Lab V  
**Multimode Optical Fibers**  
**ECE 476**

I. Introduction  
The purpose of this lab is to introduce you to multimode fiber optics. We will focus on coupling a fiber to a laser.

II. Background  

**Fiber Geometry**  
An optical fiber is illustrated in Fig. 1. It consists of a core, with a refractive index $n_{core}$, of circularly symmetric cross-section with radius $a$, and a cladding, with refractive index $n_{cl}$, which surrounds the core and has an outer diameter of $d$. Typical core diameters range from 4-8 μm for single mode fibers to 50-100 μm for multimode fibers used for communication to 200-1000 μm for large-core fibers used in power transmission applications. Communications-grade fibers will have $d$ in the range of 125-400 μm, with some single-mode fibers as small as 80 μm. In high-quality communications fibers, both the core and cladding are made of silica glass, with small amounts of impurities added to the core to slightly raise the index of refraction. There are also lower-quality fibers available which have a glass core surrounded by a plastic cladding, as well as some all-plastic fibers. The latter have very high attenuation coefficients and are used only in applications requiring short lengths of fiber. Surrounding the fiber will generally be a protective jacket. The jacket may be made from a plastic and have an outside diameter of 500-1000 μm. However, the jacket may also be a very thin layer of varnish or acrylate, material. A fiber is called single mode if the diameter is small enough that light propagates down it in only one way (one solution of Maxwell’s equations).

![Figure 1: Optical Fiber](image_url)
Fiber Mechanical Properties
Before a fiber can be used the ends must be cleaved so that they are flat. This will ensure that light will couple efficiently into the fiber. In theory, the breaking strength of glass fibers can be very large, up to 725 kpsi (where 1 kpsi =1000 pounds/sq. inch) or 5 GPa (where 1 Pa = 1 Newton/sq. meter and 1 GPa = 10^9 Pa). However, because of inhomogeneities and flaws, fibers do not exhibit strengths anywhere near these values. Before being wound on a spool, a fiber is stretched over a pair of pulleys which apply a fixed amount of strain (stretching per unit length). This process is called proof-testing. Typical commercial fibers may be proof-tested to about 50 kpsi (345 MPa), which is equivalent to about a one pound load on a 125 mm OD fiber. When a crack is introduced, the breaking strength is reduced even further. Fracture occurs when the stress at the tip of the crack equals the theoretical breaking strength, even while the average stress in the body of the fiber is still very low. The crack causes sequential fracturing of the atomic bonds only at the tip of the crack. This is the reason that a straight crack will yield a flat, cleaved, fiber face.

There are a couple of ways to cleave the fiber. One method is to use a scribe-and-break technique. A carbide or diamond blade is used to start a small crack in the fiber as illustrated in Fig. 2. Evenly applied stress, applied by pulling the fiber, causes the crack to propagate through the fiber and cleave it across a flat cross section perpendicular to the fiber axis.

Another way to cleave optical fiber is to heat the fiber with a small flame. The flame will burn away the plastic and cause the glass to crack on its own as you pull the two ends of the fiber apart.
III. Procedure

Part A: Preparing Fiber Ends

1. Get a 1-meter section of multimode fiber.

2. Use one of the following methods to cleave the ends of the fiber.

   **Scribe and Break**
   - Remove about one inch of the plastic fiber jacket from the multimode fiber. This removal can be done using a single edge razor blade held at a low angle to do the stripping of the fiber jacket. This requires some practice, but it goes quickly once you are used to it. An alternative way is to chemically strip the plastic off with methylene chloride (paint stripper). But since this is a hazardous chemical and we have no exhaust hood in the laboratory we will not use this method.
   - Use the fiber cleaver to cleave the stripped end of the fiber. Place the fiber on a smooth metal surface, press the cleaver against the fiber while pulling both ways on the fiber. You can tape one end of the fiber to hold it firmly to the smooth surface. The fiber should cleave. Remember you just want to nick the fiber with the cleaver, the pulling propagates the crack.

   **Heat with Flame**
   - Heat the fiber 1-2 inches from the end with a lighter. Immediately after blowing out the flames, pull on the fiber in opposite directions. The glass will crack on its own letting you break off the end for a clean cleave.

   *Be sure to throw the small piece of glass fiber you cleave off the end away.* If it is left on the table it could end up in someone’s eye.

3. Check the quality of the cleave by examining it under a microscope. Carefully examine the end face of the fiber. The end should appear flat and free of defects. However, chips or cracks near the outer edge of the cladding that do not extend into the core are often acceptable. If your fiber end does not look good, repeat the cleaving process, in part 3, again.

4. Repeat the above process (parts 2 and 3) for the other end of the fiber. Once you have a fiber with two good ends, view one end of the fiber under the microscope. Point the other end towards a light source (lights on the ceiling for example). You should observe that the light coming out of the fiber end under the microscope comes from the core region.

   **Part B: Coupling Laser Light Through the Fiber**
   
   **Set-up**
1. You are going use your 0.5 mW HeNe laser, a microscope lens, a fiber coupler, and a multimode fiber holder as shown in Figure 3 to couple light into the fiber. Answer the following question in your lab report: What is the danger of focused laser beams?

If you do not know the answer, talk to your TA before proceeding.

![Figure 3: Coupling of HeNe laser light into the fiber.](image)

2. Get the fiber coupler and the 20X microscope lens from your cabinet. Set up the coupler as shown in Figure 3 above. Handle the microscope lens by the metal sides, do not touch the glass lens.

3. Set up your laser and observe that the light going through the microscope lens (20X) is straight and symmetric. Visually sight along the laser path from above and ensure that all the components are well aligned. Measure the power output of the laser after it goes through the lens. You will need this measurement in the Experiment section.

4. Get the multimode fiber holder from your cabinet (depicted below in Figure 4). Run your fiber through the chuck and tighten the chuck.
5. Insert the chuck into the fiber coupler so that the end of the fiber is 1-2 mm away from the end of the microscope lens. Do not bump the fiber into the lens as this can scratch the lens and break your cleaved end. (Note: If you break your end: go back to the start of the experiment and re-cleave your end.)
6. Once the fiber is inserted, adjust the three fiber positioning knobs (x, y, and z) to couple the light to the fiber. The end of the fiber will light up when light is coupled to it. Once you have good coupling of light through the fiber, look at the light exiting the fiber. The output end should give a round/symmetric output if the cleave on the output end is good. If the light is not symmetric, the cleave at the output end of the fiber is bad and needs to be redone. I recommend leaving the fiber in the holder and cleaving it at your table. With light passing through the fiber, you can tell immediately if you have a good cleave.

7. After you confirm that the output end of your fiber has a good cleave, remove the fiber from the chuck and reverse ends. Repeat the above process for the other end.

Experiment
1. Adjust the fiber positioning knobs until the light coupled through the fiber is maximized. Measure the light exiting the fiber. Compare this value to the amount of light entering the fiber (the amount that passes through the microscope lens, as measured in the set-up). What percentage of the light is coupled through the fiber? This should be over 50%. Percentages of 75-80% are possible.

2. Describe the shape of the light exiting the fiber.

IV. Conclusion

Draw appropriate conclusions on multimode fiber optics. Was coupling the fiber to the laser as difficult as you expected?