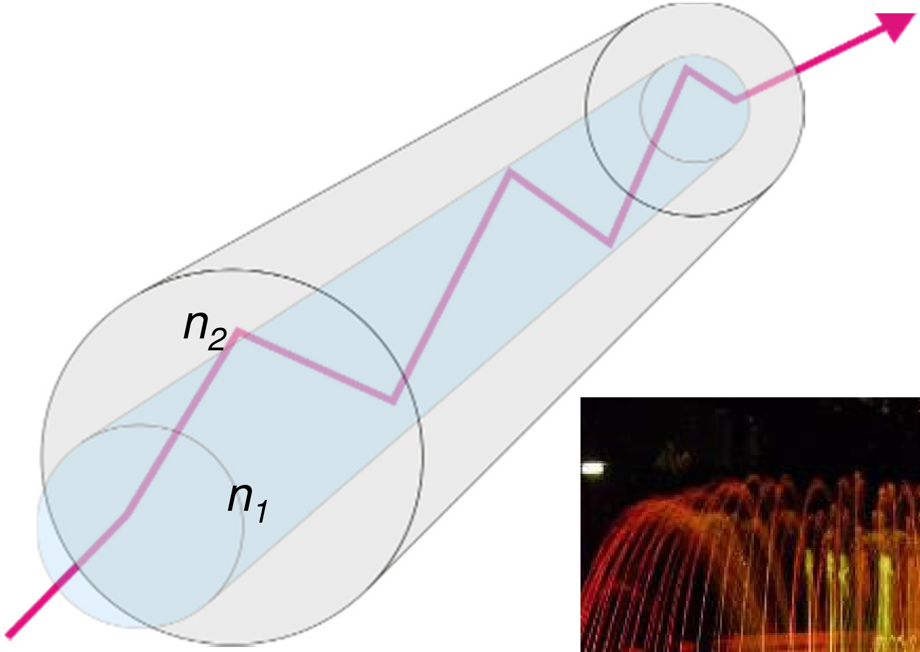
Academy of Sciences

Institute of Photonics and Electronics v.v.i.

Technology of Optical Fibers

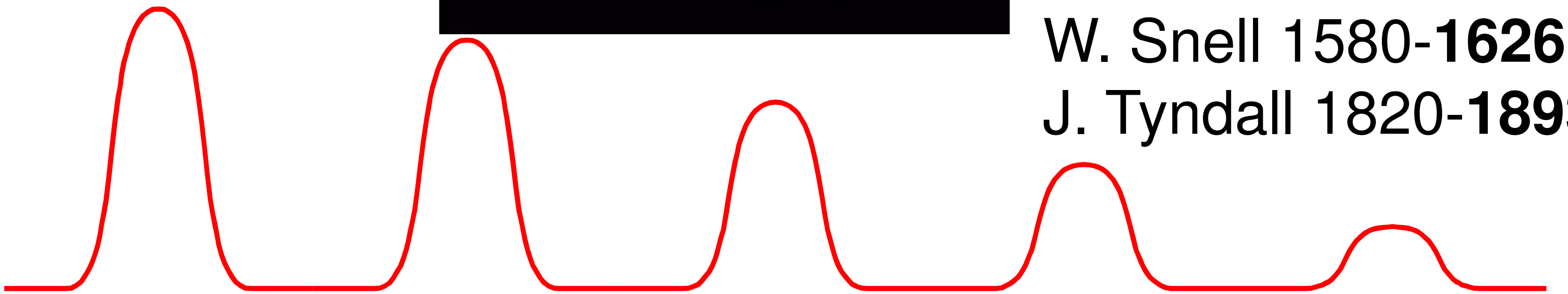
www.ufe.cz, I.Kasik

Optical fiber



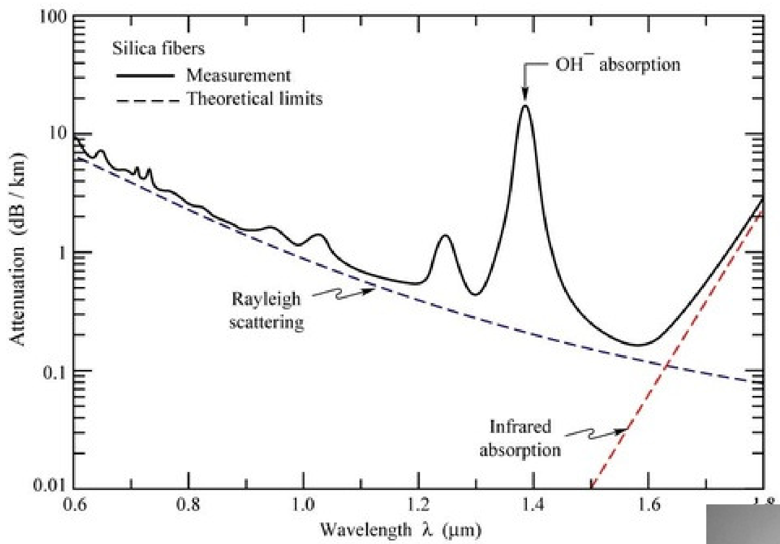
* dielectric
* mostly circular
* d >> L
* ***$n_1 > n_2$***
* ***total reflection***

W. Snell 1580-**1626**
J. Tyndall 1820-**1893**

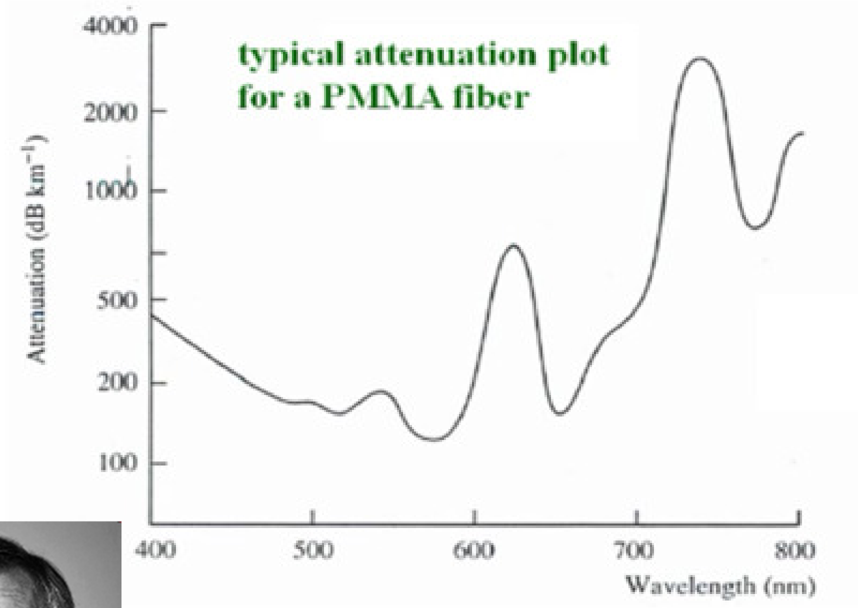


Optical fiber

<u>Optical losses in optical fibers</u> (intrinsic, extrinsic)



[Wiki]



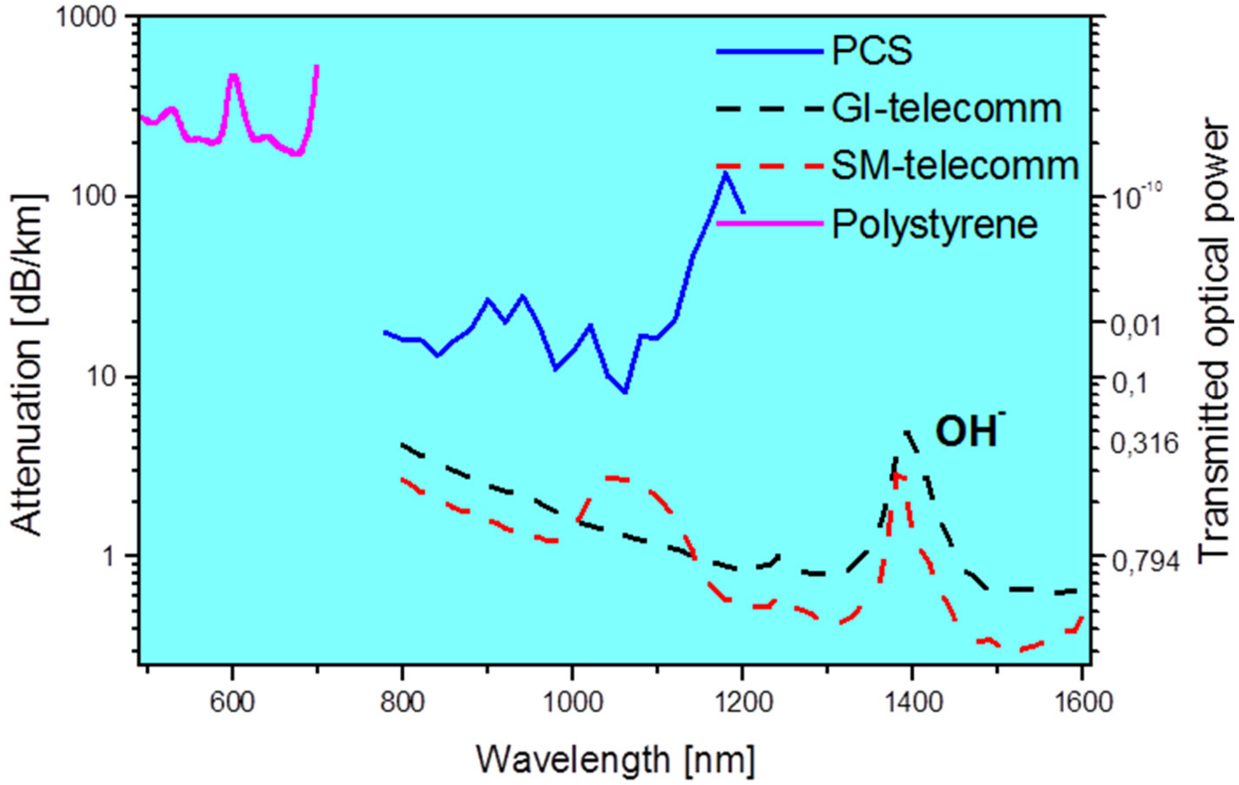
[Profimedia]

