Optical Communications

Light Sources

Part4

Fiber Optic Communications

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Fourth Edition PRENTICE HALL

Light Sources

LED

Light Emitting Diode (LED) or Laser Diode (LD) generates optic beams to carry the information .

They have small size compatible with the small diameters of fibers.

There solid structure and low power requirement are compatible with modern state electronics.

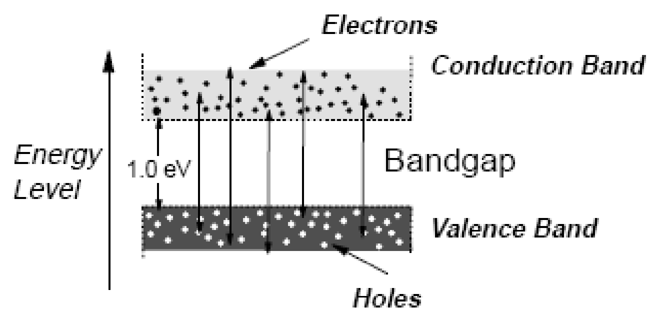
Lighting Emitting Diode (LED)

Is a pn junction semiconductor that emits light when forward biased.

The radiated wavelength of LED (in meters) is

$$\lambda = \frac{hc}{W_g}$$

W_g → Gap Energy in Joules



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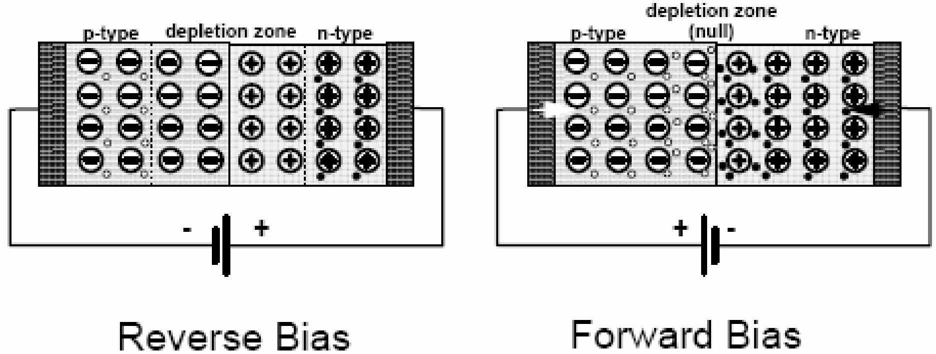
LED

The radiated wavelength of LED (in micrometers) is

$$\lambda = \frac{1.24}{W_g}$$

W_g → Gap Energy in electron volts



Forward Bias

When we connect an electrical potential across the junction with the negative pole connected to the n-type material and the positive pole connected to the p-type material then the junction conducts.

Understanding Optical Communications

Harry J. R. Dutton

Light Sources

LED

Material	Formula	Wavelength Range λ (μm)	Bandgap Energy W_g (eV)
Indium Phosphide	InP	0.92	1.35
Indium Arsenide	InAs	3.6	0.34
Gallium Phosphide	GaP	0.55	2.24
Gallium Arsenide	GaAs	0.87	1.42
Aluminium Arsenide	AlAs	0.59	2.09
Gallium Indium Phosphide	GaInP	0.64-0.68	1.82-1.94
Aluminium Gallium Arsenide	AlGaAs	0.8-0.9	1.4-1.55
Indium Gallium Arsenide	InGaAs	1.0-1.3	0.95-1.24
Indium Gallium Arsenide Phosphide	InGaAsP	0.9-1.7	0.73-1.35

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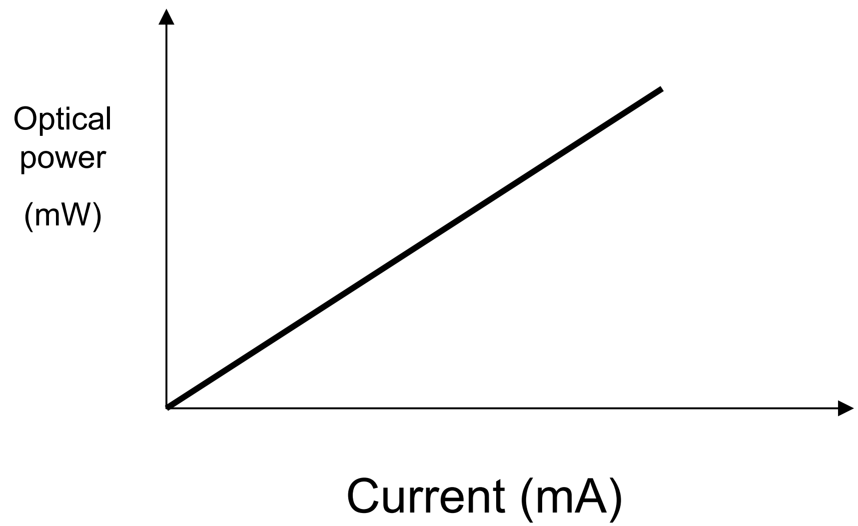
LED Characteristic

The optic power generated by an LED is linearly proportional to the forward driving current.



Number of charges per second:

$$N = \frac{i}{e}$$

e → The magnitude of the charge on each electron

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LED Characteristic

η Is the fraction of charges that will recombine to produce photons, the optic power is:

$$P = \eta N W_g = \frac{\eta W_g}{e} i$$

$$P = \eta i W_g \longrightarrow \text{Gap Energy in eV}$$

LEDs operate (50-100)mA and require a voltage of (1.2-1.8)V.

