Chapter 6

Manufacture of optical fibers (TECH)

This chapter covers three different methods for the production of preforms for optical fibers: the OVD process (outside vapor deposition), the VAD method (vapor axial deposition) and the MCVD (modified chemical vapor deposition). It also discusses the cabling of fibers.

6.1 Production of preforms

Low-attenuation optical fibers are most often based on silica (SiO$_2$). The refractive index is adjusted by an appropriate doping (see fig. 6.1).

![Diagram of refractive index of doped quartz glasses with $\lambda = 0.6 \mu$m.](Figure after: Unger, Optische Nachrichtentechnik I)

The most commonly used dopant to increase the refractive index are germanium dioxide (GeO$_2$) and P$_2$O$_5$. The most commonly used dopant to lowering the refractive index is fluorine (F).

For low-loss optical waveguides a high-purity manufacturing process is required, especially for the fiber core. Therefore, glass fibers are produced with the aid of chemical deposition from the vapor phase (CVD -
chemical vapor deposition). The starting point are halogenide, in particular chlorides, such as SiCl\textsubscript{4}. Hence fused silica (SiO\textsubscript{2}) is obtained from the oxidation.

\[ \text{SiCl}_4 + \text{O}_2 \leftrightarrow \text{SiO}_2 + 2\text{Cl}_2 \quad (6.1) \]

The reaction can proceed in both directions, with the complete conversion to SiO\textsubscript{2} for temperatures \( T > 1800 \text{ K} \). For the dopant GeO\textsubscript{2} the reaction is similar:

\[ \text{GeCl}_4 + \text{O}_2 \leftrightarrow \text{GeO}_2 + 2\text{Cl}_2 \quad (6.2) \]

The maximum conversion of GeO\textsubscript{2} proceed for \( T \approx 1800 \text{ K} \). The conversion efficiency is relatively low and is in the order of maximum 25 \%. 

1. OVD process (outside vapour deposition; Fig. 6.2)

![Figure 6.2: OVD-Process for fiber preforms (Figure from: Unger, Optische Nachrichtentechnik I)](image)

SiCl\textsubscript{4} and GeCl\textsubscript{4} are liquids at room temperature. Oxygen as a carrier bubbles through the liquids and sweeps gas vapors of these compounds along. Usually a H\textsubscript{2}O\textsubscript{2}-(oxyhydrogen gas)-burner is used as burner. The glass is deposited in layers. The control of the relative amount of SiO\textsubscript{2} and GeO\textsubscript{2} and therefore the refractive index profile is controlled by the carrier gas (O\textsubscript{2}), which is defined by the flow rate through the SiCl\textsubscript{4} and GeCl\textsubscript{4} containers. The result is a porous deposition (glass soot). However, the porous glass preform can be cleaned. By flushing with chlorine gas (dehydrogenation), for example, the OH-percentage can be reduced.

\[ \text{H}_2\text{O} + \text{Cl}_2 \rightarrow 2 \text{HCl} + \frac{1}{2}\text{O}_2 \quad \text{Hydrochloric acid} \quad (6.3) \]

The reaction takes place at temperatures above 1200\textdegree C. At the same time the porous preform becomes a glass (vitrification). Such preforms were manufactured with a mass of up to e.g. 1800 g (11 cm diameter and 80 cm length), which allows a fiber length of up to about 50 km.

2. VAD process (vapour axial deposition)
In contrast to the OVD-Process the deposition at the VAD-Process takes place not radial but axial. (Fig. 6.3).

As in the OVD process H$_2$O$_2$-burners are used. The preform is rotating while the two burners are passing different fractions of SiCl$_4$ and GeCl$_4$. By a suitable arrangement of the burners, the refractive index profile can be adjusted. The dehydration and vitrification using the VAD method takes place, similar to the OVD process, in one operation.

Since it is a closed process, a very low OH content to below 1 ppb (parts per billion $\equiv$ 1 part OH on $10^9$ parts SiO$_2$) is feasible. This corresponds to an attenuation increase at $\lambda = 1.39\, \mu m$, due to the OH-impurities, of less than 0.04dB/km.

