Glass Processing

Lecture 20 # **Introduction to Dielectric Waveguide: Optical fibers**

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Outline

- Introduction & Useful References
- Basic of Optical Fibers
    - a) Mode LP_{lm}
    - b) Optical fibers Parameters
    - c) Dispersion
    - d) Atenuation
- Fabrication Method
- Properties of Optical fibers
- Special fibers

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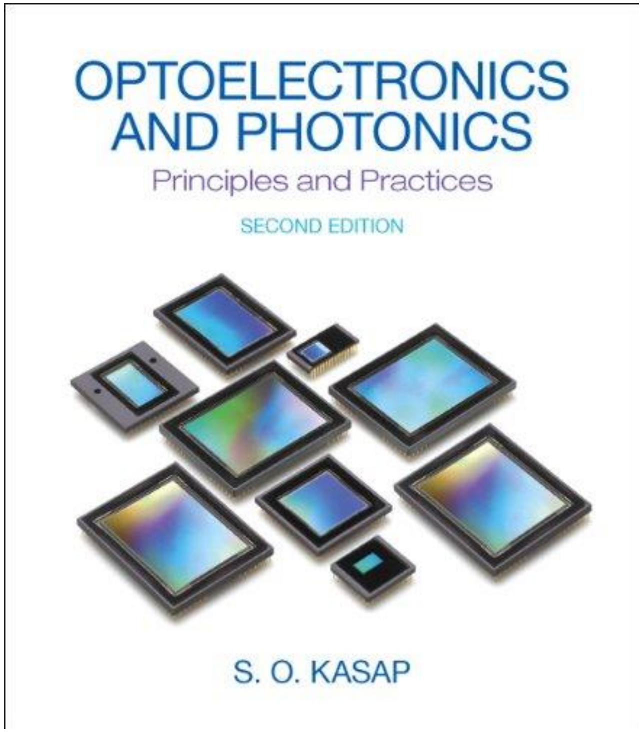
USEFUL REFERENCE

Optoelectronics & Photonics: Principles & Practices (2nd Edition) Hardcover – October 25, 2012 by Safa O. Kasap (Author)



ISBN-10: 0133081753

Second Edition Version 1.056

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Introduction

Optical Fiber Chronology

- **Light guiding in water jet,** ***Tyndall (1878)***
- **Dielectric waveguide analysis,** ***Hondros & Debye (1910)***
- **Early experiments with silica fibers,** ***Lamb (1930)***
- **Image trans. by fiber bundles,** ***van Heel, Kapany (1951)***
- **Mode analysis of optical fiber,** ***Snitzer(1961)***
- **1st. semiconductor lasers ,** ***various groups(1962)***
- **1st. POF,** ***DuPont (1963)***
- **Fiber Lasers proposed & analyzed,** ***Snitzer(1964)***

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Introduction

Optical Fiber Chronology

- **FO proposed for long distance communication, *Kao & Hockman(1966)***
- **First fiber with < 20dB/Km loss, *Corning(1970)***
- **Record low loss of 0.2dB/Km @ 1.55um (1979)**
- **Er fiber amplifier , *Payne & Desurvire (1987)***
- **Holey fibers first proposed, *Russell (1991)***
- ***Fist solid-core PCF fiber made (1996)***
- ***Bend-insensitive fiber introduced, Corning(2007)***

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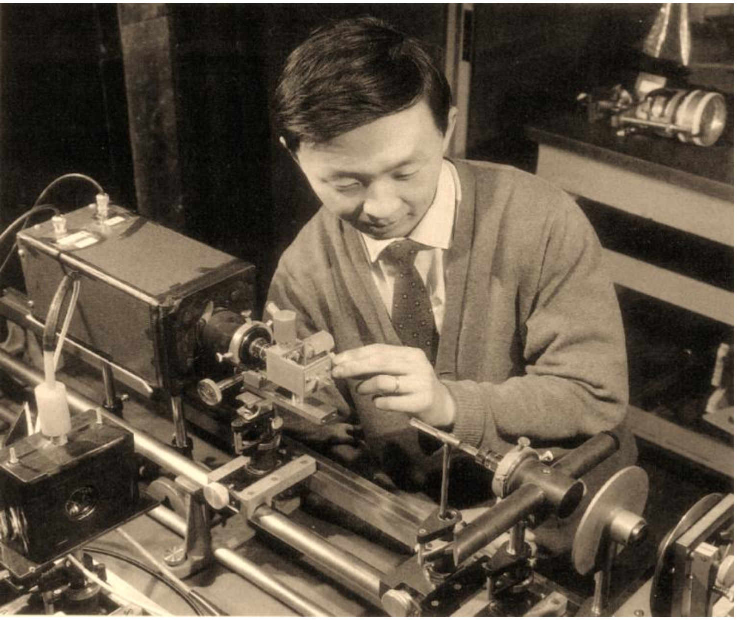
Introduction

Technological Revolution

1960

Theodore Maiman, working at Hughes Research Laboratories in Malibu, California, produced the first laser (Rubi).

(1927-2007)

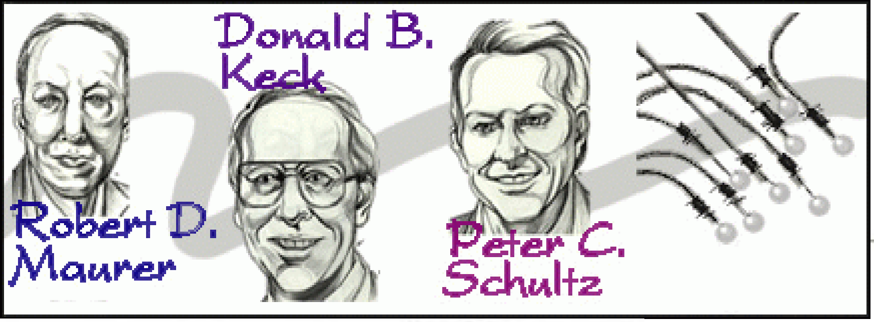


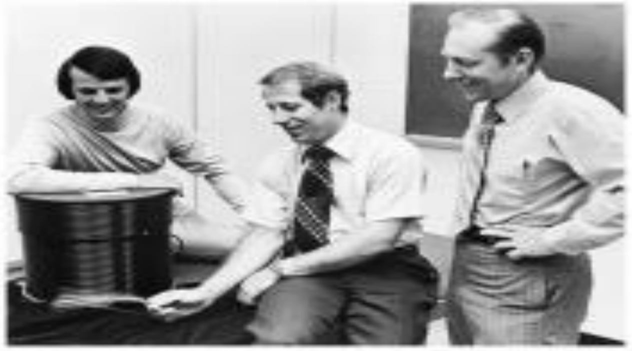
1966

The attenuation of glass is due largely to the presence of impurities, and if a glass can be developed with attenuation of only 20 dB / km, then optical communication could become a reality.

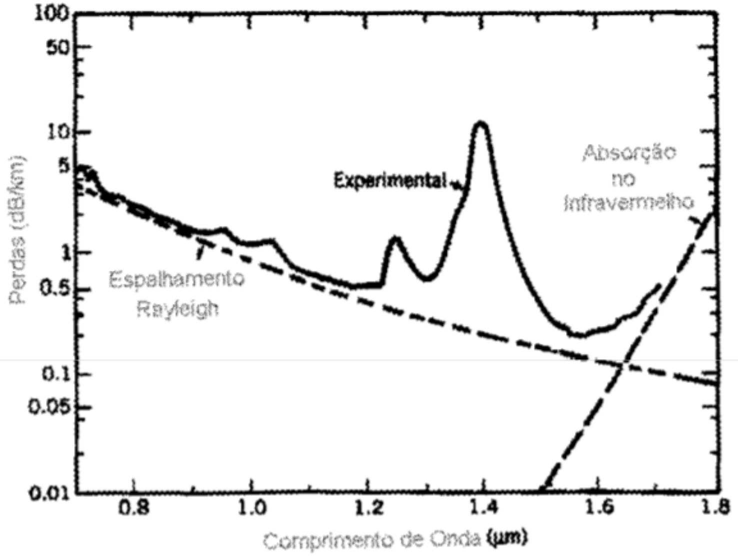
Charles Kao (1933)

2009

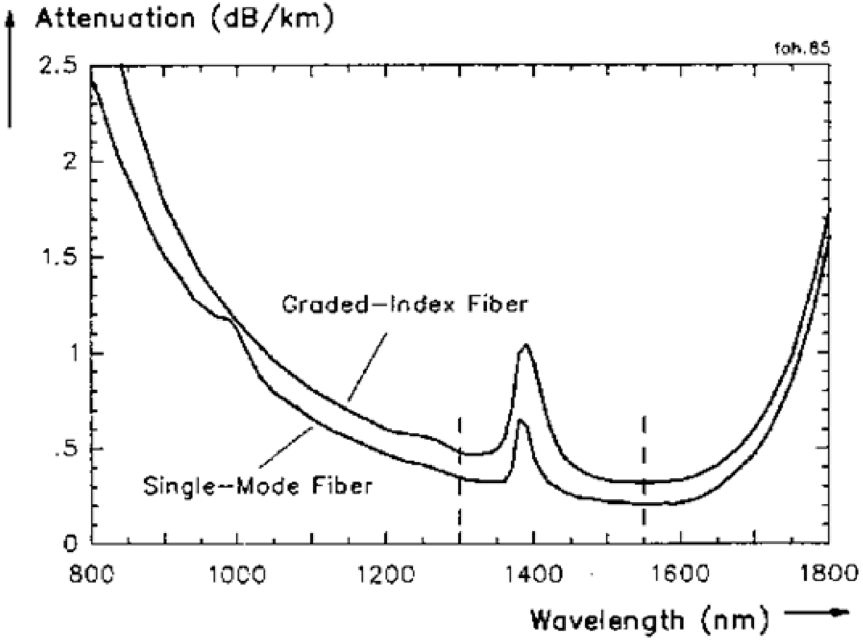




Decade 70

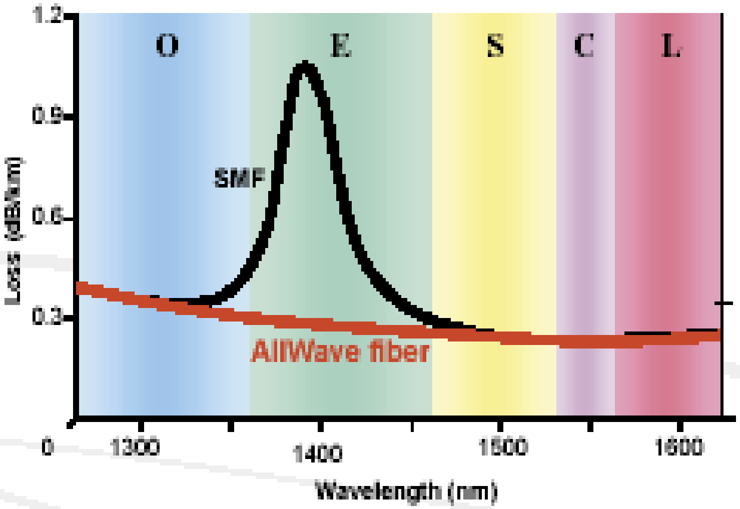


Decade 80



WAVELENGTH DEPENDENCE OF FIBER ATTENUATION

Figure 1. Comparison of Spectral Attenuation of AllWave Fiber and Conventional Single Mode Fiber



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Basic of Optical Fibers

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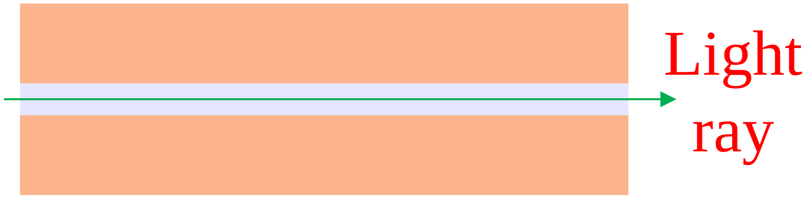
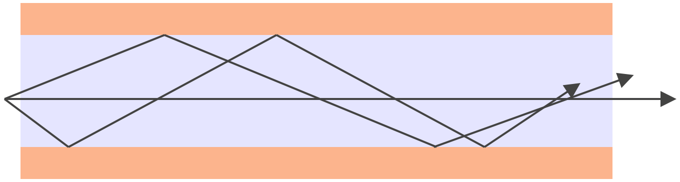
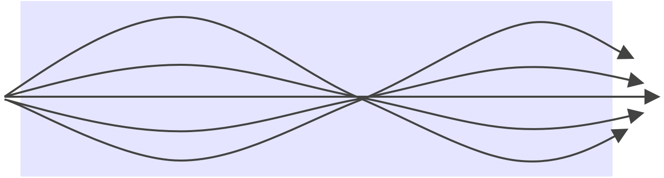
A. Types Of Optical Fiber



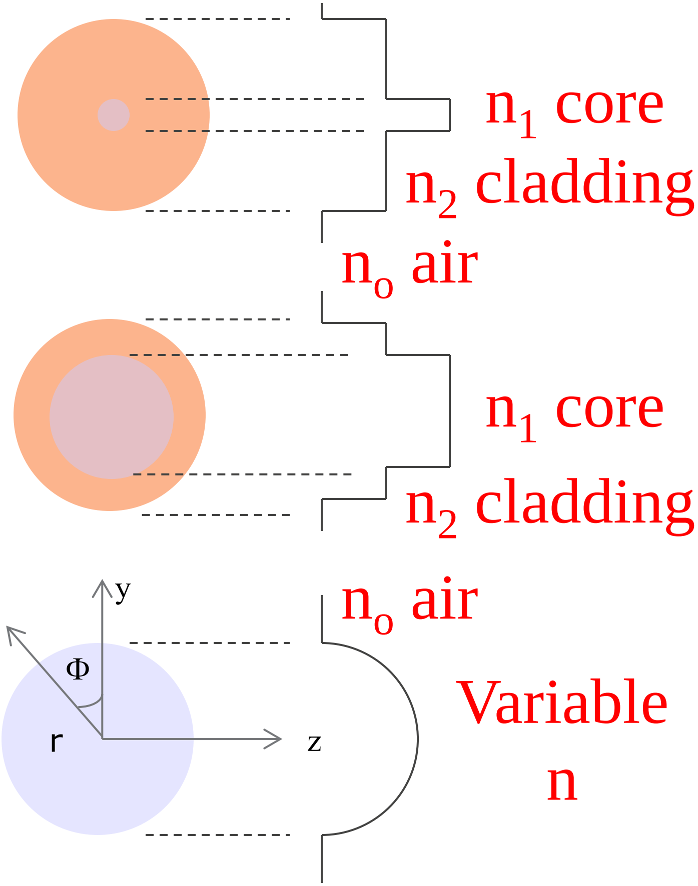
Single-mode step-index Fiber



Multimode step-index Fiber



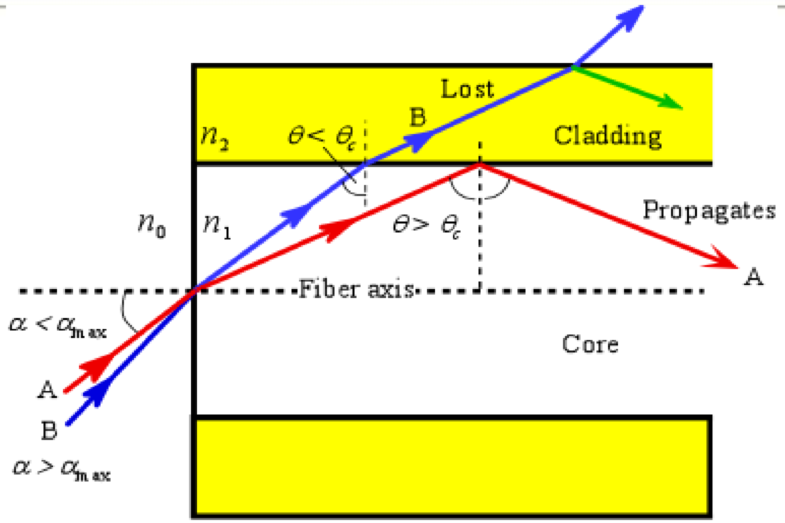
Multimode graded-index Fiber



Index profile

$$n_{Core} > n_{cladding}$$

B. Numerical Aperture (NA)



Maximum acceptance angle $\alpha_{\max}$ is that which just gives total internal reflection at the core-cladding interface, i.e. when $\alpha = \alpha_{\max}$ then $\theta = \theta_c$. Rays with $\alpha > \alpha_{\max}$ (e.g. ray B) become refracted and penetrate the cladding and are eventually lost.

$$\sin\alpha_{max} = \frac{\left(n_1^2 - n_2^2\right)^{1/2}}{n_o} = \frac{\mathrm{NA}}{n_o}$$

$$V = \frac{2\pi a}{\lambda}\mathrm{NA}$$

$$\mathrm{NA} = \left(n_1^2 - n_2^2\right)^{1/2}$$

$2\alpha_{max} =$ **total acceptance angle**

NA is an important factor in light launching designs into the optical fiber.

