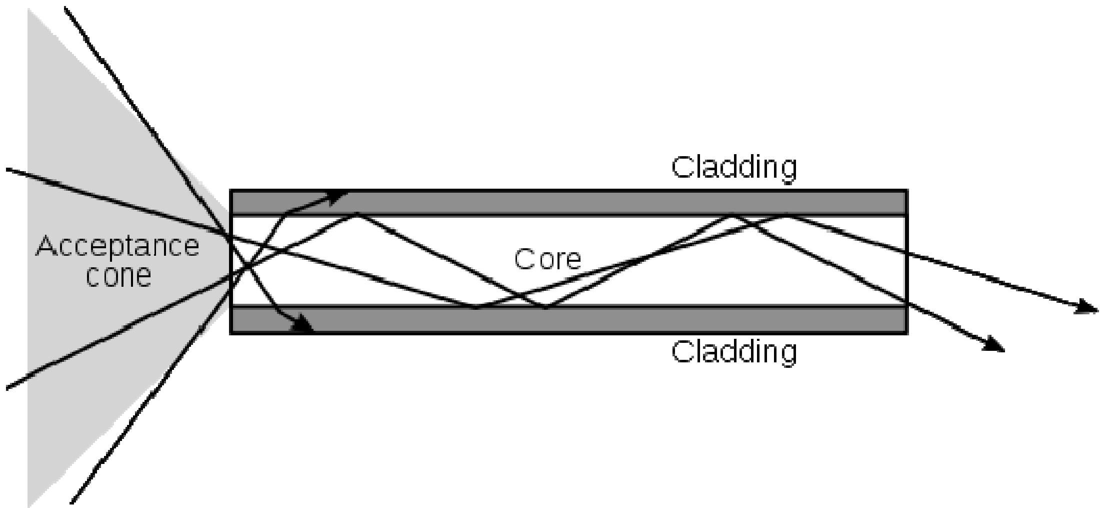
Fiber Optics

<u>Book:</u>

Optical Communication Sytems by John Gowar
Optical Fiber Communication by Gerd Keiser
Optical Fiber Communications by John M. Senior
Optical Fiber Communications by Selvarajan and Kar
Introduction to Fiber Optics by Ghatak and Thyagrajan
Optoelectronics by Wilson and Hawkes
Introduction to Optical Electronics by Keneth E Jones
Fiber Optic Communication Technology by Djafer K Mynbaev and Lowell L Scheiner



TAT-8 (Eighth Trans Atlantic under sea fiber optics Link between New Jersy (USA) to France (Europe)

TAT-7 link Predecessor of TAT-8 based on metal cables carried 5000 voice channels whereas TAT-8 carried 37800 channels.

An **optical fiber** (or **fibre**) is a glass or plastic fiber that carries light along its length.

An optical fiber is a cylindrical dielectric waveguide (nonconducting waveguide) that transmits light along its axis, by the process of total internal reflection. The fiber consists of a *core* surrounded by a cladding layer, both of which are made of dielectric materials. To confine the optical signal in the core, the refractive index of the core must be greater than that of the cladding. The boundary between the core and cladding may either be abrupt, in *step-index fiber*, or gradual, in *graded-index fiber*.

Total internal reflection

When light traveling in a dense medium hits a boundary at a steep angle (larger than the "critical angle" for the boundary), the light will be completely reflected. This effect is used in optical fibers to confine light in the core. Light travels along the fiber bouncing back and forth off of the boundary.

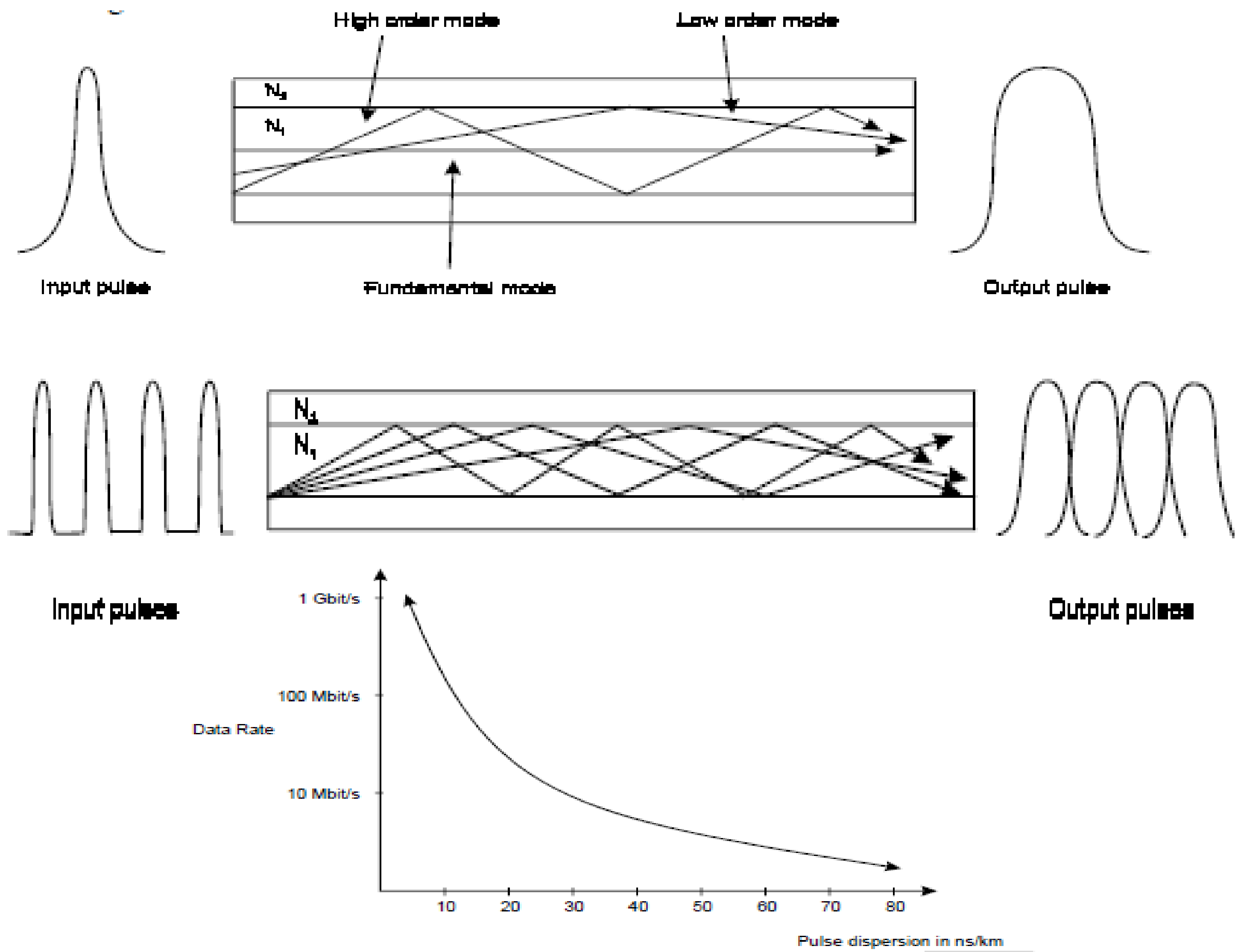
Because the light must strike the boundary with an angle greater than the critical angle, only light that enters the fiber within a certain range of angles can travel down the fiber without leaking out.

This range of angles is called the acceptance cone of the fiber. The size of this acceptance cone is a function of the refractive index difference between the fiber's core and cladding.

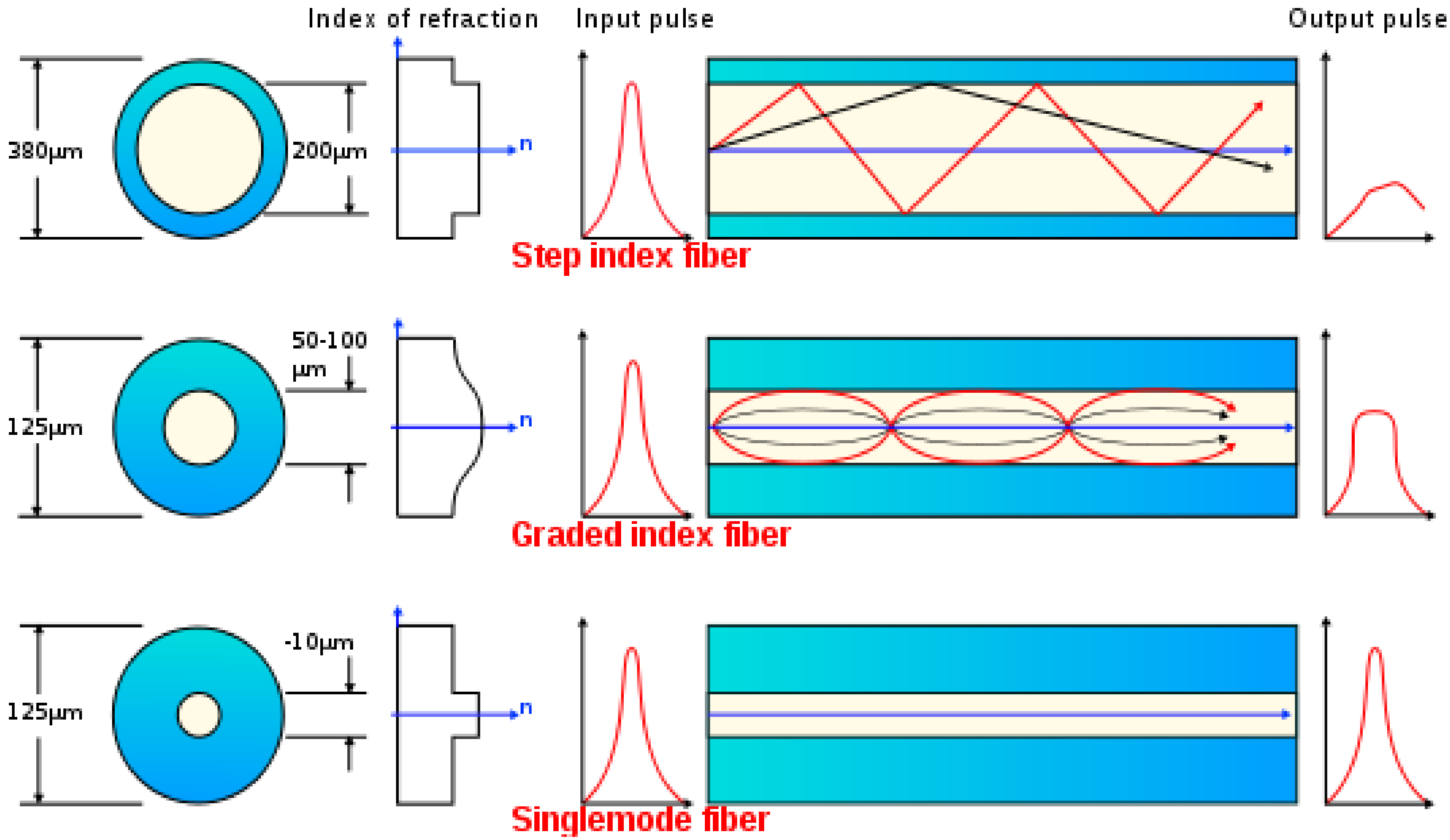
In simpler terms, there is a maximum angle from the fiber axis at which light may enter the fiber so that it will propagate, or travel, in the core of the fiber.
The sine of this maximum angle is the numerical aperture (NA) of the fiber.

