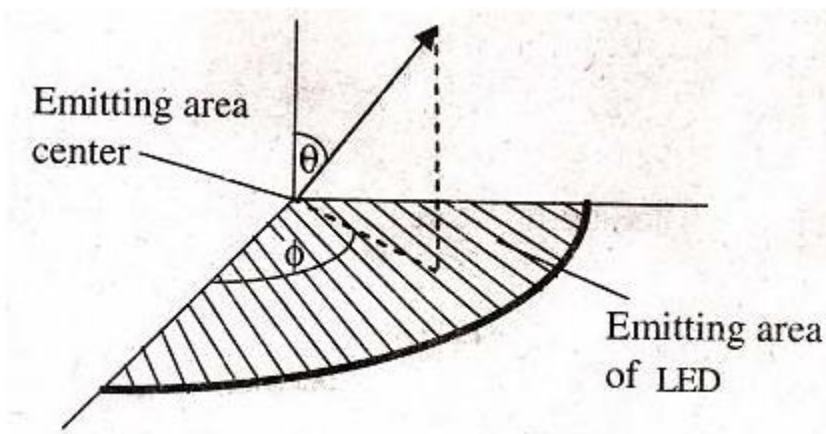
UNIT-V

OBJECTIVES:
Source to fiber power launching - Output patterns, Power coupling, Power launching, Equilibrium Numerical Aperture, Laser diode to fiber coupling, Optical receiver operation-Fundamental receiver operation, Digital signal transmission, error sources, Receiver configuration, Digital receiver performance, Probability of Error, Quantum limit, Analog receivers.

SOURCE OUTPUT PATTERN:

Consider the following figure, which shows a spherical coordinate system characterized by R, θ and φ with the normal to the emitting surface being the polar axis. The radiance may be a function of both θ and φ, and can also vary from point to point on the emitting surface. Surface emitting LEDs are characterized by their lambertian output pattern, which means the source is equally bright when viewed from any direction. The power delivered at an angle 'θ', measured relative to a normal to the emitting surface, varies as cos θ because the projected area of the emitting surface varies as cos θ with viewing direction. The emission pattern for a lambertian source thus follows the relationship.

$$B(\theta, \varphi) = B_0 \cos\theta$$



Dimensional Spherical Co-Ordinate System

The below figure, shows the radiation pattern for a lambertian source. The complexity of emission pattern is still increases, when we consider edge-emitting LEDs and laser diodes. In the planes parallel and normal to the emitting junction plane of the device. The radiances of these devices are given by, B (θ, 0°) and B (θ, 90°). Generally, these radiances can be approximated as,

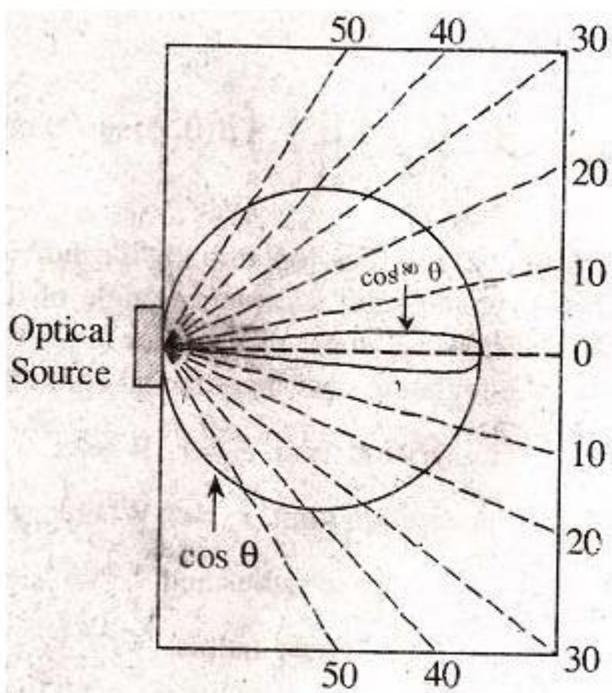
$$\frac{1}{B(\theta,\varphi)} = \frac{sin^2\varphi}{B_0 cos^T\theta} + \frac{cos^2\varphi}{B_0 cos^L\theta}$$

Where,

T = Transverse power distribution coefficient

L = Lateral power distribution coefficient.