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Modes in Optical Fibers

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Mode LP_{lm}(linearly Polarized)

Weakly guiding modes in fibers

$\Delta << 1$ weakly guiding fibers

$$E_{LP} = \underbrace{E_{lm}(r,\phi)}_{\text{Field Pattern}}\ \underbrace{\exp j(\omega t - \beta_{lm} z)}_{\text{Traveling wave}}$$

E and B are 90° to each other and z

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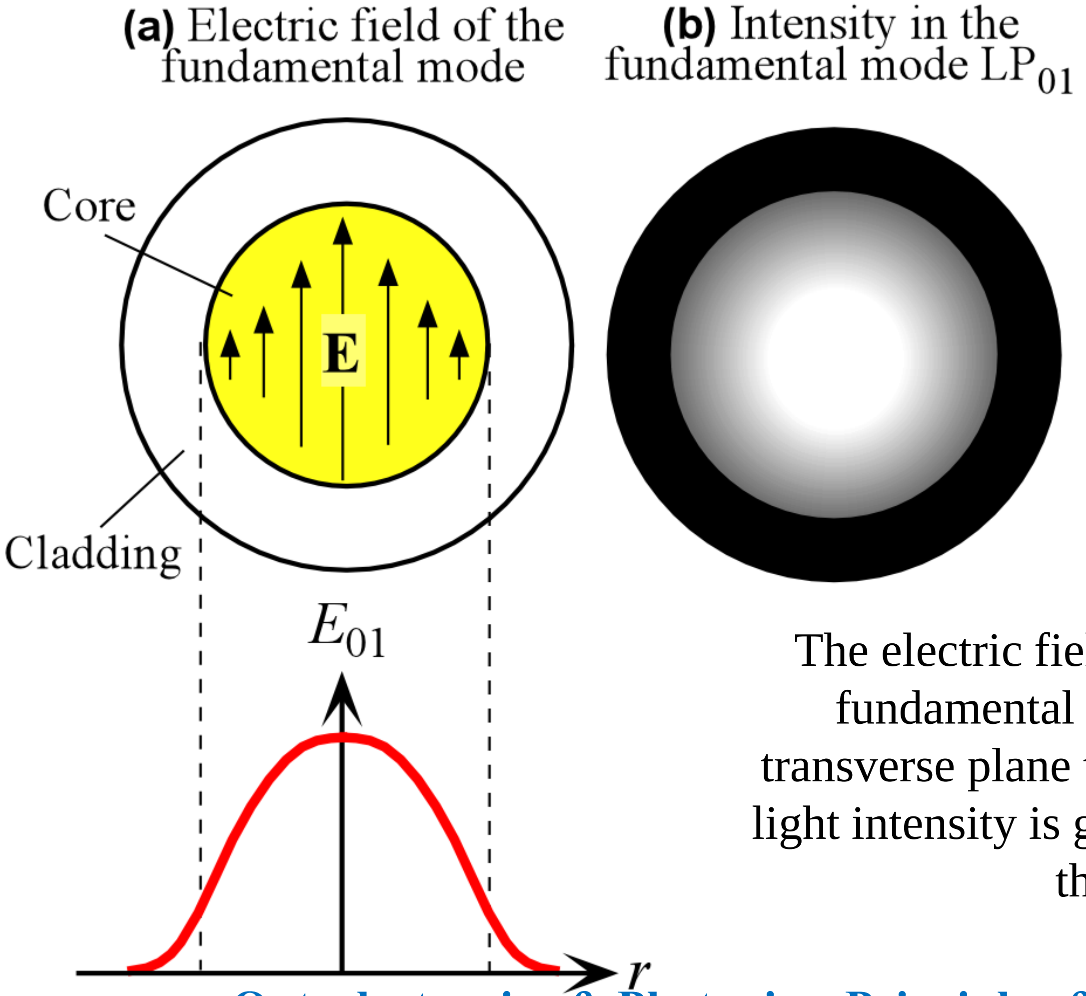
Modes in Optical Fibers

Fundamental Mode is the LP_{01} mode: $l = 0$ and $m = 1$



The electric field distribution of the fundamental mode, LP_{01}, in the transverse plane to the fiber axis z. The light intensity is greatest at the center of the fiber

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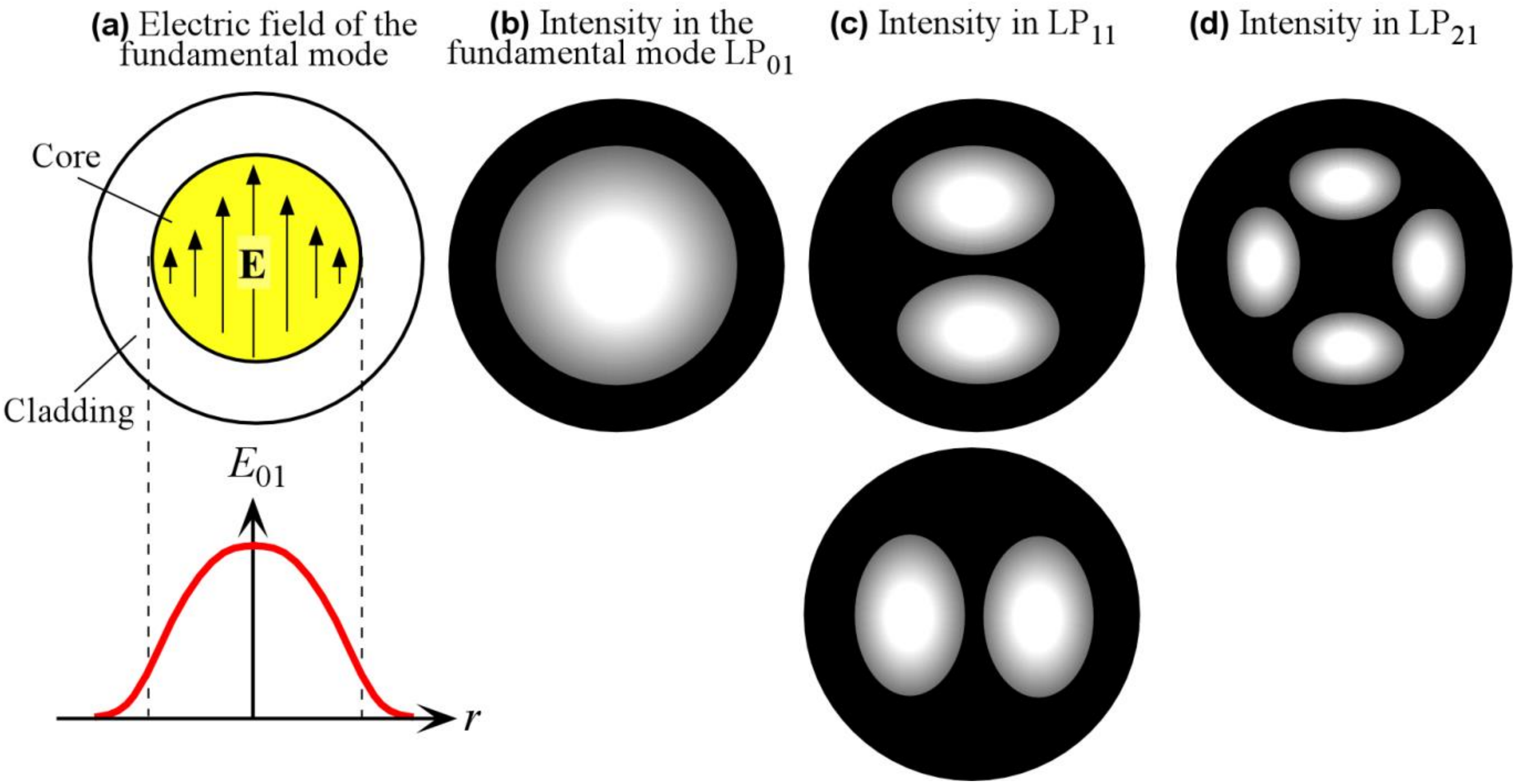
Modes in Optical Fibers


(a) Electric field of the fundamental mode

(b) Intensity in the fundamental mode LP_{01}

(c) Intensity in LP_{11}

(d) Intensity in LP_{21}

The electric field distribution of the fundamental mode in the transverse plane to the fiber axis *z*. The light intensity is greatest at the center of the fiber. Intensity patterns in LP_{01}, LP_{11} and LP_{21} modes. (a) The field in the fundamental mode. (b)-(d) Indicative light intensity distributions in three modes, LP_{01}, LP_{11} and LP_{21}.

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Modes in Optical Fibers

LP_{lm}

$$E_{\mathrm{LP}} = E_{lm}(r,\phi)\exp j(\omega t - \beta_{lm} z)$$

m = number of maxima along r starting from the core center. Determines the reflection angle θ

$2l$ = number of maxima around a circumference

l - radial mode number

l - extent of helical propagation, i.e. the amount of skew ray contribution to the mode.

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Optical Fiber Parameters

$n = (n_1 + n_2)/2$ = **average refractive index**

$\Delta =$ **normalized index difference**

$\Delta = (n_1 - n_2)/n_1 \approx (n_1{}^2 - n_2{}^2)/2$

***V*-number** $$V = \frac{2\pi a}{\lambda}\left(n_1^2 - n_2^2\right)^{1/2} = \frac{2\pi a}{\lambda}\left(2n_1 n\Delta\right)^{1/2}$$

$V < 2.405$ only 1 mode exists. Fundamental mode

$V < 2.405$ or $\lambda > \lambda_c$ Single mode fiber (SMF).

$V > 2.405$ Multimode fiber

Number of modes $$M \approx \frac{V^2}{2}$$

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Dispersion = Spread of Information

a) **Intermode (Intermodal) Dispersion: Multimode fibers**

b) Materials Dispersion

Group velocity depends on N_g and hence on λ

c) Waveguide Dispersion

Group velocity depends on waveguide structure

d) Chromatic Dispersion

Material dispersion + Waveguide Dispersion

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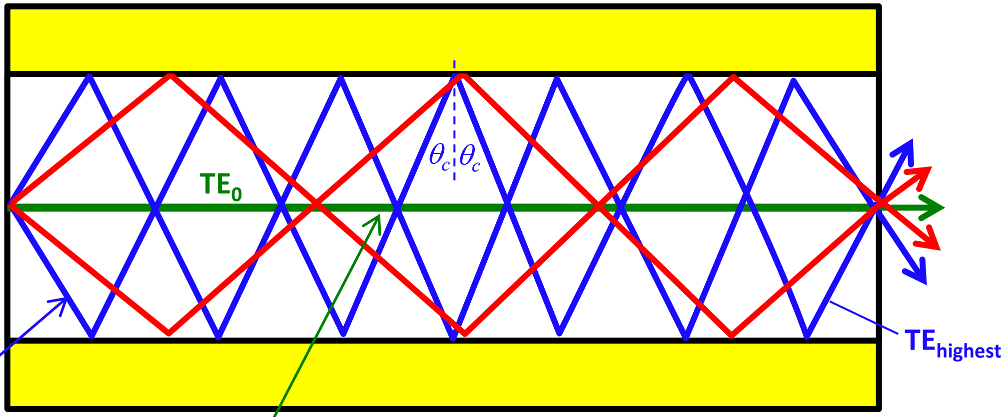
a) Intermode Dispersion (MMF)



$$v_{g\min} \approx \frac{c}{n_1}\sin\theta_c = \frac{c}{n_1}\left(\frac{n_2}{n_1}\right)$$

$$v_{g\max} \approx \frac{c}{n_1}$$

$$\Delta\tau = \frac{L}{v_{g\min}} - \frac{L}{v_{g\max}} \longrightarrow \frac{\Delta\tau}{L} = \frac{(n_1 - n_2)}{c}\left(\frac{n_1}{n_2}\right)$$

$$\frac{\Delta\tau}{L} \approx \frac{n_1 - n_2}{c}$$

$\Delta\tau/L \approx$ 10 – 50 ns / km

Depends on length!

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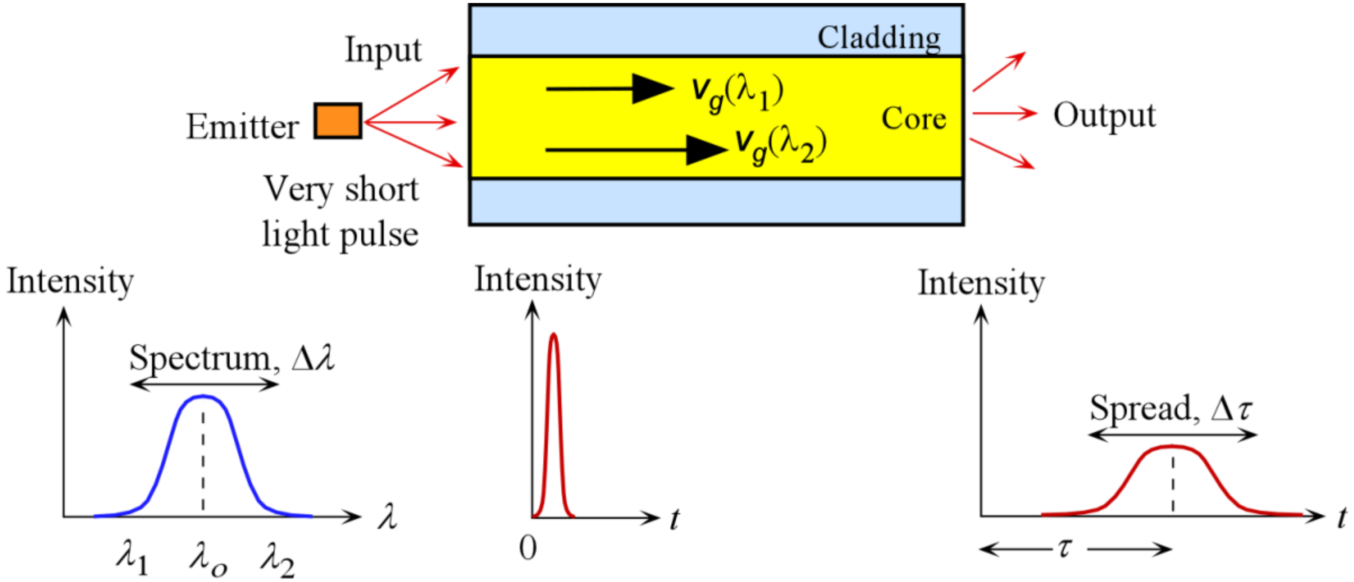
Intramode Dispersion (SMF)

Dispersion in the fundamental mode



Group Delay $\tau = L / v_g$

Group velocity v_g depends on

Refractive index = $n(\lambda)$ **Material Dispersion**

V-number = $V(\lambda)$ **Waveguide Dispersion**

$\Delta = (n_1 - n_2)/n_1 = \Delta(\lambda)$ **Profile Dispersion**

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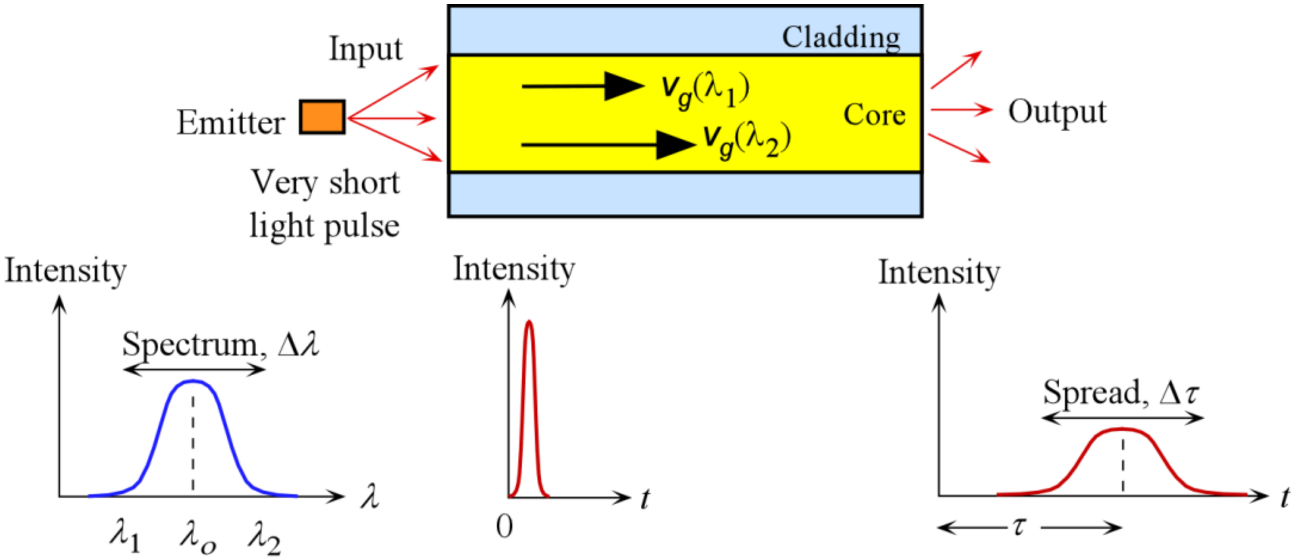
b) Material Dispersion



Emitter emits a spectrum $\Delta\lambda$ of wavelengths.

