Chapter 5

Proper choice and proper utilization require a deep understanding of fiber construction and fiber characteristics.

We will pay particular attention to attenuation, modes, and information capacity. Construction and design of fibers and fiber cables are also discussed.

Types of fibers

1. ___ Step-index fiber

2. ___ Graded-index fiber

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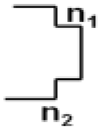
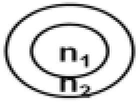
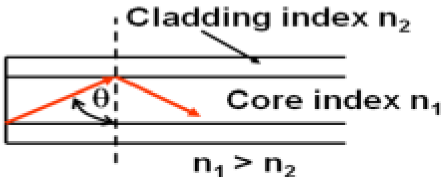
STEP-INDEX FIBER(SI)

consists of a central core whose refractive index is n_1, surrounded by a cladding whose refractive index is n_2.







sometimes referred to as the ***step-index matched-clad*** **fiber**.

As with the dielectric slab, complete guidance requires that the reflection angle θ be equal to or greater than the critical angle θ_C.

The critical angle for the SI fiber is given by

$$\sin\theta_c = \frac{n_2}{n_1}$$

The fractional refractive index change Δ is an important fiber parameter. It is given by

$$\Delta = \frac{n_1 - n_2}{n_1}$$

This parameter is always positive because n_1, must be larger than n_2 for a critical angle to exist. Typically, Δ is of the order of 0.01.

Efficient transmission requires that the core and cladding be as free of loss as possible. Although the ray diagram implies that the light travels entirely within the core, this is not precisely the case.

Step-index fibers have **three common forms**:

1. a **glass** core, cladded with a **glass** having a slightly lower refractive index;
2. a **silica glass** core, cladded with **plastic**;
3. and a **plastic core**, cladded with another **plastic**.

- Generally, the refractive-index step is smallest for **all-glass** fibers,
- a little larger for the **plastic-cladded silica** (PCS) fibers, and
- **largest** for the all-plastic construction referred as polymer optical fiber (POP).

The step sizes are due to the limited range of refractive indices available for glasses and the somewhat larger range for plastics.

As with the slab waveguide, modal distortion and numerical aperture increase with the refractive index difference, n1 — n2. Because of this, the intermodal pulse spread and NA are small for the all-glass fiber, larger for the PCS fiber, and highest for the all-plastic structure.

Fibers with little pulse spread have large rate-length products. The NA of these fibers is small, making it difficult to efficiently couple light into them.

The **attenuation** loss in an all-glass fiber is generally **lower** than in a PCS or an all-plastic fiber.

- All-glass losses of a few dB/km and less are available.
- PCS fibers have losses around 8 dB/km.
- All-plastic fibers may have losses of several hundred dB/km.

we can reach a **number of conclusions** regarding the performance and application of the three types of SI fibers

1) **All-glass** fibers have the **lowest losses** and the smallest intermodal **pulse spreading**. So, they are useful at moderately high information rates or fairly long lengths, **30 MHz x km** is an achievable rate-length product.

   The low NA results in large losses when **coupling** from a light source. The low transmission loss partially compensates this problem.

   Conventionally, the size of a fiber is core diameter/ cladding diameter (in micrometers). Typical dimensions of SI fibers are 50/125, 100/140, and 200/230.

2) Because PCS fibers have higher losses and larger pulse spreads than all-glass fibers, they are **suitable for shorter links**.

   Their higher NA increase the source coupling efficiency, but this advantage is lost in a long fiber owing to increased absorption.

suitable for path lengths are less than a few hundred meters. Core diameters of 200 μm are typical for PCS fibers. The large core diameter improves the source coupling efficiency.

3) **All-plastic fibers** are limited to very short paths by their high propagation losses. Path lengths are usually less than a few tens of meters.

   Large cores and large numerical apertures make plastic fibers usable because of the resulting high coupling efficiencies. Core diameters as large as 1 mm are typical.

All Glass

Lowest loss. Used for longest distances (up to about 100 km)

Glass/Plastic

Moderate loss. Moderate distances (up to about 100 m)

All Plastic

High loss. Short distances (up to about 10 m)

Numerical apertures, acceptance angles, and fractional refractive-index changes for fibers representative of all-glass, PCS, and all-plastic constructions are listed in Table 5-1.

$\alpha_o = 14°$

α_o is the half angle of the acceptance cone.

$2\alpha_o = 28°$

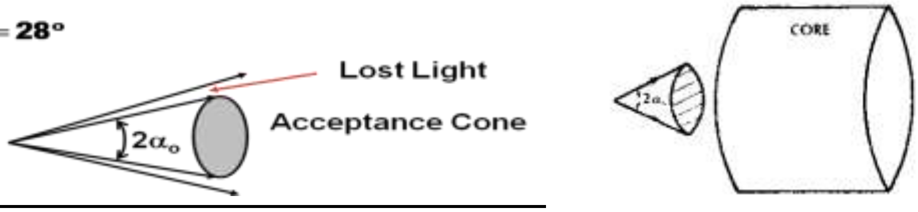


Fig 5-2 Acceptance cone for trapping of light by s step index fiber

TABLE 5-1. Typical Step-Index Fiber Characteristics

Construction	n_1	n_2	NA	α_0	Δ
All-glass	1.48	1.46	0.24	13.9°	0.0135
PCS	1.46	1.4	0.41	24.2°	0.041 -
All-plastic	1.49	1.41	0.48	29°	0.054

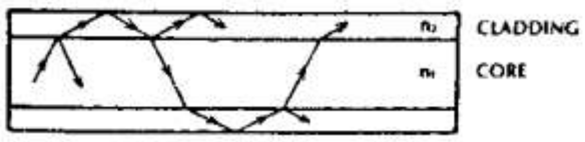
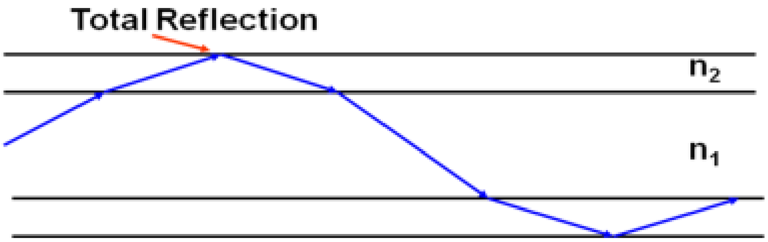


Figure 5-3 Ray paths of cladding modes. At the core-cladding interface there is partial reflection, accounting for the multiple ray paths.

