INTERNATIONAL YEAR OF LIGHT 2015

ÚFE

Academy of Sciences

Institute of Photonics and Electronics v.v.i.

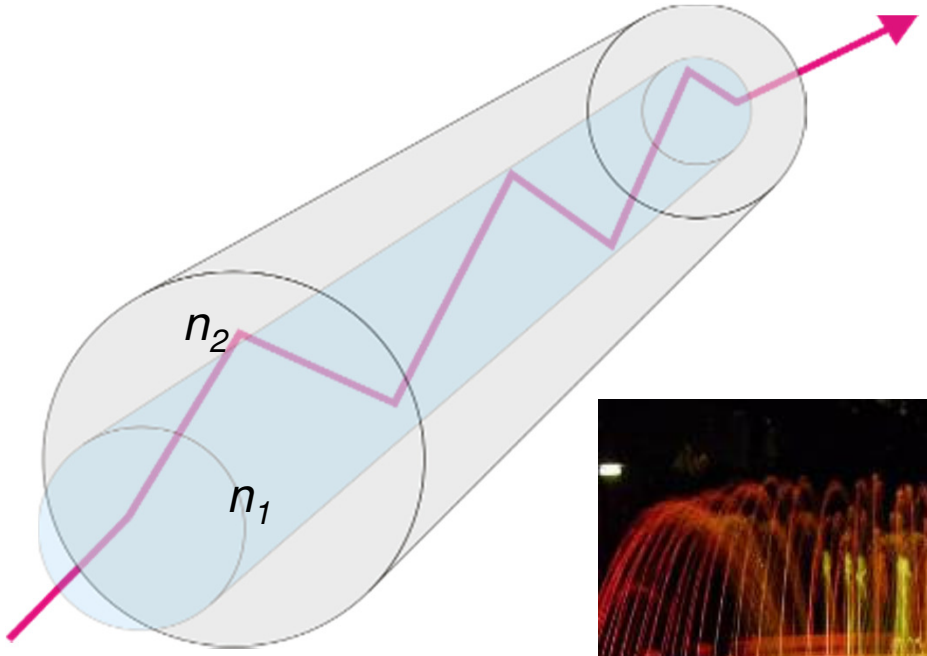
Technology of Optical Fibers

www.ufe.cz

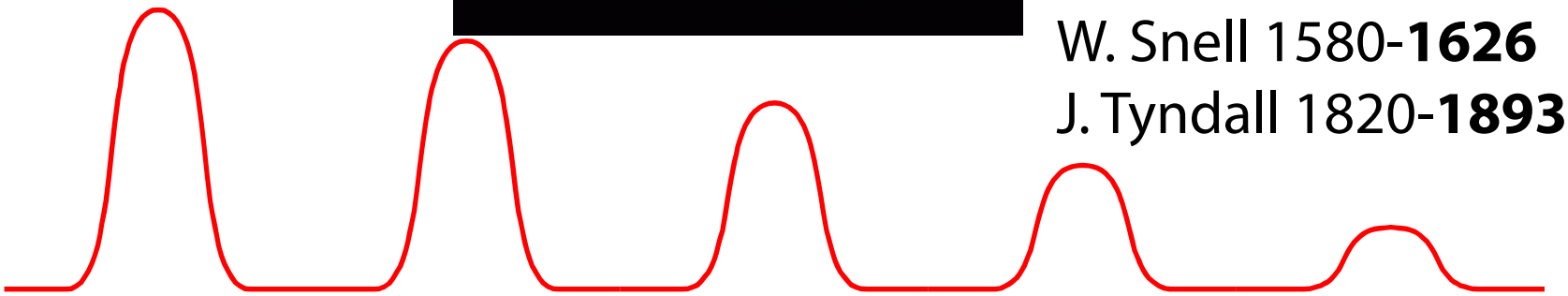
Outline

Intro	optical fibers
Technologies	MCVD preform preparation fiber drawing
Application	telecommunications fiber lasers (sensors)
Summary	
LABO	MCVD, fiber drawing, sol-gel, magnetron sputtering

Optical fibers



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



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

Optical fibers

Optical losses in optical fibers

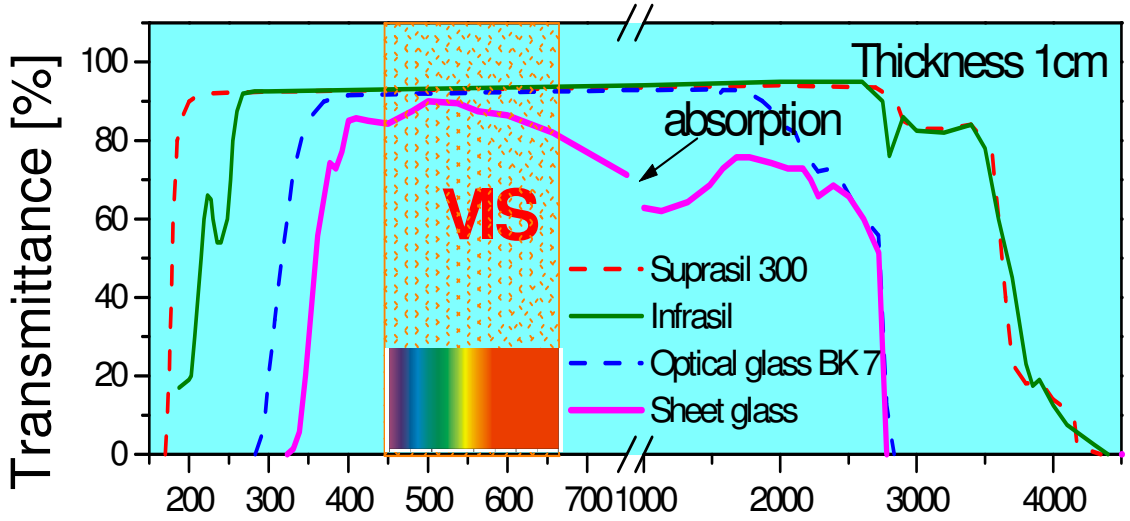
- trasparency of 3 mm of window-glass ≈ 2 km of optical fiber

Charles K. Kao

Nobel prize 2009

high-purity materials
max impurities acceptable in ppb (10^{-9})

ULTRA-PURE TECHNOLOGIES



Purity of materials

1. Per Analysis – PA (99 - 99,5 %)
2. Semiconductor – PP (99,9995 %)
3. Ultra-pure - FO Optipur / for trace analysis [ppb]

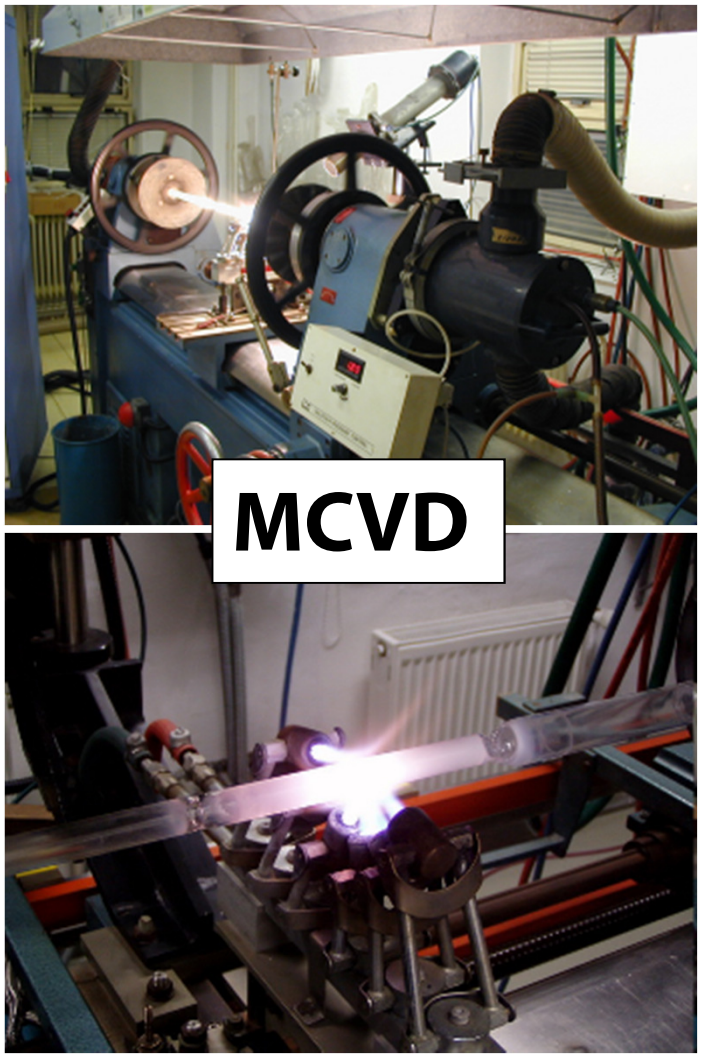
% – 10^{-2}

ppm – 10^{-6} (parts per million)

ppb – 10^{-9} (parts per billion) : content of impurities acceptable in FO Optipur materials

Ultra-pure technologies - CVD !