Waves in the guide with different free space wavelengths travel at different group velocities due to the wavelength dependence of n_1. The waves arrive at the end of the fiber at different times and hence result in a broadened output pulse.

$$\boxed{\frac{\Delta\tau}{L} = D_m \Delta\lambda}$$

D_m = Material dispersion coefficient, ps nm^{-1} km^{-1}

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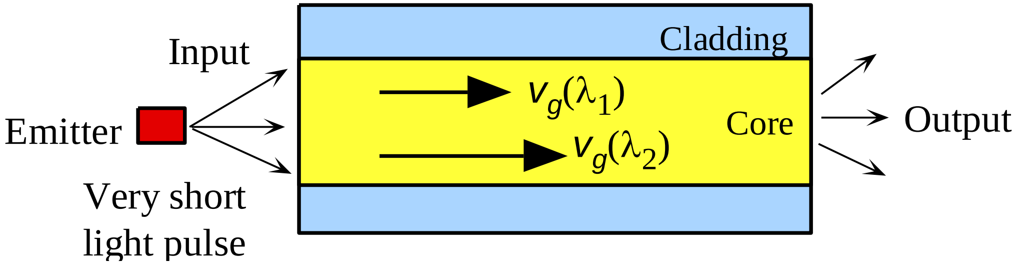
Material Dispersion


Input

Emitter

Very short
light pulse

Cladding

Core

$v_g(\lambda_1)$

$v_g(\lambda_2)$

Output

Group velocity

$$v_g = c / N_g$$

Depends on the wavelength

$$\frac{\Delta\tau}{L} = D_m \Delta\lambda$$

D_m = Material dispersion coefficient, ps nm^{-1} km^{-1}

$$D_m \approx -\frac{\lambda}{c}\left(\frac{d^2 n}{d\lambda^2}\right)$$

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c) Waveguide dispersion

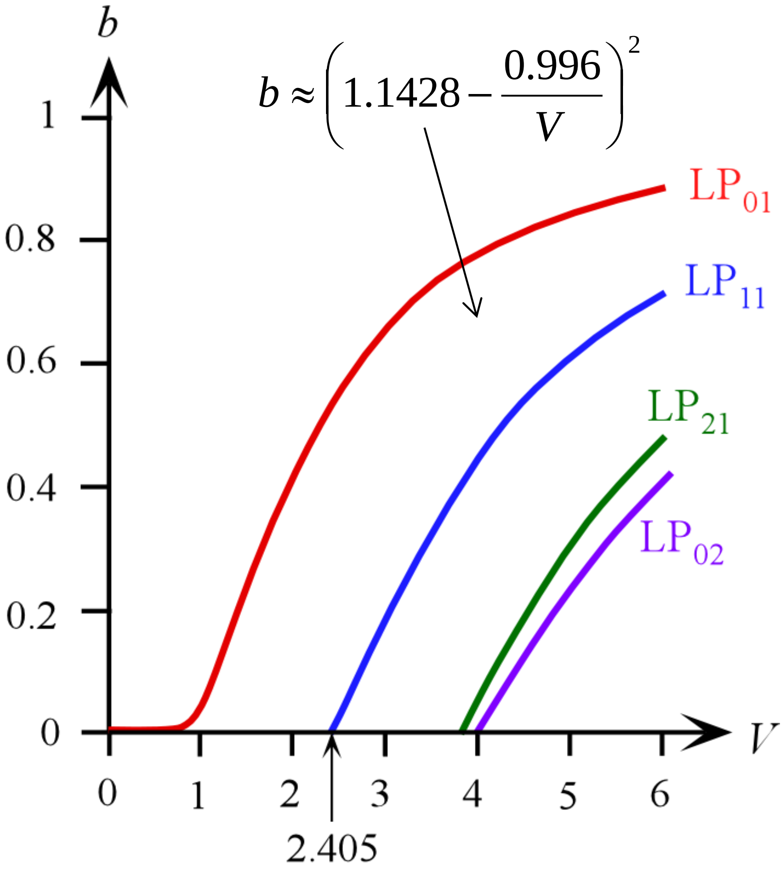
b hence *β* depends on *V* and hence on *λ*

$$V = \frac{2\pi a}{\lambda}\left(n_1^2 - n_2^2\right)^{1/2}$$

Normalized propagation constant

$$b = \frac{(\beta/k)^2 - n_2^2}{n_1^2 - n_2^2}$$

$$k = 2\pi/\lambda$$



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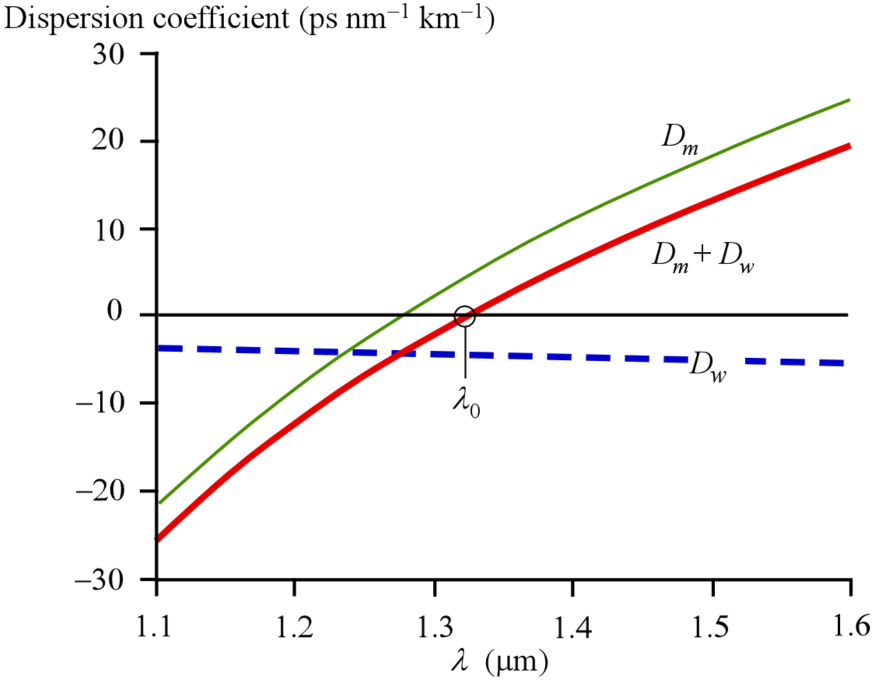
Chromatic Dispersion



Material dispersion coefficient (D_m) for the core material (taken as SiO_2), waveguide dispersion coefficient (D_w) (a = 4.2 µm) and the total or chromatic dispersion coefficient D_{ch} (= D_m + D_w) as a function of free space wavelength, λ

Chromatic = Material + Waveguide

$$\frac{\Delta\tau}{L} = (D_m + D_w)\Delta\lambda$$

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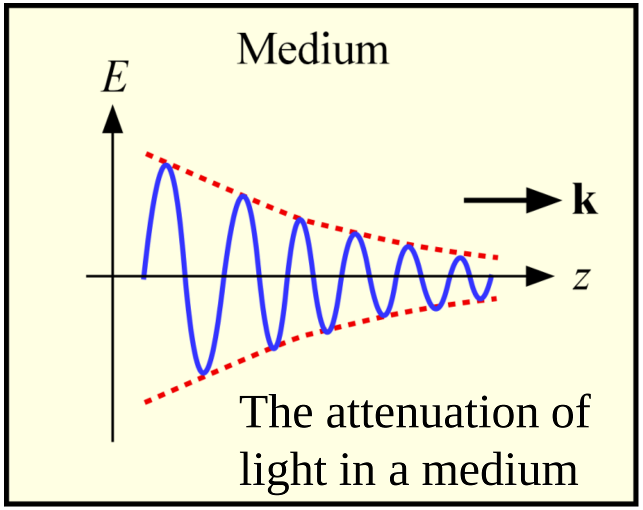
Attenuation



The attenuation of light in a medium

Attenuation = Absorption + Scattering

Attenuation coefficient α is defined as the *fractional decrease in the optical power per unit distance.* α is in m^{-1}.

$$P_{\text{out}} = P_{\text{in}}\exp(-\alpha L)$$

$$\alpha_{\text{dB}} = \frac{1}{L}10\log\left(\frac{P_{\text{in}}}{P_{\text{out}}}\right) \qquad \alpha_{\text{dB}} = \frac{10}{\ln(10)}\alpha = 4.34\alpha$$

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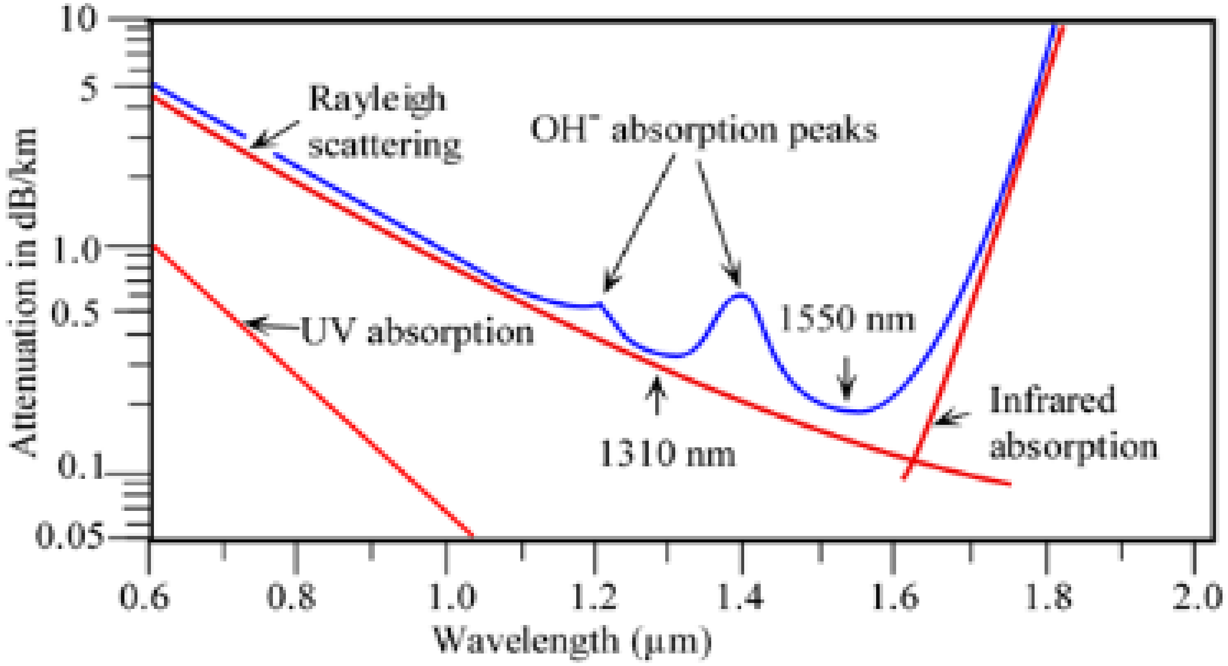
Attenuation

Absorption and Scattering Loss



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Optical Loss Mechanisms

1) Losses (Material):

a) Intrinsic Absorption

UV Region

- "Urbach tail": $$\alpha = \alpha_o \exp\left(\frac{\sigma \hbar}{k_B T}(\omega - \omega_o)\right)$$

  - SiO_2 : $\lambda_o \cong 140$ nm
  - GeO_2 : $\lambda_o \cong 185$ nm

IR Region

- $\alpha_{IR} = 7.81 \times 10^{11} \exp(-48.48/\lambda\ [\mu m])$ [dB/km]

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Optical Loss Mechanisms

b) Absorption due to impurities:

Transition Metal: Cr, Mn, Cu, Fe, Ni, etc

- 1-10 dB/km @ 1-5 ppm

hydroxyl Ions (OH^-)

- ν_{OH} (fondamental) → 2.73 μm

$2\nu_{OH} \rightarrow 1.38\ \mu m$

$3\nu_{OH} \rightarrow 0.95\ \mu m$

$2\nu_{OH} + \nu_1 \rightarrow 1.24\ \mu m$

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Optical Loss Mechanisms

c) Rayleigh scattering :

- Microscopic variations (sub-λ) density of Material.
- $\alpha_R \cong (0.75 + 66\ \Delta n_{Ge})\ \lambda^{-4}$ [µm]   [dB/km]

où Δn_{Ge} : n variation due to Ge.

- Main factor losses in the visible and near infrared

(→ 1.6 µm)

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Optical Loss Mechanisms

2) Guide Loss:

a) Guide Imperfection:

- Irregularities of the interface Core-cladding;
- Mie Diffusion (defects >> λ)
- < 0.05 dB/km for silice.

b) Bending Loss:

- Distortion mode: Distortion of indice profil.

$$n'(r) = n(r)\left(1 + \frac{r}{R}\cos\varphi\right)$$

R : Rayon de courbure

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Optical Loss Mechanisms

- $\alpha_c = \frac{A_c}{\sqrt{R(m)}} e^{-KR(m)} \qquad [\mathrm{dB/m}]$

$$\text{où : } A_c = \frac{1}{2}\left(\frac{\pi}{aw^3}\right)^{1/2}\left[\frac{u}{wK_1(w)}\right]^2 \cong \frac{30(\Delta n)^{1/4}}{\sqrt{\lambda(m)}}\left(\frac{\lambda_c}{\lambda}\right)^{3/2}\left[\frac{\mathrm{dB}}{\sqrt{\mathrm{m}}}\right]$$

$$K = \frac{4\Delta n w^3}{3aV^2 n_2} \cong 0.705\frac{(\Delta n)^{3/2}}{\lambda(m)}\left(2.748 - 0.996\frac{\lambda}{\lambda_c}\right)^3 \quad \left[\mathrm{m}^{-1}\right]$$

D. Marcuse, JOSA, 66(3), 1976

- e.g. $\Delta n = 5 \times 10^{-3}$ $\qquad \lambda = 1.0\mu\mathrm{m}$ $\qquad \lambda_c = 900$ nm

$\alpha_{2\mathrm{cm}} = 1$ dB/km $\qquad \alpha_{1\mathrm{cm}} = 10^4$ dB/km

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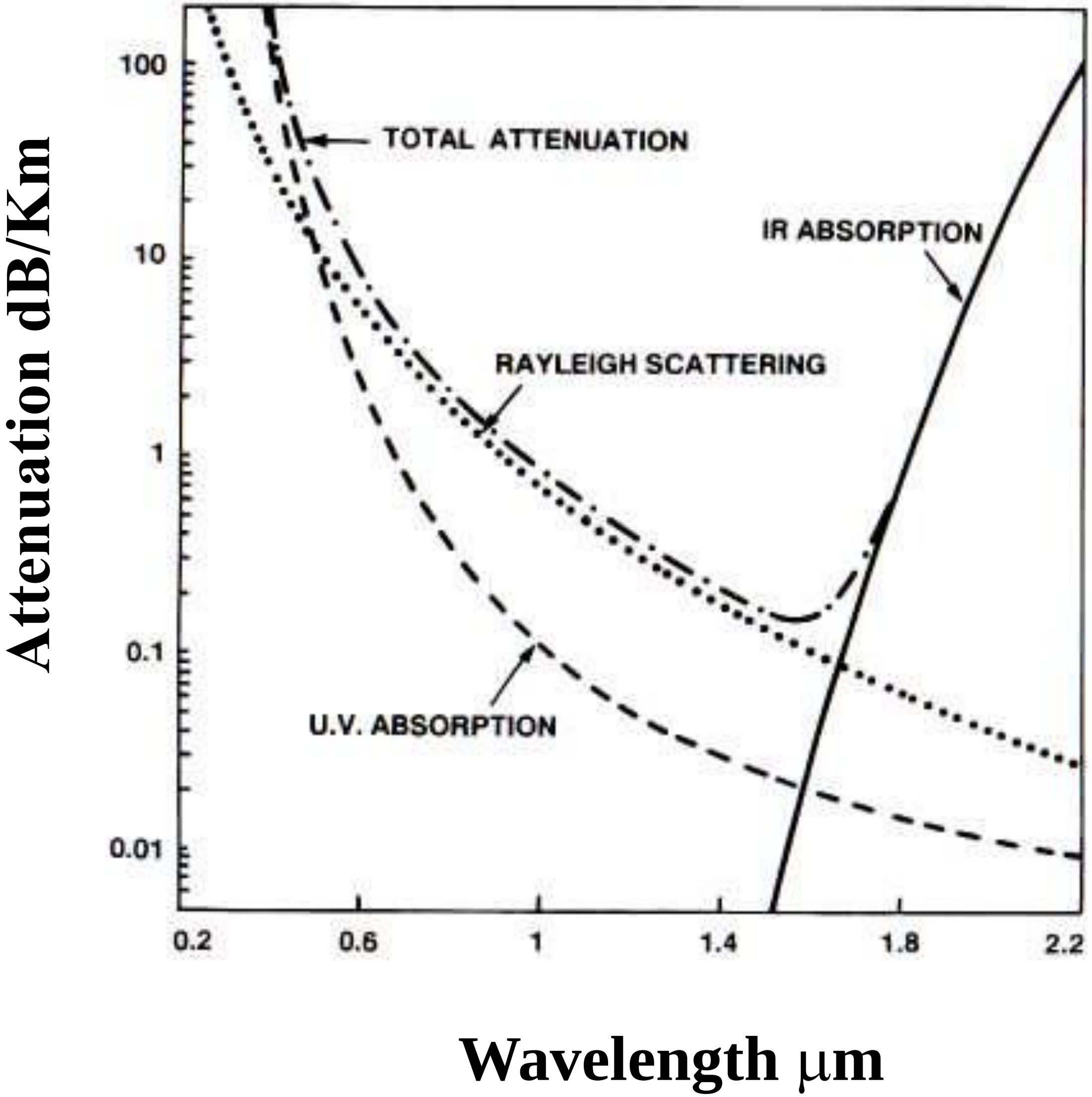
Optical Loss Mechanisms