Cladding modes may also be trapped in the fiber by total reflection at the outer boundary of the cladding



The cladding modes are lossy and do not travel far.

GRADED-INDEX FIBER

The *graded-index* (GRIN) fiber has a core material whose refractive index decreases **continuously** with distance from the fiber axis.

This structure, appears to be quite different from the SI fiber.

We will show how the GRIN fiber guides light by trapping rays, not unlike the operation of a SI waveguide.

The index variation is described by

$$n(r) = n_1 \sqrt{1 - 2\left(\frac{r}{a}\right)^{\alpha} \Delta}, \quad r \le a$$

$$n(r) = n_1 \sqrt{1 - 2\Delta} = n_2, \quad r \ge a$$

where

n_1 — refractive index along the fiber **axis**

n_2 — refractive index outside the core (**cladding index**)

a = core radius

α — parameter describing the refractive-index profile variation

Δ = parameter determining the scale of the profile change

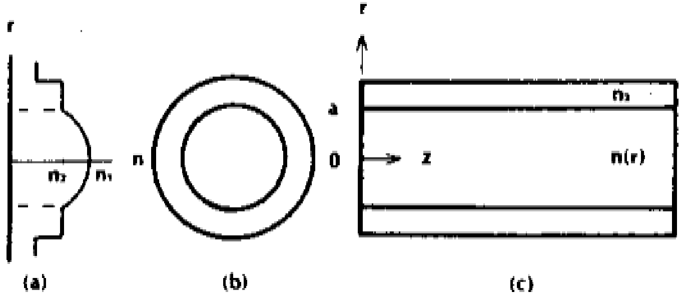
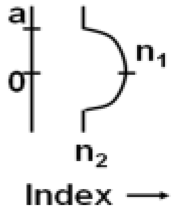
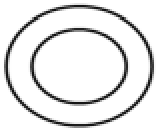


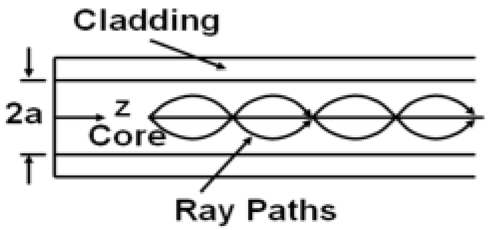
Figure 5-4 Graded-index fiber. (a) Refractive-index profile, (b) End view, (c) Cross-sectional view.



Refractive-index profile



End view



Cross-sectional view

Light rays travel through the fiber in the oscillatory fashion of Fig. 5-5.

The changing refractive index causes the rays to be continually redirected toward the fiber axis, and the particular variations cause them to be periodically refocused.

This model can be made as accurate as desired by increasing the number of steps.

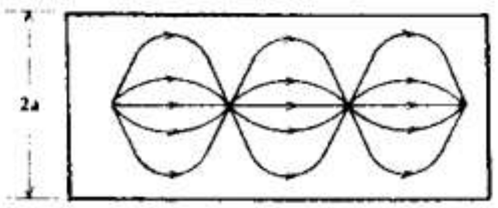


Figure 5-5 Ray paths along a GRIN fiber.

Many GRIN fibers resemble this step model because their cores are fabricated in layers.

The bending of the rays at each small step follows Snells law (Eq. (2-3)). As described in Section 2-1, rays are bent away from the normal when traveling from a high to a lower refractive index.

With this in mind, the ray trace in Fig. 5-6 becomes reasonable. A ray crossing the fiber axis strikes a series of boundaries, each time traveling into a region of lower refractive index, and thus bending farther toward the horizontal axis.

At one of the boundaries away from the axis, the ray angle exceeds the critical angle and is totally reflected back toward the fiber axis. Now the ray goes from low- to higher-index media, thus bending toward the normal until it crosses the fiber axis. At this point the procedure will repeat. In this manner, the fiber traps a ray, causing it to oscillate back and forth as it propagates down the fiber.

Rays crossing the axis nearly horizontally in Fig. 5-5 are turned back after traveling only a short distance away from the axis.

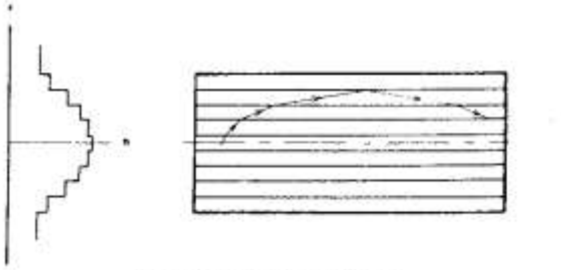


Figure 5-6 Step model of a GRIN fiber.

5-3 ATTENUATION

Signal attenuation is a major factor in the design of any communications system.

All receivers require that their input power be above some minimum level, so transmission losses limit the total length of the path.

There are several points in an optic system where losses occur.

- channel input coupler,
- splices, and
- connectors and
- within the fiber itself.

In this section we will study the losses associated with the fiber.

We need concern ourselves only with fiber losses in a range of wavelengths from about 0.5 to 1.6 μm. (most practical range)

As was mentioned earlier, fibers are made of plastics or glasses. Requirements for the material include low loss and the ability to be formed into long hair like fibers.

Additionally, the material must be capable of slight variations so that two refractive indices, one for the core and one for the cladding, can be obtained.

For a graded-index fiber a continuous variation in index must be possible. Step-index fibers can be made from plastic or glass. Graded-index fibers are normally glass, although graded-index plastic fibers have been developed. Glass fibers generally have lower absorption than plastic fibers, so they are preferred for long-distance communications.

Glass

The glass of most interest is that formed by fusing molecules of silica (silicon dioxide, SiO_2).

The resulting glass is not a compound but a mixture of SiO_2 molecules that have variations in molecular locations throughout the material.

This is quite unlike the structure of a crystal, in which the locations of the component atoms form fixed and repetitive patterns.

To obtain different refractive indices, other materials are added to the mixture. This **doping** is done with titanium, thallium, germanium, boron, and other materials.

The result is a high-silica-content glass, which can be formed into a low-loss fiber if high chemical purity is achieved.