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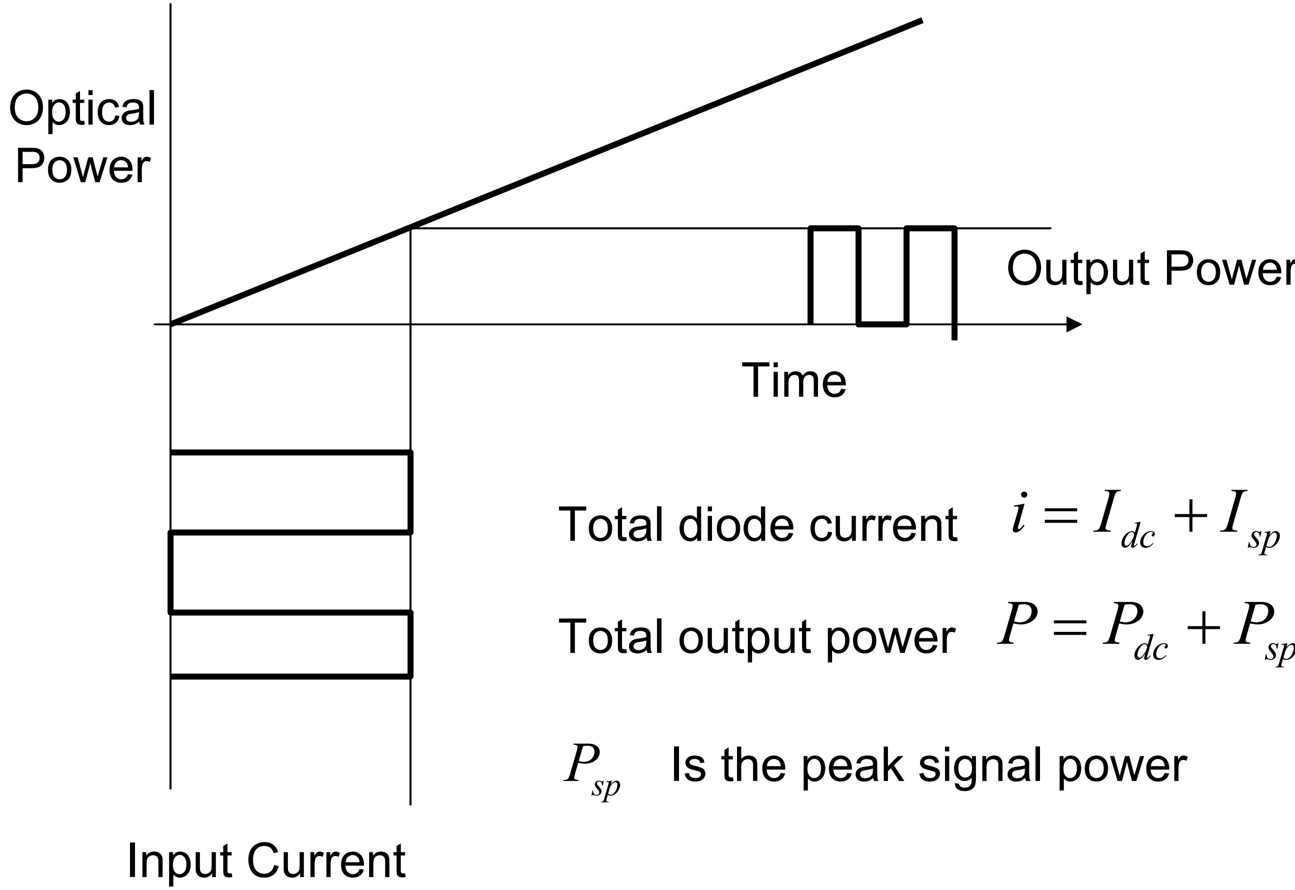
LED Modulation

Because of linearity, the shape of output power is the same of the input power



Total diode current $i = I_{dc} + I_{sp} \sin \omega t$

Total output power $P = P_{dc} + P_{sp} \sin \omega t$

P_{sp} Is the peak signal power

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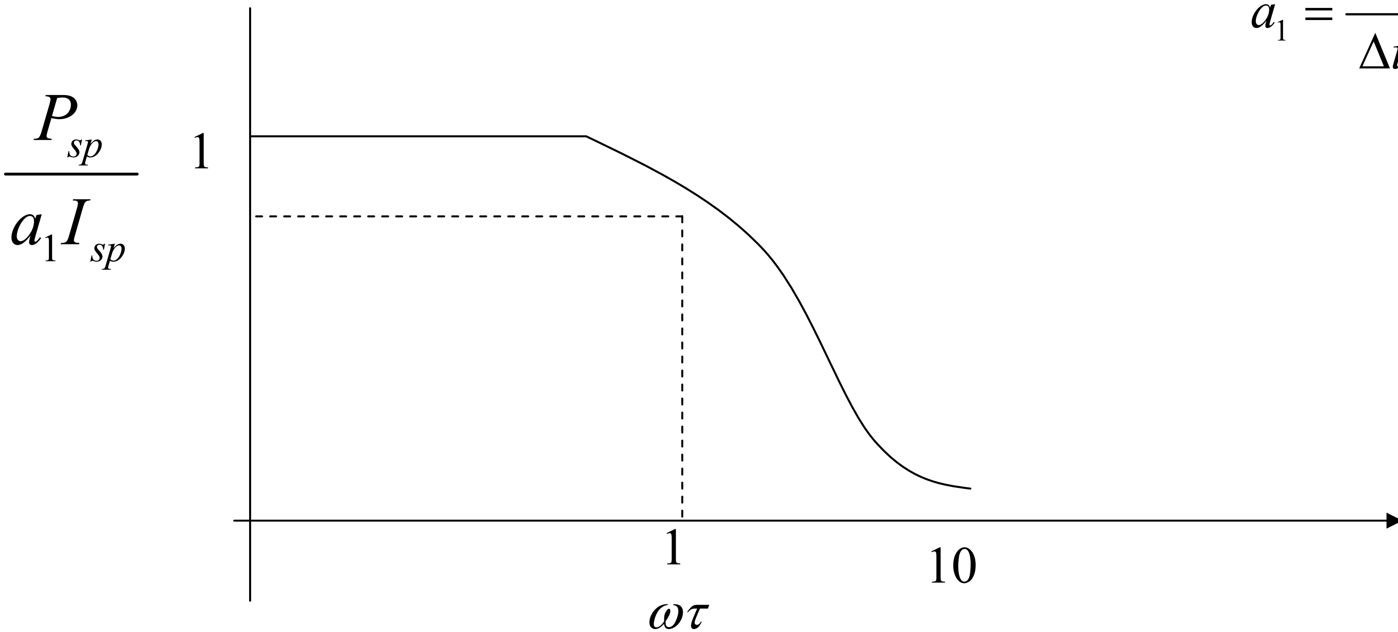
LED Modulation