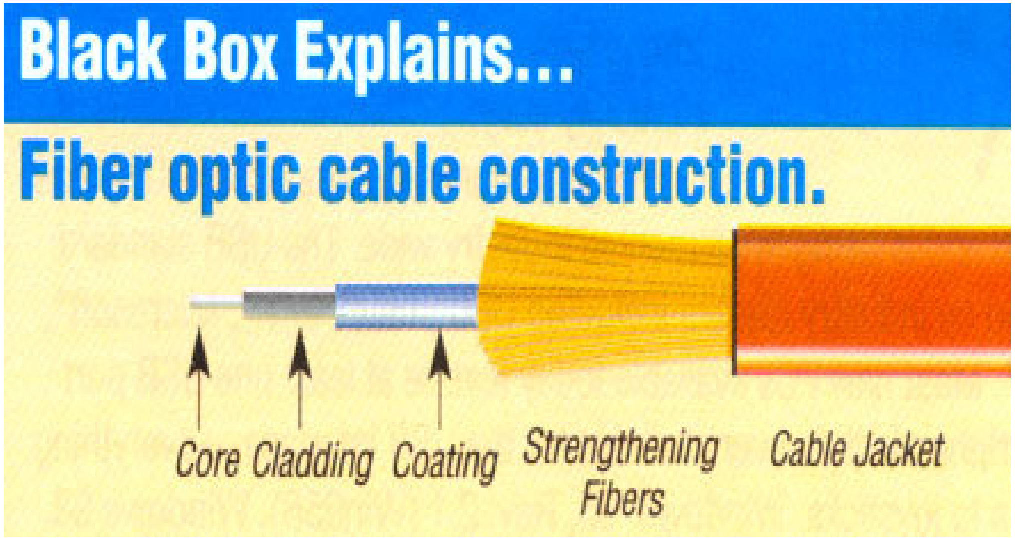
Fiber with a larger NA requires less precision to splice and work with than fiber with a smaller NA. Single-mode fiber has a small NA.

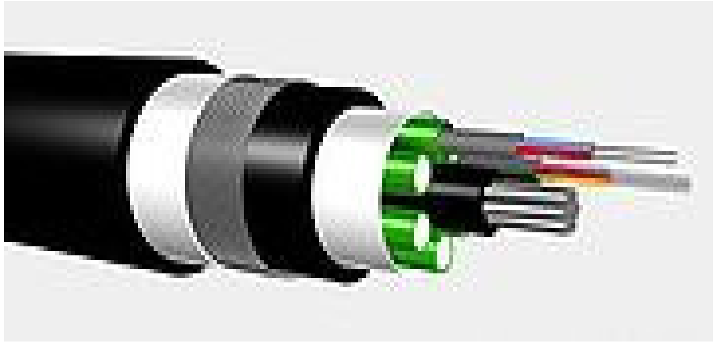
Modal Dispersion

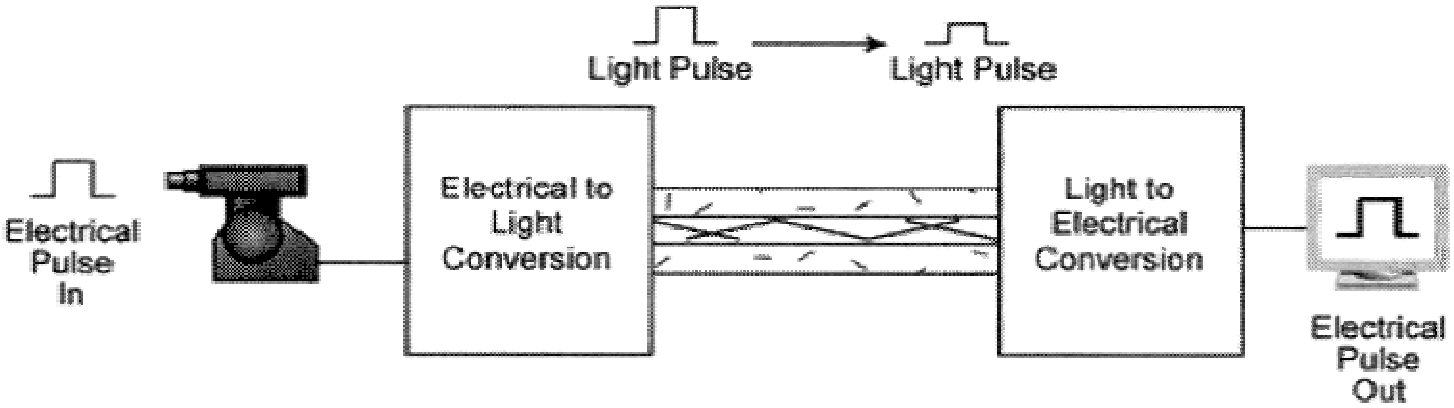


Fiber Types


Index of refraction
Input pulse
Output pulse
380µm
200µm
n
Step index fiber
50-100
µm
125µm
n
Graded index fiber
-10µm
125µm
n
Singlemode fiber

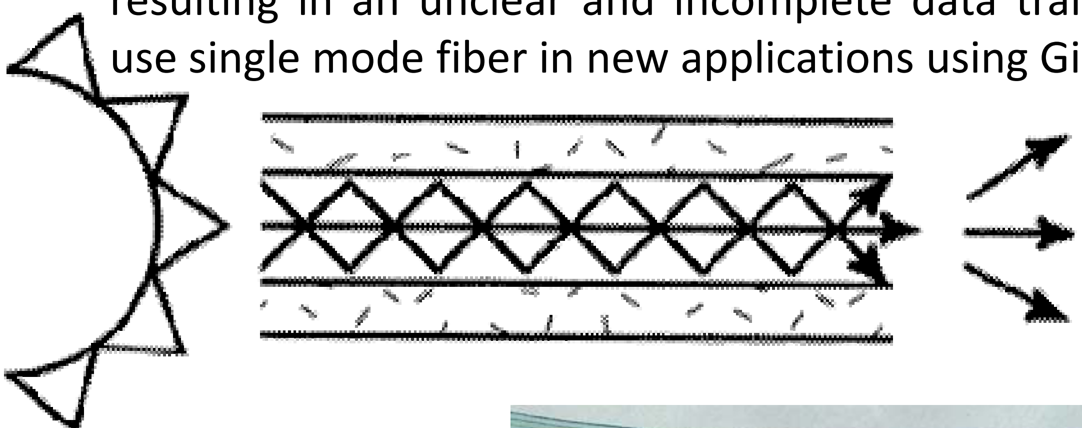

Black Box Explains...
Fiber optic cable construction.
Core
Cladding
Coating
Strengthening Fibers
Cable Jacket

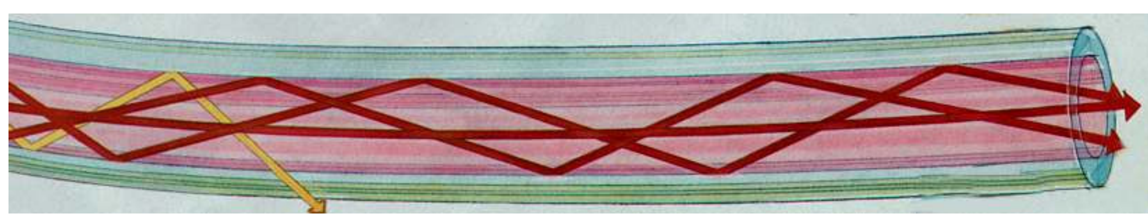



Light Pulse
Light Pulse
Electrical Pulse In
Electrical to Light Conversion
Light to Electrical Conversion
Electrical Pulse Out

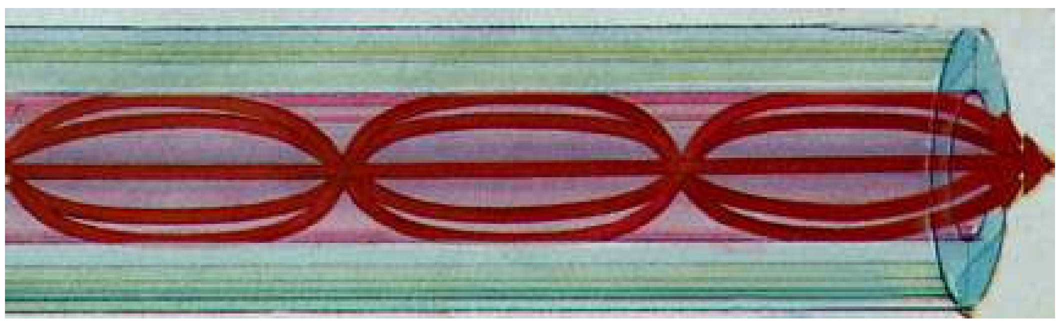
Step Index Multi-Mode cable has a little bit bigger diameter, with a common diameters in the 50-to-100 micron range for the light carry component (the most common size is 62.5um). POF is a newer plastic-based cable which promises performance similar to glass cable on very short runs, but at a lower cost. Multimode fiber gives high bandwidth at high speeds (10 to 100MBS - Gigabit to 275m to 2km) over medium distances.

Light waves are dispersed into numerous paths, or modes, as they travel through the cable's core typically 850 or 1300nm. Typical multimode fiber core diameters are 50, 62.5, and 100 micrometers. However, over long runs multiple paths of light can cause signal distortion at the receiving end, resulting in an unclear and incomplete data transmission so designers now use single mode fiber in new applications using Gigabit and beyond.