The losses occurring in glass fibers can be classified as *absorption, scattering,* and *geometric effects.*

Absorption

Even the purest glass will absorb heavily within specific wavelength regions.

This is ***intrinsic absorption***, a natural property of the glass itself. Intrinsic absorption is very strong in the short-wavelength ultraviolet portion of the electromagnetic spectrum.

The absorption, owing to strong electronic and molecular transition bands, is characterized by peak loss in the ultraviolet and diminishing loss as the visible region is approached.

The ultraviolet is far removed from the region where fiber systems are operated, so this loss is unimportant. The tail end of UV absorption probably extends into the visible region but is generally considered to contribute very little loss at this point.

Ultraviolet absorption is indicated in Fig. 5-9. Intrinsic absorption peaks also occur in the infrared. The peaks are between 7 and 12 μm for typical glass compositions, far from the region of interest.

The infrared loss is associated with vibrations of chemical bonds such as the silicon-oxygen bond. Thermal energy causes the atoms to be moving constantly, so the SiO bond is continually stretching and contracting. This vibration has a resonant frequency in the infrared range.

As illustrated in Fig. 5-9, the edges of this absorption mechanism extend downward in wavelength toward the region where fiber systems operate.

They contribute a small loss at the upper limit of our range, 1.6 μm. In fact, they prohibit the use of silica fibers much beyond this wavelength.

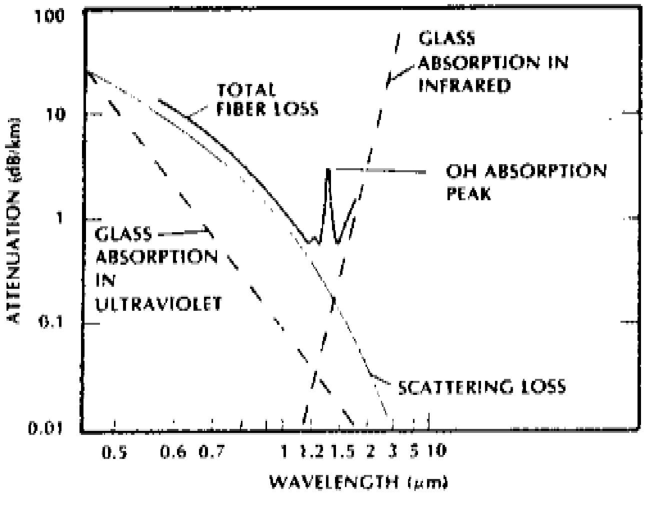


Figure 5-9 Attenuation of a germanium-doped silica glass fiber.

Rayleigh Scattering

Molecules move randomly through the glass in the molten state during manufacture. The heat applied provides the energy for the motion. As the liquid cools, the motion ceases. Upon reaching the solid state, the random molecular locations are frozen within the glass. This results in localized variations in density and, thus, local variations in refractive index throughout the glass.

These variations may be modeled as small scattering objects embedded in an otherwise homogeneous material. The size of these objects is much smaller than optic wavelengths.

A beam of light passing through such a structure will have some of its energy scattered by these objects, as illustrated in Fig. 5-10.

This type of loss is known as *Rayleigh scattering,* which applies whenever a wave travels through a medium having scattering objects smaller than a wavelength. Because Rayleigh scattering is proportional to λ^{-4}, it becomes increasingly important as the wavelength diminishes.

The scattering-loss dependence is indicated in Fig. 5-9.

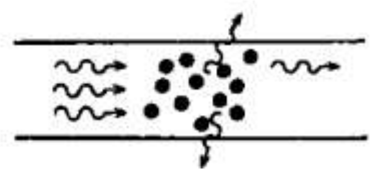


Figure 5-10 Rayleigh scattering, showing attenuation of an incident stream of photons owing to localized variations in refractive index.

The density and compositional losses just described are intrinsic losses. They cannot be removed by any processing techniques.

They can be removed only by actually changing the composition.

The scattering losses introduced by these **two phenomena** are considered to be a minimum below which a fiber cannot be manufactured for a given glass.

1) Inhomogeneities

Material inhomogeneities unintentionally introduced into the glass during manufacture also cause scattering losses. Imperfect mixing and dissolution of chemicals can cause inhomogeneities within the core.

These losses can be controlled by proper manufacturing techniques.

2) Geometric Effects

Bending a fiber causes attenuation. Two types of bends are *macroscopic* and *microscopic.*

Macroscopic refers to large-scale bending, such as that which occurs intentionally when wrapping the fiber on a spool or pulling it around a corner. As a practical example, 125-μ*m* diameter fibers can be bent with radii of curvature as small as 25 mm with negligible loss. Typically, breaking will not occur unless the bend radius is much smaller. For example, the fiber will not fracture unless the bend radius is less than 10 mm. This example illustrates the great flexibility of glass fibers, allowing them to be installed where frequent bending is required.

Figure 5-11 Radiation at a bend.

Loss is not the only adverse affect of bending. In addition, bending reduces the fiber's tensile strength. A fiber's strength depends on the microscopic flaws located on its surface. These flaws will grow over time if the fiber is subjected to stress (or moisture), weakening the fiber. Thus, the stress owing to bending may cause the early failure of a fiber. For commercial 125μm fibers, the minimum bend radius of 25 mm that assures negligible loss also ensures negligible strength loss.

