Optical Fibers and Cables

ECE 6323

Optical Fibers and Cables

- Optical fiber manufacturing
- Types of optical fibers
- Optical fiber cables
- Types of cable

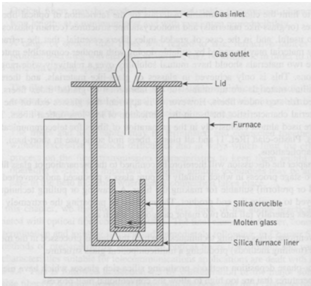
The challenges of optical fibers and cables for telecom applications

- Can be manufactured, meeting certain requirements on quality, performance, cost-effectiveness: desirable transmission characteristics for very long length
- Flexibility in fiber designs to meet different applications
- Can be handled with the same manner with older cables (copper)
- Can meet requirements of cutting, connecting, joining… with similar ease as older cables

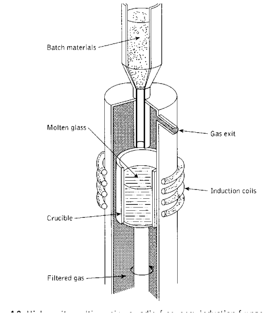
Optical fiber manufacturing

- Very very important: years after years, improvement and innovation are still being made. Every little improvement counts! Because the global telecom system is so big.
- Ultra pure glass and other materials
- Two main methods:
  - Liquid phase (melting): the earlier method
  - Vapor phase: advanced method

High purity preparation



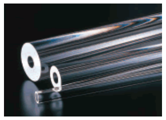
Furnace melting



RF melting

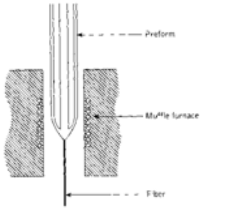
- Ultrapure materials (~ parts in 10^9)
- Avoiding contamination is the key

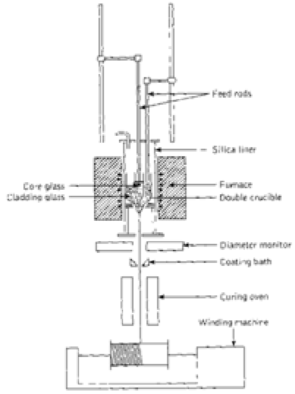
Preform



Fiber drawing

Double crucible method





Older method, but still useful
Not used much anymore for high-performance single-mode fibers

Materials for multi-component fibers

Vapor-phase deposition techniques 175

Table 4.1 Material systems used in the fabrication of multicomponent glass fibers by the double crucible technique

Step index	
Core glass	Cladding glass
Na_2–B_2O_3–SiO_2	Na_2O–B_2O_3–SiO_2
Na_2–LiO–CaO–SiO_2	Na_2O–Li_2O–CaO–SiO_2
Na_2–CaO–GeO_2	Na_2O–CaO–SiO_2
Tl_2O–Na_2O–B_2O_3–GeO_2–BaO–CaO–SiO_2	Na_2O–B_2O_3–SiO_2
Na_2O–BaO–GeO_2–B_2O_3–SiO_2	Na_2O–B_2O_5–SiO_2
P_2O_5–Ga_2O_3–GeO_2	P_2O_5–Ga_2O_3–SiO_2
Graded index	
Base glass	Diffusion mechanism
R_2O–GeO_2–CaO–SiO_2	$Na^+ \rightleftharpoons K^+$
R_2O–B_2O_3–SiO_2	$Tl^+ \rightleftharpoons Na^+$
Na_2O–B_2O_3–SiO_2	Na_2O diffusion
Na_2O–B_2O_3–SiO_2	CaO, BaO, diffusion

Vapor phase deposition

- Capable of producing highest purity silica-rich glass and lowest loss fiber
- The materials were deposited from the gas phase for chemical reaction producing high uniformity
- Allow flexibility in materials and structure design: producing multi-component fibers, complex refractive index profile
- Two main categories:
  - Flame hydrolysis
  - Chemical vapor deposition