Nobel prize
2009
Ch.K.Kao

Optical fiber

- **high-purity**
- **silica based materials,**

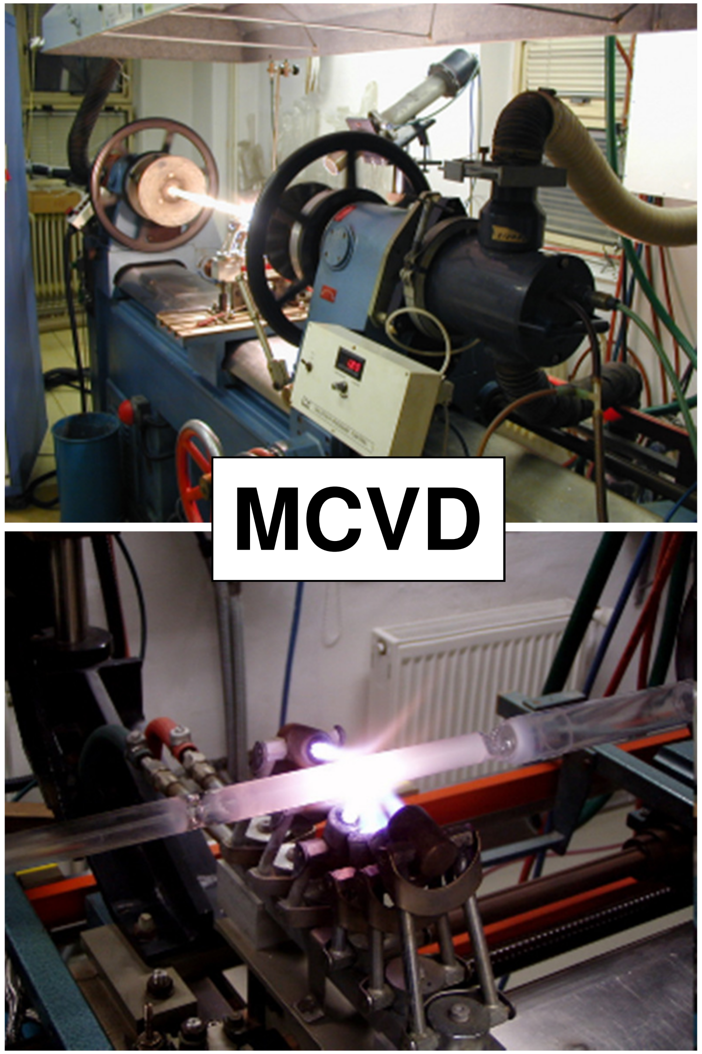
max. impurities acceptable in ppb (10^{-9})



Conventional glassmaking =>

ULTRA-PURE TECHNOLOGIES

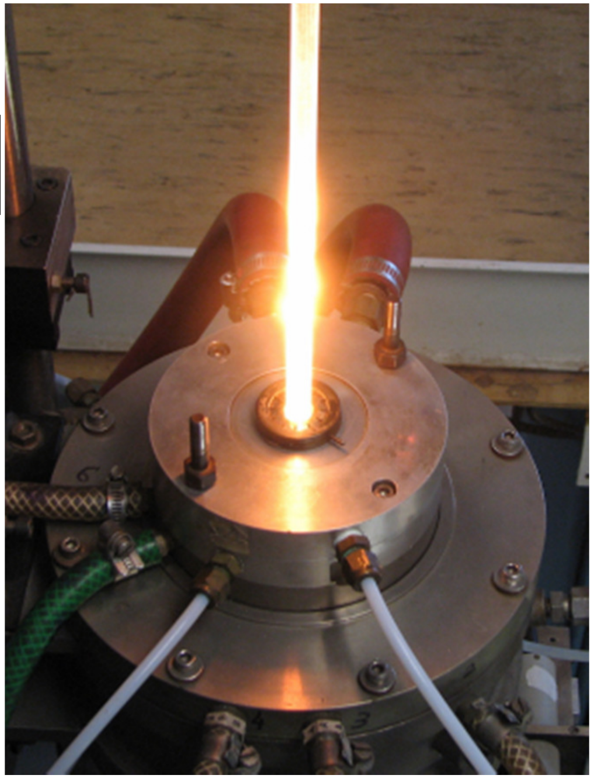
Optical fiber preparation - technology



MCVD

1. Preform

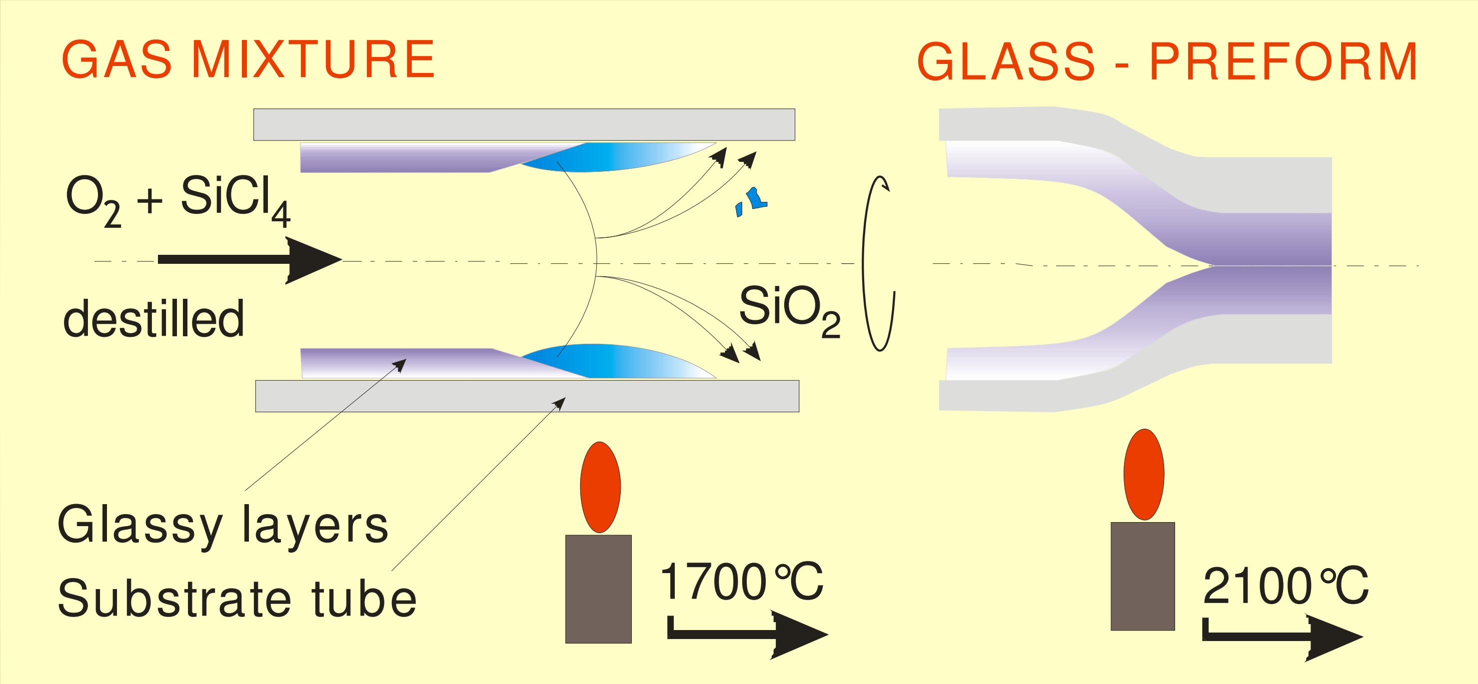
2. Fiber drawing



Preform preparation - MCVD

MCVD – (Modified) Chemical Vapor Deposition

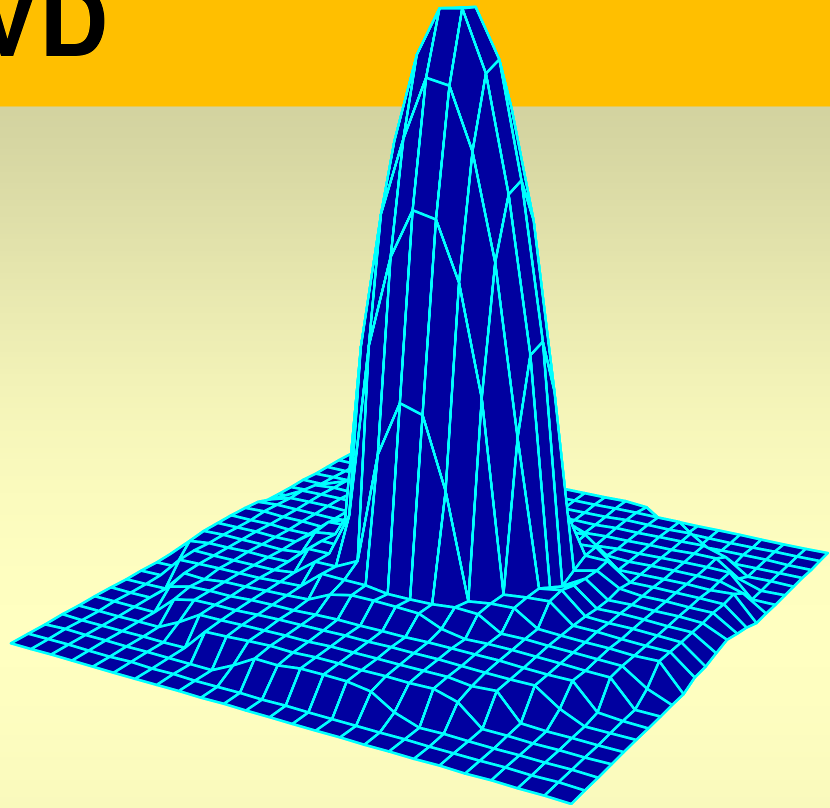
1. Deposition of layers 2. Collapse



- Sequential sintering of **thin glassy layers** (of thickness 1-20 µm) onto inner wall of silica substrate **resulting in bulk material – preform** . **A (g) + B(g) = AB (s)**
- **high purity** (~ 10^1 ppb) **high precision** (better than 1 %)

