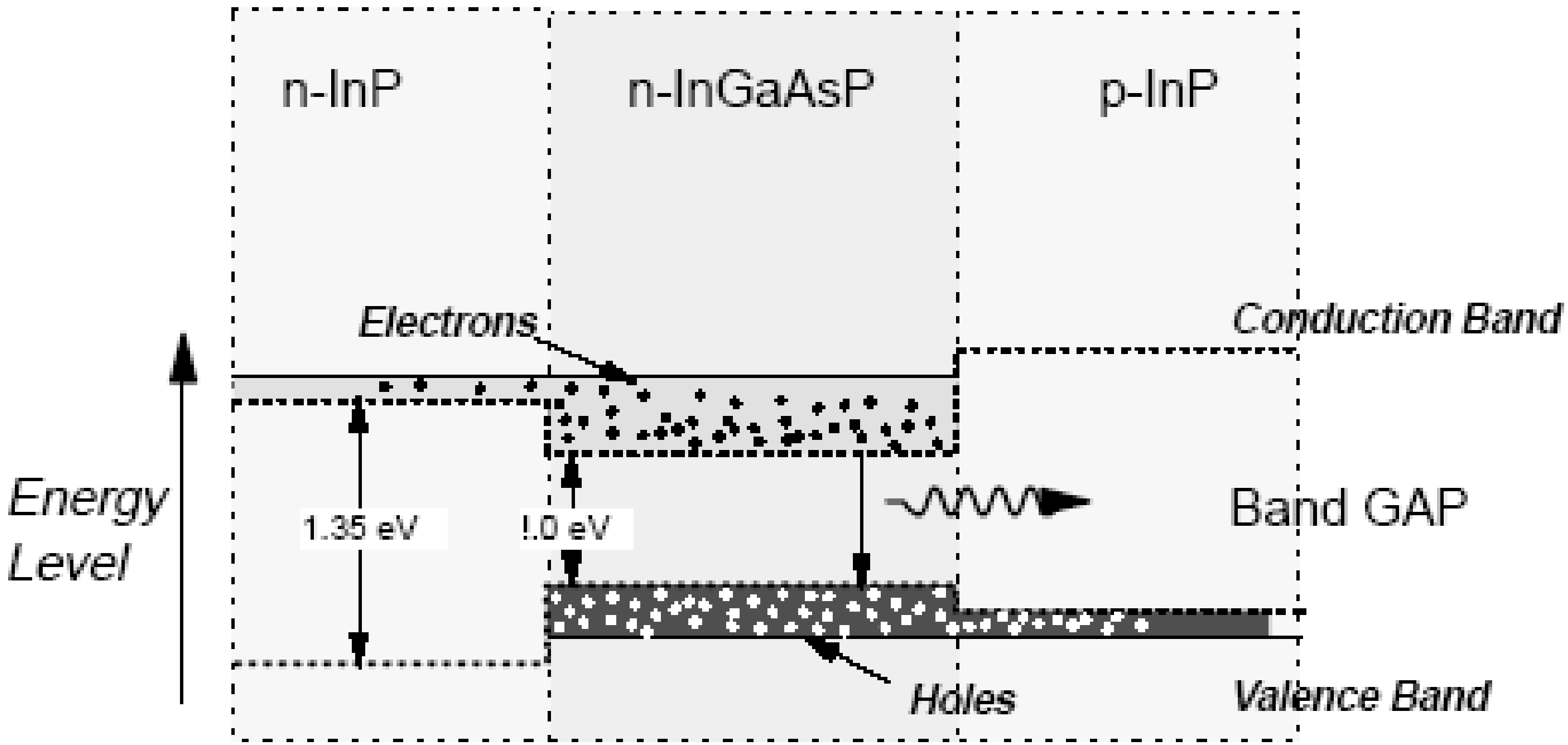
*By confining the charge carrier and optical emission high radiance and high quantum efficiency can be achieved

LED Structures

To achieve carrier and optical confinement double heterostructure of two different alloy layers on each side of active region is used.

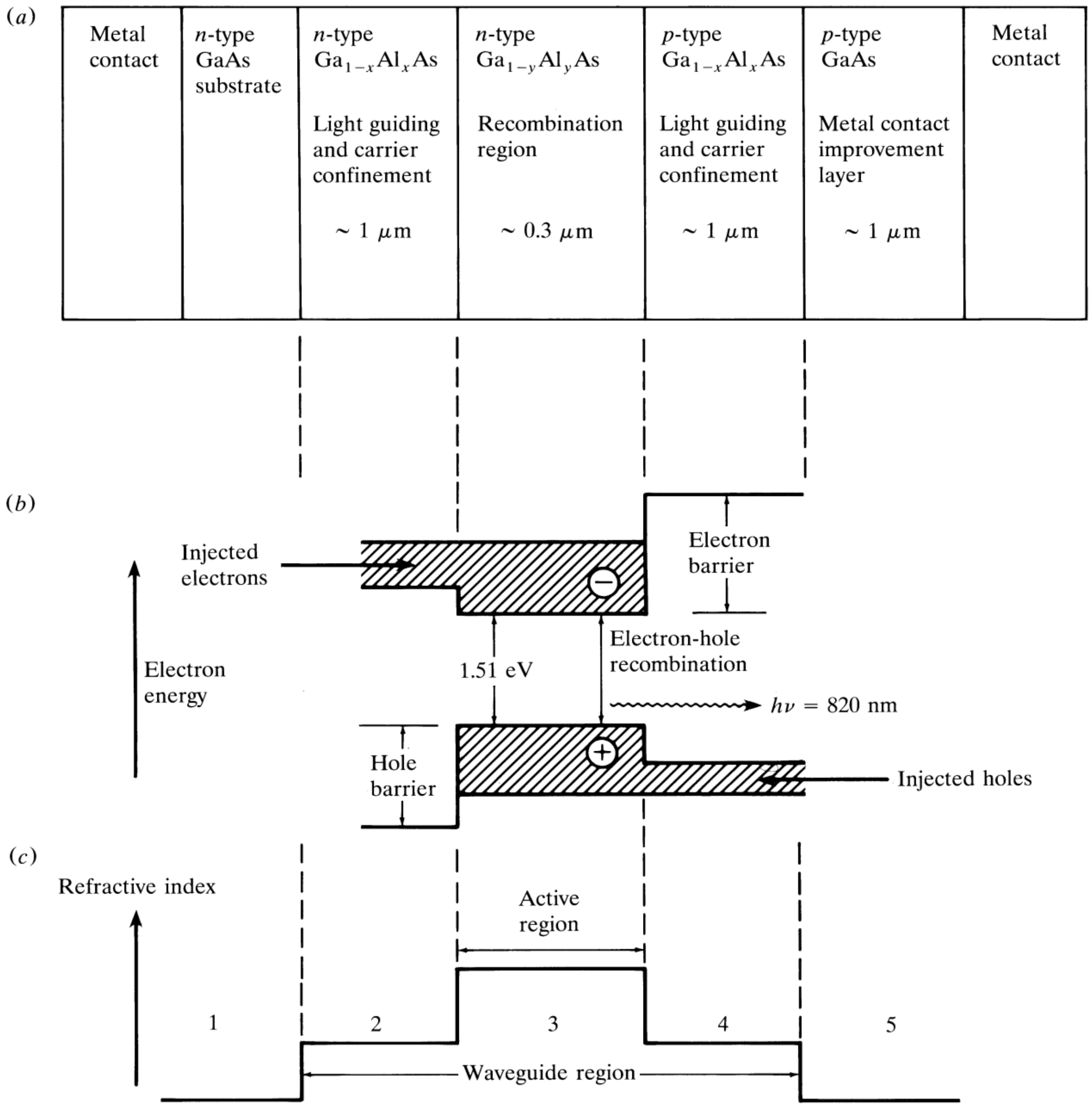
The band gap differences of adjacent layers confine the charge carriers, while the difference in the indices of refraction of adjoining layers confine the optical field to the central active region.

This dual confinement leads to both high efficiency and high radiance.



***Energy Bands in a Double Heterojunction**

Double-heterostructure configuration



Surface-emitting LED

- Emitting region is perpendicular to the axis of the fiber
- The circular active area in practical surface emitters is nominally 50 um in diameter and up to 2.5 um thick.
- The emission pattern is essentially isotropic with a 120 half power beam width.

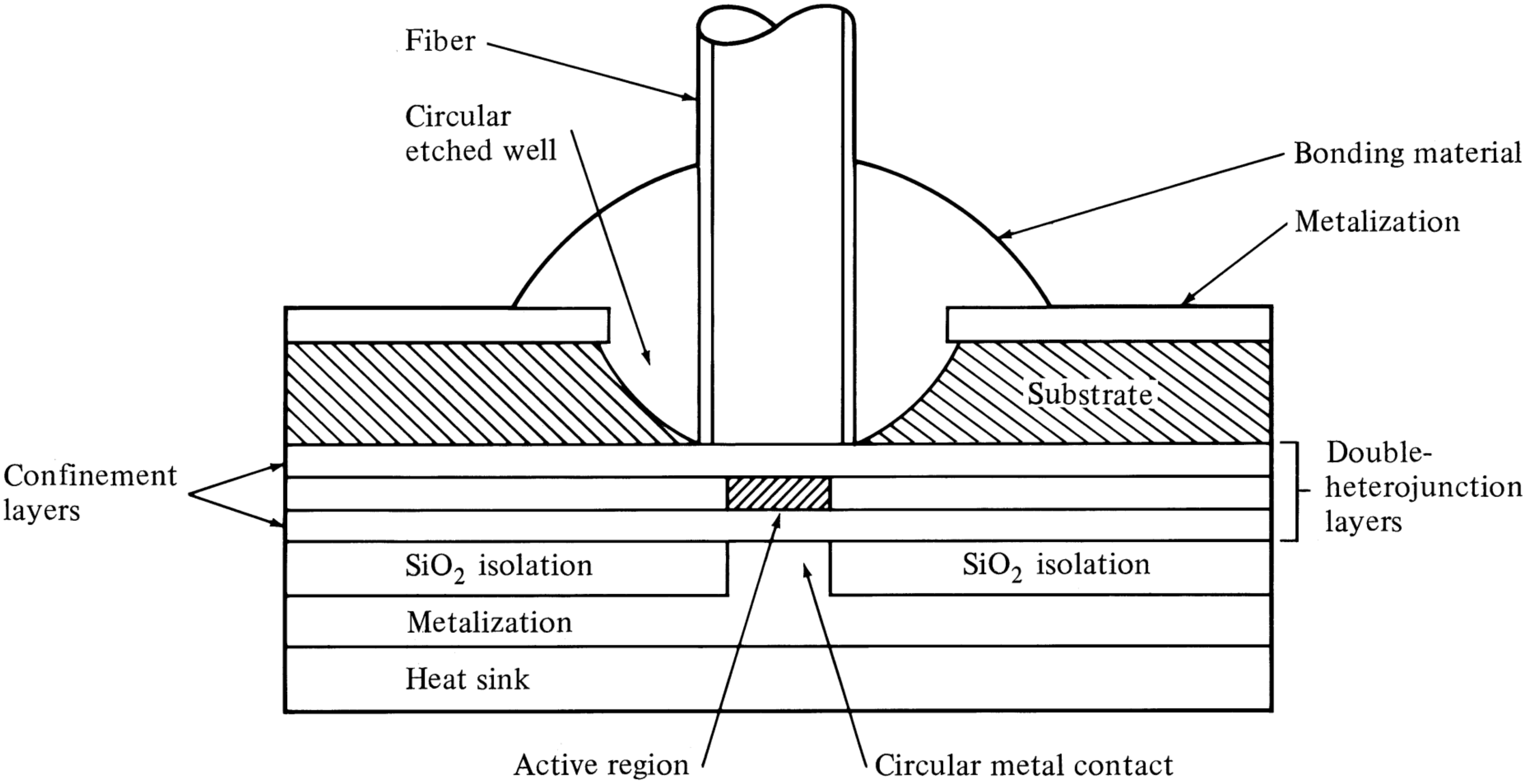
Surface-Emitting LED's

- The surface-emitting LED (SLED) emits light over a vary wide angle. This type of light source is often called a Lambertian emitter, because of the nature of the emission pattern

- This broad emission angle is attractive for use as an indicating LED, therefore it is difficult to focus more than a small amount of the total light output in the fiber.

Surface-Emitting LED’s

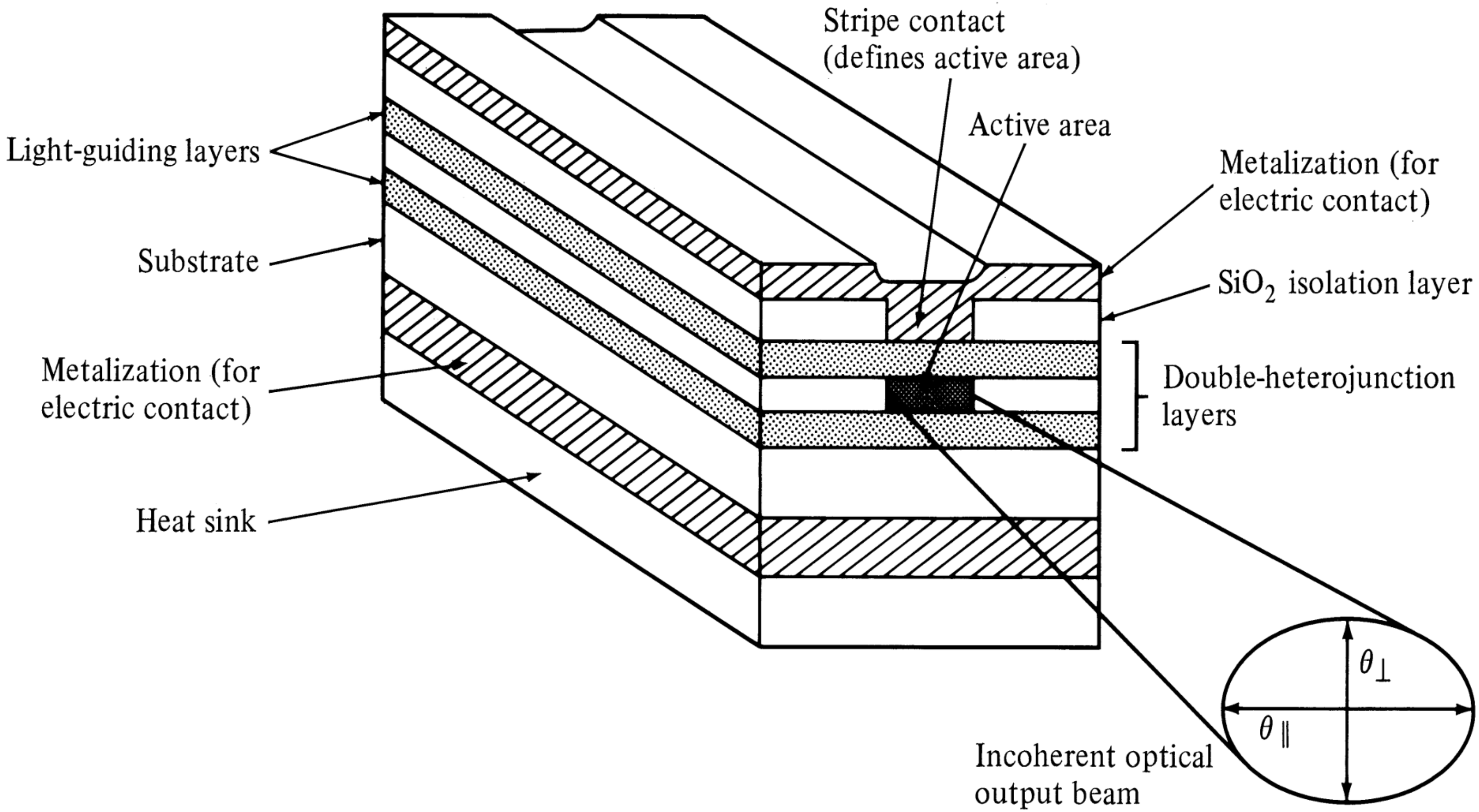
- The key advantage of surface-emitting LED’s is their low cost, making these light emitters the dominant type in use.