The carrier life time limited response of a LED to electrical signals of radian ω

$$P_{sp} = \frac{a_1 I_{sp}}{\sqrt{1+\omega^2\tau^2}}$$

Is the slope of the curve

$$a_1 = \frac{\Delta P}{\Delta i}$$



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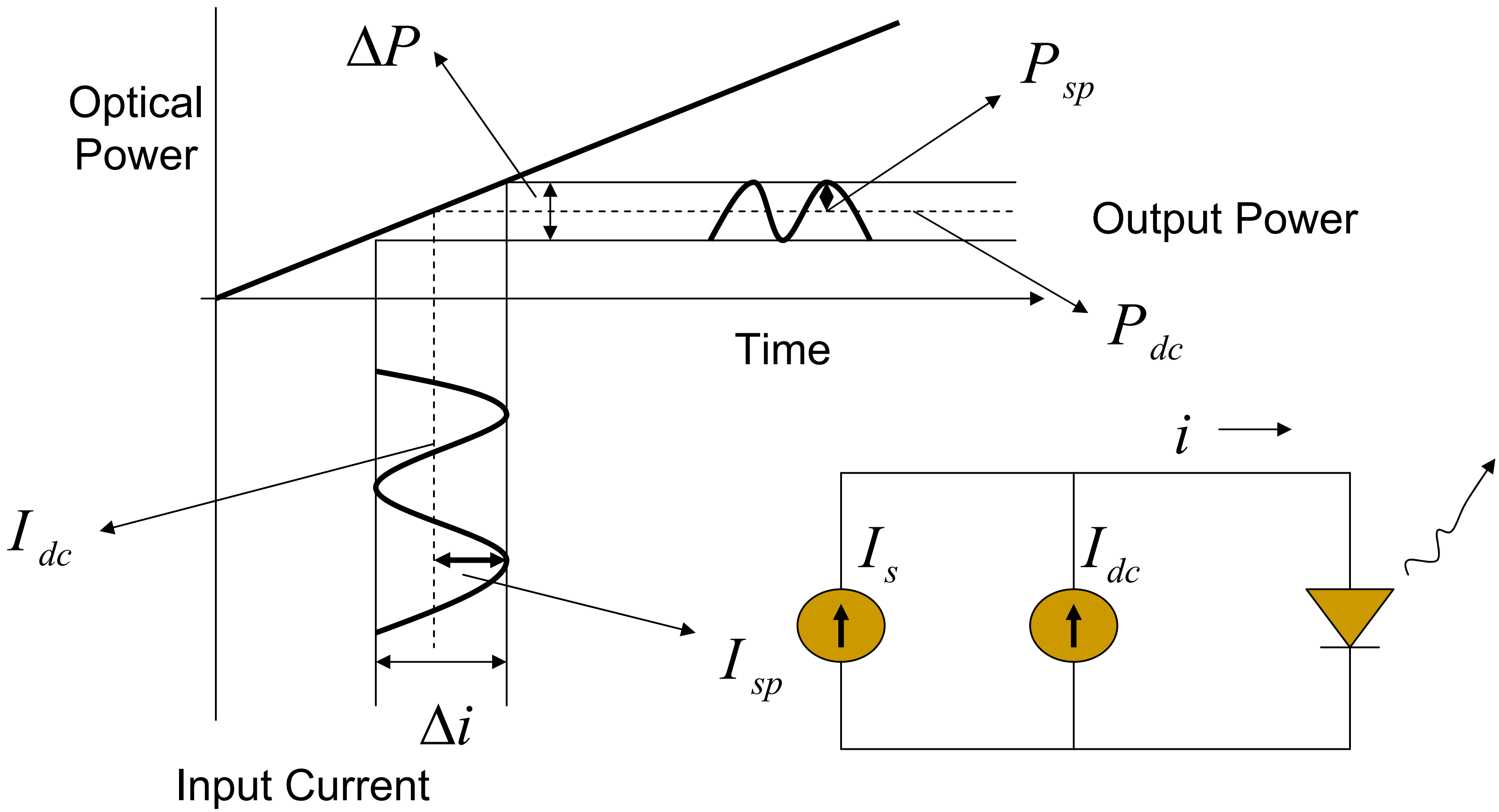
LED Modulation



