EXPERIMENT 5
LIGHT COUPLING TO MULTIMODE GRADED INDEX FIBERS

OBJECTIVES:

The objective of this experiment is to couple HeNe laser light to a multimode grade index fiber. Both direct and lens coupling will be done. The coupling efficiency is to be measured in each case and the experimental results are to be compared with theoretical prediction.

EQUIPMENT REQUIRED

1- Optical power meter: INFOS, Model # M100.
2- HeNe laser: Coherent, Model # 31-2090-000 on a horizontal and translation stage, all assembled on a ¼ m bench.
3- Mells Griot horizontal and vertical translation stages, (0.01 mm resolution) with a fiber holder assembled on a Mells Griot bench base.
4- GI $50\mu m$ optical fiber [Orange]. About 2 meter long.
5- Thin lens ($f = 5\,cm$).
6- Lens holder.
7- Translation stage assembled on ¼ m bench: Ealing Electro-Optics.

PRELAB ASSIGNMENT:

Read the introduction to this experiment before attending the laboratory.

INTRODUCTION:

In this experiment HeNe laser light will be first coupled *directly* to a $50\mu m$ GI optical fiber. This will be followed by *indirect* coupling by focusing the laser light into the GI fiber using a thin lens.

Let us turn our attention first to the direct coupling of a laser beam to a highly multimode GI fiber of core radius a, as shown in Figure 1. Electromagnetic theory predicts that the coupling efficiency η in this case is given by the simple relationship:

$$\eta = (a^2 / w^2) \qquad \text{for} \qquad a \le w \tag{1}$$

Where w is the laser spot size (assumed to be Gaussian) and a is the core radius of the fiber. The corresponding dB loss in this case is given by:

$$dB_{loss} = -10\log\eta = -10\log(a/w)^2 = -20\log(a/w) \tag{2}$$

In this experiment we will verify the theoretical prediction of equation (2), by coupling a laser beam of known power and measure the resulting dB loss in the case of *direct* laser/ fiber coupling. This method tends to couple part of the light power into the *cladding modes* of the fiber. Cladding modes are *very lossy* modes, which decay after few meters or few tens of meters depending on the type of fiber and method of excitation. The fiber used in this experiment is relatively short, so there is a strong possibility that the measured fiber transmission efficiency, in the case of direct coupling, will be somewhat higher than the prediction of equation (1). This also means that the experimental dB loss may be somewhat smaller than the prediction of equation (2). We can use the theoretical and experimental coupling efficiencies to *roughly estimate* the optical power coupled to the cladding modes (*and ultimately reaching the power meter*) in the case of direct coupling.

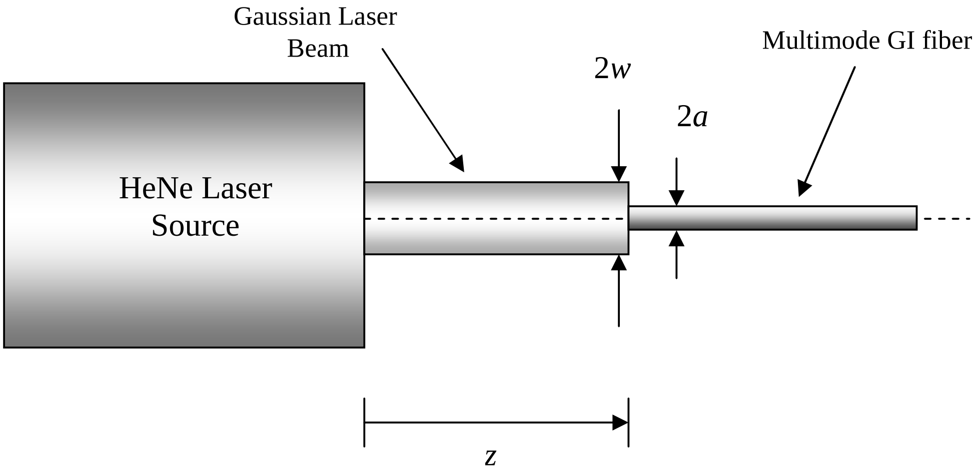

Figure 1: Direct Coupling of the HeNe Laser Source to a Multimode GI Fiber of Core Radius a.

LASER/FIBER LENS COUPLING:

Based on equation (1), when the laser spot size w is reduced, the coupling efficiency η increases. One way to reduce w is by focusing the laser beam using a lens, before the light is coupled into the fiber input end, as shown in Figure 2.