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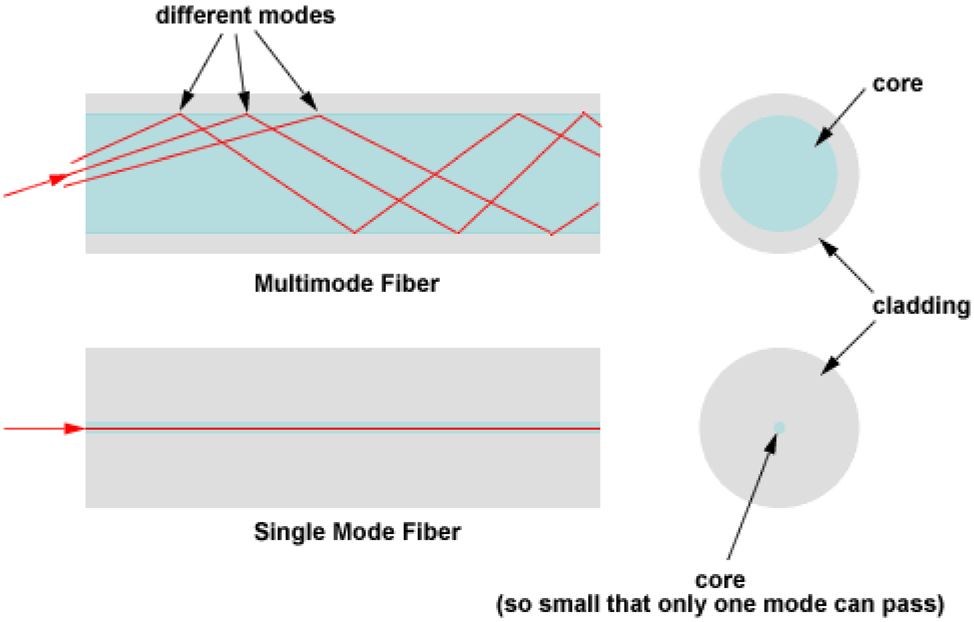
Optical Fiber Mode

What is Fiber Mode?

An optical fiber guides light waves in distinct patterns called *modes*. Mode describes the distribution of light energy across the fiber. The precise patterns depend on the wavelength of light transmitted and on the variation in refractive index that shapes the core. In essence, the variations in refractive index create boundary conditions that shape how light waves travel through the fiber, like the walls of a tunnel affect how sounds echo inside.

We can take a look at large-core step-index fibers. Light rays enter the fiber at a range of angles, and rays at different angles can all stably travel down the length of the fiber as long as they hit the core-cladding interface at an angle larger than critical angle. These rays are different modes.

Fibers that carry more than one mode at a specific light wavelength are called multimode fibers. Some fibers have very small diameter core that they can carry only one mode which travels as a straight line at the center of the core. These fibers are single mode fibers. This is illustrated in the following picture.



5-7 CONSTRUCTION OF OPTIC FIBERS

Fibers have been fabricated by a number of techniques.

- Two methods will be described for directly **producing fibers**
- Several methods for producing **preforms** than,
- Fibers are pulled from preforms in a separate procedure.

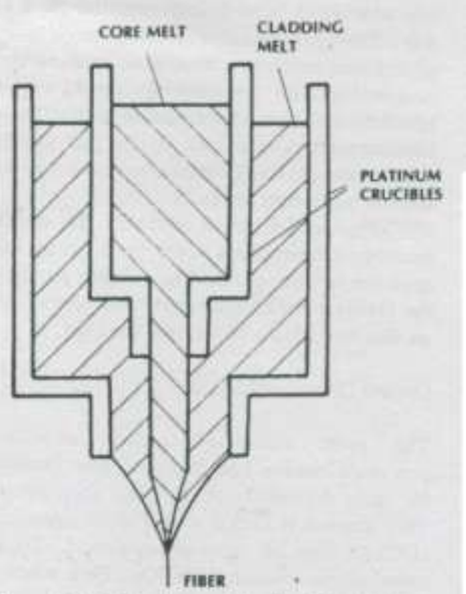


Figure 5-31 Double-crucible fiber fabrication process.

Double Crucible

The double-crucible **method** is illustrated in Fig. 5-31. Molten core glass is placed in the inner vessel and molten cladding glass occupies the outer vessel. The two glasses come together at the base of the outer container forming a glass-cladded core. This molten mixture is pulled into a fiber.

At first glance it would appear that the double-crucible technique could produce only step-index fibers. This is not true.

Graded fibers may be produced by allowing the core and cladding glasses to interdiffuse after they come together. Diffusion causes a gradual change of refractive index between that of the core and cladding glasses.

With some care, glass can be continually added to the crucibles, making it possible to obtain long continuous lengths of **fiber**

Rod In Tube

In the rod-in-tube **procedure** a rod of core glass is placed inside of a tube of cladding glass. Both rods are typically a meter long.

The diameter of the core rod may be a few centimeters and the inner diameter of the cladding rod just a bit larger.

The end of this combination is heated, softening the glass so that a thin fiber can be pulled from it.

Great care must be taken to ensure that contaminants do not enter the empty region between the core and cladding rods.

This technique is probably the easiest method of fabricating fibers for a group that does not produce glass. They simply purchase the highly purified glass rods and tubes from another manufacturer and **pull the fiber**.

Doped Deposited Silica

The most extensively used fabrication processes involve building up a **fiber preform** by **vapor deposition** of the glass constituents.

This process is called *doped deposited silica* (DOS), *chemical vapor deposition* (CVD). or *vapor-phase oxidation* (VPO).

Pure silica is used as a base, and small amounts of dopants (such as GeO_2, B_2,O_3 and P_2O_5 are added to produce the slight changes in refractive index that are required.

As noted in Section 5-3, germanium doping of the core increases its refractive index beyond that of the cladding as required for total internal reflection. The resulting cylindrical preform has the desired refractive-index variation, but its cross-sectional area is many times that of the finished fiber.

A representative preform has a 1-m length and a 2-cm diameter. This diameter is 160 times that of a fiber having a 125-µm cladding diameter.

Continuous fibers of several kilometers can be drawn from preforms of this size.

We will describe **three DOS processes**:

- external deposition,
- axial deposition, and
- internal deposition.

External Deposition

External deposition by flame hydrolysis, illustrated in Fig. 5-32, is referred to as *external chemical vapor deposition* (external CVD), *outside vapor-phase oxidation* (OVPO). *outside vapor deposition* (OVD), and probably by other names as well.

The material vapors are oxidized in a flame. The torch moves laterally, depositing the glass particles onto a rotating bait or mandrel.

The deposition forms a powder or *soot* on the mandrel.

After deposition has been completed, the material is sintered and the bait is removed.

The resulting tube is then thermally collapsed (by heating to temperatures high enough to soften it), creating a solid preform.