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LED Modulation

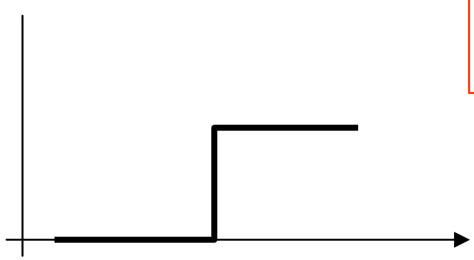
For $\omega = 1/\tau$ the power is reduced by 0.707 and the current of the output of the receiver will be reduced $(0.707)^2=0.5$(3 dB). For this reason we call 0.5 is the 3-dB modulation bandwidth of LED or its 3-dB electrical bandwidth in Hz:

$$f_{3-dB} = \frac{1}{2\pi\tau}$$

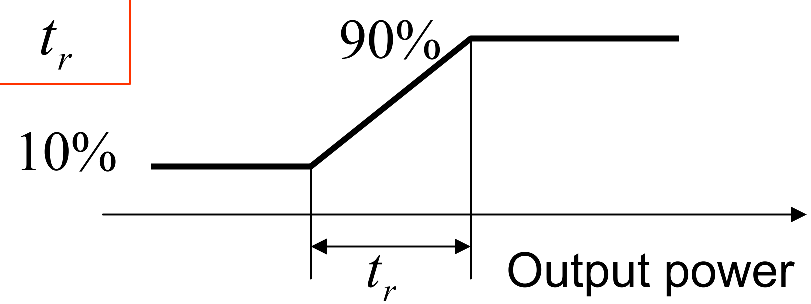
The rise time of the source:

Is the time takes for the output to change from 10% to 90% of its final value when the input is a step current. For typical LED t_r=250ns

$$f_{3-dB} = \frac{0.35}{t_r}$$



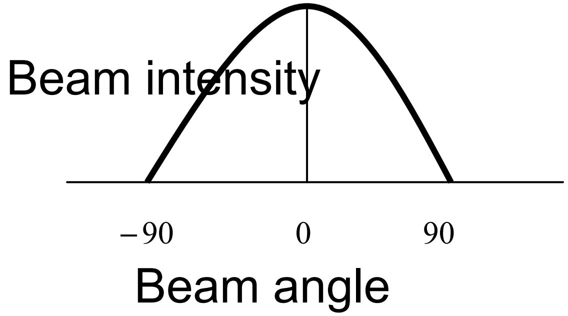
Input current

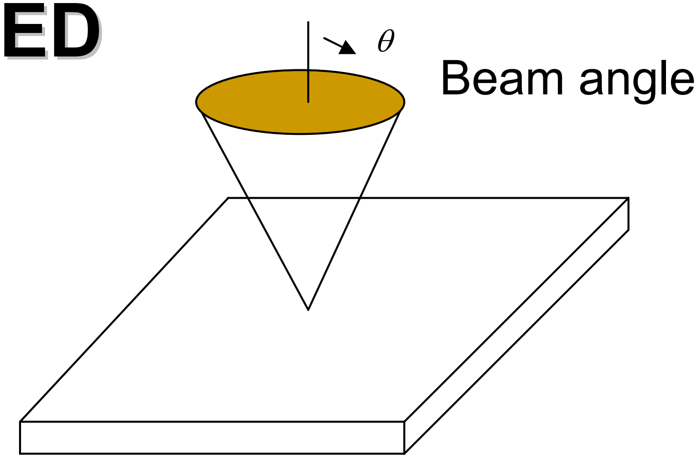


Coupling efficiency

Coupling efficiency depends on the radiation pattern of an emitter.

1- Surface-emitting LED





Lambertian radiation from a surface-emitting LED

The power down 50% if $\theta = 60$ because $\cos\theta = \cos 60 = 1/2$

The total half-power beamwidth is 120^0 for a Lambertian emitter. Since the acceptance angle for a fiber having NA=0.24 is 14^0 (total cone angle 28^0) a large amount of power generated by a surface emitter will be rejected.

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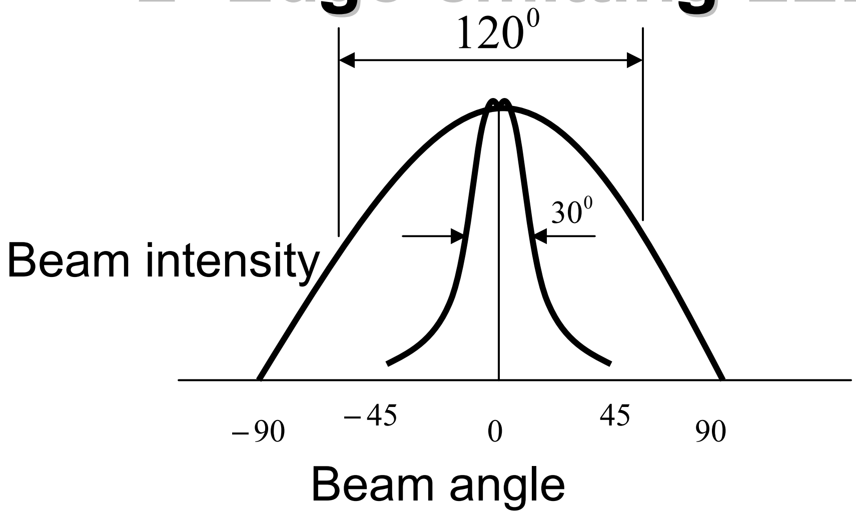
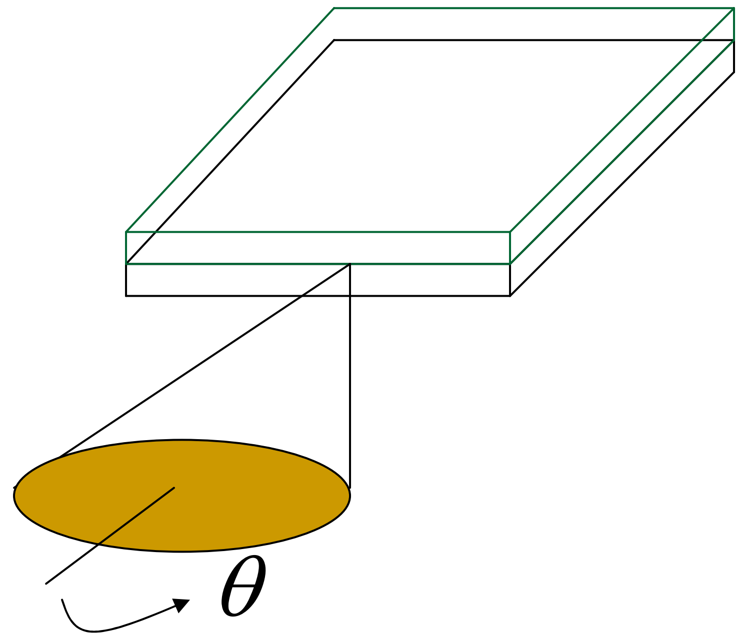
Coupling efficiency