MCVD

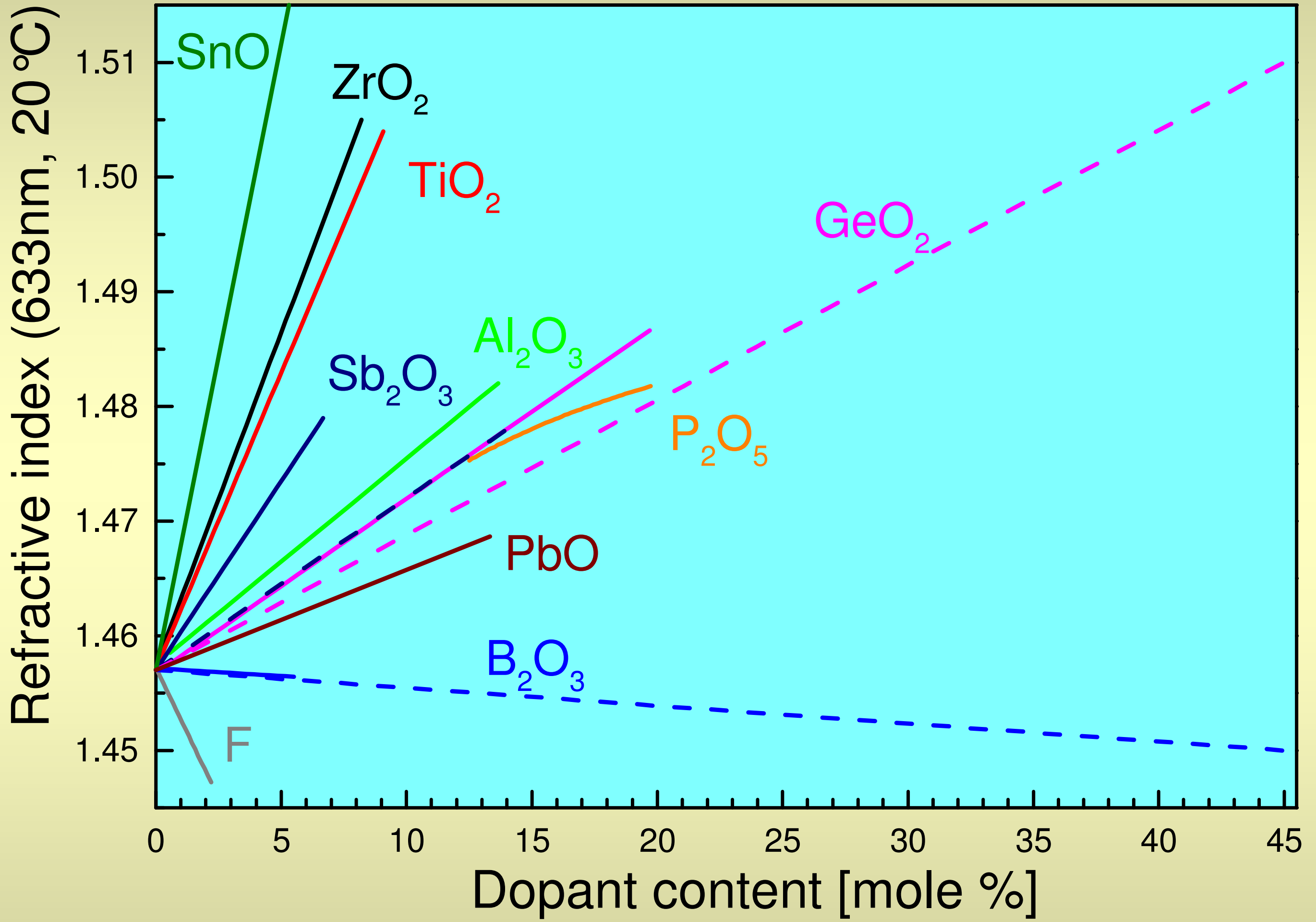
Microphoto of cross section of produced preform



Tomography of the refractive-index profile of preform

- High purity material due to FO-Optipur purity starting materials.
- High quenching rate ranging from 10^2 to 10^3 °C/s !

MCVD process model



[A.B. Chynoweth, 1979, M. Shimizu, 1986, Y. Ohmori, 1983, S. H. Wemple, 1973, H. Wehr 1986, I. Kasik, 2005, K. Sanada, 1980, M. M. Karim 1994]

MCVD model

Process parameters :

Variable :

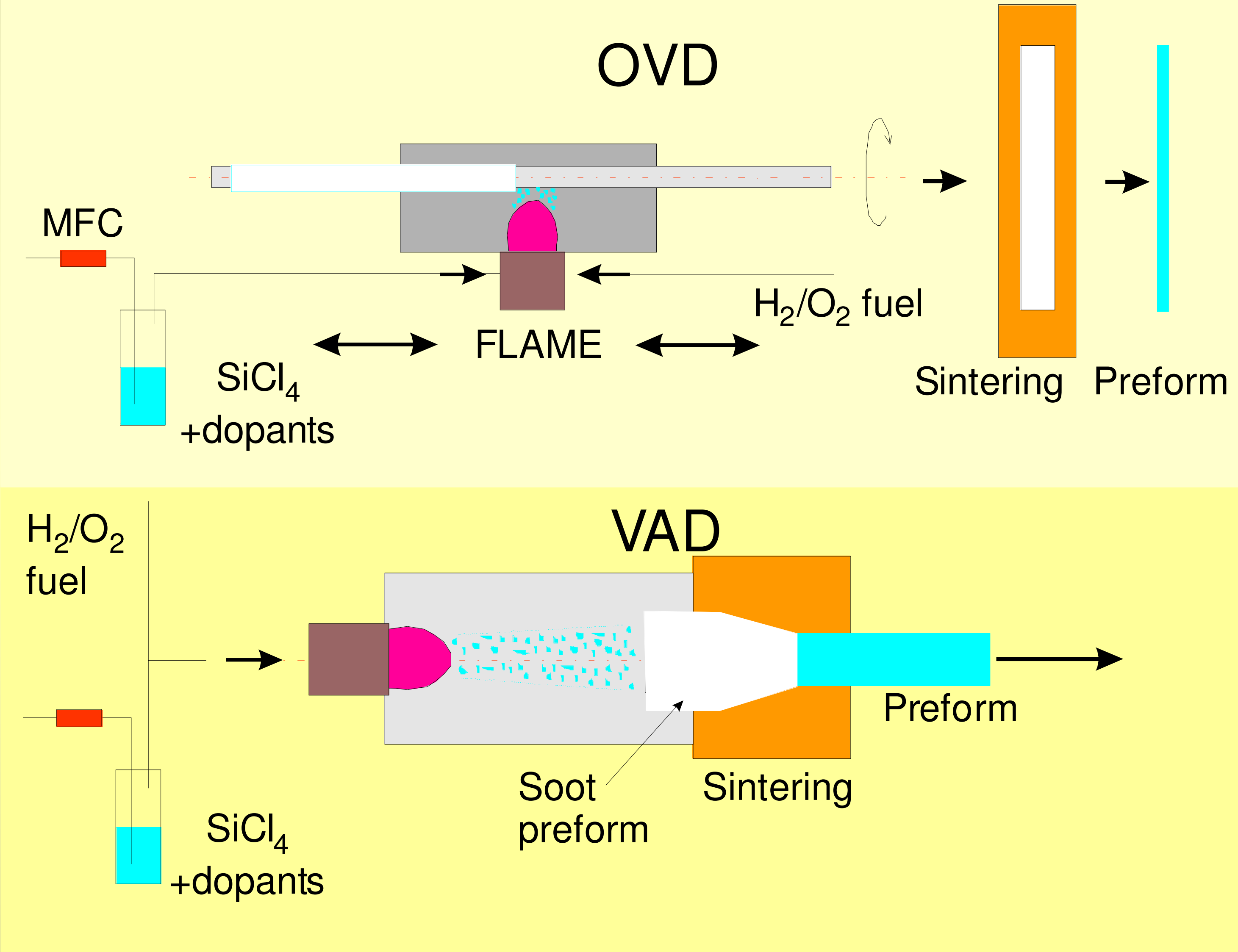
- flow rates (Si, Ge, P, B, F, Ox …)
- deposition temperature

Adjustable :

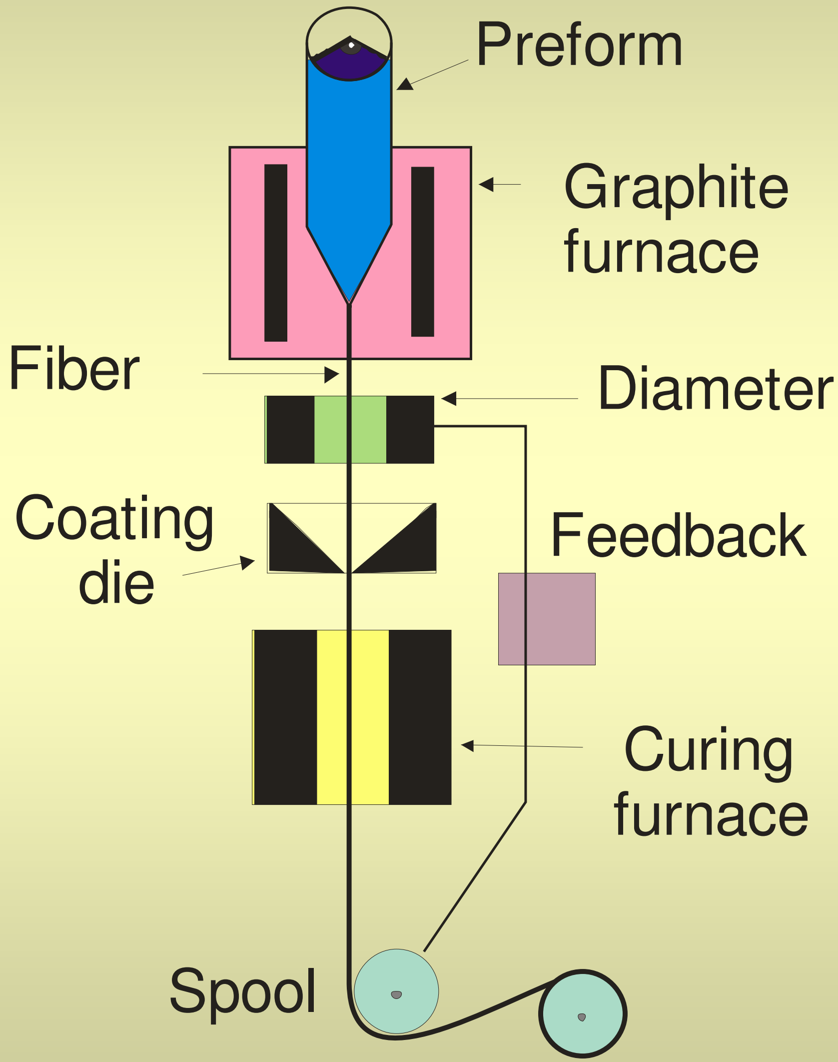
- temperature of starting materials (liquids)
- burner speed
- pressure
- rotation speed of the substrate tube
- substrate tube dimensions

[McChesney and Nagel, 1982, Wood, 1987, Kirchhof, 1986]

Other CVD technologies



Drawing of optical fiber from preforms



- Diameter
  80-1000 µm
- Temperature
  1800-2100°C

- No textile
- No thermo-insulation

Comparison
CVD (Chemical) x **PVD** (Physical)

CVD (Chemical)	PVD (Physical)
MCVD OVD etc.	DC magnetron sputtering vacuum evaporation etc.

