Photonics laboratory
Physics 472
Spring 2024

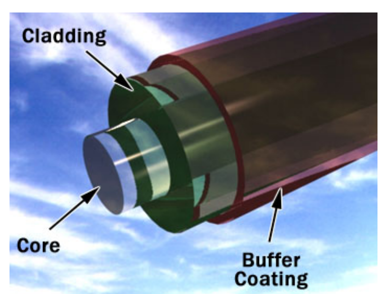
Experiment# 6 Preparing and inspecting optical fibers.

In this first project, you will learn how to prepare fiber ends for use in the laboratory and you will be able to observe the geometry of a fiber using a digital microscope. Using a translational stage and the microscope you will be able to measure the diameter of the fiber. In addition, you will use diffraction of light to measure the diameter of a fiber.

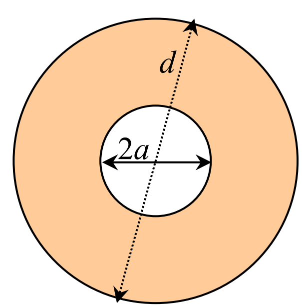
OPTICAL FIBER MATERIALS

The main force behind further activities in the development of fiber optics was in improving material quality of glass. High levels of purity were required of perform to address the enormous economic and technological potential of a worldwide communications network.
The material is usually glass, quartz or plastic. For special applications, other exotic materials such as liquid light guides, sapphire, fluoride or calcogenide may be used. There are some unavoidable requirements for good light transmission, such as pure glass materials for the core and cladding and high transparency for the spectrum of interest. Minimal optical dispersion (dependence on wavelength) is also desired. Process parameters such as glass transformation temperature, viscosity, inclusions and chemical affinity dictate the economics and quality of the fiber product.

FIBER GEOMETRY

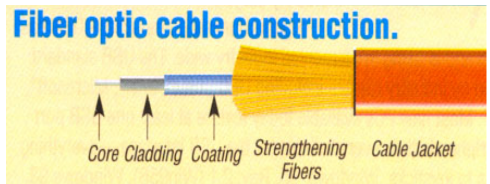


An optical fiber is illustrated in the Figure. It consists of a core (the light-carrying part), with refractive index n_{co} of circularly-symmetric cross section of radius a, and diameter $2a$, and a cladding, with refractive index n_{cl}, which surrounds the core and has an outer diameter of d. The surrounding cladding provides the difference in refractive index that allows total internal reflection of light through the core. The index of the cladding is less than 1% lower than that of the core. Typical values, for example, are a core index of 1.47 and a cladding index of 1.46. Fiber manufacturers must carefully control this difference to obtain desired fiber characteristics. Typical core diameters range from 4-8 μm for single-mode fibers to 50-100 μm for multimode fibers used for communications to 200-1000 μm for large-core fibers used in power transmission applications. (We will discuss these applications later). Communications-grade fibers will have d in the range of 125-140 μm, with some single-mode fibers as small as $80\ \mu m$.



In high-quality communications fibers, both the core and the 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 (losses) coefficients and are used only in applications requiring short lengths of fiber.

Surrounding the fiber will generally be a protective jacket (Buffer Coating). This 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. The coating has no optical properties affecting the propagation of light within the fiber. This coating, then, is a shock absorber.

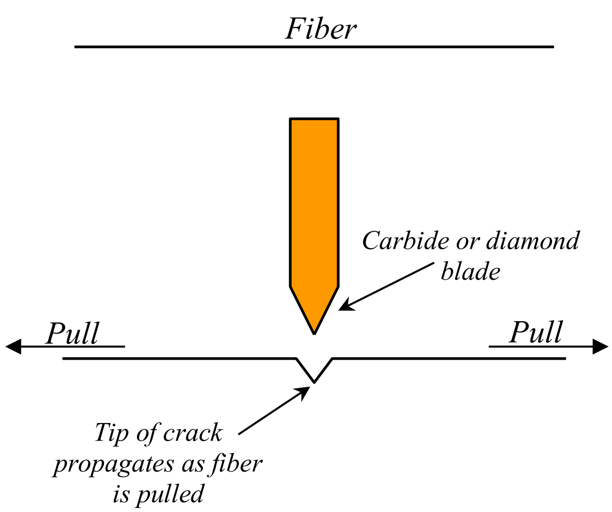


Fiber optic cables contain several fibers each of which consists of a core, cladding, buffer coating, strengthening fibers, and cable jacket.