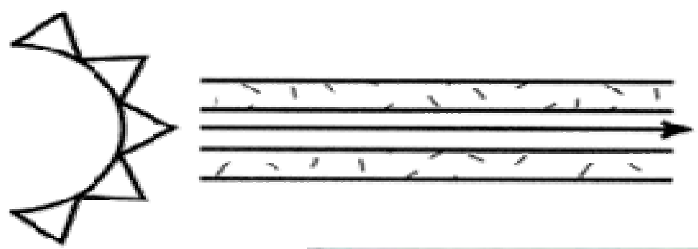


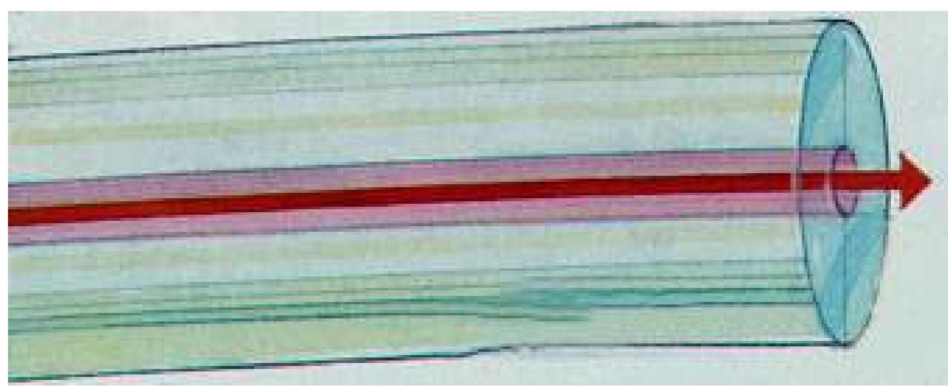
GRADED-INDEX MULTIMODE FIBER contains a core in which the refractive index diminishes gradually from the center axis out toward the cladding. The higher refractive index at the center makes the light rays moving down the axis advance more slowly than those near the cladding. Also, rather than zigzagging off the cladding, light in the core curves helically because of the graded index, reducing its travel distance. The shortened path and the higher speed allow light at the periphery to arrive at a receiver at about the same time as the slow but straight rays in the core axis. The result: a digital pulse suffers less dispersion.



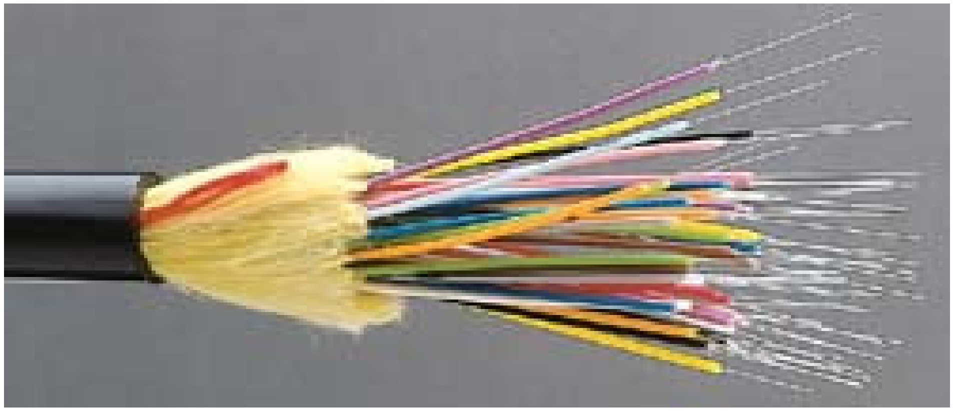
SINGLE-MODE FIBER has a narrow core (8-10 microns), and the index of refraction between the core and the cladding changes less than it does for multimode fibers. Light thus travels parallel to the axis, creating little pulse dispersion. It is a relatively narrow diameter, through which only one mode propagate typically 1310 or 1550nm. Synonyms mono-mode optical fiber, single-mode fiber, single-mode optical waveguide, uni-mode fiber.

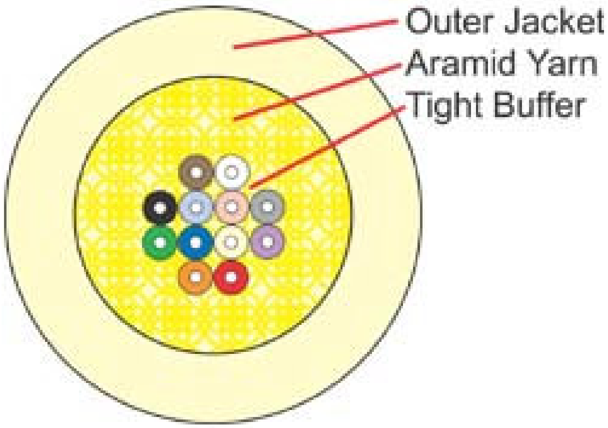
"Single mode fiber"
single path through the fiber



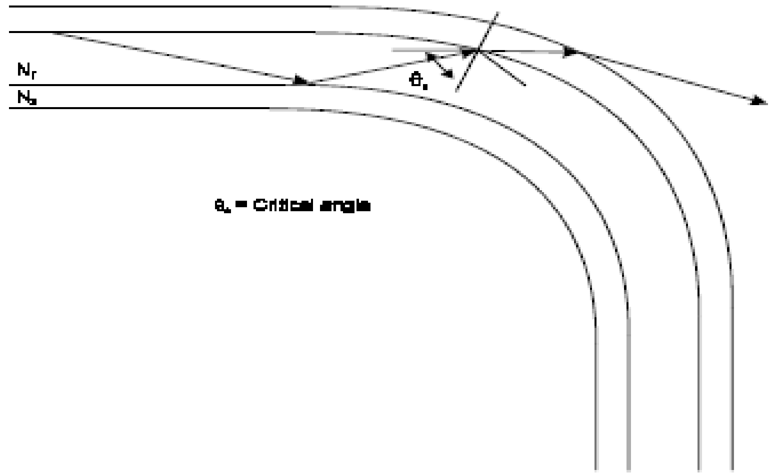


Distribution Cables

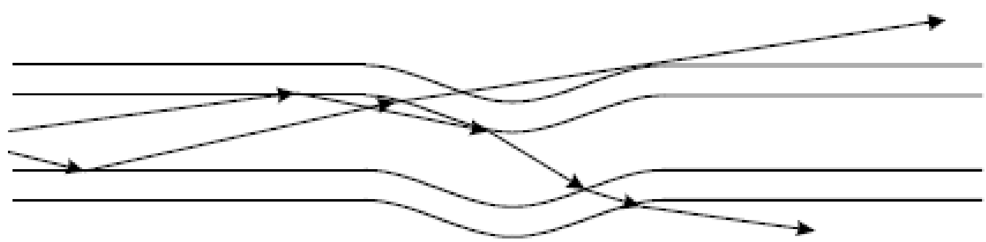


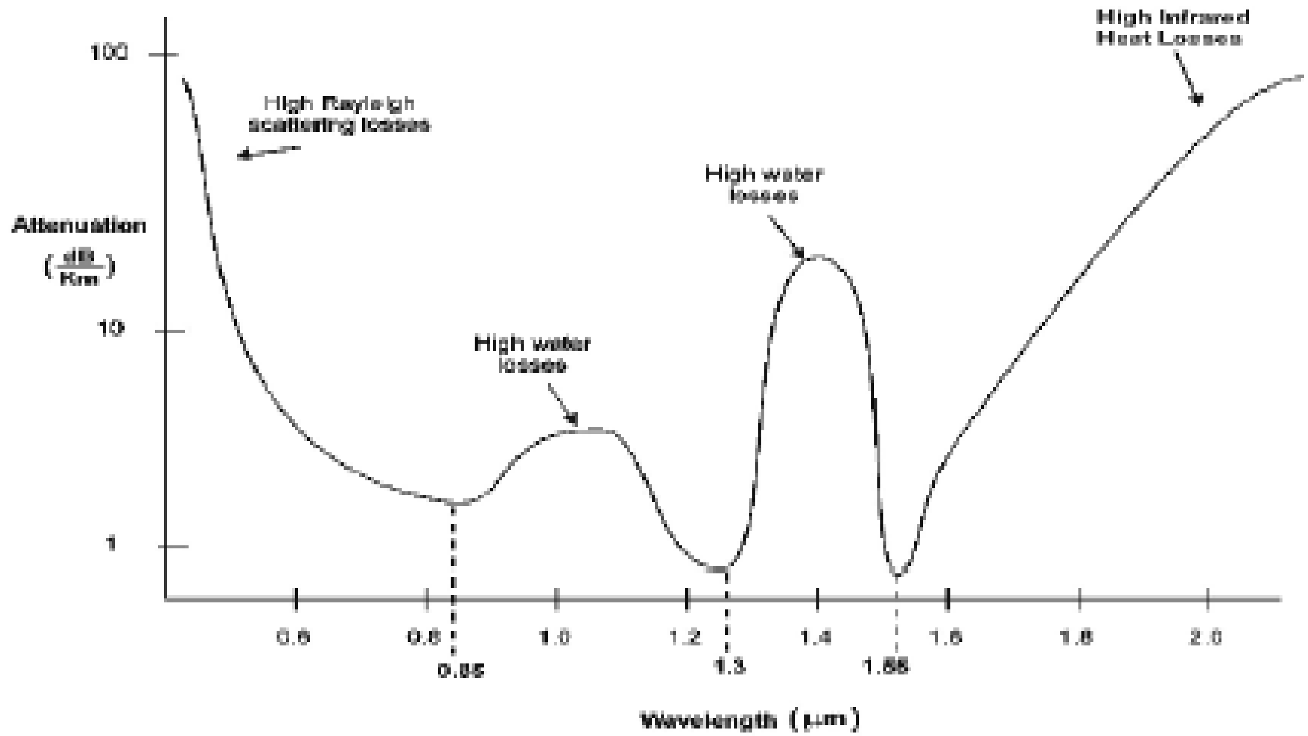


Losses due to macrobending



Losses due to microbending





High Infrared
Heat Losses
High Rayleigh
scattering losses
High water
losses
High water
losses
Attenuation
(dB/Km)
100
10
1
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0.85
1.3
1.55
Wavelength (µm)

Fiber Materials

Two main type of materials are there for making optical fibers.

1. Plastics Fibers

The plastics offers advantages in terms of cost, ease of fabrication and have high mechanical flexibility. They have high transmission losses and are often useful for short distance communication.

Polystyrene core (refractive index = 1.6) and Polymethylmethaacrylate (PMMA) cladding (refractive index = 1.49) => NA=0.583 and acceptance angle =35.66 deg.

Polymethylmethaacrylate core (refractive index = 1.49) and Polymer cladding (refractive index = 1.40) => NA=0.51 and acceptance angle = 30.66 degrees.