2- Edge-emitting LED





Unsymmetric radiation from edge-emitting LED

More concentrate radiation (500 Mbps)

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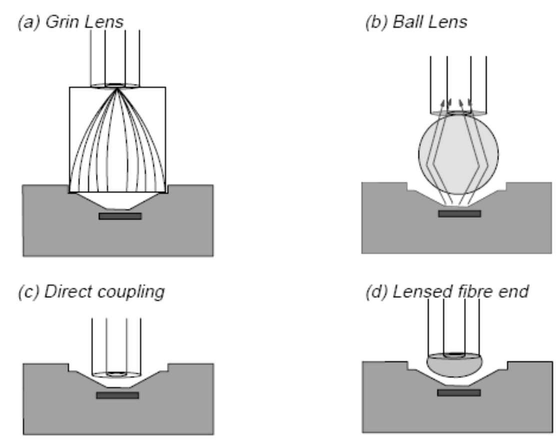
LED Properties

LEDs are very reliable and long lasting if operated within the power, current and temperature.

The lifetime of the LED is the time it takes for the power to reduce to half its initial value (10^5 hours)

Temperatures between -65^0 and 125^0 C. a representative decrease depending on the temperature is 0.012 dB/^{o}C. The output power can be maintained at a constant level by increasing the drive current as the temperature increases.

1. Use of a Graded Index Lens (GRIN lens) is fairly common. A GRIN lens is very similar to just a short length of graded index fibre (albeit with a much larger diameter). The lens collects and focuses the light onto the end of the fibre.
2. 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.
3. The Direct Coupling method is becoming increasingly popular. Just mount the fibre end so that it touches the LED directly. A common way to do this is to mount the LED inside a connector so that when a fibre is plugged in (mounted in the other half of the connector) you get firm mounting in good position. This has the advantage of low cost and low complexity.
4. Another common way is to fix a ball lens to the end of the fibre as shown in the diagram.



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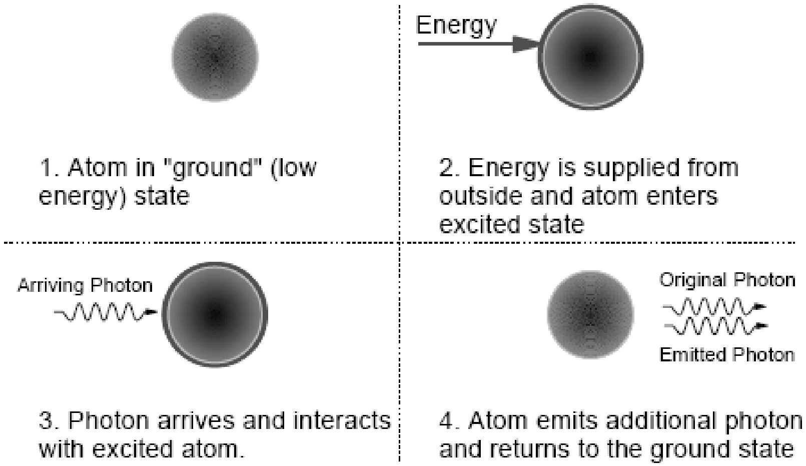
Laser Diode (LD)



1. An electron within an atom (or a molecule or an ion) starts in a low energy stable state often called the "ground" state.
2. Energy is supplied from outside and is absorbed by the atomic structure whereupon the electron enters an excited (higher energy) state.
3. A photon arrives with an energy close to the same amount of energy as the electron needs to give up to reach a stable state. (This is just another way of saying that the wavelength of the arriving photon is very close to the wavelength at which the excited electron will emit its own photon.)
4. The arriving photon triggers a resonance with the excited atom. As a result the excited electron leaves its excited state and transitions to a more stable state giving up the energy difference in the form of a photon.