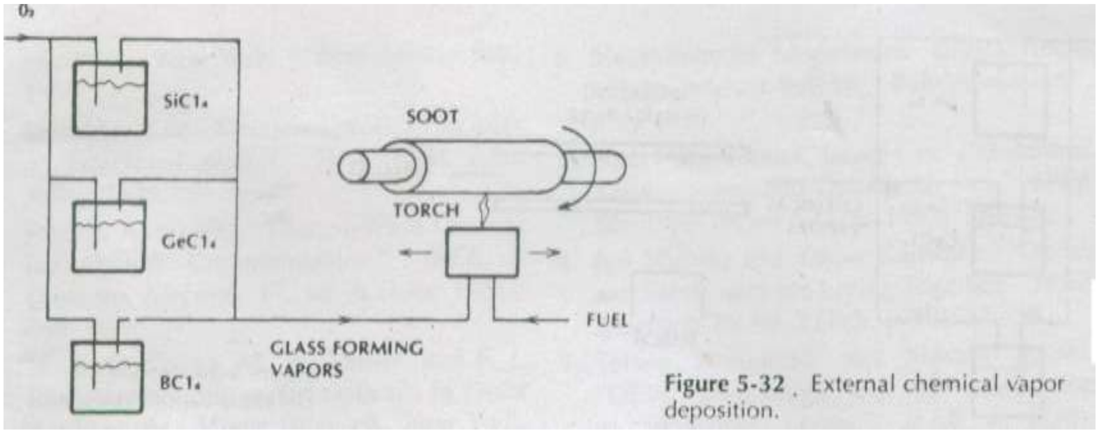


Figure 5-32 . External chemical vapor deposition.

Axial Deposition

Axial deposition is illustrated in Fig. 5-33. This process, known as *axial vapor deposition* (AVD) or *vapor axial deposition (*VAD), is another form of external deposition.

In this case, the deposition occurs on the end of the rotating bait, which is withdrawn as the preform builds up.

A very long core preform can be constructed in this manner. The cladding can be deposited on the core by flame hydrolysis.

Alternatively, a cladded fiber can be constructed by inserting the core preform inside a lower-refractive-index glass tube and pulling the fiber from the tube. This is the *rod-in-tube* configuration.

The VAD process produces both SI and GRIN fibers. GRIN fibers result when the deposited particle density varies owing to temperature gradients in the plane perpendicular to the core axis.

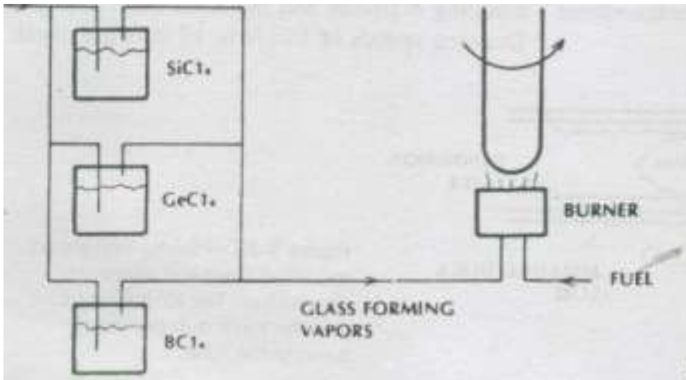


Figure 5-33 Axial vapor deposition

Internal Deposition

Internal deposition[25] is illustrated in Fig. 5-34. Its various aliases are *internal chemical vapor deposition* (internal CVD), *modified chemical vapor deposition* (MCVD), and *inside vapor deposition* (IVD).

In this process the chemical vapors are deposited on the **inside** of a glass tube that is rotating in a glass lathe.

A traveling oxyhydrogen torch moves along the tube, fusing the deposited material to form a transparent glassy film.

Layer upon layer is deposited as the torch repeatedly traverses the length of the tube.

Typically, 30-100 layers are deposited. By changing the concentration of dopants, the refractive index can be changed from layer to layer, creating a graded-index profile. Very fine control of the profile can be obtained by this technique.

Deposition is completed before the tube closes. The tube is thermally collapsed into a solid preform before the fiber is drawn.

Increased fabrication rates can be obtained by the ***plasma-enhanced*** **MCVD process (PCVD)**, shown in Fig. 5-35.

The plasma, a region of electrically heated ionized gases, increases the chemical reaction rates within the tube.

The deposition proceeds more quickly than with conventional **MCVD**.

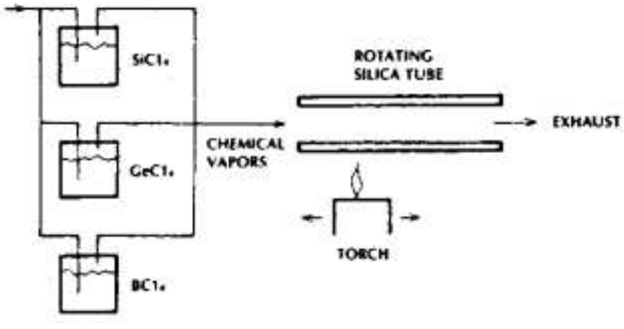


Figure 5-34 Modified chemical vapor deposition.

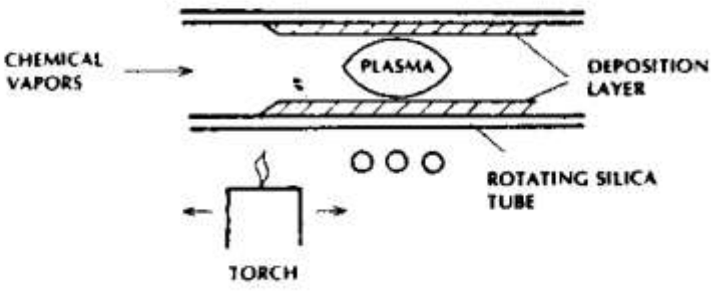


Figure 5-35 Plasma-enhanced modified chemical vapor deposition. The RF heating coil and the torch independently traverse the tube.

Fiber Drawing

Preforms are drawn into fibers by structures like that shown in Fig. 5-36.

The preform is attached to a **precision feed** that moves it into the **furnace** at the proper speed.

The **drawing process** is designed to produce fibers with as little variance in diameter to minimize fiber attenuation and improves strength.

Precise **diameter control** is also needed to make fibers compatible with precision connectors designed for low connection loss. Diameter is continually monitored by device like laser micrometer.

Primary coating is applied to the fiber immediately after it has been drawn and measured.

The coating is a buffer needed to protect the fiber from moisture and abrasion, which would seriously weaken the fiber.