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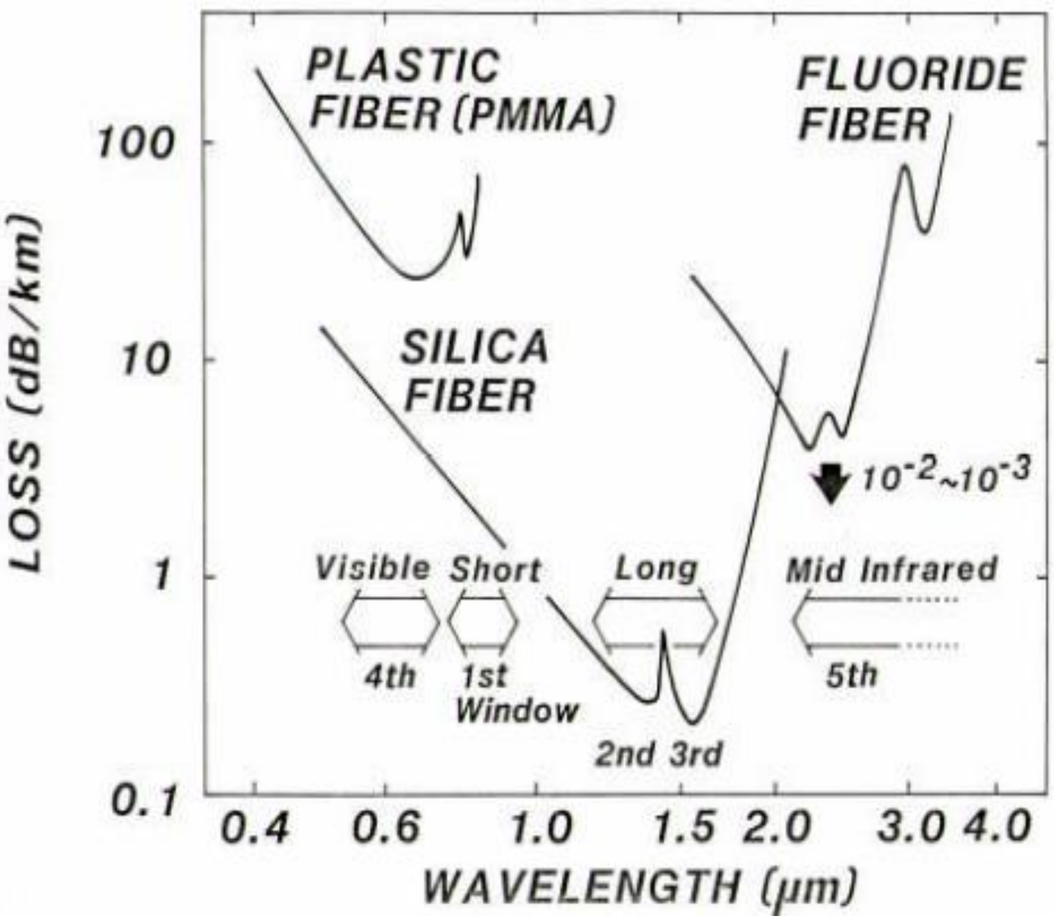
Optical Loss for different Materials

Transmission Window:

Optical Loss for Different Fiber Materials



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Fabrication Methods

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Optical Fiber Fabrication Methods

- **Glass**
  - CVD preform→ fiber drawing

  - Rod-in-tube prefrom → fiber drawing
  - Cast preform → fiber drawing
  - Double crucible → direct draw
  - Sol gel preform → fiber drawing
  - Stack and draw → PCFs

- **Polycrystalline**
  - Extrusion
  - Hot rolling

- **Monocrystalline**
  - Seed crystal growth from melt
  - Zone melting

- **Polymer**
  - Extrusion
  - Cast prefrom → fiber drawing

MCVD—Modified Chemical Vapor Deposition
PMCVD—RF Plasma Enhanced MCVD
PCVD—Microwave Plasma CVD
OVD—Outside Vapor Deposition
VAD—Axial Vapor Deposition

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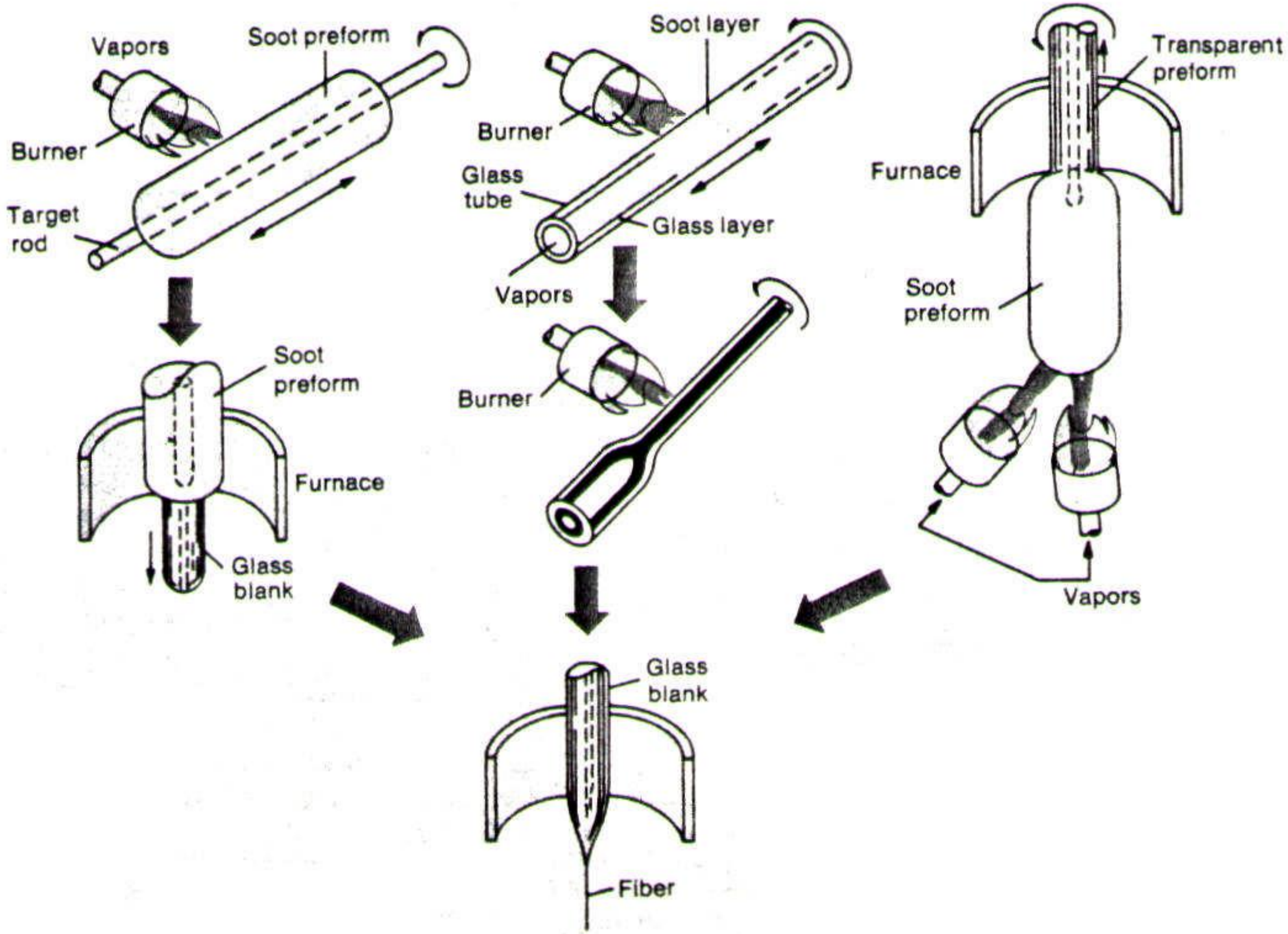
Optical Fiber Fabrication Methods

OVD **MCVD** **AVD**



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MCVD system

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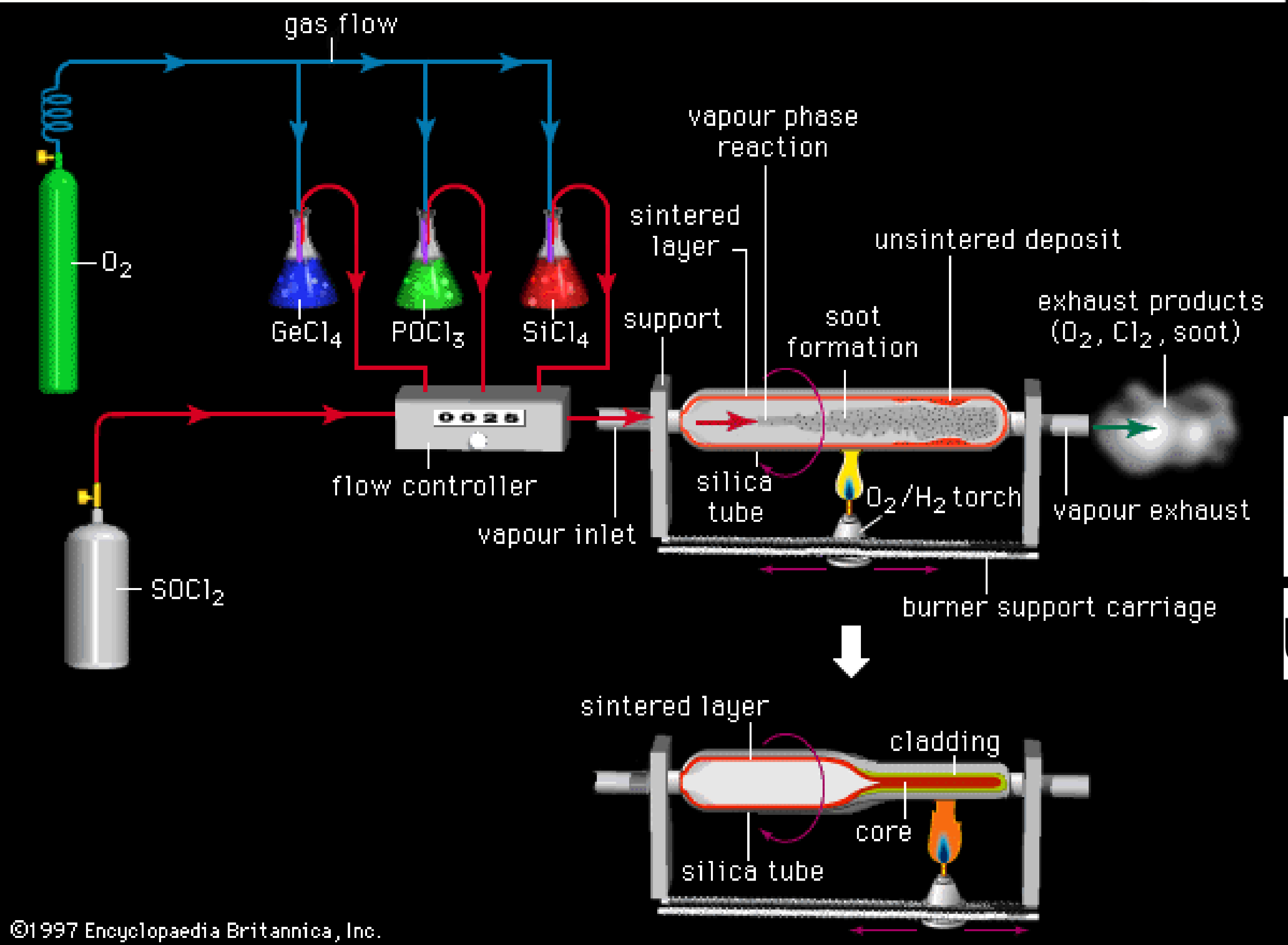
MCVD Process



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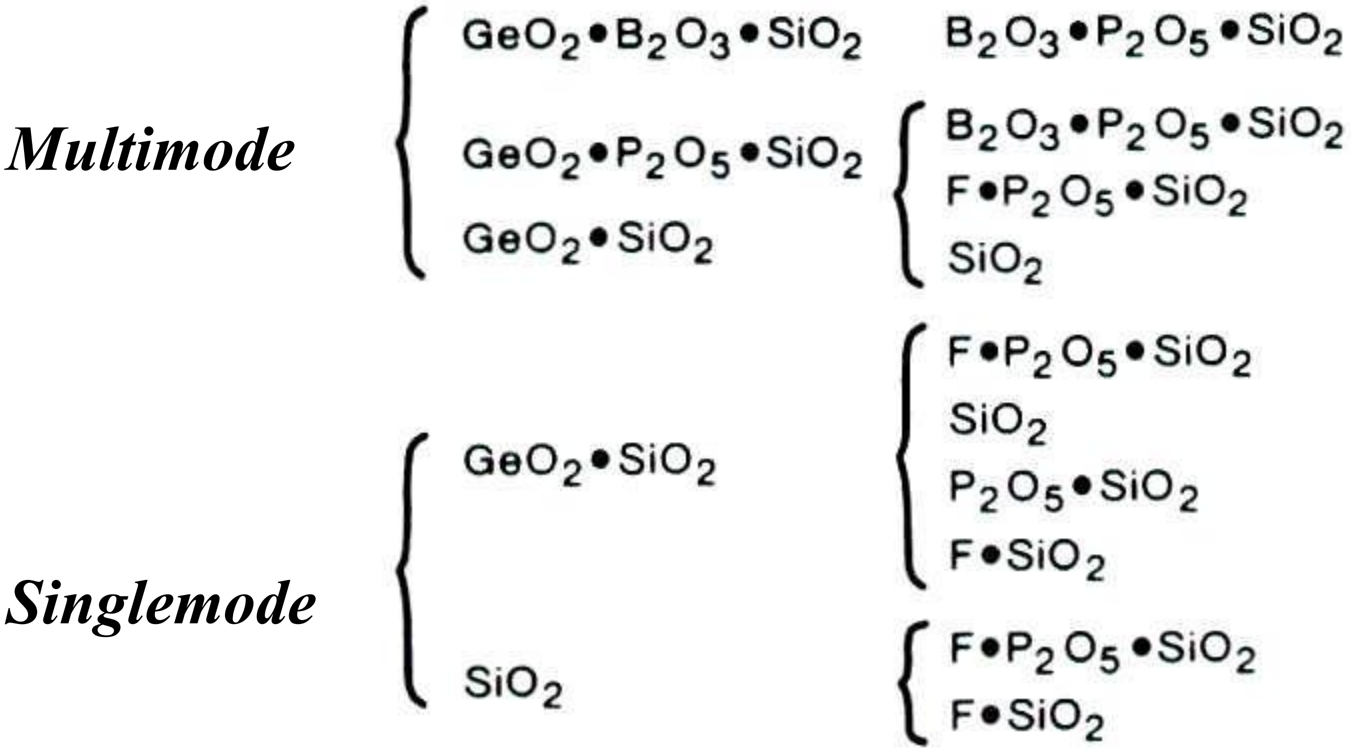
Typical Glass Fiber Compositions



Multimode

- $GeO_2 \bullet B_2O_3 \bullet SiO_2$
  - $B_2O_3 \bullet P_2O_5 \bullet SiO_2$
- $GeO_2 \bullet P_2O_5 \bullet SiO_2$
- $GeO_2 \bullet SiO_2$
  - $B_2O_3 \bullet P_2O_5 \bullet SiO_2$
  - $F \bullet P_2O_5 \bullet SiO_2$
  - SiO_2

Singlemode

- $GeO_2 \bullet SiO_2$
  - $F \bullet P_2O_5 \bullet SiO_2$
  - SiO_2
  - $P_2O_5 \bullet SiO_2$
  - $F \bullet SiO_2$
- SiO_2
  - $F \bullet P_2O_5 \bullet SiO_2$
  - $F \bullet SiO_2$

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Dopant Effects in Silica Glass

	INDEX n	EXPANSION α	VISCOSITY η	STABILITY	DURABILITY	DISPERSION λ_0	RAYLEIGH SCATTERING	IR LOSS	COST
GeO_2	↑	↑	↓	●	↓	↑	↑↑	●	↑
P_2O_5	↑	↑	↓↓	●	↓↓	●	↑	↑	●
B_2O_3	↓	↑	↓↓	●	↓↓	●	?	↑	●
F	↓↓	●	↓	●	↓↓	●	?	●	●
TiO_2	↑↑	↓	↓	↓	?	↑	?	●	●
Al_2O_3	↑	↑	↓	↓↓	?	↑	?	●	●

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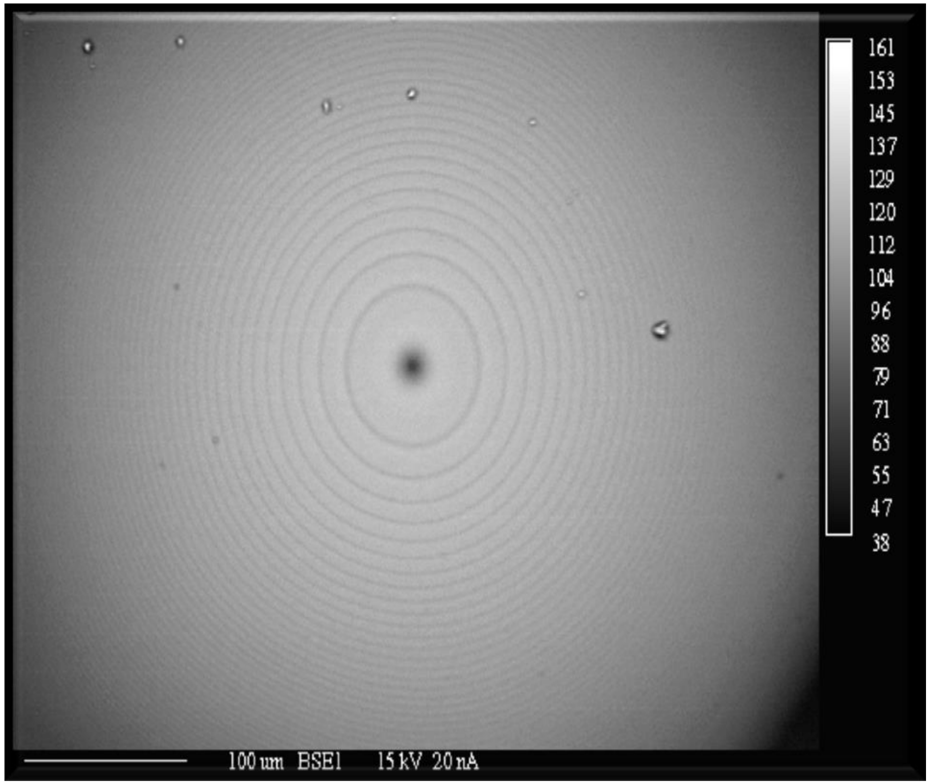
Indice Profil of the Preform



