EXPRIMENT 3

COUPLING FIBERS TO SEMICONDUCTOR SOURCES

OBJECTIVES

In this lab, firstly you will learn to couple semiconductor sources, i.e., light-emitting diodes (LED's), to optical fibers. The coupling will be achieved using a 0.29-pitch graded-index (GRIN) rod lens. You will also experimentally determine the electrical and optical characteristics of LED's.

THEORY

1. TYPES OF SOURCES

Two types of semiconductor light sources are generally used with optical fibers in fiber optic systems. These are light-emitting diodes (LED's) and injection laser diodes (ILD's).

A light source may be characterized by the distribution of power emitted from its surface among all of the possible ray directions. Sources are generally divided into two types, depending on the radiation distribution. These two types are Lambertian sources and collimated sources. A Lambertian source is one which emits light in all directions from each differential source element. A surface-emitting LED closely approximates a Lambertian source. A source that emits light only into a very narrow range of angles about the normal to its surface produces a collimated beam. The output of a He-Ne laser approximates a collimated beam.

In general, the angular distribution of the source brightness can be expressed as

$$B(\theta) = B_0 \, (\cos \theta)^m, \, \theta < \theta_{max}, \qquad (3\text{-}1)$$

Where θ_{max} is the maximum angle from the normal at which light is emitted and is determined by the geometry of the source. For a diffuse source, $m = 1$. For a collimated source, m is large. For intermediate cases, the source may be called a partially collimated source. The ILD is a special case. The far-field distribution of the

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radiation from an ILD diverges in a fan-shaped pattern with angles which are typically on the order of 15° x 30°. This is because the small emittance area of these devices (on the order of 1 μm on a side) causes the collimation of the far-field distribution of the radiation to be limited by diffraction at the output. Fig. 3.1 show the output radiation characteristics, in polar coordinates, for two sources, one with m = 1 (typical of an LED) and one with m = 20 (typical of an ILD).
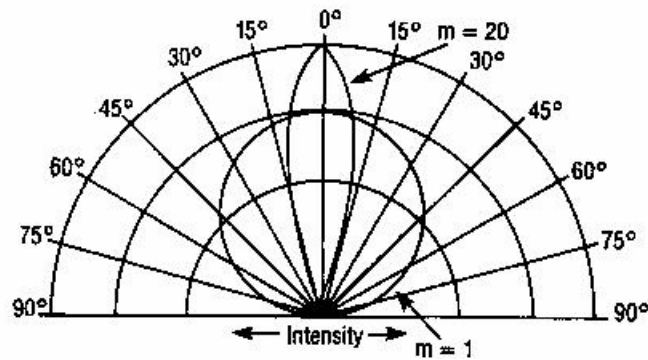

Fig. 3.1 Polar plot of radiation patterns from typical ILD and LED sources.

There are other properties which distinguish light-emitting diodes from laser diodes. These include the optical power-current curves which are characteristic of the devices and the polarization of the output beam. These properties were discussed in other references.

2. COUPLING EFFICIENCY

The amount of light energy which can be coupled into a fiber is dependent on the NA of the fiber. Since a fiber will accept only those light ray which are contained within a cone defined by the fiber's NA and core diameter coupling loss will occur for sources which have an angular emission cone larger than the acceptance cone of the fiber's NA.

In some cases the fiber will be butt-coupled to the source. Butt-coupling is defined as coupling by placing the flat fiber end directly against the source, without the aid of any lens system. Butt-coupling cannot be achieved when the source is mounted in a package with a covering window glass. If the fiber is directly butt-

coupled to the light source, the ratio of the power accepted by the fiber to the power emitted by the source can be shown to be

$$P_t/P_s = 0.5\ (m + 1)[\alpha/(\alpha+2)]\ NA^2, \qquad\qquad (3\text{-}2)$$

where α is the index profile of the fiber. $(\alpha/(\alpha + 2))$ is a mathematical expression of the fact that a parabolic graded-index would accept only one-half as much light as a step-index fiber.) The coupling efficiency to either a graded-index ($\alpha = 2$) or a step-index ($\alpha =\infty$) fiber is proportional to the square of the numerical aperture and increases with increasing directionality (increasing m) of the source. The coupling loss in dB will be $-10\ \log_{10}\ (P_f/P_s)$. Fig. 3.2 shows the theoretical coupling loss as a function of fiber NA for some values of m.