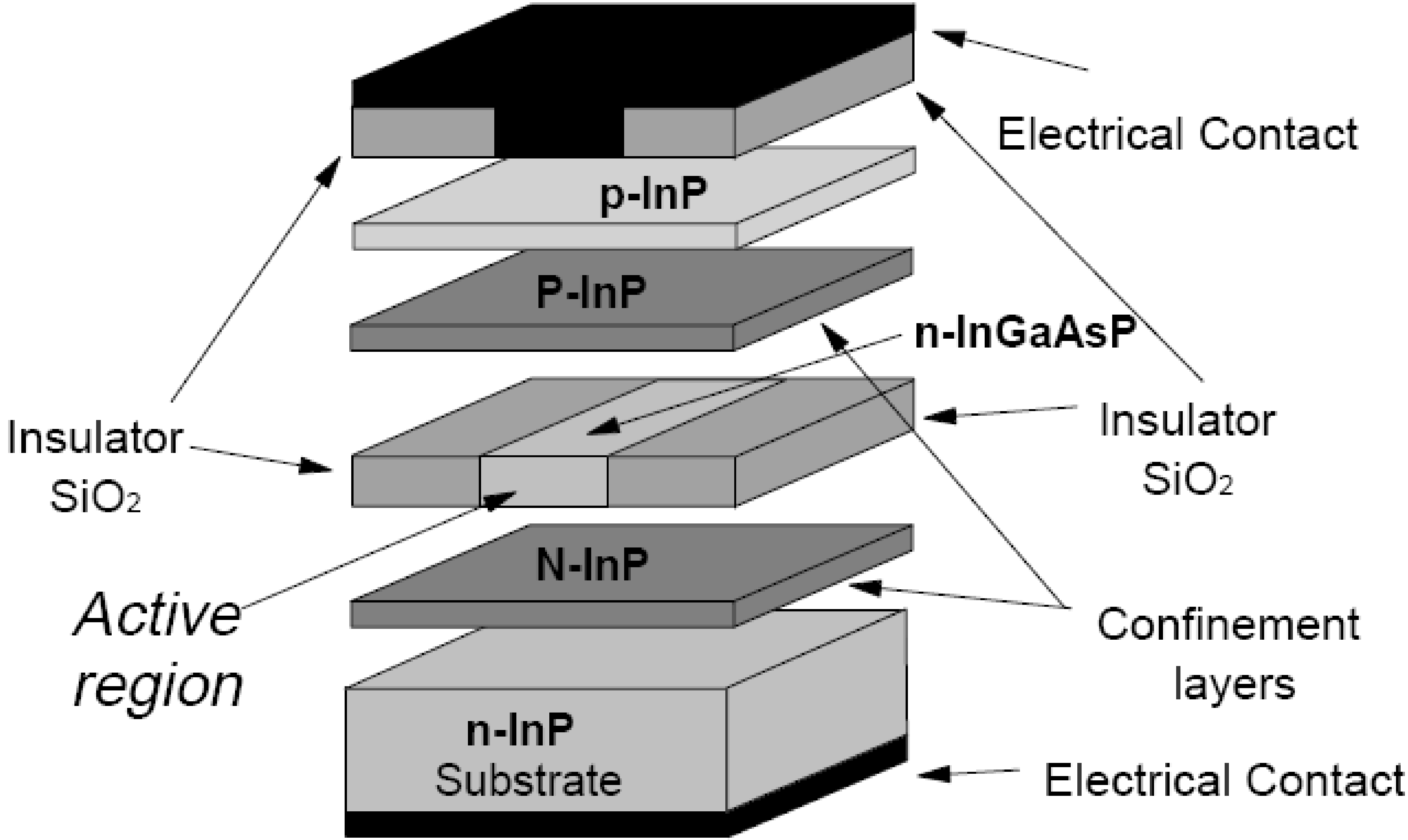
High radiance surface emitting LED. The active region is limited to a circular section having an area compatible with the fiber core end face

Edge-Emitting LED’s

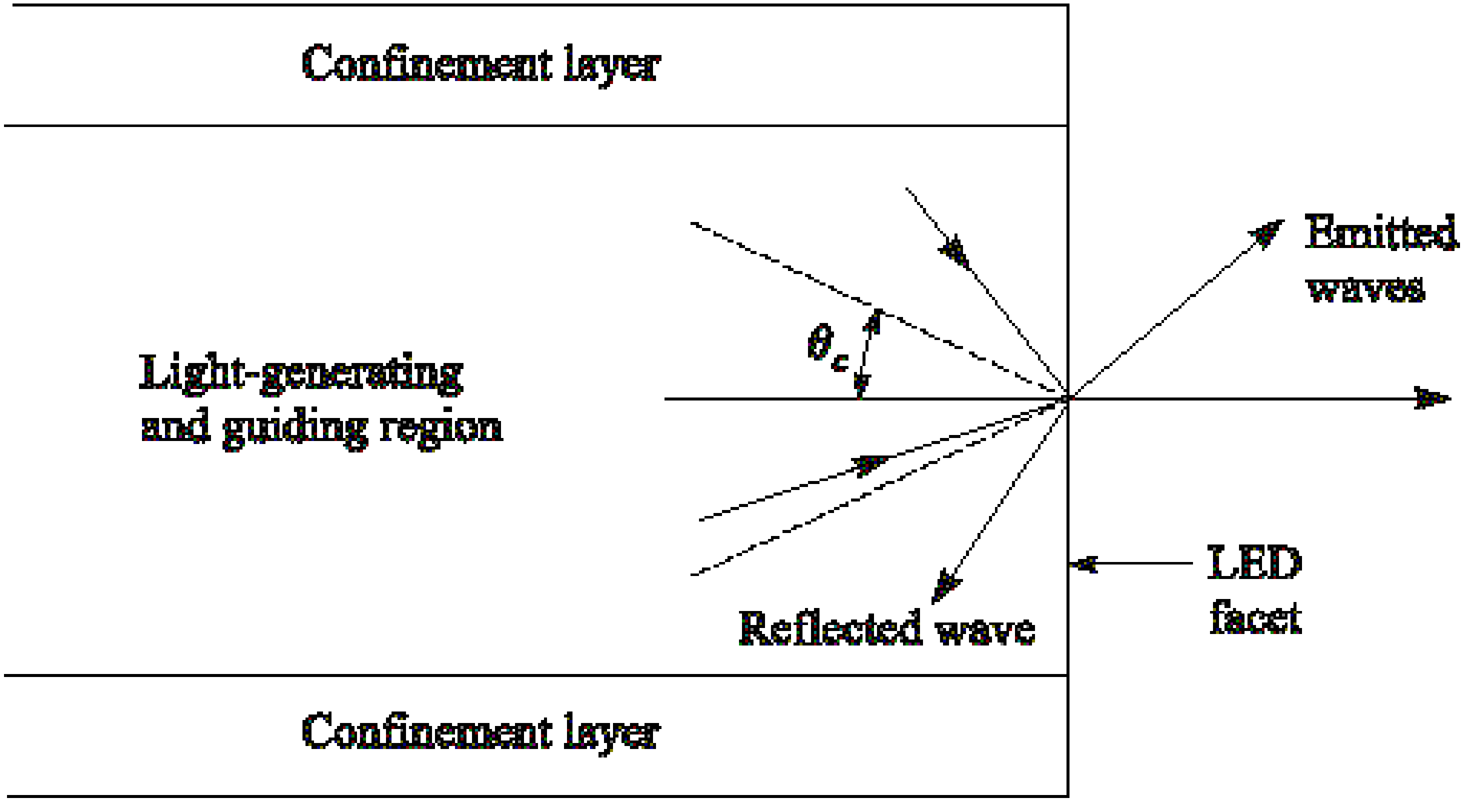
- This type has a much narrower angle of light emission and also has a smaller emitting area.
- This allows a larger percentage total light output to be focused into the fiber core.
- The disadvantage of ELED’s is that they are very temperature sensitive compared to SLED’s.



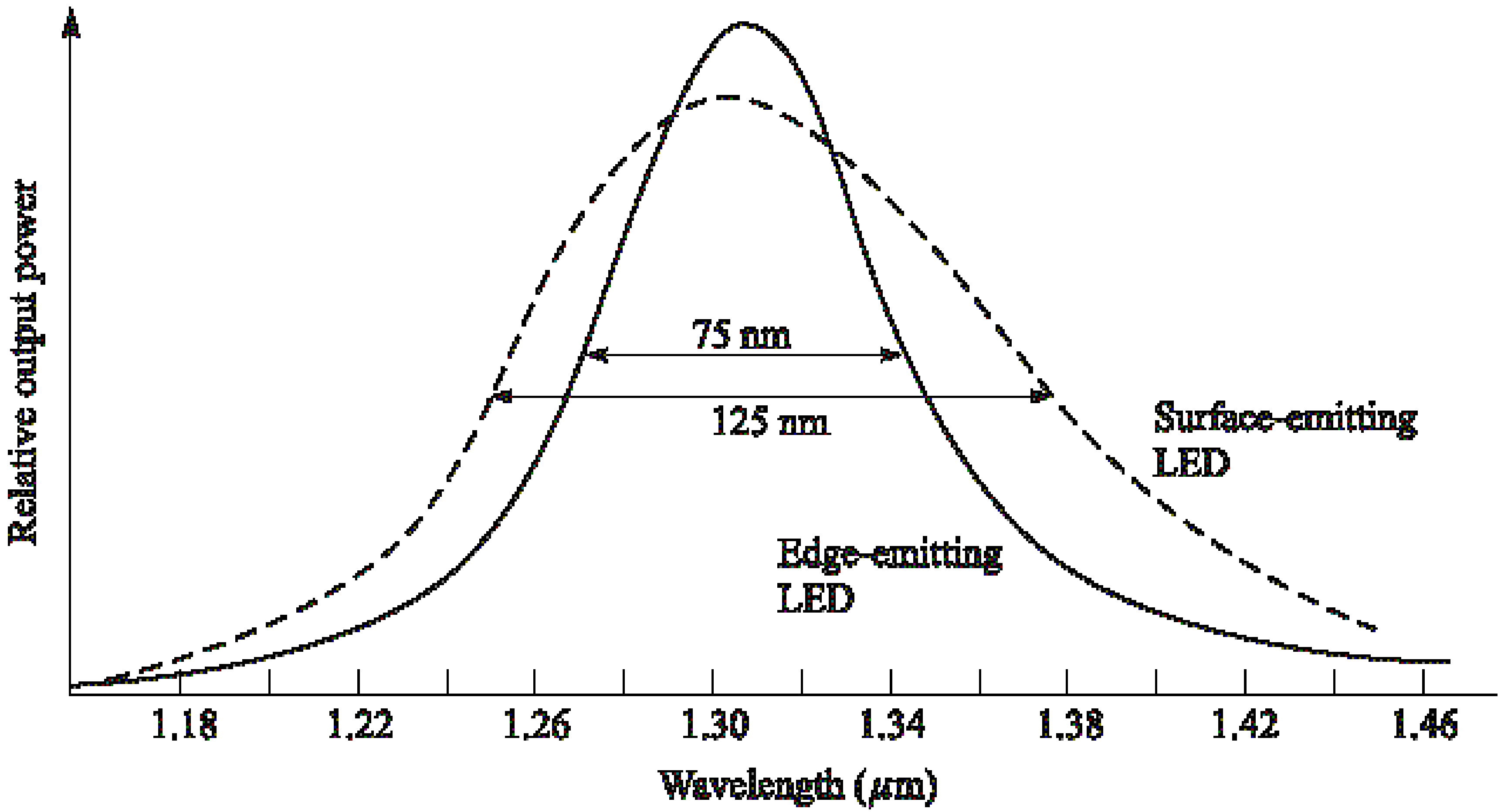
Edge emitting double heterojunction LED.


Electrical Contact
p-InP
P-InP
n-InGaAsP
Insulator
SiO2
Insulator
SiO2
N-InP
Active
region
Confinement
layers
n-InP
Substrate
Electrical Contact

Light-emission cone



Only light falling within a cone defined by the critical angle will be emitted from an optical source.



LED spectral patterns

Some LED and Laser Diode Material Mixtures and their Characteristics

Material	Wavelength range, nm	Bandgap energies, eV
GaAs	900	1.4
GaAlAs	800–900	1.4–1.55
InGaAs	1000–1300	0.95–1.24
InGaAsP	900–1700	0.73–1.35

Quantum Efficiency

The active region of an ideal LED emits one photon for every electron injected.
Each charge quantum-particle (electron) produces one light quantum-particle (photon).
Thus the ideal active region of an LED has a quantum efficiency of unity.

The internal quantum efficiency is defined

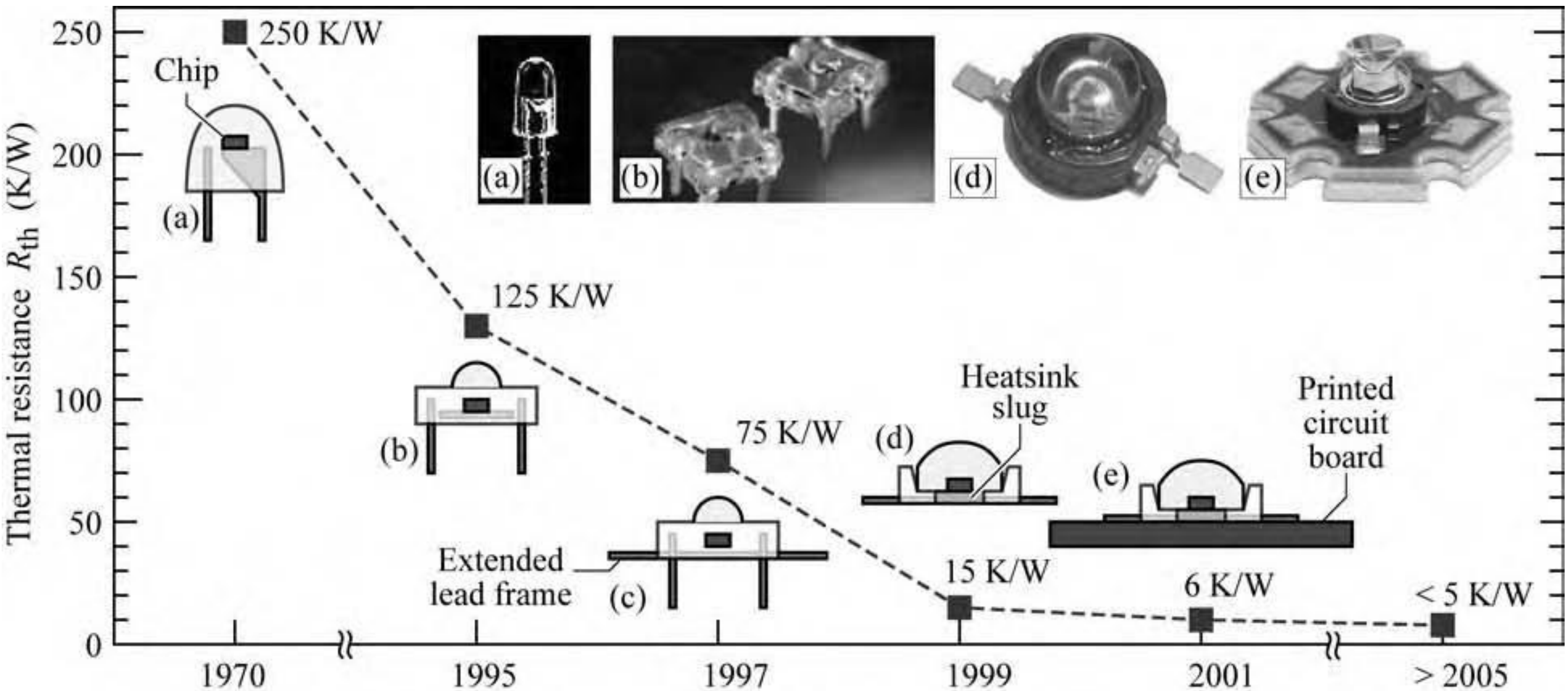
$$\eta_{int} = \frac{\text{number of photons emitted from active region per second}}{\text{number of electrons injected into LED per second}}$$

Quantum Efficiency

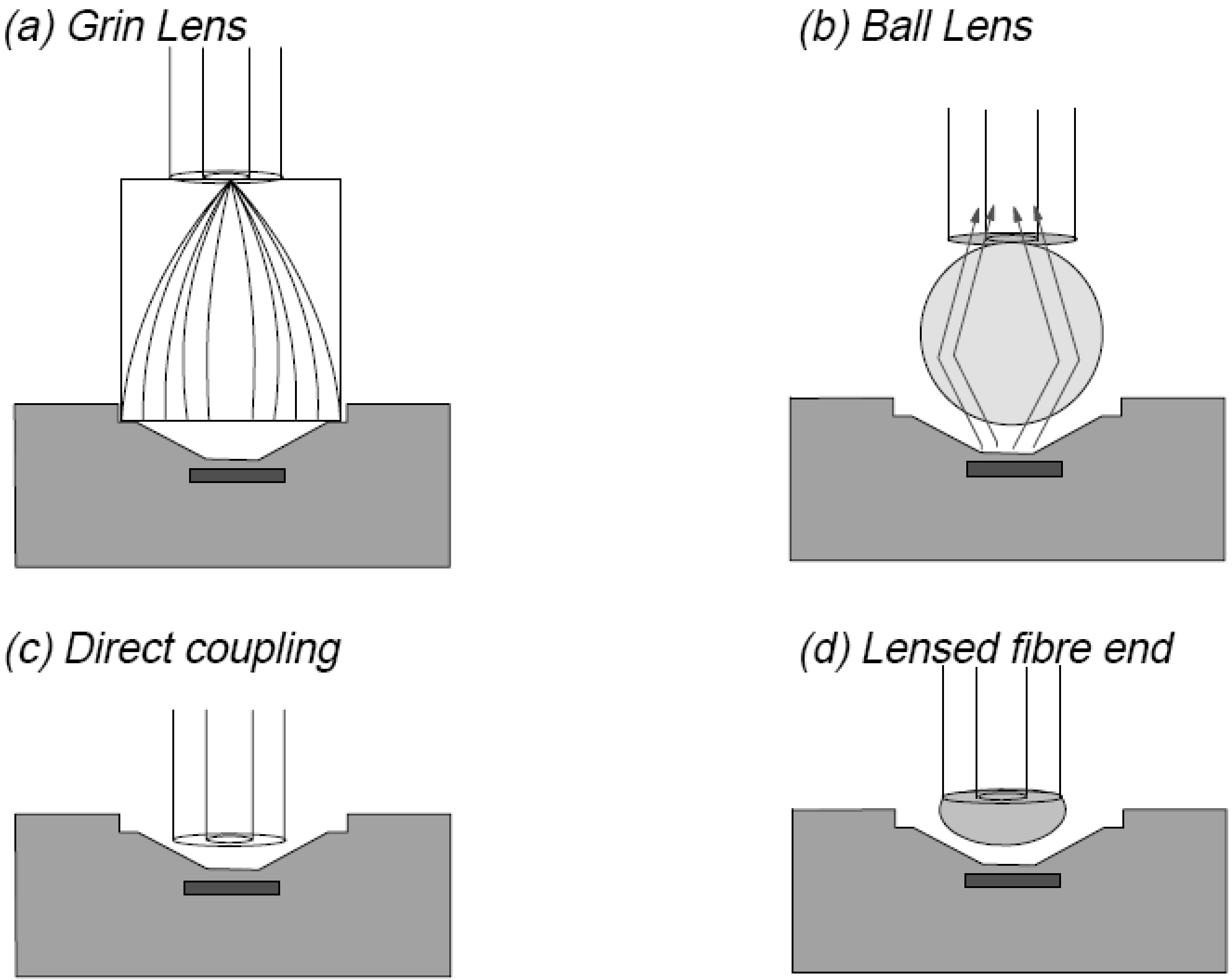
The external quantum efficiency is defined as

$$\eta_{ext} = \frac{\text{number of photons emitted into free space per second}}{\text{number of electrons injected into LED per second}}$$

The external quantum efficiency gives the ratio of the number of useful light particles to the number of injected charge particles.



