Optical Sources for Fiber Optic Communication

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Brief Outline

- **Basic LED Operation**
- **Heterojunction (Single, Double)**
- **Basic Laser Operation**
- **Double Heterostructure Stripe Geometry Laser**
- **Distributed Feedback Laser, DBR Laser, Vertical Cavity Surface Emitting Laser**
- **Quantum Well Laser**
- **In-Fibre Lasers**
- **Fiber Ring Laser**
- **Laser Characteristics**
- **Fiber Optic Communication Basics**
- **Modulation of Laser – Direct, External**
- **Wavelength Division Multiplexing (WDM)**

Emission of light (Optical Source)

- **When an electron jumps from a higher energy state (E_c) to a lower energy state (E_v) the difference in energy $E_c - E_v$ is released either**
  - **as a photon of energy $E = h\nu$ (radiative recombination)**
  - **as heat (non-radiative recombination)**

- **Emission of light, (in the form of a photon) can take place either <u>spontaneously</u> or it can be <u>stimulated</u> by the interaction of another photon having right energy level.**

- **For spontaneous or stimulated emission to occur, <u>energy must be supplied to boost the electron from its low energy state to a higher energy state.</u>**

- **The light energy can come from many sources: Heat (Incandescent light), Electrical Discharge (D_2, Hg, Na lamps), Electrical Current (LED, LD), Bioluminescence (Fire fly-luciferase enzyme)**

Optical Sources suited to Fiber Optic Communication:

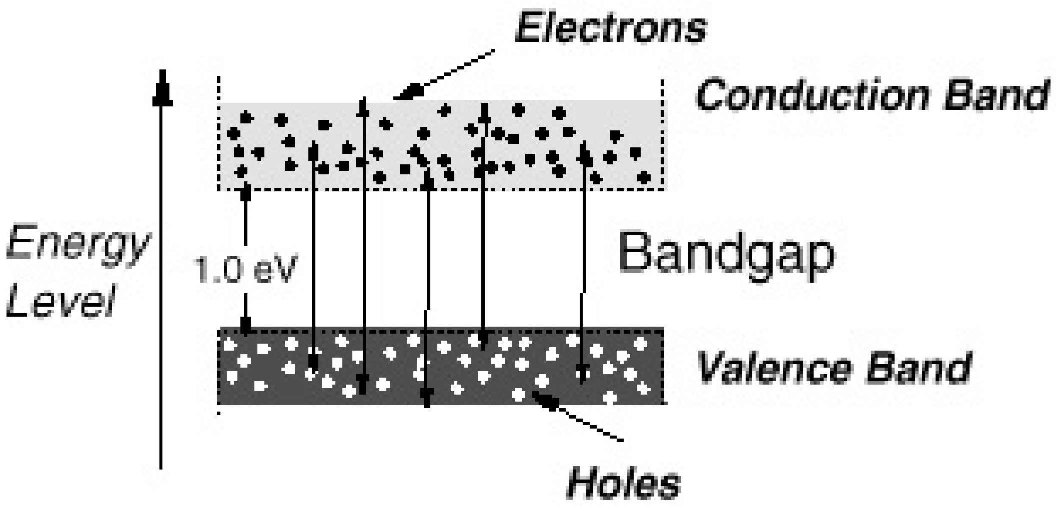
- **Light Emitting Diode (SLED, ELED, SLD)**
- **Semiconductor Laser (DFB, DBR, Vertical-Cavity Surface-Emitting Laser(VCSEL) , Multi Quantum Well , In-Fiber Lasers, Fiber Ring Lasers)**

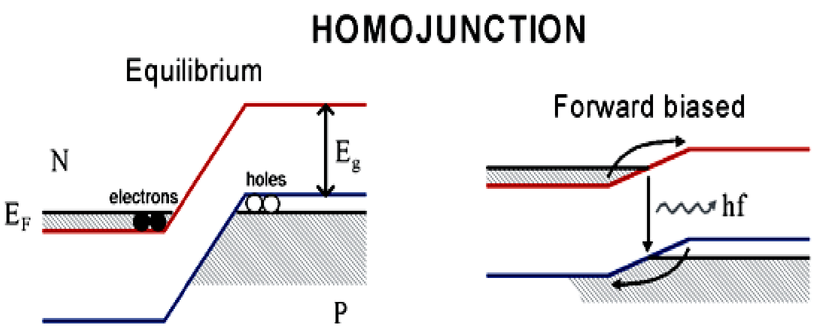
Optical Source Requirements:

- **Physical dimensions to suit the optical fiber geometry**
- **Narrow radiation pattern (beam width)**
- **Ability to be directly modulated by varying driving current**
- **Fast response time**
- **Adequate output power to couple into the optical fiber**
- **Narrow spectral width**
- **Driving circuit issues**
- **Stability, Efficiency, Reliability and cost**

Basic LED operation

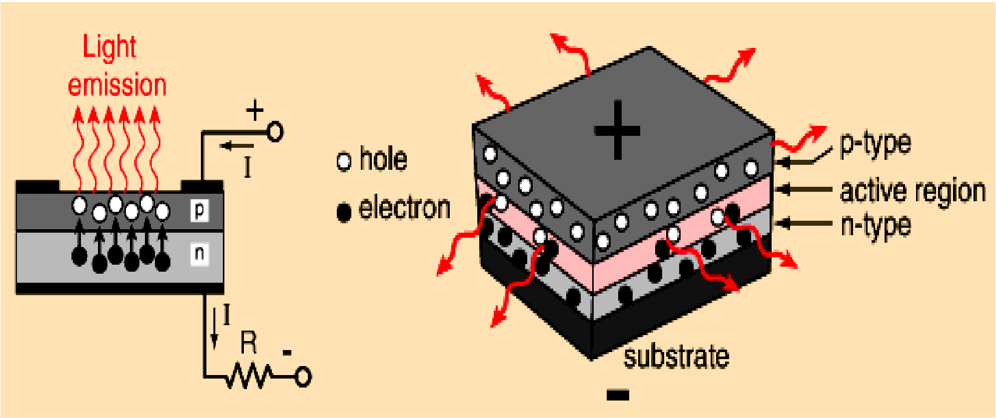
- **A PN junction acts as the active or recombination region.**
- **When PN junction is forward biased, electrons and holes recombine either radiatively (emitting photons) or non-radiatively (emitting heat). This is simple LED operation.**





- **Emitted wavelength depends on bandgap energy**
- **Transitions take place from any energy state in either band to any state in other band. Results in a range of wavelengths produced (spontaneous emission). Typically the wavelength range is more than 80 nm.**

Light Emitting Semiconductors



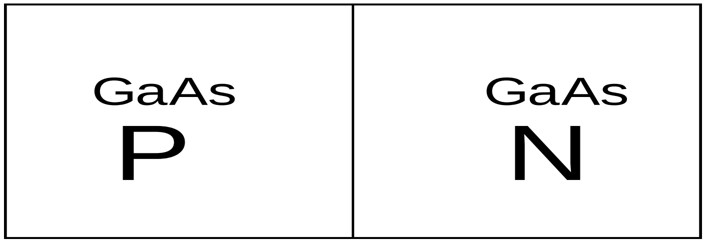
Material	Wavelength Range (μm)	Bandgap Energy (eV)
AlGaInP	0.61 - 0.68	1.82 - 1.94
GaAs	0.9	1.4
AlGaAs	0.8 - 0.9	1.4 - 1.55
InGaAs	1.0 - 1.3	0.95 - 1.24
InGaAsP	0.9 - 1.7	0.73 - 1.35

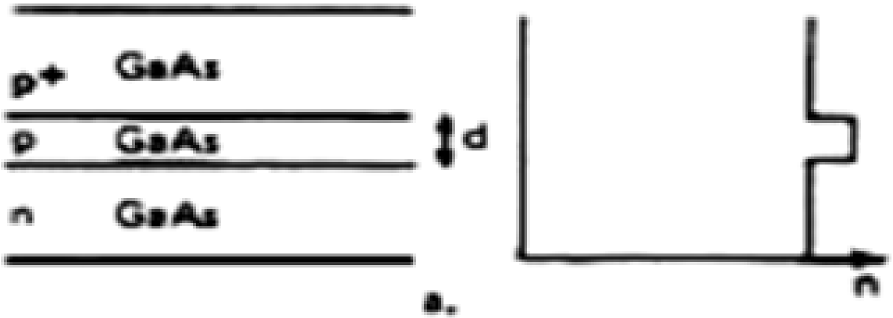
- **Light is emitted at the site of carrier recombination which is primarily close to the junction.**
- **The amount of radiative recombination and the emission area within the structure is dependent upon the semiconductor materials used and the fabrication of the device.**

Light Source Material

- **Most of the semiconductor light sources contain III-V ternary & quaternary compounds.**
- $Ga_{1-x}Al_xAs$ **by varying x it is possible to control the band-gap energy and thereby the emission wavelength over the range of 800 nm to 900 nm. The spectral width is around 20 to 40 nm.**
- $\mathbf{In_{1-x}Ga_xAs_yP_{1-y}}$ **by changing 0<x<0.47; y is approximately 2.2x, the emission wavelength can be controlled over the range of 920 nm to 1600 nm. The spectral width varies from 70 nm to 180 nm when the wavelength changes from 1300 nm to 1600 nm. These materials are lattice matched.**
- **850nm region: GaAs and AlGaAs**
- **1300–1550nm region: InGaAsP and InP**

- **Homojunctions: P- type and N-type from same material**





- Carriers are not confined
- Light is not confined

Structure and index of refraction in gallium arsenide with a junction width d

- <u>**LED should have a high radiance (light intensity), fast response time and a high quantum efficiency for Fiber Optic Communication system**</u>

Heterojunction

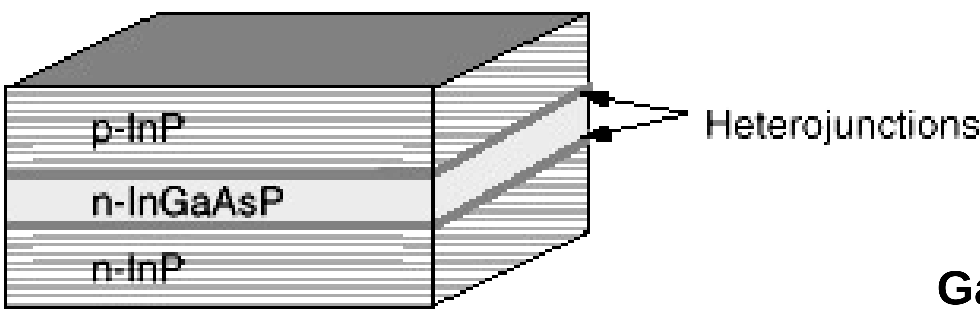
- **Heterojunction is the advanced junction design to reduce diffraction loss in the optical cavity.**
- **This is accomplished by modification in the material to control the index of refraction of the cavity and the width of the junction.**
- **The index of refraction of the material depends upon the impurity used and the doping level.**
- **The Heterojunction region is actually lightly doped with p-type material and has the highest index of refraction.**
- **The n-type material and the more heavily doped p-type material both have lower indices of refraction.**
- **This produces a light pipe effect that helps to confine the light to the active junction region. In the homojunction, this index difference is low and much light is lost.**
- **Double or single hetero-structure junction with better light output**

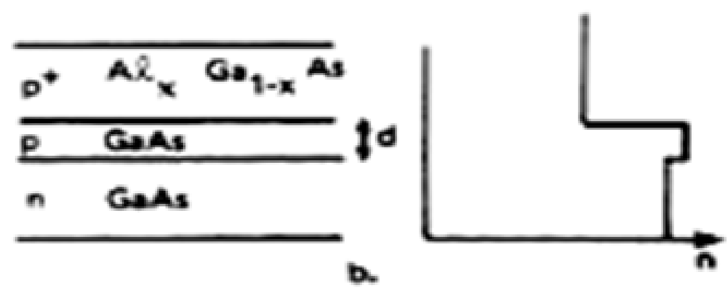
Heterojunctions: Different p- and n- materials

- Carriers are confined
- Light is also confined
- Single Heterojunction, Double Heterojunction.

➢ A heterojunction is a junction between two different semiconductors with different bandgap energies.

➢ The difference in bandgap energies creates a one-way barrier. Charge carriers (electrons or holes) are attracted over the barrier from the material of higher bandgap energy to the one of lower bandgap energy.