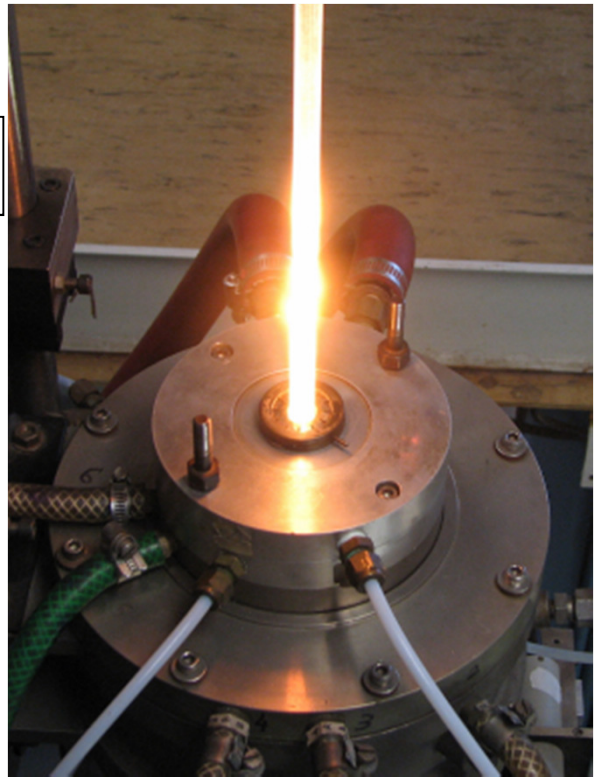
Optical fiber preparation - technology



MCVD

1. Preform

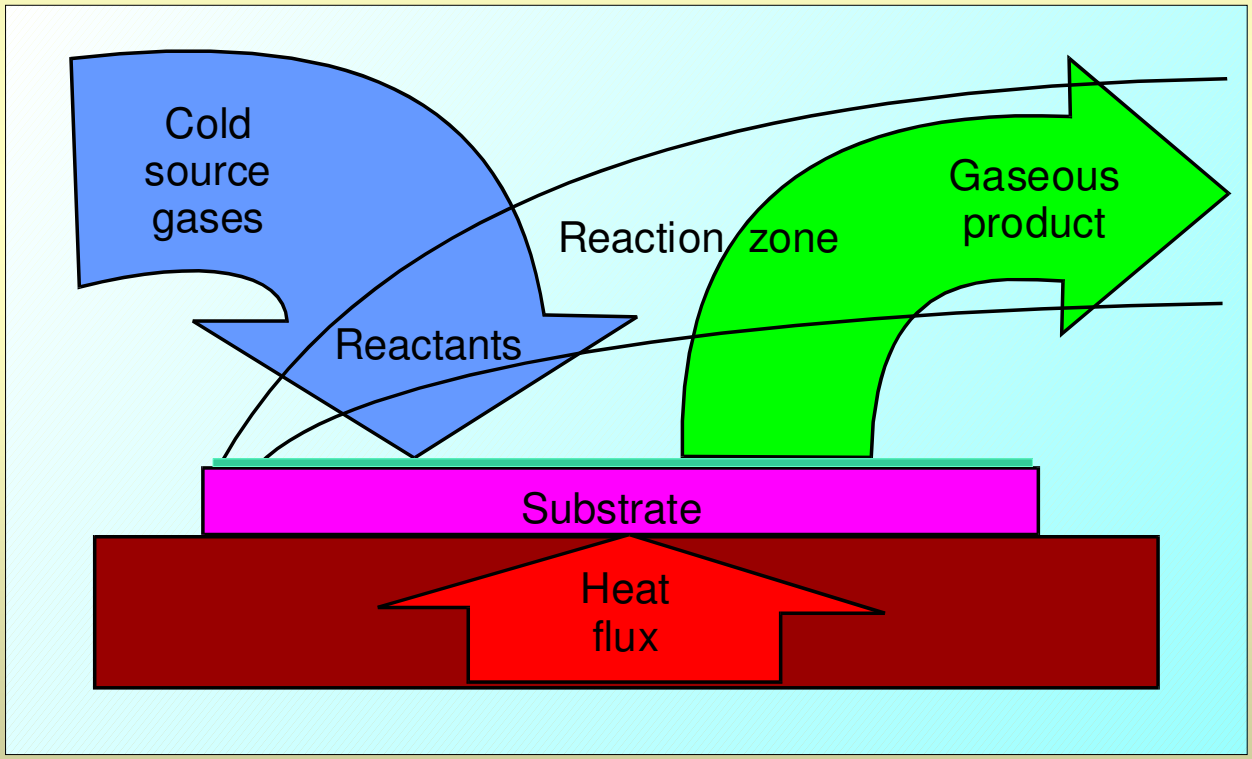
2. Fiber drawing



CVD - Chemical Vapor Deposition TECHNOLOGIES

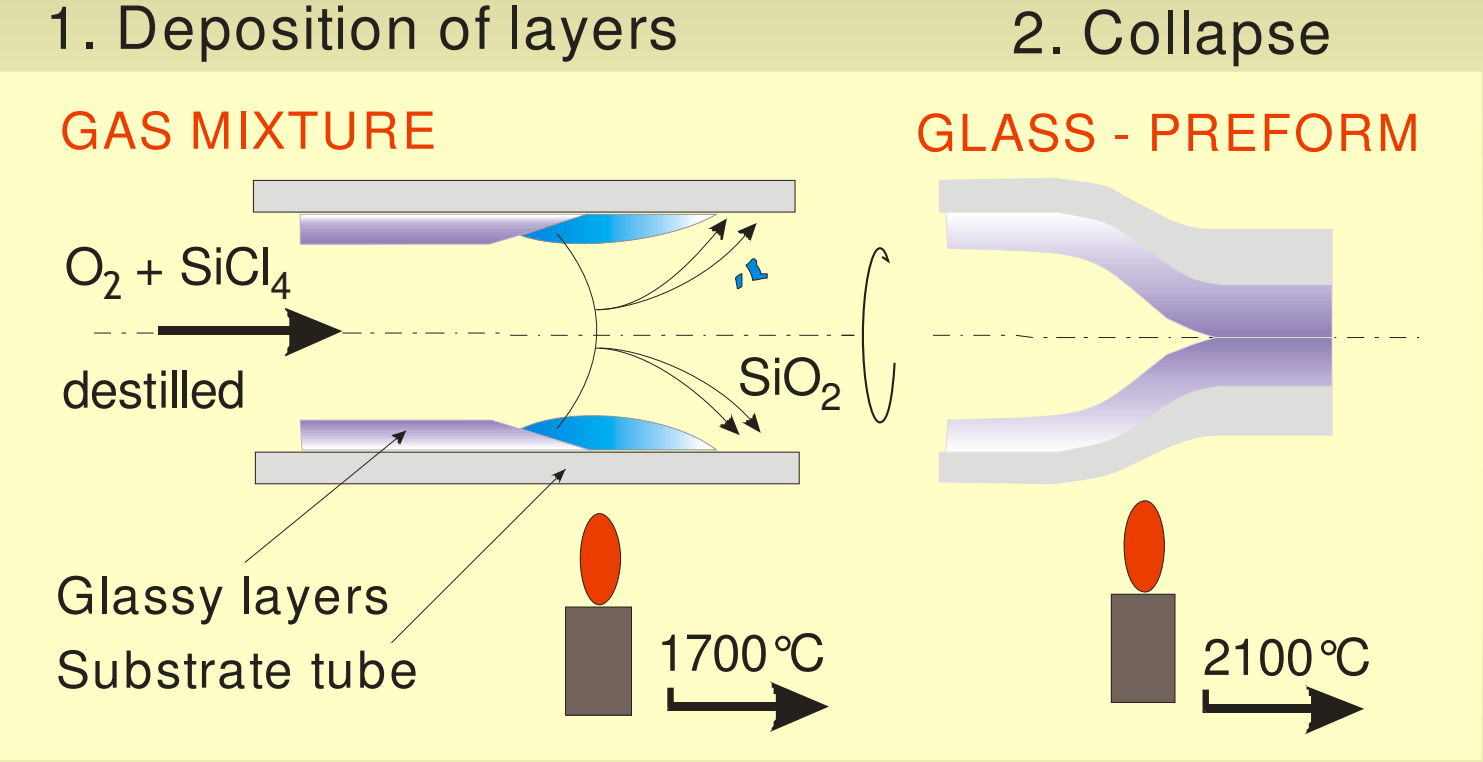
Production and deposition of material in solid state from starting materials in gaseous state through a chemical reaction :