Thermal resistance of LED packages: (a) 5mm (b) low-profile (c) low-profile with extended lead frame (d) heatsink slug (e) heatsink slug mounted on printed circuit board (PCB). Trade names for these packages are "Piranha" (b and c, Hewlett Packard Corp.), "Barracuda" (d and e, Lumileds Corp.), and "Dragon" (d and e, Osram Opto Semiconductors Corp.)



Coupling light output to a fibre is the most difficult and costly part of manufacturing a real LED or laser device

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Laser Diodes

"LASER" is an acronym of

Light **A**mplification by **S**timulated **E**mission of **R**adiations.

Advantages:

- Ideal laser light is **single-wavelength** only. This is not exactly true for communication lasers.

- Lasers can be **modulated** **(controlled) very** **precisely.**

- Lasers can produce relatively **high power**. Indeed some types of laser can produce kilowatts of power. In communication applications, semiconductor lasers of power up to about 20 milli watts are available

- Because laser light is produced in **parallel beams**, a **high percentage** (50% to 80%) can be **transferred into the fibre**.

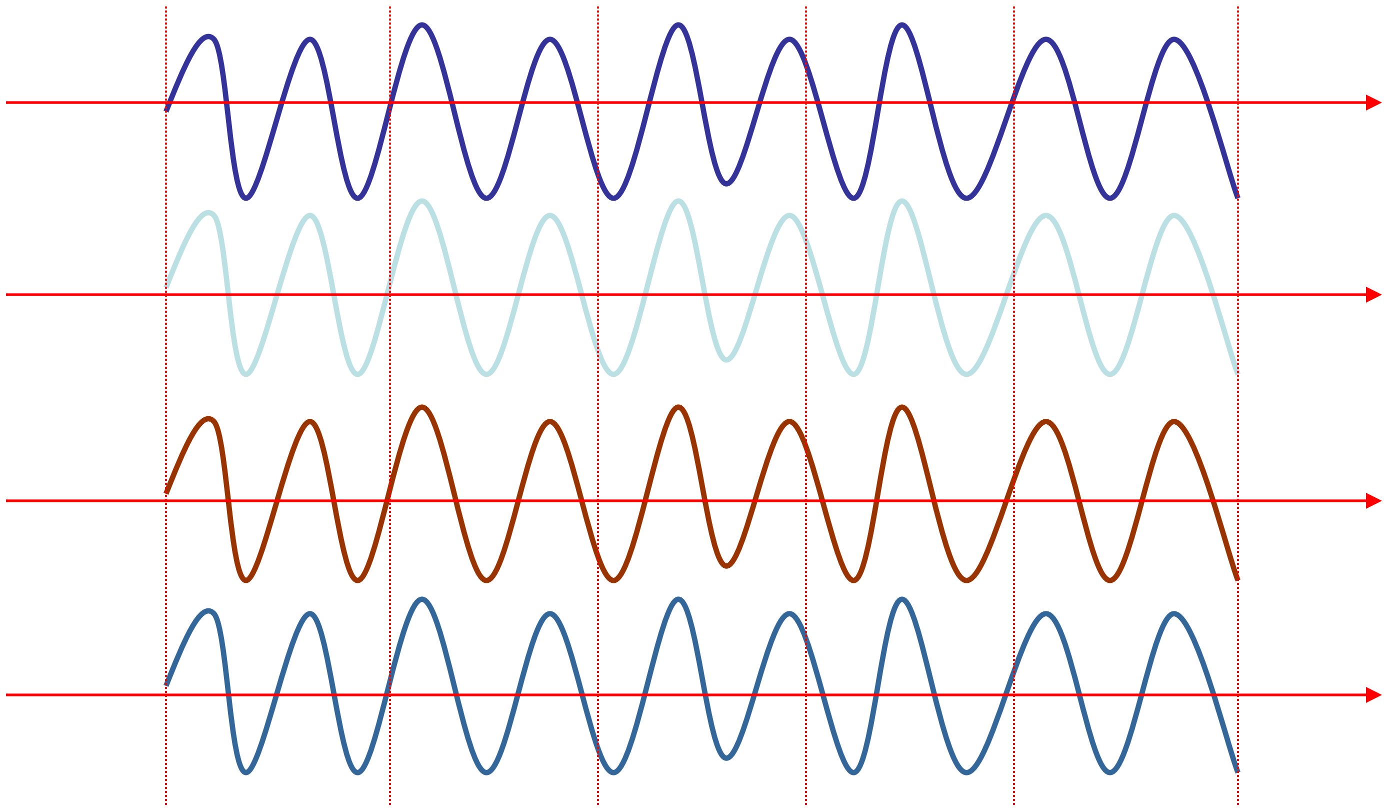
Disadvantages:

Lasers have been **quite expensive** by comparison with LEDs.
Reason: Temperature control and output power control is needed.

The **wavelength** that a laser produces is a **characteristic of the material used** to build it and of its physical construction. Lasers have to be individually designed for each wavelength they are going to use.

Amplitude modulation using an analogue signal is **difficult** with most lasers because laser **output signal** power is **generally non-linear** with input signal power

An Ideal Beam of LASER Radiation



Properties of LASER

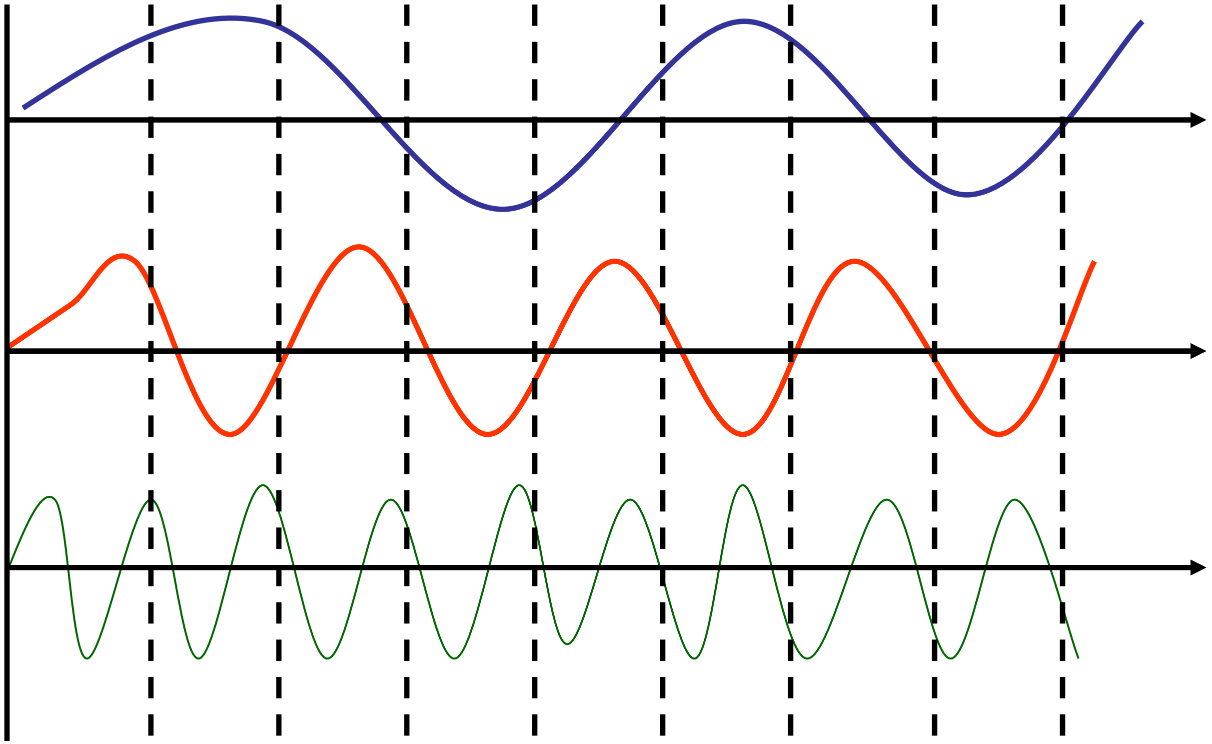
LASER has three main characteristics:

- Monochromatic
- Coherent
- Collimated

Properties of LASER

Monochromatic

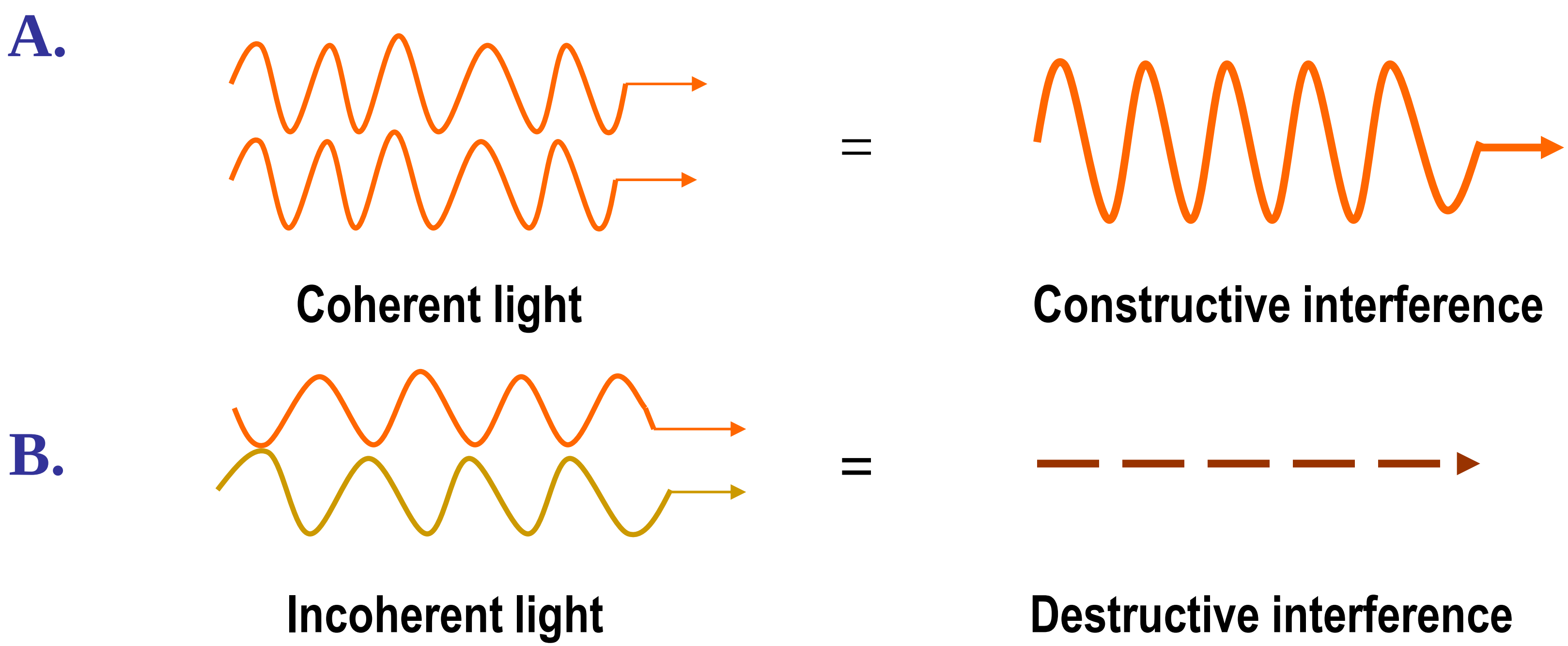
Radiation which occurs at a single wavelength or color.



Properties of LASER

Coherent

It means all waves vibrate in step, there by constructively reinforcing each adjacent wave.

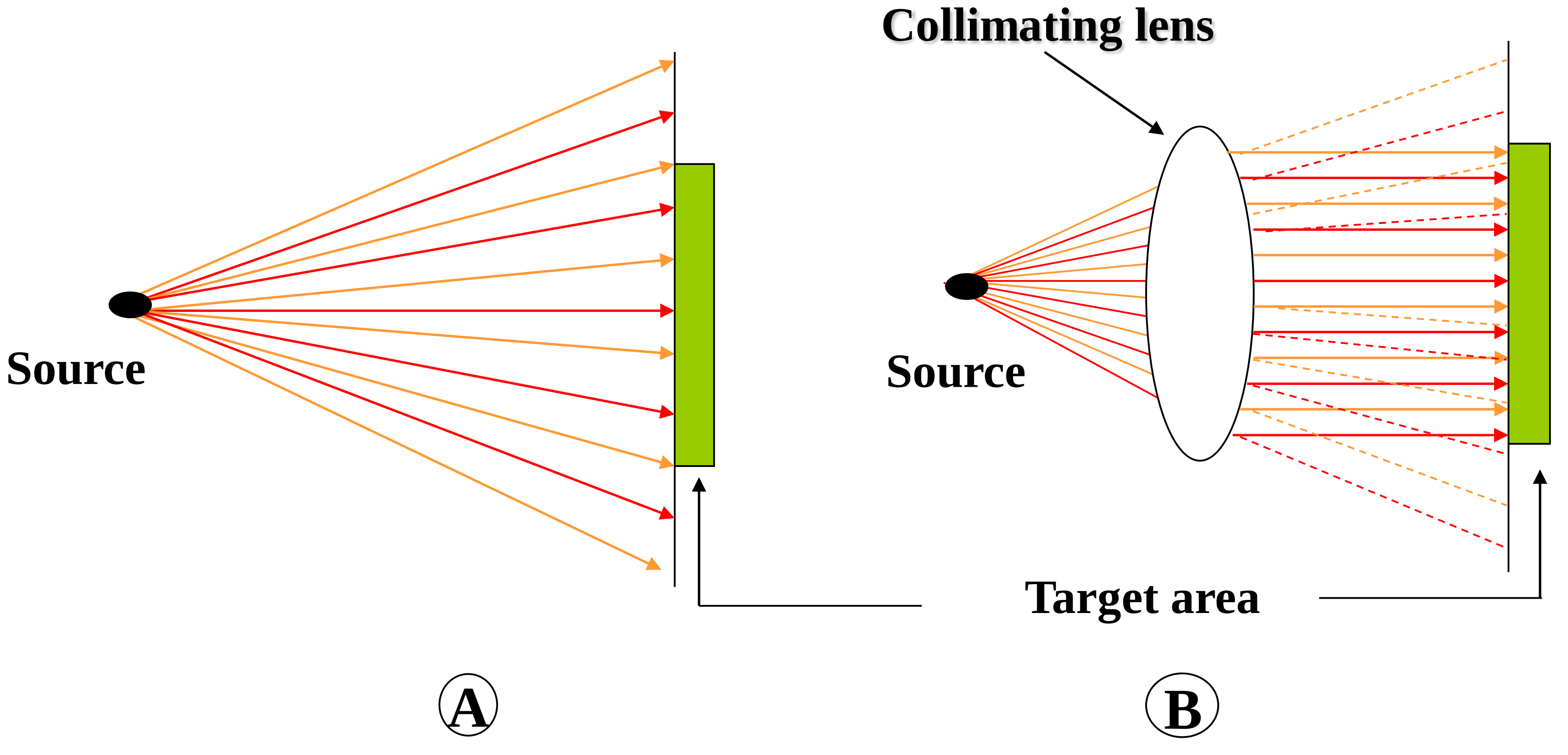


OPTICAL INTERFERENCE

Properties of LASER

Collimated

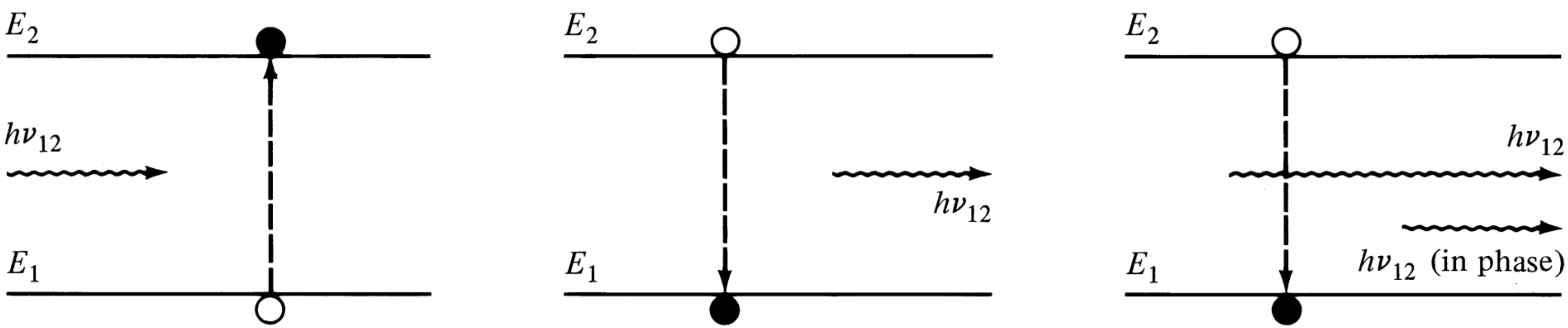
It means rays are travelling in the same direction on parallel paths.