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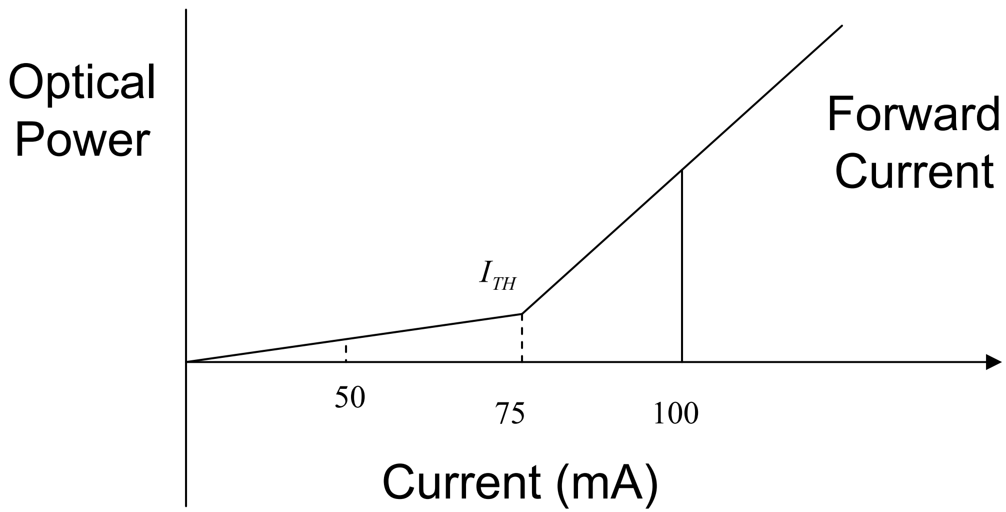
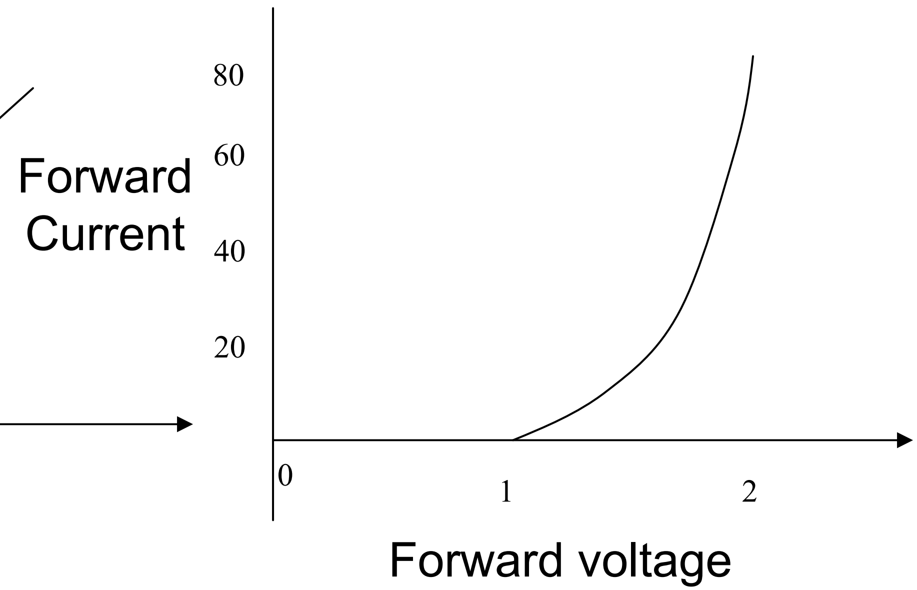
LD operating characteristics

The threshold current is 75 mA





The voltage of the order (1.2-2)V at threshold

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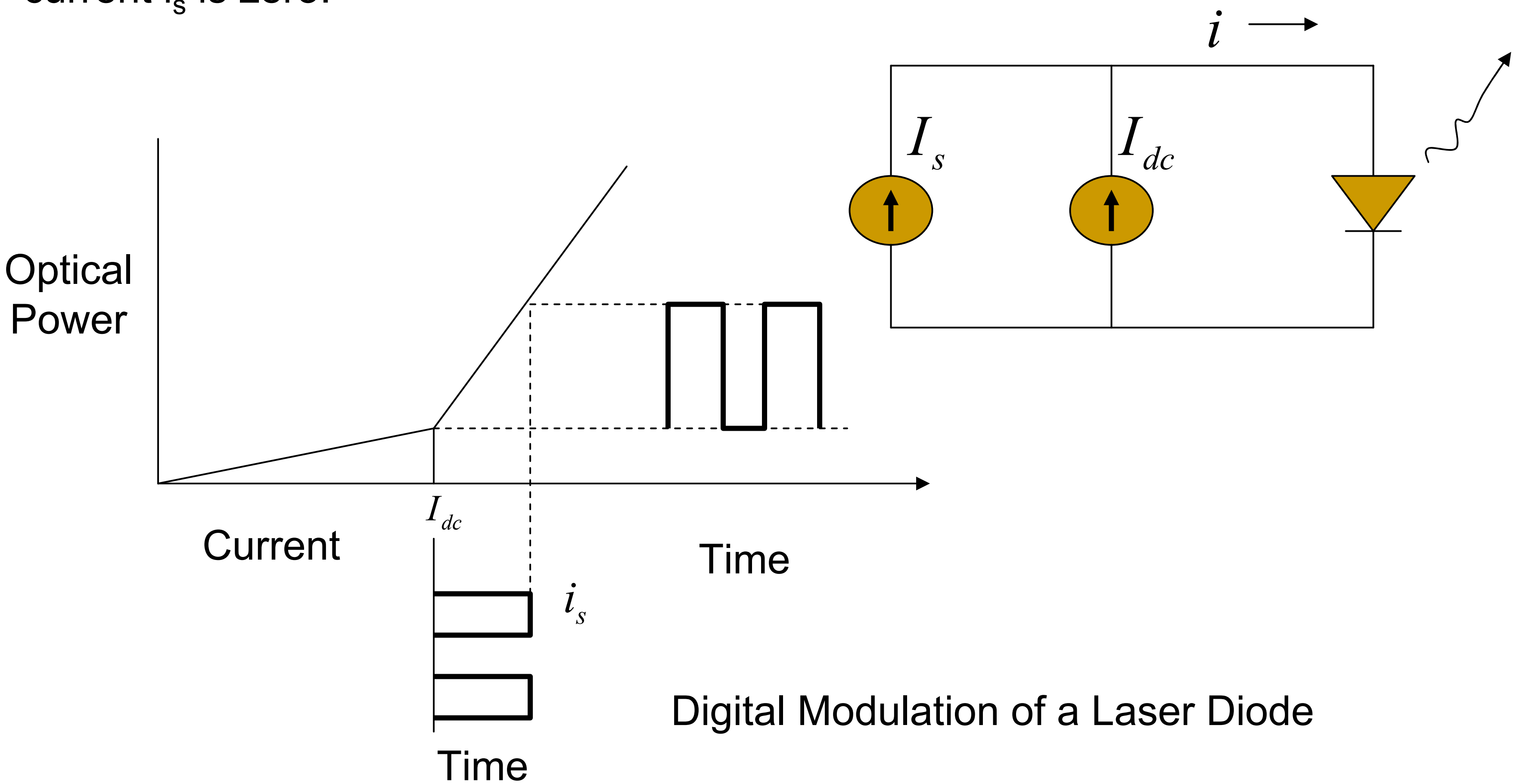
(LD) Digital Modulation

A dc bias current I_{dc} is added to place the current at threshold when the signal current i_s is zero.