Appropriate coating materials are Kynar, epoxy, silicone RTV, and UV-cured resin.

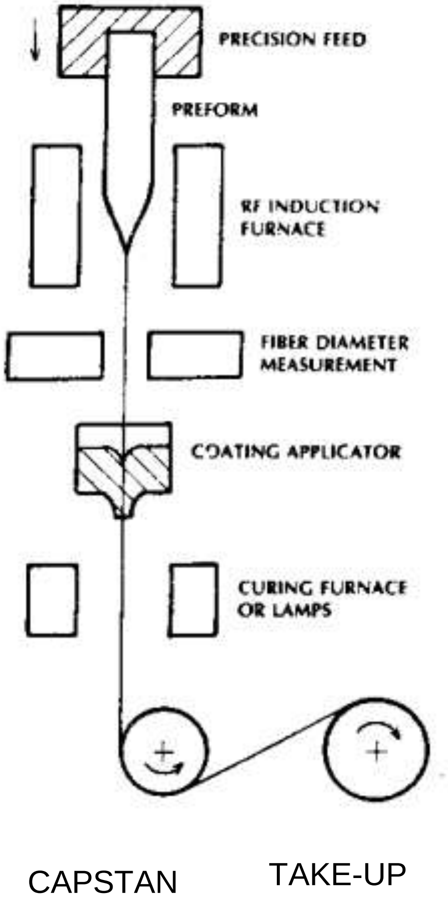


Figure 5-36 Fiber drawing and coating system.

A **secondary buffer** coating is often applied during the drawing process to improve cushioning, increasing the fiber's crush resistance.

All production fibers are proof-tested to meet minimum tensile-strength requirements.

The test is performed as part of the drawing process after the coating has been applied or as an independent procedure following the pulling procedure.

For economic reasons, a fast pulling rate is desirable. The speed is limited by the need to maintain the precision of the fiber cladding diameter and maintain fiber strength. Drawing speeds of 1 m/s to 10 m/s are usual.

Preforms typically have diameters of 1-6 cm in diameter and lengths of 1-2 m. When drawn into 125-µm outer cladding diameters, they produce fiber lengths from 15 km to over 100km.

TABLE 5-3. Graded-index Multimode Fibers

Core Diameter (μm)	Cladding Diameter (μm)	Axial Numerical Aperture
50	125	0.2
62.5	125	0.275
85	125	0.26
100	140	0.29

Plastic-Gladded Silica

Plastic-cladded Silica (PCS) fibers can be made by drawing a pure silica preform in the manner shown in Fig. 5-36. The coating applicator, noted in the figure, contains the plastic cladding material.

5-8 OPTIC FIBER CABLES

The amount of protection a fiber needs varies from one application to another. In a laboratory setting, a fiber protected by a thin buffer coating might be quite serviceable, while a **transoceanic** fiber would need considerable protection during transportation, installation, and operation.

A variety of cable designs have been implemented to meet the requirements of different fiber applications.

Cabling should improve the mechanical characteristics of a fiber without causing a deterioration of its optic properties.

The types of strengthening and protection needed follow:

1. **Tensile strength.**

   High tensile strength is required when a cable is installed by **pulling** it through a duct.

   Tensile members must support the **weight of the cable** when it is hung in a vertical duct, when it is suspended between poles, & or under the ocean.

2. **Crush resistance.**

   Cables are often subjected to large lateral forces, which can crush a glass fiber. Some cabled fibers must survive being stepped on or being run over by large vehicles.

3. **Protection from excess bending.**

   Sharp bends produce two problems:

   - Radiation loss at the bend and
   - Possible breaks in the fiber.

   A good cable will be stiff enough to prevent excessive bending but flexible enough for easy handling and installation.

4. **Abrasion protection.**

   Glass fibers will deteriorate severely if they suffer abrasions. Small defects caused by abrasions increase losses significantly.

5. **Vibration isolation.**

   Vibration will increase fiber losses. Cables are designed to cushion the fiber, damping out excessive motion.

6. **Moisture & chemical protection.**

   Moisture & chemicals degrade glass fibers after prolonged exposure. Some cables guard the fiber against contact with these contaminants.

In addition to being strong and chemical resistant, good fiber cables are light, small, flexible, flame retardant, rodent resistant, and temperature insensitive.

Several **general structural forms** that produce adequate cables have evolved.

Single-fiber cables and **multi-fiber** cables

1. **Tightly** packed fibers (referred to as *tight buffer)* and **loosely** held fibers (called *loose-tube* buffer)
2. **Centralized** strengthening members and **externally** located strengthening members
3. **Dielectric** strengthening members and **metallic** strengthening members
4. **Circular** geometries and **ribbon** geometries

We will now discuss these **options**.

single-fiber cable vs **multi-fiber cable**

If only one fiber is required, then a **single-fiber cable** is certainly the best choice. In some instances, future needs might be economically accommodated by installing a **multi-fiber cable**.

Unused fibers can be used later. The cost of transporting and installing a multi-fiber cable is not much more than that for a single-fiber cable.

A multi-fiber cable makes better use of space than does a single-fiber cable because the fibers share common strengthening members.

As the number of fibers in a cable increases, the cost per fiber decreases.

Multi-fiber cables are ideal for trunk transmission links in which many messages travel the same route.

Simple two-fiber cables are designed for **duplex communications** systems.

loose buffer vs tight buffer

The **buffered fiber** may be completely enclosed in a cushioning material as the next step in the cabling process.

This is the ***tight-buffer*** construction. Soft plastic can be used for the coating. The cushioning helps minimize micro-bending and provides crush resistance and vibration isolation but adds little to the cable's tensile strength.

An alternative to the tight-buffer cushioning is illustrated in Fig. 5-37, where the fiber lies loosely inside a surrounding plastic tube. This is the ***loose-tube* construction**.

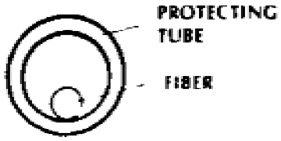


Fig 5-37 loose-tube construction

Moisture protection can be added by placing a **foam or jelly** inside the tube. In another form of the loose construction, the fiber lies in a large slot provided in a **central strengthening member**, as shown in Fig. 5-38.

In the figure, four fibers arc accommodated. Tape surrounds the slotted core, keeping the fibers in their grooves.