LASER Principles

- **Laser action is the result of three key process**

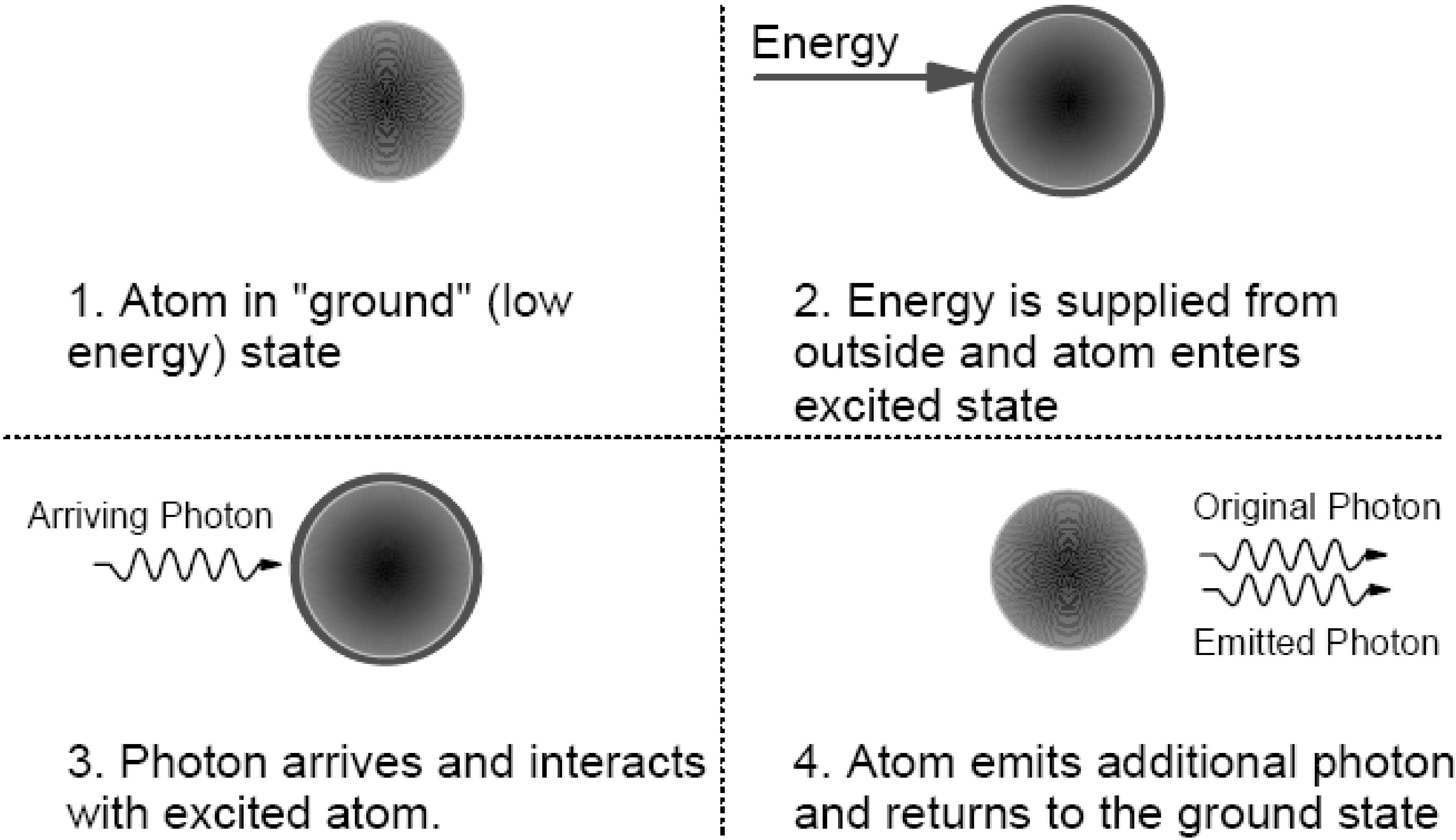
1. **Photon absorption**
2. **Spontaneous emission**
3. **Stimulated emission**



(*a*) Absorption (*b*) Spontaneous emission (*c*) Stimulated emission

Laser transition processes

LASER Principles



LASER Principles

Spontaneous emission

When an electron is elevated to a high energy state this state is usually unstable.

Electron will **spontaneously return** to a more stable state very quickly (within a few picoseconds) emitting a photon as it does so.

When light is emitted spontaneously:

•Its direction and phase will be random

•Wavelength will be determined by the amount of energy that the emitting electron must give up.

LASER Principles

Stimulated emission

In some situations when an electron enters a high energy **(excited) state** it is able to **stay there for a relatively long time** (a few microseconds) before it changes state spontaneously.

When an electron is in this semi-stable (metastable) high energy state it **can be "stimulated" by the presence of a photon of light** to emit its energy in the form of another photon.

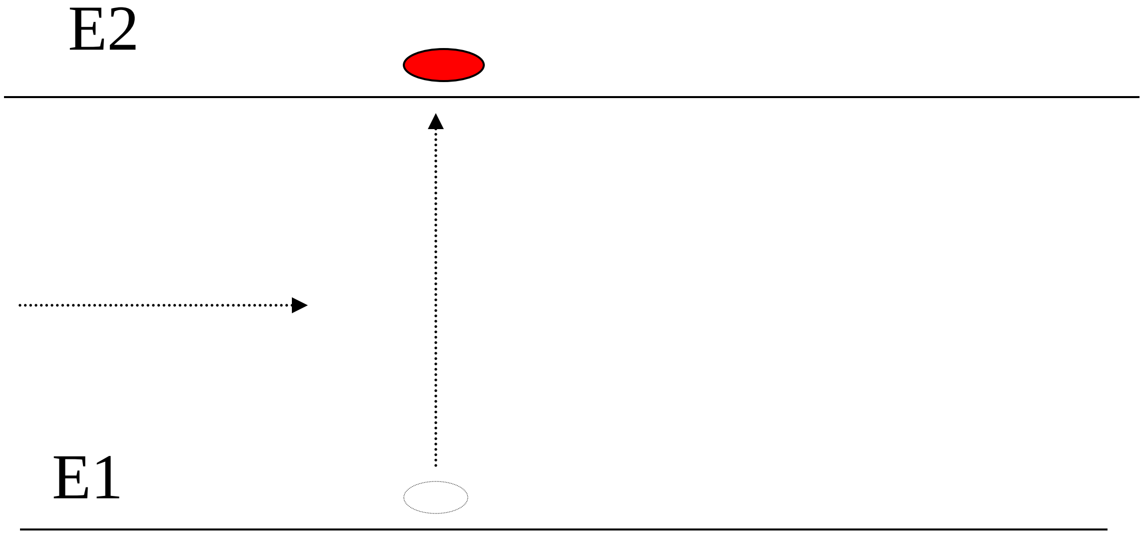
Stimulated emission

****It is of fundamental importance to understand that when stimulated emission takes place the emitted photon has exactly the same wavelength, phase and direction as that of the photon which stimulated it.**

****The photon that triggered (stimulated) the emission itself is <u>not absorbed</u> and continues along its original path <u>accompanied by the newly emitted photon.</u>**