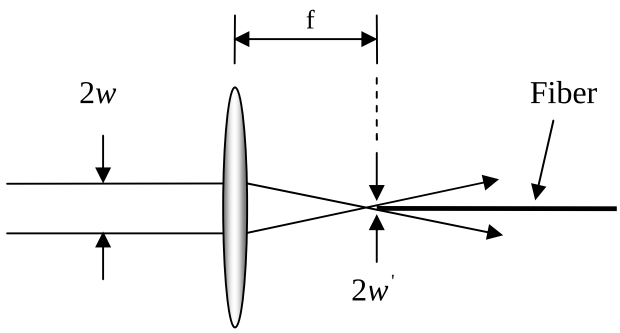

Figure 2: Laser/Fiber Lens Coupling.

In theory, we can obtain a maximum efficiency of $\eta \approx 1$ if we reduce the laser spot size from w to w' and *match it* to the radius $a = 25\mu m$ of the GI fiber (i.e. $w' = a = 25\,\mu m$). To successfully achieve this task, we need first to design the lens coupling system. The Gaussian spot size w' at the focal point (see Figure 2) is given by the well-known relationship:

$$w' = \frac{\lambda f}{\pi w} \qquad (3)$$

From experiment 2, we have measured the minimum spot size w_o (at $z = 0$) of the HeNe laser and found it to be $w_o \approx 0.28\,mm$. Using this spot size, along with equation (3), we can find the focal length of the lens required to focus this spot size into $w' = 25\,\mu m$, as follows:

$$f = \pi w' w/\lambda = \pi \times (25\times10^{-6}\,m)\times(0.28\times10^{-3}\,m)/(0.633\times10^{-6}\,m) = 3.47\,cm$$

The nearest available lens has a focal length $f = 5\,cm$. Thus, we will use this lens in this experiment. However, if we use this lens, the focused spot size w' will be larger than the target spot size $w' = 25\,\mu m$ (see equation 3). What should be the value of w that can be focused into $w' = 25\,\mu m$ when a lens of focal length $f = 5\,cm$ is used? Using equation (3), the answer is $w = 0.4\,mm$. This spot size can be obtained if we increase the distance z from the laser output end to the lens, since the Gaussian beam emitted by the laser expands with z. Previous *experimental* results show that at $z \approx 37\,cm$, the spot size is $w = 0.4\,mm$ (see experiment 2).

This method of excitation *tends not* to excite the cladding modes, provided the beam is properly focused directly into the fiber's core and the spot size is reduced to match the core radius.

PROCEDURE:

HENE LASER TOTAL POWER MEASUREMENT:

1- Turn on the HeNe laser and wait for it to stabilize.
2- Remove the cover of the optical power meter.
3- Measure the *total power* emitted by the laser source. Because the sensor of the power meter has a smaller area than the laser beam, you need to first *partially focus* the laser light into the light sensitive area of the power meter. *Do not overly focus the light into the light sensitive area of the meter, because this causes sensor saturation and leads to meter readings that are less than the actual power*. To measure the total power emitted by the laser, use the following procedure (Refer to Figure 3):

- Place the lens at about 20 cm from the laser output end.
- Place the light sensitive area of the meter at about $L \approx 9\,cm$ from the lens. [Insure that the laser beam size is *slightly smaller* than the dimension of the light sensitive area. *The light sensitive area must capture all the laser light*].
- Turn the power meter on and set it to dBm and $\lambda = 0.85\,\mu m$ and record the meter's reading in table 1.

- Repeat the above for $L \approx 8, 7, 6$ and $4cm$. Record the values in table 1

4- Take the *maximum* of the five readings in table 1 and call it P_l and record its value in table 1. *Also record the same value of P_l in table 2.*

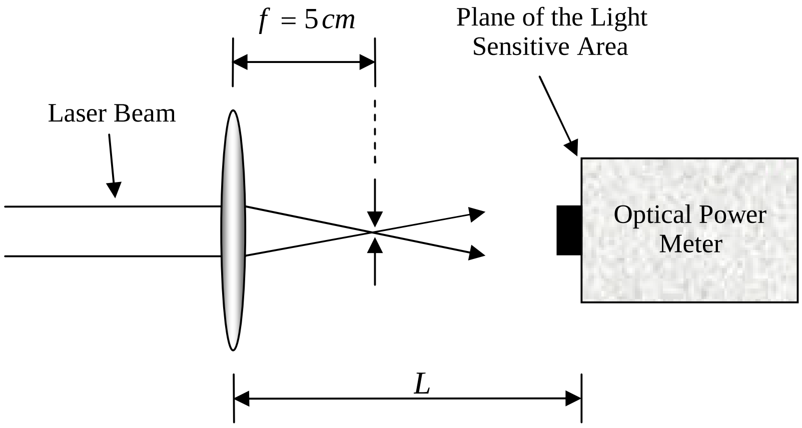

Figure 3: Arrangement Used to Measure The Total Power of the HeNe Laser Source.