2. Glasses Fibers

Mainly two types of glass fibers are there based on the

(i) Silica glass (SiO_2)

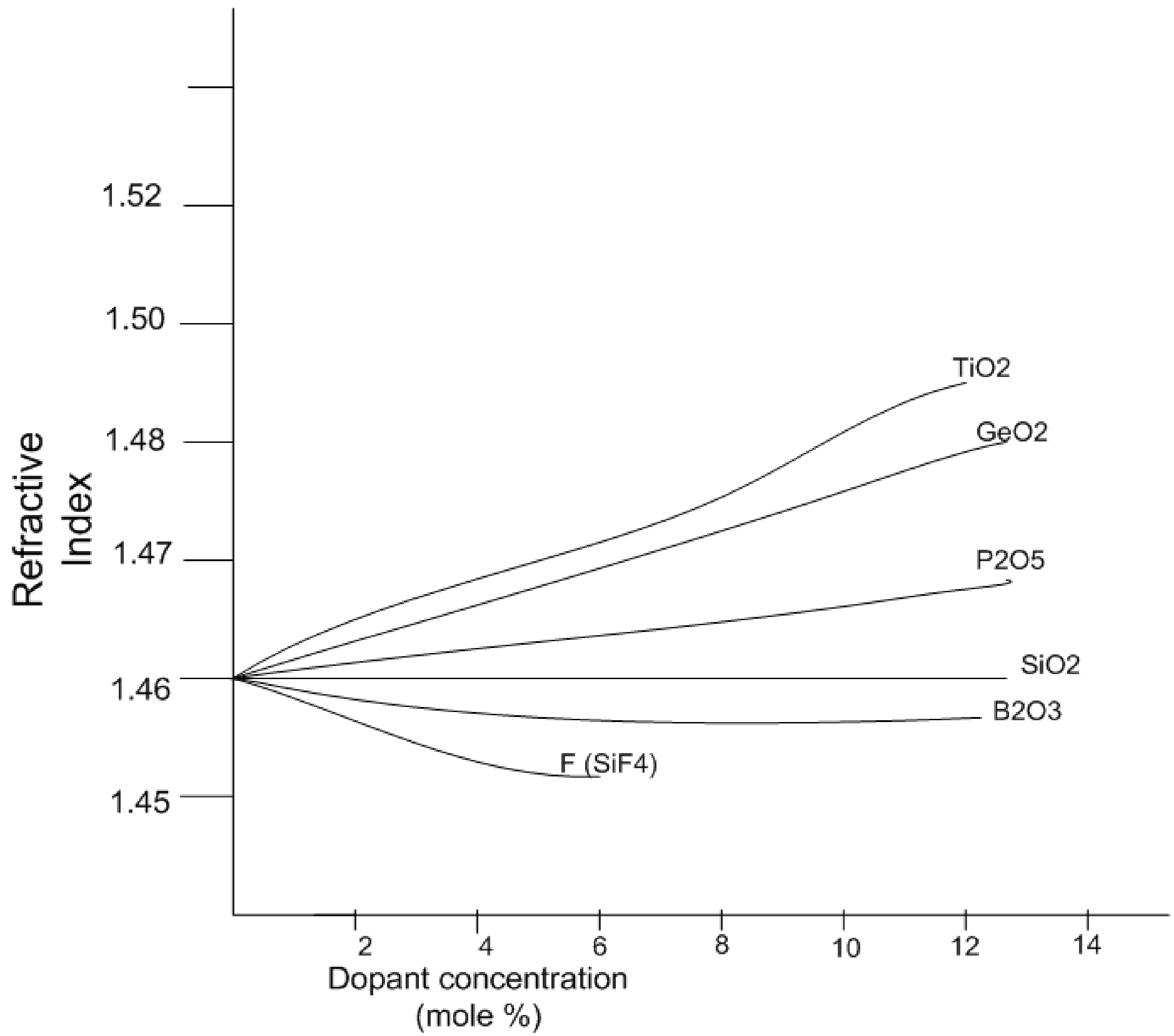
(ii) Soft glasses such as Sodium borosilicates, Sodium calcium silicates, and Lead silicates. These are high purity low loss optical fibers.

Obvious requirement of the material is that it must be possible to vary the refractive index by addition of other impurities.

Pure Silica has refractive index =1.46 at 1 micron.

Other dopants like (Fluorine, Boron, Phosphorus, Germanium, Aluminium and Titanium are added to it to change its refractive index.

Glass fibers can be made with a relatively wide range of refractive index but the control of impurity content is more difficult than with silica where it can be controlled up to 1ppb level.



Refractive Index
1.52
1.50
1.48
1.47
1.46
1.45
TiO2
GeO2
P2O5
SiO2
B2O3
F (SiF4)
2
4
6
8
10
12
14
Dopant concentration (mole %)

Fiber Fabrication Methods

Among the various fabrication techniques there are two methods used for making low loss optical fibers.

Double Crucible Method
Chemical Vapour Deposition Techniques

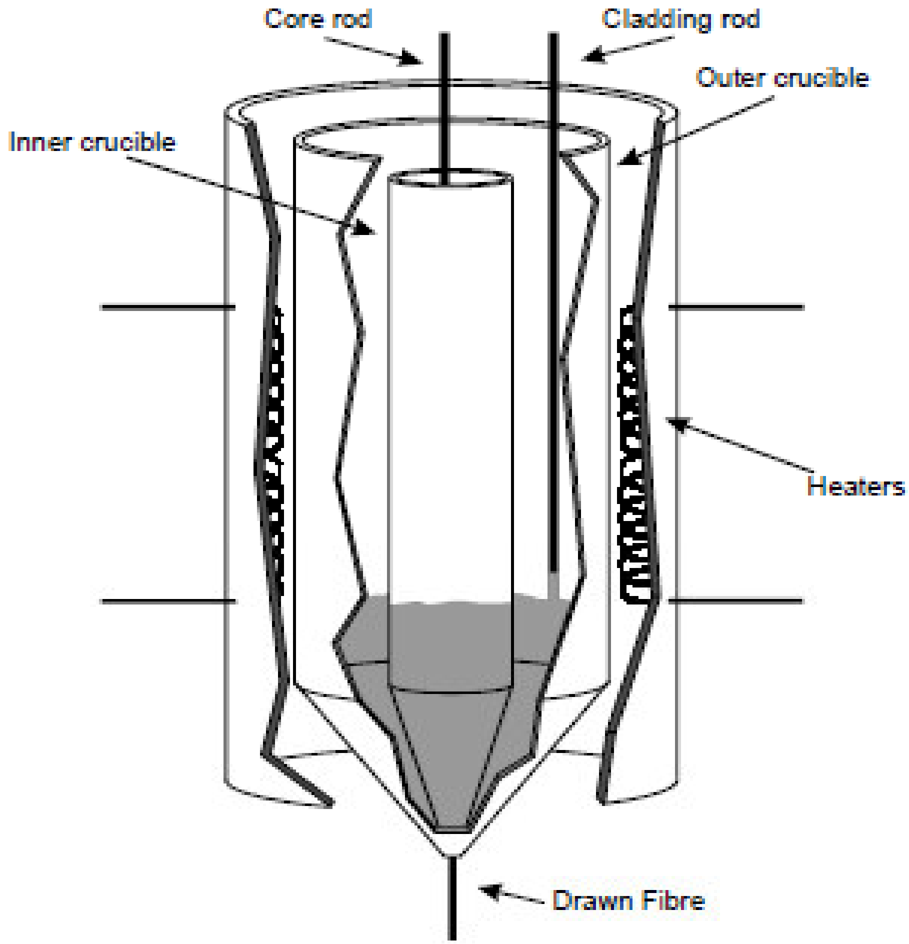
Double Crucible Method

Pure glass material with appropriate dopants is taken in two platinum crucibles. At the bottom of each crucibles is a circular nozzle, both being concentric, the inner nozzle is slightly above the outer one.

The inner crucible contains core material and the outer one contains cladding material. The two crucibles are kept inside the furnace which is heated to high temperature. When the temperature of the furnace is raised sufficiently high by switching on the heating power, the core material flows through the inner nozzle into the center of the flow stream of the outer crucible.

The fiber is then allowed to pass through a bath containing molten plastic for protective coating of plastic over the fiber. Below this is curing oven and then a rotating take up drum on which composite fiber is wound onto it.

If the two materials remain separated then step index fiber will result. By using glasses that diffuses (or by having dopants that do so) graded index fiber can be obtained. The index profile can be controlled by diffusion process.


Core rod
Cladding rod
Outer crucible
Inner crucible
Heaters
Drawn Fibre

Standard optical fibers are made by first constructing a large-diameter *preform*, with a carefully controlled refractive index profile, and then *pulling* the preform to form the long, thin optical fiber.

The preform is commonly made by chemical vapor deposition methods: inside vapor deposition, outside vapor deposition

Chemical Vapour Deposition Techniques

It is one of the variety of vapour phase deposition techniques, that produces fibers having minimal impurity content. In this techniques a doped silica layer is deposited onto the inner surface of a pure silica tube. The deposition occurs as a result of a chemical reaction taking place between the vapour constituents that are being passed through the tube. Typical vapours used are SiCl4, GeCl4, BCl3, SiF4, TiCl4, etc. and the various reactions that may takes place may be written as follows:

$SiCl_4 + O_2 = SiO_2 + 2Cl_2$

$GeCl_4 + O_2 = GeO2 + 2Cl_2$

$SiF_4 + O_2 = SiO2 + 2F_2$

$TiCl_4 + O_2 = TiO2 + 2Cl_2$

$4BCl_3 + 3O_2 = 2B2O3 + 6Cl_2$

$4POCl_3 + 3O_2 = 2P2O5 + 6Cl_2$

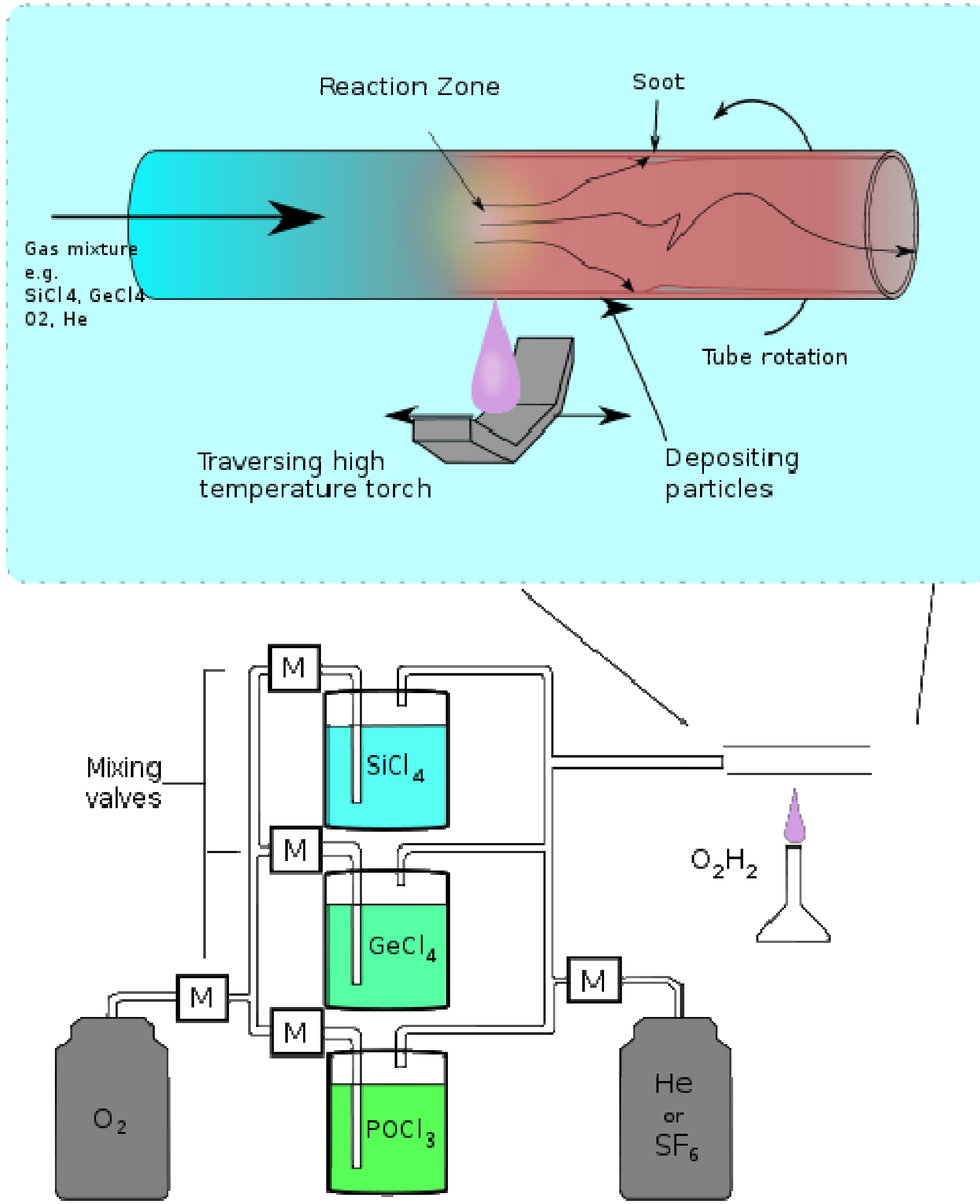
The zone where reaction takes place is moved along the tube by locally heating the tube to the temperature in the range 1200-1600C with a travelling oxy-hydrogen flame as shown in figure. If the process is repeated with different input concentrations of the dopant vapours, the layers of different impurity concentrations may be built up sequentially. This technique thus allows the fabrication of graded index fiber with much greater control over the index profiles than does the double crucible method.

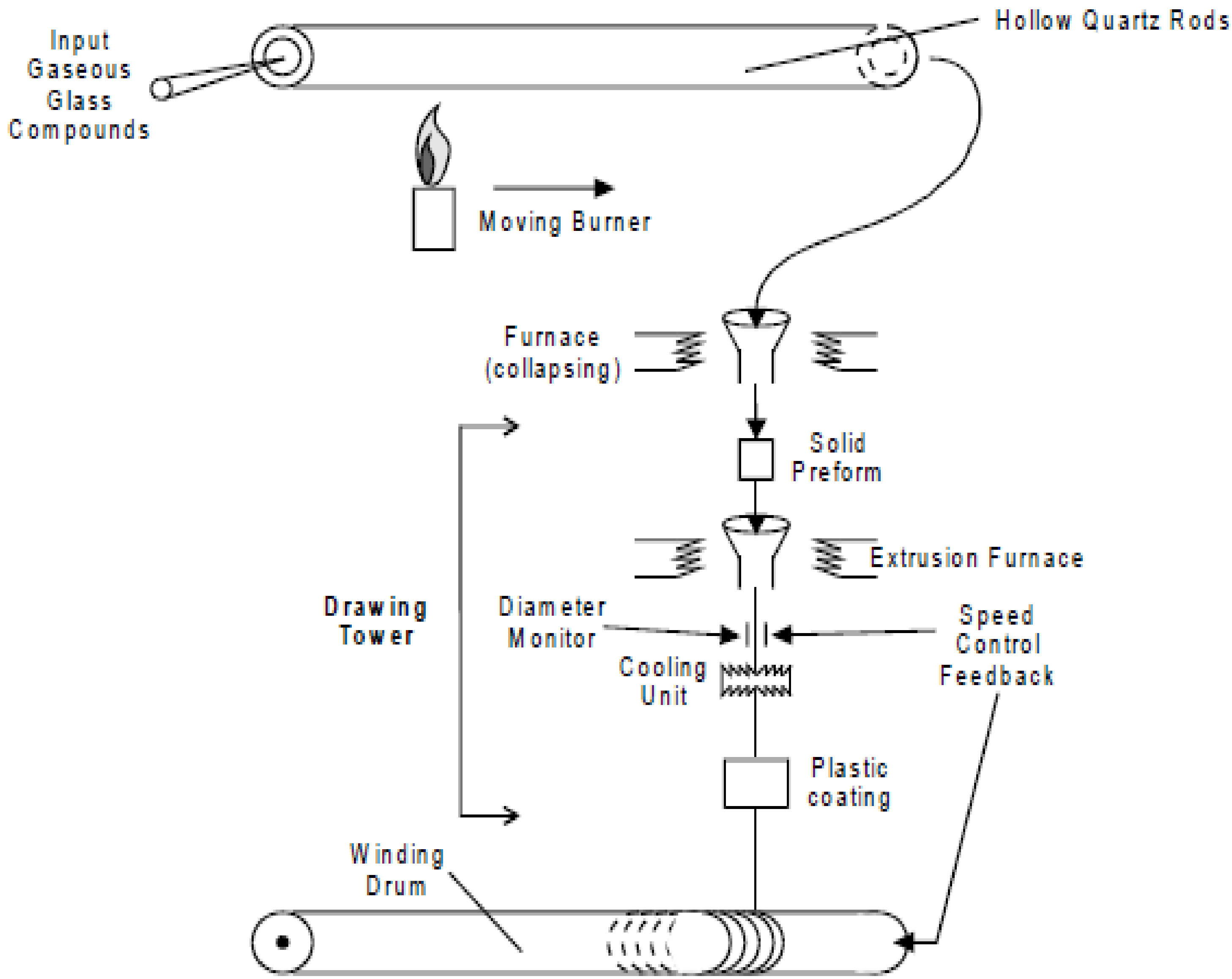
After the deposition process is complete, the tube is heated to its softening temperature (~2000ºC). The tube then collapses into a solid rod called ***perform***.

The fiber is subsequently produced by drawing from the heated tip of the perform as it is lowered into a furnace. To have finite control over the fiber diameter, a thickness monitoring gauge is used before the fiber is drawn onto the take up drum and feedback is applied to the take up drum speed.

Similar to earlier method a protective plastic coating is often applied to the outside of the fiber and resulting coating is then cured bypassing it through a further furnace.

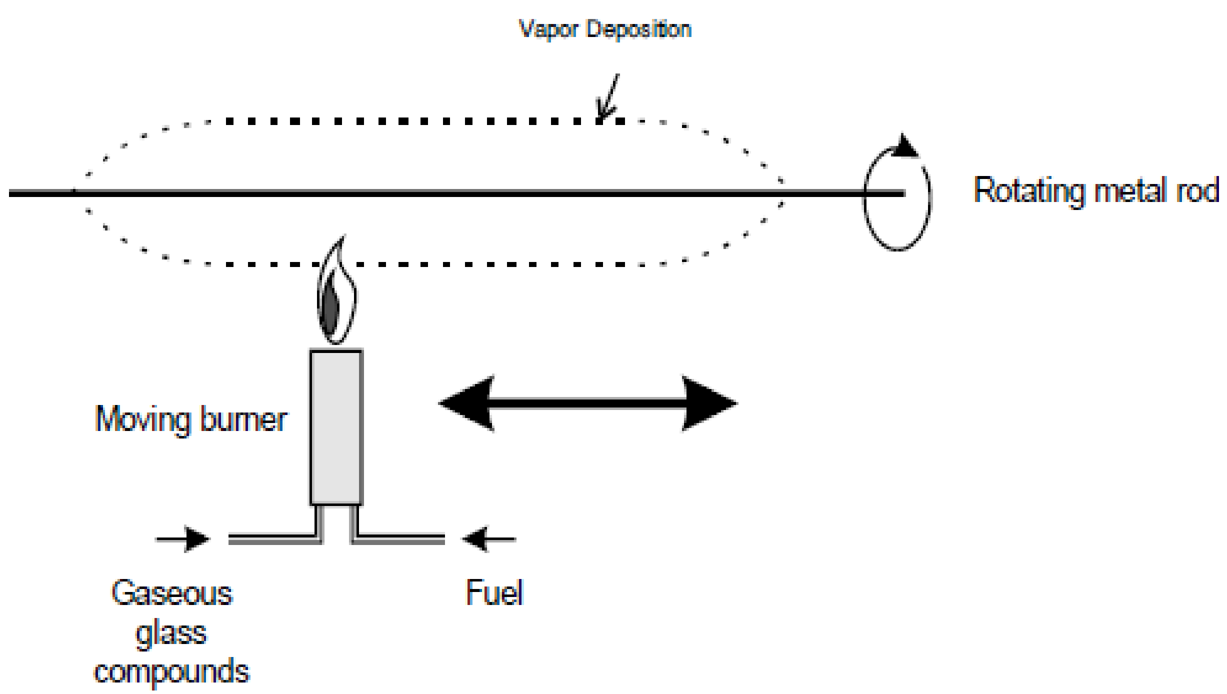
Modified chemical vapour deposition (inside) process




Input
Gaseous
Glass
Compounds
Hollow Quartz Rods
Moving Burner
Furnace
(collapsing)
Solid
Preform
Extrusion Furnace
Drawing
Tower
Diameter
Monitor
Speed
Control
Feedback
Cooling
Unit
Plastic
coating
Winding
Drum

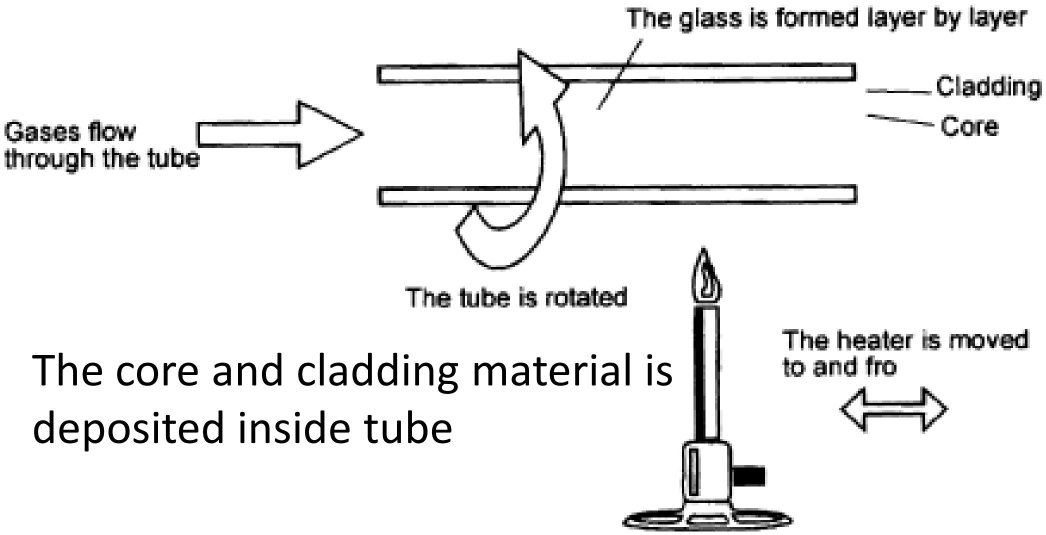
Outside chemical vapor deposition

This is a similar fabrication process to that described above except that the glass is layered on the outside of a rotating metal rod. The glass gaseous compounds are fed into the burner and are formed into layered glass onto the outside of the rod, as the burner moves along the rod. Once the glass formation is completed, the metal rod is removed and the glass tube is fed into a furnace and collapsed into a preform. Once the preform is complete, the fiber is drawn in the manner described above. This process is illustrated in Figure 3.30.