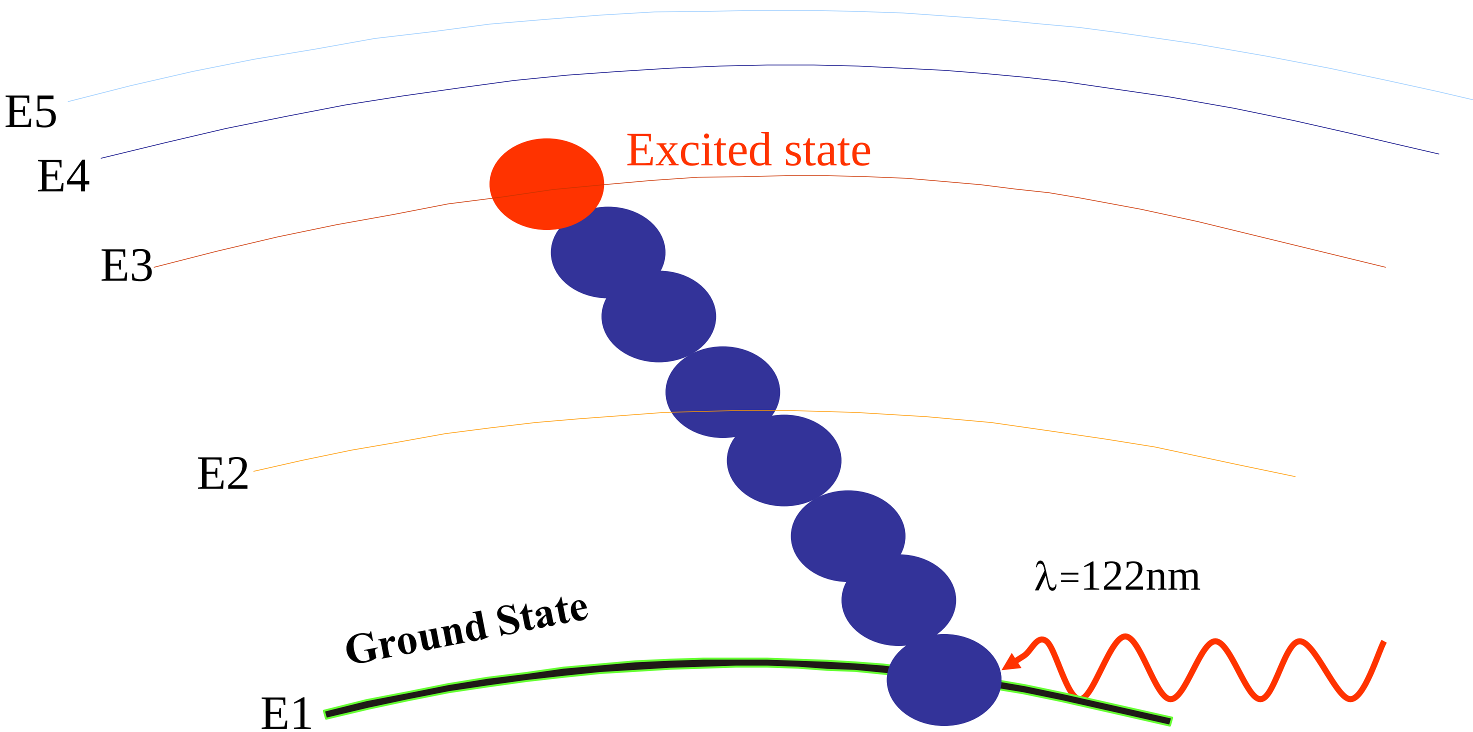
LASER Principles

- Photon absorption



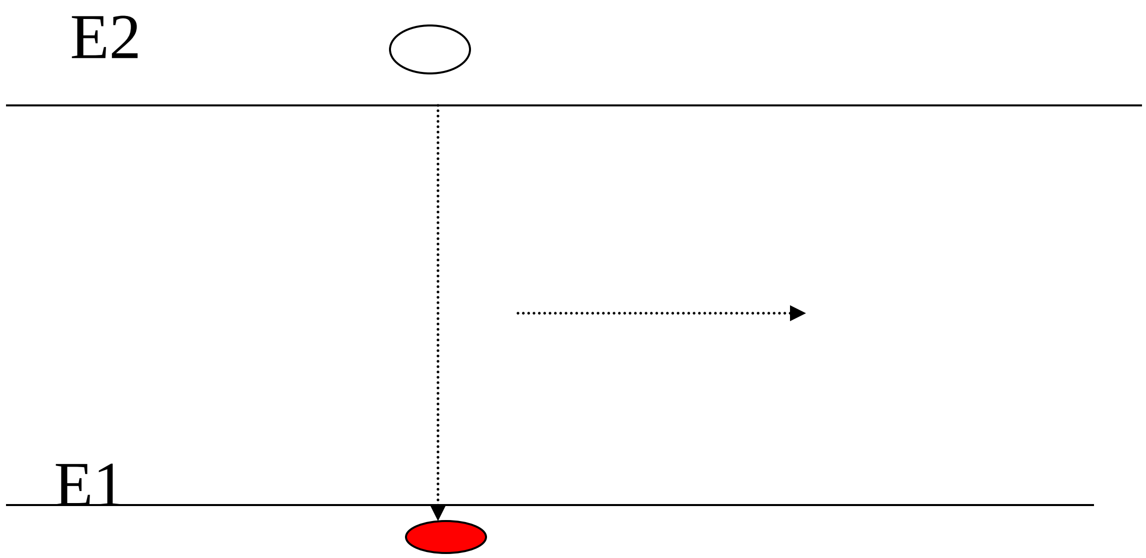
LASER Principles

Absorption



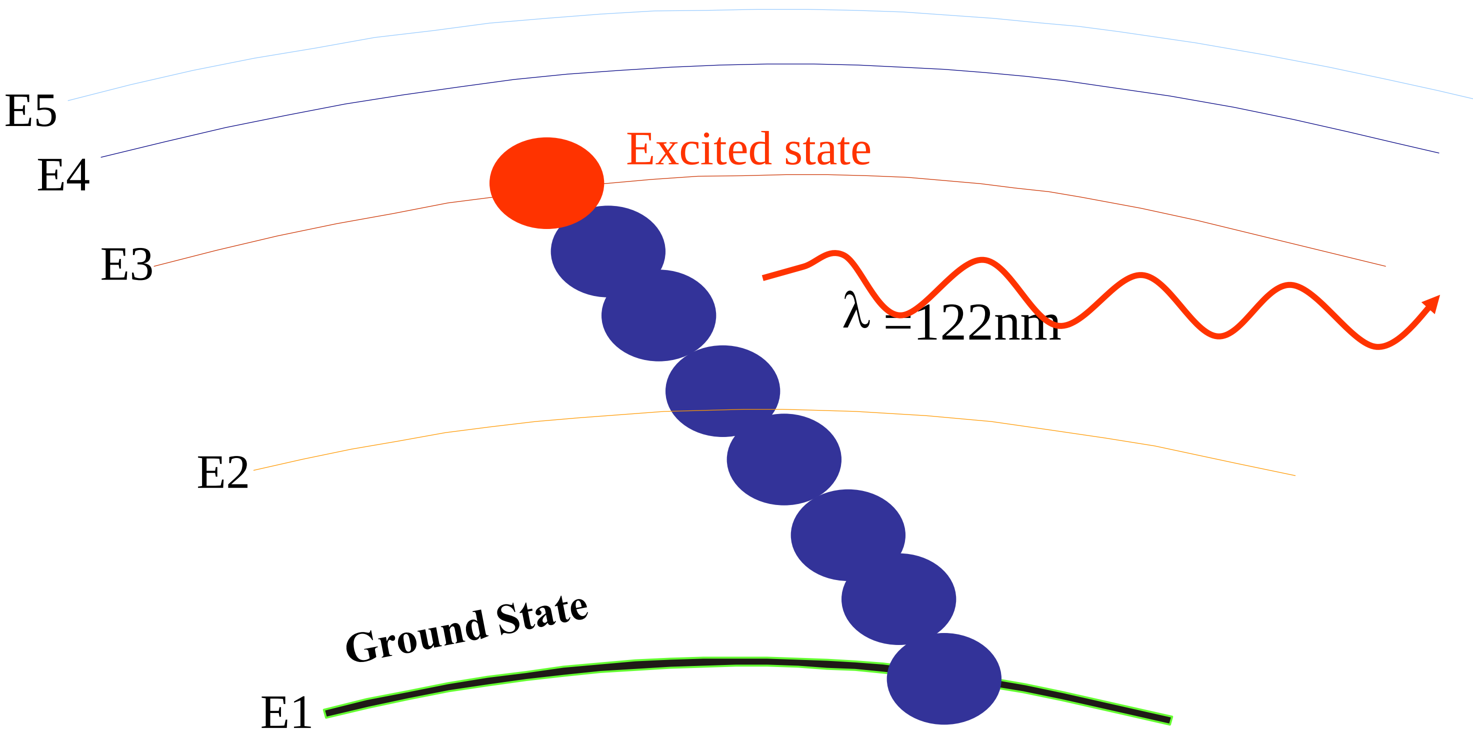
LASER Principles

– Spontaneous emission



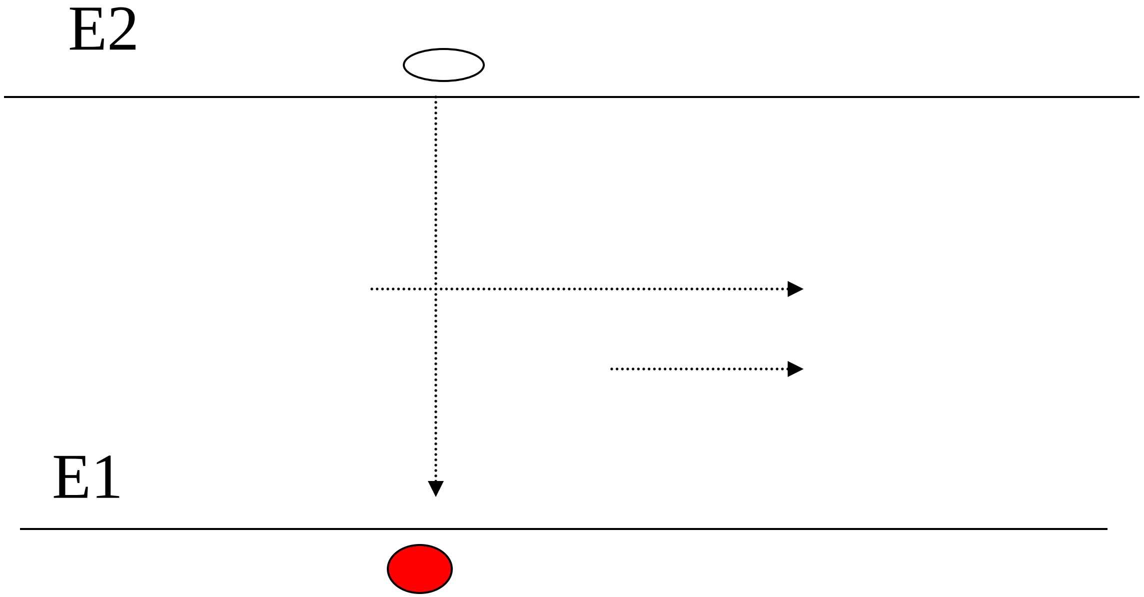
LASER Principles

Spontaneous Emission



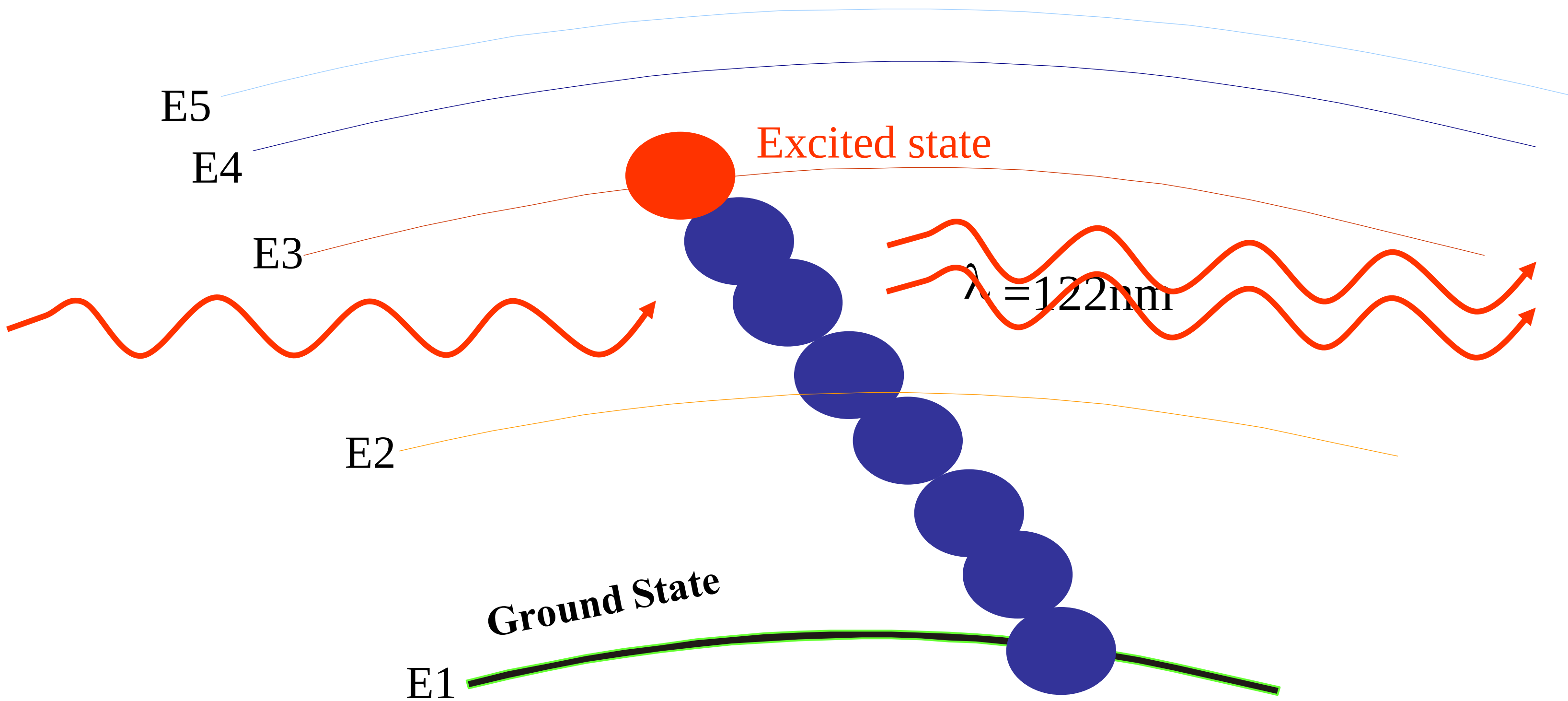
LASER Principles

- Stimulated emission



LASER Principles

Stimulated Emission



Population Inversion

- Under normal conditions, the **population of unexcited atoms** greatly exceeds the population of excited atoms.

- This result, predominance of the **spontaneous emission** and the resulting radiation is largely **incoherent**.

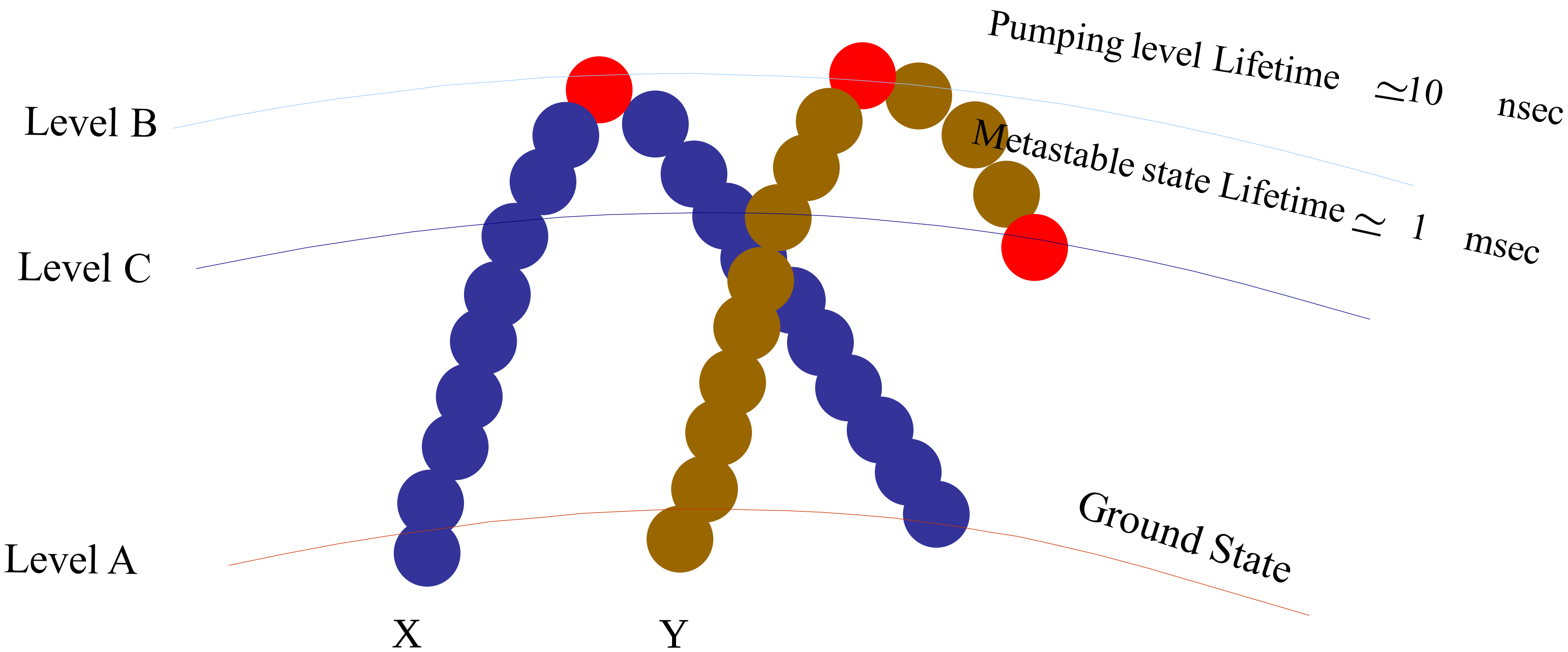
Population Inversion

- For a LASER to operate, **situation must be reversed**, called population inversion.

- Once the **majority of the atoms** in a material are in an excited state, **stimulated emission will be greater than spontaneous.**

Population inversion is achieved by various "Pumping" techniques.

Energy Pumping



Energy level diagram for a typical laser material.

Energy Pumping

- The energy population in a Lasing medium is inverted by a method known as energy pumping.
- Energy can be pumped, into a material in a number of ways, depending upon the composition of the material
  - Optical pumping.
  - Electronic pumping.

The amount of light **leaving the end mirror** (partially reflected) **equals** the amount of **energy being pumped** into the cavity ,**minus losses** .

The amount of **reflectivity needed** in the end mirrors is a **function of the amount of gain** in the **cavity.**

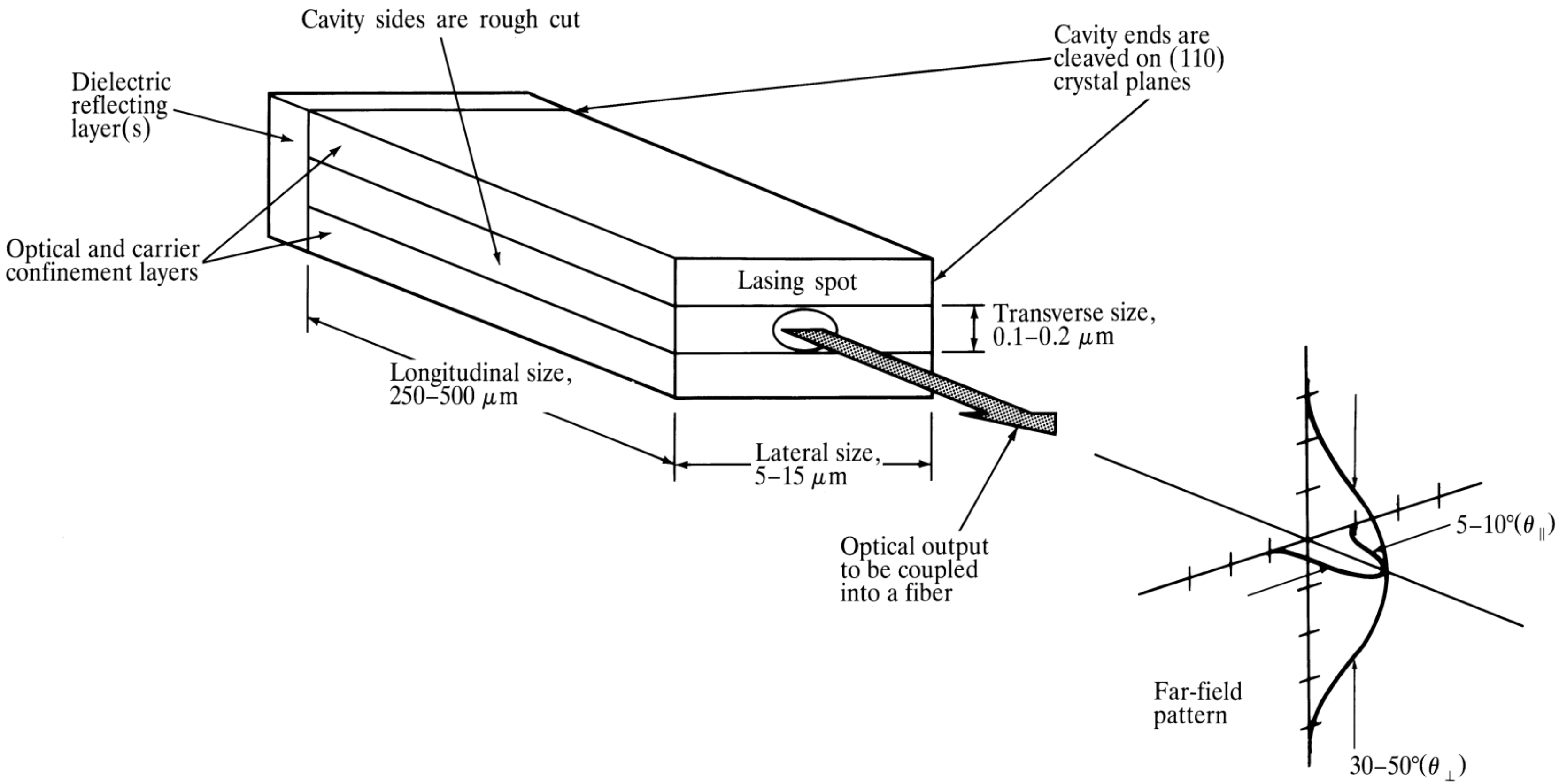
Types of LASER Diodes

- Fabry-Perot LASER Diode
- Distributed Feedback LASER Diode
- Vertical Cavity Surface-emitting LASER Diode

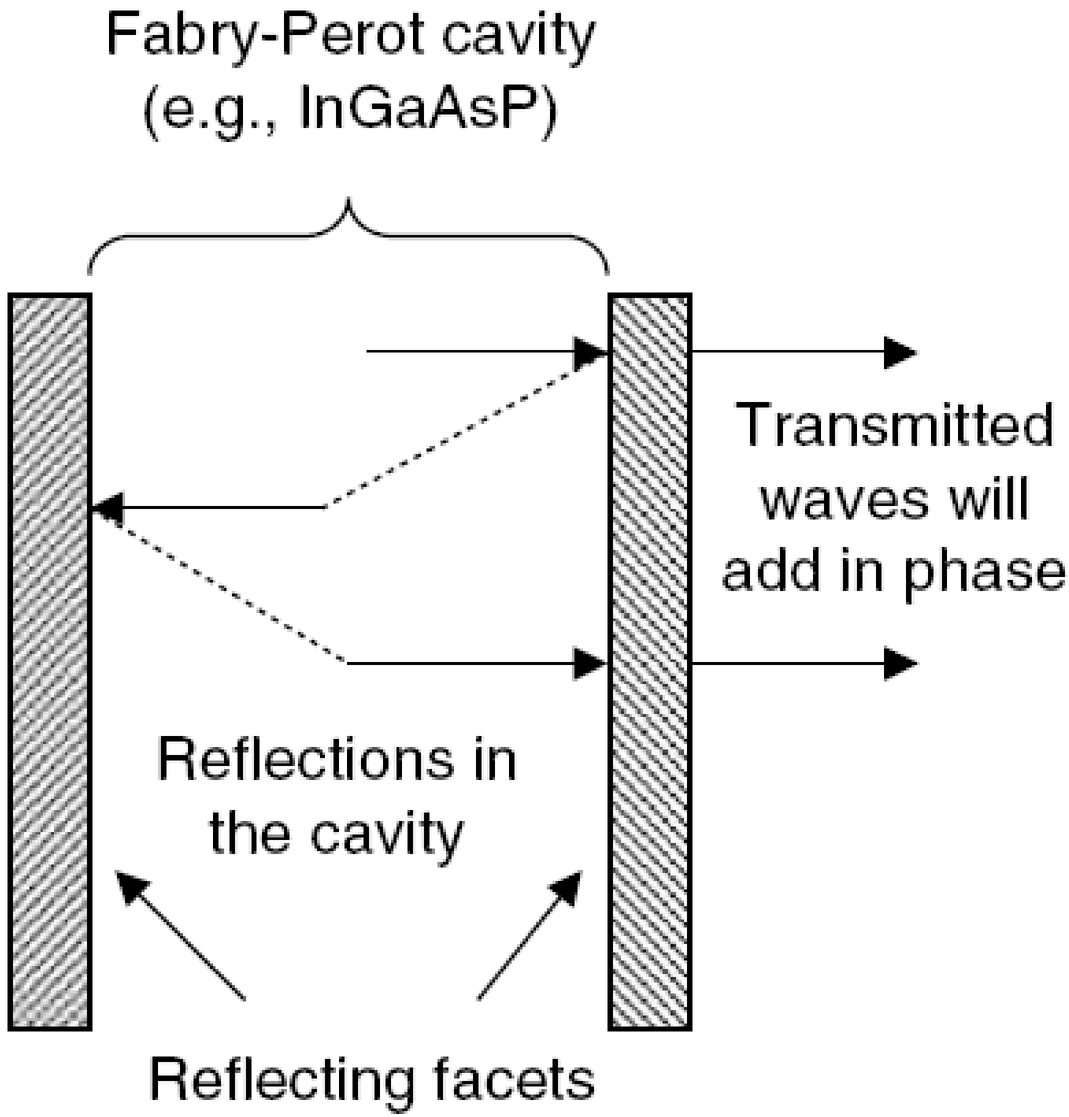
Fabry-Perot LASER Diode

- Radiation is generated by the cavity
- Cavity size is very small like **250-500 Um** long, **5-15 um** wide and **0.1 to 0.2 um** thick
- **Reflecting mirrors** are used at both sides of the cavity
- Mirrors provide **strong feedback** to the cavity to have the mechanism
- The side of the cavity are formed by roughening the edges to reduce unwanted emission