A (g) + B(g) = AB (s)



Preform preparation - MCVD

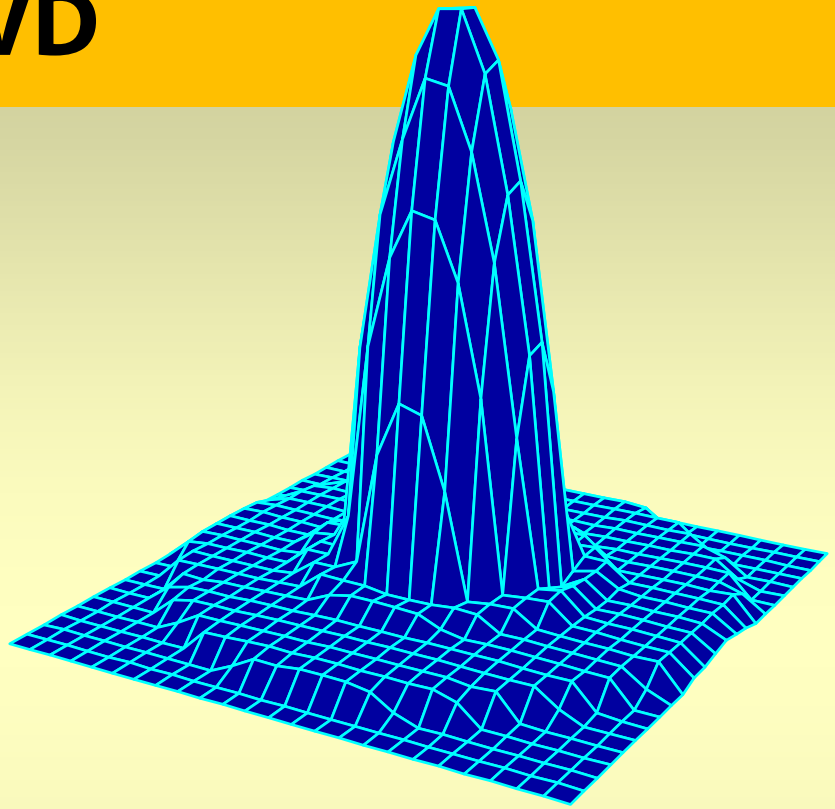
MCVD – (Modified) Chemical Vapor Deposition



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

MCVD

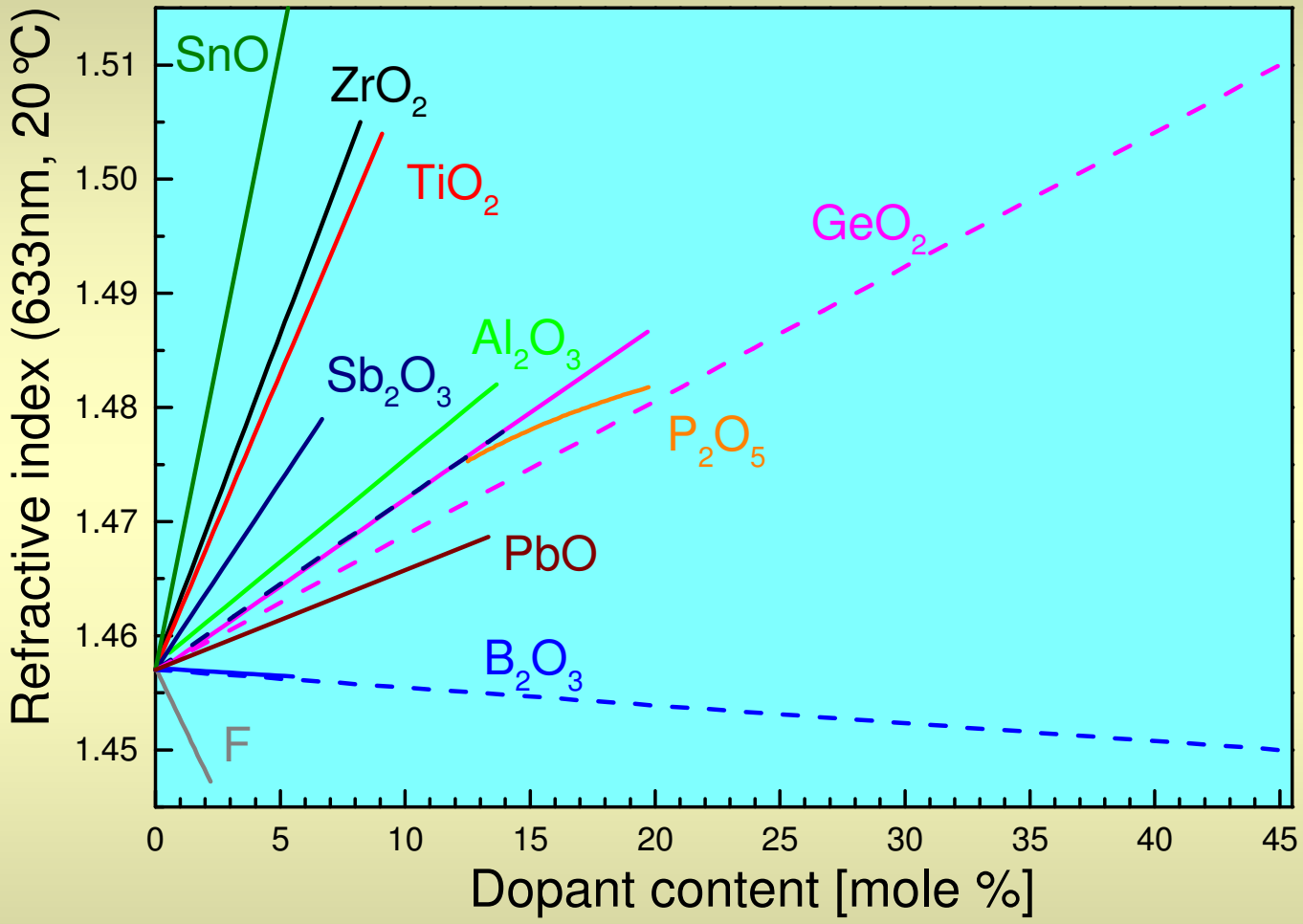
Microphoto of cross section of produced preform



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 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 :