Refractive index engineering

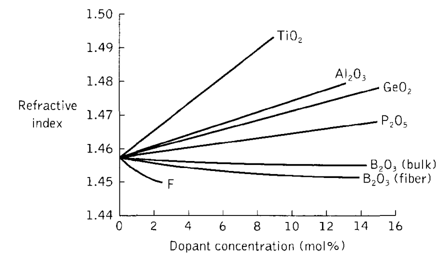
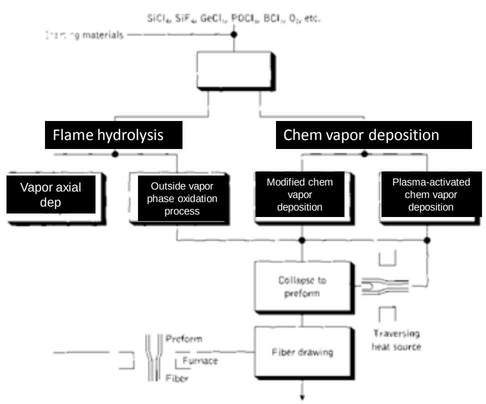


Figure 4.5 The variation in the refractive index of silica using various dopants. Reproduced with permission from the publishers, Society of Glass Technology, *Phys Chem. Glasses*, 21, p. 5, 1980

Schematic of VPD techniques



Chemical reaction for VPD

$$\underset{\text{(vapor)}}{SiCl_4} + \underset{\text{(vapor)}}{2H_2O} \xrightarrow{\text{heat}} \underset{\text{(solid)}}{SiO_2} + \underset{\text{(gas)}}{4HCl}$$

$$\underset{\text{(vapor)}}{SiCL_4} + \underset{\text{(gas)}}{O_2} \xrightarrow{\text{heat}} \underset{\text{(solid)}}{SiO_2} + \underset{\text{(gas)}}{2Cl_2}$$

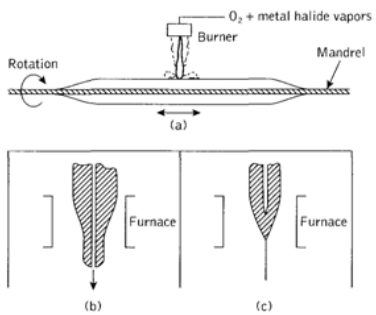
$$\underset{\text{(vapor)}}{GeCl_4} + \underset{\text{(gas)}}{O_2} \xrightarrow{\text{heat}} \underset{\text{(solid)}}{GeO_2} + \underset{\text{(gas)}}{2Cl_2}$$

$$\underset{\text{(vapor)}}{TiCl_4} + \underset{\text{(gas)}}{O_2} \xrightarrow{\text{heat}} \underset{\text{(solid)}}{TiO_2} + \underset{\text{(gas)}}{2Cl_2}$$

- Essence: oxidation of group IV – metal halides (chlorides)

Outside VPD

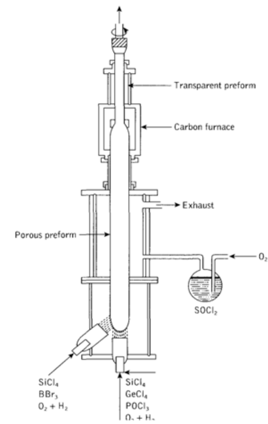
Soot deposition



Preform sintering

Fiber drawing

Vapor axial deposition



Continuous creation of preform

Modified Chemical Vapor Deposition

Vapor-phase deposition techniques 181

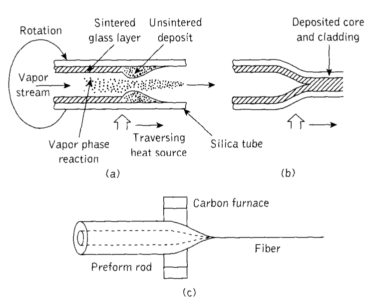


Figure 4.9 Schematic diagram showing the MCVD method for the preparation of optical fibers: (a) deposition; (b) collapse to produce a preform; (c) fiber