Fabry-Perot resonator cavity

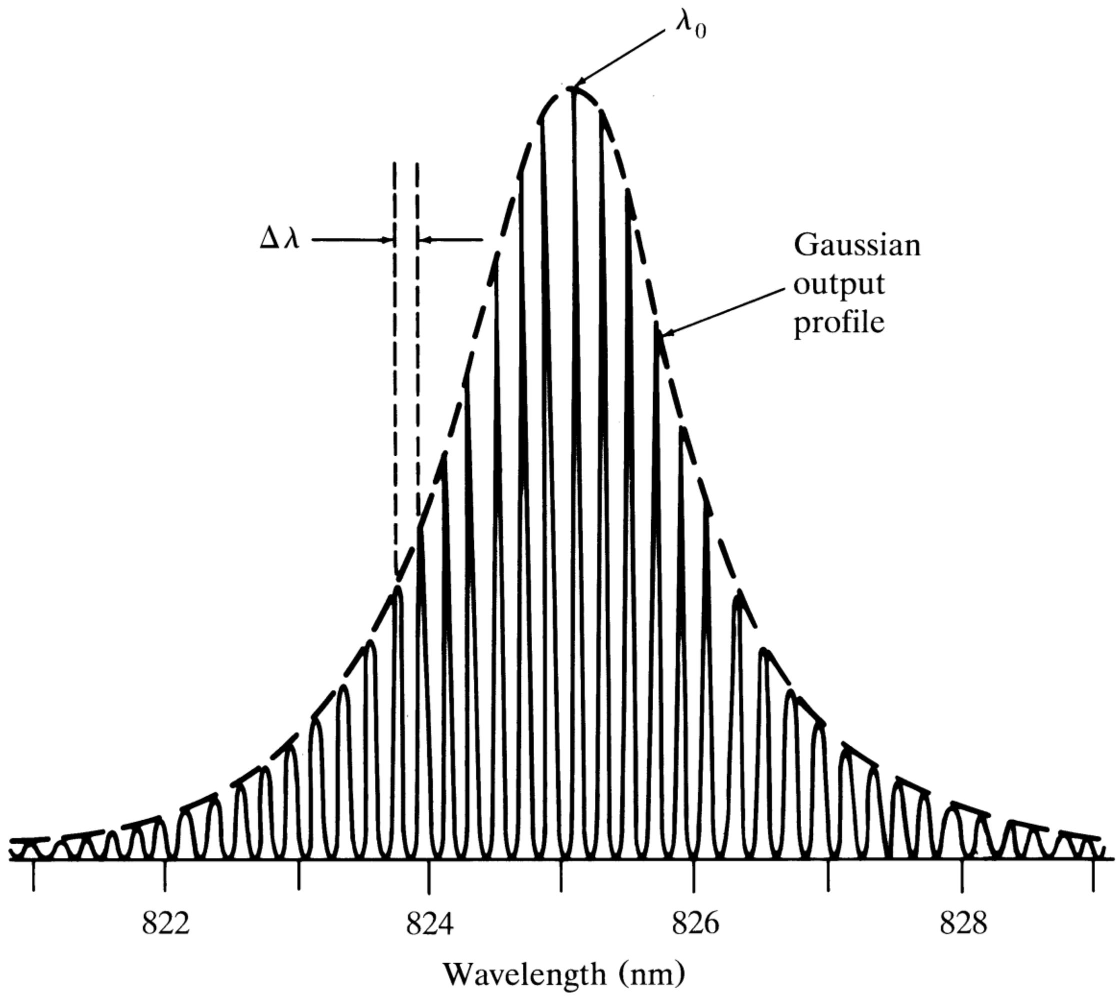


Fabry-Perot resonator cavity for a laser diode. The cleaved crystal ends function as partially reflection mirrors. The unused end (the rear facet) can be coated with dielectric reflector to reduce optical loss in the cavity. Note that the light beam emerging from the laser forms a vertical ellipse, even though the lasing spot at the active-area facet is a horizontal ellipse.



Two parallel light-reflecting surfaces define a Fabry–Perot cavity or etalon.

Fabry-Perot laser spectrum



Typical spectrum from a Fabry-Perot GaAls/ GaAS aser diode

Distributed Feedback LASER (DFB)

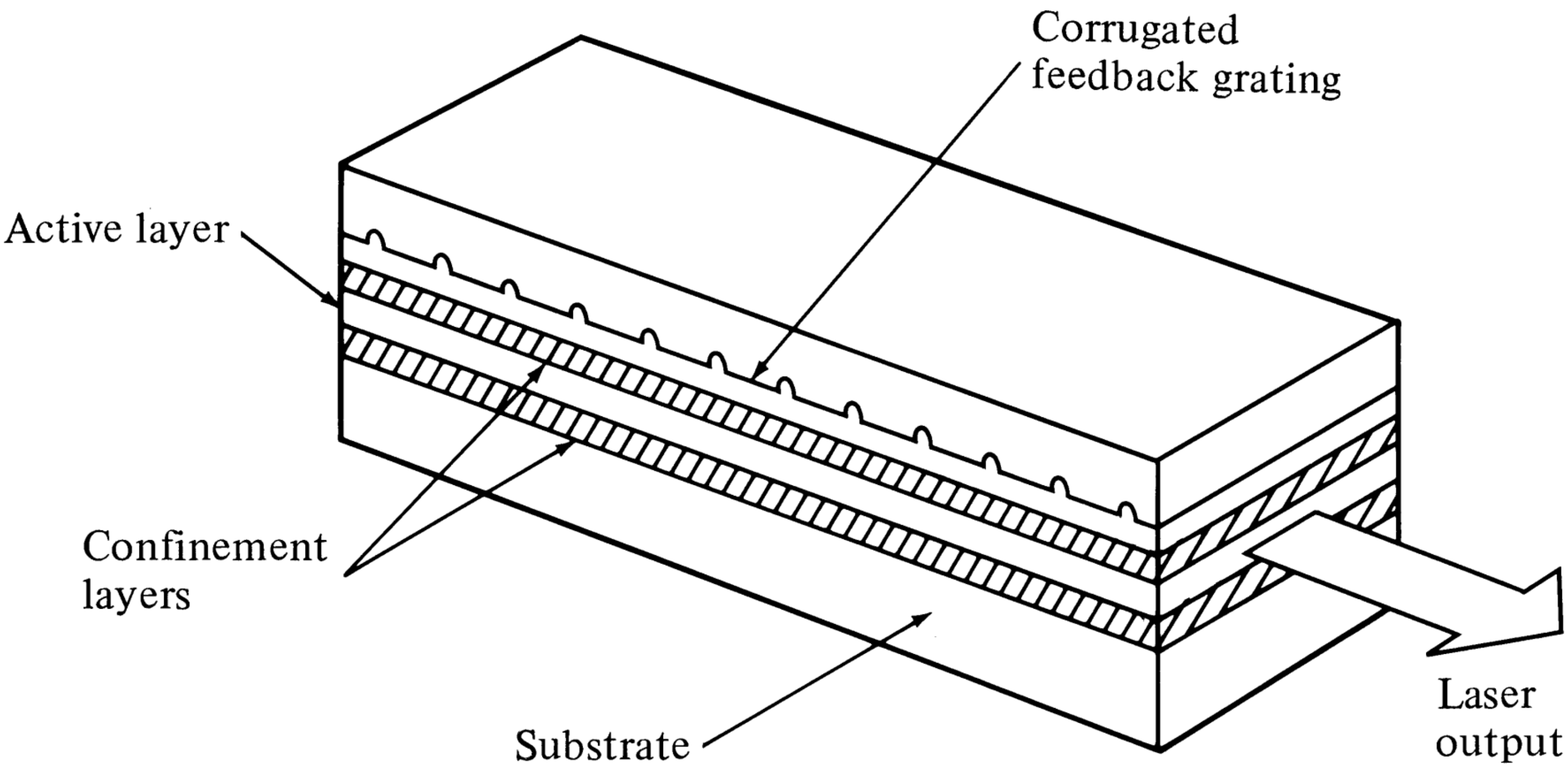
- DFB LASERs offer better performance, less noise and also higher cost than FP.

- They are nearly monochromatic.

- DFB LASERs are used for high speed digital application and for most anloge application because of their faster speed, low noise and superior linearity.

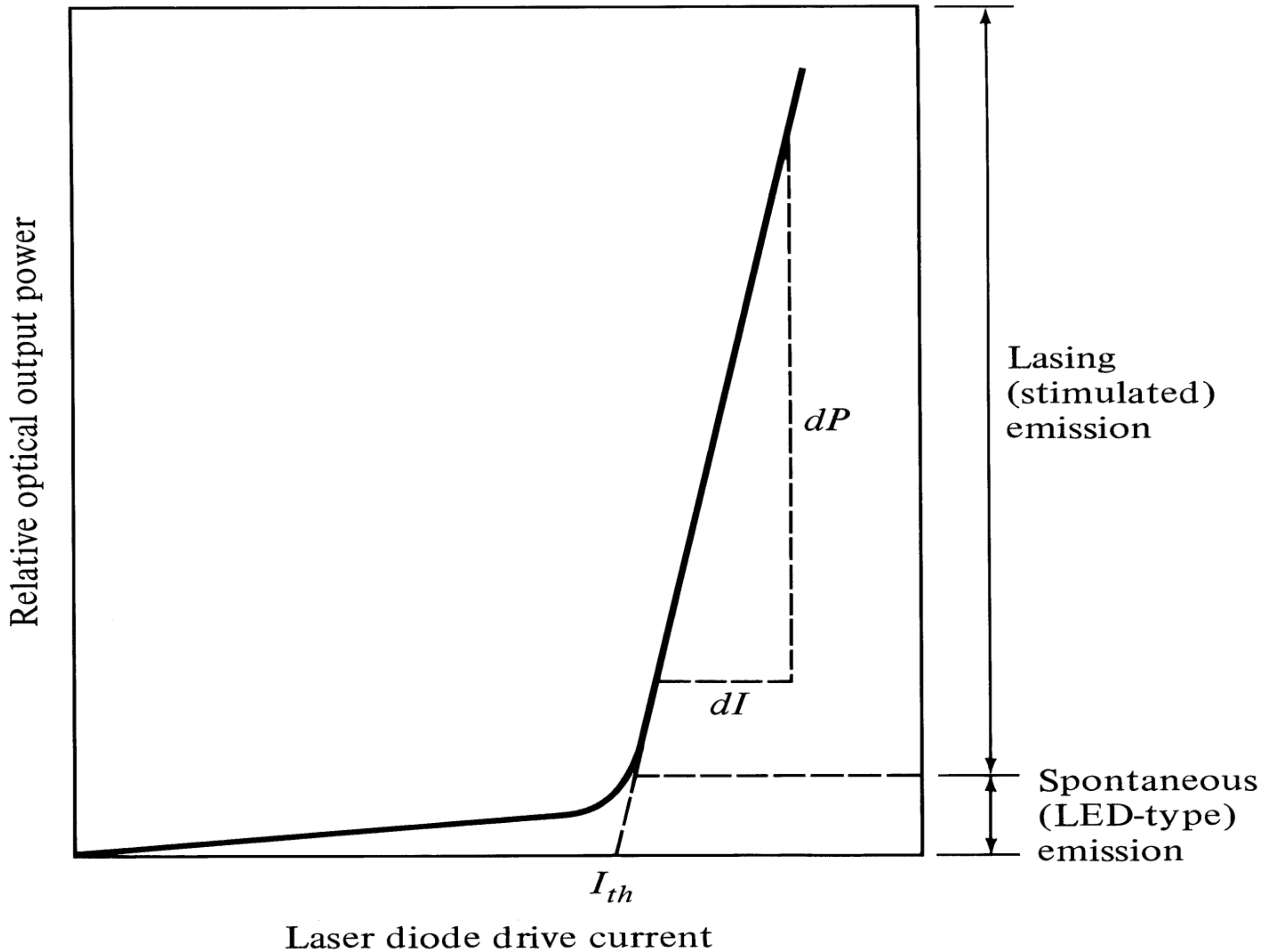
- **Lasing is achieved from the Bragg reflectors (gratings) along the length of the diode**

DFB laser



Structure of a distributed feedback (DFB) laser diode

Optical output vs. drive current



Relationship between optical power and laser diode drive current. Below the lasing threshold the optical output is a spontaneous LED-type emission.

Vertical Cavity Surface-emitting LASER Diode

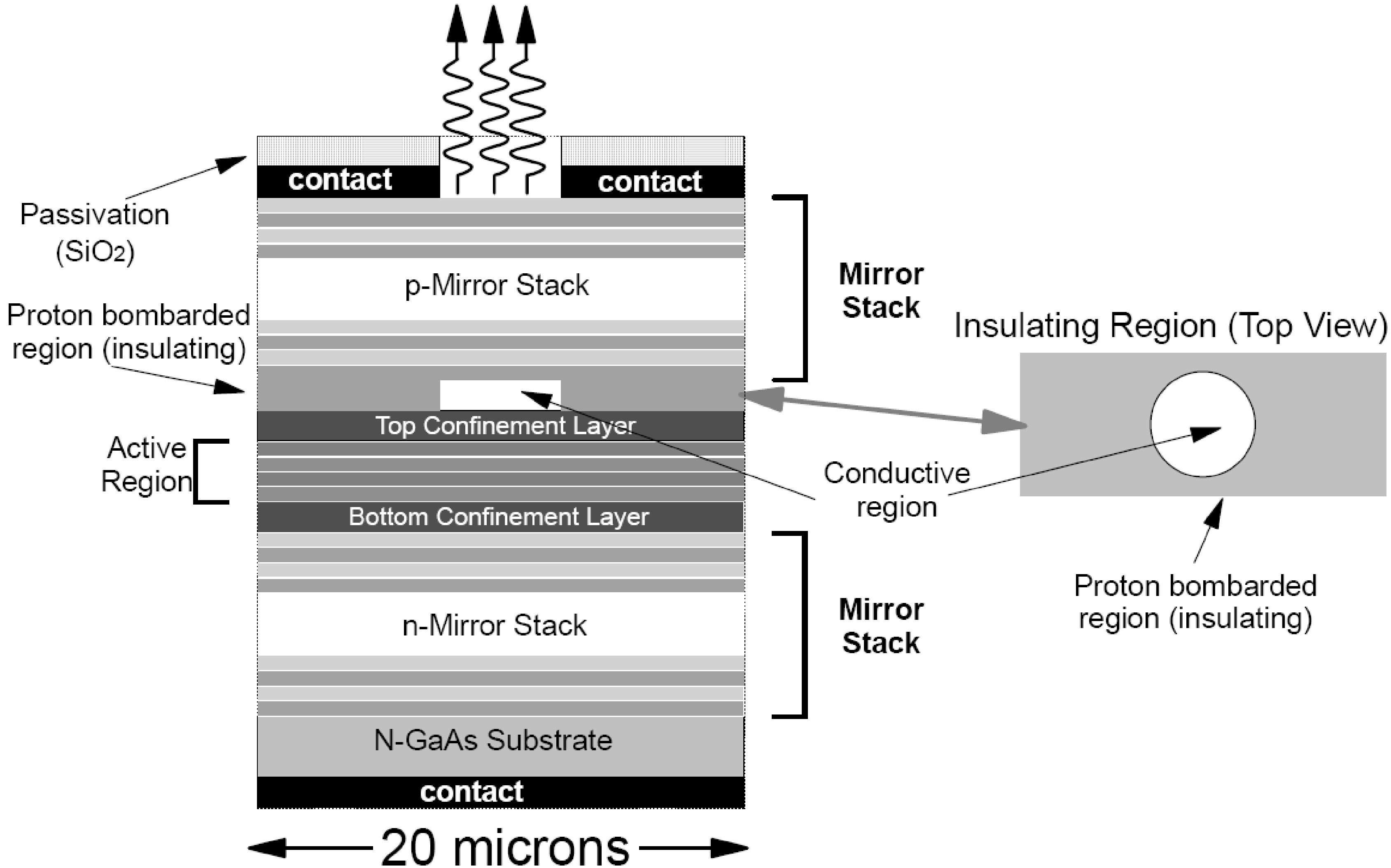
- VCSELs don't use monitor photodiode as they emit their light in a vertical plane perpendicular to the semiconductor wafer.

- Dramatically reduce the cost of LASERs to near those of LEDs

- Available @ 850 nm
  - Generates interest @ 850 window

Vertical Cavity Surface-emitting LASER Diode

- 1300 nm VCSELs to be ready
  - Currently Conventional LASERs used @ 1300nm
- VCSELs are manufactured in such a way that they are ideal for application requiring arrays of devices.



Vertical Cavity Surface Emitting Laser (VCSELs)

Modulation of Laser Diodes

The process of putting information onto a light wave is called modulation.

Two types:

1. Direct Modulation

2. External Modulation

For Data rates of **less than** approximately **10 Gb/s** (Typically 2.5 Gb/s), the process of imposing information on a laser-emitted light stream can be realized by direct modulation.

For **higher data rates external modulator** is used to temporally modify a steady optical power level emitted by the laser.

Modulation of Laser Diodes

The basic **limitation on the direct modulation** rate of laser diodes depends on:

1. **Spontaneous emission carrier lifetimes.**

2. **Stimulated emission carrier lifetimes.**

3. **Photon lifetime.**

Spontaneous carrier life time is a function of the **semiconductor band structure and the carrier concentration.**

Stimulated carrier life time depends on the **optical density** in the lasing cavity.