Layer thickness

$1 – 10^1$ **μm**	$1 - 10^1$ **nm**

(however, both are reported as "thin layers")

Deposition rate

HIGH	LOW

Products

Layers, bulks	Layers only

Comparison
(M)CVD x conventional

Starting materials

(M)CVD	conventional
gaseous (g) or liquid (l)	(s) solid state
melting point of oxides different	melting point comparable

Purification methods

(M)CVD	conventional
distillation	recrystallisation, remelting

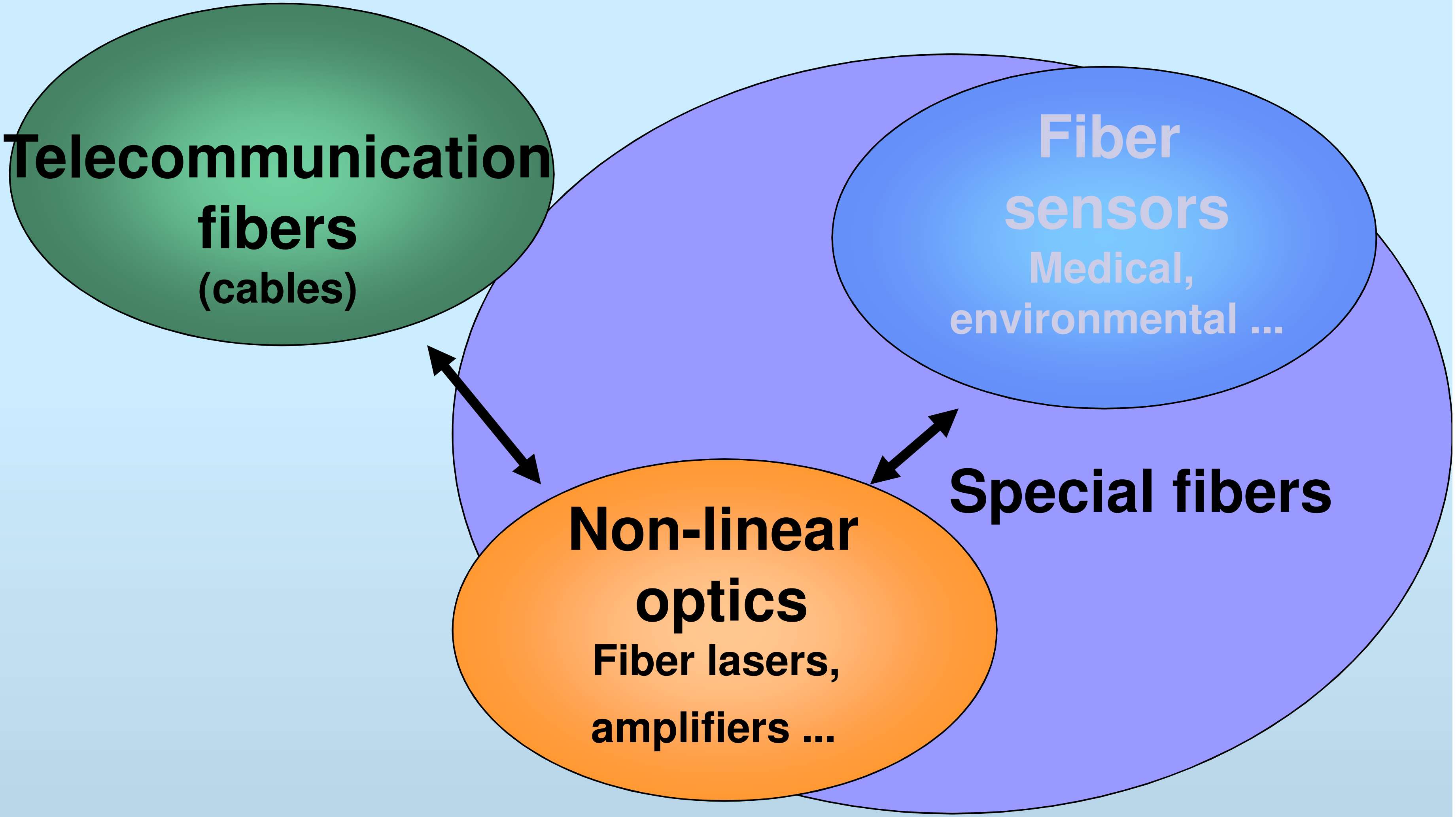
Structure of products

(M)CVD	conventional
Graded - profiles	Homogeneous

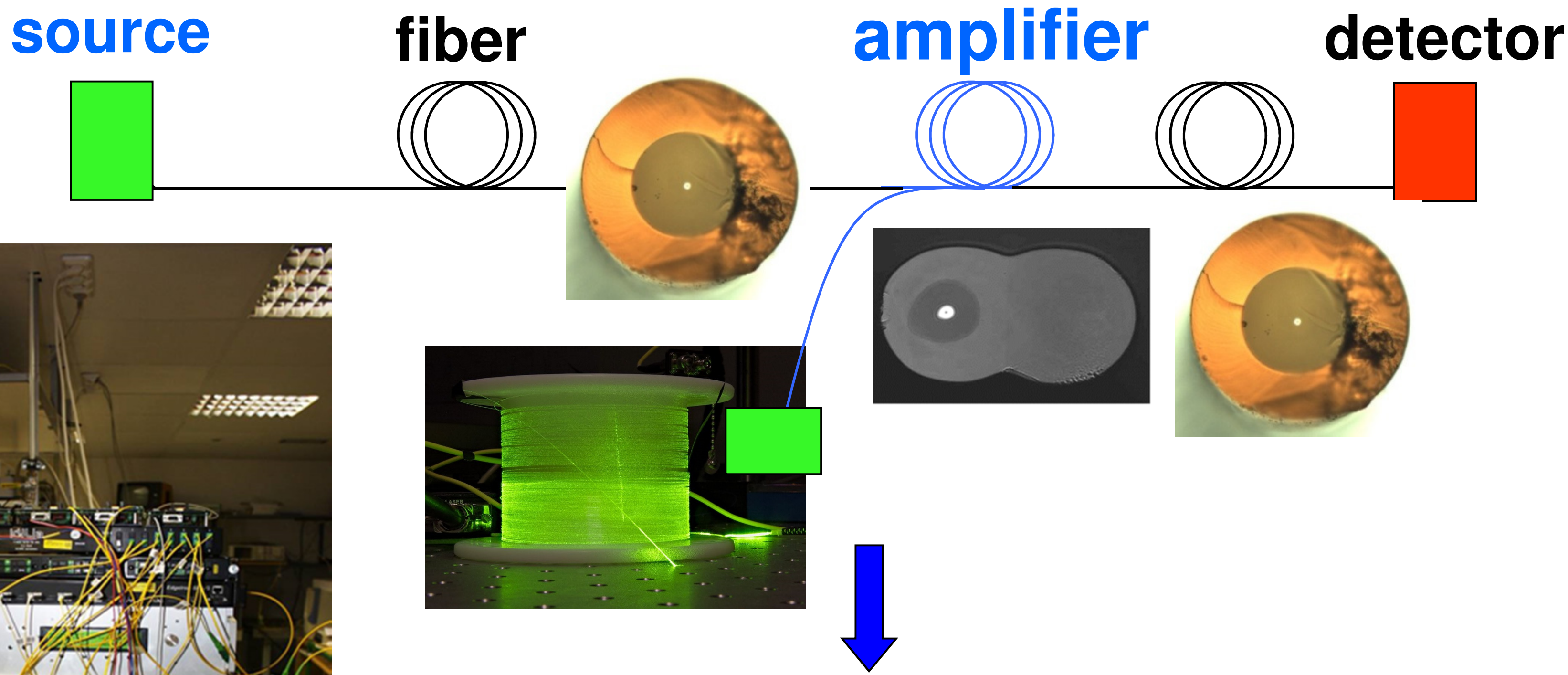
Material purity

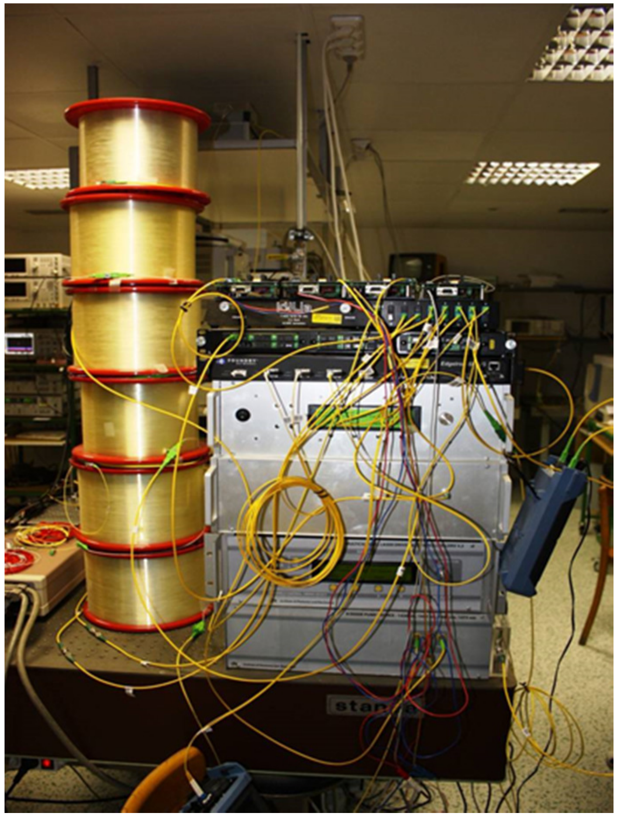
(M)CVD	conventional
ppb (10^{-9}, i.e. 10^{-7} mol%)	10^{-3} mol% (99,999%)

Application



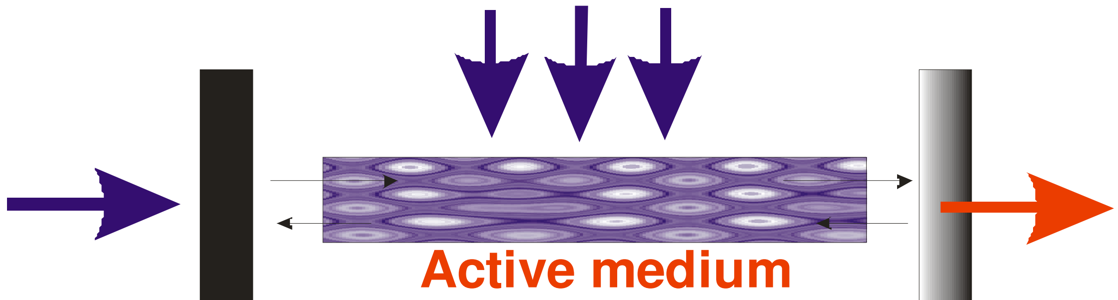
Telecommunications





Fiber amplifier, laser

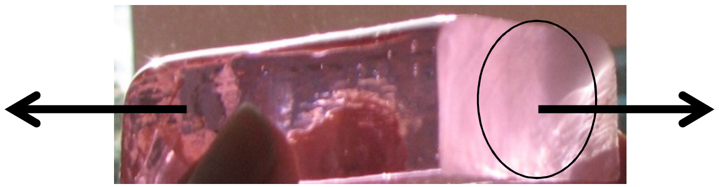
Silica specialty optical fibers for fiber lasers and amplifiers