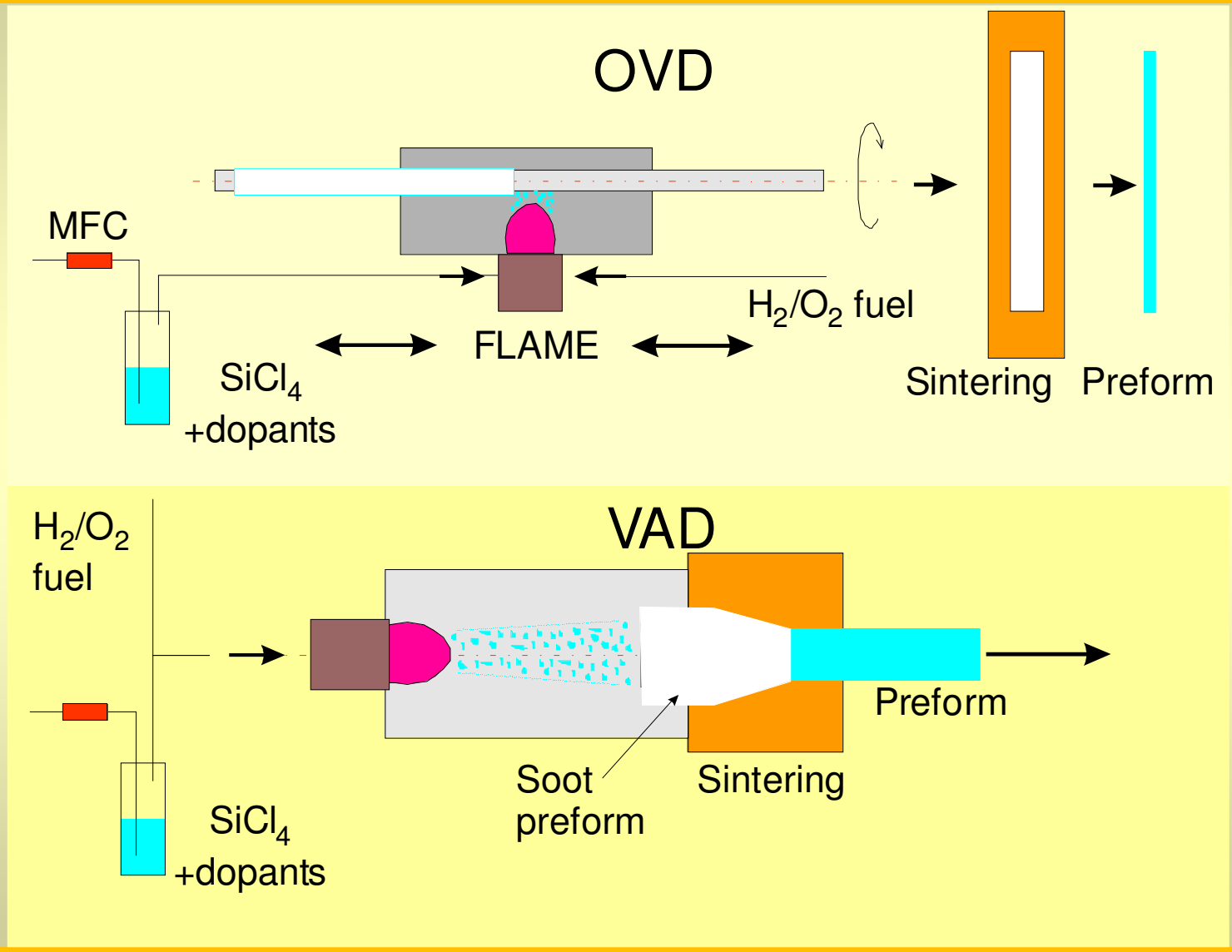
- flow rates (Si, Ge, P, B, F, Ox …)
- deposition temperature

Adjustable :

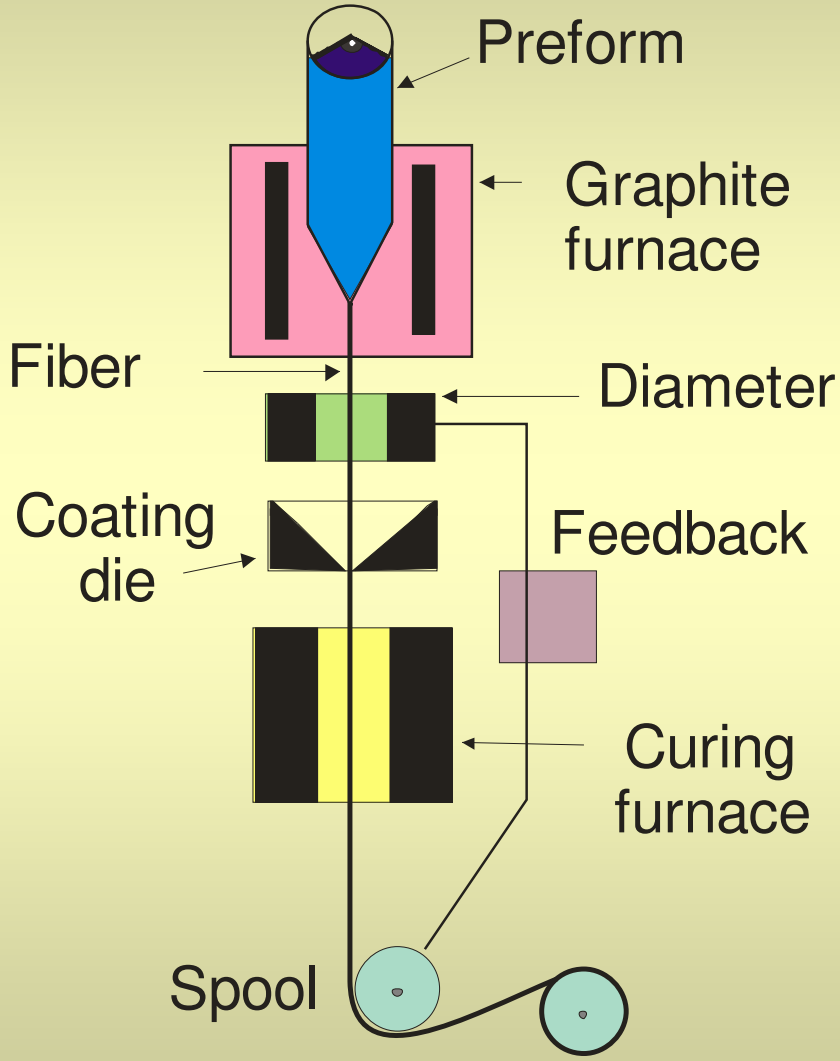
- temperature of starting materials (liquids)
- burner speed
- pressure
- rotation speed of the substrate tube
- substrate tube dimensions

[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)

MCVD	DC magnetron sputtering
OVD etc.	vacuum evaporation etc.