The fibers can freely slide within the slots when the cable itself is pulled, twisted, or bent. Cables with loosely held fibers are normally larger than those with tightly held fibers.

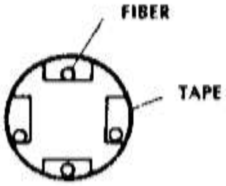
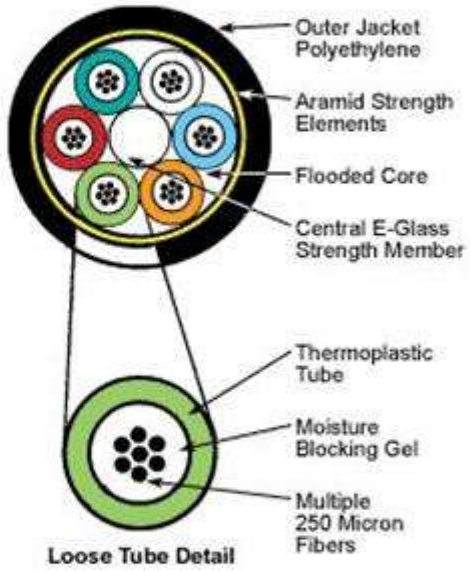


Fig 5-38 loose-fiber, slotted construction



When there will be multiple fibers in a cable, it is **necessary to color** each fiber so that the fibers can be identified separately.

Strengthening members are added to fiber cables to help fibers withstand pulling, shearing, and bending.

Steel wires and textile fibers are the most popular materials .The strengthening materials should be strong and light. Steel is strong but heavier than the textile fibers.

Steel is found in some commercial cables. The **textile fiber Kevlar**, a very strong polymer, is one of the most frequently used strengthening materials. Its effective strength-to-weight ratio is almost four times that of steel. It is commonly applied in filaments that are twisted and stranded around a buffered and cushioned fiber. It can also be braided around a tube in the loose-tube construction. Keviar significantly increases the tensile strength of the fiber cable.

A light-duty cable can be completed by surrounding the Kevlar braiding with an outer jacket. The jacket provides cut and abrasion resistance. Materials such as polyurethane, polyethylene, poly vinyl chloride (PVC), and Hytrel have been successfully employed in commercial cables.

A representative light-duly cable is sketched in Fig. 5-39. This cable weighs **12.5 kg/km** and can be safely bent to a radius of 5 cm. It contains a single, tightly packed fiber and an external strengthening member. The term *external* means other than at the center of the cable. The cable shown in the figure can withstand a tensile load of 400 N during installation and can be loaded up to 50 N in operation.

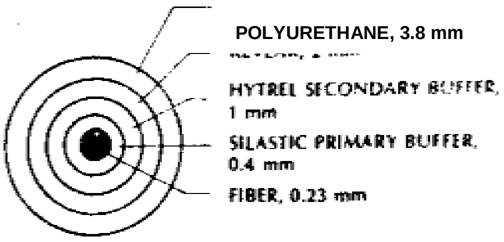
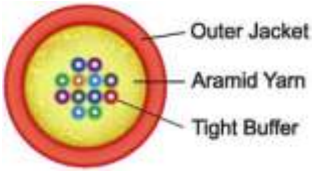


Fig 5-38 Light-duty, tight-buffer fiber cable



The **tensile strength of a cable** is the axial force it can tolerate. In commercial literature, this force may be given in any of three units: Newton’s, kilograms, or pounds. Force and mass are related by Newton's second law:

$$F = ma \qquad (5\text{-}23)$$

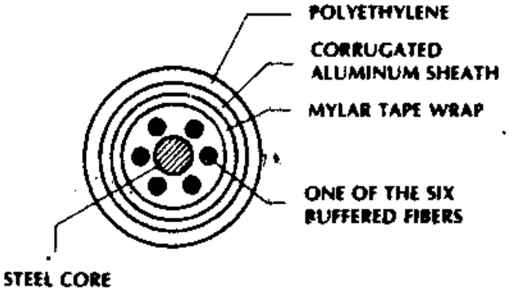


Figure 5-40 Multifiber cable having a centralized strengthening member and an armored sheath (Valtec Corporation).

Our next cable, in Fig. 5-40, contains **six fibers** and has a **centralized steel** strengthening member. The steel core provides a breaking strength of nearly **5000 N**. The fibers are individually buffered and strengthened. A corrugated aluminum sheath provides resistance to crushing forces and to water seepage. This cable has an outer diameter of 16,5 mm and weighs 185 kg/km.

It is possible to include insulated copper conductors (for electrical transmission) in the space between the fibers and within the Mylar wrapping. The conductors may be used for low-rate signaling or for transmitting power to a distant location, as be required for a remote repeater. The very strong cable can be placed in service *by* conventional pulling equipment designed for installation of metal transmission lines.

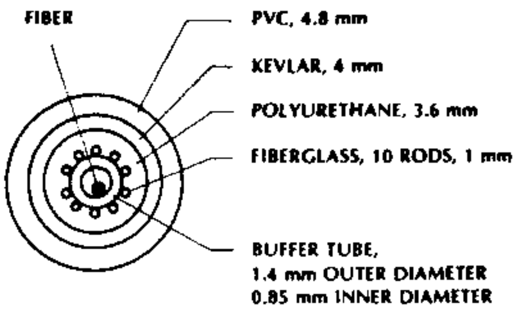


Figure 5-41 Loose-tube cable (Siecor Corporation). The dimensions given are the diameters. The coated fiber has a 0.153-mm diameter.

In Fig. 5-41 we show an example of the loose-tube construction. The strength is provided by 10 fiberglass rods that are embedded in polyurethane.

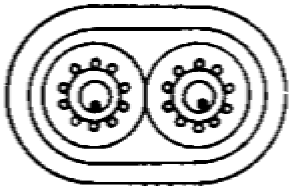


Fig 5-42 Loose tube two fiber version of the cable in Fig 5-41

The next cable we wish to show demonstrates the **ribbon construction**. It is drawn in Fig. 5-43. This cable was developed for **the telephone system**, in which large numbers of channels need to be transmitted along a common path between interchanges.

There are up to 12 fibers in each thin ribbon. In one version the fibers are individually buffered with polymer coating and then placed in a flat array and held in position by sandwiching between a top and bottom layer of adhesive-backed tape. The fibers are color coded for identification.

