5.0 PROJECT #5: COUPLING FIBERS TO SEMICONDUCTOR SOURCES

(Est. Time Required: 3:00 hrs.)

This project is an exercise in coupling semiconductor sources, i.e., laser diodes and light-emitting diodes (LED's), to optical fibers. Laser diodes and LED's are the sources generally used with optical fibers in communications and sensor applications. Also presented is a procedure to experimentally determine the electrical and optical characteristics of these sources.

The coupling will be achieved using a 0.29-pitch graded-index (GRIN) rod lens. GRIN-rod lenses have become widely accepted for use in fiber optic applications because of their small size, convenient focal lengths and working distances, and high-quality images with low distortions.

The sources which will be used are infrared devices, with the laser diode emitting at approximately 780 nm and the LED centered at about 830 nm. Since these devices emit invisible radiation, proper safeguards must be used to ensure that the possibility of injury is eliminated. Never look directly into a laser beam or its reflection.

5.1 TYPES OF SOURCES

Two types of semiconductor light sources are used in fiber optic systems. These are light-emitting diodes (LED's) and Laser diodes. The theory of semiconductor devices was outlined in **Section 0.4.2** and is detailed elsewhere.[1,2] In this project, we will be concerned with the coupling of these devices to optical fibers.

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 which emits light only into a very narrow range of angles about the normal to its surface produces a collimated beam. The output of a HeNe laser approximates a collimated beam.

In general, the angular distribution of the source brightness can be expressed as (recalling Eq. 0-22)

$$B(\theta) = B_0 (\cos \theta)^m, \ \theta < \theta_{max}, \qquad (5\text{-}1)$$

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 laser diode is a special case. The far-field distribution of the radiation from a laser diode diverges in a fan-shaped pattern with angles which are typically on the order of 15° × 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. 5.1 shows 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 a laser diode).

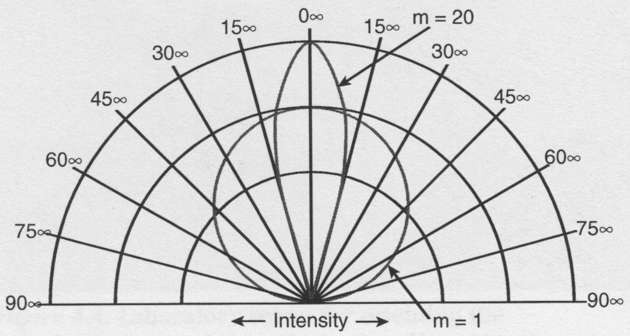

Figure 5.1. Polar plot of radiation patterns from typical laser diode and LED sources.

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 **Section 0.4.2**.

5.2 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 rays 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[3]

$$P_f / P_s = 0.5(m + 1)[\alpha/(\alpha + 2)]\, NA^2, \qquad (5\text{-}2)$$

where α is the index profile of the fiber. (In **Section 0.2.3**, it was stated that a parabolic graded index would accept only one half as much light as a step index fiber. The factor $\alpha/(\alpha + 2)$ is a mathematical expression of this fact.) 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. 5.2** 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. This was discussed in detail in **Section 0.4.3.**

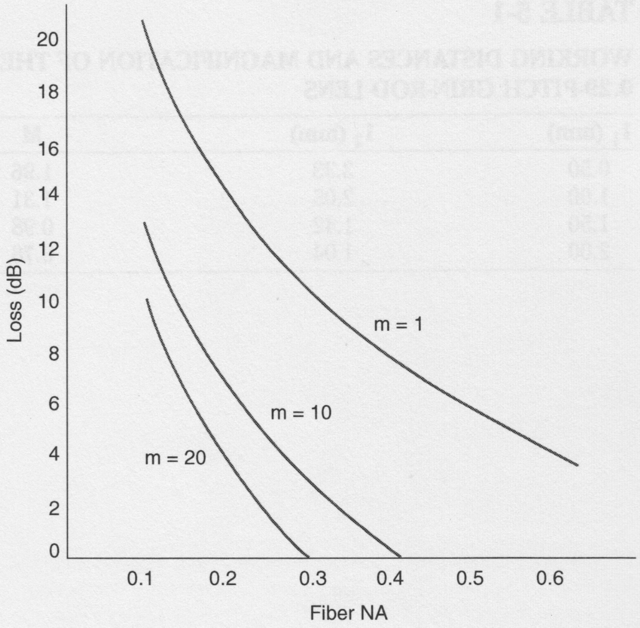

Figure 5.2. Plot of coupling loss as a function of fiber NA for various values of m, using Equation 5.2.

5.3 LENS COUPLING USING A GRIN ROD LENS

This project 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, which was described in **Section 0.2.4**, is a glass rod, 1.0 to 3.0 mm in diameter, with a radially dependent index of refraction. This index of refraction is a maximum on the axis of the rod lens, and can be expressed as

$$n(r) = n_0 (1 - Ar^2/2), \qquad (5\text{-}3)$$

where n_0 is the index of refraction at the lens axis and A is referred to as the quadratic gradient constant. (This is really a restatement of **Eq. 0-13**, with $A=2\Delta/a^2$.)