Gallium Arsenide-Aluminum Gallium Arsenide <u>single heterojunction</u>

Double Heterojunction

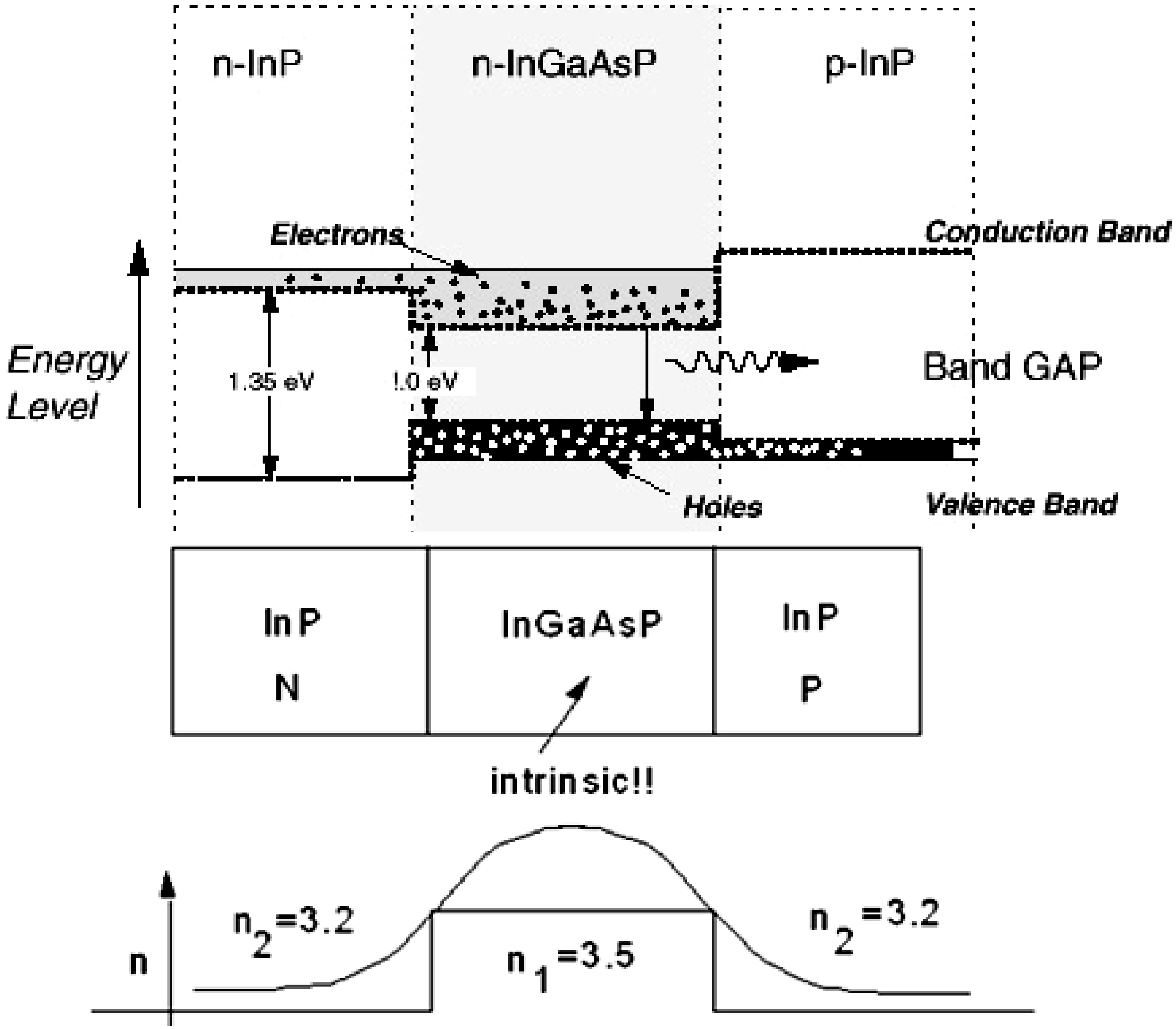
- **When a layer of material with a lower bandgap energy is sandwiched between layers of material with a higher energy bandgap a *double heterojunction* is formed. This is called a double heterojunction because there are two heterojunctions present - one on each side of the active material.**

- **The <u>double heterojunction forms a barrier which restricts the region of electron-hole recombination to the lower bandgap materia</u>l. This region is then called the “active” region**

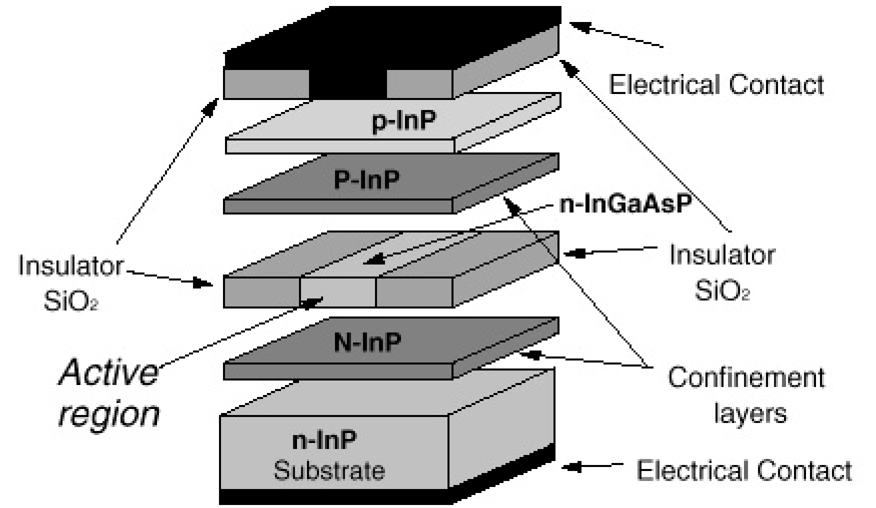
Double Heterojunction

- The valence band of n-InGaAsP is at a higher energy than the valence band of the adjacent n-InP. The conduction band is at a lower energy level.

- p-InP has higher energy levels than n-InP but the bandgap is the same

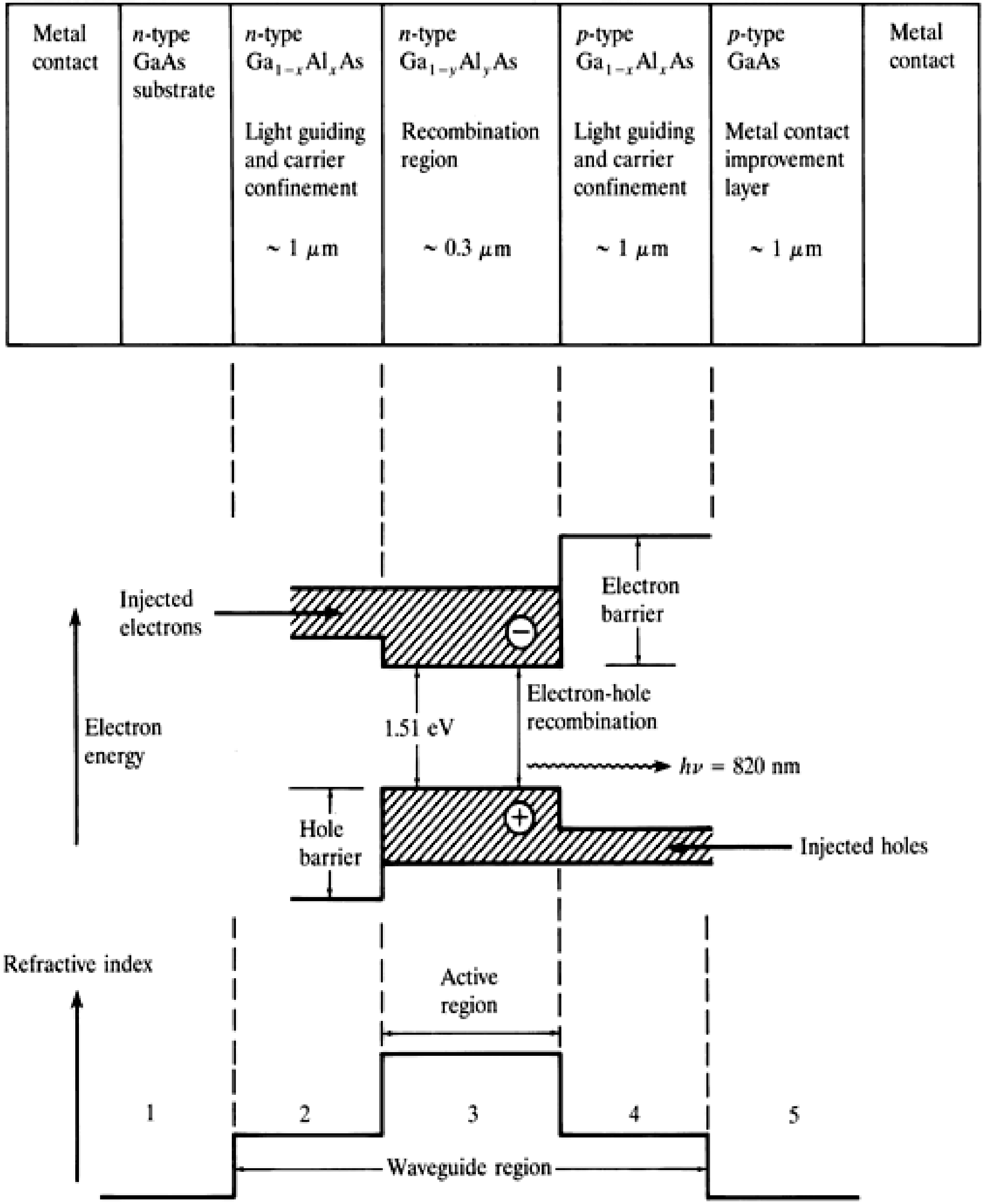


- Electrons are attracted across the left-hand junction from the n-InP to the n-InGaAsP.
- Holes are attracted across the right-hand junction from the p-InP into the n-InGaAsP.



- Recombination takes place in the n-InGaAsP and spontaneous emission (or lasing) occurs.
- The heterojunction allows to have a small active region where the light is produced.
- The material in the <u>active region has a higher refractive index</u> than that of the material surrounding it. This means that a <u>mirror surface effect</u> is created at the junction which helps to confine and direct the light emitted.

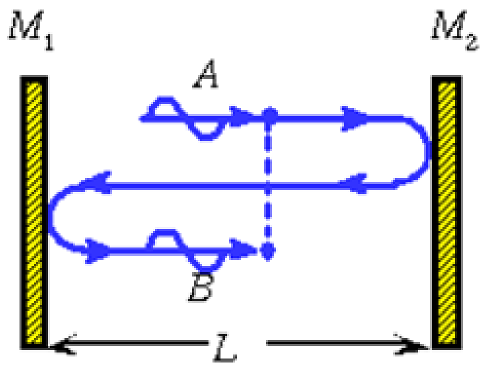
Double Heterojunction



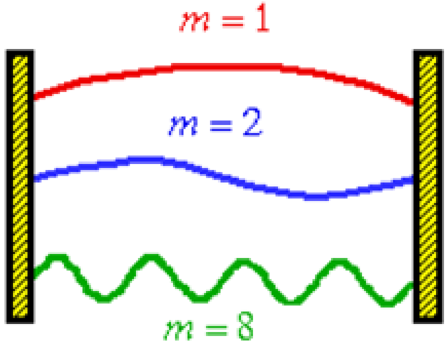
Confining and Guiding the Light within the Device

- Within the device the light must be confined and directed to the exit aperture so that it can be directed into the fibre which is done using <u>insulating materials SiO_2 to confine the active region and the current path</u>.
- The active region in a heterostructure has a higher refractive index.
- This junction forms a mirror layer and helps to confine the light to the <u>active layer</u>. For this reason, the outer layers are often called <u>"confinement layers"</u>

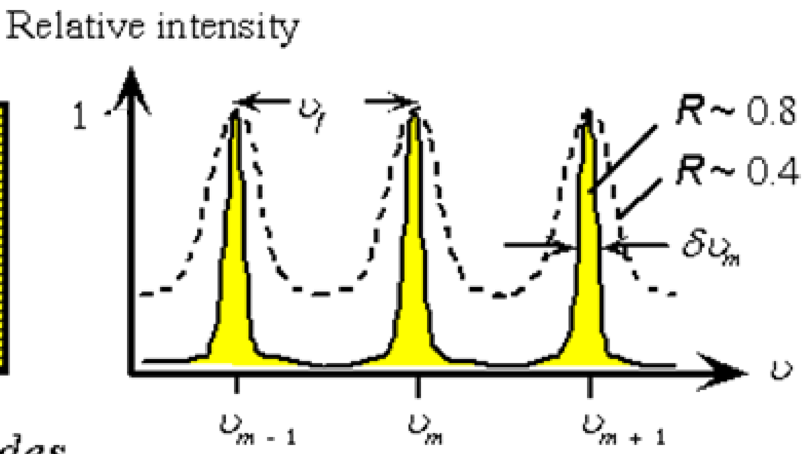
Fabry-Perot Resonator



Reflected waves interfere



Only standing EM *modes*, of certain wavelengths are allowed in the cavity



Intensity vs. frequency for various modes. R is mirror reflectance

Schematic illustration of the Fabry-Perot optical cavity

$$\text{Resonant modes:} \quad kL = m\pi \quad m = 1,2,3,..$$

k : optical wave number

LASER DIODE

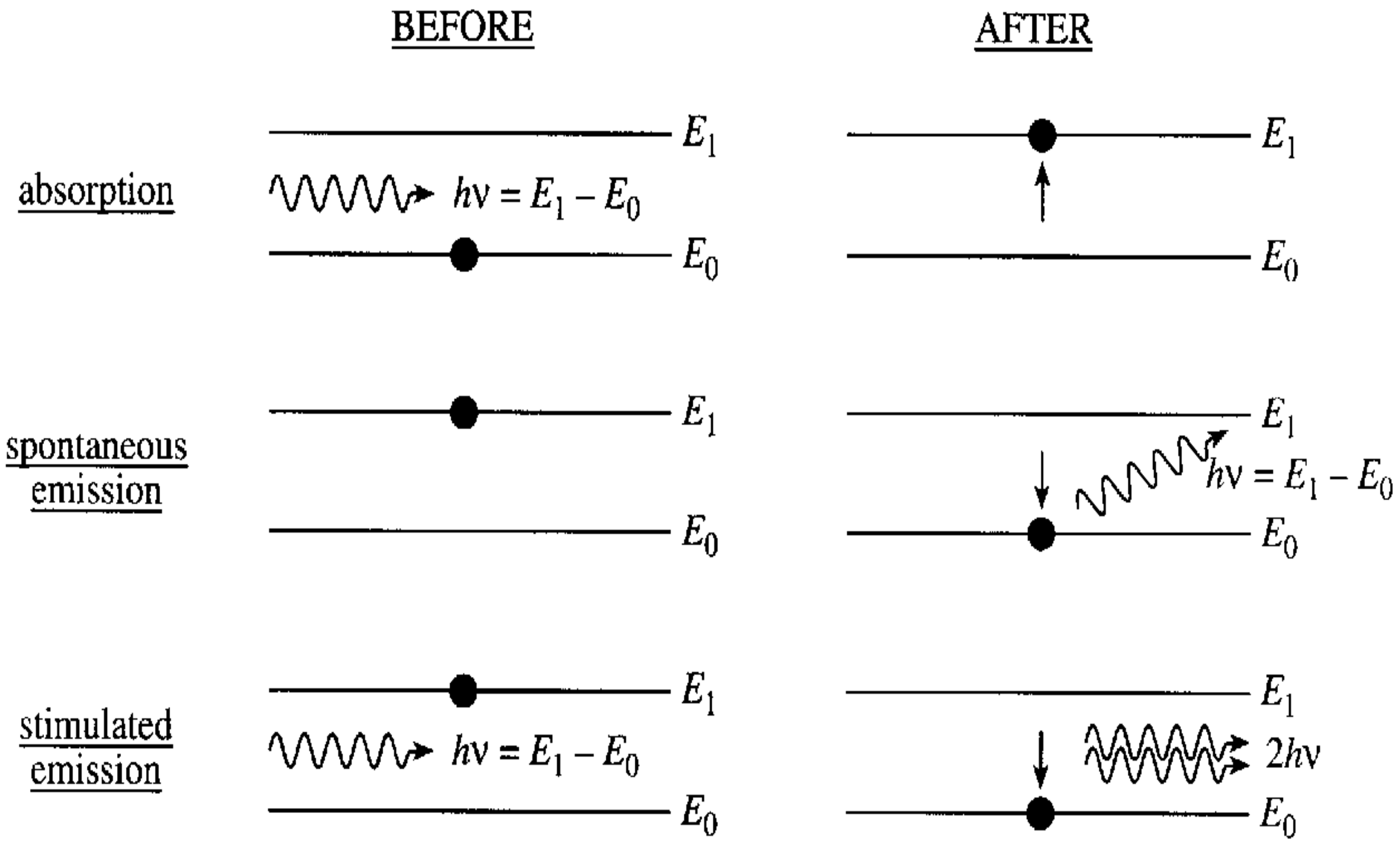
LASER is an acronym for "Light Amplification by Stimulated Emission of Radiation".