Plasma-activated CVP
Plasma-assisted CVP

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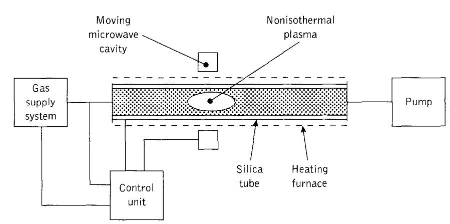

Figure 4.10 The apparatus utilized in the PCVD process

High uniformity (rotation unneeded)
High efficiency, accuracy

Key features of various vapor phase deposition

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Table 4.2 Summary of vapor-phase deposition techniques used in the preparation of low-loss optical fibers

Reaction type	
Flame hydrolysis	OVPO, VAD
High-temperature oxidation	MCVD
Low-temperature oxidation	PCVD
Depositional direction	
Outside layer deposition	OVPO
Inside layer deposition	MCVD, PCVD
Axial layer deposition	VAD
Refractive index profile formation	
Layer approximation	OVPO, MCVD, PCVD
Simultaneous formation	VAD
Process	
Batch	OVPO, MCVD, PCVD
Continuous	VAD

Additional presentation

http://www.youtube.com/watch?v=lII8Mf_faVo&feature=related

http://www.youtube.com/watch?v=EFl1dHUJj98

http://www.youtube.com/watch?v=b9fVozUSnro&feature=related

Main fiber types

- Multi-mode step-index fiber
- Multi-mode graded-index fiber
- Single-mode fiber
  - Step-index conventional fibers
  - Non-dispersion shifted
  - Non-zero dispersion shifted
- Plastic-clad fibers
- Plastic optical fibers

Multi-mode step-index fiber

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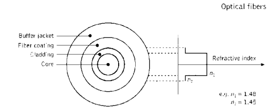


Figure 4.11 Typical structure for a glass multimode step index fiber

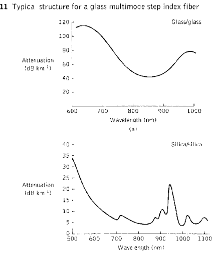
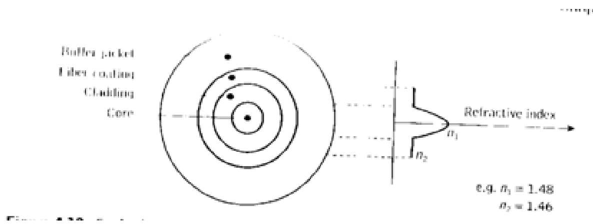


Figure 4.12 Attenuation spectra for multimode step index fibers: (a) multicomponent glass fiber; (b) doped silica fiber

Multi-mode graded index fibers



Conventional single-mode fiber

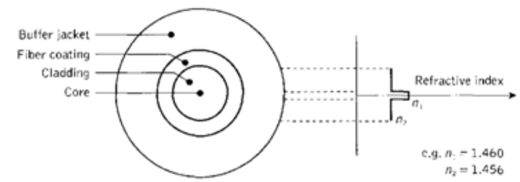
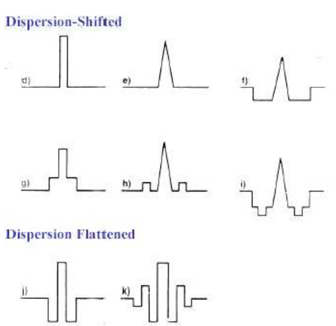
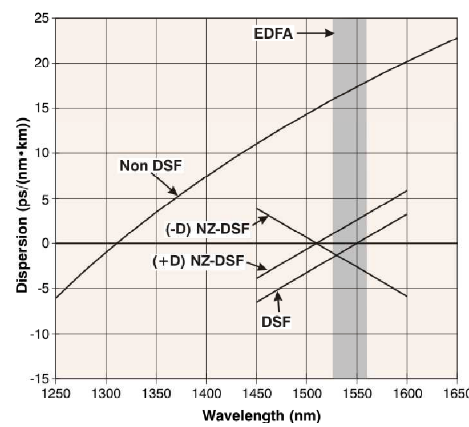