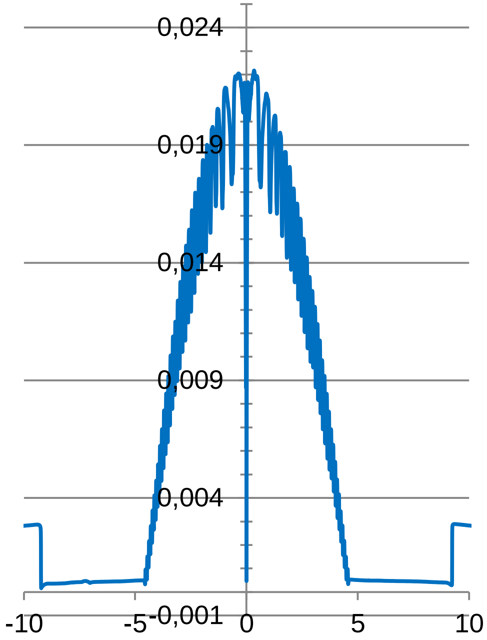


Image BSE of the GRIN preform

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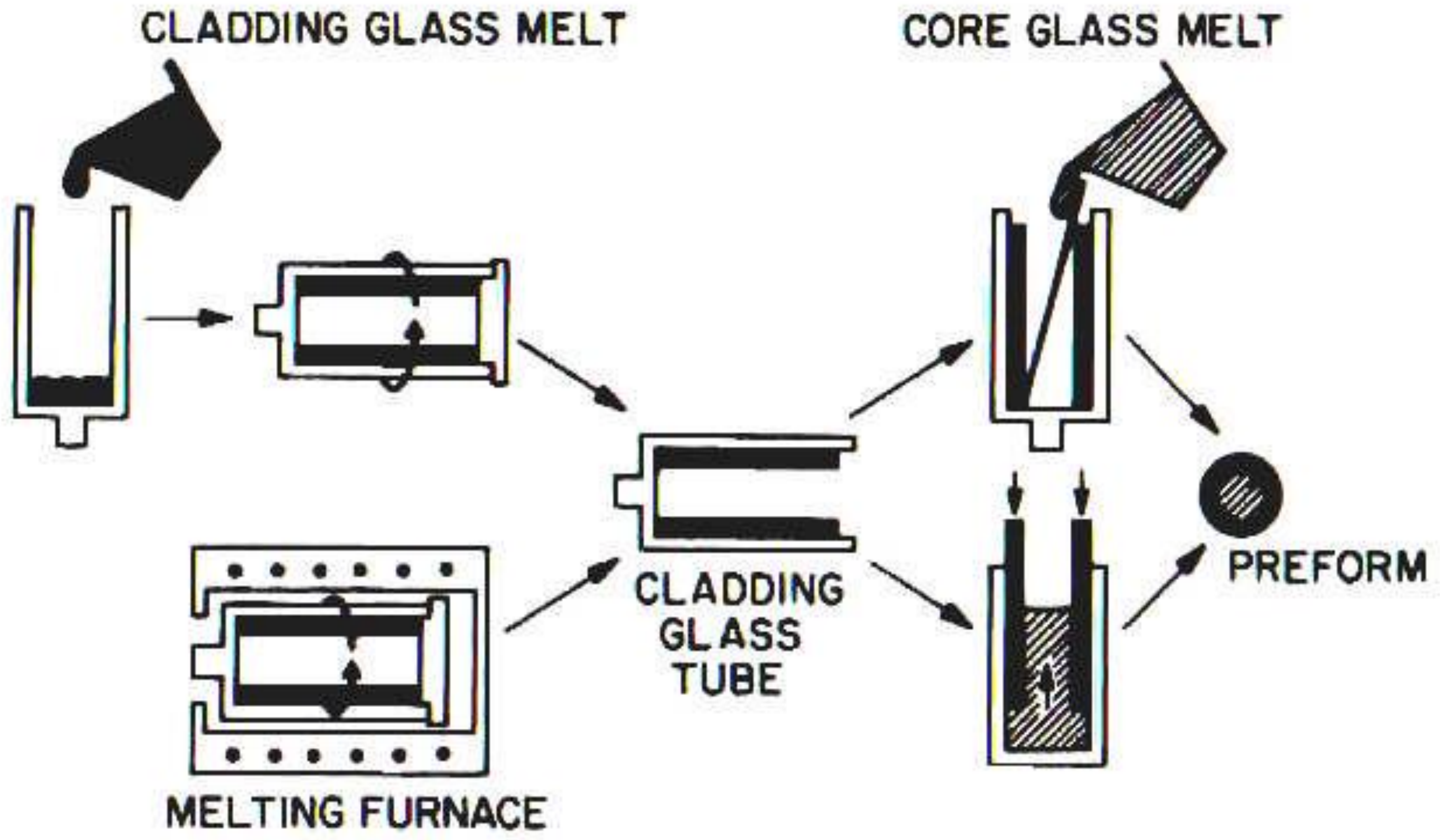
Other Method: Rotational Casting



Rotational Preform Casting Process

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Optical Fiber Coatings

- **Environmental Protection**
  - Abrasion
  - Moisture ingress
  - Hydrogen diffusion
  - Chemical attack
  - Temperature resistance
  - Mechanical bending

- **Sensing**
  - Fluorescence
  - Swelling
  - Chem/Bio reactive
  - Magnetic
  - Acoustic
  - Piezoelectric

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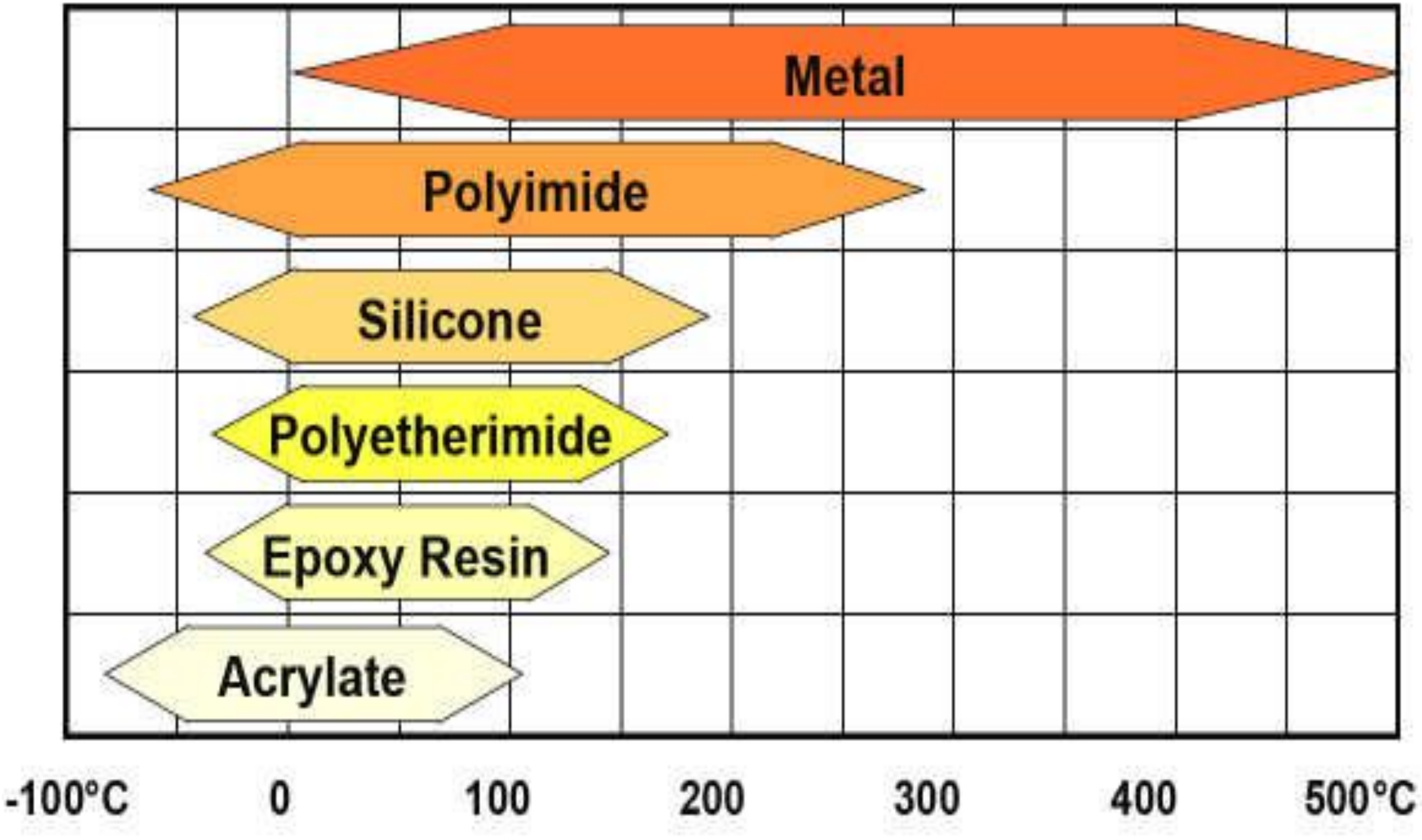
Coatings Materials



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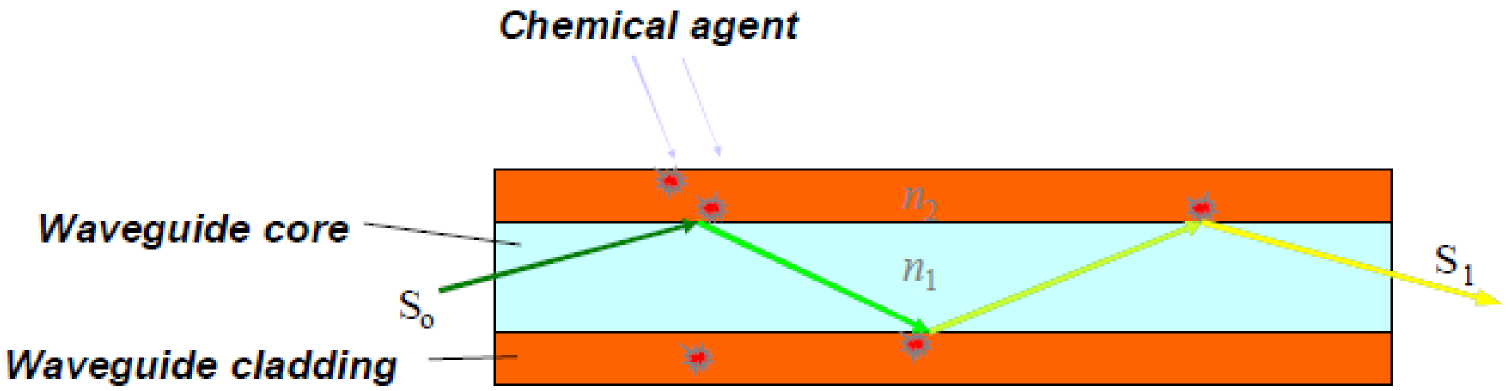
Evanescent-Wave Sensor Principle

Chemically-Induced Cladding Change



- Presence of chemical agent in cladding region changes optical properties
-
- Light propagating through sensor waveguide is affected by changes in exposed region

Fiber Drawing Process

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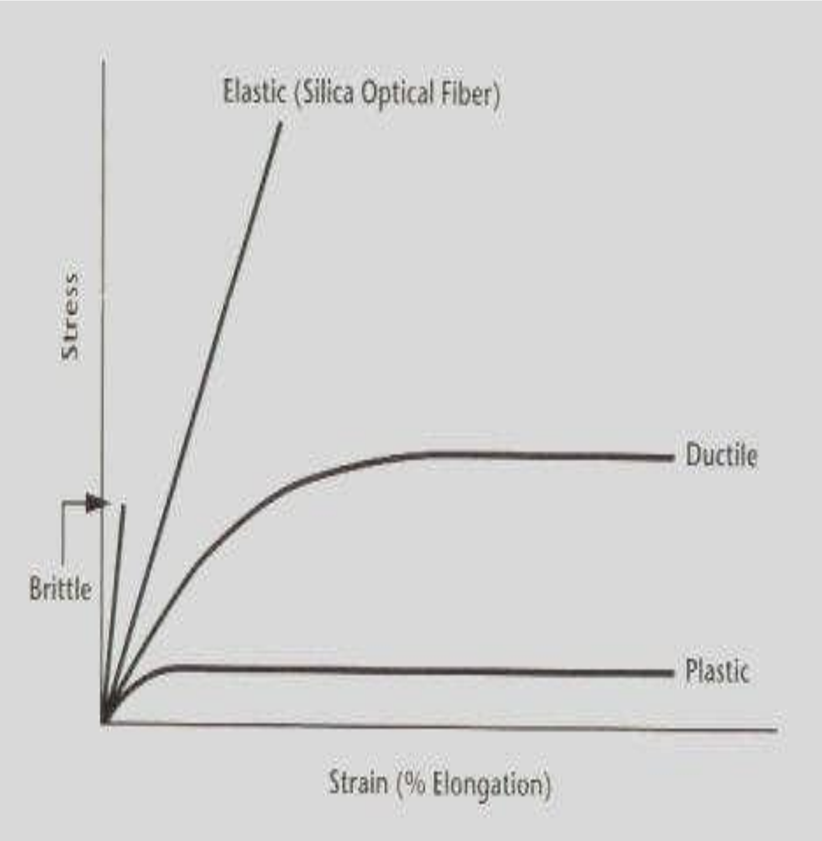
Mechanical Properties

Silica Fiber Strength



- Optical fibers behave as an elastic material up to the point of failure.
- Theoretical strength of silica glass determined by cohesive bond strength of constituent atoms > 20 GPa (3-5Mpsi)!
- Glass fiber strengths are on the order of **4-6 GPa** (~800Kpsi).
- Actual strength is limited by **surface flaw distribution**.

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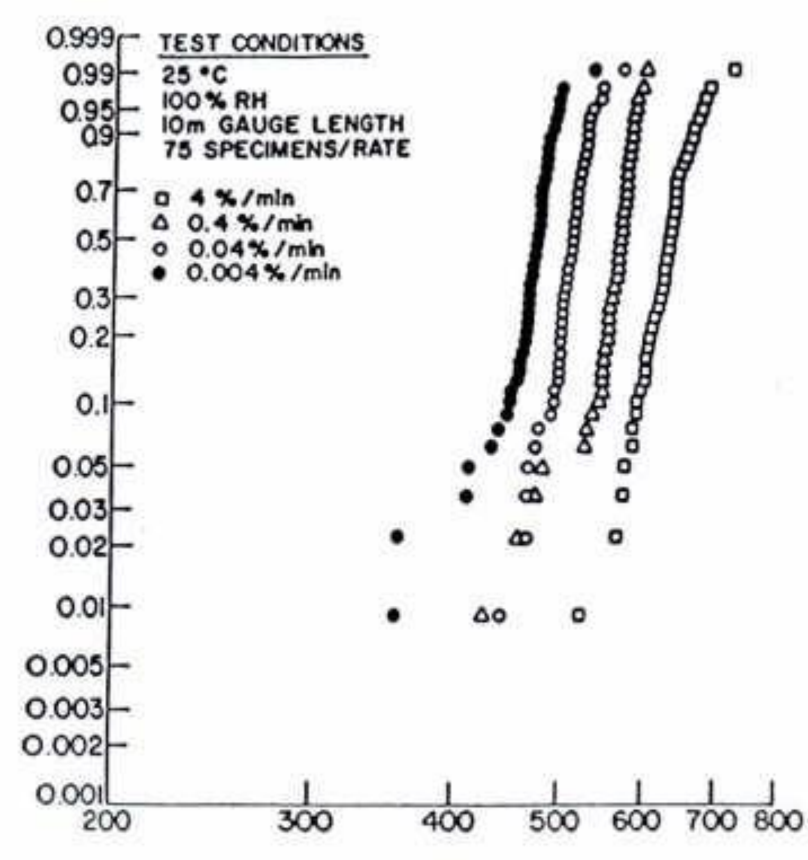
Breaking Strength

Effective fiber strength is a function of:

- *Length*
- *Strain rate*
- *Temperature*
- *Relative Humidity*
- *Chemical or mechanically induced flaws*



Strength Kpsi

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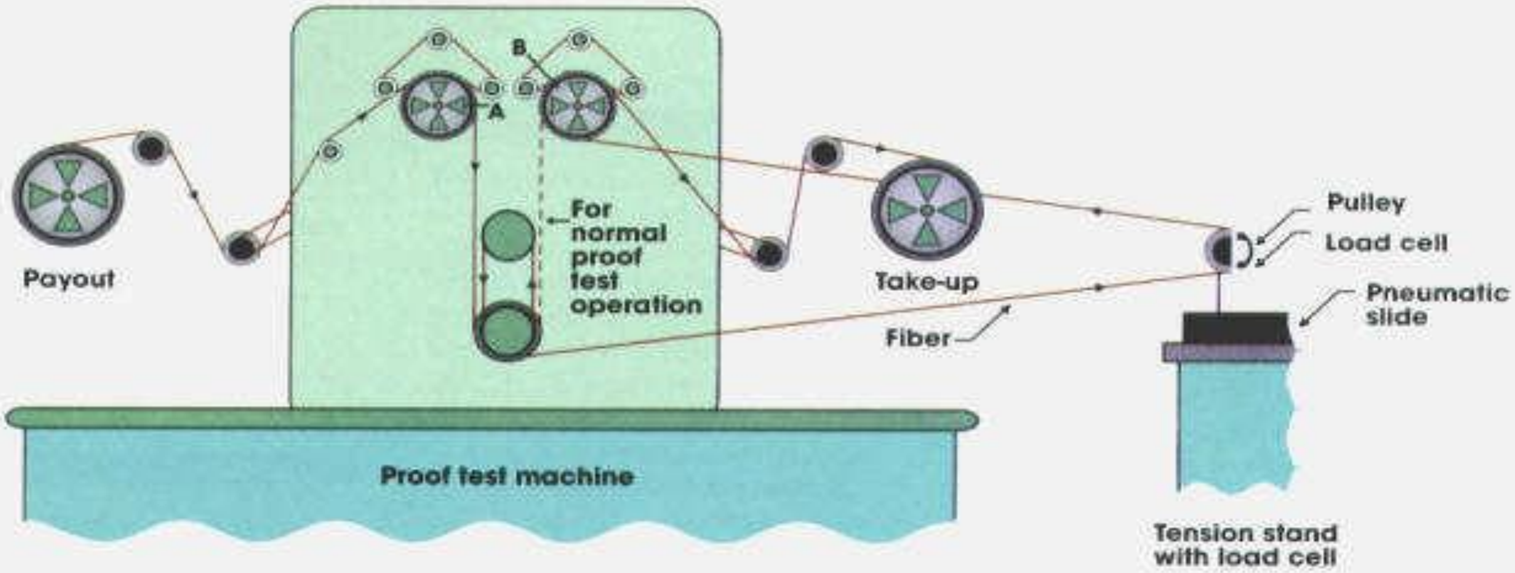
Proof-Testing