- **Coherent light**
- **Narrow beam width**
- **Lasers can produce high output power. In fiber optic communication applications, semiconductor lasers power more than 20 milliwatts are available.**
- **As Laser light is Coherent, a high percentage (50% to 80%) can be coupled into the fiber core.**

LASER : Basic Operation

Fundamental Lasing Operation

- Absorption
- Spontaneous emission
- Stimulated emission

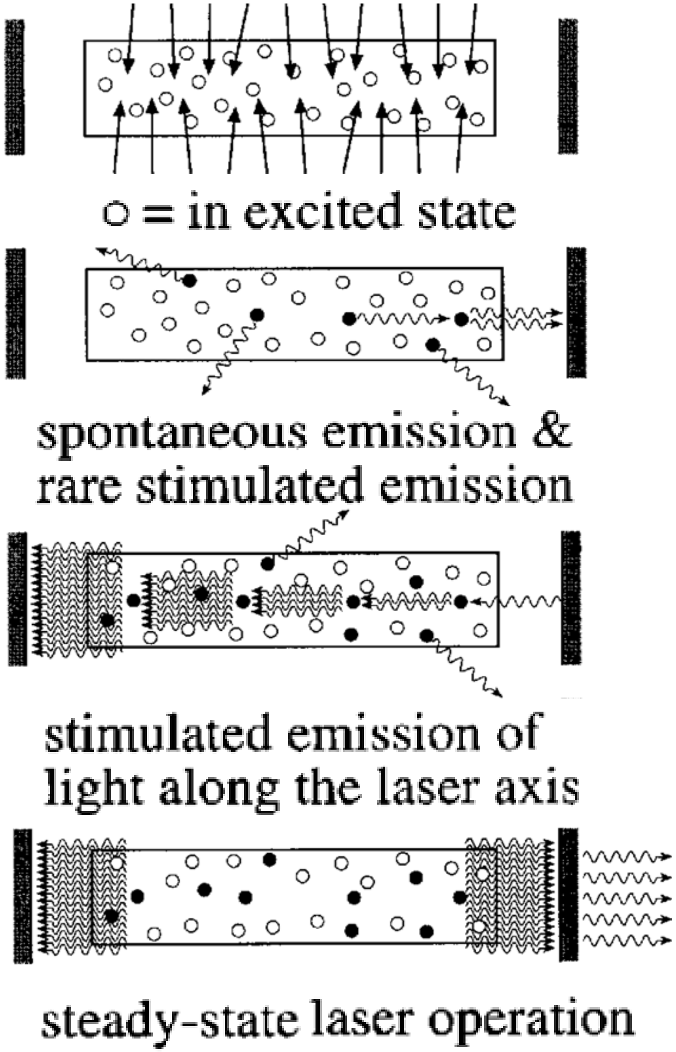


Energy absorbed from the incoming photon

Random release of energy

Coherent release of energy

Conditions for Large Stimulated Emissions

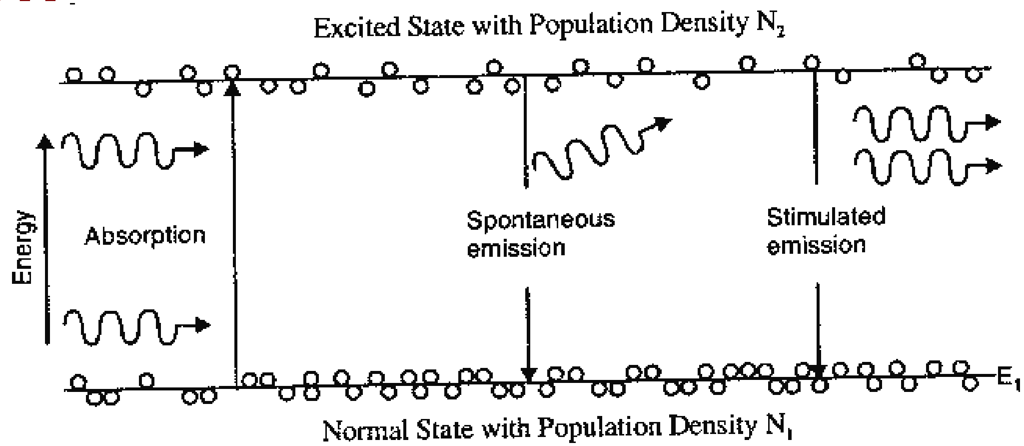


All three processes occur together with a balance between absorption and emission

Two conditions to be satisfied for stimulated emissions to overwhelm the spontaneous emissions are:

- **The population of excited level should be greater that that at the lower energy level and**
- **The radiation density in the medium should be very large.**

Population Inversion



Absorption and Emission process in steady state of material

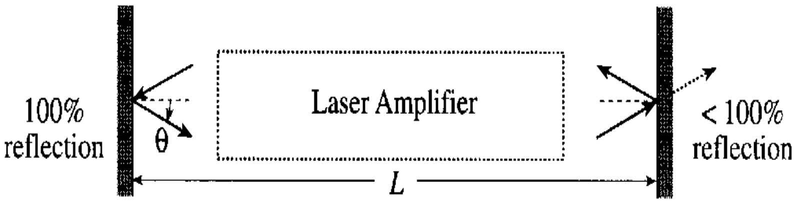
- **At thermal equilibrium : Photon absorption and emission processes take place side by side, but because $N_1 > N_2$; absorption dominates.**
- **Laser operation requires stimulated emission exclusively and to achieve this, majority of atoms should be at higher energy level than at lower level.**
- **Energy is to be supplied to the laser medium to raise atoms from the lower level to the excited level**
- **The process by which atoms are raised from the lower level to the upper level is called <u>pumping</u>.**

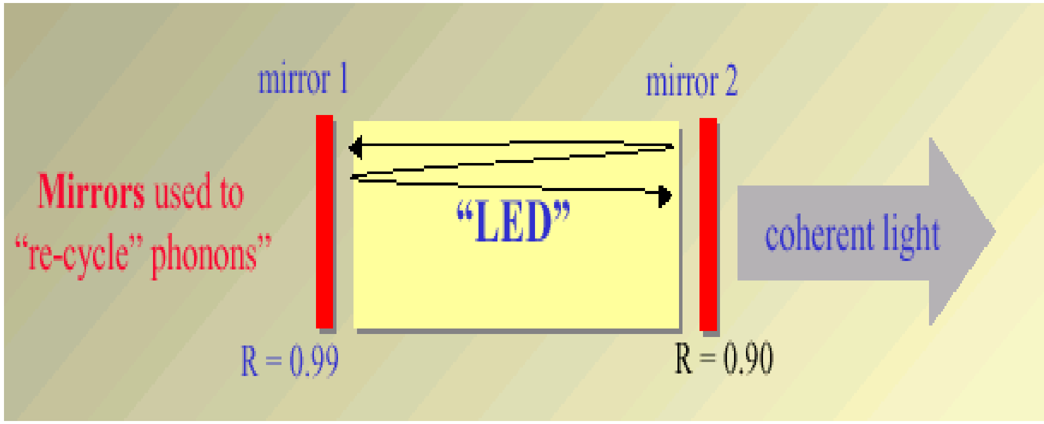
In Stimulated Emission incident and stimulated photons will have

- Identical energy → Identical wavelength → Narrow linewidth
- Identical direction → Narrow beam width
- Identical phase → Coherence and
- Identical polarization

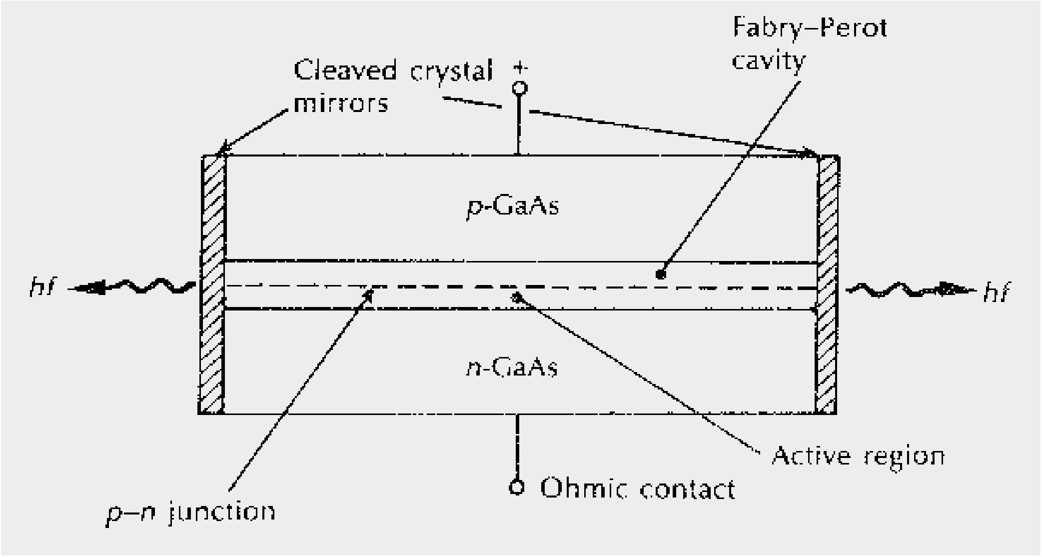
Basic LASER Structure

- **Homojunction device with cleaved ends demand for high <u>threshold current density (>10^4 A cm^{-2}) </u>due to lack of carrier containment – hence inefficient light source**