Figure 4.14 Typical structure for a standard single-mode step index fiber



Typical index profiles of a) 1300 nm-optimized,
b) dispersion-shifted, and
c) dispersion-flattened
single-mode fibers

Engineering fiber dispersion



Plastic clad fibers

Structure

Core diameter:	Step index	100 to 1000 μm
	Graded index	50 to 100 μm
Cladding diameter:	Step index	300 to 1400 μm
	Graded index	125 to 150 μm
Buffer jacket diameter:	Step index	500 to 1600 μm
	Graded index	250 to 1000 μm
Numerical aperture:	Step index	0.2 to 0.5
	Graded index	0.2 to 0.3.

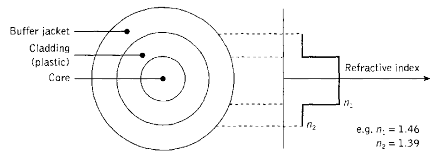


Figure 4.15 Typical structure for a plastic-clad silica multimode step index fiber

PMMA plastic optical fiber

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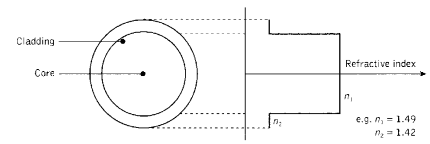

Figure 4.16 Typical structure for a PMMA plastic fiber

Transmission characteristics of POF

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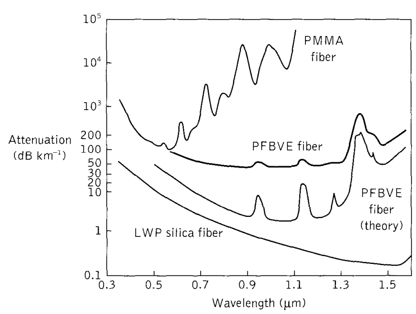
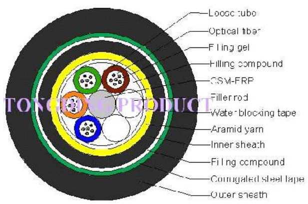
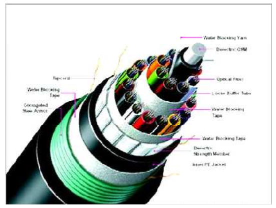


Figure 4.17 Spectral attenuation for plastic optical fibers. Adapted from Refs [34] and [46]

Optical fiber cables





Buffering fiber cable

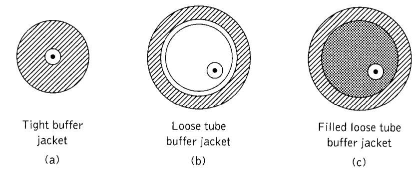


Figure 4.24 Techniques for buffering of optical fibers [Ref. 65]: (a) tight buffer jacket; (b) loose tube buffer jacket; (c) filled loose tube buffer jacket

- Critical for mechanical strength, environmental stability, service, and lifetime
- Approaches for environment: indoor, outdoor, land, submarine

Loose buffer design

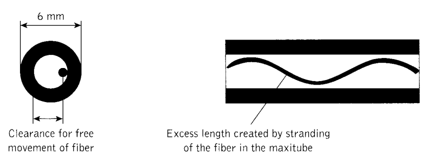
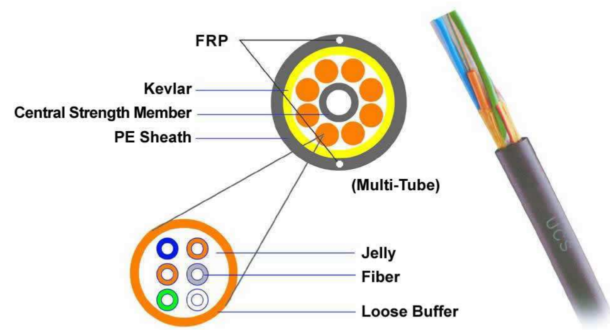