Layer thickness

1 – 10^1 **µm**	1 - 10^1 **nm**

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

Deposition rate

HIGH	LOW

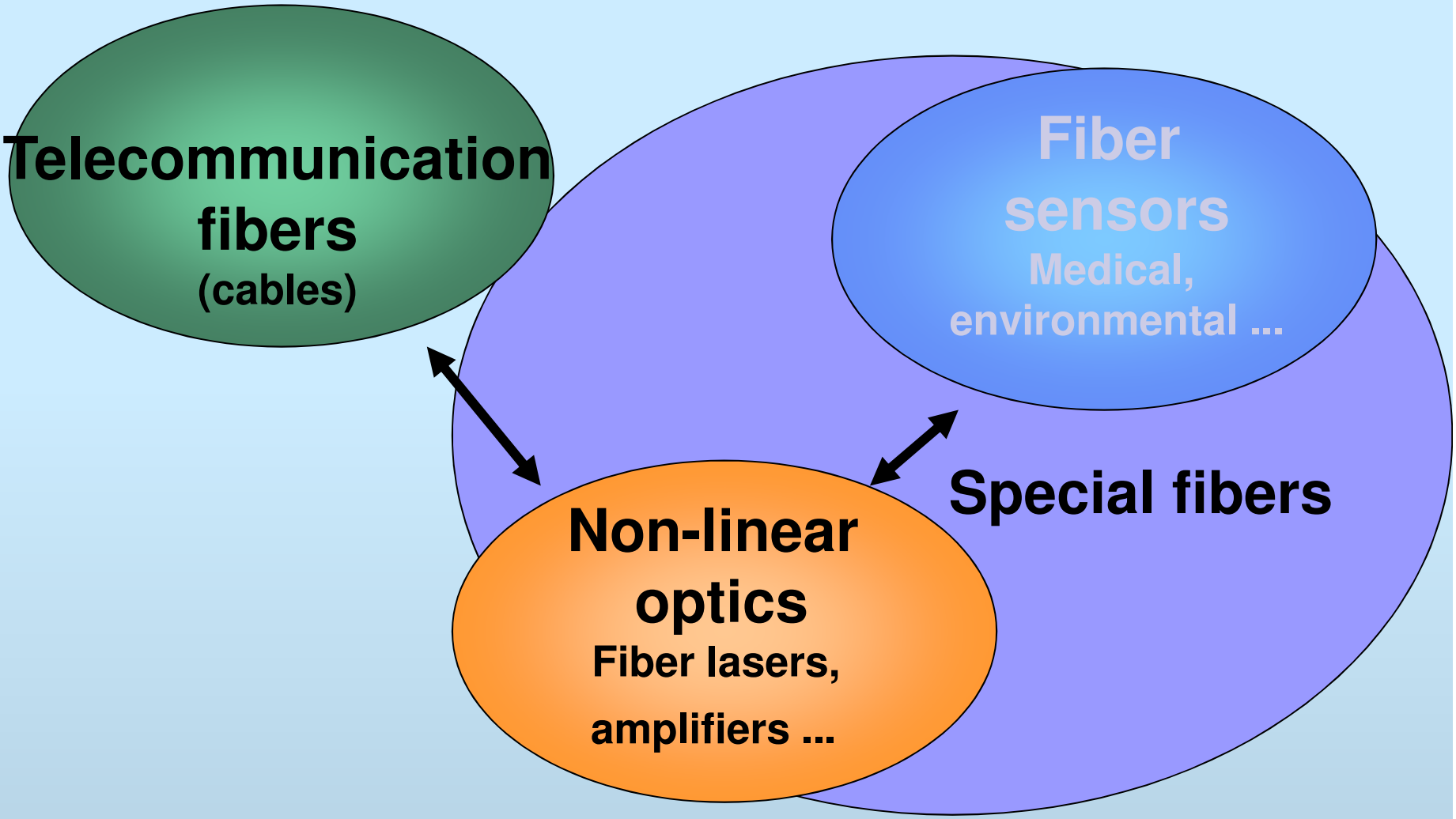
Products

Layers, bulks	Layers only

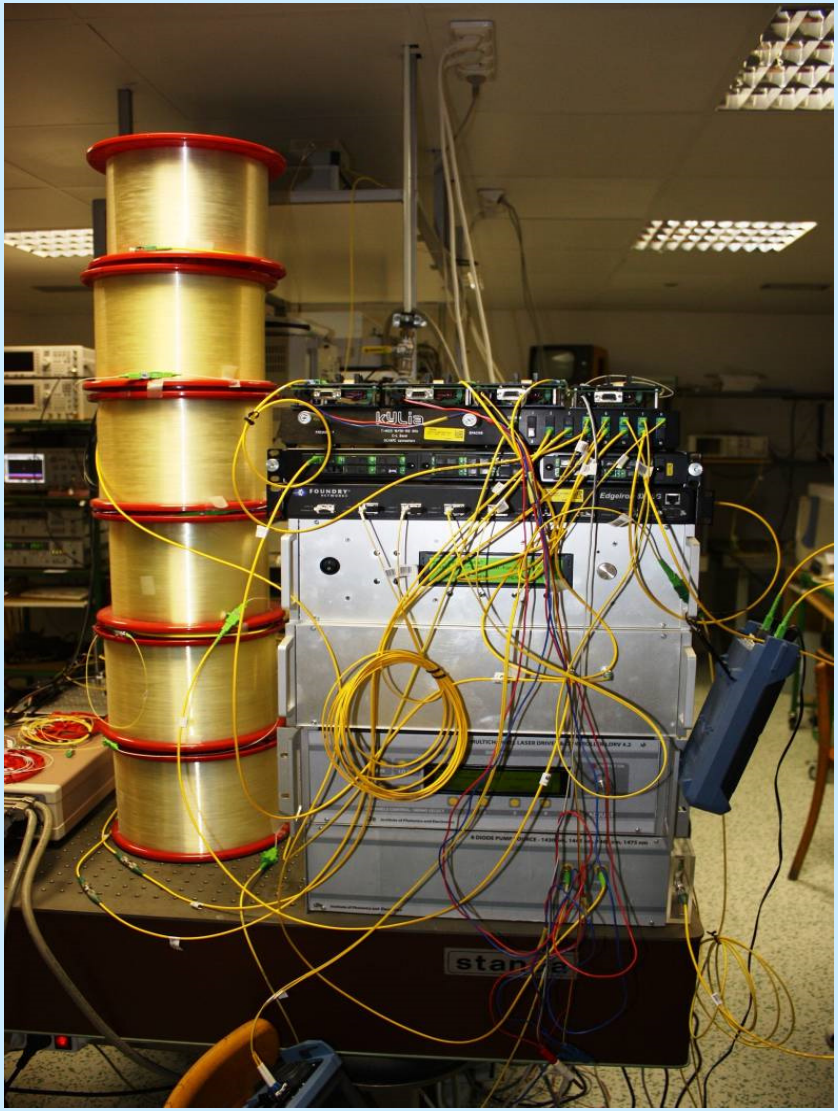
Comparison

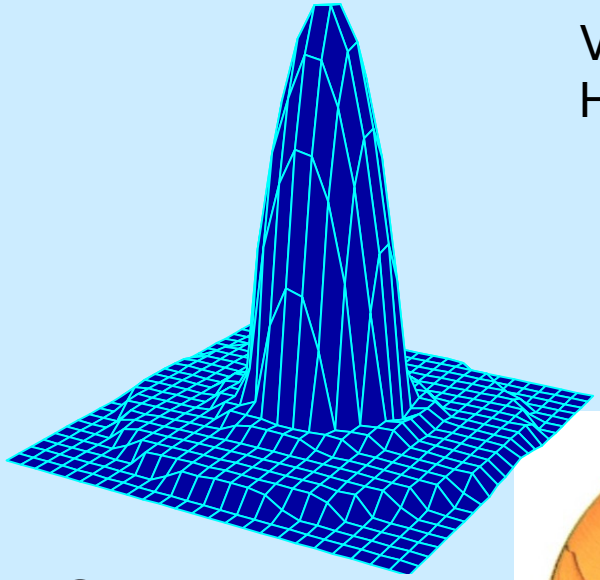
(M)CVD	x	conventional
Starting materials		
gaseous (g) or liquid (l)		(s) solid state
melting point of oxides different		melting point comparable
Purification methods		
distillation		recrystallisation, remelting
Structure of products		
Graded - profiles		Homogeneous
Material purity		
ppb (10^{-9}, i.e. 10^{-7} mol%)		10^{-3} mol% (99,999%)