Total Laser Power (dBm)	
$L \approx 9cm$	
$L \approx 8cm$	
$L \approx 7cm$	
$L \approx 6cm$	
$L \approx 4cm$	
Maximum (P_l)	

Table 1: Total Laser Power Measurement.

LASER/FIBER DIRECT COUPLING:

[IMPORTANT: INSURE THAT THE FIBER HAS BEEN RECENTLY CLEAVED AND CLEANED BEFORE YOU BEGIN. IF THE FIBER IS NOT PROPERLY CLEAVED, EXTREMELY LARGE EXPERIMENTAL ERRORS WILL RESULT].

1- Connect the fiber to the fiber's holder on the horizontal/vertical translation stage (Stage XY) and adjust the distance between the laser to the fiber's tip to $z = 37\,cm$ (see Figure 4).
2- Connect the other end of the fiber to the power meter and insure it is set to the same previous setting.
3- Move stage XY in both the horizontal and vertical directions until you obtain maximum meter reading (as you did in experiment 2). The fiber now should be

located at the beam's center. Record the maximum measured power value in table 2 and call it P_{direct}. [*You should obtain a value of about* $-15\,dBm$ *or higher by a few dBms. If the received power is much lower than* $-15\,dBm$, *consult your laboratory instructor, because the fiber may not be properly cleaved, or it may be dirty. Another possible reason is that the connector used to connect the fiber to the power meter is either dirty or not well prepared*].

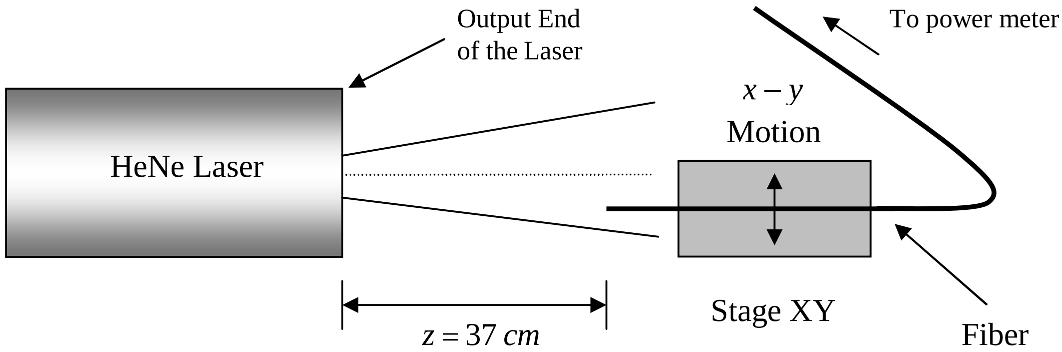

Figure 4: Direct Light Coupling Setup.

LASER/FIBER LENS COUPLING:

[<u>WARNING</u>: WHEN MAXIMUM COUPLING IS ACHIEVED USING THE PROCEDURE YOU ARE ABOUT TO DO, ALMOST ALL THE LASER POWER WILL BE COUPLED INTO THE FIBER. DO NOT REMOVE THE FIBER FROM THE POWER METER, BECAUSE THIS MAY CAUSE SERIOUS EYE INJURY].

1- Setup the lens coupling arrangement shown in Figure 5.
2- Attach one end of the test fiber to the fiber holder and connect the other end to the power meter.
3- Turn the laser on.
4- Now you need to accurately align your setup. Use the following procedure experimental setup and laser alignment:

- Use the holes on the optical table to insure the ¼ m optical bench (that carries the laser) and the Mills Griot optical bench (that carries stage XY) are *parallel* to each other.
- Using a meter stick to align the laser in order to insure that it is *parallel* to the optical table. Bring the meter stick close to the laser and record the *exact height* where the laser hits the meter stick (A height $h = 25-30\,cm$ is recommended). Repeat this step at a distance of about 1 meter. If the *laser beam's center* hits the meter stick at a different height, then adjust the vertical tilt of the laser until the laser hits the stick at the same height.
-Now confirm your alignment by moving the stick in the horizontal direction to insure that the laser hits the stick at the same height h regardless of distance from the laser (see Figure 6).
- Finally, align the laser with respect to the fiber to insure that it is perfectly *perpendicular* to the fiber.