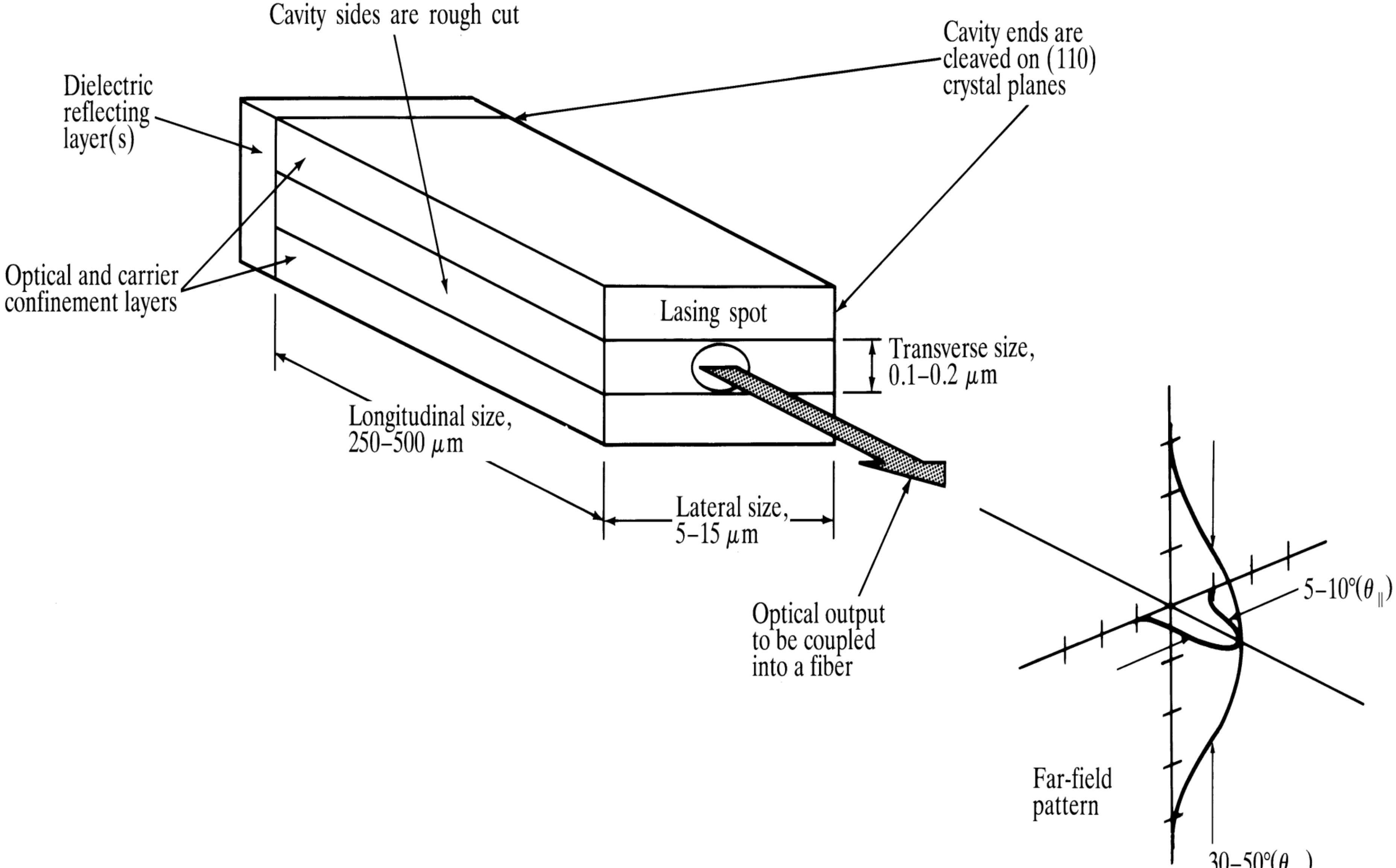




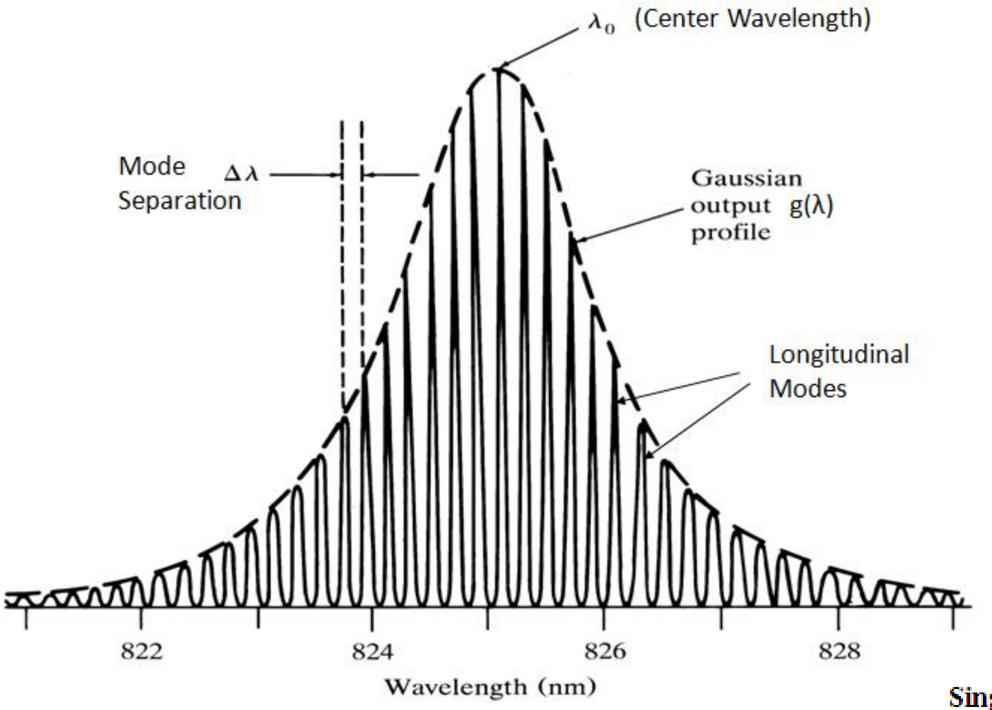
Schematic diagram of a GaAs homojunction injection laser with a Fabry-Perot cavity



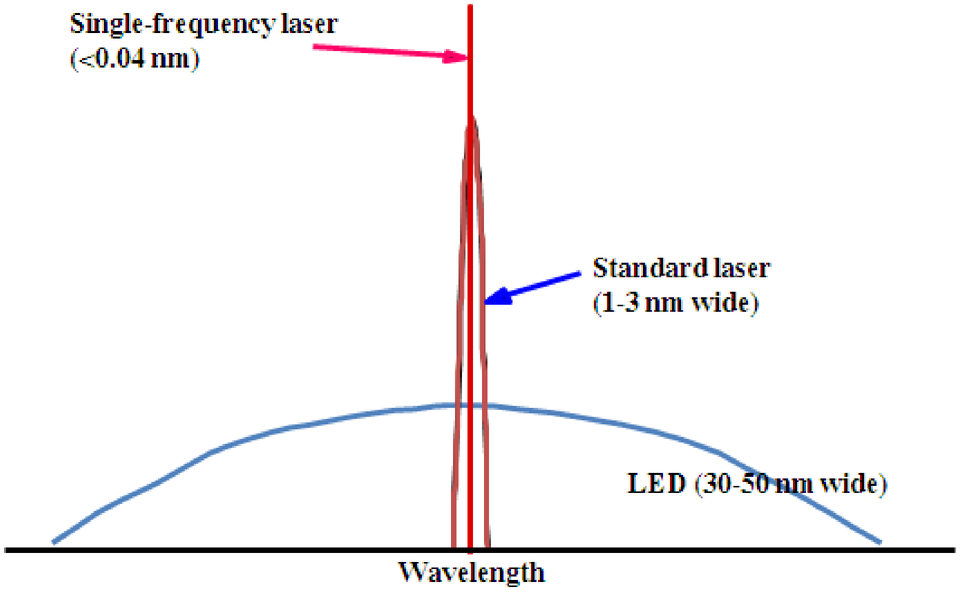
Fabry-Perot Laser (resonator) cavity



Laser Output Spectrum



Laser spectral width



Heterojunction structures

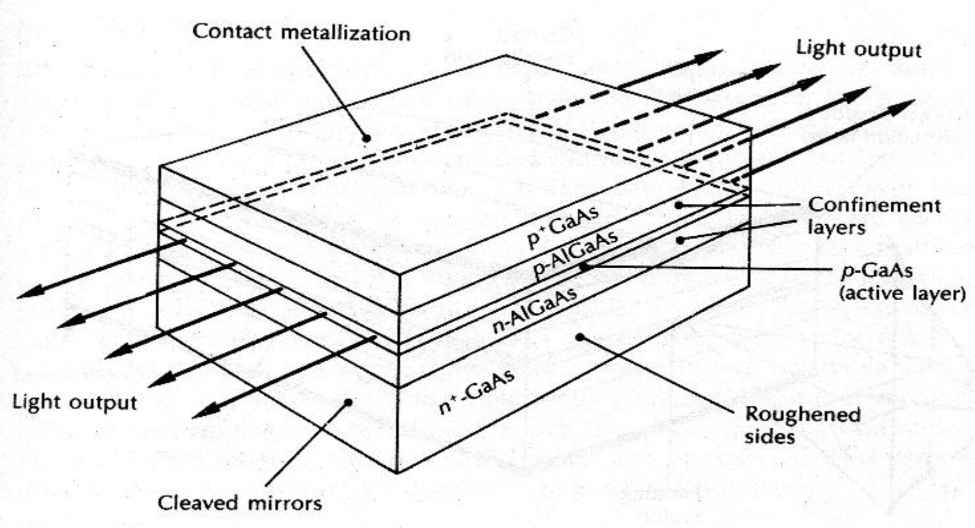
- Improved carrier confinement thus lower current densities(~10^3 A cm^{-2})
- DH ILD fabricated from lattice matched III-V semiconductor provided both carrier and optical confinement on both sides of the p-n junction

Stripe Geometry

DH laser structure provides optical confinement in the vertical direction through the refractive index step at the heterojunction interfaces, but lasing takes place across the whole width of the device.

Broad Area DH laser

- Sides of cavity formed by roughening the edges of device
- Reduce unwanted emission in these directions
- Limit the number of horizontal transverse modes



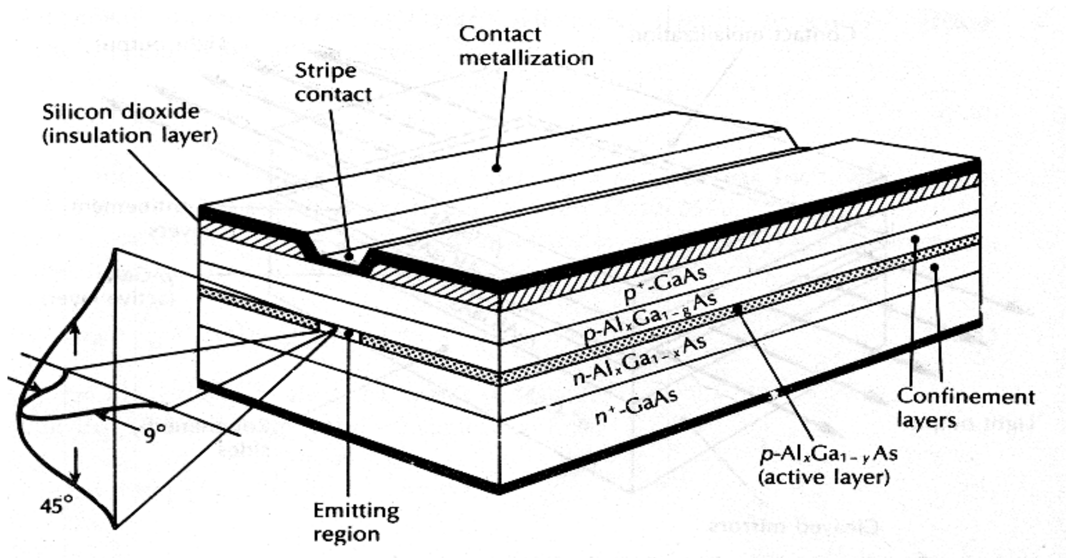
Broad area GaAs/AlGaAs DH injection laser

- Broad emission area creates several problems including difficult heat sinking, relatively wide active area, unsuitable light output geometry for efficient coupling to fibers etc.

DH Stripe Contact Laser

- To overcome broad emission problems while also reducing the required threshold currents
  - a laser structures in which active region does not extend to the edges of the device were developed.

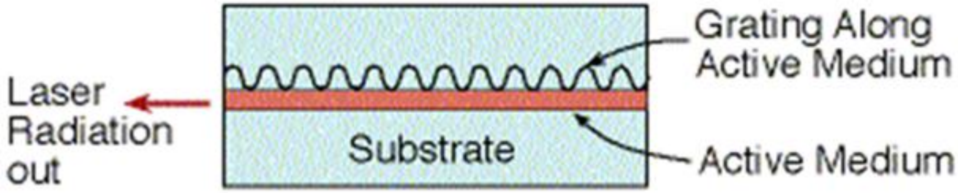
- In this structure, the major current flow through the device and hence the active region is within the stripe.
- Generally, stripe is formed by creation of high resistance areas on either side by techniques such as ***Proton Bombardment*** **or** ***Oxide Isolation***.



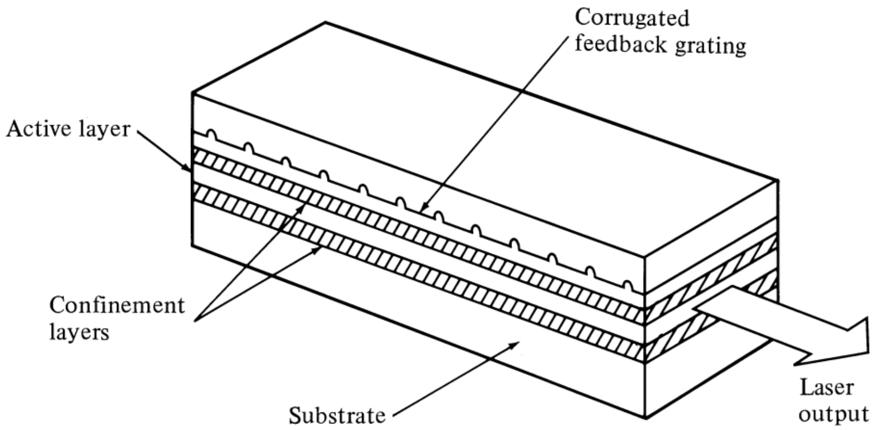
Schematic representation of an oxide stripe AlGaAs DH injection laser.

The stripe therefore acts as a guiding mechanism which overcomes the major problems of the broad area device.