By far the most popular choice of GRIN-rod lens length is one-quarter 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. 0.11a**. The quarter-pitch lens will be used in **Projects #7**, **#9**, and **#10**.

Also widely used is the 0.29-pitch lens (which was illustrated in **Fig. 0.11b**), which is provided for use in this project. This lens is used to couple a laser diode to a fiber or a fiber to a detector. The lens which you will be using has $n_o = 1.599$ and $\sqrt{A} = 0.332\ \text{mm}^{-1}$. 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 5-1 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 about 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 $\sin\theta \sim 0.4$. 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 project has a diode-to-window distance of approximately 2.0 mm. Because of this, achieving a magnification of 2.0 will not be possible. The result is that the coupling loss will be about 4 dB when the laser-fiber coupling is optimized using the 0.29-pitch GRIN-rod lens.

TABLE 5-1

WORKING DISTANCES AND MAGNIFICATION OF THE 0.29-PITCH GRIN-ROD LENS

l_1 (mm)	l_2 (mm)	M
0.50	3.33	1.96
1.00	2.05	1.31
1.50	1.42	0.98
2.00	1.04	0.78

5.4 REFERENCES

1. H. Kressel and J. K. Butler, *Semiconductor Lasers and Heterojunction LED's,* Academic Press (New York), 1977

2. S. M. Sze, *Physics of Semiconductor Devices,* John Wiley & Sons (New York), 1969

3. M. K. Barnoski, in *Fundamentals of Optical Fiber Communications,* 2nd Edition, M. K. Barnoski, ed., Academic Press (New York), 1981, p. 158

5.5 PARTS LIST

Cat#	Description	Qty.
F-MLD	100/140 MM Fiber, 50 meters	1
F-CL1	Fiber Cleaver	1
1918-C	Power Meter	1
918D-SL-OD3	Low Power Detector, Silicon	1
FK-BLX	Allen Wrench Set	1
SK-25A	Screw Kit, ¼-20	1
423	Translation Stage	3
SM-13	Micrometer, 13 mm	3
360-90	Angle Bracket	1
B-1A	Base	1
VPH-2	Post Holder, 2"	2
SPV-2	Post, 2"	3
F-925	GRIN-Rod Lens Fiber Coupler	1
FK-18281-30B	Laser Diode	1
FL-ILD	Laser Diode Assembly	1
FK-LED	Light-Emitting Diode Assembly	1
505B	Laser Diode/LED Driver	1
LGI830-6	0.29-p GRIN Lens (without filter)	1
FK-POL	Polarizer Sheet	1
F-IRC1	IR Phosphor Card	1
CA-2	Universal Clamp	1
F-STR-175	Fiber Coating Stripper	1
FK-STRAP	Grounding Wrist Strap	1
IMIC-1	Fiber Inspection Microscope	1
FPH-S	Fiber Holder	1
818-FA2	Fiber Optic Adapter	1
FP3-FH1	Bare Fiber Holder	1

Optional Equipment: Newport G3919 Laser Goggles

5.6 INSTRUCTION SET

CAUTION: READ THESE WARNINGS BEFORE PROCEEDING WITH THIS PROJECT.

The LED and laser diode devices provided for use in this project are infrared devices which emit radiation which can damage the human eye even though it is invisible. Proper precautions must be taken to ensure that the beams cannot enter the eye. This means knowing exactly what the beam path is at all times, including the possibility of specular 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 (e.g. a lens, which can focus the light) with this product will increase eye hazard.

Also, it is important to remember that semiconductor infrared sources are highly sensitive devices. Wear the grounding wrist strap at all times when working with the laser diodes or LED's. When going through the instruction set, 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 either the laser diode or the LED. Before each use visually inspect the laser diode in the FL-ILD assembly to check for damage to the diode.

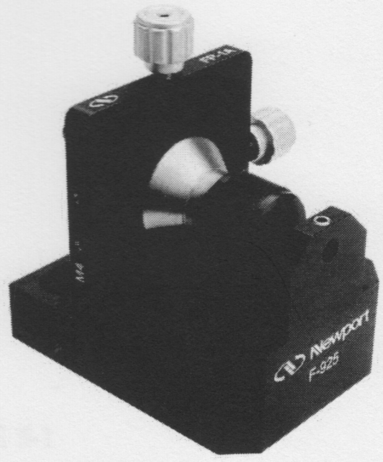

Figure 5.3. Placing a 0.29-pitch GRIN-rod lens in the V-groove of the Model F-925 GRIN-Rod Lens Coupler.