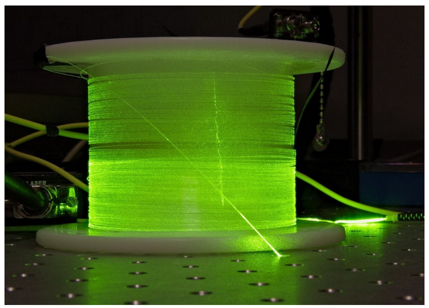


Mirror
100%

Gas, Liquid
Solid state :
* semidonductor
* glass
* OPTICAL FIBER

Mirror
8-99%



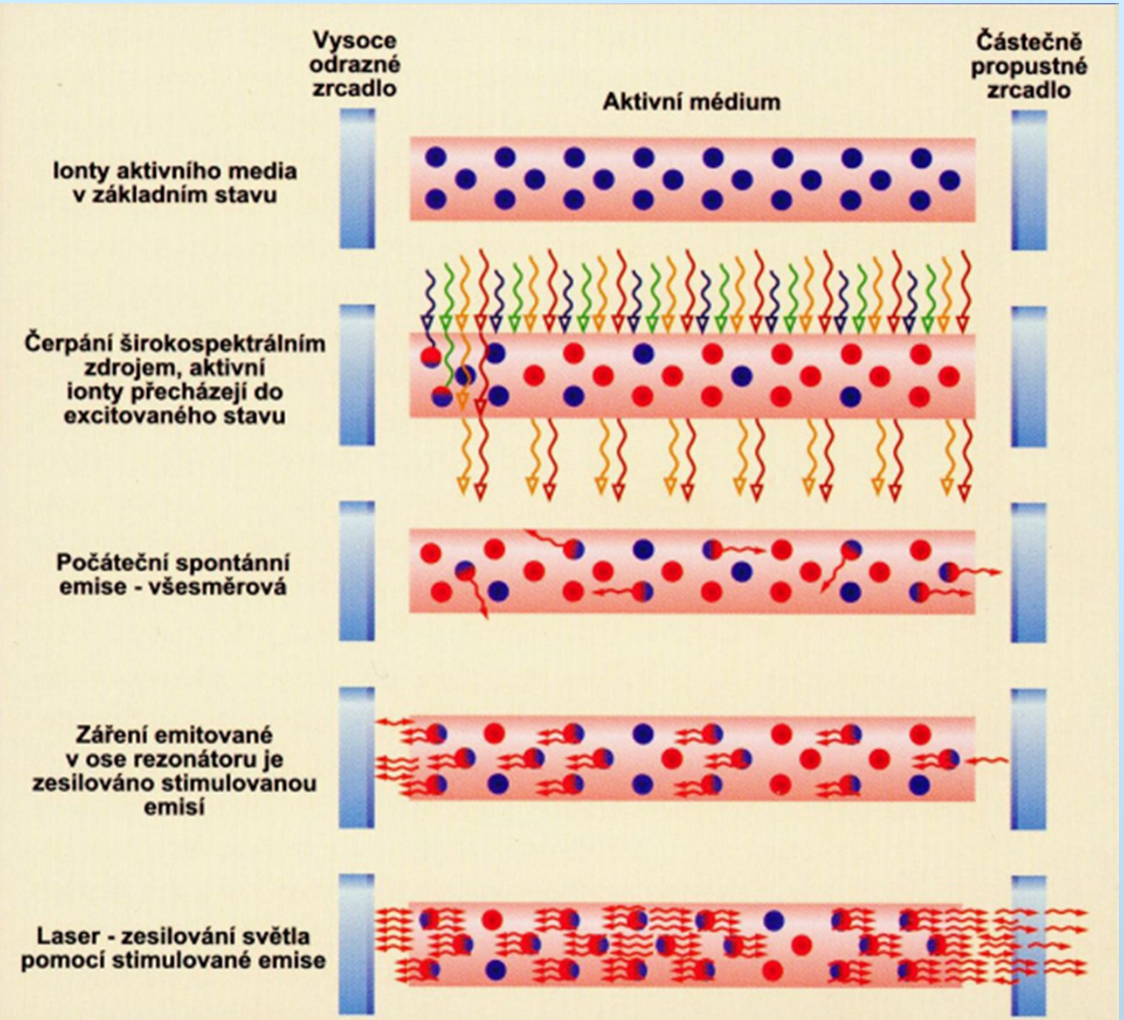


Er^{3+}

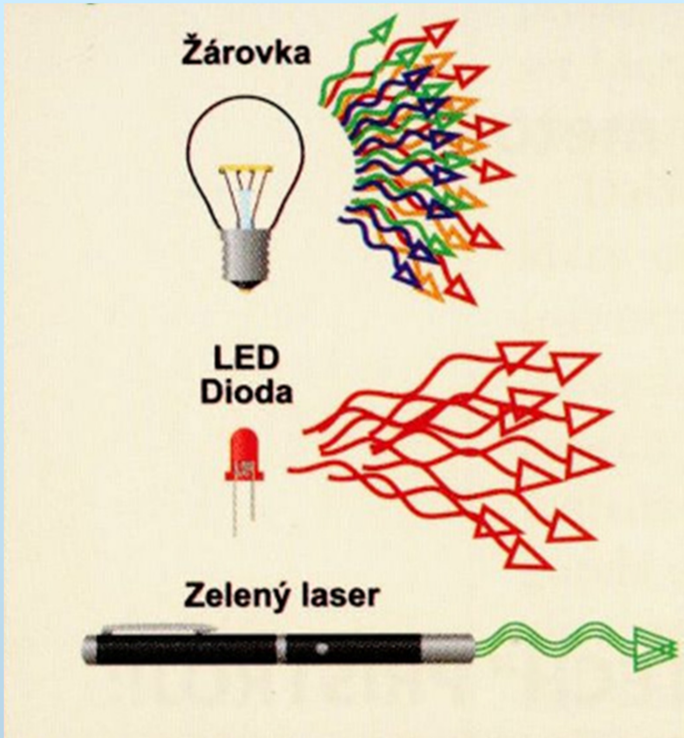
[C.J. Koester, E. Snitzer, Appl.Opt. (3) 1964, 1182] , [S.B. Poole, J.Lightwave Tech. LT-4 (**1986**), 870], [E.Desurvire, J.Lightwave Tech. LT-7 (1987), 835]

Stimulated emission → laser

Amplification by Stimulated Emission of Radiation



tyč (preforma) →
dopované vlákno →
vláknový laser

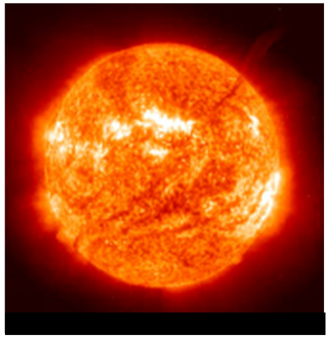


[H. Jelínková, Čs. Časopis pro fyziku, No. 4-5, 2011]

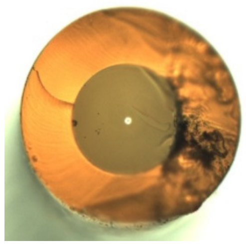
Fiber lasers mW → kW

* high conversion efficiency (fiber lasers ~70-90%) - savings
* high quality beam (nearly Gaussian, low divergency)
* **high brightness** (high concentration of power)
* good thermal management (cooling)
* effective pumping
* tunability
* compactness
* size (long resonator in small space)

[IPG]



sun	63 MW/m^2
fiber laser	12.7 GW/m^2



Fiber lasers vers. solid state lasers (SSL)

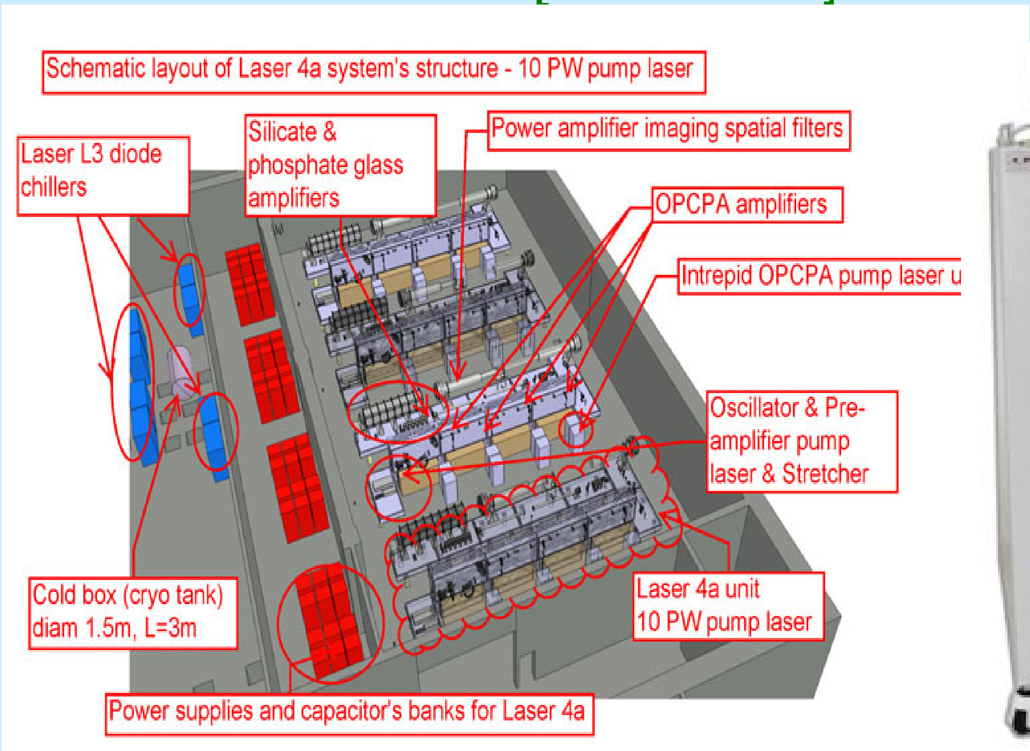
- **High brightness + flexibility**

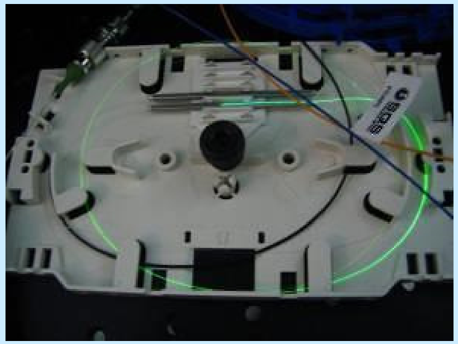
fs pulses **5 PW** / 25x25 cm

ELI Beamlines [10^{15} W/um^2]

CW 40- **100 kW** / 10 um^2

IPG Photonics [10^{15} W/ um^2]