Distributed Feedback Laser



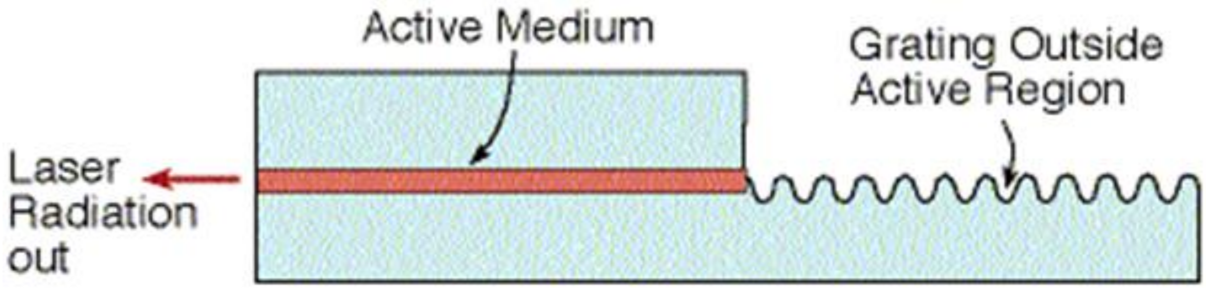
$$\lambda_B = \frac{2n_e\Lambda}{k}$$

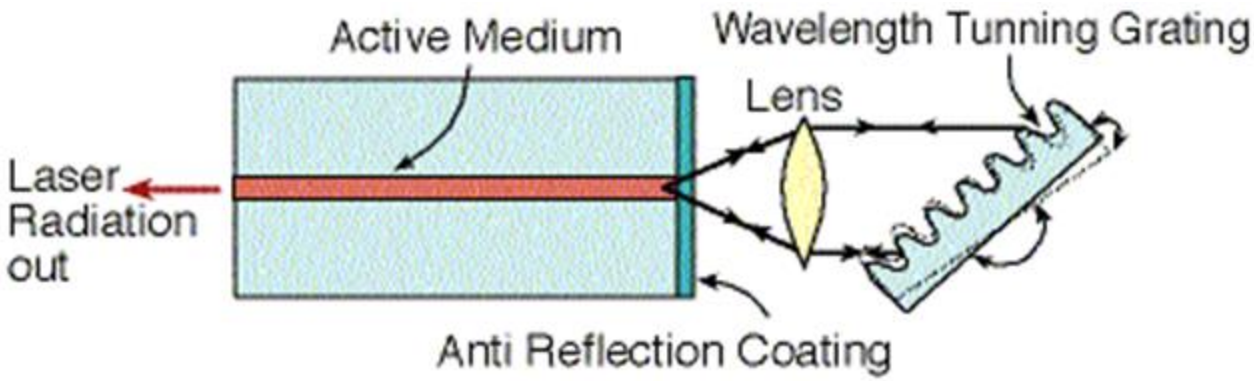


- **A distributed feedback laser (DFB) is a type of laser diode where the active region of the device is periodically structured as a diffraction grating.**
- **The structure builds a one-dimensional interference grating (Bragg Scattering) and the grating provides optical feedback for the laser.**
- **DFB laser diodes do not use two discrete mirrors to form the optical cavity (as they are used in conventional laser designs).**
- **The grating acts as the wavelength selective element for at least one of the mirrors and provides the feedback, reflecting light back into the cavity to form the resonator.**
- **The grating is constructed so as to reflect only a narrow band of wavelength, and thus produce a single longitudinal lasing mode.**

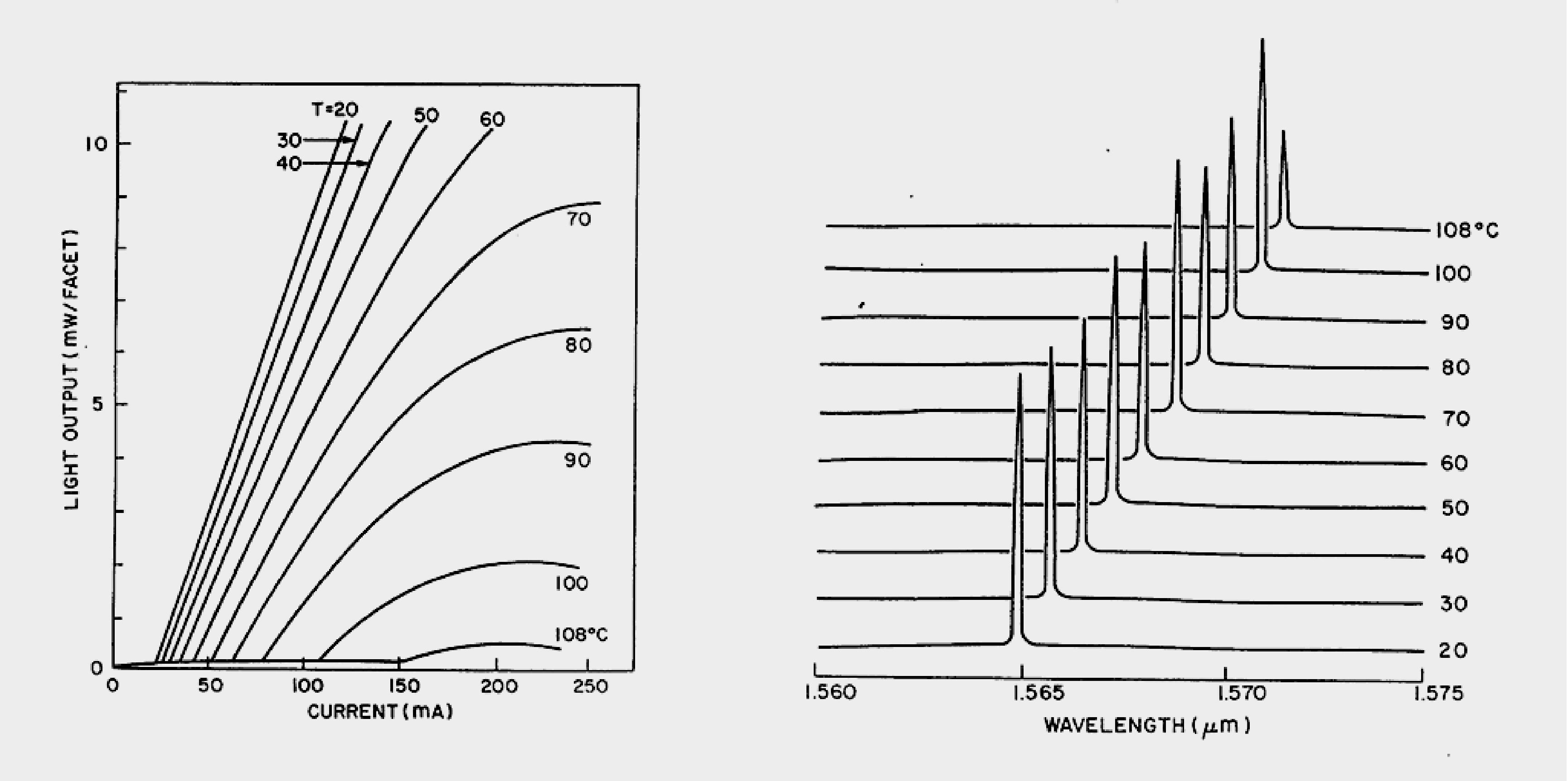
- **This is in contrast to a Fabry-Perot Laser, where the facets of the chip form the two mirrors and provide the feedback.**
- **Temperature dependence of the oscillation wavelength of DFB laser is determined by the temperature dependence of refractive index of the material (~0.1nm/°C) of DFB laser active region.**
- **A change in the refractive index alters the wavelength selection of the grating structure and thus the wavelength of the laser output, producing a Tunable Diode Laser.**
- **DFBs are antireflection coated on one side of the cavity and coated for high reflectivity on the other side (AR/HR).**
- **In this case the grating forms the distributed mirror on the antireflection coated side, while the semiconductor facet on the high reflectivity side forms the other mirror.**
- **These lasers generally have higher output power since the light is taken from the AR side, and the HR side prevents power being lost from the back side.**

Distributed Bragg Reflector(DBR) Laser



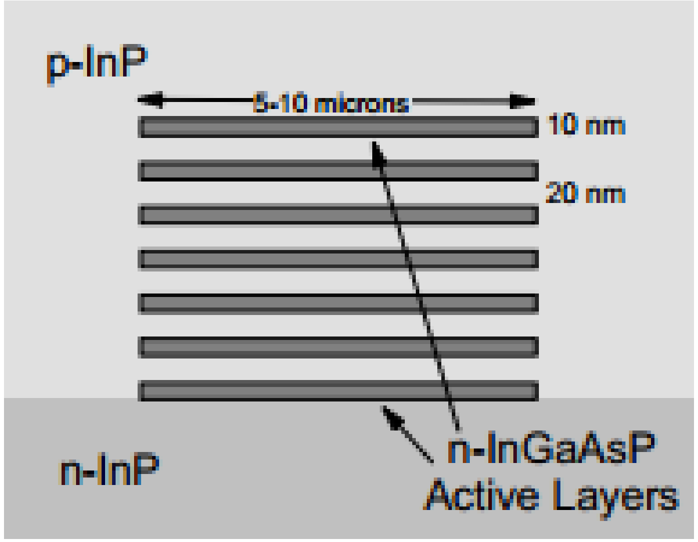


Thermal Properties of DFB Lasers



Light output and slope efficiency decrease at high temperature

Quantum Well Laser



Cavity Structure of a Multiple Quantum Well Laser

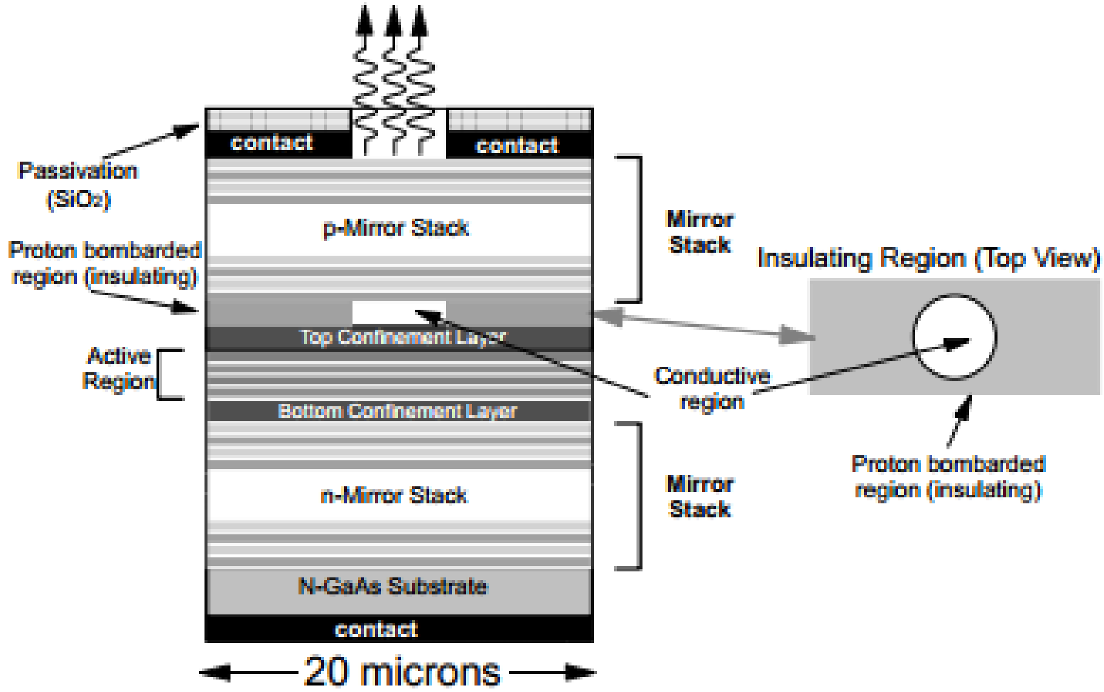
- **When light is confined into a cavity smaller than its wavelength, it behaves as a particle (quantum) rather than as a wave.**

- **Most semiconductor lasers are very thin (20 microns or so) in the vertical direction but this is not thin enough to cause quantum behavior. In QW lasers <u>cavity height is reduced to around 10 or 20 nm</u>. <u>Cavity width is generally from 5 to 10 microns</u>.**

- **The amount of material in the active region is substantially reduced which <u>reduces the amount of energy needed to achieve lasing</u> and thus the lasing threshold.**

- **Quantum well lasers have a much <u>reduced sensitivity to temperature change</u> (compared to DBR and DFB structures).**
- **The quantum well structure produces only one line which has a <u>narrower linewidth</u> than for non-QW structures. The <u>wavelength of the light emitted</u> by a quantum well laser is determined by the <u>width of the active region</u> rather than just the bandgap of the material from which it is constructed.**
- **Lasers with a single active region are called "Single Quantum Well" (SQW) lasers and number of quantum wells are used one on top of another to build "Multiple Quantum Well" structures. The separating layers between the cavities are very thin (10 to 20 nm). MQW structures produce higher gain and greater total power.**
- **By applying MQW structure to the active region of the laser, the performances of the laser such as threshold current, temperature characteristics and modulation frequency were significantly improved.**
- **A disadvantage is that MQW lasers produce a broader linewidth than SQW ones (but still narrower than comparable non-QW structures).**

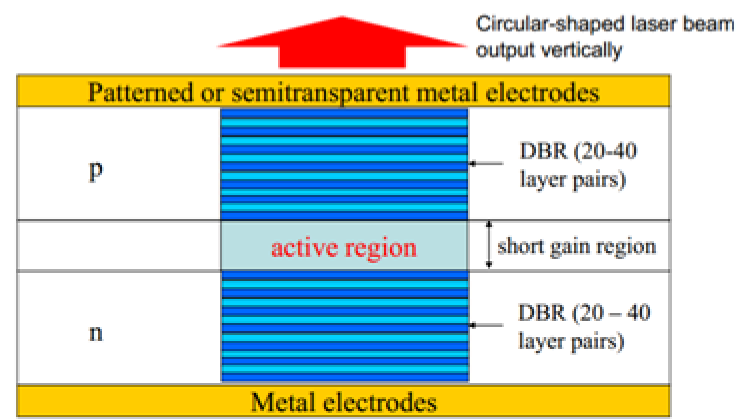
Vertical-Cavity Surface-Emitting Laser (VCSEL)



VCSEL Structure

In DFB, DBR lasers, the light propagates in the plane of the semiconductor wafer whereas, in VCSEL, light travels perpendicularly to the wafer and is emitted from the surface. The mirrors are provided by growing multilayer dielectric stacks above and below the quantum well active layer.

VCSEL schematic



The upper DBR is partially transmissive at the laser-output wavelength.

The multilayer stacks must have reflectivities as high as 99.8 percent and the layer thickness must be precisely controlled to ensure that the resonator frequency falls within the gain bandwidth of the quantum well.

VCSEL demands low power requirements

- Thresholds can be well below 5mA
- Low-divergence, nearly circular beam profile, well suited to optical fibers coupling.