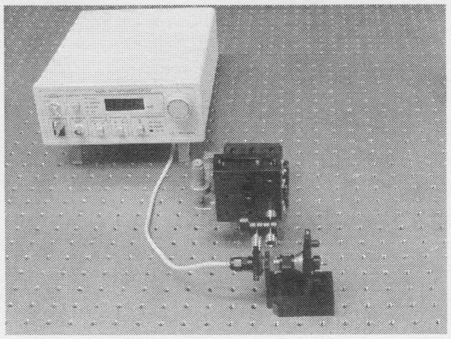

Figure 5.4. Laboratory set-up for coupling semiconductor sources to optical fibers. Use CA-2 Universal Clamp on the stage assembly if matching the optical axis of the laser diode and that of the fiber coupler is difficult.

5.6.1 LASER DIODE

1. Install SM-13 micrometers onto each of the three 423 translation stages. Mount one stage to the table and use the other two stages along with the 360-90 angle bracket to construct an xyz configuration.

2. The FL-ILD Laser Diode mounting assembly is premounted in an MH-2PM optics holder. Put the FK-STRAP grounding wrist strap on and connect it to the grounding post on the back of the 505B laser diode driver. Remove the cover plate on the laser diode mount, which is held on by (2) small button head hex screws. Removing this plate will expose the 3- pin socket. Remove the laser diode from the box and orient the pins correctly to match the socket in the mounting assembly. Install the laser diode into the socket, pushing gently to avoid damaging the pins. Reinstall the cover plate and post mount this assembly using two SPV-2 Posts and the CA-2 Universal Clamp. Mount this on the Z axis of the 423 stage system from **Step 1**.

IT IS VERY EASY TO BLOW OUT A LASER DIODE BY EXCEEDING CURRENT SPECIFICATIONS OR BY STATIC DISCHARGE FROM YOUR BODY. A GROUNDING WRIST STRAP SHOULD BE WORN BY EACH PERSON WHO WILL BE HANDLING THE LASER DIODE AND THE LED. MAKE THE FOLLOWING CONNECTIONS ONLY WHEN THE DIODE POWER SUPPLY IS OFF. PLUG THE GROUNDING WRISTBAND INTO THE GROUNDING POST ON THE REAR OF THE MODEL 505B LASER DIODE DRIVER. ALWAYS WEAR THE WRISTBAND WHEN HANDLING THE LASER DIODE OR LED.

3. Connect the laser diode to the model 505B driver circuit.

4. Place the 918D-SL-OD3 detector head directly in front of the laser window. Increase the diode current to the operating current listed for the device. Monitor the output power as the current is increased. Make note of the power obtained when the listed optimum operating current (I_{op}) is reached.

5. Reduce the current through the laser to zero. Now, slowly increase the current, recording the coupled output power as a function of diode current. Record data for current values from 0 to I_{op}.

6. Plot the results. Draw a line along the rise in power above the onset of lasing. Extend this line down through the current axis. Compare the current at this point with the listed threshold current. This is one of the techniques used to determine the laser's threshold current.

7. The F-IRC1 IR Phosphor Card may be used to view the laser output. Place the phosphor card in the path of the beam at a convenient viewing distance. Measure the width of the beam parallel and perpendicular to the width of the diode junction. Using this and the distance from the device, calculate the divergence of the beam. The manufacturer specifies a divergence of about 15° × 30° for this laser.

8. Place the FK-POL Polarizing Sheet with a known polarization axis in the laser beam and determine the plane of polarization of the laser output.

9. Place the LGI830-6 0.29-pitch GRIN-Rod Lens into the groove of the F-925 coupler, as shown in **Fig. 5.3**. The lens should extend out of the coupler ~1 mm toward the laser

diode. 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. The proper setup is shown in Fig. 5.4.

10. Optimize the coupling and determine the coupling loss, using the power coupled into the fiber and the power out of the laser diode which you measured in **Step 5**. The best coupling will be attained with the laser window as close to the lens as possible. With the laser diode which is used here, and the F-MLD fiber, a coupling loss of about 4 dB should be obtained.

11. Turn the 505B Laser Driver output off. Disconnect the 9-pin laser diode connector from the Model 505B.

5.6.2 LIGHT EMITTING DIODE

1. Post mount the FK-LED Light-Emitting Diode Assembly in the same way as the laser diode. (See **Fig. 5.4**)

2. Connect the LED to the model 505B driver unit. Turn the current up to 100 mA and record the power out of the device.

3. Reduce the LED current to zero. Record the power out of the coupled LED as a function of current from zero to approximately 110 mA (or 10% over the specified operating current). The data should provide a good fit to a straight line, a characteristic typical of LED's.

4. Place the F-IRCl 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 5.1**. However, you will still see a marked contrast to the output of the laser diode.

5. Place the polarizer used previously in the LED output beam. Confirm that the LED output is unpolarized.

6. Couple the LED to the fiber using the F-925 GRIN lens coupler as you did in **Steps 9** and **10** of the previous section. Calculate the coupling loss using the power coupled into the fiber and the power out of the LED which you measured in **Step 3**.