Up to 12 of the ribbons are stacked as indicated in the figure, producing a rectangular structure containing 144 fibers. A total of 28 external steel-strengthening members are embedded in the surrounding polyethylene sheath. This sturdy cable makes very efficient use of the space it occupies, packing 144 fibers within a diameter of 12 mm.

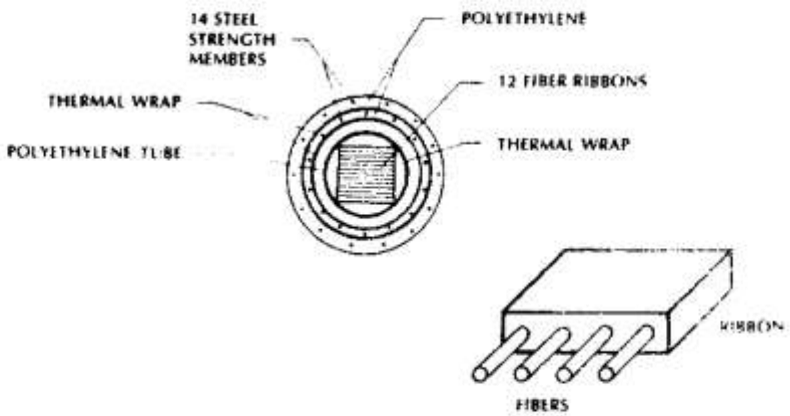


Fig 5-43 144 fiber ribbon cable. The outer diameter is 12mm. The ribbon is constructed by sandwiching up to 12 buffered fibers between two adhesive-backed polyester tapes.

In another form of ribbon, 12 fibers are bonded together with a UV-curable matrix material. Up to 18 of these ribbons are stacked in an arrangement similar to that shown in Fig. 5-43, allowing a total of 216 fibers. The ribbons can be sheathed with a variety of protective materials, depending upon the application,

A particularly interesting application of fibers has occurred in the utilities industry. The utilities have constructed telecommunications networks using existing and newly installed overhead transmission and distribution facilities. For new installations the fiber is embedded in the overhead power ground wire (OPGW) cable as illustrated in Fig. 5-44. For existing installations, a fiber cable can be lashed to the previously installed overhead ground wire. The fiber's immunity to electromagnetic interference makes it suitable for communications in the noisy environment surrounding power transmission lines.

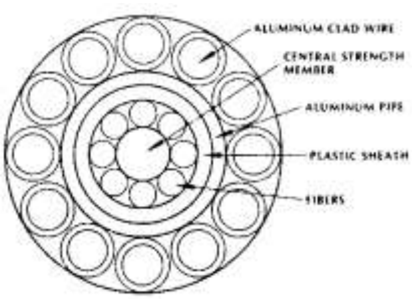


Fig 5-44 Fiber optic overhead power ground wire

The final cable to be discussed illustrates one developed for an extremely harsh environment, the ocean floor. As indicated in Fig. 5-45, the cable contains six fibers. They are embedded in an elastomer, which cushions them and minimizes micro-bending losses. The fibers are helically wound around the central steel wire. The combination of elastomer cushioning and the helical winding approximates the protective effects of the loose-tube construction. Numerous steel strands provide cable strength. Electrical power is needed to supply regenerators for long under-sea links. This power is carried by the copper conductor shown on the figure. The copper cylinder also serves as a water and hydrogen diffusion barrier. The outer diameter of this cable is only 21 mm.

In the many years since fibers were first proven to be practical, numerous cables have been developed for various fiber applications. This development continues as new applications and environments emerge. We have illustrated only a small percentage of the cables available. However, the illustrations do point out most of the general features to be found in all useful cable designs.

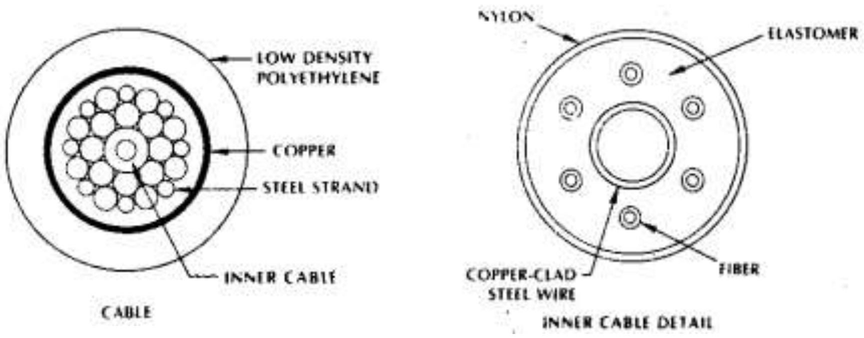
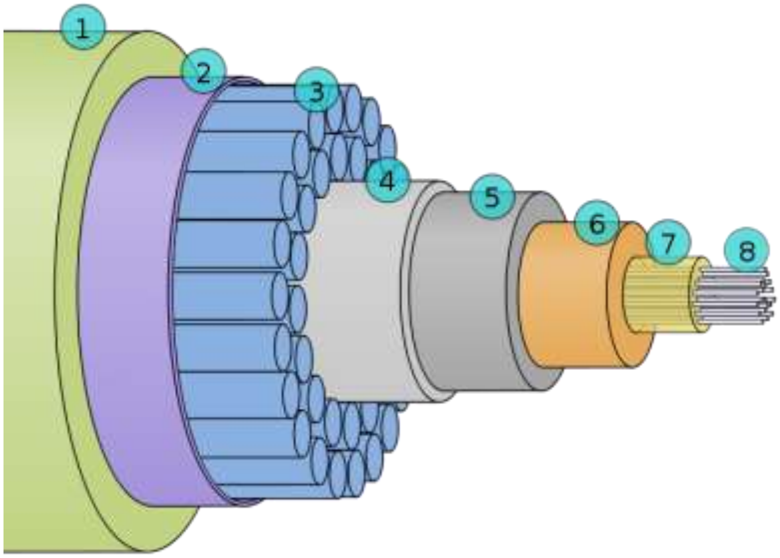


Fig 5-45 Undersea fiber cable.



http://www.cooper.edu/engineering/projects/gateway/ee/solidmat/modlec5/modlec5.html