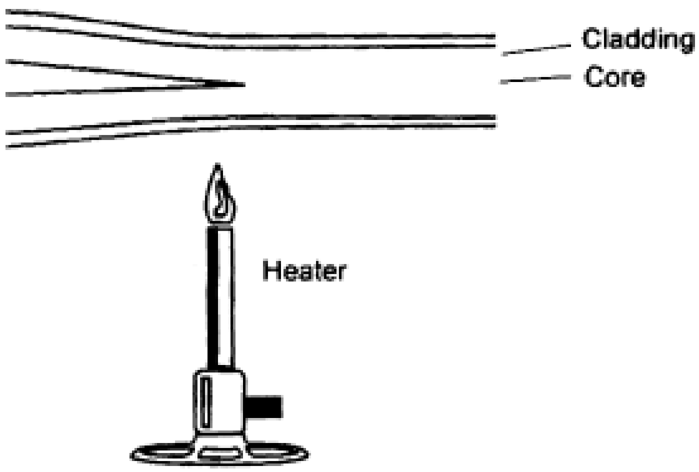


The preform, however constructed, is then placed in a device known as a drawing tower, where the preform tip is heated and the optic fiber is pulled out as a string. By measuring the resultant fiber width, the tension on the fiber can be controlled to maintain the fiber thickness.

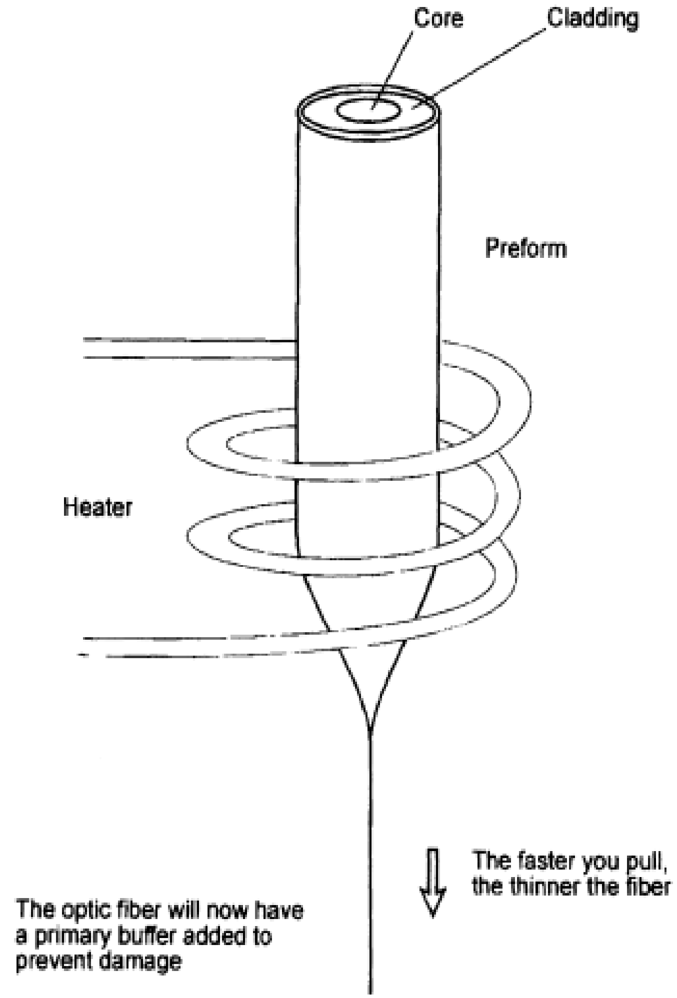
Fiber optic coatings are UV-cured urethane acrylate composite materials applied to the outside of the fiber during the drawing process. The coatings protect the very delicate strands of glass fiber—about the size of a human hair—and allow it to survive the rigors of manufacturing, proof testing, cabling and installation.



The core and cladding material is deposited inside tube



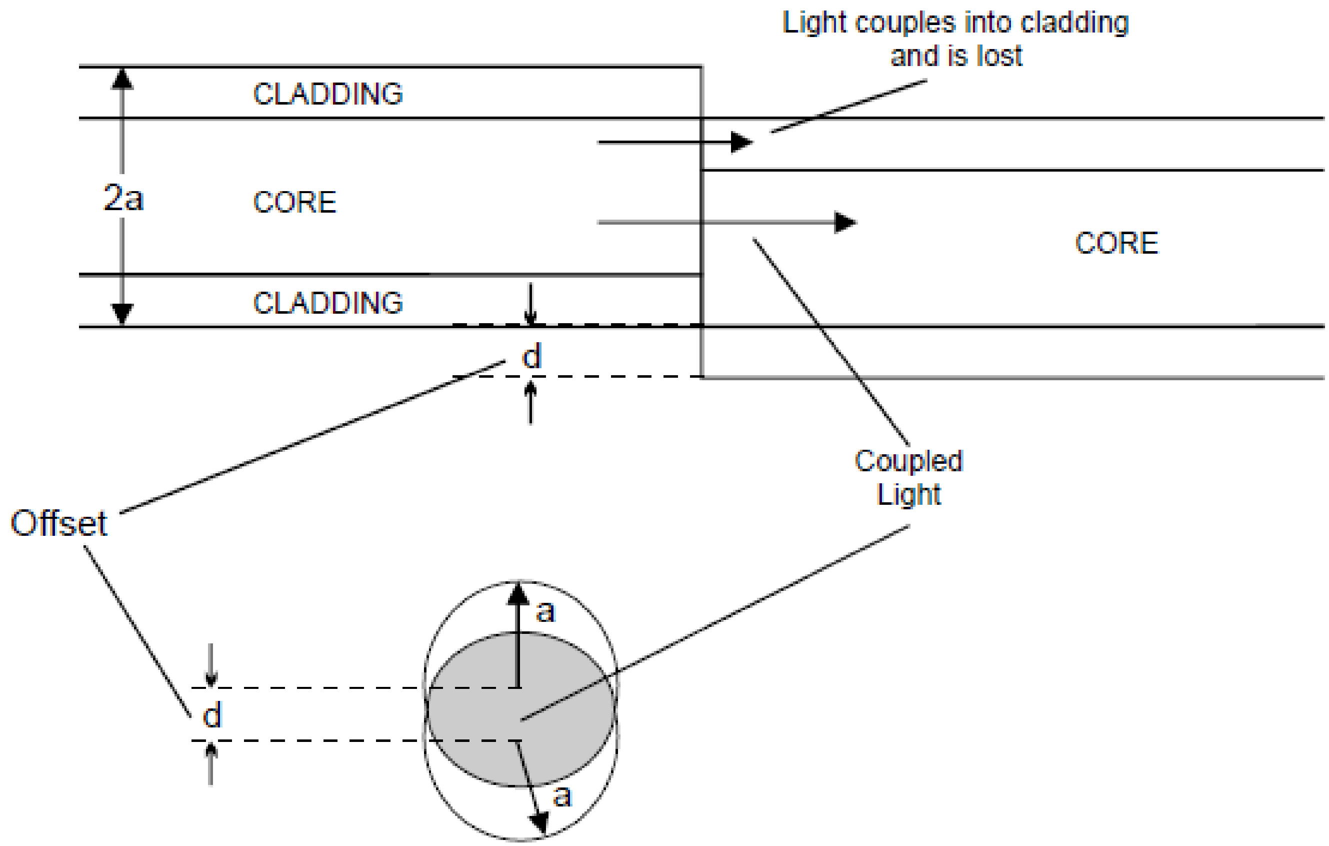
Further heating collapses the tube



Fiber wire drawing

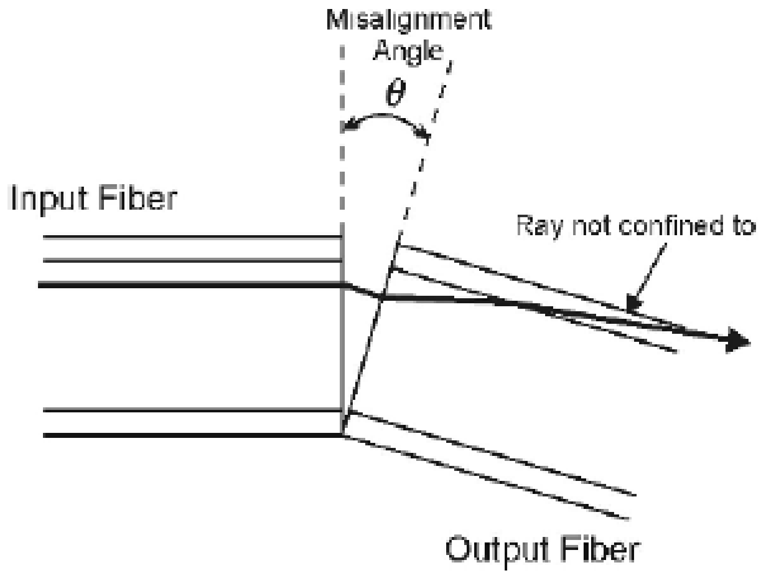
Lateral misalignment of fiber cores

Here, it is assumed that fibers of the same diameter are displaced by a distance *d*, and are otherwise perfectly aligned as shown in Figure 5.1. For simple, worst-case analysis, it is assumed that the power is uniformly distributed across the fiber cores.