To realize how small the fiber size, note that human hair has a diameter of about 65-100 μm. Fiber sizes are usually expressed by first giving the core size, followed by the cladding size: thus, 50/125 means a core diameter of 50 μm and a cladding diameter of 125 μm; 100/140 means a 100-μm core and a 140-μm cladding. Through these small sizes are sent thousands of telephone conversations.

FIBER PREPARATION

Before measuring the optical characteristics of a fiber, it will be necessary to prepare the ends of the fiber so that light can be efficiently coupled in and out of the fiber. This is done by using a scribe and-break technique to cleave the fiber. A carbide or diamond blade is used to start a small crack in the fiber, as illustrated in the figure below. Evenly applied stress, applied by pulling the fiber, causes the crack to propagate through the fiber and cleave it across a flat cross section of the fiber perpendicular to the fiber axis.

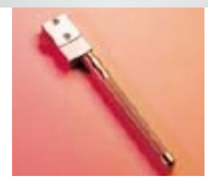


In theory, the breaking strength of glass fibers can be very large, up to about 725kpsi (where 1 kpsi = 1000 pounds/ sq. inch) or 5 GPa (where 1 Pa = 1 Newton/sq. meter and 1 GPa = 109 Pa). However, because of inhomogeneities and flaws, fibers do not exhibit strengths anywhere near that value. Before 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). When a crack is introduced, this is reduced even further in the neighborhood of the crack. 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.

MATERIAL AND EQUIPMENT REQUIRED

1. Sulfuric acid or methylene chloride for stripping fiber jacket. (Many commercially available paint thinners contain methylene chloride and work well for this purpose. Methylene chloride is toxic and can be absorbed through the skin. Any methylene chloride which gets on your skin should be immediately washed off.) Sulfuric acid is capable of burring your skin so be very careful.
2. Single or double-edge razor blades may also be used to strip fiber jackets.

3. Fiber coating stripper is the best way to remove the fiber buffer coating.
4. F-CLl Fiber Cleaver is a hand-held, low-cost device for cleaving any size glass fiber. It produces the mirror flat end faces required on optical fibers for efficient input/output coupling and low interconnection losses. It consists of a finely honed silicon carbide blade secured in a holding block at the end of a stainless-steel handle. An optically smooth fiber surface is obtained by the "scribe and break" method.



5. Fujikura is a high precession fiber cleaver. It is an excellent device that will enable you to cleave the fiber without much effort. No skills are required as in the case of the hand-held cleaver. I will give you instructions bout the usage of this device.

6. A microscope for viewing the cleaved ends of fibers is essential. We will use Intel Play digital microscope. Its maximum magnification is 200.

EXPERMENTS

Task#1: Fiber Preparation

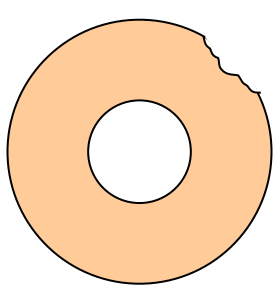
1. Remove - 1-1/2 inches of fiber jacket from a – 30 cm segment of F-MLD (100/140 µm) fiber, by dipping the fiber end in sulfuric acid and letting it soak for - 3 minutes. You could use a single-edge razor blade held at a low angle to do the stripping of the fiber jacket. This requires some practice, but goes much faster once you are used to it. Also, you could use the fiber coating stripper to remove the jacket. This will be the preferred method for the rest of the semester. But it is important that you become familiar and skilled with different methods of removing the fiber buffer coating. Therefore, you need to use the three methods mentioned above. Finally, clean the bare fiber surface with tissue paper dampened with alcohol.

2. Use the F-CLl Fiber Cleaver to cleave the stripped end of the fiber. The cleaver should be placed on the top of the table with the blade pointing up. Draw the fiber over the blade with a light motion. Be sure that the fiber is normal to the blade. You should not attempt to cut the fiber with the cleaver. You are only starting a small nick which will propagate through the fiber when you pull it. Gently, but firmly, pull the fiber to cleave it.