Application



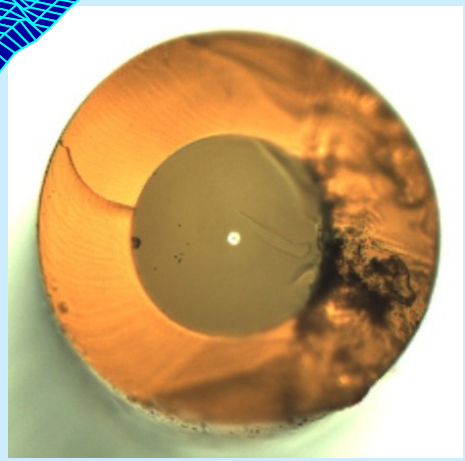
Telecommunications





VÚSU Teplice,
Hesfibel - TR

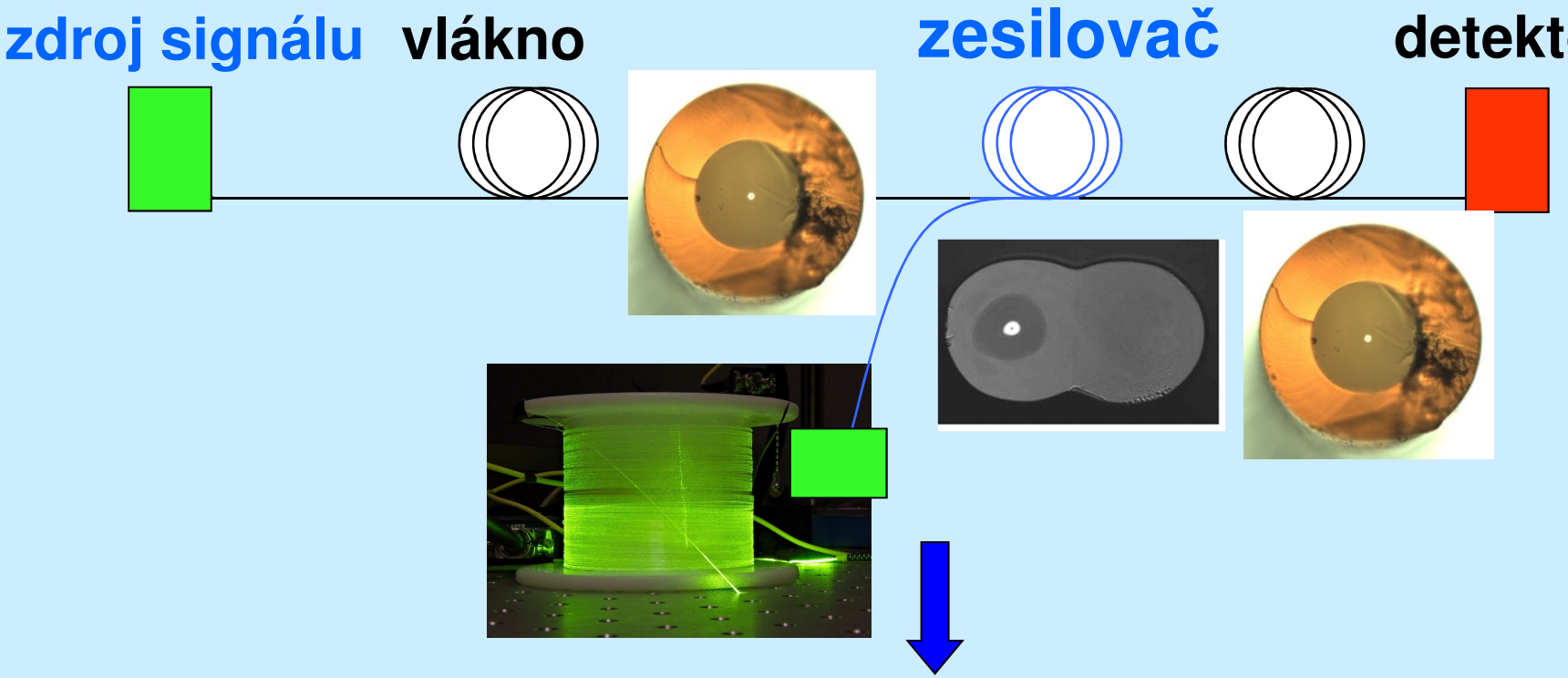
GI - multimode



SM - singlemode

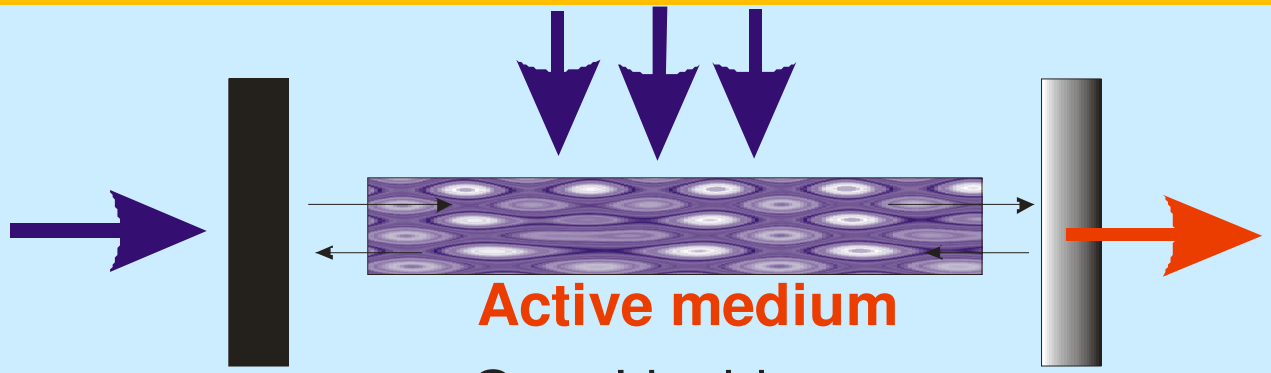
200 km telecom line - test

Telecommunications



Vláknový zesilovač, laser

Silica specialty optical fibers for fiber lasers and amplifiers [mW→kW]

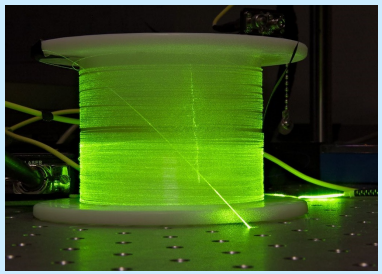


mW = telecom
kW = raw power

Mirror
100%

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

Mirror
8-99%



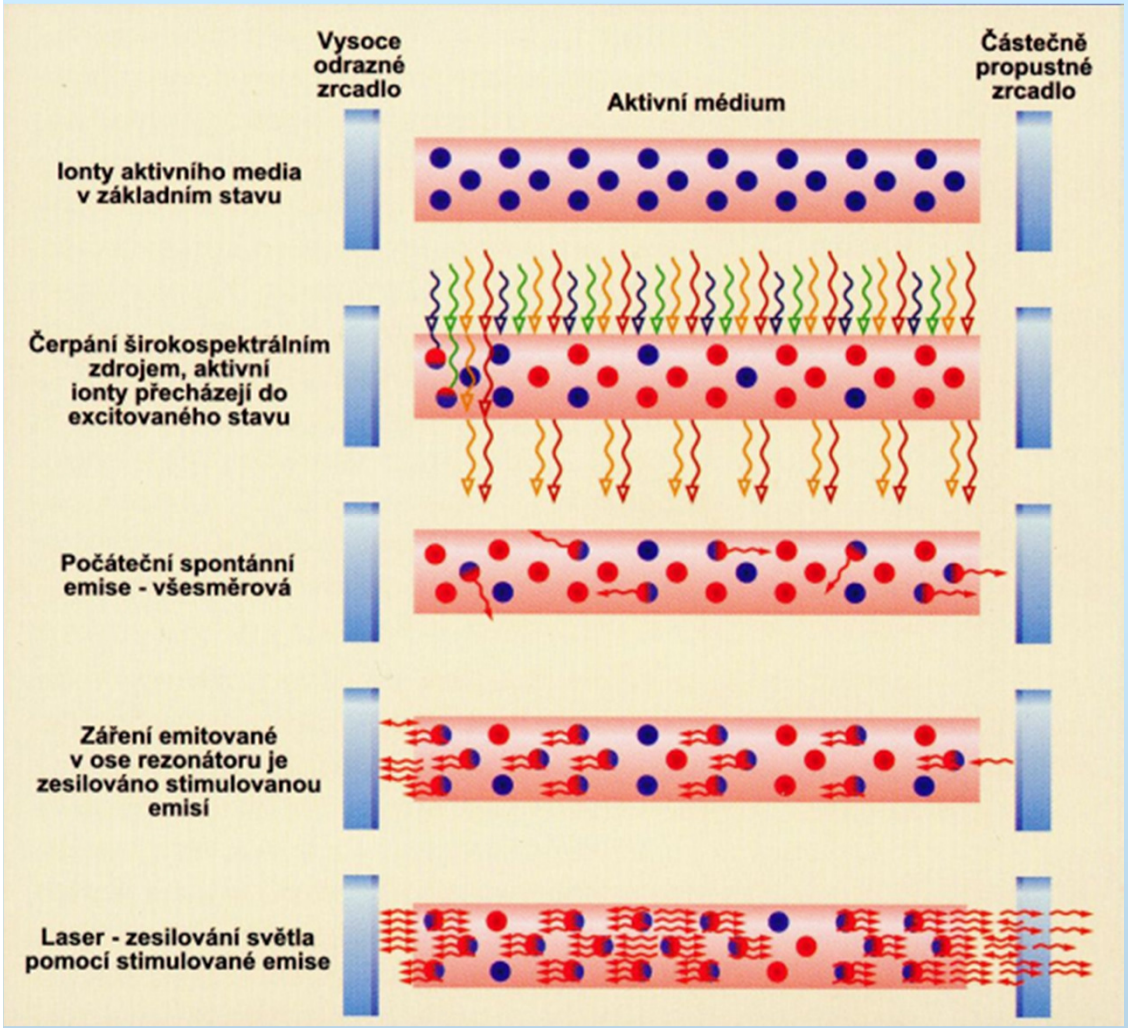
Er^{3+}

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

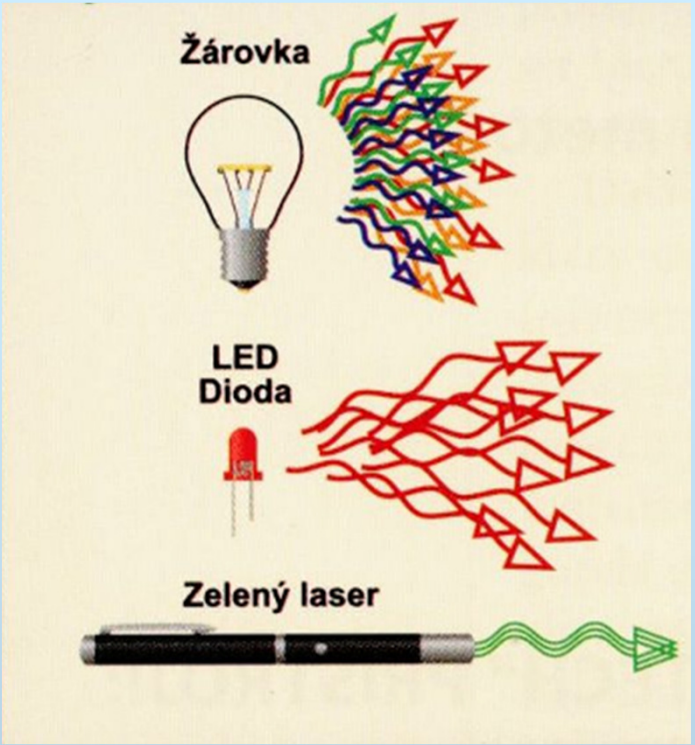
[C.J. Koester, E. Snitzer, Appl.Opt. (3) 1964, 1182] , [S.B. Poole, J.Lightwave Tech. LT-4 (**1986**), 870], [E.Desurvire, J.Lightwave Tech. LT-7 (1987), 835]