Angular fiber misalignment

When the axes of fibers are not aligned, the light enters the second fiber at greater angles and depending on the numerical aperture *NA*, some of the rays are unable to be confined to the core. This is illustrated in Figure 5.3.



Splicing fibers

Two basic techniques are used for splicing of fibers; fusion splicing or mechanical splicing. With mechanical splicing, the fibers are held together in an alignment structure, using an adhesive or mechanical pressure. With the fusion splicing technique, the fibers are welded together, requiring expensive equipment but will produce consistently lower loss splices with low consumable costs. Mechanical splicers require lower capital cost equipment but have a high consumable cost per splice.

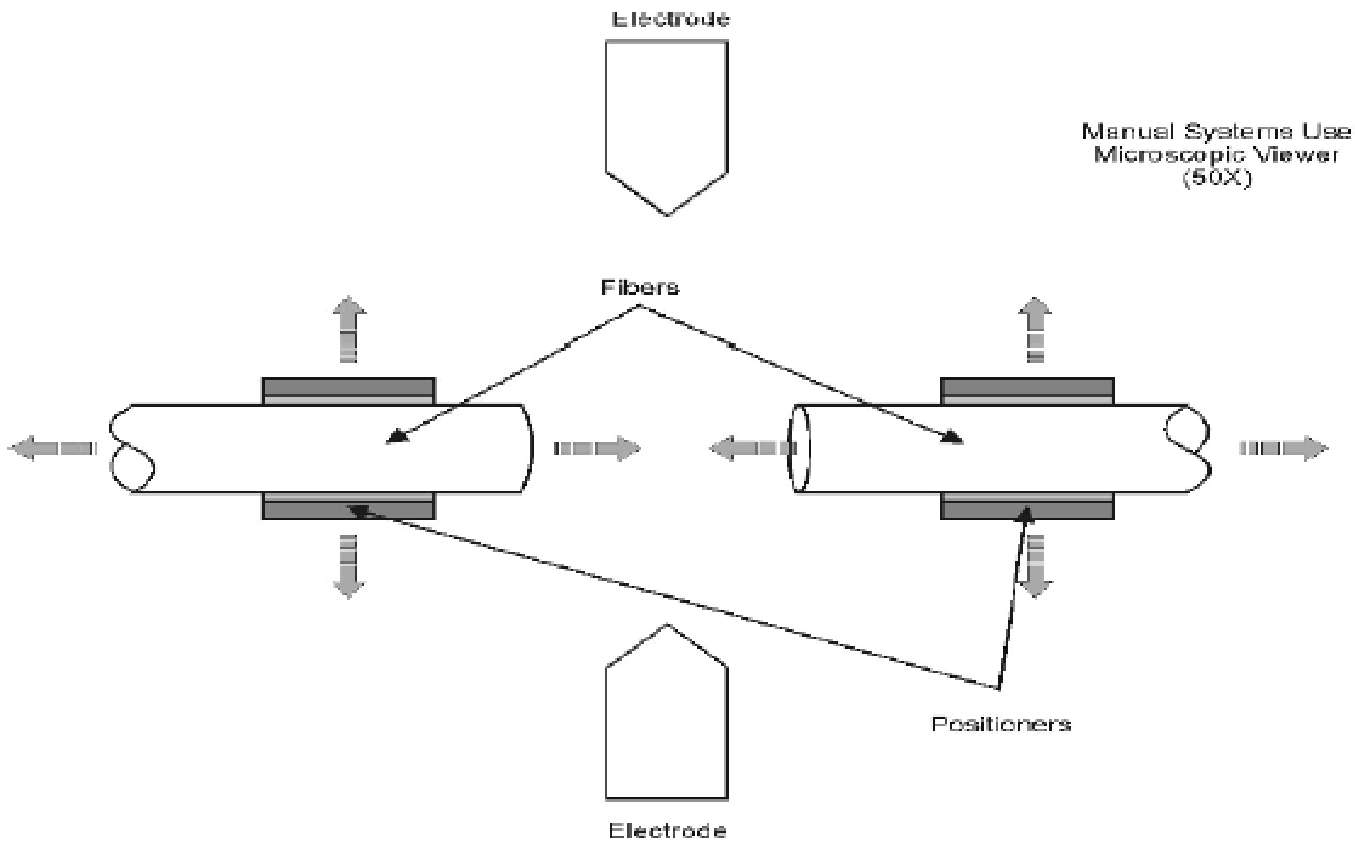
Today, fusion splicing is the main technique for joining fibers. It is far better joining with significantly lower loss. Over the long term, it is also far more reliable.

Fusion splicing

Fusion splices are made by melting the end faces of the prepared fibers and fusing the fibers together. Practical field fusion splicing machines use an electric arc to heat the fibers. Factory splicing machines often use a small hydrogen flame. The splicing process needs to precisely pre-align the fibers, then heat their ends to the required temperature and move the softened fiber ends together sufficiently to form the fusion joint, whilst maintaining their precise alignment.

During fusion, surface tension tends to naturally align the fiber axes minimizing any losses caused by lateral misalignment as discussed in section 5.1.1. Properly made fusion splices are as strong as the original fibers. Production fibers breaking under the proof test are simply fusion spliced for repair by the manufacturer. Such factory splices have typically less than 0.1 dB loss and have a tensile strength comparable to that of the original fiber. Commercial field splicing equipment, in skilled hands, can consistently produce splices with losses less than 0.1 dB.

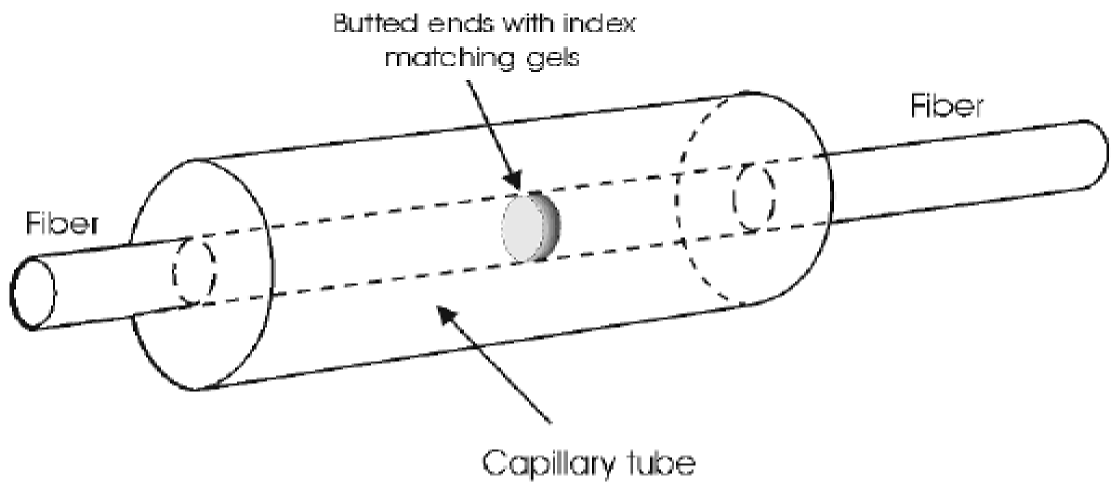
Fusion Splicer



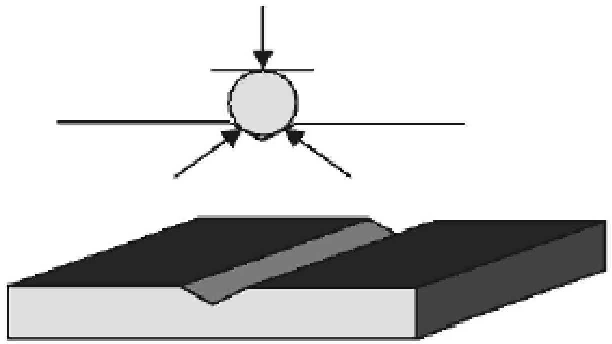
Mechanical splicing

Mechanical splicing involves many different approaches for bringing the two ends of the fibers into alignment and then clamping them within a jointing structure or gluing them together. Mechanical splices are generally used for short-term fixes only. Longer term fixes are provided by using fusion splices.

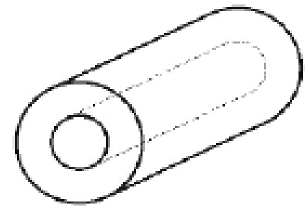
Mechanical splices generally rely on aligning the outer diameters of the fiber cladding and assume that the cores are concentric with the outside of the cladding. This is not always the case, particularly with singlemode fibers. Some systems therefore allow active alignment where the fiber loss is monitored and the fibers rotated within the jointing structure to minimize the splice loss. Various mechanical structures are used to align the fibers, including V-grooves, sleeves, 3-rods and various proprietary clamping structures.