For edge emitter L=1 and T is significantly large value.



Radiation Pattern of Lambartian Source

EQUILIBRIUM NUMERICAL APERTURE:

Generally, the source is perfectly coupled into a system fiber by supplying a light source with short fiber fly lead. This fly lead should be connected to a system fiber with identical NA and core diameter. At this junction, around 0.1 to 1 dB optical power is lost. An excess power loss will occur in the system fiber in addition to the coupling loss, which is due to the nonpropagating modes scattering out of the fiber as the launched modes come to an equilibrium condition. This loss has a severe effect on surface-emitting LED's (i.e., the power is launched into all modes of the fiber) but, the fiber coupled lasers (i.e., the power is launched into fewer non-propagating fiber modes) are less prove to this effect. Because of the variation in effect of excess power loss on different type of fibers, it can be analyzed carefully in any system design. Figure shows the plot of excess power loss in terms of the fiber numerical aperture. The optical power in the fiber after the launched modes have come to equilibrium is,

$$P_{eq} = P_{50}\left[\frac{NA_{eq}}{NA_{in}}\right]^2$$

Where,

P_{50} = Power expected in the fiber at 50m point based up on the launch NA

NA_{eq} = Equilibrium numerical aperture

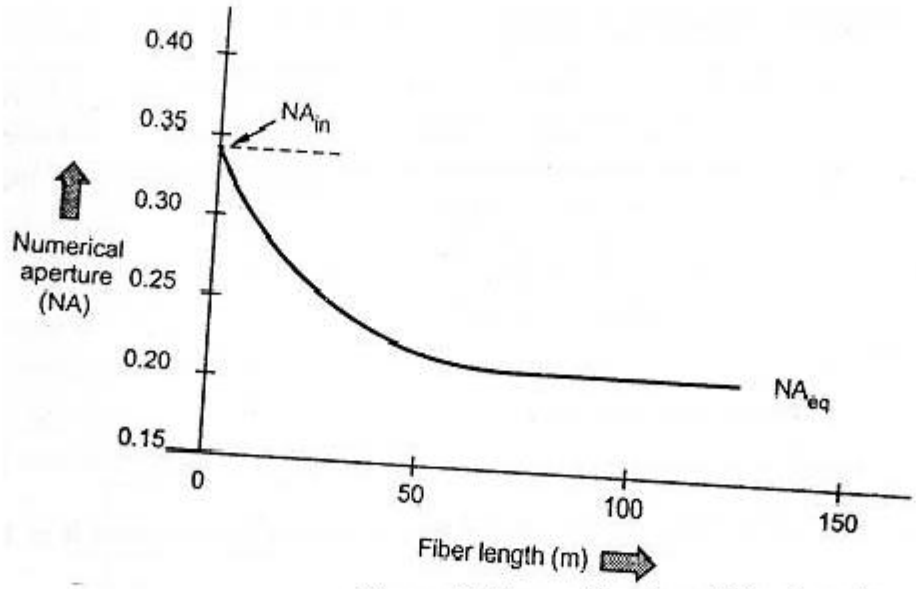
NA_{in} = Launch Numerical Aperture

The power coupled into the fiber, when the light emitting area of the LED is less than the cross-sectional area of the fiber-core is given by,