Stimulated emission → laser

Amplification by Stimulated Emission of Radiation



tyč (preforma) →
dopované vlákno →
vláknový laser

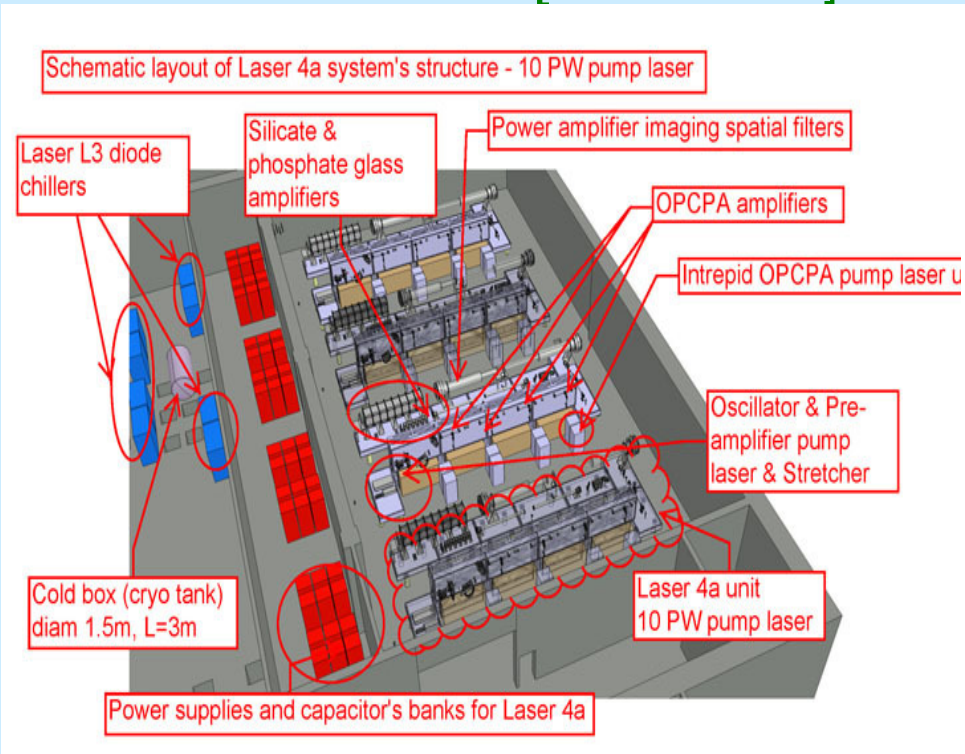


* H. Jelínková, Čs. Časopis pro fyziku, No. 4-5, 2011

Fiber lasers vers. solid state lasers (SSL)

- **High brightness + flexibility**

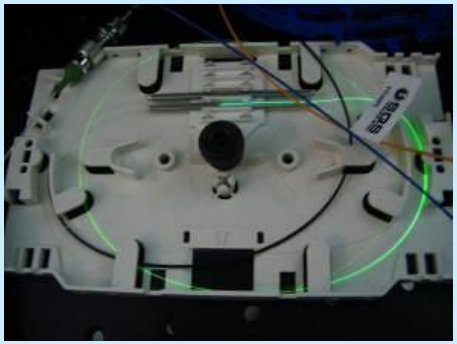
fs pulses **5 PW** / 25x25 cm
ELI Beamlines [10^{15} W/um^2]



100 m

CW 40- **100 kW** / 10 um^2
IPG Photonics [10^{15} W/ um^2]

