Manufacturing of Optical Fibers

Optical fiber is a single, hair fine filament drawn from molten silica glass. Today, it has replaced metal wires in high speed communication.

In a fiber optic communications system, cables made of optical fibers connect datalinks that contain lasers and light detectors. To transmit information, a datalink converts an analog electronic signal into digital pulses of laser light. These travel through the optical fiber to another datalink, where a light detector reconverts them into an electronic signal. It makes people to wonder how something only 1/8 of a mm - 0.005 inches - in diameter can be made with such precision. So here is brief explanation of how optical fiber is made.

![Fig. 1. Optical fibers](image)

Raw Materials

Optical fiber is mostly made from silicon dioxide (SiO$_2$) but some little amount of other materials such as fluorozirconate, fluoroaluminate, and chalcogenide glasses as well as crystalline materials like sapphire, are used for longer-wavelength infrared or other specialized applications. Chemical compounds such as germanium tetrachloride (GeCl$_4$) and phosphorus oxychloride (POCl$_3$) can be used to produce core fibers and outer shells, or clad *dings*, with function-specific optical properties.

why silica?
Silica, which can be drawn into fibers at reasonably high temperatures, has a fairly broad glass transformation range. One other advantage is that fusion splicing and cleaving of silica fibers is relatively effective. Silica fiber also has high mechanical strength against both pulling and even bending, provided that the fiber is not too thick and that the surfaces have been well prepared during processing. Even simple cleaving (breaking) of the ends of the fiber can provide nicely flat surfaces with acceptable optical quality. Silica is also relatively chemically inert. In particular, it is not hygroscopic (does not absorb water) also it can be doped with various materials. Silica fiber also exhibits a high threshold for optical damage. But, pure silica is not best suitable for optical fiber, because it exhibits a low solubility for rare earth ions. This can lead to quenching effects due to clustering of dopant ions. These properties makes silica most widely use material for optical fibers.

**Process of Manufacturing**

There are two main steps in the process of converting raw materials into optical fiber ready to be shipped.

- Manufacturing of the pure glass preform
- Drawing of the preform

The first step in manufacturing glass optical fibers is to make a solid glass rod, known as a preform. Ultra-pure chemicals -- primarily silicon tetrachloride (SiCl4) and germanium tetrachloride (GeCl4) -- are converted into glass during preform manufacturing. These chemicals are used in varying proportions to fabricate the core regions for the different types of preforms. The basic chemical reaction of manufacturing optical glass is:

- SiCl4 (gas) + O2 > SiO2 (solid) + 2Cl2 (in the presence of heat)
- GeCl4 (gas) + O2 > GeO2 (solid) + 2Cl2 (in the presence of heat)
The core composition of all standard communication fibers consists primarily of silica, with varying amounts of germania added to increase the fiber's refractive index to the desired level. Single-mode fibers typically have only small amounts of germania and have a uniform composition within the core. Multimode fibers typically have a much higher refractive index, and therefore much higher germania content. Also, the core composition and the refractive index of graded-index multimode fibers changes across the core of the fiber to give the refractive index a parabolic shape.

Today Three methods are used to manufacture perform.

Modified Chemical Vapor Deposition (MCVD)

First, a cylindrical preform is made by depositing layers of specially formulated silicon dioxide on the inside surface of a hollow substrate rod. The layers are deposited by applying a gaseous stream of pure oxygen to the substrate rod. Various chemical vapors, such as silicon tetrachloride (SiCl₄), germanium tetrachloride (GeCl₄), and phosphorous oxychloride (POCl₃), are added to the stream of oxygen. As the oxygen contacts the hot surface of the rod-a flame underneath the rod keeps the walls of the rod very hot-silicon dioxide of high purity is formed. The result is a glassy soot, several layers thick, deposited inside the rod. This soot will become the core. The properties of these layers of soot can be altered depending on the types of chemical vapors used.
Fig 3. Illustration of MCVD (inside) process [4]
After sufficient layers are built up, the tube is collapsed into a solid glass rod referred to as a preform. It is now a scale model of the desired fiber, but much shorter and thicker. The preform is then taken to the drawing tower, where it is pulled into a length of fiber up to 10 kilometers long.