3. MCVD process (modified chemical vapor deposition)

The initial source is a quartz tube (it later forms the fiber cladding) into which the reaction gases are fed (Fig. 6.4).

The formation of SiO$_2$ and the vitrification takes place in one step. About 30 to 100 layers are grown. A change in the refractive index profile is possible by changing the gas flow from layer to layer. Since the reaction takes place only in the quartz tube, there is only a little risk of contamination. A disadvantage of the MCVD method is that no dehydrogenation is possible, because no porous preform is produced. One first obtains a quartz tube with the deposited doped layers (see figure 6.5a). The preform is produced by collapsing of the preform tube. At temperatures of 2000$^\circ$ C the tube collapse together to a rod by the surface tension (see figure 6.5b). The OH concentration of a MCVD fiber is typically in the order of less than 1 ppm.

6.2 Fiber fabrication

Fig. 6.5 shows the drawing furnace schematically. The drawing furnace is part of the fiber drawing machine (Fig. 6.6). The drawing speed is typically more than 10 m/s. During the drawing process, the fibers are applied with a plastic coating to provide mechanical protection (thickness in the order of about 50 $\mu$m).
There is also the possibility to coat a quartz fiber with a low-loss plastic, that has a lower refractive index (e.g. silicone resin). The quartz fiber thus corresponds to the fiber core and the plastic coating is the fiber cladding. Such fibers are so called PCS fibers (plastic-clad-silica). The attenuation characteristic of such a fiber is shown in fig. 6.7. Such fibers are multi-mode step-index fibers and can be used for short transmission distances (e.g. in vehicles).

### 6.3 Fiber Strength

The manufactured optical fiber consists of the actual fused-silica fiber and the plastic coating, applied during the drawing process (see fig. 6.6). The achievable strength is given solely by the strength of quartz glass. In fact, quartz glass can be stressed heavily (Elongation or tensile stress about 5 %), as long as the surface is not disturbed by scratches or similar partial damages. Hence, the plastic coating is designed to protect the quartz fiber surface from scratches or other damages. As a result a very high strength can be obtained. The strength of fibers can be specified as a percentage of broken fibers at a given tension $\sigma$. This relation is plotted in the so-called Weibull Diagramm. An example of high strength fibers is shown in figure 6.8.

Due to fig. 6.8, a strength of about $4 \text{ GPa} = 4 \cdot 10^9 \text{ N/m}^2$ results, i.e. for a fiber with a diameter of 125 $\mu$m, a strength of approximately 50 N can be determined.
Figure 6.5: (a) Quartz tube with deposited layers, (b) collapsed preform tube, (c) Fiber manufacturing by drawing of preforms
Figure 6.6: Schematic illustration of a fiber drawing machine (Fig after: Unger, Optische Nachrichtentechnik I)

Figure 6.7: Attenuation characteristic of a fiber with quartz fiber core and silicone resin cladding (Fig after: Unger, Optische Nachrichtentechnik I)
6.4 Fiber cabling

If possible, the wiring should be implemented in order to avoid mechanical stress on the fiber and micro-bending. A commonly used method is the hollow core technology. Up to about 20 fibers are placed loosely in a hollow core. In general, the hollow core is then filled with a gel-like filler compound. Cables can be constructed from multiples of this hollow core. The illustrations 6.9, 6.10 and 6.11 show examples, wherein the wiring forces are absorbed by a retain element (commonly used steel or high quality plastics, e.g. Kevlar) (see lecture: R. Engel, "Lichtwellenleiterkabel", in E. Voges, K. Petermann, "Optische Kommunikationstechnik", Springer, 2002).
Figure 6.10: Example for a 70-core cable (Fig after: Unger, Optische Nachrichtentechnik I)

Figure 6.11: Example for a 2000-core cable (Fig after: Unger, Optische Nachrichtentechnik I)