For optimum coupling efficiency, one needs to match the source diameter-NA product to the fiber core diameter-NA product.
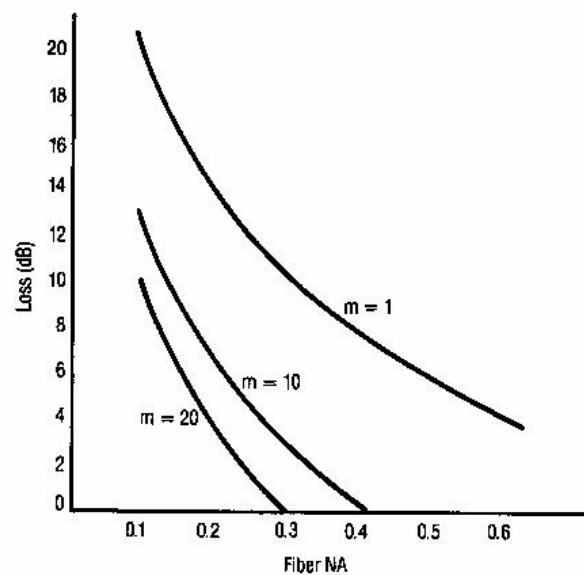

Fig. 3.2 Plot of coupling loss as a function of fiber NA for various values of m, using Equation 3-2.

3. LENS COUPLING USING A GRIN-ROD LENS

This lab uses a graded-index (GRIN)-rod lens to facilitate source-to-fiber coupling. Most optical devices used in fiber-optic systems employ lenses, and for most of these devices, GRIN-rod lenses have advantages over conventional lenses.

The GRIN-rod lens is a glass rod, 1.0 to 3.0 mm in diameter, with a radically dependent index of refraction. This index of refraction is a maximum on the axis of the rod lens, and can be expressed as

$$n(r) = n_0 (1-Ar^2 / 2), \qquad (3-3)$$

where n_0 is the index of refraction at the lens axis and $\sqrt{A}$ is referred to as the quadratic gradient constant.

By far the most popular choice of GRIN-rod lens length is one-quarter (0.25-) pitch. This is because a beam travels exactly one quarter of a sinusoidal period in that distance. Therefore, a collimated beam incident on one end of the lens will be focused to a point on the opposite end of the lens. Conversely any point source at the surface of a quarter-pitch lens will become a collimated beam at the far end, as was seen in Fig. 3.3a. The quarter-pitch lens will be used in next lab.
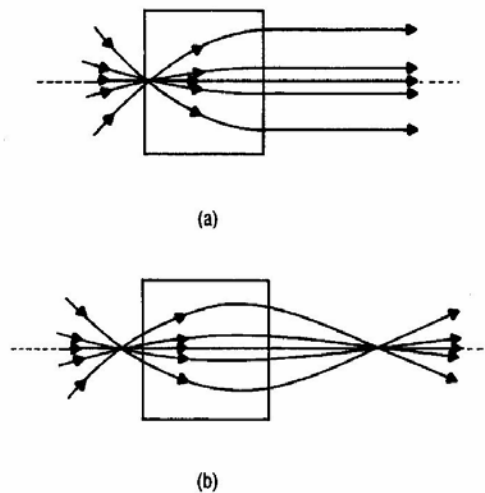

(a)

(b)

Fig. 3.3 Graded-index (GRIN) lens. (a) 0.25 pitch lens. (b) 0.29 pitch lens.

Also widely used is the 0.29-pitch lens (which was illustrated in Fig. 3.3b), which is provided for use in this lab. This lens is used to couple a laser diode to a fiber or a fiber to a detector. The lens which will be used in the lab has n_0=1.599 and $\sqrt{A}$=0.332 mm^{-1}. Since the length of this lens is slightly more than one quarter

pitch, the light from a point source will be converted to a converging beam, rather than a collimated beam.

Table 3-1 Working distances and magnification of the 0.29-pitch GRIN-rod Lens

L_1 (MM)	L_2 (MM)	M (magnification)
0.50	3.33	1.96
1.00	2.05	1.31
1.50	1.42	0.98
2.00	1.04	0.78

Table 3.1 gives examples of the relationships between the working distances, l_1, and l_2, and the beam magnification, M, for the 0.29 pitch lens at a wavelength of 0.83 µm. l_1 is the working distance from the source to the lens, while l_2 is the working distance from the lens to the receiving fiber. The table may be used to optimize laser and fiber working distances. For example, a typical laser diode output may have a beam divergence cone with half angle of abut 15° at the half-power points in the direction perpendicular to the diode junction. Therefore, the e^{-2} power point for the Gaussian output beam will be at sin θ~0.4. Since the numerical aperture of a typical multimode communications fiber is ~0.2, a magnification of about 2 will optimize the laser-fiber coupling. If the physical dimensions of the device permit, l_1, and l_2, can now be adjusted to fit the required magnification. Note that the magnification in the table is the image size magnification; the beam divergence will be reduced by the same factor. The laser diode provided for use in this lab has a diode-to-window distance of approximately 2.0 mm. Because of this, you will not be able to achieve a magnification of 2.0. The result is that the coupling loss will be about 4 dB when the laser-to-fiber coupling is optimized using the 0.29pitch GRIN-rod lens.