- **VCSELs instead of emitting from the edge, it emit from the surface. It is constructed by laying down a large number (500) of thin layers of semiconductor material. The device emits light vertically through the stack of material layers.**

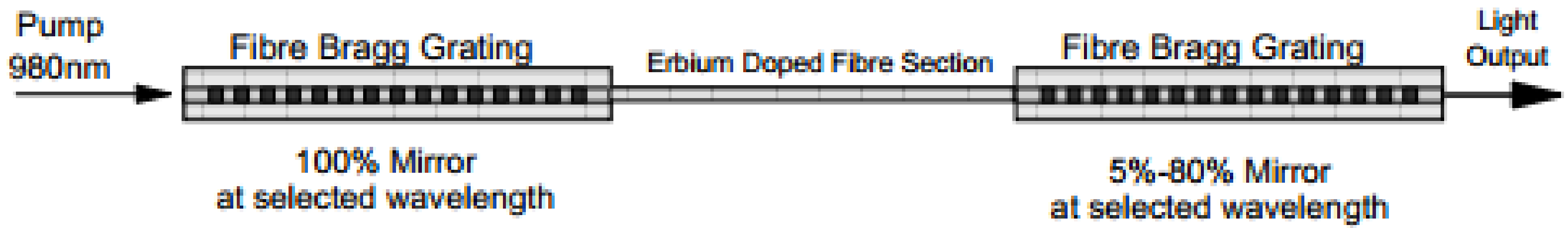
- **The mirrors are made of alternating layers of material of different refractive indices with controlled thickness. The <u>stack forms a Bragg grating which is a wavelength-selective Mirror</u>.** Ÿ

- **The laser is so confined that it forms a “quantum well” in which light behaves as individual photons rather than as waves or rays. Typical dimensions are about 12 microns in diameter (for single mode operation) and 20 microns (for multimode operation).**

- **Current VCSELs on the market offer one of two possible wavelengths: 980 nm or 850 nm.**

- **Ÿ Typical VCSELs have very low threshold currents (less than 5mA). Very low power dissipation and low modulation current requirements, so <u>no special driver circuitry</u> is required. Ÿ VCSELs have high modulation bandwidths (2.4 GHz has been demonstrated).**

In-Fiber Lasers



In-Fibre Laser Using FBGs.

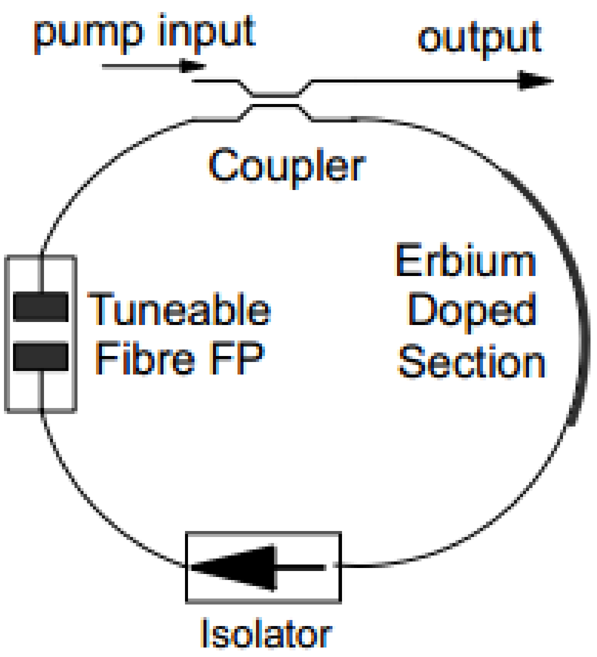
- **A fiber laser is constructed from two In-FBGs which acts as wavelength-selective mirror and a length of Erbium doped fibre as the gain section (cavity).**
- **The laser is pumped with a wavelength (980nm or 1480nm for Erbium) appropriate to the lasing medium.**
- **Pump laser light at 980nm enters the cavity through the left-hand FBG. Both FBGs are reflective at a very specific wavelength (as designed) in the 1550nm band. So 980nm light will pass straight through the FBG without attenuation.**

Ÿ

- **Spontaneous emission will commence in the erbium and most spontaneous emissions will not be at exactly the right wavelength to be reflected by the FBGs and so will pass out of the cavity and mirrors.**
- **But some spontaneous emissions will (by chance) have exactly the right wavelength and will happen to be in the guided mode.ŸIn this case these emissions will be reflected by the FBGs and amplified in the cavity and lasing will commence.**

Fiber Ring Lasers

- A fiber ring structure can be used to make a very narrow linewidth laser.
- The wavelength is controlled by the tuneable FP filter and is tuneable over a range of up to 40nm
- An isolator is necessary to prevent a counter-propagating lasing mode being generated.
- Output is already in a fiber so there is no pigtailing involved in connecting to a fibre
- Output power can be quite high (up to 50 mW).
- Stable wavelength with very narrow linewidth produced
- An <u>external modulator</u> is required as there is no way to modulate the laser intensity by controlling the pump



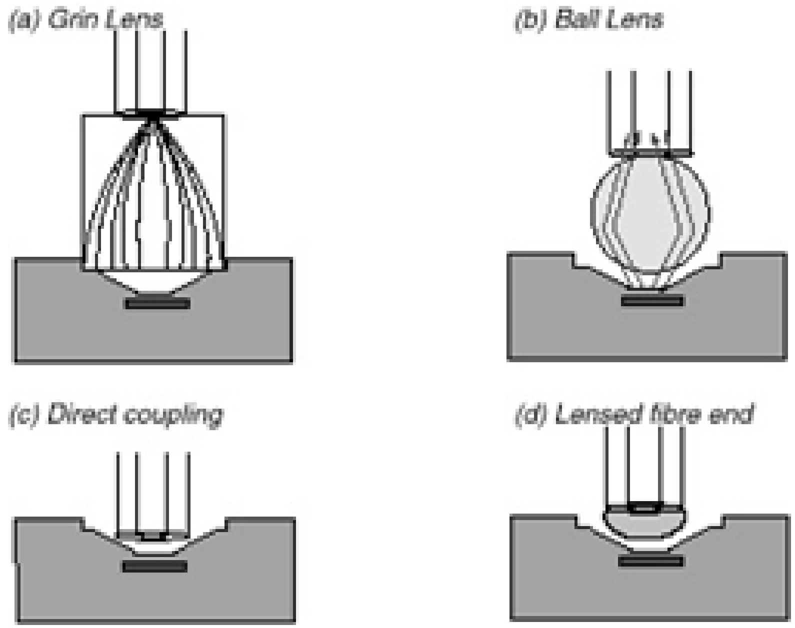
Tuneable Fibre-Ring Laser

Dependence of coupled power to optical fiber

The amount of optical power coupled into the fiber is the relevant optical power. It depends on the following factors:

- **The angles over which the light is emitted**
- **The size of the source's light-emitting area relative to the fiber core size**
- **The alignment of the source and fiber**
- **The coupling characteristics of the fiber (such as the NA and the refractive index profile)**
- **Typically, semiconductor lasers emit light spread out over an angle of 10 to 15 degrees.**
- **Semiconductor LEDs emit light spread out at even larger angles.**

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

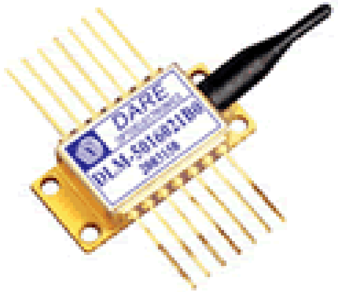


Four common methods are used:

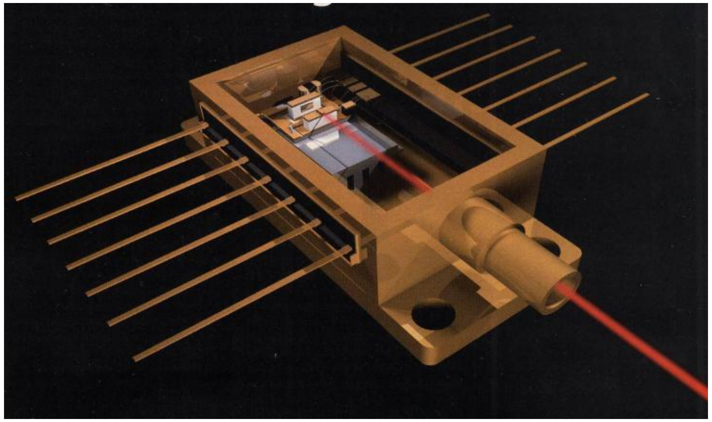
- **Use of a Graded Index Lens (GRIN lens) is fairly common. The lens collects and focuses the light onto the end of the fibre.**
- **A Ball lens is also often used. This is bonded to the surface of the LED with an epoxy resin that has a specific refractive index. However, the RI of the epoxy can't match to both the RI of the fibre and the RI of the semiconductor since the semiconductor will have an RI of around 3.5 and the fibre of around 1.45.**
- **The Direct Coupling method is to mount the fibre end so that it touches the LED directly i.e. to mount the LED inside a connector so that when a fibre is plugged in (mounted in the other half of the connector) one get firm mounting in good position.**
- **To fix a ball lens to the end of the fibre**

Commercial DFB

Parameters	Symbo l	Min	Typ	Max	Unit
CW Output power(25C)	Pf	10	---	30	mW
Threshold current	It h	--	25	60	mA
Operating current	If	--	300	--	mA
Forward voltage	Vf	--	2.0	3.0	V
Center Wavelength	λc	1540	1550	1570	nm
Linewidth	Δ λ	--	2	--	MHz
Monitor Current	Im	--	200	--	μA
Monitor dark current(Vr=-5V)	Id	--	--	100	nA
Isolation(Optional)	Iso	-30	--	--	dB
TEC current	ITEC	--	1.2	--	A
TEC voltage	VTEC	--	3.2	--	V
Thermistor resistance(at 25℃)	Rt h	9.5	10	10.5	kΩ
Operating Temperature Range	To	-20	--	65	C
Storage temperature	Tst g	-40	--	85	C



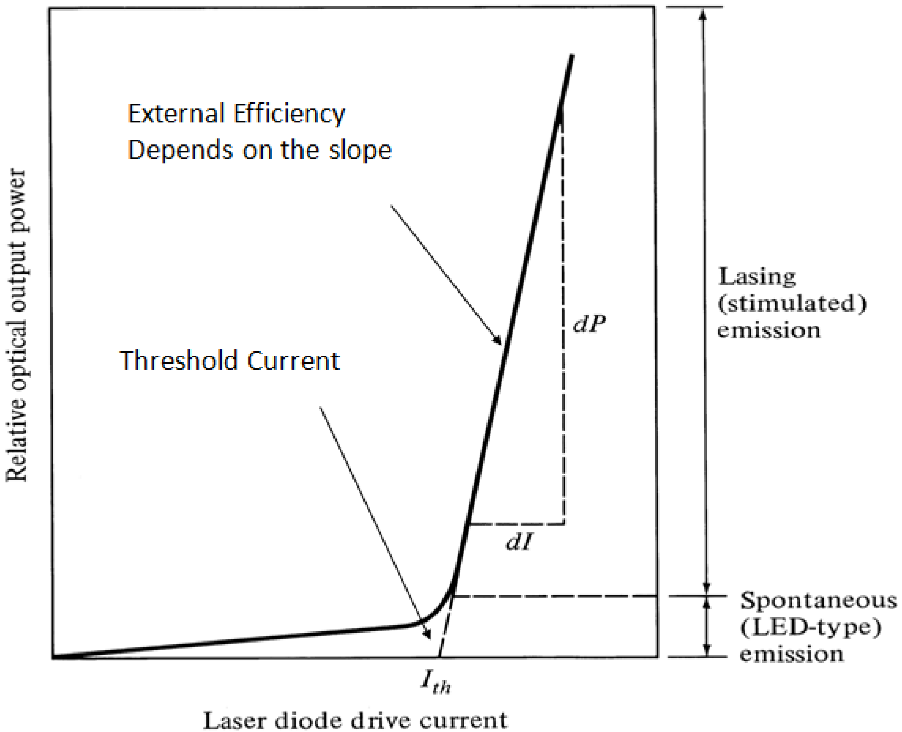
- **Components**
  - DFB diode
  - Thermoelectric cooler
  - Thermistor
  - Photodiode
  - Optical isolator
  - Fiber-coupled lens



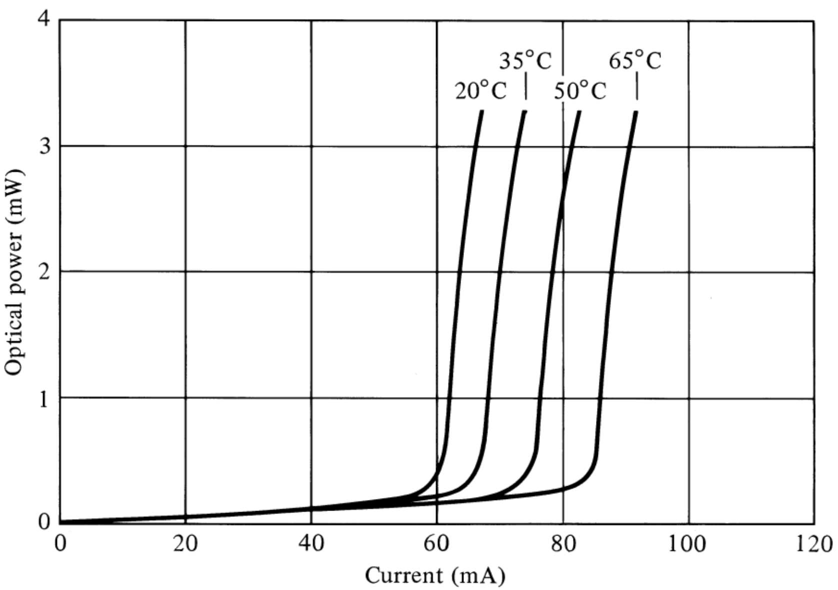
Laser Characteristics

Full Width Half Max, Peak Wavelength, Linewidth, Threshold Current, Operating current, Rise time, Output Power, Operating Temperature,