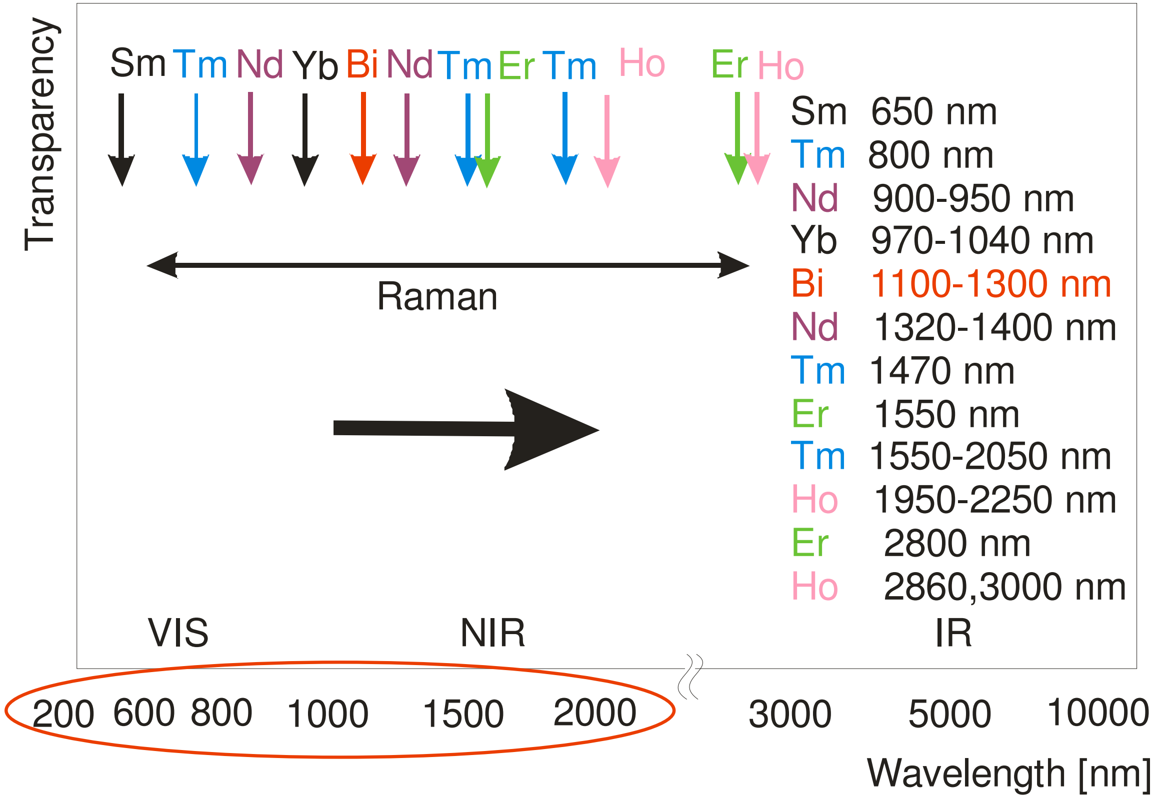
100 m

1 m

0.1 m

Silica (VIS-NIR) specialty optical fibers for fiber lasers and amplifiers

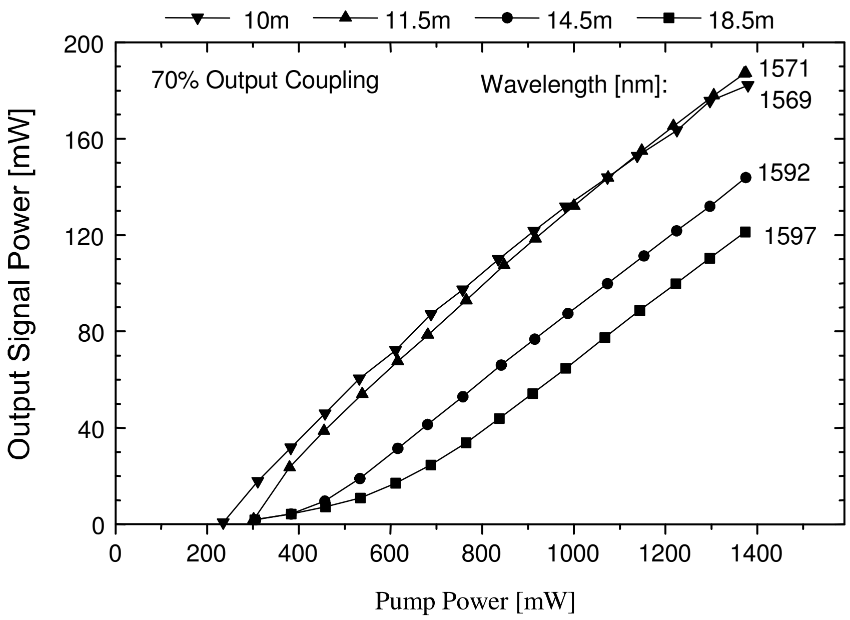
Dopants

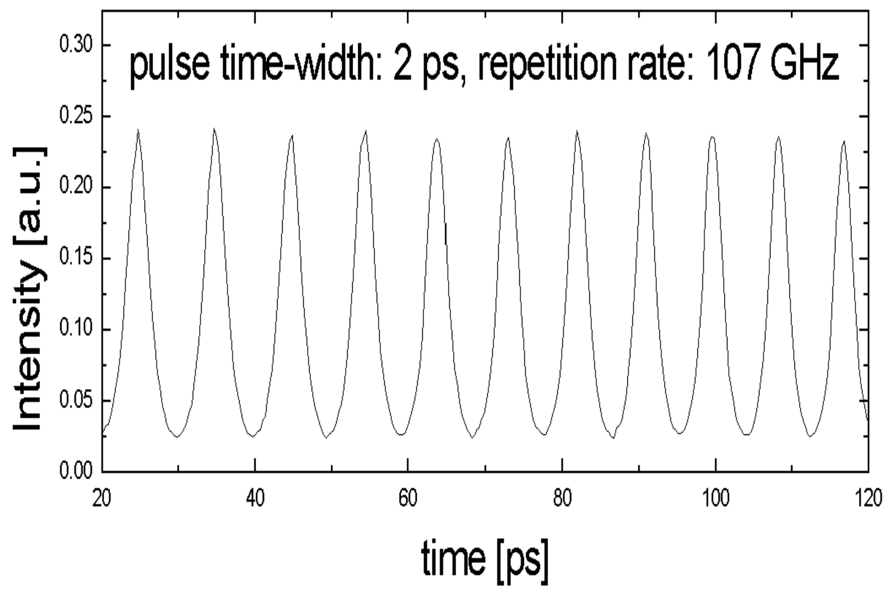


Dopant combination : effective pumping due to energy transfer

High-power lasers : **Er (1.5 um), Yb (1.1 um), Tm (1,9 um)**

Er/Yb fiber for soliton laser at 1 550 nm





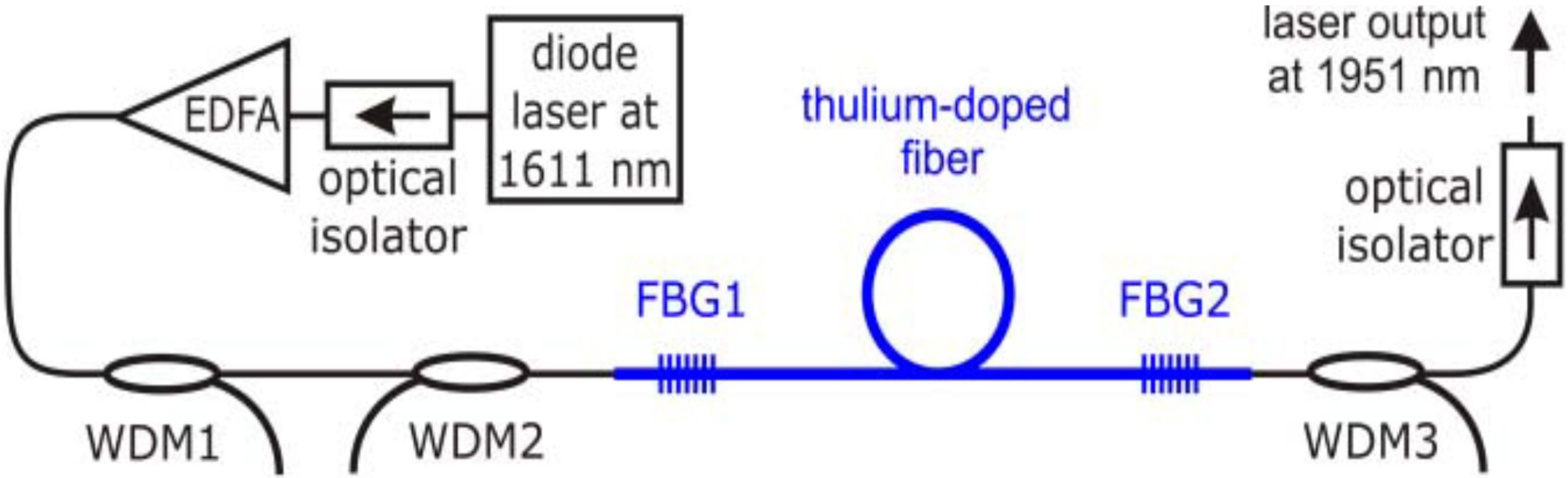
Er^{3+}/Yb^{3+} : 1000/10 000 ppm, Al_2O_3-SiO_2

[Kasik, V. Matejec, J. Kanka, P. Honzatko : Pure and Appl. Opt. **7** (1998) 457-465]

[I. Kasik, V. Matejec, M. Pospisilova, J. Kanka, J. Hora : Proc. **SPIE 2777** (1995) 71-79]