PROCEDURE

CAUTION:

The LED device provided for use in this lab is an infrared device with the wavelength approximately centered at about 830 nm. It emits invisible radiation which can damage the human eye. Proper precautions must be taken to ensure that the beams cannot enter the eye. **Never look directly into a laser beam or its reflection**! This means knowing exactly what the beam path is at all times, including the possibility of specula reflections.

CAUTION: Use of controls or adjustments or performance of procedures other than those specified herein may result in hazardous radiation exposure.

CAUTION: The use of optical instruments with this product will increase eye hazard.

Also, it is important to remember that semiconductor infrared sources are highly sensitive devices. When going through the procedures check and double-check to be sure that all connections have been properly made, and carefully follow all directions for device operation. A wrong connection can cause the catastrophic failure of the LED.

1. The FK-LED Light-Emitting Diode Assembly is mounted in a threaded plate. Insert this plate into a MH-2PM Optics Holder. Posts mount this assembly using a SP2 Post and the CA-1 Universal Clamp. Mount this on a B-1 Base. Secure the base to the table using two l/4-20 thumbscrews from the BS-05 Thumbscrew kit.

2. With the Model 505 Laser Diode Driver powered off, connect the LED to the rear connector. Upon powering on the Laser Diode Driver, the display defaults to the PRESET current. **Do not turn on the OUTPUT yet**. This PRESET current mode allows setting the diode current with the control knob before actually turning on the current to the diode. Press the button in the DISPLAY box and toggle the indicator light to the LIMIT position. Using a small screwdriver, adjust LIMIT SET to 120 mA. This adjustment is critical in order to protect the LED and will

limit the current to the LED under all conditions, even when the LED is externally modulated. Additionally leave the driver in the default 200 mA range.

3. Place the detector head of the 1815-C Power Meter directly in front of the LED window. Now on the Laser Diode Driver toggle the display back to the PRESET mode and adjust the control knob to 0.0 mA. Now toggle the display back to CURRENT. Turn on the current to the LED by pressing the button in the OUTPUT box. About 2 seconds later you will hear a relay click inside the Laser Diode Driver and the ON light will illuminate. Turn up gradually the diode current to 100mA. Monitor the output power measured on the 1815-C Power Meter as the current is increased. Make note of the power obtained when the listed optimum operating current (100mA) is reached. **The LED driver circuit has a current limiter at 120 mA.**

4. Reduce the current through the laser to zero. Now slowly increase the current from zero to approximately 110 mA (10% over the optimum current), recording the coupled output power as a function of diode current. Take data between current = 0 and the listed operating current. Plot the results. The data should provide a good fit to a straight line, a characteristic typical of LED's.

5. Place the F-IRC1 IR Phosphor Card in the path of the LED output. The LED has a microlens over the semiconductor chip; all of the output power will not be accepted by the lens, and the output will appear to be better collimated than might be expected from the discussion of section #1(Theory-1).

6. Place a polarizer sheet in the LED output beam. Confirm that the LED output is unpolarized. (Rotating the sheet polarizer in front of the LED out beam doesn't affect the power through the sheet.)

7. Place the 0.29-pitch GRIN-rod lens into the groove of the F-925 coupler, as shown in Fig. 3.4. The lens should extend out of the coupler ~l mm toward the LED. Insert a cleaved segment of F-MLD fiber into the FP-l of the coupler using the FPH-S holder and couple the laser output into the fiber through the GRIN-rod lens.

Fig. 3.4 Place a 0.29-pitch GRIN-rod lens in the V-groove of the Model F-925 GRIN-rod Lens Coupler.

8. Optimize the coupling and determine the coupling loss, using the power coupled into the fiber and the power out of the LED which you measured in Step 2. You will get the best coupling with the laser window as close to the lens as possible.

9. Reduce the laser current to zero. Disconnect the diode from the circuit before turning off any other part of the circuit.

Questions:

1. What are the differences between LED light source and ILD light source?

2. How would you calculate the coupling loss? What kind of coupling did you use in the lab? What are the limitations of this kind of coupling?

3. Can you actually adjust the distance between source and lens or between lens and the end of fibers to achieve the optimum coupling results? What is the problem?

4. What kind of curve is expected after you draw the relationship between the diode current and the coupled output power?