Figure 4.25 Maxitube loose buffer design showing fiber excess length

Loose buffer cable



Multifibers cable structures

Cable design 205

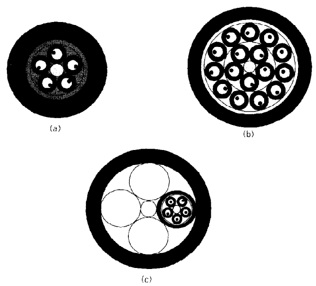


Figure 4.26 Optical fiber cable structures: (a) one-layer cable incorporating single-fiber loose tube buffers; (b) layer cable incorporating single-fiber loose tube buffers in two layers; (c) unit cable construction

Slotted core cable design

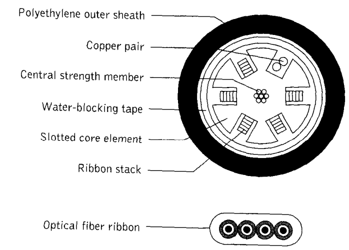
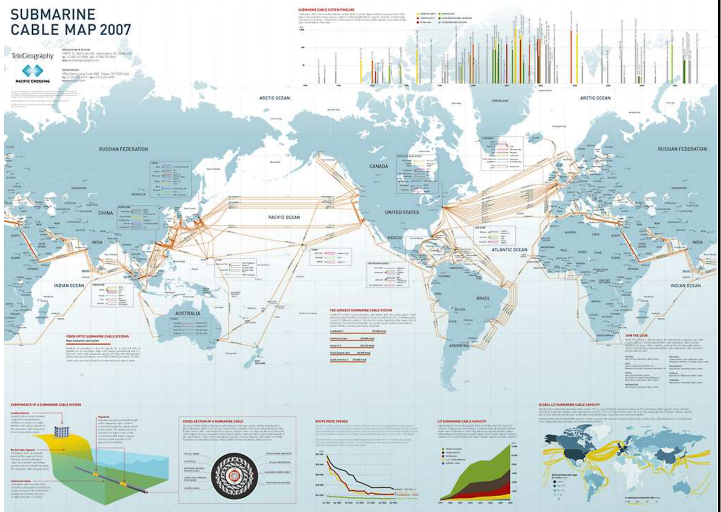


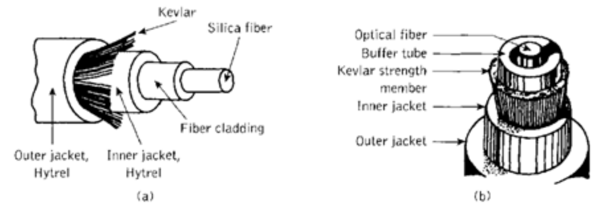
Figure 4.27 Slotted core cable with four fiber ribbons incorporating a total of 100 fibers

Reinforcement

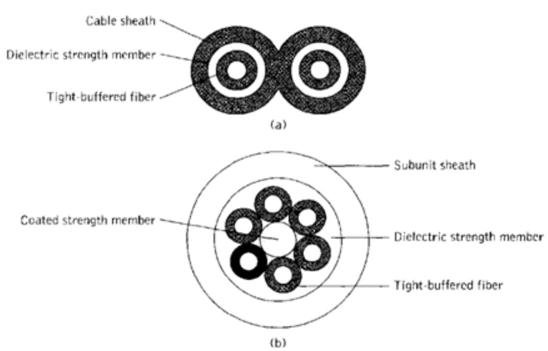
Types of Cables



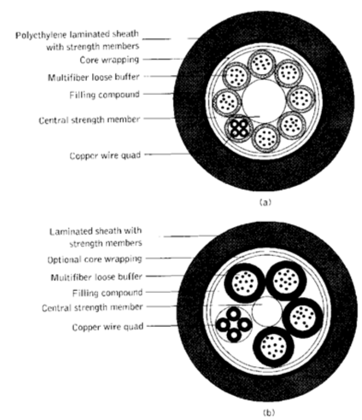
Single-fiber cable



Indoor cable



Outdoor cable (multi-fiber)



Loose tube/loose buffer cable