$P_{LED} = P_{50}\,(NA)^2$

Where $NA = NA_{in}$

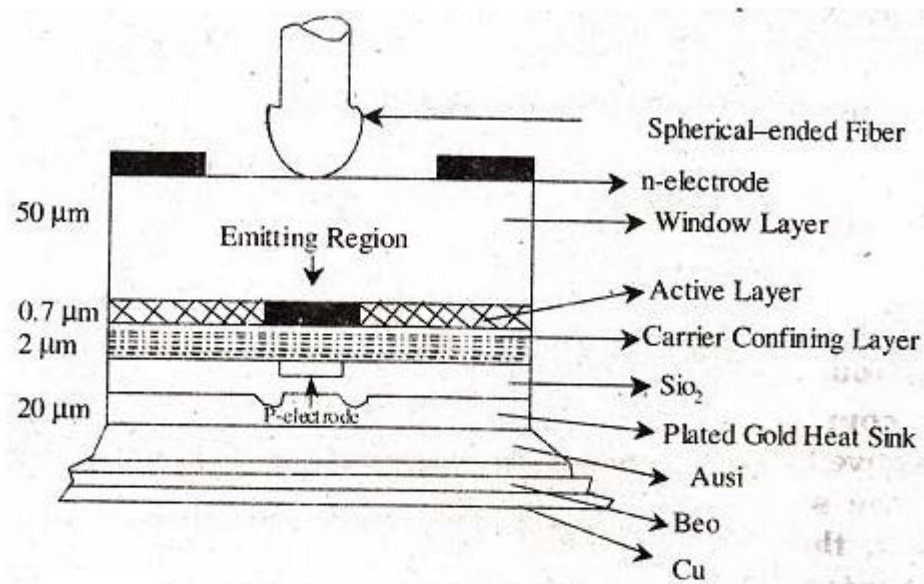
The degree of mode coupling is primarily a function of core-cladding index difference, which may vary significantly from one fiber to another. The value of NA has great importance in launching optical power in telecommunication systems as most of fibers attain 80-90% of equilibrium numerical aperture after about 50 m.



Change in NA as a function of Fiber Length

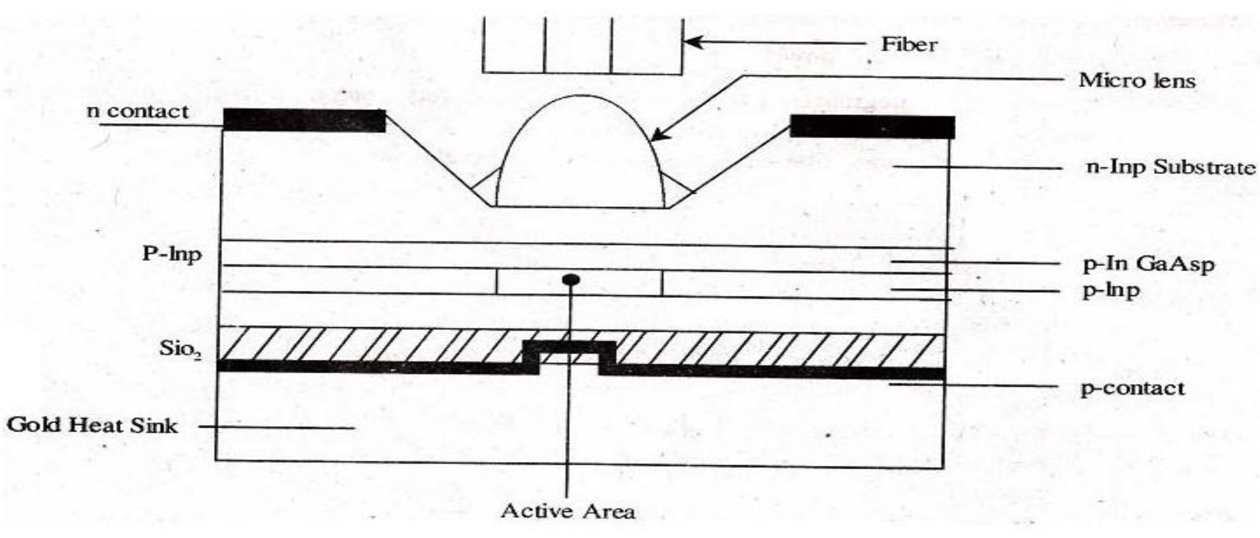
LENSING SCHEMES FOR COUPLING EFFICIENCY IMPROVEMENT:

Practically much of the light emitted from LEDs is not coupled into the narrow acceptance angle of the fiber It has been found that greater coupling efficiency may be obtained if lenses are used to collimate the emission from the LED, particularly when the fiber core diameter is significantly larger than the width of the emission region There are several lens coupling configurations which include spherically polished structures, spherical ended or tapered fiber coupling, truncated spherical micro lenses, GRIN-rod lenses and integral lens structures. The below figure shows a GaAs/AlGaAs spherical ended fiber coupled LED.