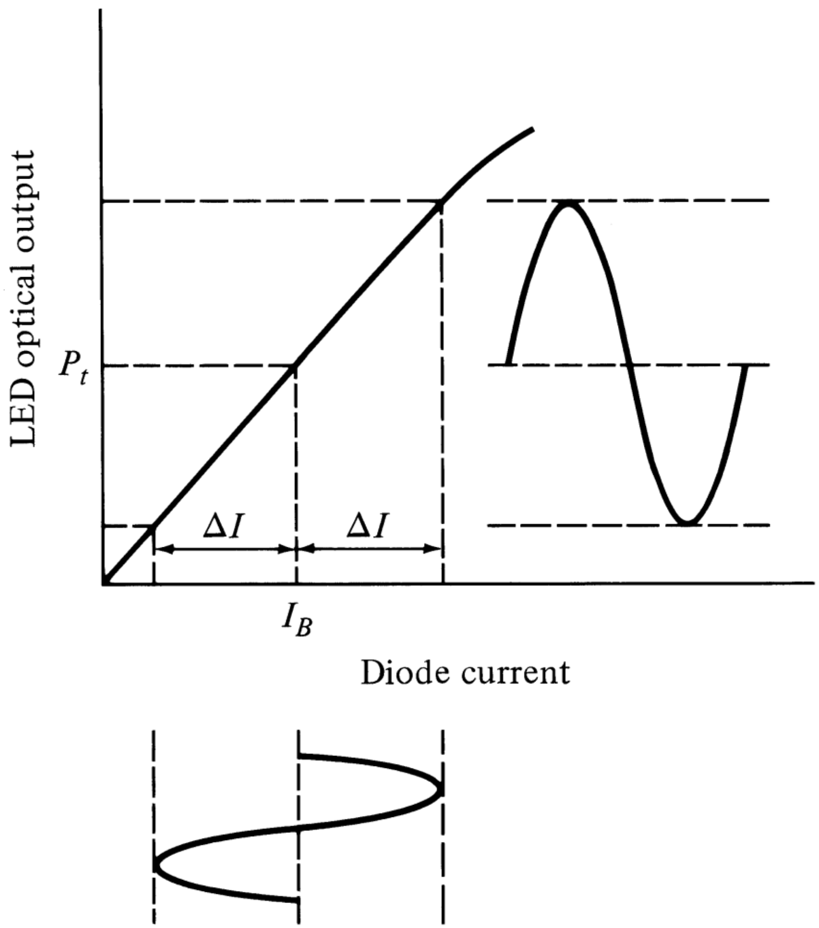
The photon lifetime is the average time that the photon resides in the lasing cavity before being lost either by absorption or by emission through the facets.

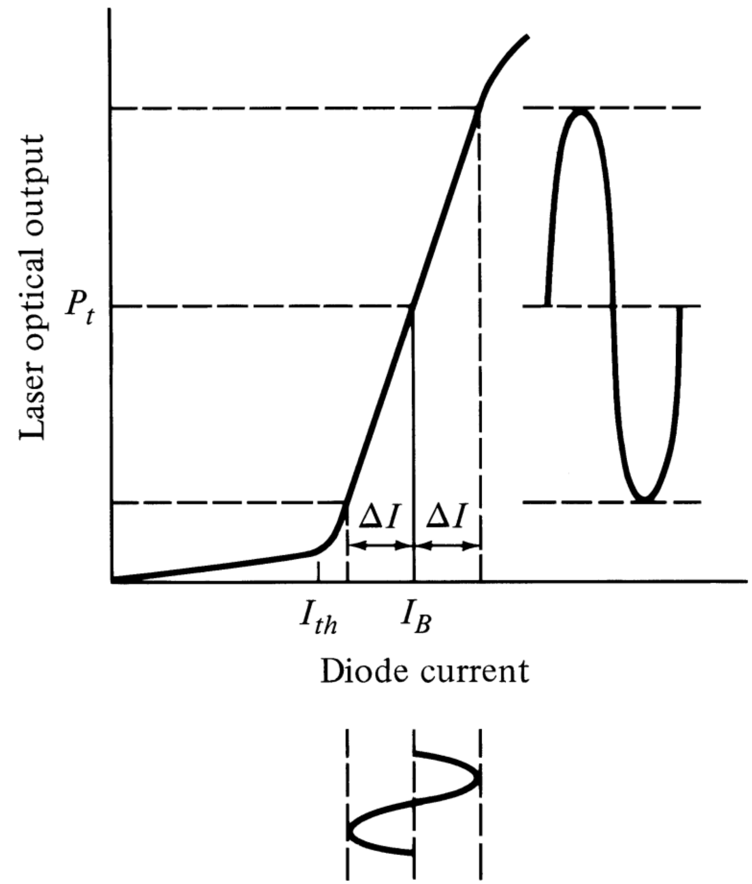
Modulation of Laser Diodes

Pulse modulation is carried out by **modulating** the laser only in the operation region **above threshold.**

In this region the carrier lifetime is now shortened to the **stimulated emission lifetime**, so that the high modulation rates are possible.

Modulation methods





Modulation of Laser Diodes

Directly modulated laser diode, the **modulation frequency** can be **no larger than the frequency of the relaxation oscillations** of the laser field.

The **relaxation oscillation** depends on both the spontaneous lifetime and the photon lifetime.

$$f = \frac{1}{2\pi} \frac{1}{(\tau_{sp}\tau_{ph})^{1/2}} \left(\frac{I}{I_{th}} - 1 \right)^{1/2}$$

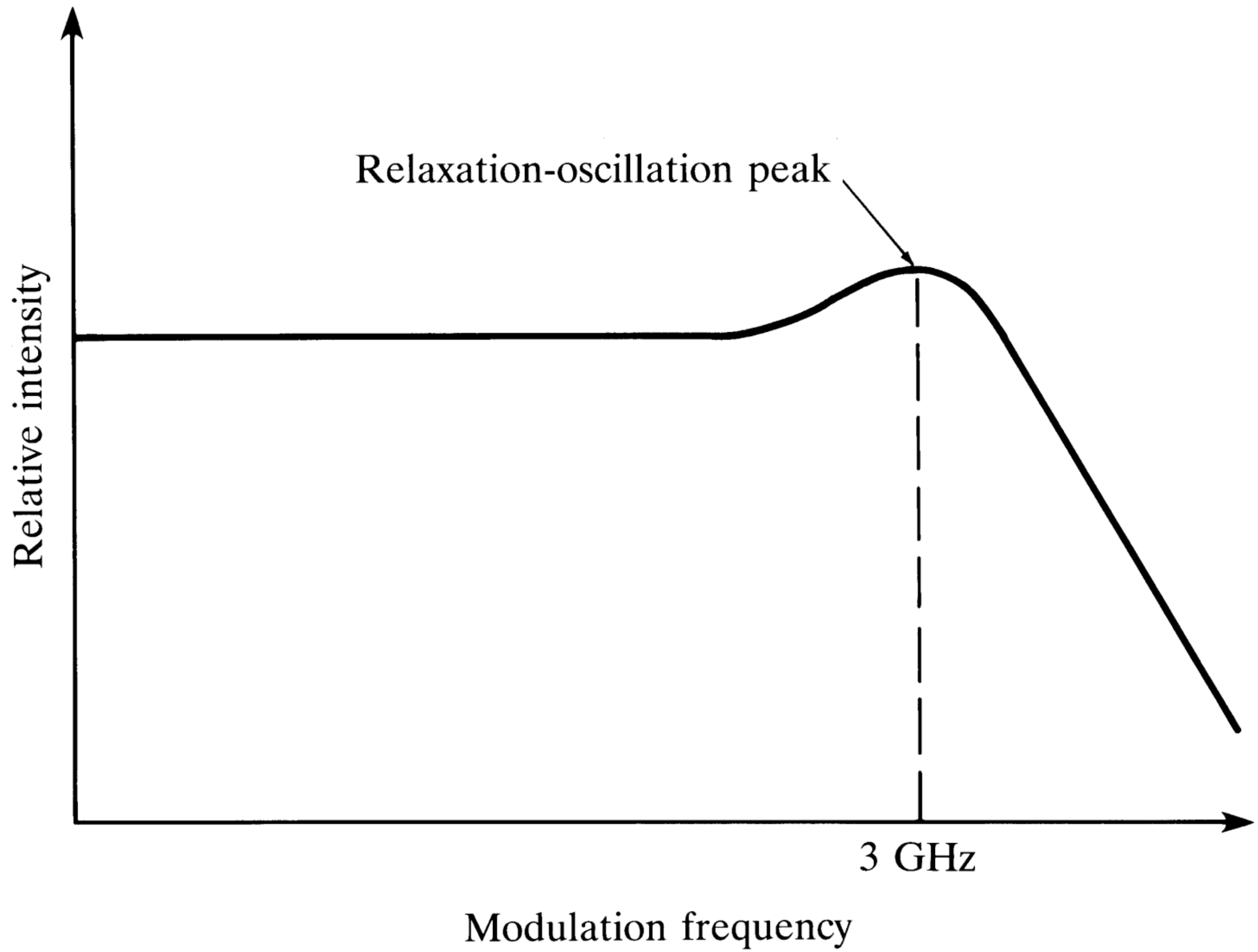
Spontaneous life time

Photon life time

Threshold current

Total current

Relaxation oscillation peak



External Modulation

Directly modulated lasers can not operate smoothly at data rates greater than 2.5 Gbps. It is suitable to use external modulators above this data rate.

There are two types of external modulators

1. **Electrooptical modulator**
2. **Electroabsorption modulator**

1.Electrooptical modulator

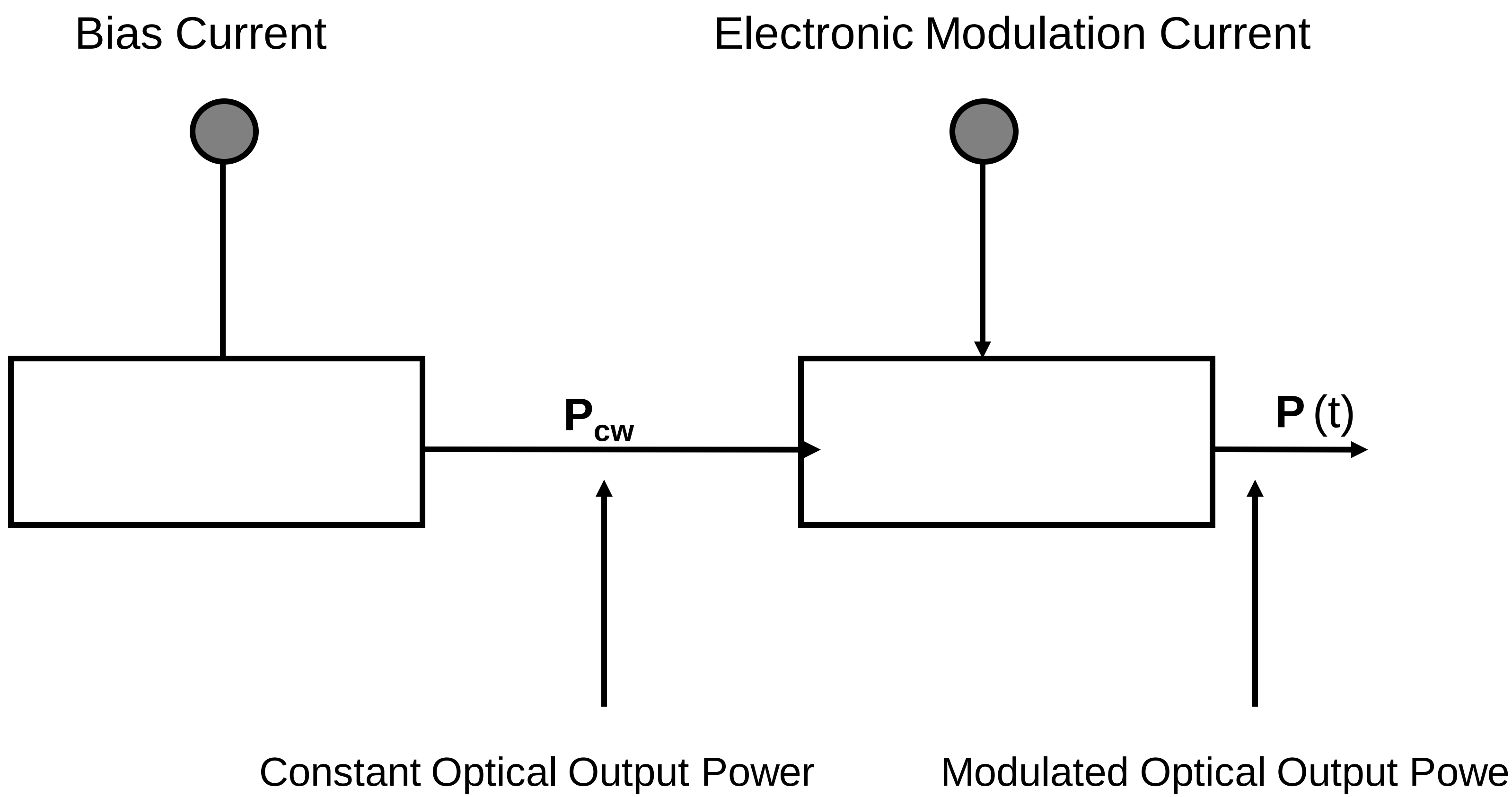
The electrooptical (EO) modulator typically is made of lithium niobate (LbNiO3).

1. Light beam is split in half
2. A high-speed electric signal then changes the phase of the light signal in one of the paths.
3. The constructive recombination produces a bright signal and corresponds to a 1 pulse.
4. Destructive recombination corresponds to a 0 pulse.

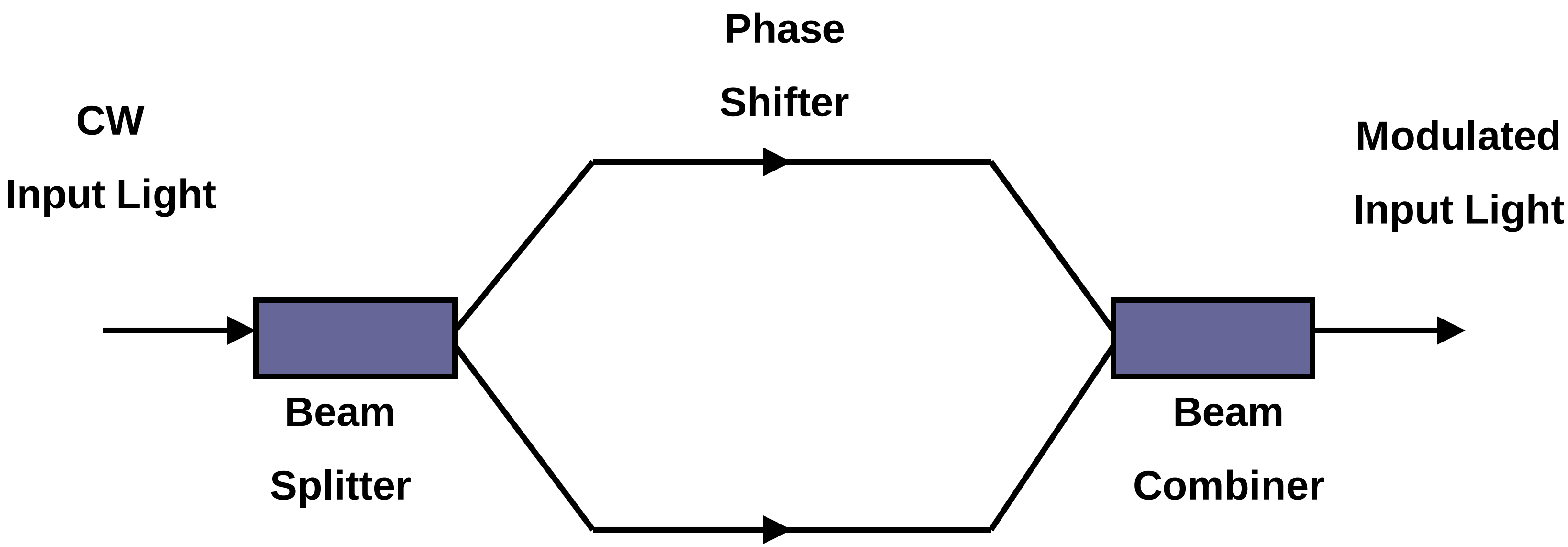
2. Electroabsorption modulator

The electroabsorption modulator (EAM) typically is constructed from indium phosphide (InP).

It operates by having an **electric signal** change the transmission properties of the **material in the light** path to make it either **<u>transparent</u>** during a **1 pulse** or **<u>opaque</u>** during a **0 pulse**



Operational concept of generic external modulator



Operational concept of an electrooptical lithium niobate external modulator

Temperature Effects

Threshold current I_{th} **(T)** of laser diode also depends on the **temperature**. This parameter **increases with temperature** in all types of semiconductor lasers.

So, output optical power can be stabilized in two ways:

1. Controlling dc-bias current level.

2. Controlling temperature level.

Adjustment in the dc-bias (varies with temperature) current level is necessary for constant optical power level.

One possible method for achieving this automatically is an optical feedback scheme.