Monolitic Tm fiber laser at 1951 nm

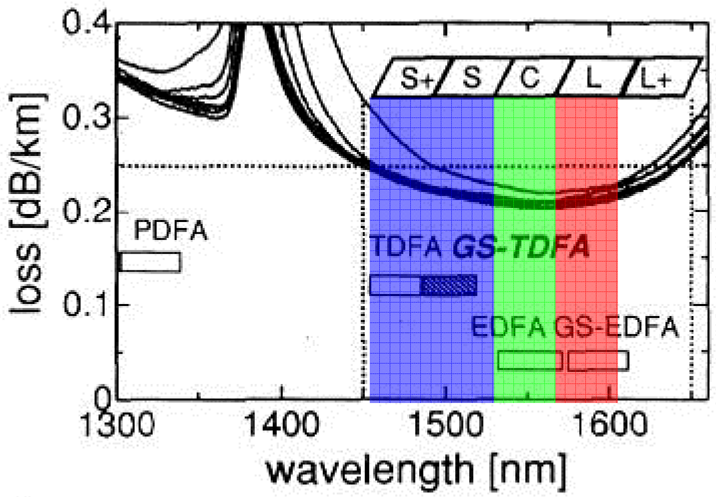
Eye-safe spectral region

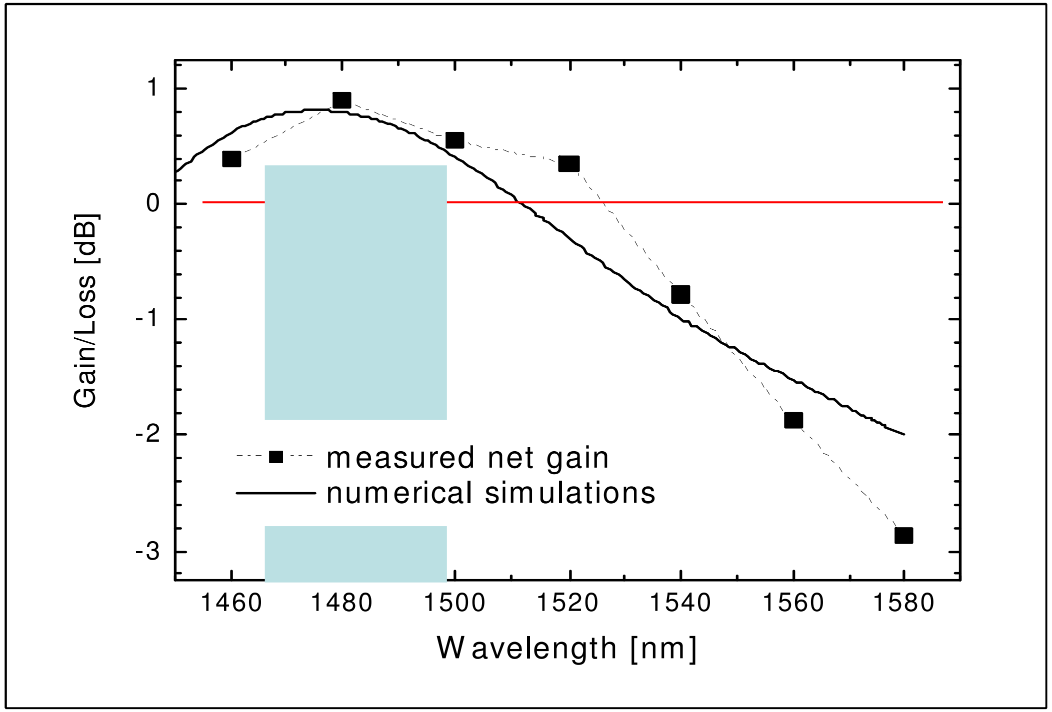


* 1000 ppm Tm^{3+}, 11mol% Al_2O_3, 0 mol% P_2O_5 or GeO_2,
* **deep-UV inscription of FBG**

[P.Peterka, Photonic Technol Lett, 25, 2013, 1623]

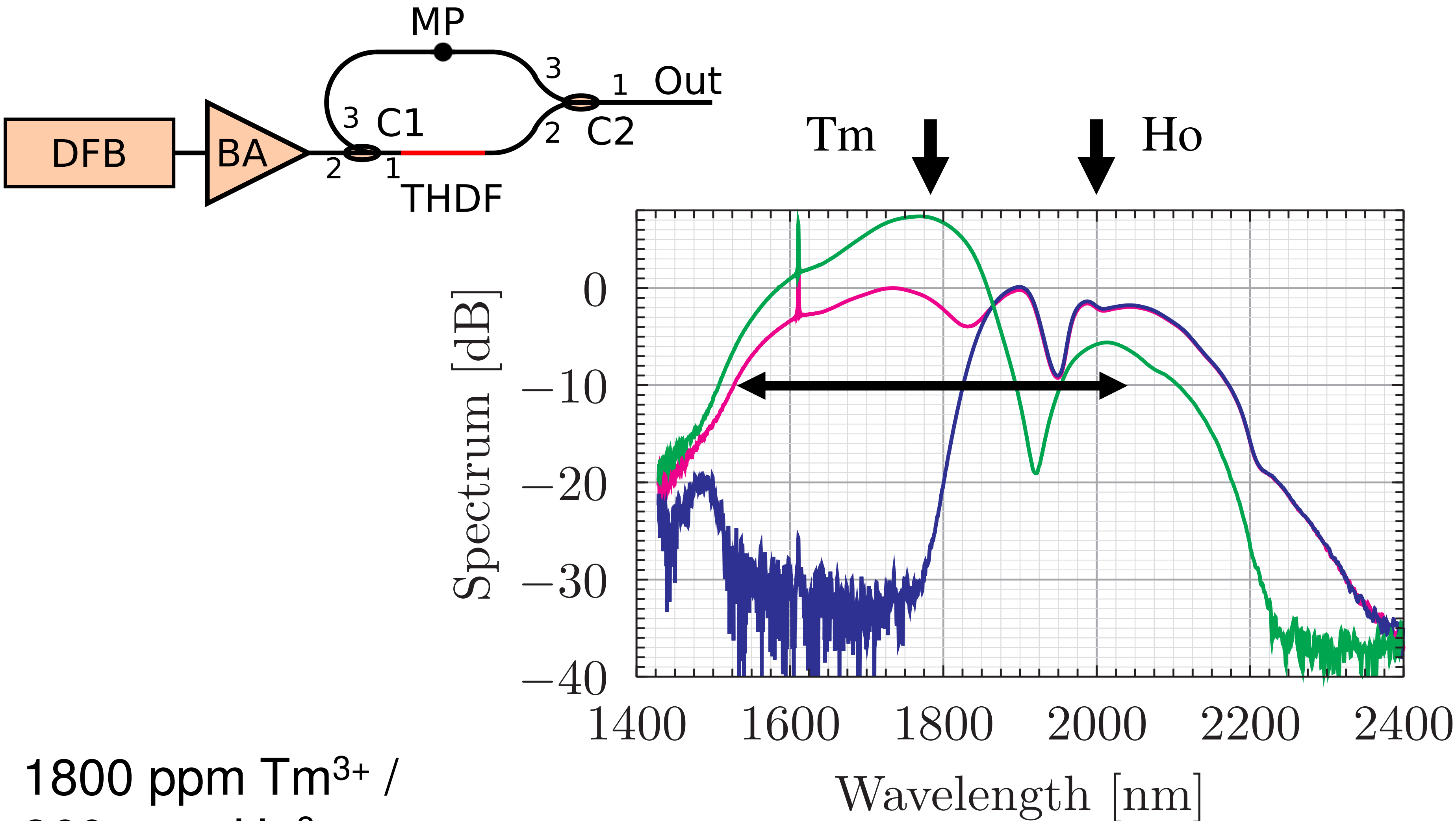
Tm fiber for amplifier at 1470 nm





[P.Peterka, Opt. & Quantum El., 36 2004, 201], [W.Blanc, Proc. SPIE 6180, 2006, 61800V.1], [P.Peterka, Optical Materials 30 (2007) 174]

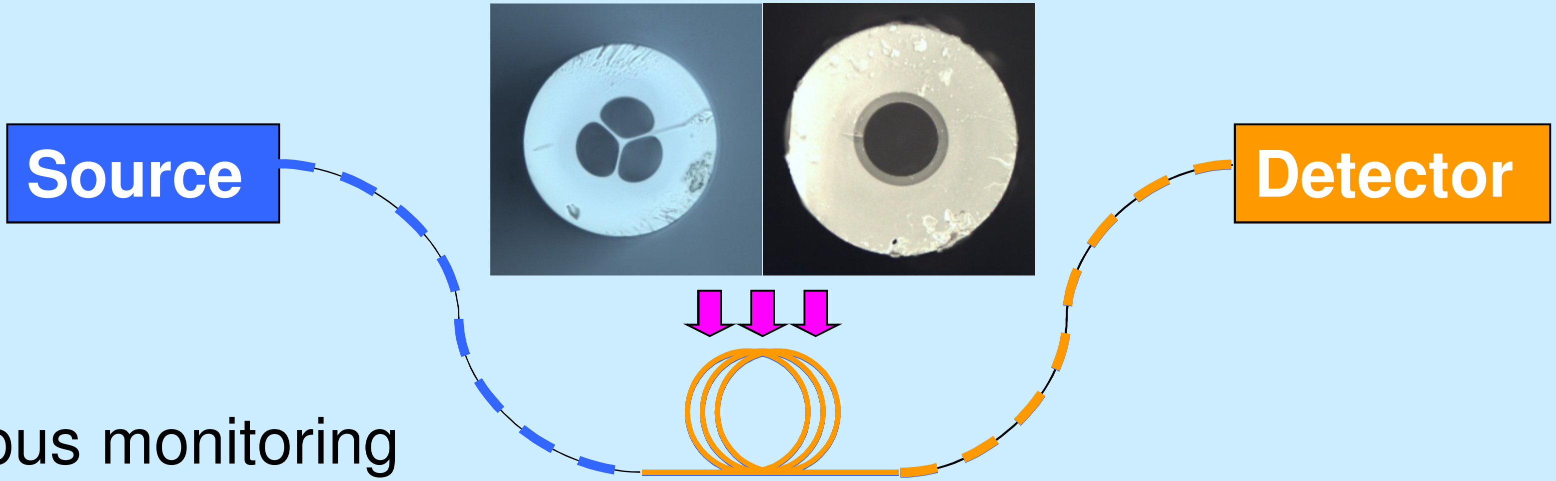
Tm/Ho fiber for ASE (1550-2050 nm) source



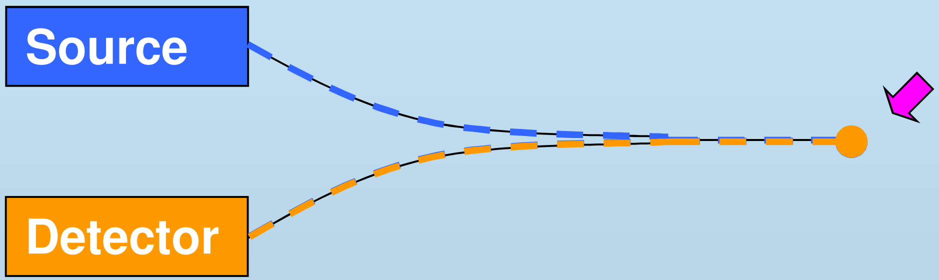
1800 ppm Tm^{3+} /
360 ppm Ho^{3+}

[P.Honzatko, Optics letters 39 (2014) 3650-3653]

Optical fiber sensors



Continuous monitoring of (bio)chemicals and their concentration.