GaAs/AlGaAs Spherical ended fier coupled LED

It consists of a planar surface emitting structure with the spherical ended fiber attached to the cap by epoxy resin. An emitting diameter of 35 µm is fabricated into the device and light is coupled into fibers with core diameters or 75 µm and 110 µm. For increased coupling efficiency.

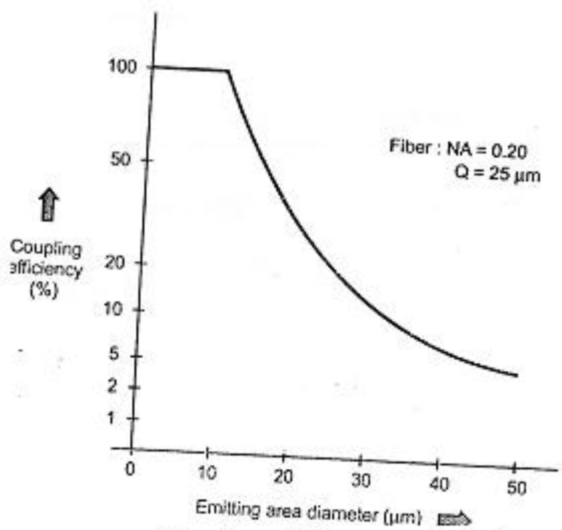


It is necessary that the active diameter of the device be substantially less than the fiber core diameter by a factor of 2. In this case a coupling efficiency of 6% is obtained. Another lens coupling technique employs a truncated spherical micro lens. This is shown in the above figure.

Efficient coupling is obtained when diameter of emission region is much smaller than the core diameter of the fiber. In this case the best results are obtained with a 14 μm active diameter and an 85 μm core diameter step index fiber with a numerical aperture of 0.16. The coupling efficiency was increased by a factor of 13. The integral lens structure has a useful power coupling strategy for use with surface emitters. In this technique a low absorption lens is formed at the exit face of the substrate material instead of it being fabricated in glass and attached to a planar sLED with Epoxy. This method provides an advantage that the semiconductor epoxy lens interface is eliminated which can limit the maximum lens gain of sLEDs. Lens coupling can also be usefully employed with edge emitting devices. Practically lens attached to the fiber ends or tapered fiber lenses are widely used to increase coupling efficiency.

LASER DIODE-TO-FIBER COUPLING:

We know that the edge emitting laser diodes have the emission pattern that nominally has a Full-Width at Half-Maximum (FWHM) of 30° - 50° in the perpendicular plane to the active area junction and an FWHM of 5° to 10° in the parallel plane to the junction. Since the fiber acceptance angle is smaller than the angular output distribution of the laser and since the fiber core is much greater than the laser emitted area, spherical (or) cylindrical lenses (or) optical fiber tapers can also be used to improve the coupling efficiency between edge emitting laser diodes and optical fibers. This phenomenon also works well for Vertical Cavity Surface Emitting Lasers (VCSELs). Here the outcome 35% of coupling efficiencies to multimode fibers for mass-produced connections of laser arrays to parallel optical fibers are possible by direct coupling from a single Vertical Cavity Surface Emitting Lasers (VCSELs) source to a multimode fiber.



Coupling efficiency vs Emitting area diameter

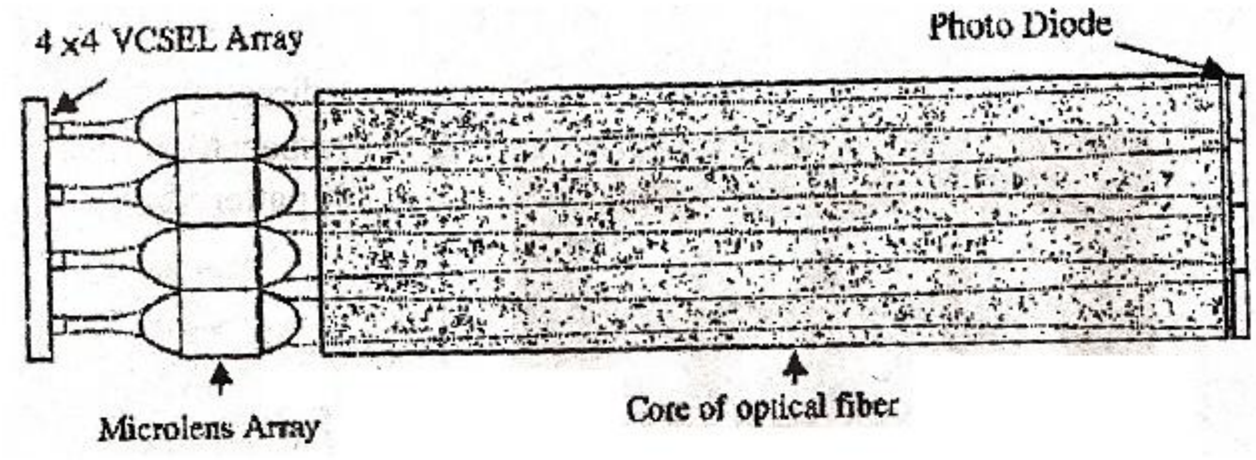
The measured FWHM value of the laser output beams are,