- Fiber is subjected to a short-term tensile strain during or subsequent to production. Applied load is the proof-stress value.
- Establishes minimum strain capability: fiber will break for large cracks larger than the proof-stress value.
- Typical proof-stress levels: 50Kpsi & 100Kpsi



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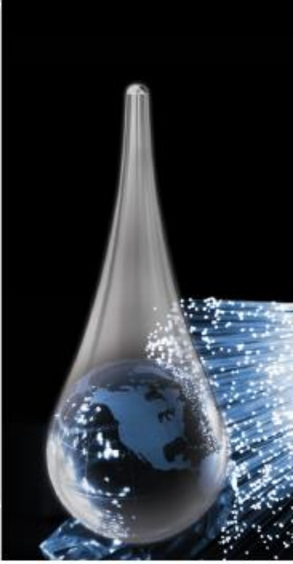
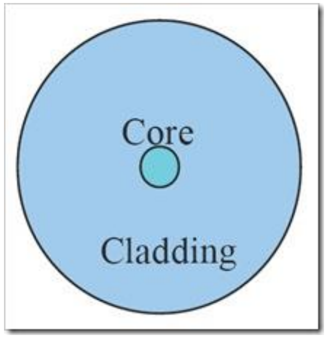
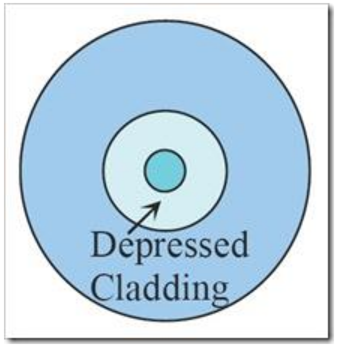
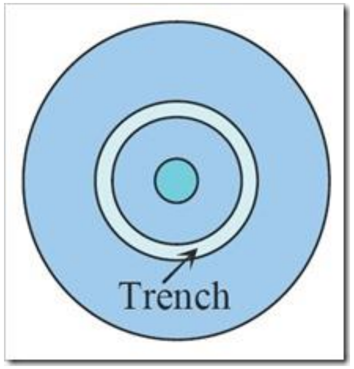




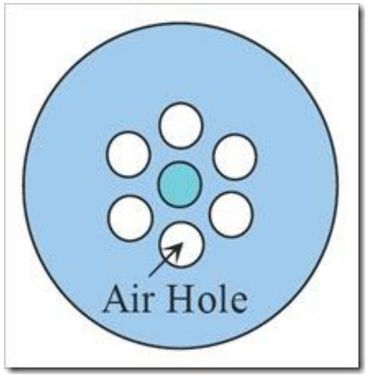
Reducing the mode field diameter



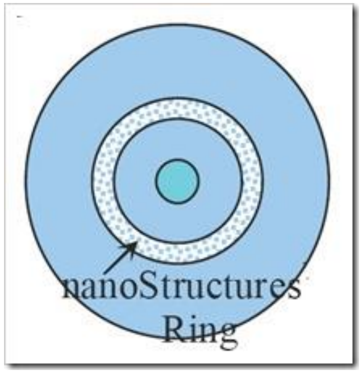
Depressing the cladding



Adding a low index trench



Symmetric holes within the cladding



NanoStructures Ring
Corning (2007)

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Special Optical Fibers

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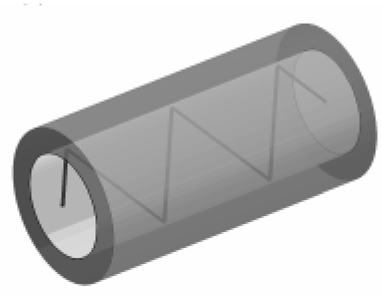
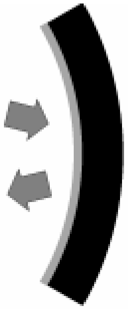
Hollow Core Optical Fibers

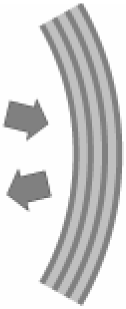
In contrast to solid core glass fibers, hollow core fibers can propagate light by:



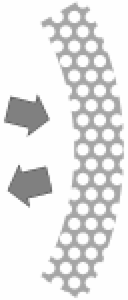
Hollow-core fiber



Metallic Cladding



Multilayer Dielectric Mirror



2D Photonic Crystal cladding

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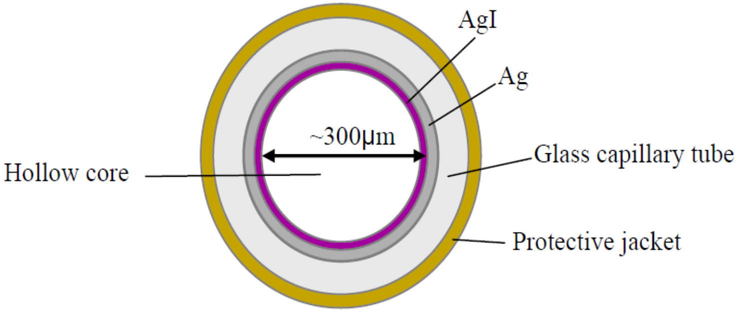
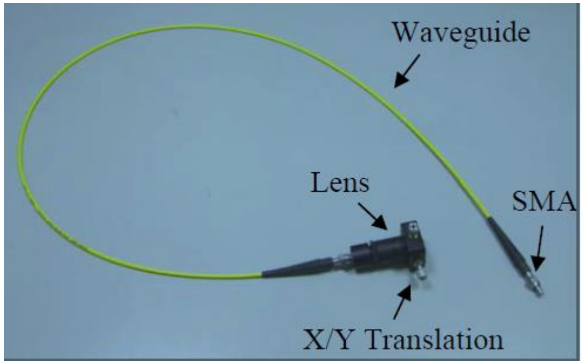
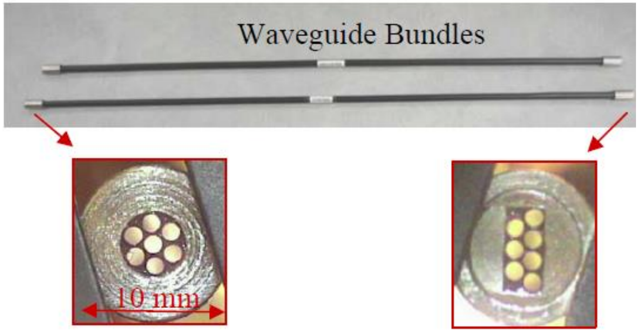
Hollow Core Optical Fibers







Waveguide probes are currently being developed for applications in : **beam delivery**, **trace gas detection**, **signal collection**, and **IR imaging**.

Jason M. Kriesel, SPIE defence, April (2011)

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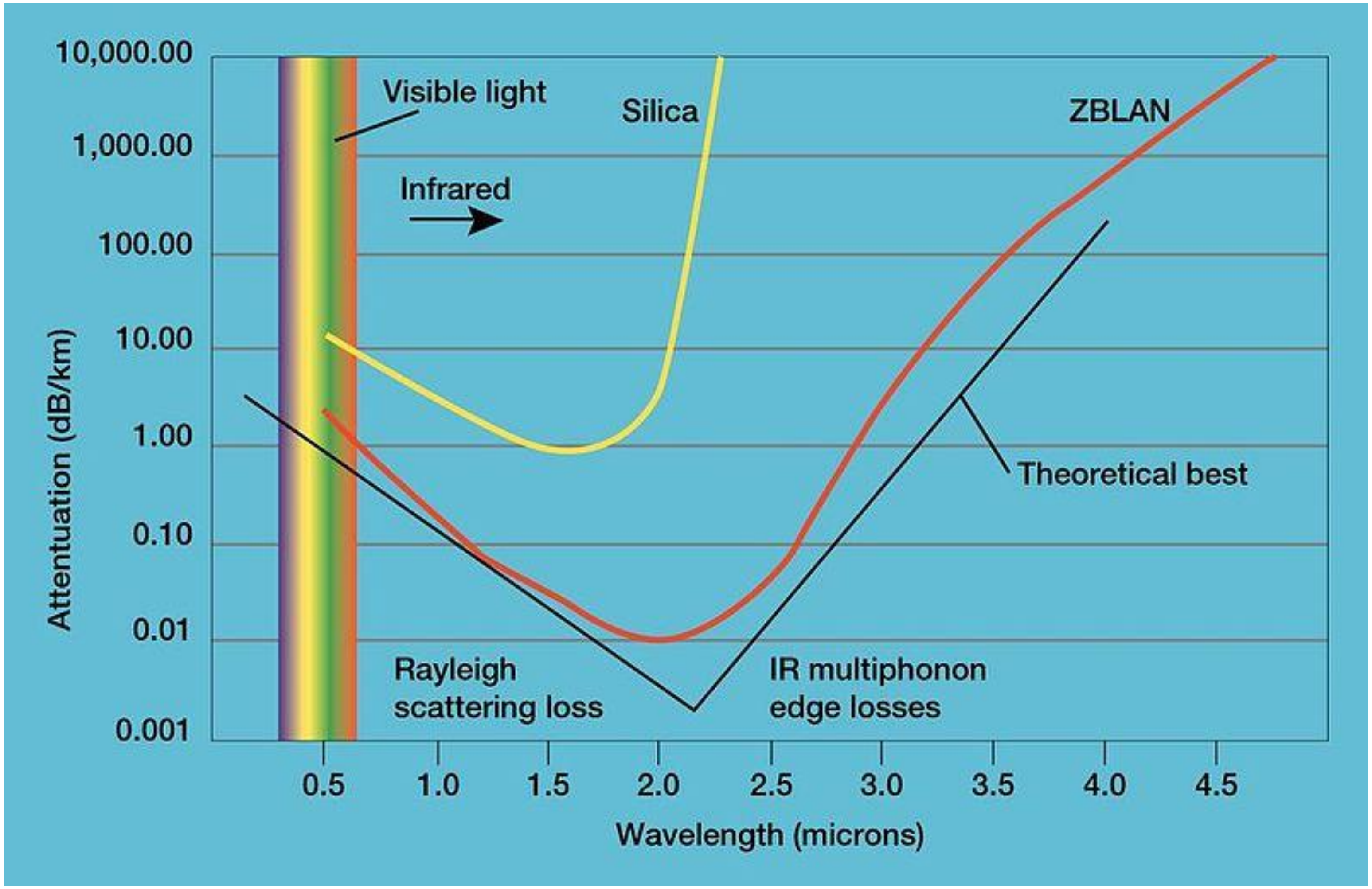
Fluoride Glasses

- 1974- Fluoride glasses (M. Poulain)



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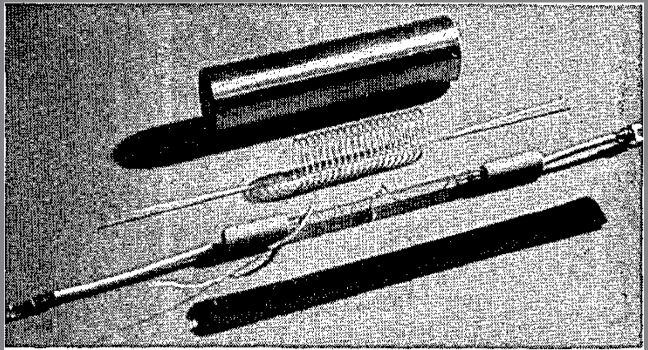
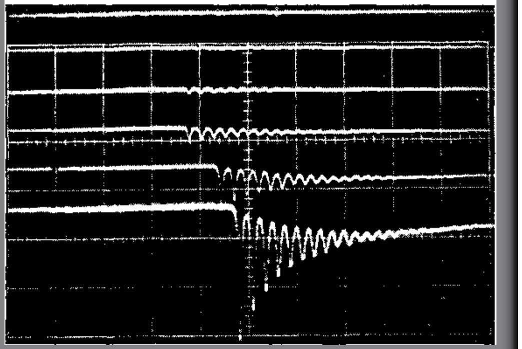
E.Snitzer

Fiber Amplifier

Nd^{3+} doped fiber and amplification at 1060nm.





E.Snitzer, Appl.Optics, 3, 10 (1964)

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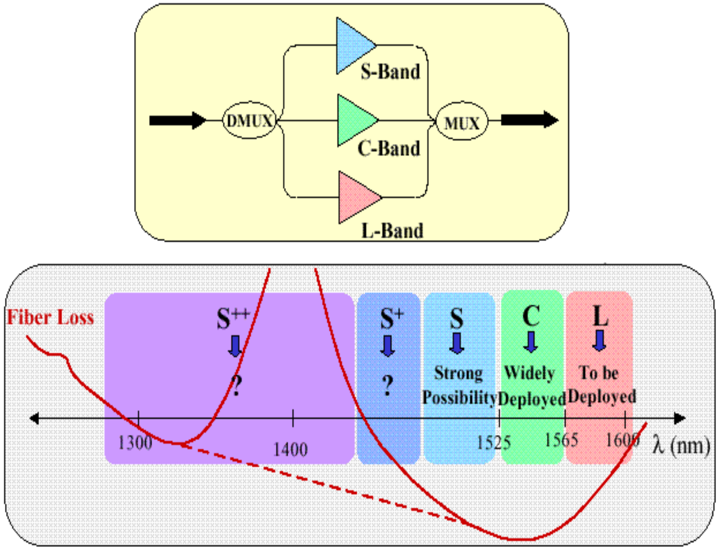
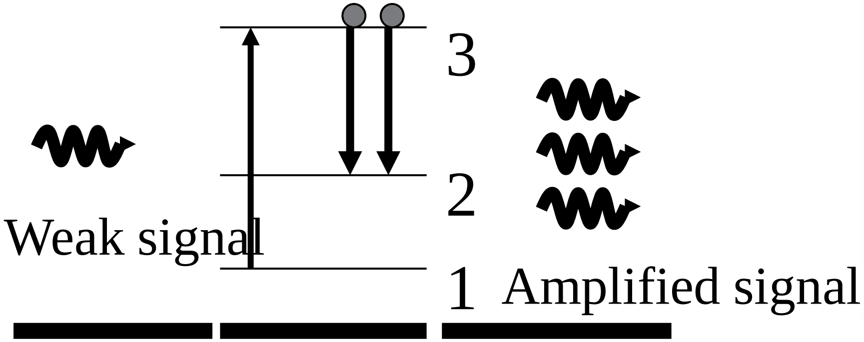
Potential λ Regions for Systems Expansion



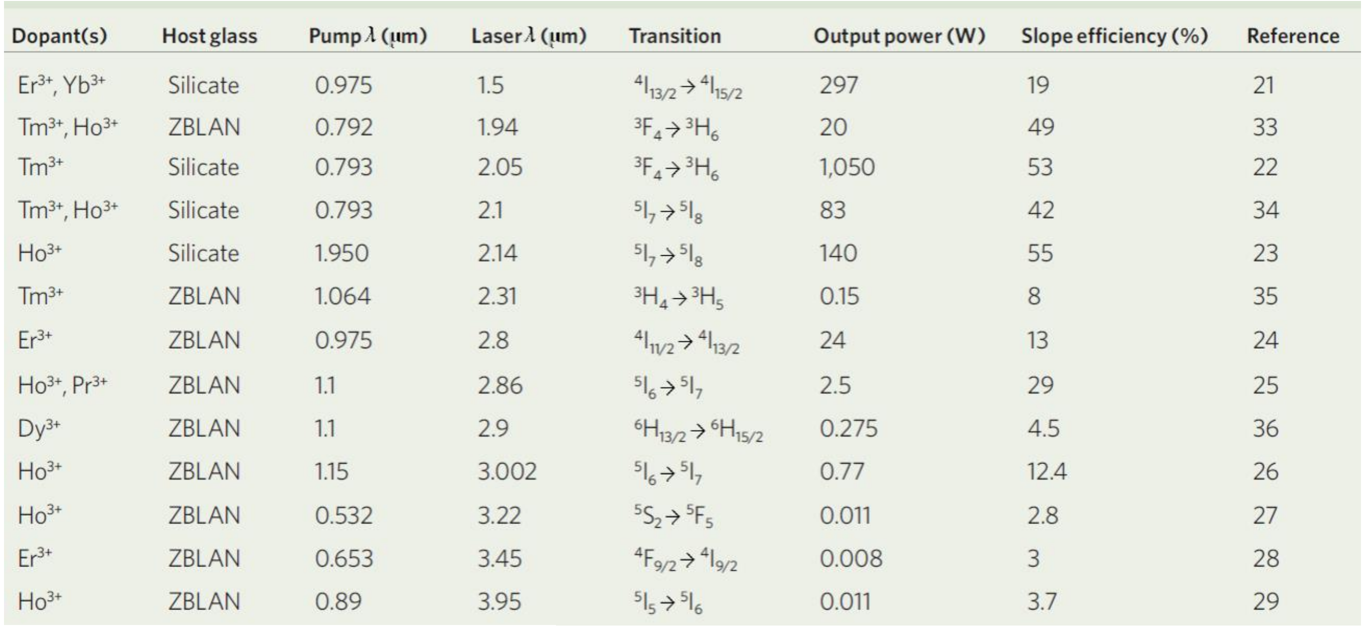


Transmitting Fiber (Km)