Digital Modulation of a Laser Diode

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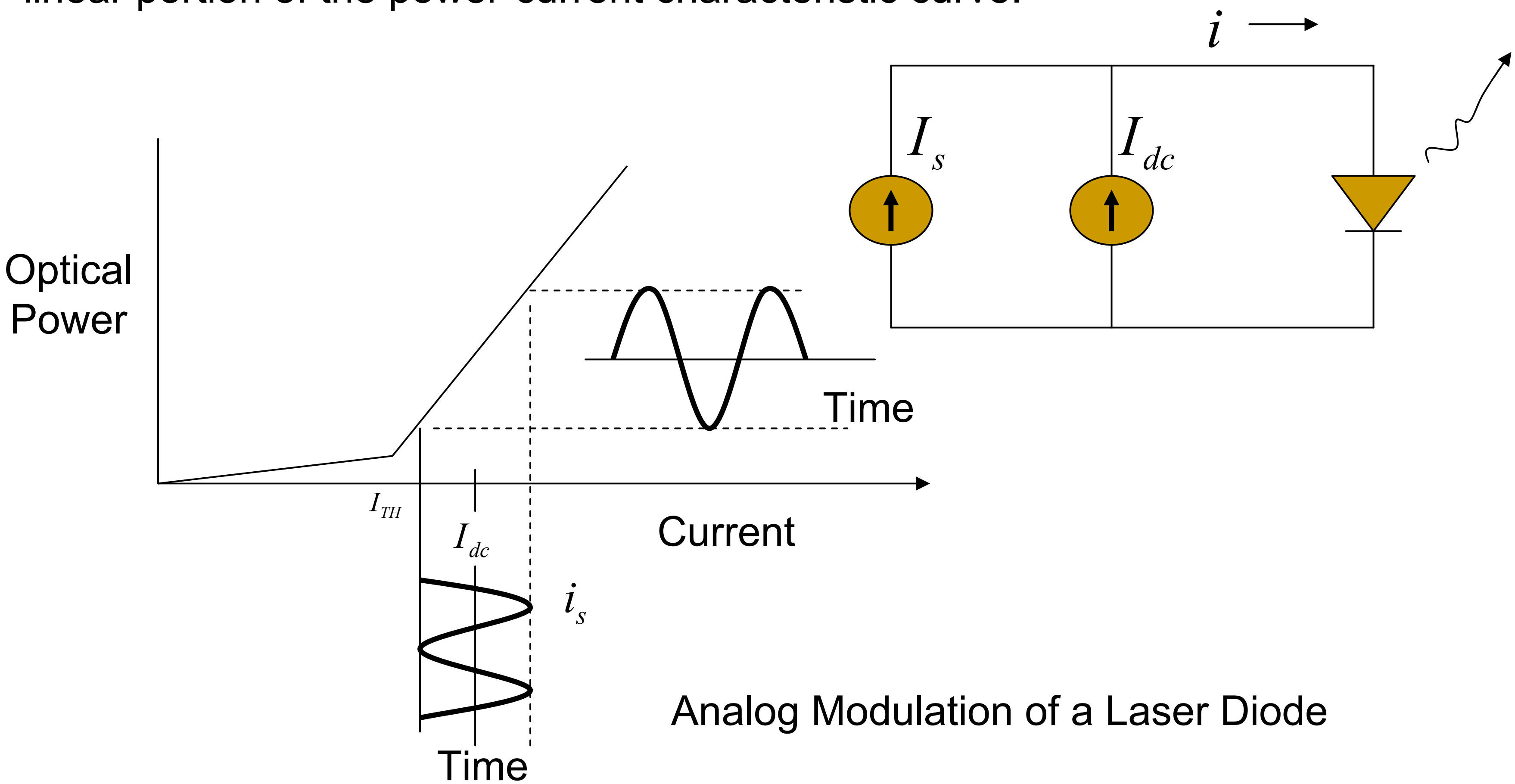
(LD) Analog Modulation

The dc bias is moved beyond threshold, so that operation will be a long the linear portion of the power-current characteristic curve.



Analog Modulation of a Laser Diode

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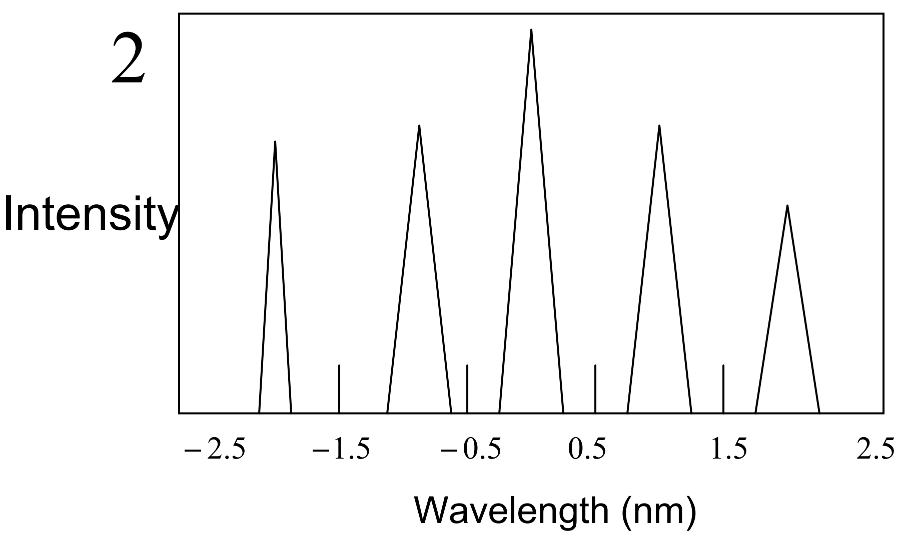
Laser Diode Properties

Laser diodes are much more temperature sensitive than LEDs.