5- Place the lens at a distance $z = 35\,cm$ (less the target value $z = 37\,cm$ for a reason that will be clear shortly) from the laser.
6- Adjust the position of the lens until the laser hits the *exact center* of the lens. To insure this, use the following procedure:

- Remove the lens from the lens holder.
- Use a meter stick and place it about 1 meter from the laser and mark the *exact point* where the laser hits the stick. *Keep the meter stick in its exact place, don't move it*.
- Place the lens in the lens holder. Insure that the laser beam is perpendicular to the beam.
- Adjust the lens *both in the horizontal and vertical* directions until the *center* of the *expanded laser spot* hits the meter stick at *exactly the same previous point*. (see Figure 7).

7- Now you need to *exactly* place the fiber's tip at the focal point of the lens. This procedure requires a little patience because of the small spot size of the focused beam spot size ($w' \approx 25\,\mu m$). This can be done using the following procedure:

- *Initially,* place the fiber's tip at $7\,cm$ from the lens (larger than $f = 5\,cm$). At this position, the laser beam being focused by the lens is relatively wide and therefore easier to locate (see Figure 7).
- Adjust stage XY in the horizontal and vertical directions and monitor the meters reading until you obtain maximum power reading.
- Adjust Stage Z to move the lens *towards* the fiber's tip, and monitor the meter's reading until you obtain maximum meter reading.
- Again, adjust stage XY in the horizontal and vertical directions and monitor the meters reading until you obtain maximum power reading.
- If necessary repeat the above steps until you obtain the *maximum possible* meter reading. When successfully done, the fiber's tip should be at the focal point of the lens. Make a final *visual* check to see if the fiber's tip is at the focal point of the lens, 5 cm away from the lens. Record the maximum power reading in table 2 and call it P_{lens}.

[*When the above procedure is successfully done, the power meter should register a dBm power slightly less than the total laser power you measured in the first part of the experiment*].

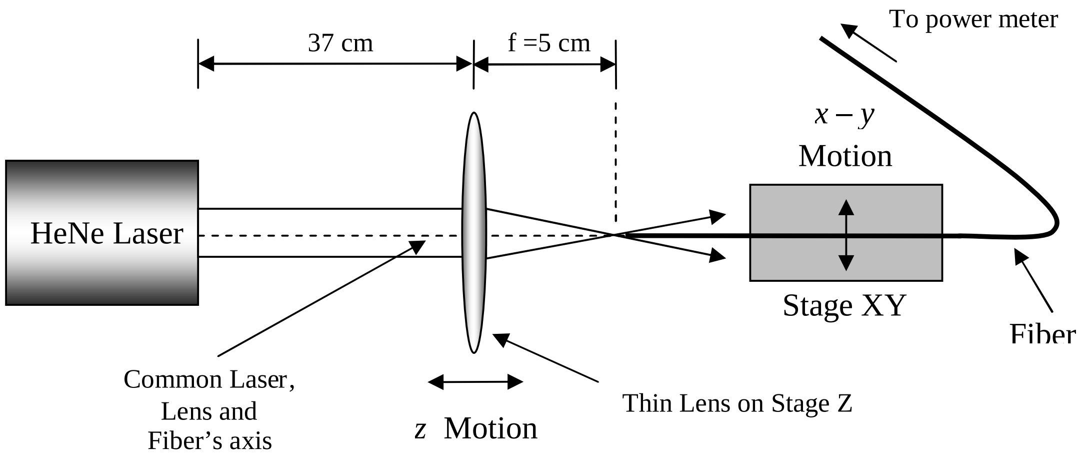

Figure 5: Thin Lens Light Coupling Setup.

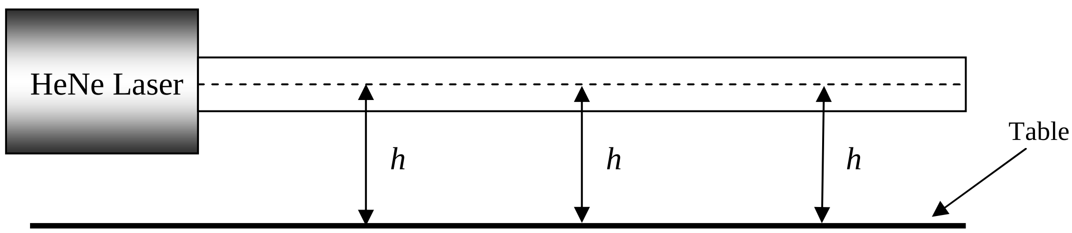

Figure 6: Illustration of Laser Alignment with Respect to the Optical Table.