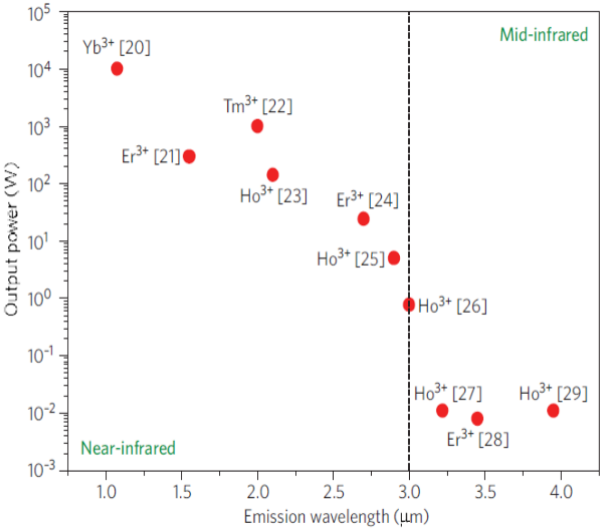
Fiber amplifier (m)

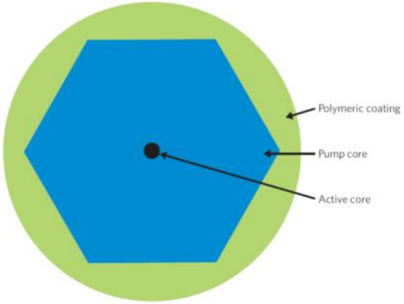
Transmitting Fiber (Km)

Fiber Laser



Dopant(s)	Host glass	Pump λ (μm)	Laser λ (μm)	Transition	Output power (W)	Slope efficiency (%)	Reference
Er^{3+}, Yb^{3+}	Silicate	0.975	1.5	$^4I_{13/2} \rightarrow {}^4I_{15/2}$	297	19	21
Tm^{3+}, Ho^{3+}	ZBLAN	0.792	1.94	$^3F_4 \rightarrow {}^3H_6$	20	49	33
Tm^{3+}	Silicate	0.793	2.05	$^3F_4 \rightarrow {}^3H_6$	1,050	53	22
Tm^{3+}, Ho^{3+}	Silicate	0.793	2.1	$^5I_7 \rightarrow {}^5I_8$	83	42	34
Ho^{3+}	Silicate	1.950	2.14	$^5I_7 \rightarrow {}^5I_8$	140	55	23
Tm^{3+}	ZBLAN	1.064	2.31	$^3H_4 \rightarrow {}^3H_5$	0.15	8	35
Er^{3+}	ZBLAN	0.975	2.8	$^4I_{11/2} \rightarrow {}^4I_{13/2}$	24	13	24
Ho^{3+}, Pr^{3+}	ZBLAN	1.1	2.86	$^5I_6 \rightarrow {}^5I_7$	2.5	29	25
Dy^{3+}	ZBLAN	1.1	2.9	$^6H_{13/2} \rightarrow {}^6H_{15/2}$	0.275	4.5	36
Ho^{3+}	ZBLAN	1.15	3.002	$^5I_6 \rightarrow {}^5I_7$	0.77	12.4	26
Ho^{3+}	ZBLAN	0.532	3.22	$^5S_2 \rightarrow {}^5F_5$	0.011	2.8	27
Er^{3+}	ZBLAN	0.653	3.45	$^4F_{9/2} \rightarrow {}^4I_{9/2}$	0.008	3	28
Ho^{3+}	ZBLAN	0.89	3.95	$^5I_5 \rightarrow {}^5I_6$	0.011	3.7	29





S.D.Jackson, Nature Photonics, 6,423 (2012)

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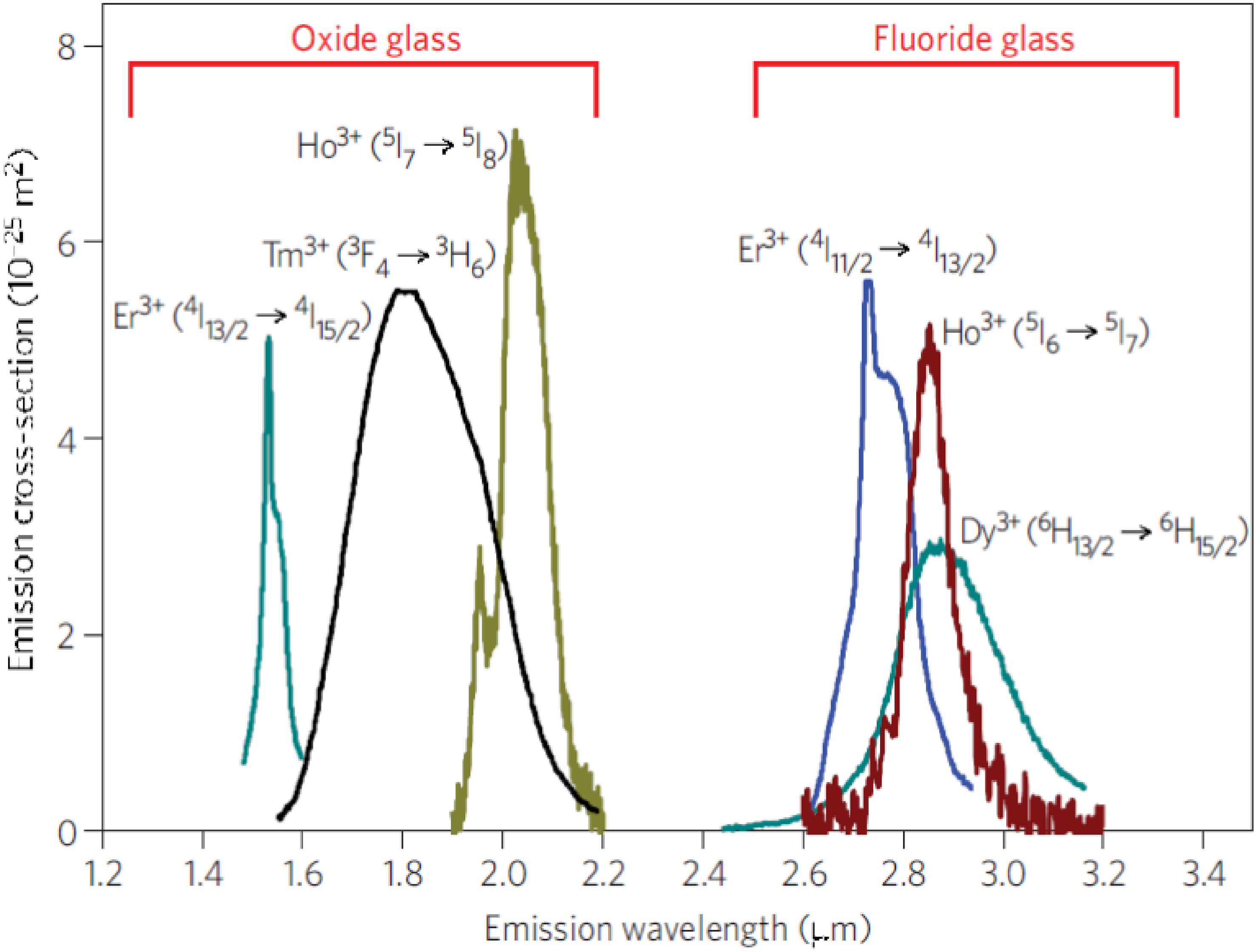
Fiber Laser



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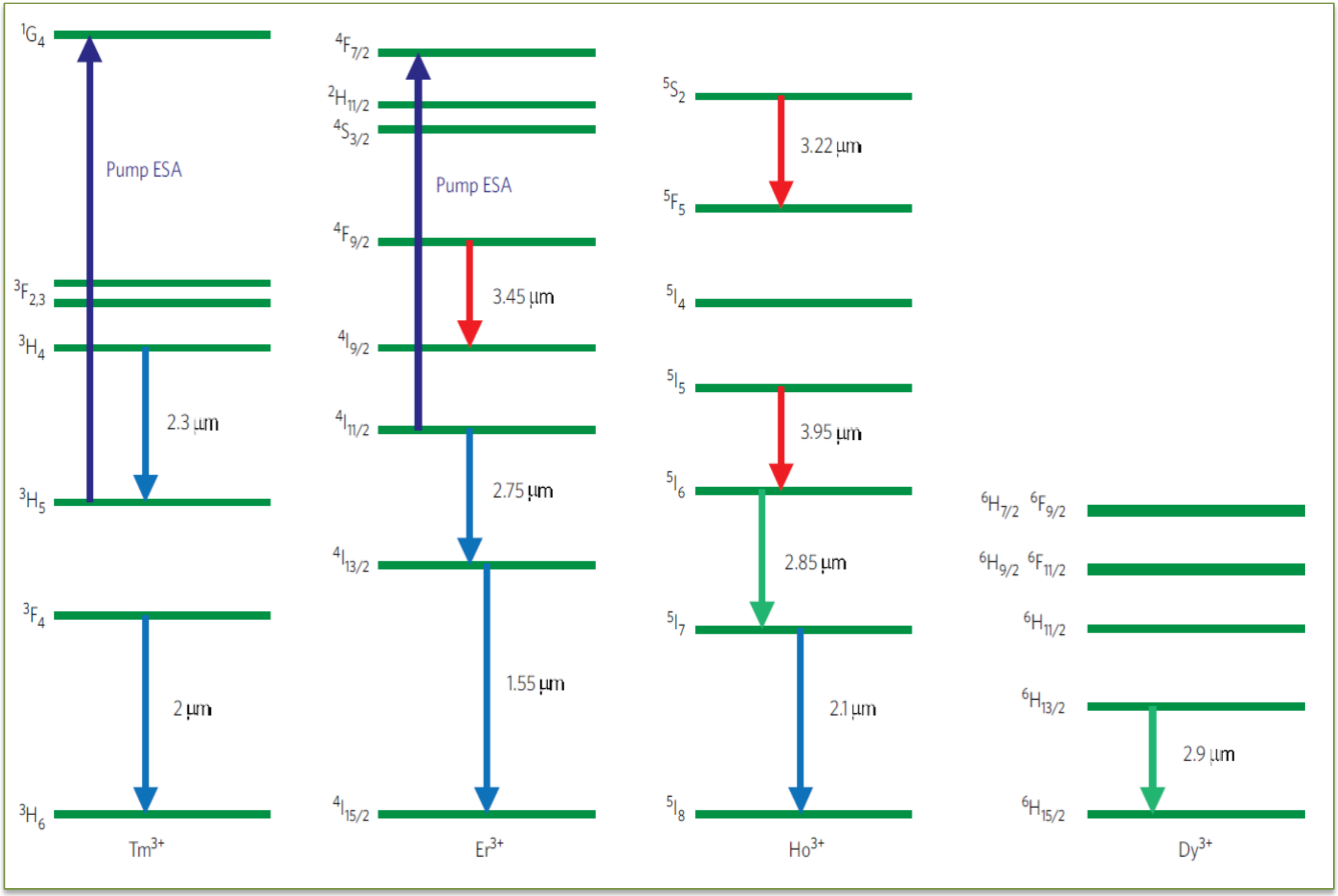
Fiber Laser



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Microstructure Fibers

Optical fiber constructed with a lattice of voids (air holes) along its length → provide unique optical properties impossible to obtain with solid fibers.

Very large index of refraction differences

– 1.0 (air) to 1.45 (undoped silica): Δn ~0.45

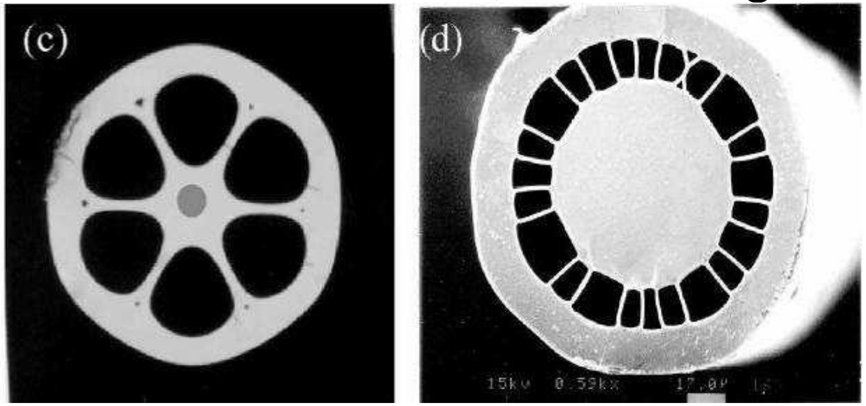
– Doped silica fiber: Δn ~0.03

Voids can be filled with functional materials allowing dynamic properties

– Control local index with temperature, electrical field, magnetic field, etc.

Photonic bandgap operation

– Periodic structure creates resonance, like a 2-D gratings.



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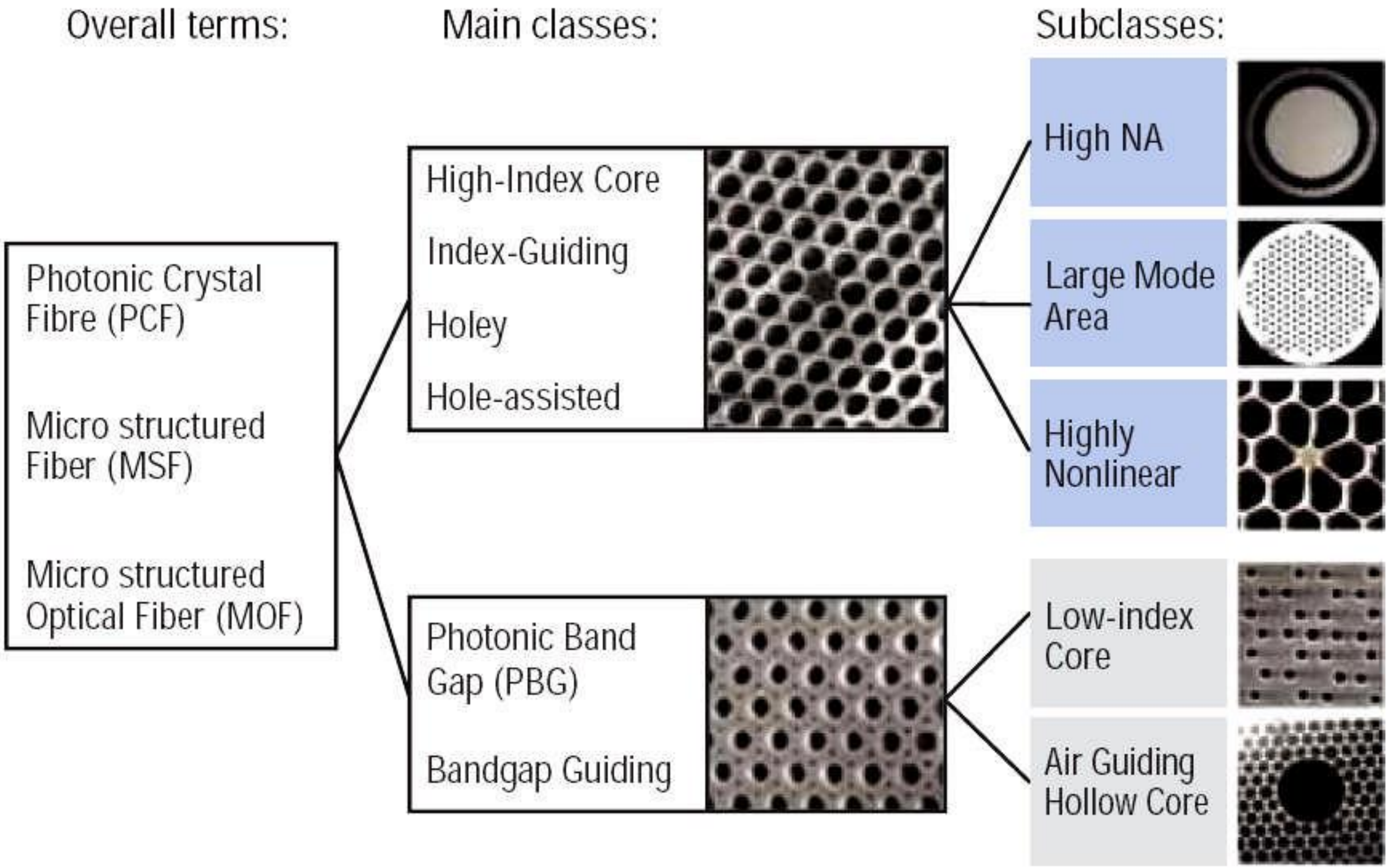
Microstructure Fibers



Overall terms:

Photonic Crystal Fibre (PCF)

Micro structured Fiber (MSF)

Micro structured Optical Fiber (MOF)

Main classes:

- High-Index Core
- Index-Guiding
- Holey
- Hole-assisted

- Photonic Band Gap (PBG)
- Bandgap Guiding

Subclasses:

- High NA
- Large Mode Area
- Highly Nonlinear

- Low-index Core
- Air Guiding Hollow Core

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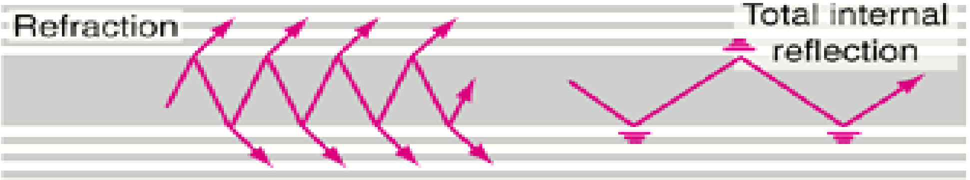
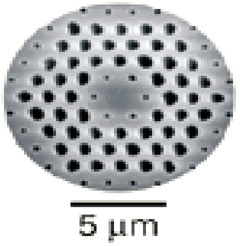
PCF: Index Guided

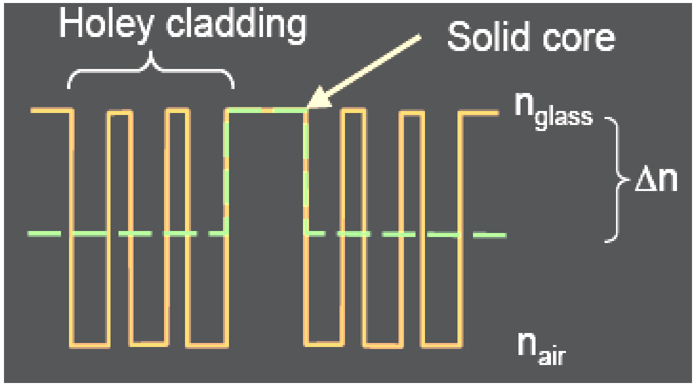




Un-doped silica glass is used for both core and cladding regions. **Core is solid.**

Placement of air channels (n = 1) in the cladding creates an "effective " index below that of the solid core region. Light is confined and guided by total internal reflection. NA can approach 1.