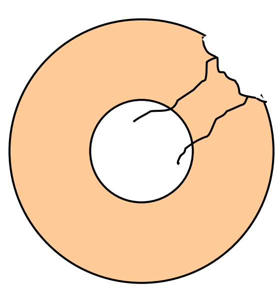
   Another way

   Tape the exposed fiber end onto a flat surface and apply tension by pulling on the fiber. While the fiber is still under tension, nick it with the cleaver gently and perpendicularly to the fiber axis. Do not saw back and forth or allow the fiber to rotate. The purpose is to scribe the fiber without breaking it in one single smooth stroke. Then, pull straight on the fiber with more tension until it snaps at the cleavage point. Now, examine the fiber end with a microscope or a magnifier. ***NOTE: The F-CL1 (Hand-held) Fiber Cleaver is highly dependent on your skill.***

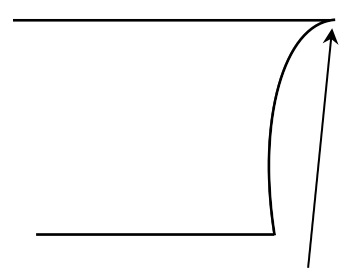
3. Check the quality of the cleave by examining it under a high-power microscope. Carefully examine the end face of the fiber. The end face should appear flat and should be free of defects. However, chips or cracks which appear near the periphery of the fiber are acceptable if they do not extend into the central region of the fiber. Some good and poorly cleaved fiber ends are illustrated below. The problems associated with the poor cleaves are discussed in Step 4.



Good cleave



Cracks running into the core (bad cleave)



Side view of a lip on the end of a fiber (bad cleave)

4. If the inspection of the fiber end face in Step 3 does not show that the end face has been properly cleaved, you should consider the following common sources of error: There are two principal reasons for obtaining a bad cleave.
   a) a poor scribe and
   b) a non-uniform pull of the fiber.

   A scribe which is too deep may cause an irregular cleave and may cause multiple cracks to propagate through the fiber (as shown above). A scribe which is too shallow will be the same as no scribe at all and the fiber will break randomly.

   If the pull which propagates the crack through the fiber is not uniform, and especially if it includes twisting of the fiber, irregularities may show up on the fiber end face or a lip may be formed on the end of the fiber, as shown above.

   If the fiber end is cleaved at an angle, the fiber was probably scribed at an angle other than 90° across the fiber axis, although this, too, can be caused by a non-uniform pull of the fiber.

5. Once you have a fiber segment with two well-cleaved ends, you may look at the geometry of the fiber, as it was described in the introduction. View a fiber end as you did in Step 3. Use an incandescent lamp or fluorescent light to illuminate the far end of the fiber. You will be able to see the light shining through the central portion of the fiber. This is the fiber core. The region surrounding the core is the fiber cladding. You will not be able to see the fiber jacket, because you have stripped that away from the end of the fiber.

Tak#2: Fiber Examination Using the Microscope

1. Place the fiber in the Fiber chuck then loaded to the fiber positioner.

2. Adjust the height of the fiber until you see a clear image while at 10X magnification. Increase the magnification to 60X and get a clear image. Then use the 200X to obtain the largest image.

3. Examine the quality of the cleave by rotating the fiber so you can see the different sides.

4. Use a flashlight or any reasonable source of light to help you determine whether the cleave is flat or not. ***How?***
5. Obtain several images of the fiber for different sides and include in your report.

Task#3: Fiber Diameter Using Translation Stage and the Microscope

While you have a clear image at the 200X use one of the markers on the computer screen as a reference. Use the micrometer on the translational stage to determine the diameter of the fiber before and after stripping. Report you results with diagrams.

Task#4: Fiber Diameter Using Diffraction

Determine the width of the Fiber with and without the Jacket. Tape the fiber across the front of the laser beam. From the diffraction pattern calculate the diameter of the fiber. You may need to place a stop at the center of the pattern to block the bright central spot and make the secondary ones clearly visible. The Diameter of the fiber D is relater to the wavelength of the laser by

$$\frac{D}{4}\sin(\theta) = m\lambda \qquad \text{for the } m^{\text{th}} \text{ minimum}$$

Find D using at least 4 different values of m.

Compare your results for the diameter with that of the manufacturer. Find the percent error. Determine the uncertainty in the fiber diameter using your data. Express you result for the diameter on the following form $D = \overline{D} \pm \Delta D$ where $\overline{D}$ is the average diameter and ΔD is the uncertainty in D. Compare you results to those of the previous method. Discuss any discrepancies. Which one of the methods is more accurate and why?