Temperature Effects

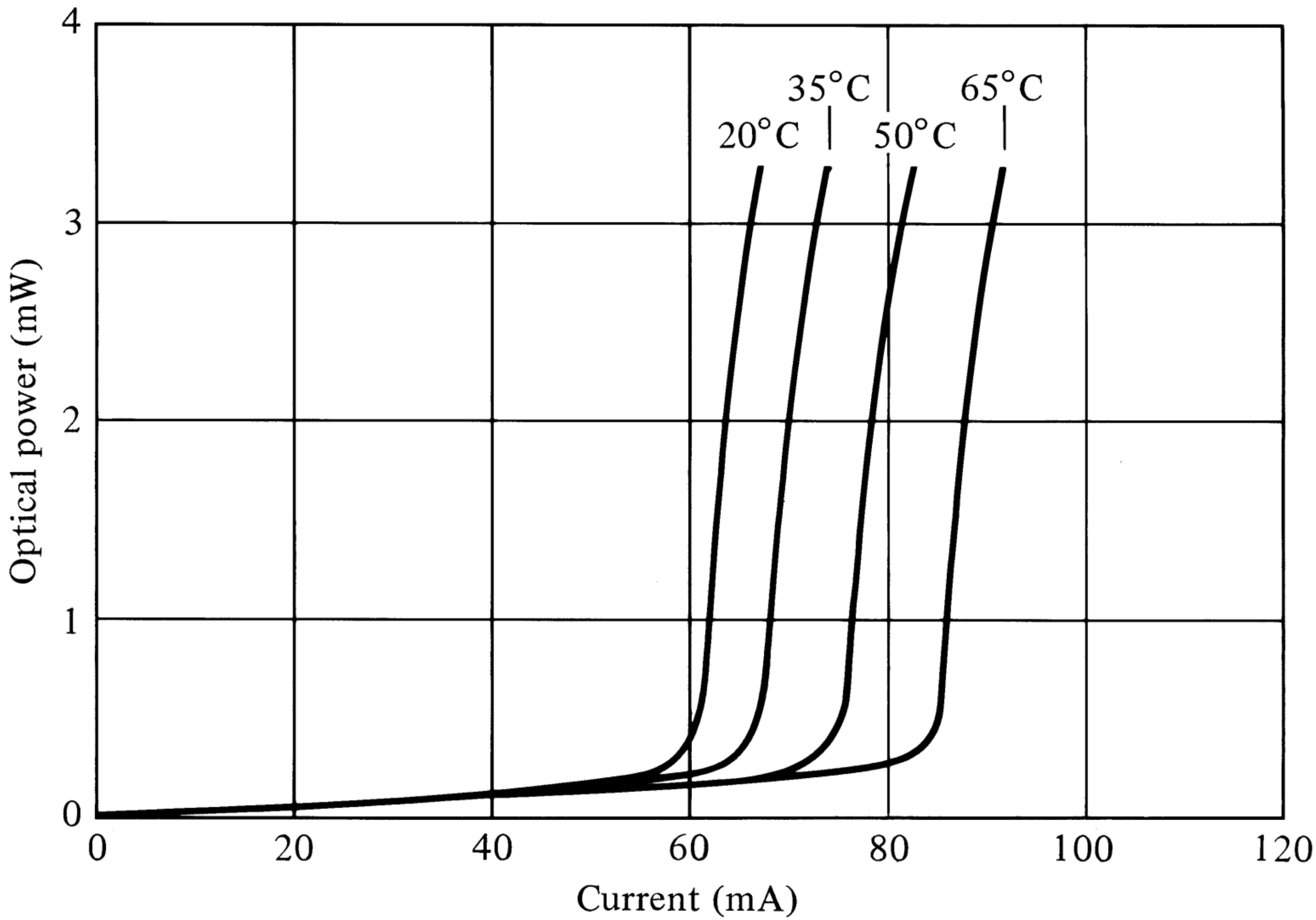
Optical feedback can be carried out by using a **photodetector** either to sense the variation in optical power emitted from the **rear facet** of the laser or to **tap off** and monitor a small portion of the fiber-coupled power emitted from the **front facet**.

The Photodetector compares the optical power with a reference level and adjusts the dc-bias current level automatically to maintain a constant peak light output relative to the reference.

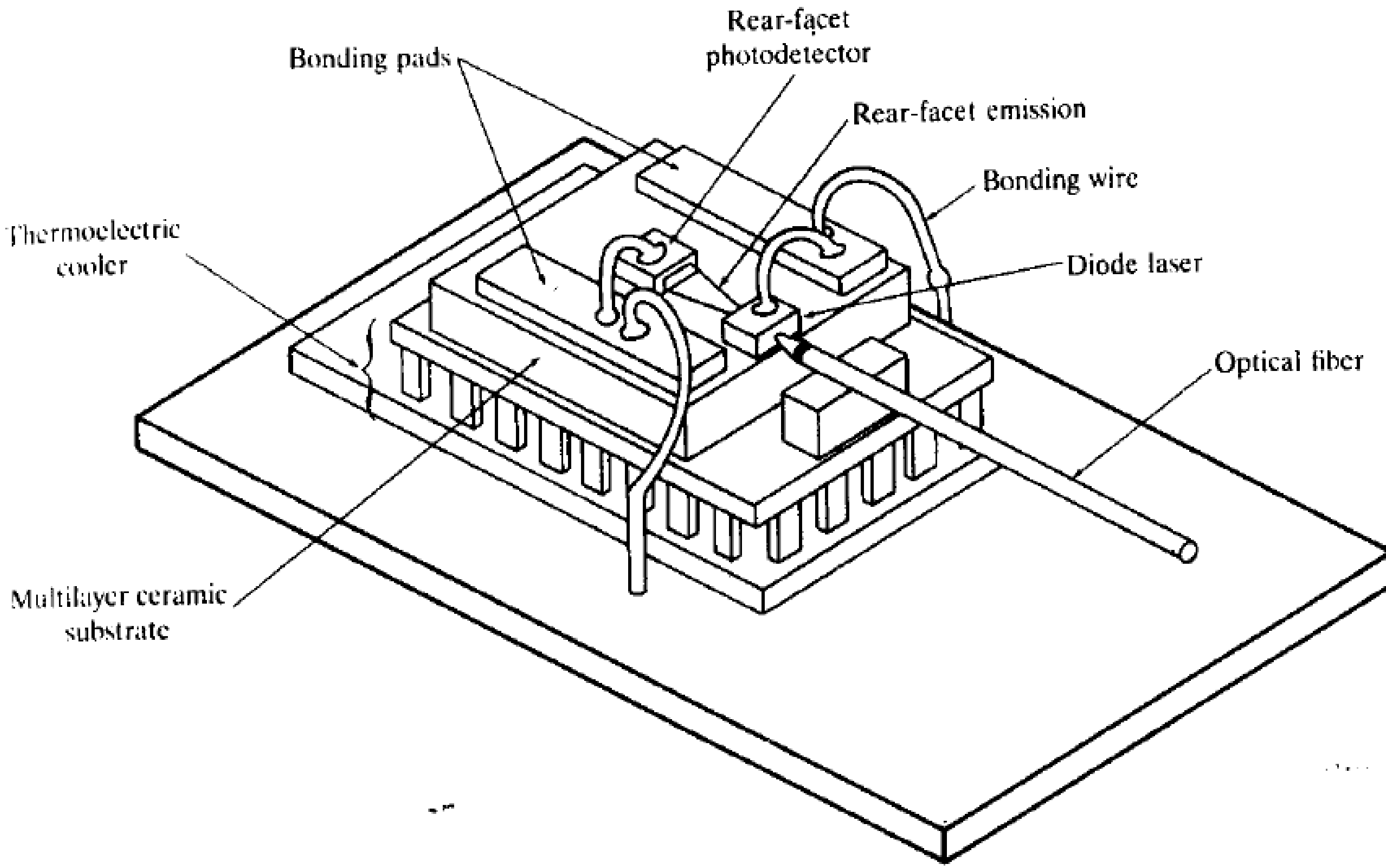
Another standard method of stabilizing the optical output of a laser diode is to use a **miniature thermoelectric cooler.**

Normally both methods are used together

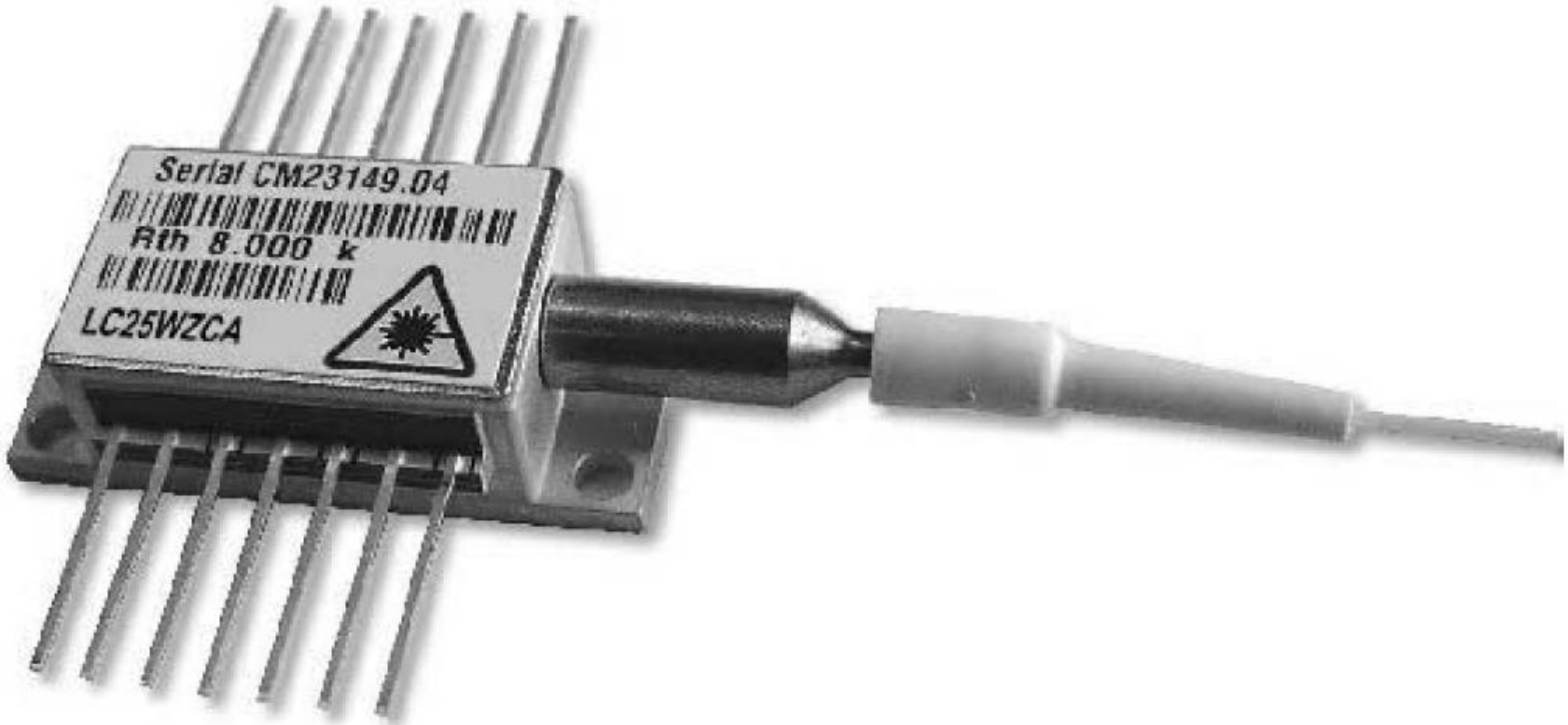
Temperature dependence



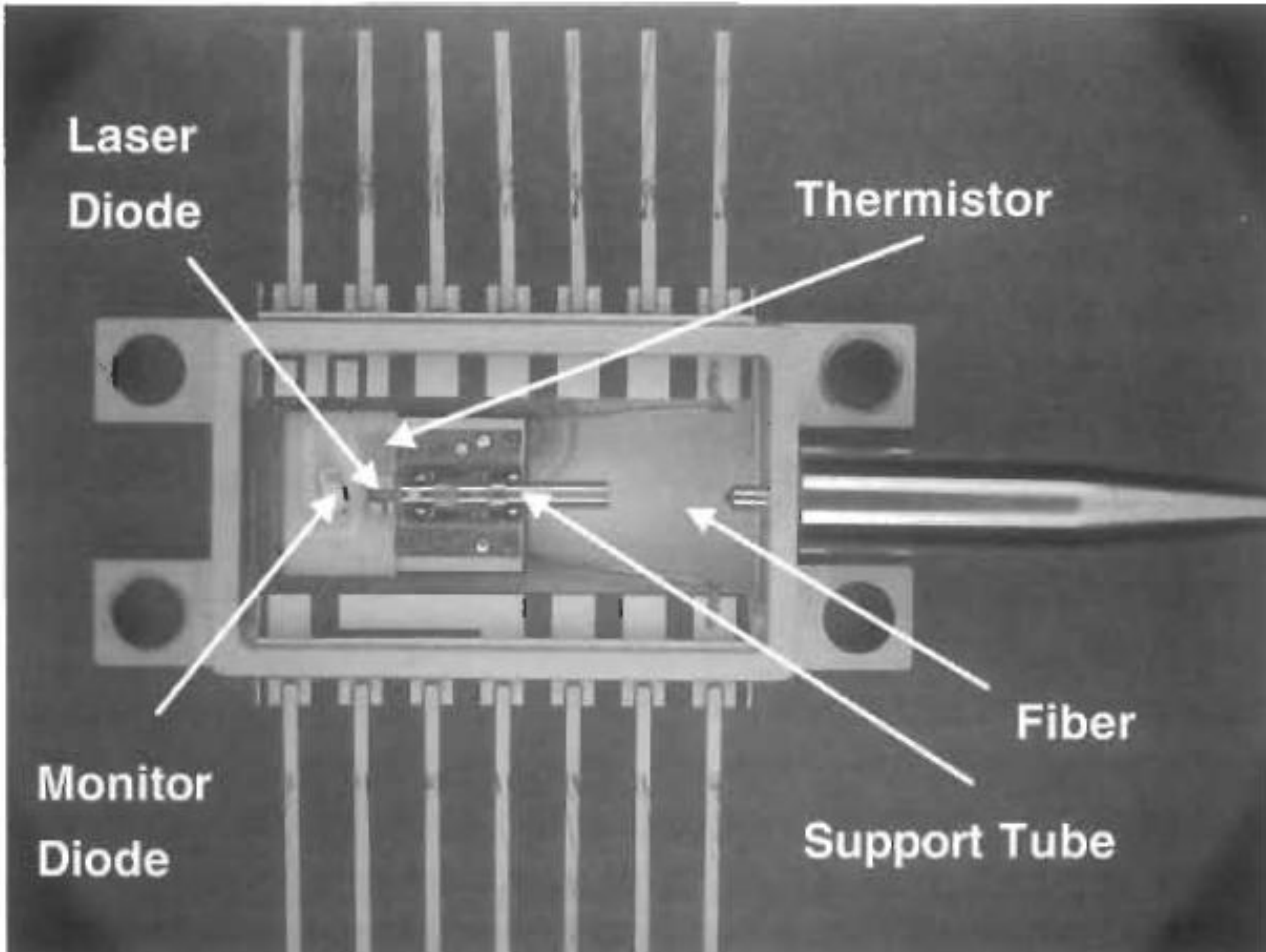
Temperature-dependent behavior of the optical output power as a function of the bias current for a particular laser diode.

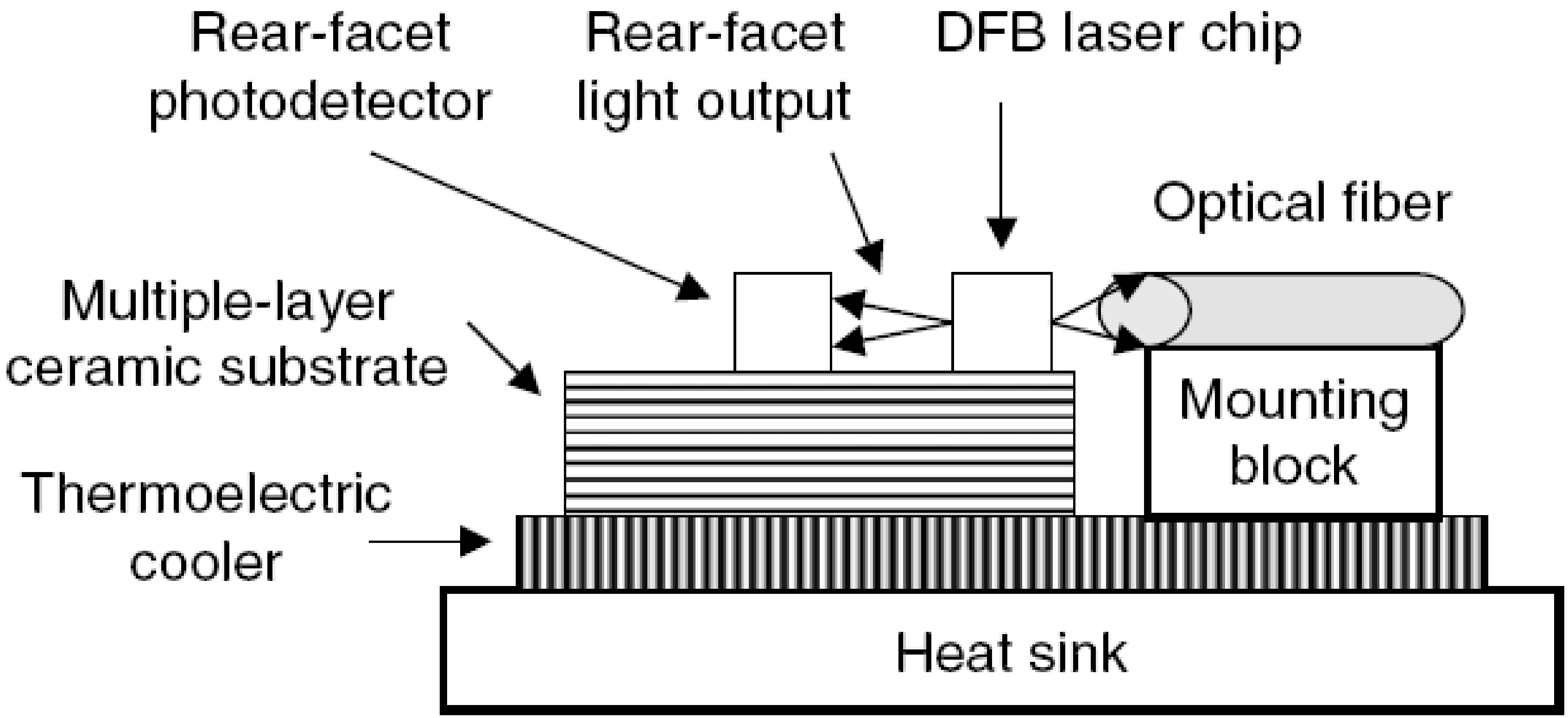


Construction of a laser transmitter that uses a rear-facet photodiode for output monitoring and a thermoelectric cooler for temperature stabilization



Laser diode module


Laser
Diode
Thermistor
Monitor
Diode
Fiber
Support Tube



High-performance optical transmitter containing a DFB laser, a fiber mounting block, a thermoelectric cooler, and a monitoring photodiode.