Optical output vs. drive current of a laser



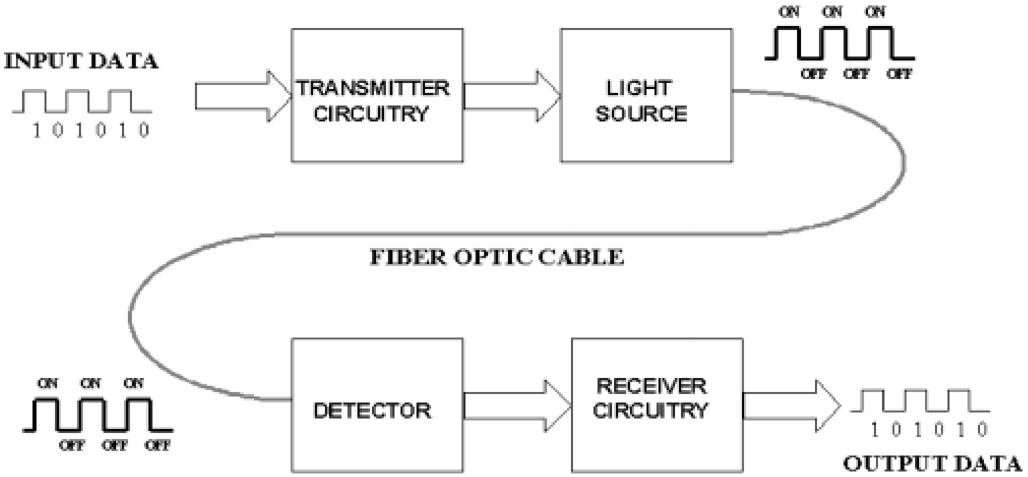
Laser threshold depends on Temperature



Optical Communication

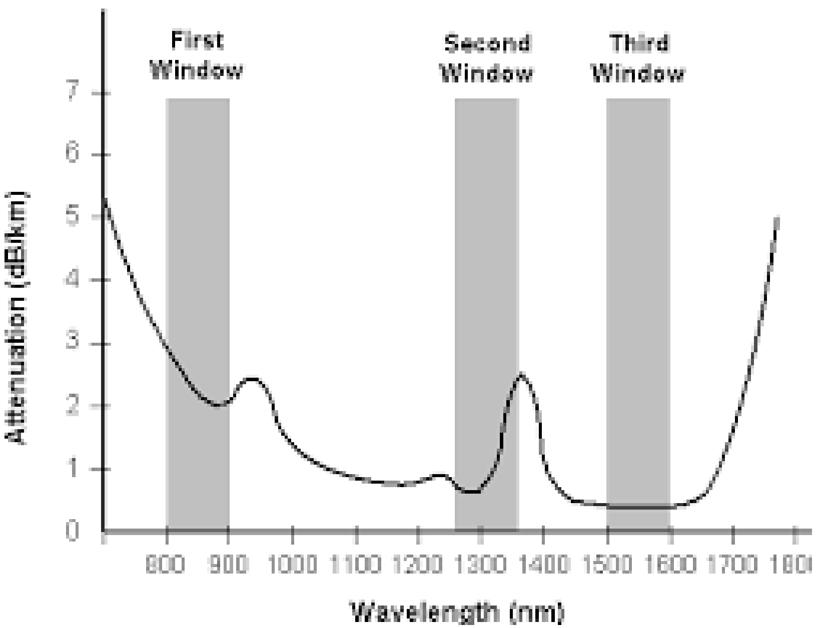
- **A communication link is established by transmission of information reliably**
- **Optical modulation is embedding the information on the optical carrier for this purpose wherein either its amplitude or frequency or phase is modulated**
- **The information can be digital (1,0) or analog (a continuous waveform)**
- **The bit error rate (BER), signal to noise ratio (SNR) is the performance measure**

Basic Fiber Optic Communication system



- The ultimate goal of the optical signal transmission is to achieve the predetermined bit-error rate (BER) hence, the system has to be properly designed so as to provide the reliable operation during its lifetime.
- Three parameters important from system engineering point of view are (a) optical signal parameters that determine the signal level (b) the optical noise parameters that determine the BER and (c) the impairment parameters that determine the power margin to be allocated.
- The number of impairments that deteriorate the signal quality during transmission are fiber attenuation, chromatic dispersion, polarization mode dispersion, fiber nonlinearities, insertion loss, frequency chirp

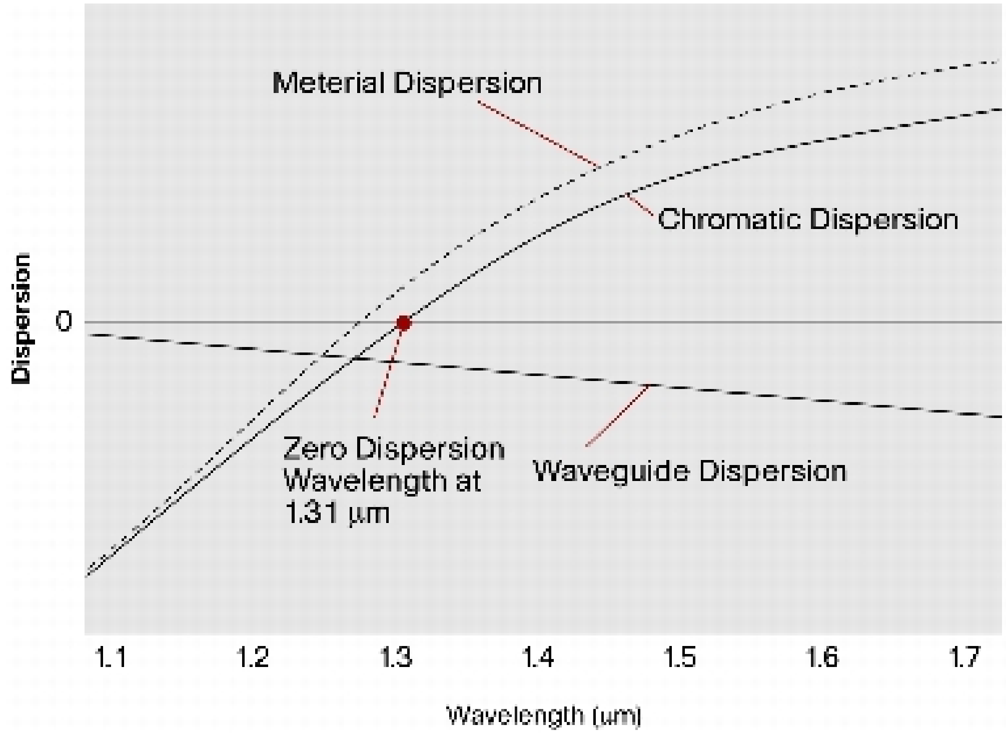
Optical Fiber Characteristics



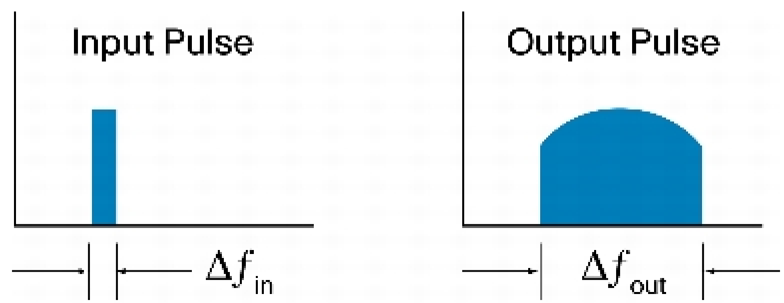
Fiber Optic Transmission Windows

Window	Operating Wavelength
800 – 900 nm	850 nm
1250 – 1350 nm	1310 nm
1500 – 1600 nm	1550 nm

Optical Fiber Attenuation vs. Wavelength



Chromatic Dispersion in Optical Fiber



Pulse spreading due to Dispersion

When designing a optical communication system (FO) some of the following factors must be taken into consideration:

- **Which modulation and multiplexing technique is best suited for the particular application?**
- **Is enough power available at the receiver (power budget)?**
- **Rise-time and bandwidth characteristics**
- **Noise effects on system bandwidth, data rate, and bit error rate**
- **Are erbium-doped fiber amplifiers required?**
- **What type of fiber is best suited for the application?**
- **Cost**

The received power at the detector is a function of:

1. **Power emanating from the light source (laser diode or LED) — (P_L)**
2. **Source to fiber loss (L_{sf})**
3. **Fiber loss per km (F_L) for a length of fiber (L)**
4. **Connector or splice losses (L_{conn})**
5. **Fiber to detector loss (L_{fd})**

The allocation of power loss among system components is the power budget. The power margin is the difference between the received power P_r and the receiver sensitivity P_s by some margin L_m.

$L_m = P_r - P_s$ where L_m is the loss margin in dB, P_r is the received power, P_s is the receiver sensitivity in dBm .

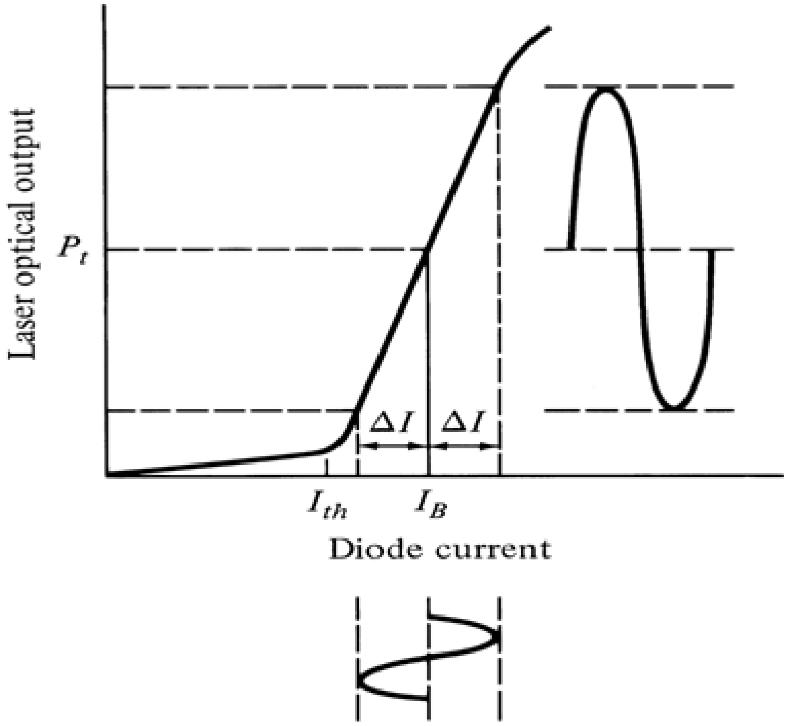
If all of the loss mechanisms in the system are taken into consideration, the loss margin can be expressed as

$$L_m = P_L - L_{sf} - (F_L \times L) - L_{conn} - L_{fd} - P_s$$

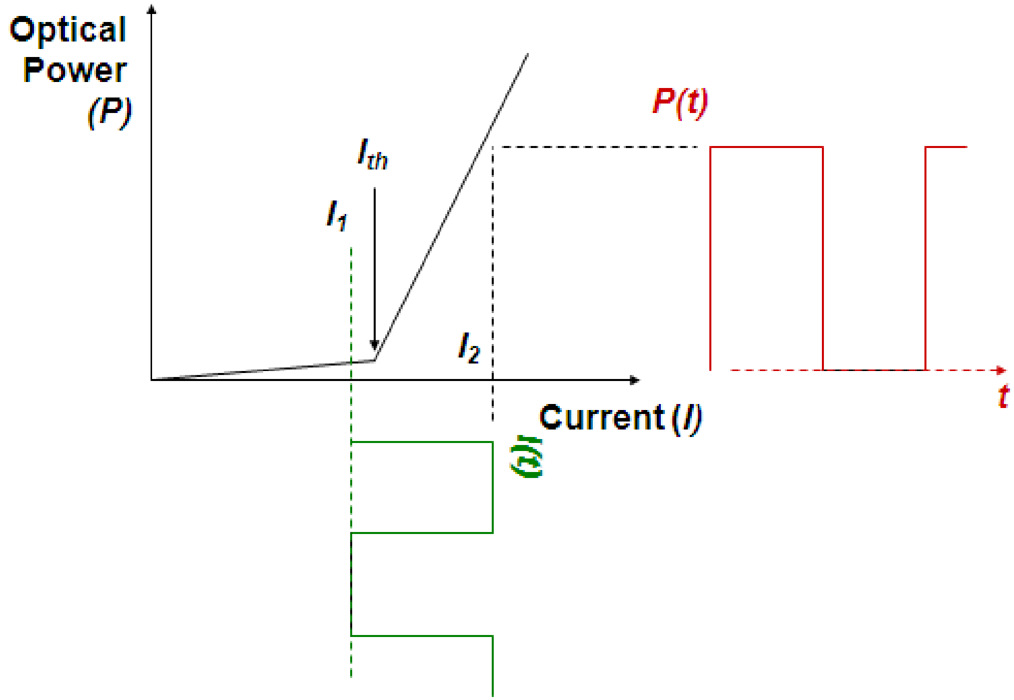
Modulation of Laser Diodes

- Lasers source can be modulated either directly or externally.
- Direct modulation is done by modulating the driving current according to the message signal which can be digital or analog. It is simple but suffers from non-linear effects in case of Laser.
- In external modulation, the laser emits continuous light wave (CW) and the light modulation is done externally. This is used for data rates greater than 2Gb/s, system is more complex but provides higher performance.