1. For near field parallel to junction lies between 3 and 9 urn.
2. For field perpendicular to the junction lies between 30° and 60°.
3. For field parallel to the junction lies between 15° and 55°.

In practice, the coupling efficiencies range between 50% and 80%.

POWER COUPLING FROM A VERTICAL CAVITY SURFACE EMITTING LASER (VCSEL) DIODE TO A SINGLE MODE FIBER:

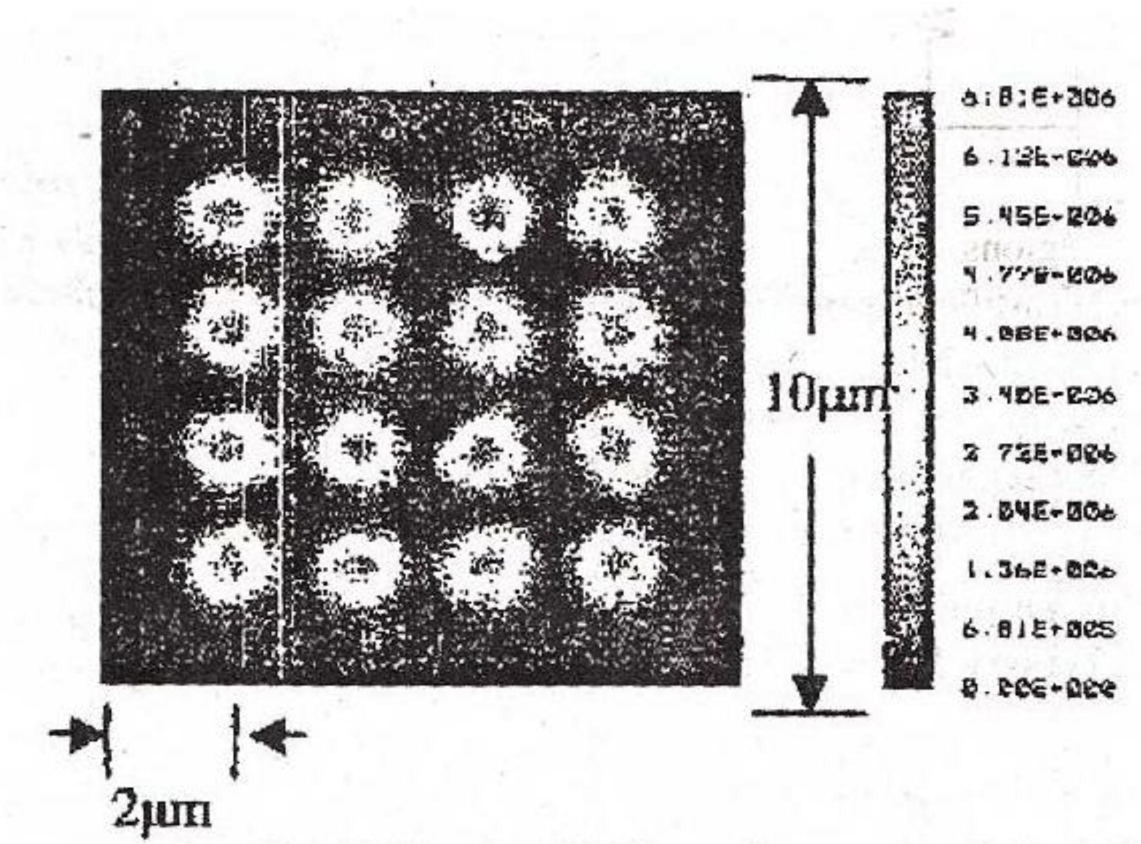
The development of Vertical Cavity Surface Emitting Laser (VCSEL) is done in order to allow high data rate transmission. It is a single crystal nano wire, used as a single mode optical wave guide, like an optical fiber. The important issue is the light coupling from VCSEL array to a single mode fiber for increasing optical power coupling efficiency and brightness in micro-optical system. In order to obtain a highly optical power coupling efficiency, micro lens arrays are used. Let us consider the light coupling from a 4 x 4 nano-scale VCSEL array to a single mode fiber. The overall size of our considered 4 x 4 nano-scale VCSEL array is setup as 8 μm^2 with 2µm core pitch and 850nm wavelength The below figure shows the schematic diagram of the array lens for propagating 16 elements of