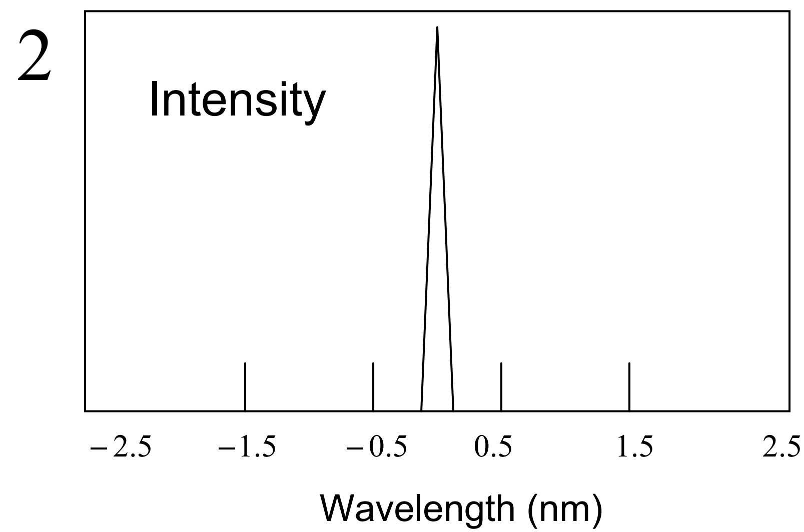
As temperature increases, the diodes gain decreases, so that more current is required before oscillation can begin. (1.5%/^{o}C)

Rise time for a good laser between 0.1 and 1 ns.

Laser diodes typically posses linewidth of 1-5 nm, considerably smaller than the output spectra of LEDs



Output spectrum of 1.3 micrometer multimode LD



Output spectrum of 1.3 micrometer single mode LD

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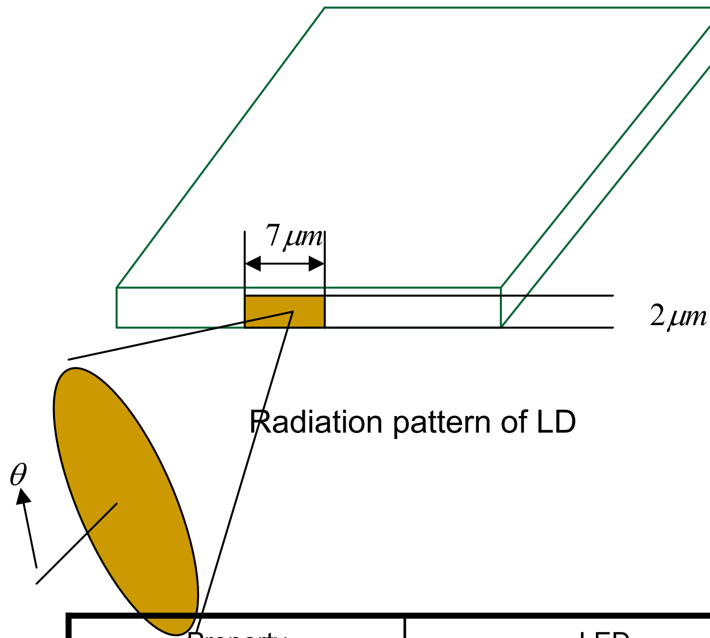
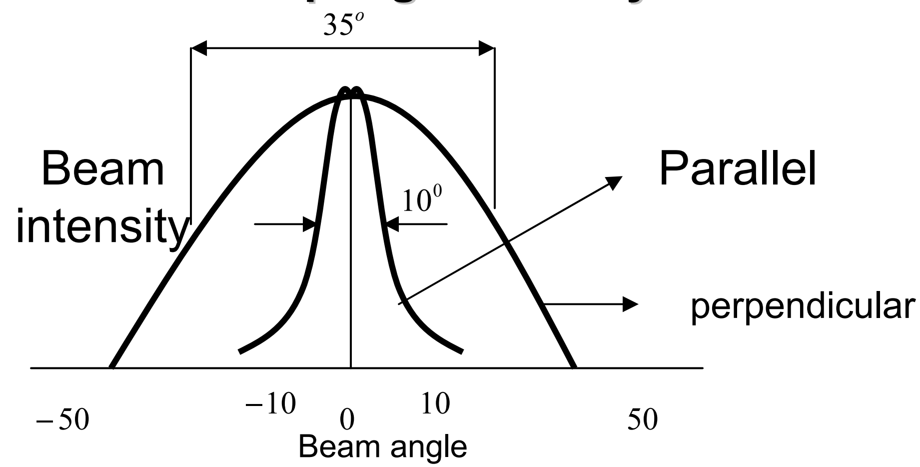
Coupling efficiency





Property	LED	LD	Single-Mode LD
Spectral width (nm)	20-100	1-5	<0.2
Rise time (ns)	2-250	0.1-1	0.05-1
Modulation Bandwidth (MHz)	<300	2000	6000
Coupling efficiency	Very low	Moderate	High
Compatible fiber	Multimode (SI,GRIN)	Multimode GRIN single mode	Single-mode
Temperature sensitivity	Low	High	High
Circuit Complexity	Simple	Complex	Complex
Life time (Hrs)	10^5	10^4-10^5	10^4-10^5
Costs	Low	High	Highest
Primary use	Moderate path + data rates	Long paths ,high data rates	v. Long paths ,v. high data rates