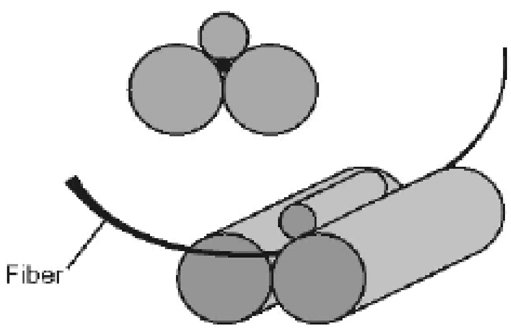
Splice alignment structures



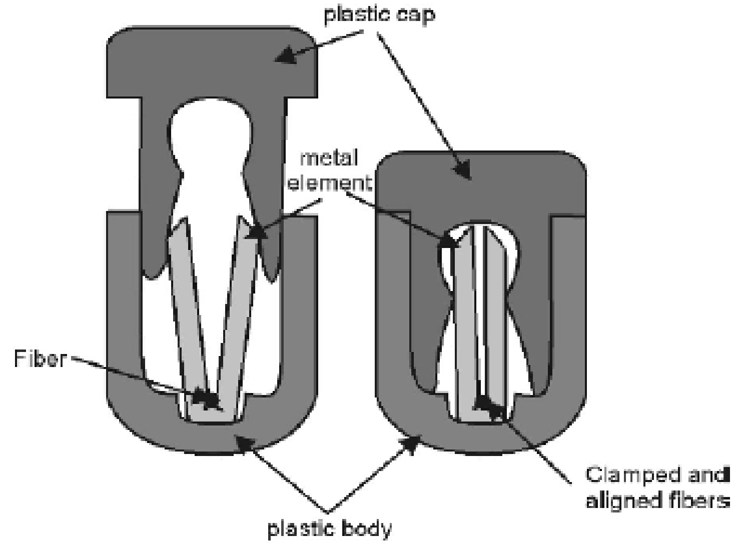
V- Groove



Capillary Tube

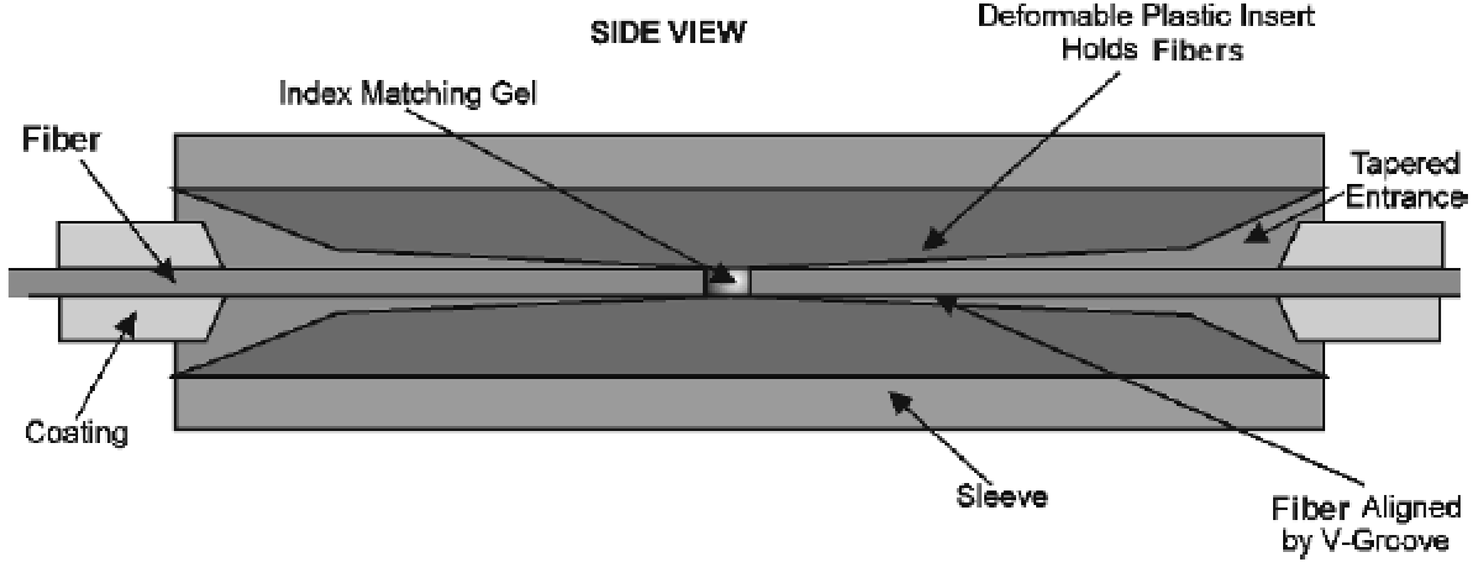


Three Rods

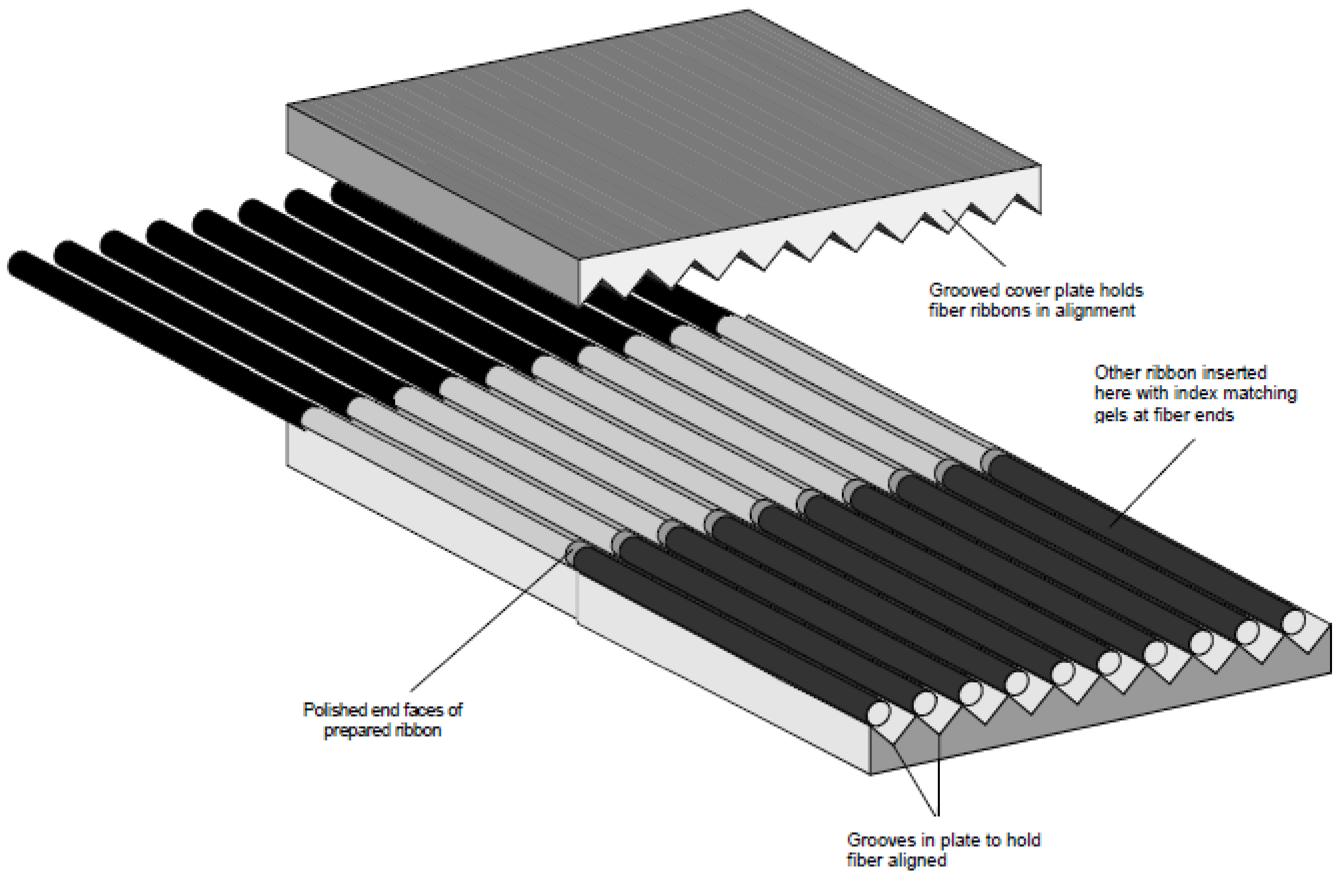


Proprietary "FIBRLOK"™ (3M)

Elastomeric mechanical splices

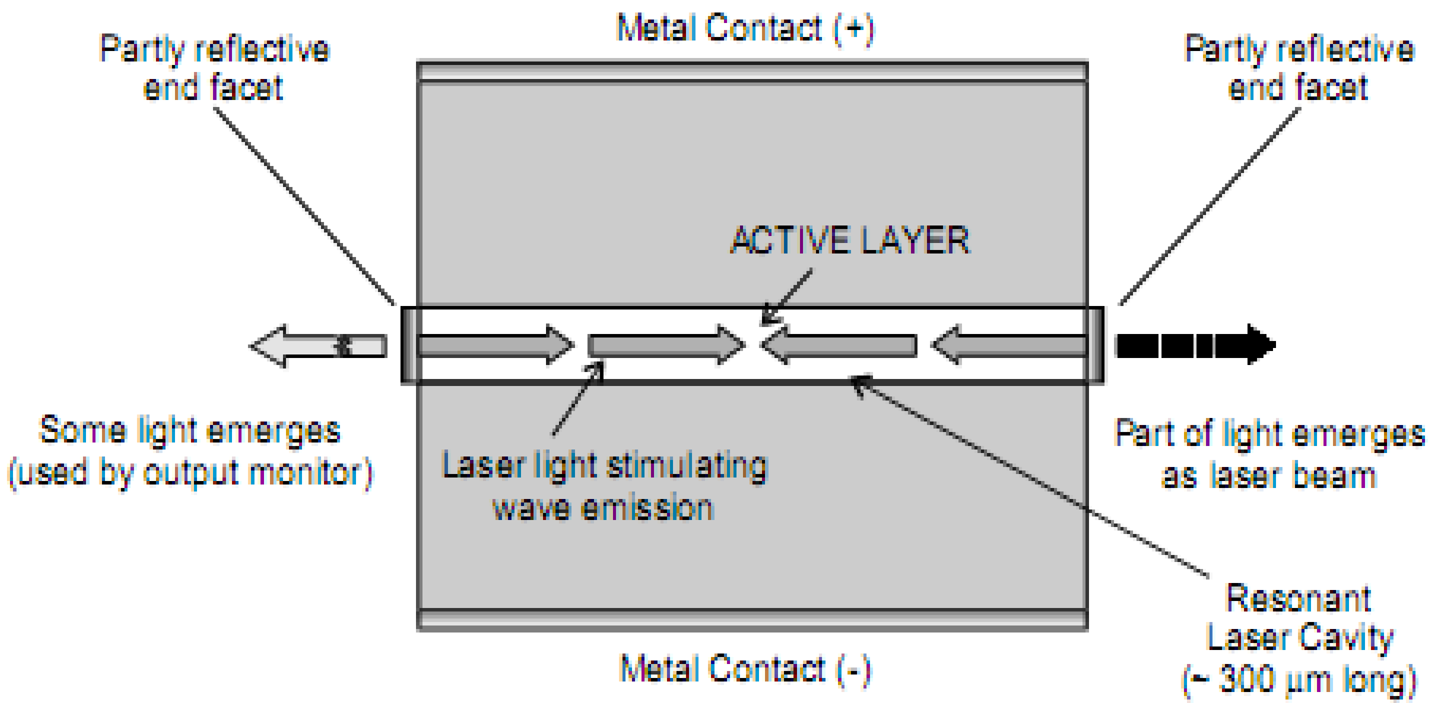


Multiple fiber splicing



Sources for Optical Fibers

Laser diode



REPEATERS

As was mentioned earlier, even though modern optical fibers are extremely transparent, attenuation of the intensity of the light traveling along the fiber still occurs, and over long distances the light signal must be boosted back to a larger value. This process was traditionally carried out with a ***repeater***. This is a device incorporating a light detector, processing electronics, and a new laser. An incoming stream of optical pulses, corresponding to the transmitted information in binary code, is detected and becomes an equivalent stream of electrical pulses. These electrical pulses are amplified, reshaped electronically to restore their original shape, and are then used to drive the new laser to re-transmit the information along the next stretch of fiber. In this way, a stream of optical pulses can be transmitted over great distances, such as under the Atlantic Ocean, by spacing a series of repeaters along the fiber cable. Typically repeaters are spaced every 45-70 km. Consequently, a long fiber cable must incorporate conventional electrical wires to provide the power to drive the repeaters.