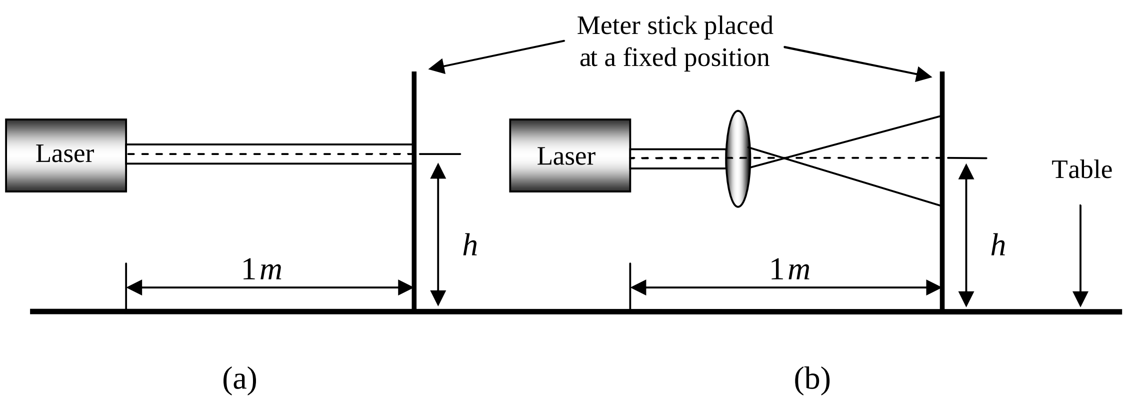

Figure 7: Illustration of Laser Alignment with Respect to the Lens Center. (a) Without Lens. (b) With Lens.

P_l (dBm)	
P_{direct} (dBm)	
P_{lens} (dBm)	

Table 2: Summary of Power Measurements.

REPORT REQUIREMENTS:

1- Calculate the optical power loss in dB when direct laser/fiber coupling is used. In dB, this loss is given by $dB_{loss} = P_l - P_{direct}$. Record the value in table 3.
2- Calculate the theoretical loss in dB using equation (2) and write down the result in table 3.
3- Repeat the above for the laser/fiber *lens* coupling. Write the results in table 3.
4- Compare the theoretical and experimental measurements of the dB loss in table 3 and suggest some possible sources of error.
5- To identify some of the sources of error, think of the additional loss due to light reflection from the lens surfaces (Fresnel reflection) and the variation of the NA of the GI fiber with distance from the core axis. In addition, the connector from the fiber to the optical power meter may give additional loss. Is the laser spot size at $z = 37\,cm$ exactly equal to $0.4\,mm$? What about coupling to the cladding modes in the case of direct coupling?
6- Discuss how far away your result (for the lens coupling method) is from optimal efficiency (i.e. how far it is from the zero dB loss).
7- In the case of direct coupling, use the theoretical and experimental coupling efficiencies to *estimate* the dBm power coupled to the lossy claddings modes that reaches the optical power meter. This can be done as follows: theoretically *estimate* the power (in mW) that is coupled to the fiber's core using equation (1). Then find the total power (in mW) that has actually been coupled to the fiber (including core and cladding). Take the difference between the two powers in mW. This gives an estimate of the power (in mW) coupled to the cladding modes in the case of direct coupling. Finally, convert this power to dBm. Do you expect this power to be reduced if the fiber is much longer?
8- Discuss the overall experimental results. Write some comments and conclusions.

dB_{loss} (dB)	Theoretical	Experimental
Laser/Fiber (Direct)		
Laser/Fiber (Lens)		

Table 3: Theoretical and Measured Coupling Losses in dB.

QUESTIONS:

1- It is easier to *optimize* lens coupling using a highly multimode fiber or a single mode fiber. Discuss the experimental difficulties that you expect to face if you try to lens couple light into a single mode fiber having a *diameter* of $5\ \mu m$.

2- You are given a set of lenses, with the following *standard* focal lengths:

$f = 3.06\, cm$, $f = 1.674\, cm$, $f = 0.855\, cm$, and $f = 0.4488\, cm$

Suppose you want to achieve *maximum* coupling efficiency from the HeNe laser into the single mode fiber presented in question 1. You can achieve this by focusing the laser light into a spot size that equals the core radius of the single mode fiber. Which lens is the most appropriate to use? [*The distance from the laser to the lens should not exceed 40 cm*]. Sketch the experimental setup showing the lens that you have selected and the distance from the laser to the lens.

3- Estimate the loss in dB due the lens in the last part of this experiment.