Outside Vapor Deposition (OVD)

One of many variations of vapour deposition technique for fabricating optical fiber. Here an inert rod is layered with core and cladding glass deposits built up on the outside. Once enough layers are in place, the rod is removed and the layers consolidated into a solid preform which can be drawn into fiber. Silicon chloride, SiCl4 and germanium chloride, GeCl4 are oxidised to form silica and germania particles for the deposition.

![Diagram of OVD process](image)

*Fig. 4. Outside vapor deposition [3]*

Vapour Phase Axial Deposition (VPAD)

In this diagram, we see how the preform is made. A seed rod is slowly rotated and pulled upward. As the seed rod is pulled, two burners deposit fine glass soot. The lower burner in this diagram is depositing the core glass material, and above it is a burner depositing the cladding glass. The rate at which the seed rod is pulled is carefully controlled by servo mechanisms. After deposition the glass soot rod is dehydrated and sintered into a solid preform in a furnace.
Drawing the fiber

The next process in manufacturing the fiber optics is to convert into hair-thin fiber. Fiber draw is the phenomenon for the manufacturing those hair-thin fiber. The tip of the performance is lowered into high-purity graphite furnace. Pure thin glass are injected into furnace and in furnace, tightly controlled temperature approaching 1900 celcius soften the tip of the perform. Once the softening point of the tip is reached, gravity takes over and occurs free fall until it has been stretched into thin strand. Then those fiber are pulled by tractor belt shown in the figure below.

Drawing process only begins when the operator threads this strands into coating dies. Diameter of the fiber during draw is controlled to 125 microns within 1 micron tolerance. The rate for sampling the fiber is 750 times per second while the actual value of diameter is compared to 125 micron target. Drawing speed is higher if the diameter is above than target diameter and vice versa. After diameter case two layer coating is applied to the fiber with soft inner coating and hard outer coating which will be more discussed on coating for the protection of fiber in section below.
Coating the Fiber for Protection

The coating is vital for optical fiber to provide mechanical protection against surface cracks and to provide integrity.

Protection coating consist of two parts: a soft inner + hard outer coating. “The overall thickness of the coating varies between 62.5 and 187.5 m, depending on fiber applications” [3]

After the fiber is taken from the preform, a coating is applied fast after the formation of the thin fiber as shown below on the scheme.

*Fig. 7. Coating the fiber [3]*

Test & Measurement

Then the drawn fiber goes through compulsory tests, where all optical and geometrical parameters are checked to meet strict quality requirements.

*Fig. 8. Fiber testing in environment [7]*
Tensile strength of fiber is tested first: reel of drawn fiber is clamped through a series of capstans and loaded to test the minimal tensile strength required. The fiber is then placed onto reels for distribution and separated equally to required lengths.

Next fiber is tested for any faults using Optical Time Domain Reflectometer (OTDR), which manipulates dispersed light to indicate the exact point of defects along the whole length.

*Geometrical parameters* are tested for all types of fiber [1]:

- core diameter
- core non-circularity
- cladding diameter
- cladding non-circularity
- coating outer diameter
- coating outer non-circularity
- coating concentricity error
- core-clad concentricity error

The reel fiber is tested for *transmission qualities and parameters* automatically:

- bandwidth: capacity of waveguide (higher capacity required for multimode);
- attenuation: signal strength decrease over distance;
- cut-off wavelength: above which only a single mode propagates;
- numerical aperture: light acceptance angle of an optical fiber is measured;
- mode field diameter: the radial width of the light pulse in the fiber in single-mode fiber; required for interconnecting;
- chromatic dispersion: rays of different wavelengths have different velocity through the core and spread short pulses of light; for single-mode fiber it limits information bandwidth.

![Fig. 9. Optical fibers](image)

In addition, *mechanical and environmental testing* is also done for the fiber to comply optical and mechanical integrity of product and customer requirements [1]:

- temperature-humidity cycling
- temperature dependence of attenuation
- operating temperature range
- accelerated aging
- coating strip force
- water immersion
After all tests passed fiber becomes ready for cabling (which is used to protect the fiber) and installation in environment.

References