Array lens for propagating 16 Elements Of VCSEL

VCSEL in a single mode fiber, the distance between VCSEL arrays to micro lens is set as 640 nm. The input end of single-mode fiber is placed at 890 nm far from micro lens output end. The detector is set as 10 p.m2 behind 1000 mm single mode fiber. The core pitch between lenses is also 2 um. The core diameter of silica is 10 µm and the cladding diameter of fibers is 125 Jim. The figure shows the transmission loss from the laser source.

The transmission loss is 1.9 dB at 1000 mm far from VCSEL array. The spot size of laser source is 360 nm. But here, the spot size is 2000 nm at 500 mm far from the VCSEL array, and the spot size is still below 2000 nm at 1000 mm far from the VCSEL array. Therefore, using the array lens, we can increase the irradiation field distribution of VCSEL array in a single-mode fiber. The below figure shows the irradiance distribution and pattern of the 4 x 4 VCSEL array light output after propagating 1000 mm long of single-mode fiber through 4 x 4 micro lens array.



Output Optical field Intensity of VCSEL array after propagating of 1m length of a single mode fiber by our proposed array lens

Array using 4 x 4 BK7 micro lens array, we can simultaneously convey each laser beam, from 360 nm to 2000 nm into a 1000 mm long single mode fiber.

SOURCE TO FIBER POWER LAUNCHING:

Launching optical power from source into fiber needs te following considerations:
(i) Numerical Aperture
(ii) Core Size
(iii) Refractive index profile
(iv) Core cladding index difference to the fiber
(v) Radiance
(vi) Angular power distribution of the optical source

A measure of the amount of optical power emitted from a source that can be coupled into a fiber usually given by the coupling efficiency η is defined as

$$\eta = P_F/P_S$$

Where P_F is the power coupled into the fiber and Ps is the power emitted from the light source. The launching or coupling efficiency depends on the type of fiber that is attached to the source and on the coupling process, many source suppliers offer devices with short length of optical fiber (lm or less) attached in an optimum power configuration.

This section of fiber is generally referred to as fly lead devices. These fly lead sources reduce many power-launching problems and make the coupling easier.

The effects to e considered are:

(i) Fiber misalignment

(ii) Different core sizes

(iii) Numerical apertures

(iv) Core refractive index

(v) The need for clean and smooth fiber end faces that are perpendicular to the fiber axis. While considering the source to fiber power coupling efficiency, the radiance (spatial distribution of optical power) is important rather than the total output power.

PROBLEMS

* **For an optical source having refractive index of 3.6 coupled to a fiber of 1.48 refractive index. Considering the medium between fiber and source has similar index as that of fiber. Calculate Fresnel reflection and loss of power in dBs.**

Ans:

Given data,

Source refractive index, $n_1 = 3.6$

Fiber refractive index, $n = 1.48$

Fresnel reflection $R = \left(\frac{n_1 - n}{n_1 + n}\right)^2$

$$R = \left(\frac{3.6-1.48}{3.6+1.48}\right)^2$$

$$R = 0.1741$$

Power loss $L = -10 \log(1-R)$

$L = -10 \log(1-0.1741)$ $L = 0.83$ dB.