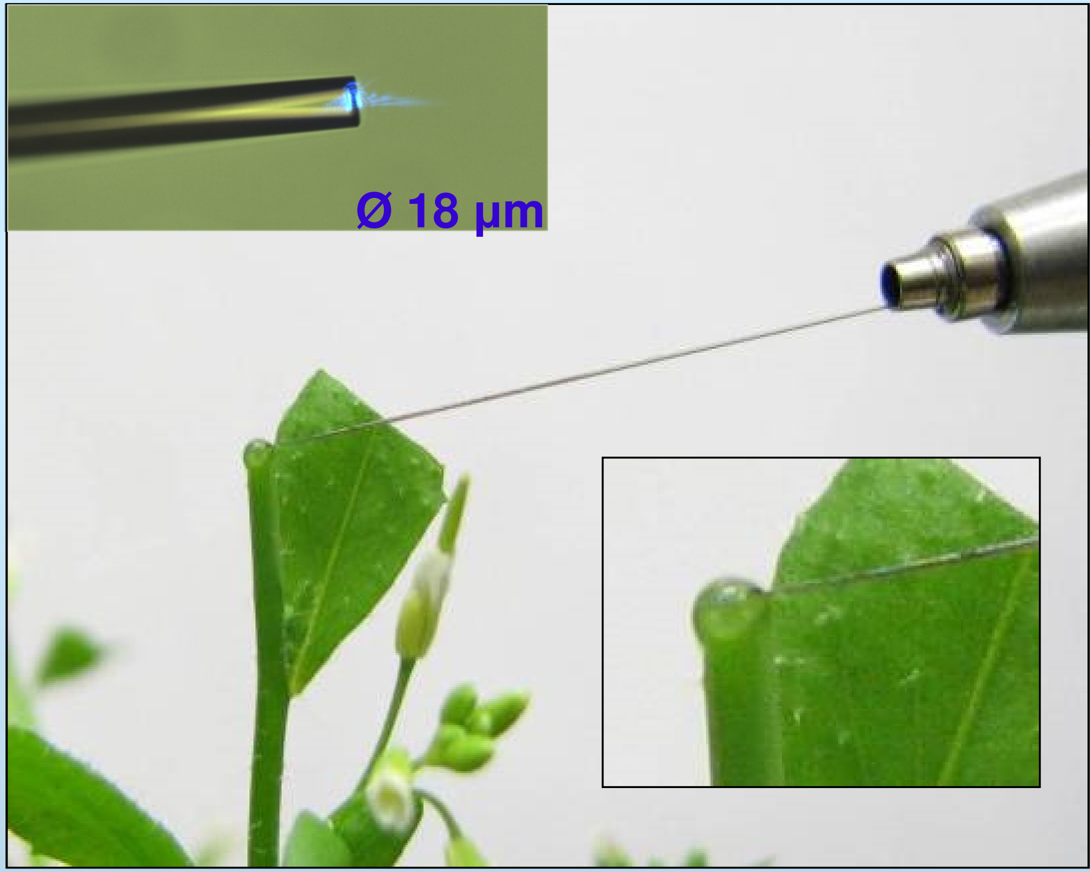


Suitable for :

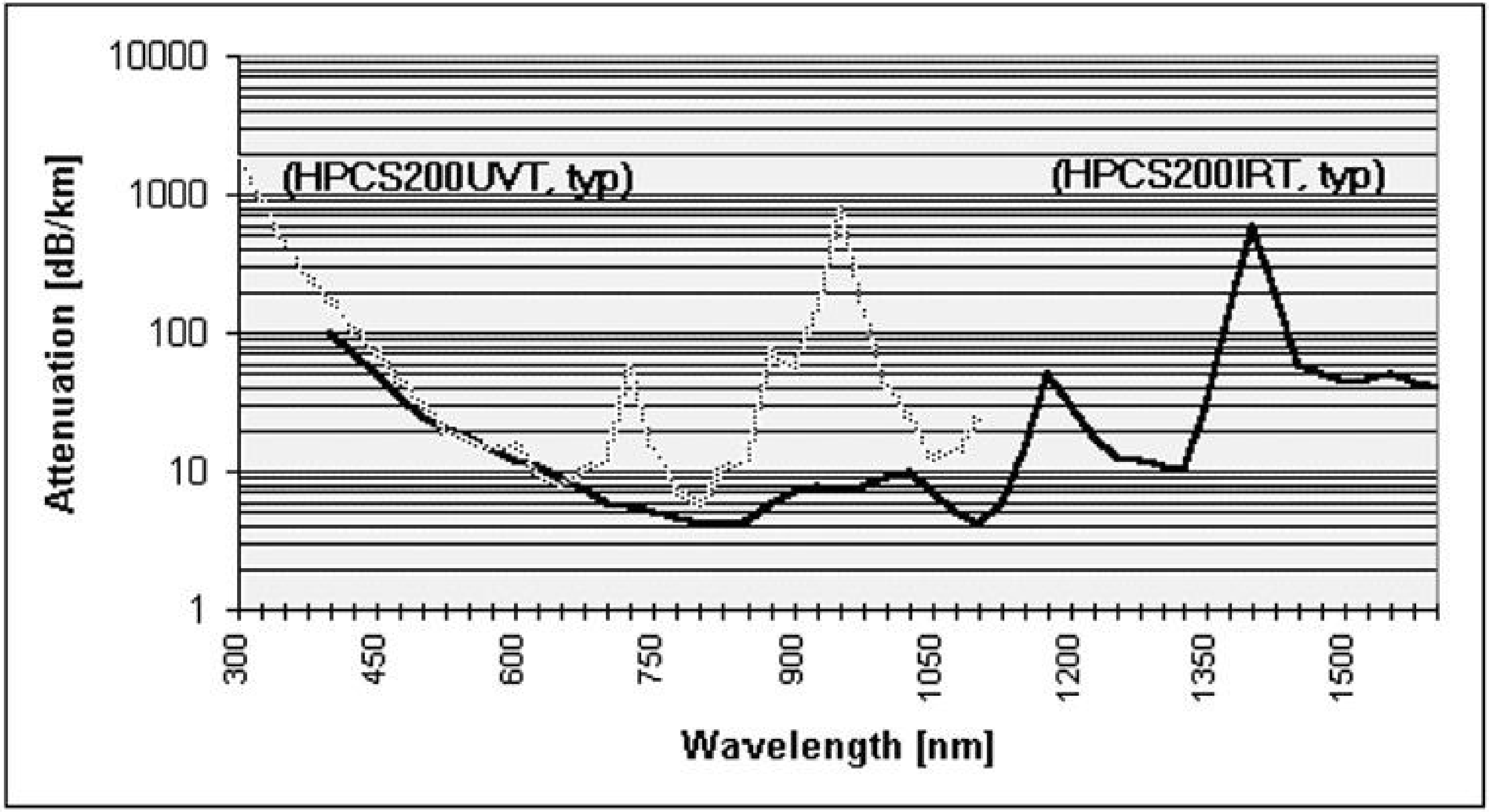
- remote sensing
- distributed sensing
- flammable or explosives
- in high-voltage areas
- human body

Optical fiber sensors

In vivo detection of pH in small samples (droplets, cells)



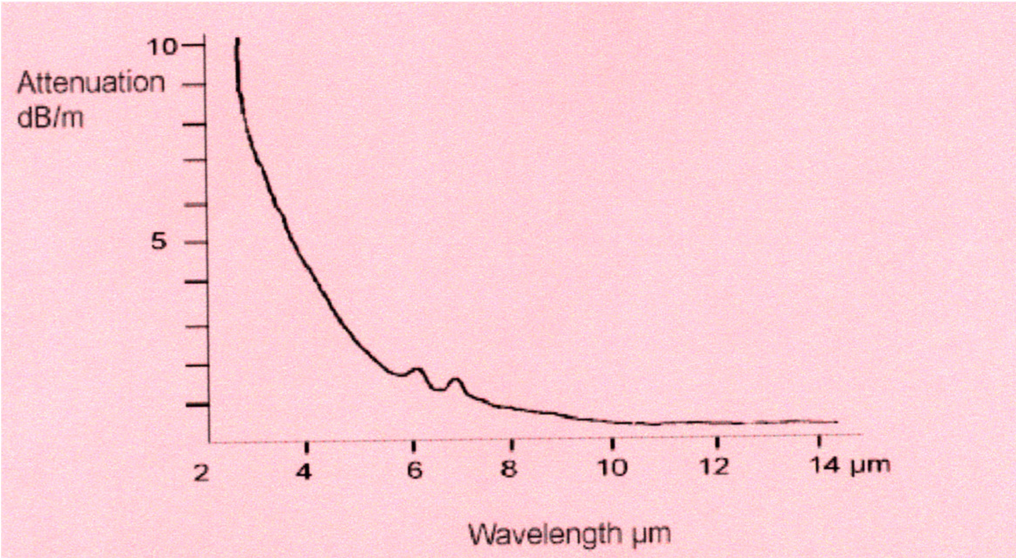
OPTICAL FIBERS – Materials - UV



- silica fibers - SUPRASIL $n_{200\ nm} = 1.55$ [ceramoptec.de, OceanO, IPE …]
- planar silica, crystalline CaF_2 (MgF_2) – [edmundoptics, technicalglass …]

OPTICAL FIBERS – VIS/NIR, IR

Silica n_{633} =1.457 & doped silica n_{633} = 1.45-1.50 [corning, lucent, ocean_o, IPE]
Glass (silicate - Simax, Vycor, Pyrex) n_{588} =1.5-1.95 [schott, LiFaTec.de, IPE…]
Plastic n_{588} =1.5-1.6 [mitsubishi.com, luceat.it, unlimited-inc.com…]



- fluoride glasses [univ-rennes1.fr …] (up to ~4 µm)
- **sapphire [CRYTUR] (up to ~4 µm)**
- silver-halides $AgCl_xBr_{1-x}$ (up to 15 µm)
- chalco glasses (Se, As_2S_3, As_2Se_3…) [oxford-electronics, orc.soton.ac.uk] (< 20 µm)
- refractive indexes $_{2\text{-}20um}$ ~ 2 – 2.5 >> silicate glasses [LiFaTec]

SUMMARY

1. Fiber technology : preparation of structures of high precision from materials of ultra-high purity (impurities in ppbs only). Difference between CVD and PVD.
2. Fiber preparation in two steps : preform preparation and fiber drawing. (M)CVD technique (preform) makes possible to prepare multilayered tailored structures of suitable level of purity.
3. Fibers conventional (passive) and special (active).
4. Research of optical fibers (CR) :

References

- **J. M. Senior** : Optical fiber communications - Principle and practise, Pearson Education Limited, Harlow, England, 2009.
- **A. Mendez, F.T. Morse** : Specialty optical fibers handbook, Elsevier Science & Technol, USA, 2006.
- **J. Schrofel, K. Novotný** : Optické vlnovody, SNTL, 1986
- **Saaleh,** Fotonika (1 - 4), Matfyzpres

- **S. R. Nagel, J. B. McChesney, K. L. Walker :** An overview of the MCVD process and performance, IEEE J. Quantum Electron. QE-18 (1982) 459-477

- **Peterka - Vláknové lasery**
- Československý časopis pro fyziku 1/2010, 4-5/2010, 1/2011
- Jemná mechanika a optika (2015)
- Sdělovací technika 3/2011