Different designs can be achieved by varying index delta, channel spacing, size & diam.



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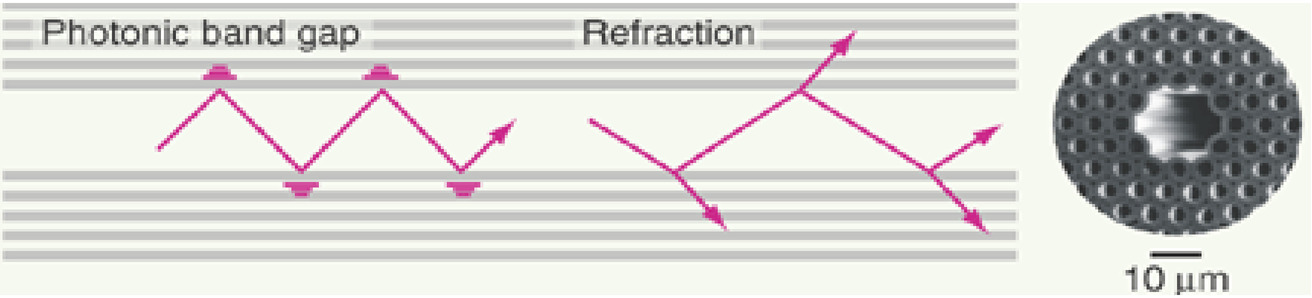
PCF: Photonic Band Gap Guided

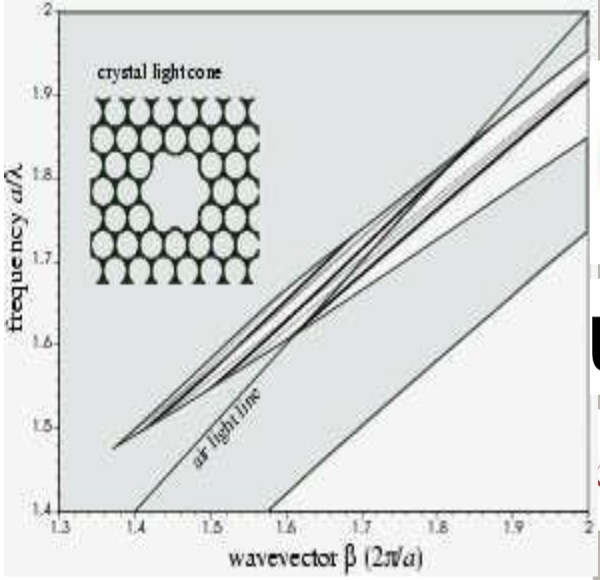


Un-doped silica glass is used for both core and cladding regions. Core is hollow (air).

Placement of air channels (n = 1) in the cladding creates a 2-D photonic bandgap structure.

Constructive interference is produced by scattered light refracted at the core/cladding interfaces of the periodic lattice structure.

Light can only propagate in specific regions.



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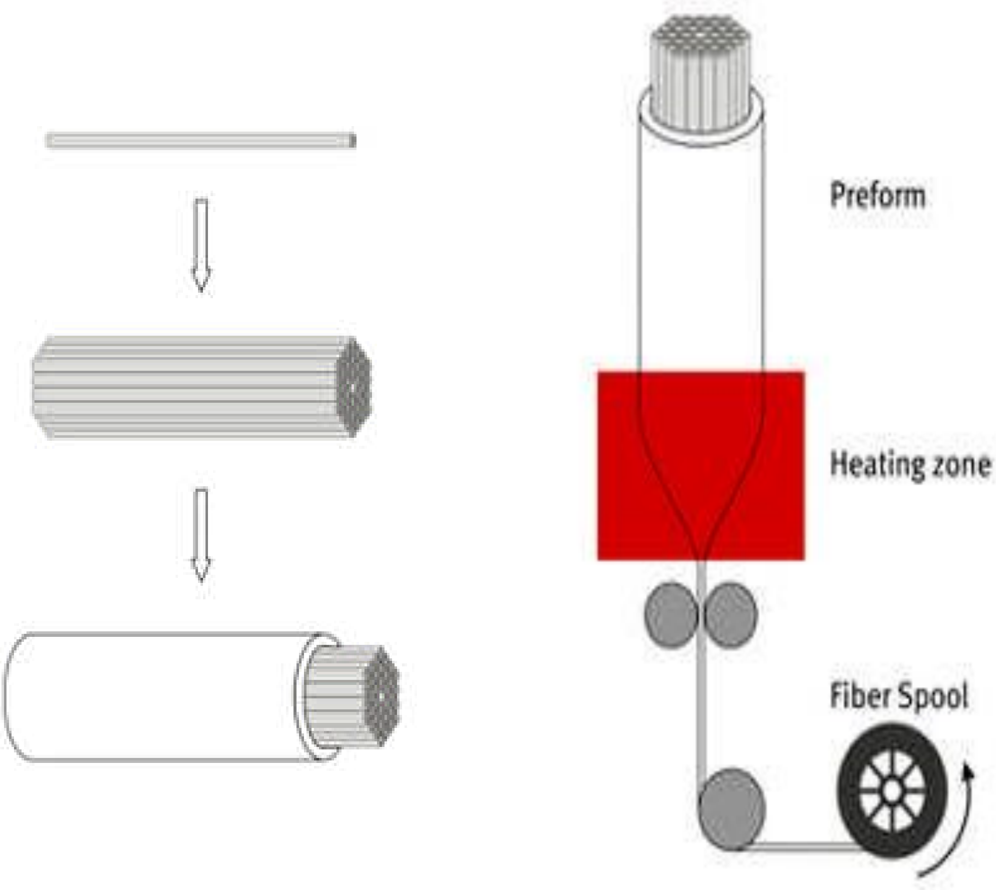
Special Fibers

PCF Fabrication:

Stack-and-Draw Process



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Special Fibers

PCF Applications

- **Telecommunications**

– Dispersion compensation
– Transmission fibers
– Broadband SM fibers

- **Lasers**

– Double Clad fibers (laser cavity)
– Large Area fibers (high power transmission)
– White Light Sources

- **Sensing**
- **Metrology**
- **Medical**

– Optical Coherence Tomography

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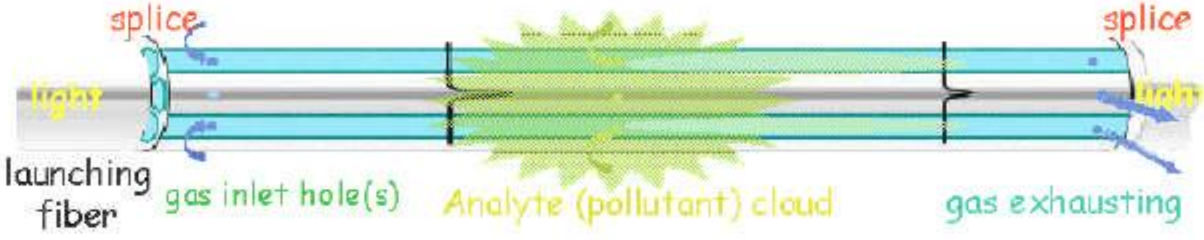
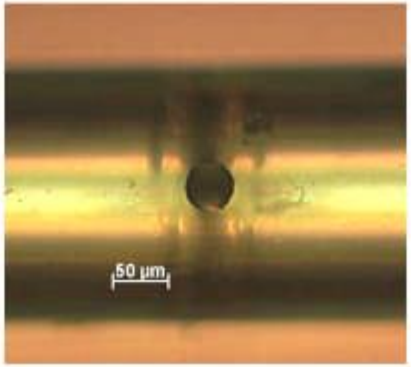
Special Fibers

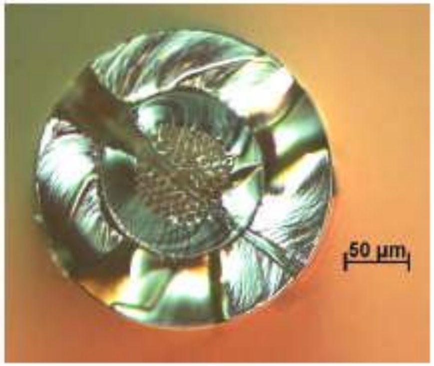
PCF Applications

Gas Sensor





laser drilled gas inlet hole



laser drilled PCF (cross section)

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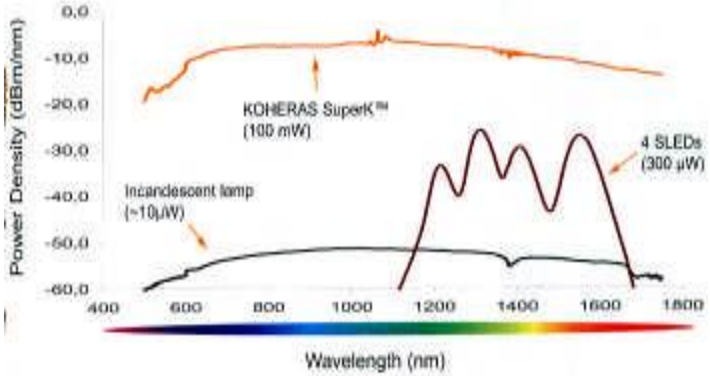
Special Fibers

PCF Applications

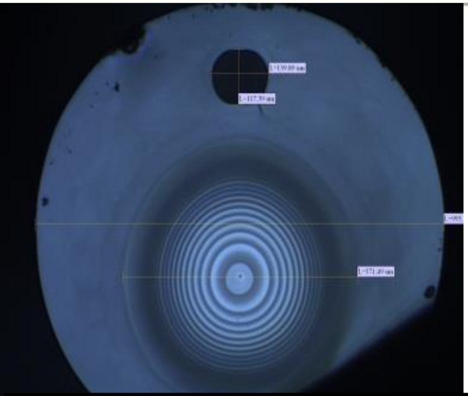
Ultra-Broad White Light Source

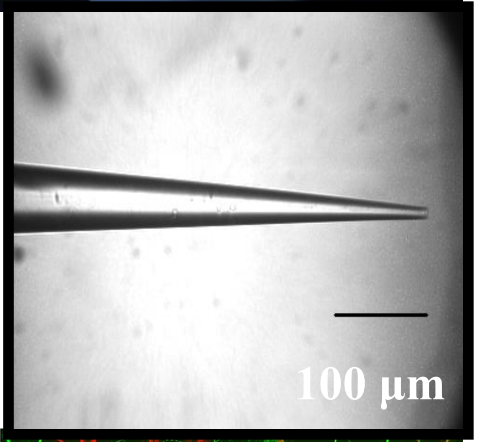
- High brightness
- Ultra broad spectrum
- Compact robust design
- No cooling

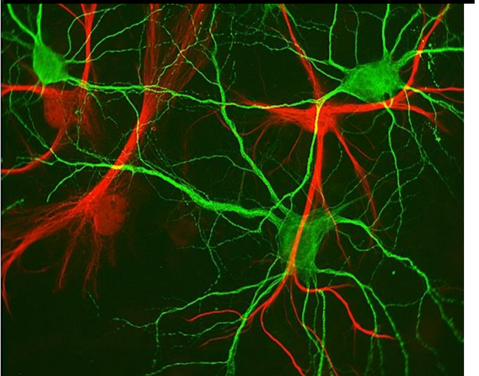


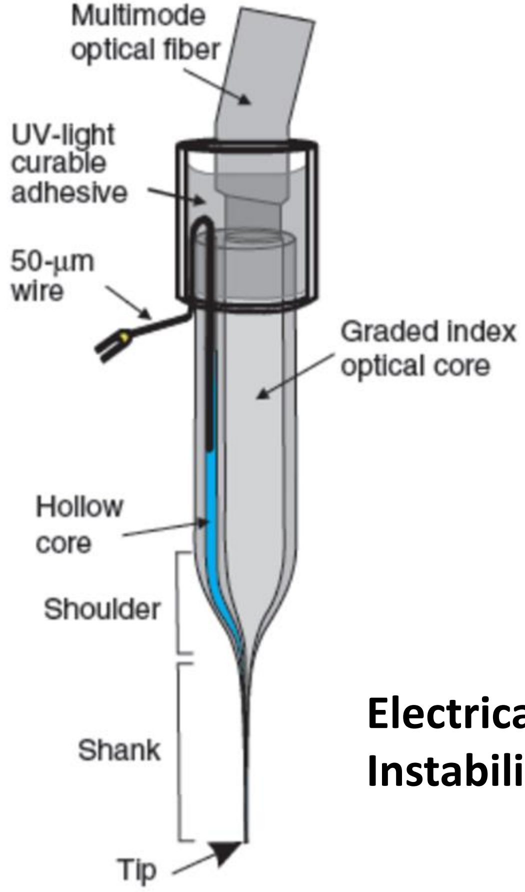
Ranka, J. K., Windeler, R. S., and Stentz, A. J.,
Conference on Lasers and Electro-Optics, 1999.

Special Fibers









Electrical Resistance : 6-26 MΩ
Instability of the driver medium

Y.Lechasseur, Nature Method,v8,4,319 (2011)

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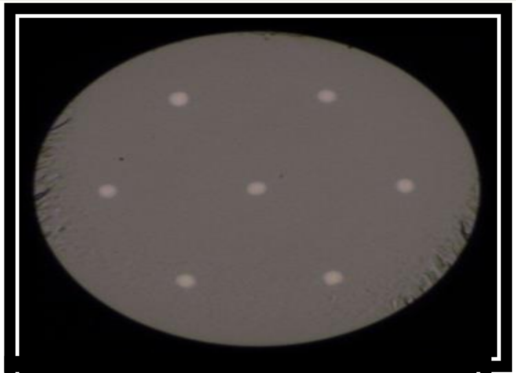
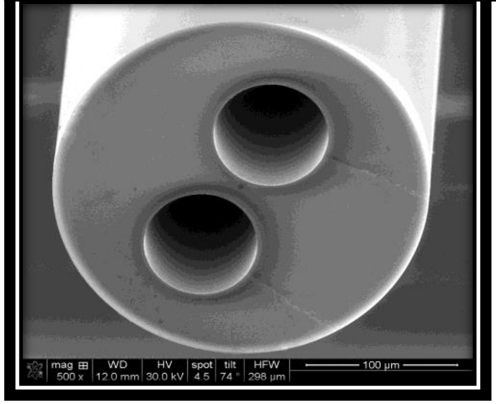
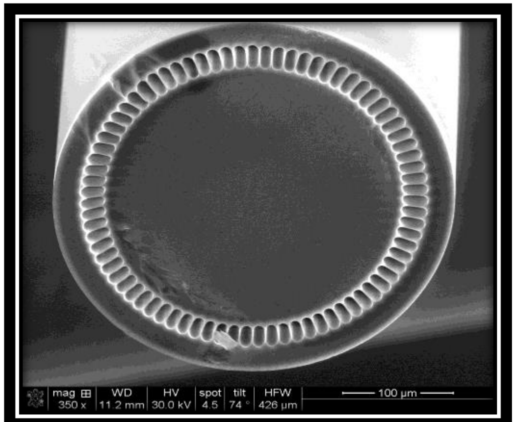
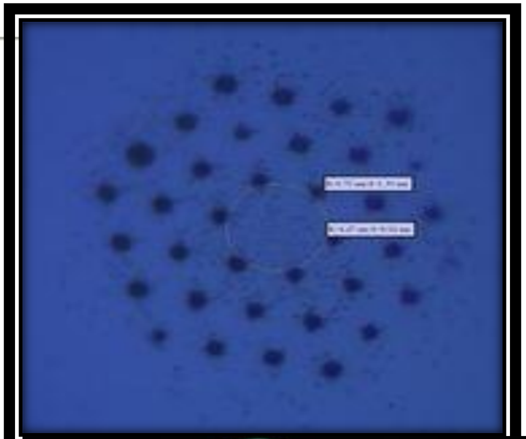
Special Fibers

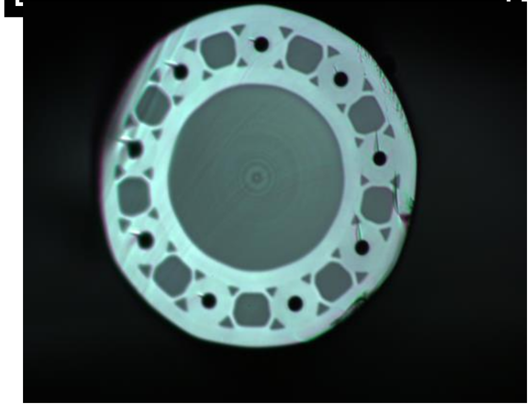






Fiber Designs at COPL





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COPL
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