Direct Modulation



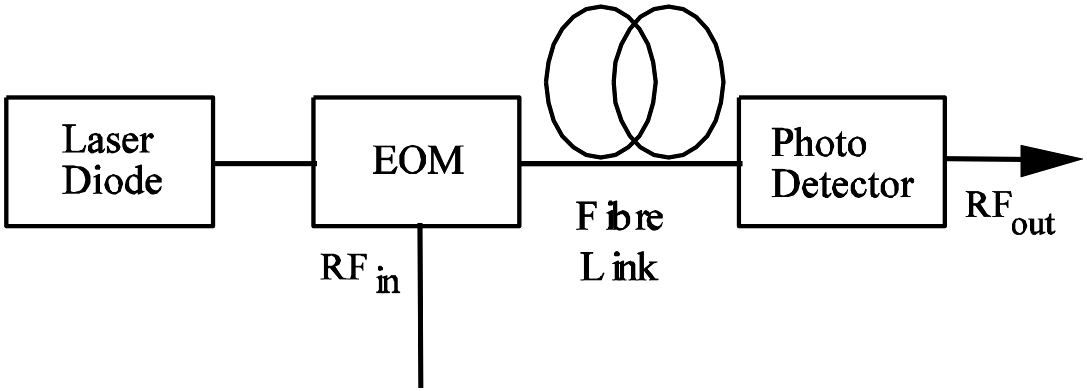
Analog Modulation



Digital Modulation

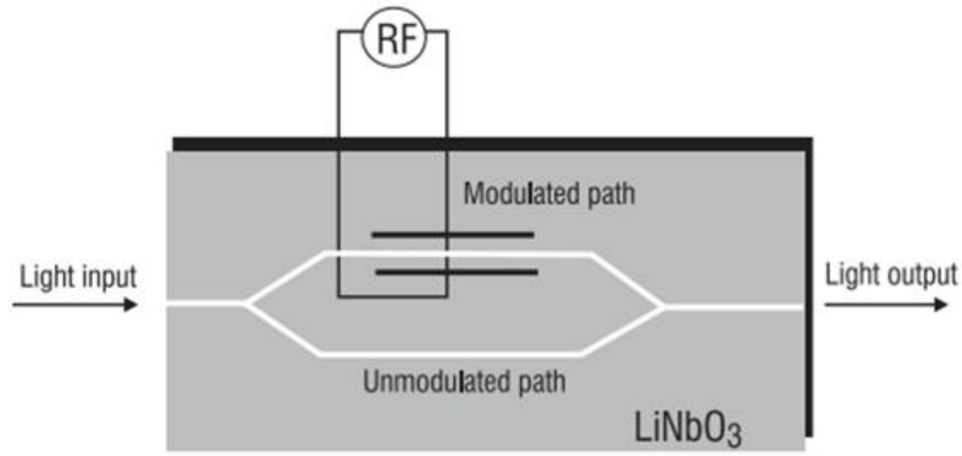
- The message signal is superimposed on the bias current (dc) which modulates the laser and is simple, hence widely used
- **Issues**: Turn on delay, laser nonlinearity, Extinction Ratio Penalty, Laser Resonance frequency, Chirp,

External Optical Modulation

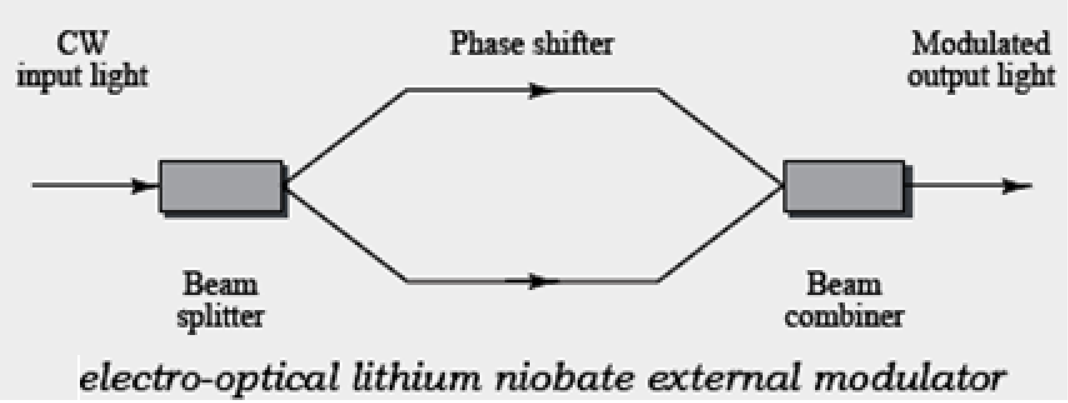


- Modulation and light generation are separated
- Offers much wider bandwidth → up to 60 GHz
- More expensive and complex, Used in high end systems

External Optical Modulation



The optical source injects a constant-amplitude light signal into an external modulator. The electrical driving signal changes the optical power that exits the external modulator. This produces a time-varying optical signal.

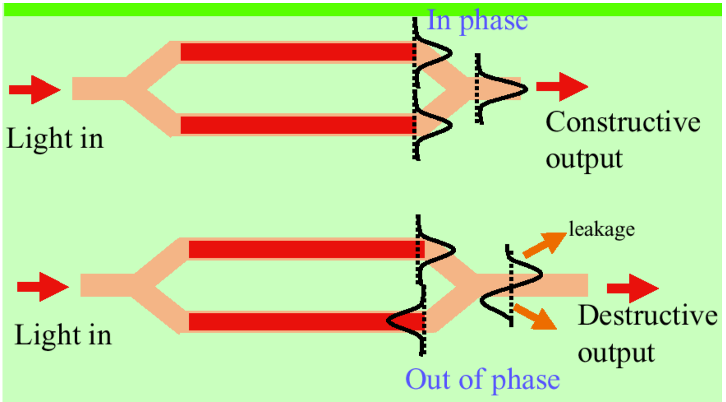


The electro-optical (EO) phase modulator (also called a Mach-Zhender Modulator or MZM) typically is made of $LiNbO_3$.

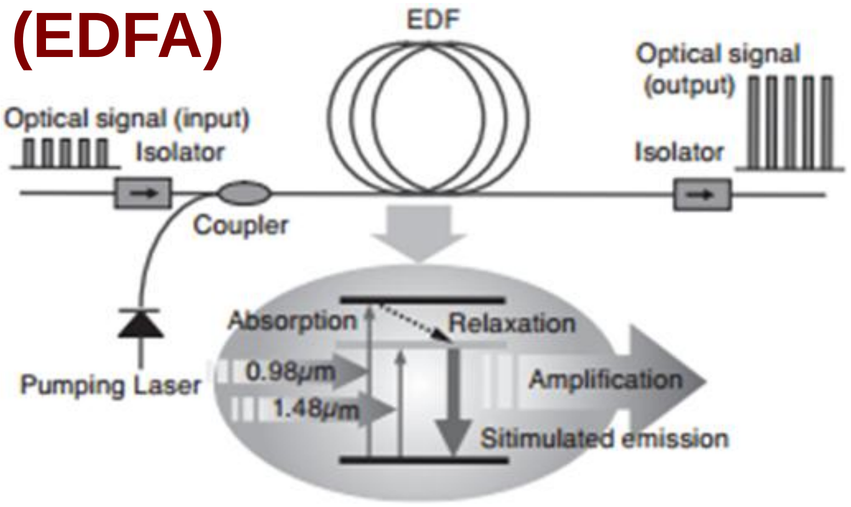
- Offers wider bandwidth up to 60GHz
- More expensive and complex

Phase shift = $\Delta\theta = 180° \times V_{in}/V_{\pi}$

input voltage associated with a 180° phase shift is known as V_{π}

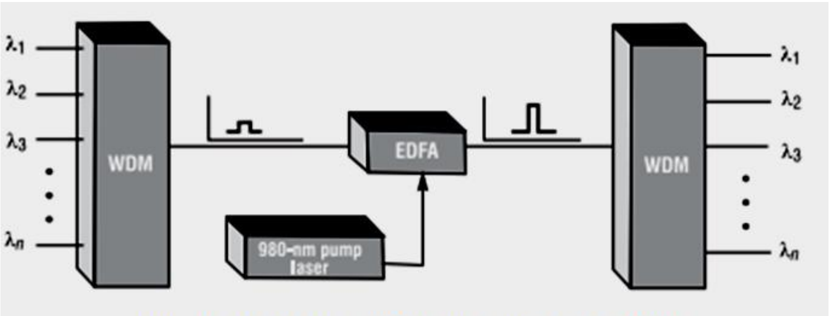


Erbium doped fiber amplifier (EDFA)

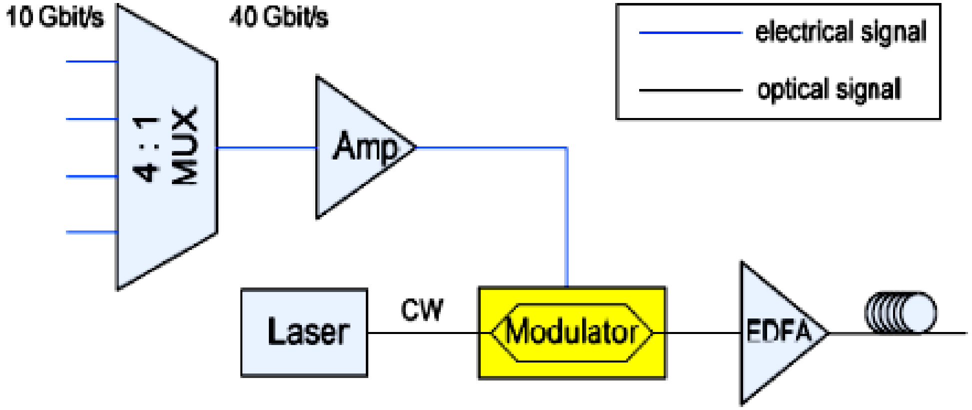


Principle of erbium-doped fiber amplifier (EDFA)

Optical fiber amplification technology, enables to amplify an optical signal in a relatively wide wavelength range without converting an optical signal into an electrical signal regardless of transmission speed and format. **Erbium doped fiber amplifier (EDFA)** is commonly used for the amplification of 1.5 µm band optical signal by the excitation of 0.98 µm, and/or 1.48 µm high power laser.

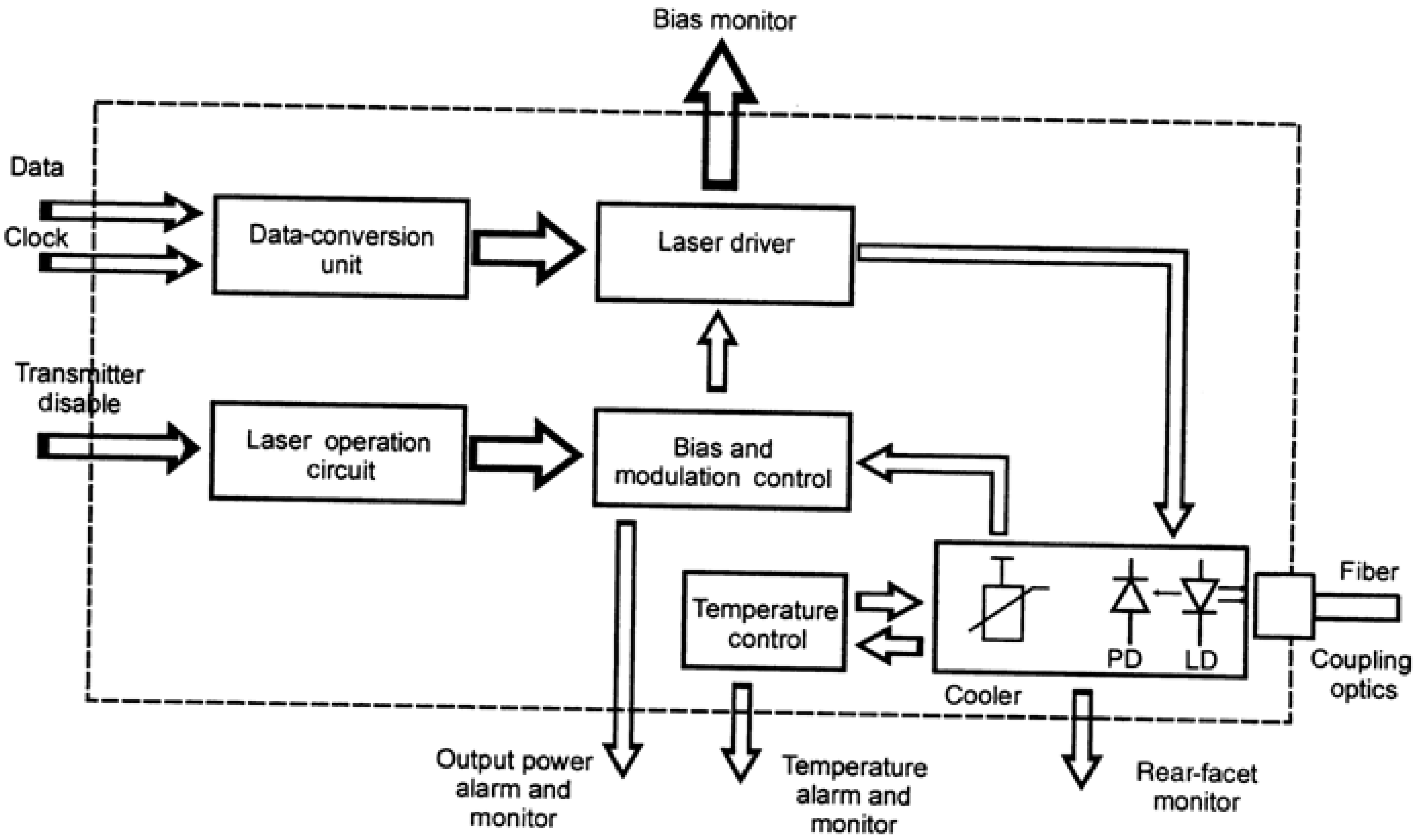


Wavelength-division multiplexing system using EDFAs



Electooptic Modulator Function in the Transmitter System.

Laser Diode Transmitter Block Diagram



Functional block diagram of a transmitter.

Thank You