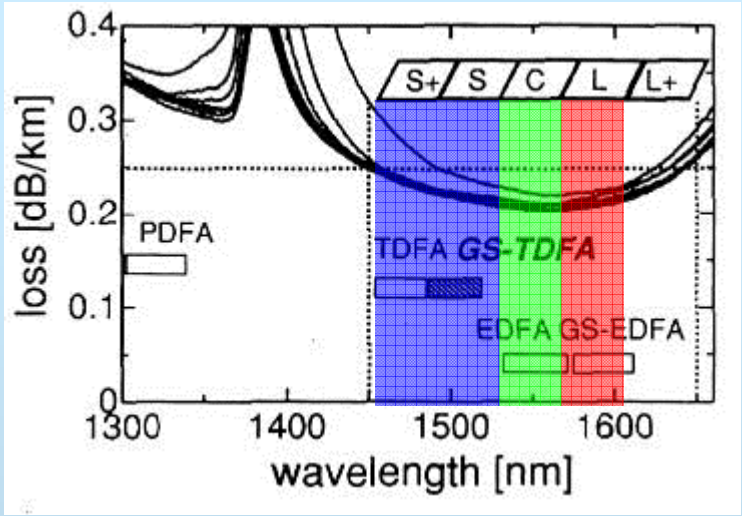
1 m

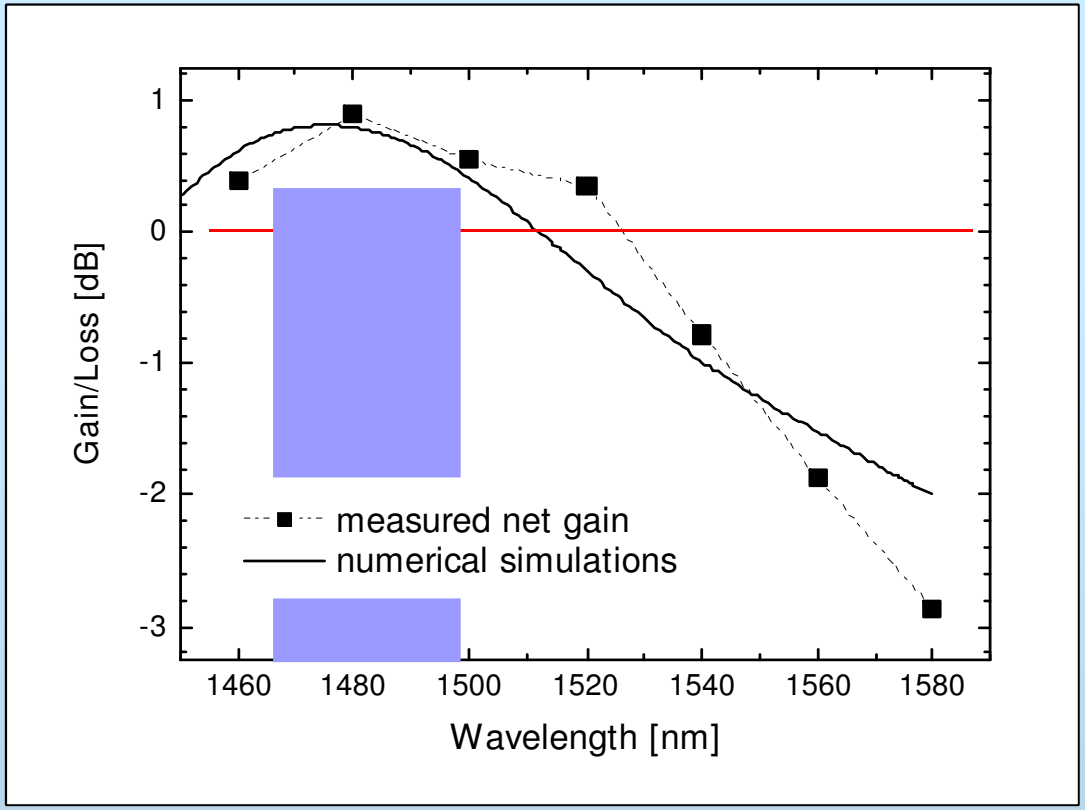


0.1 m

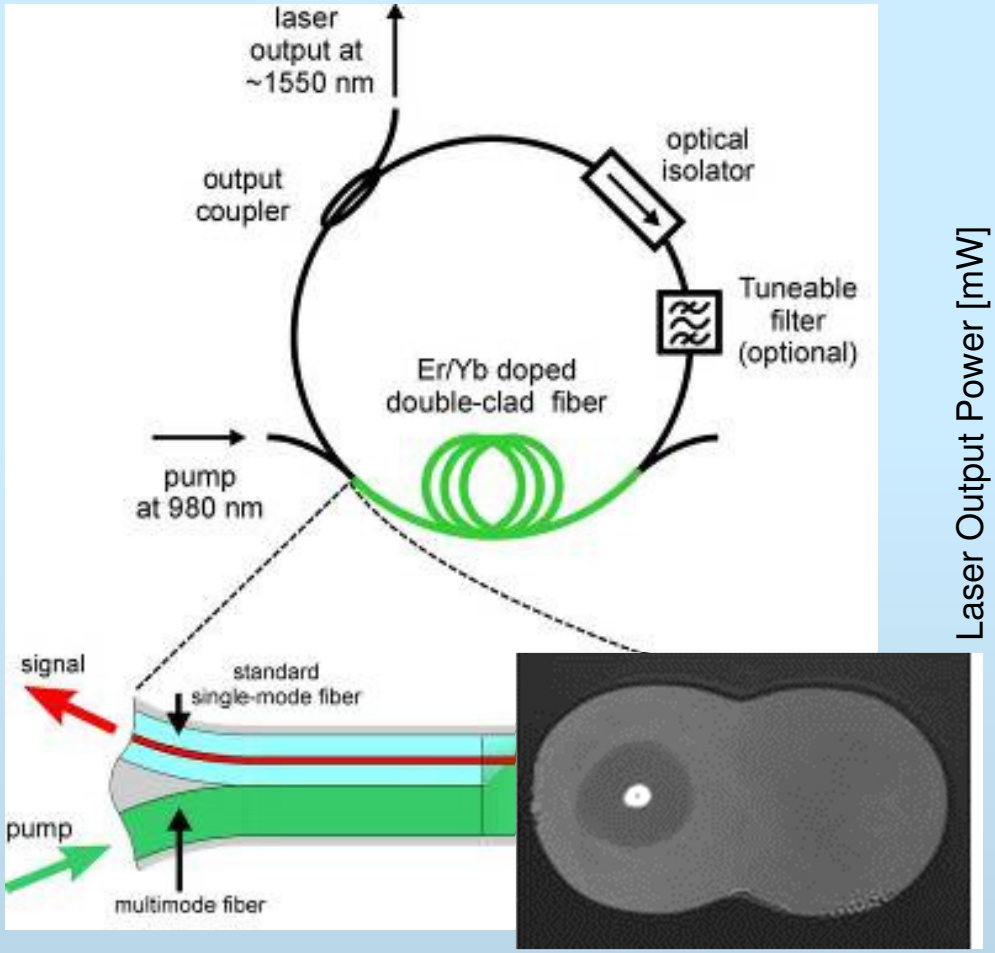
SPECIAL OPTICAL FIBERS for fiber lasers & amplifiers

Tm^{3+}-Al_2O_3-SiO_2 fibers for Tm -doped fiber amplifier at 1470 nm

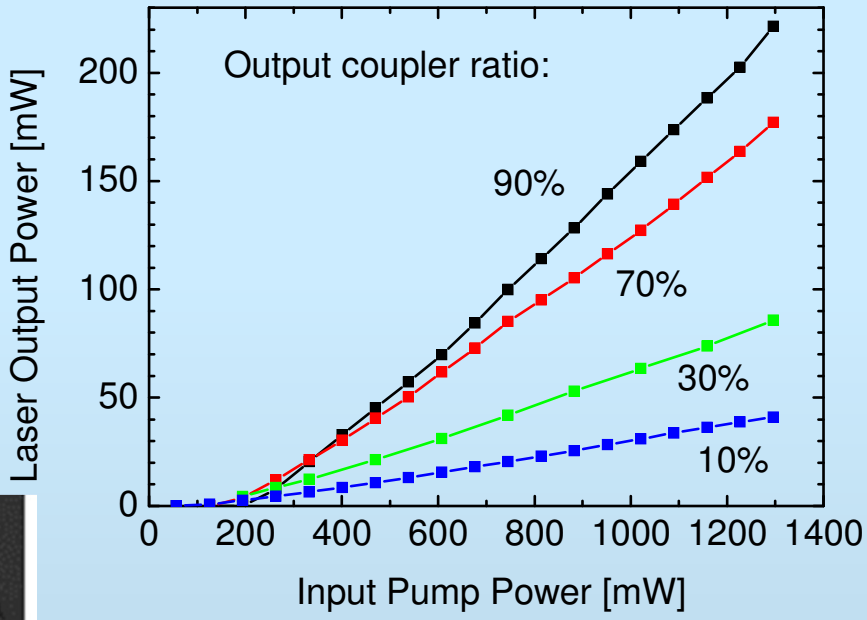




SPECIAL OPTICAL FIBERS
for fiber lasers & amplifiers

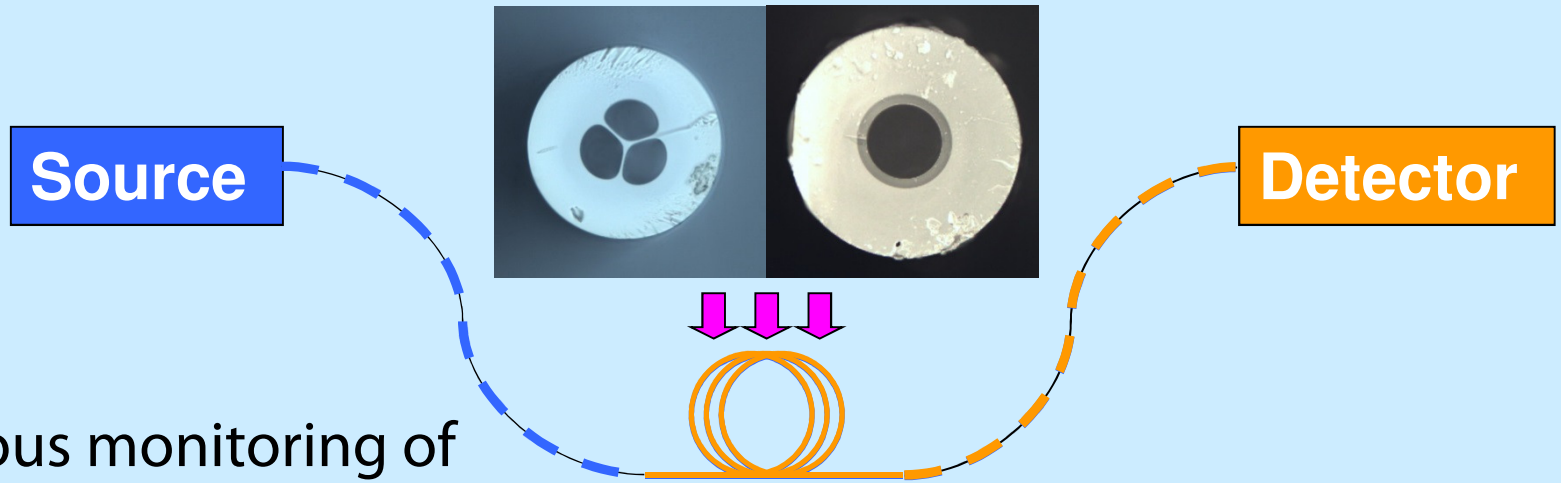


Er/Yb -doped DC fibers

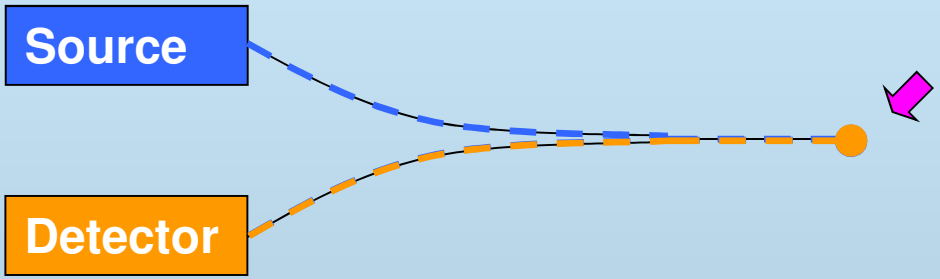


PCE 19 → 40%

Optical fiber sensors



Continuous monitoring of (bio)chemicals and their concentration.

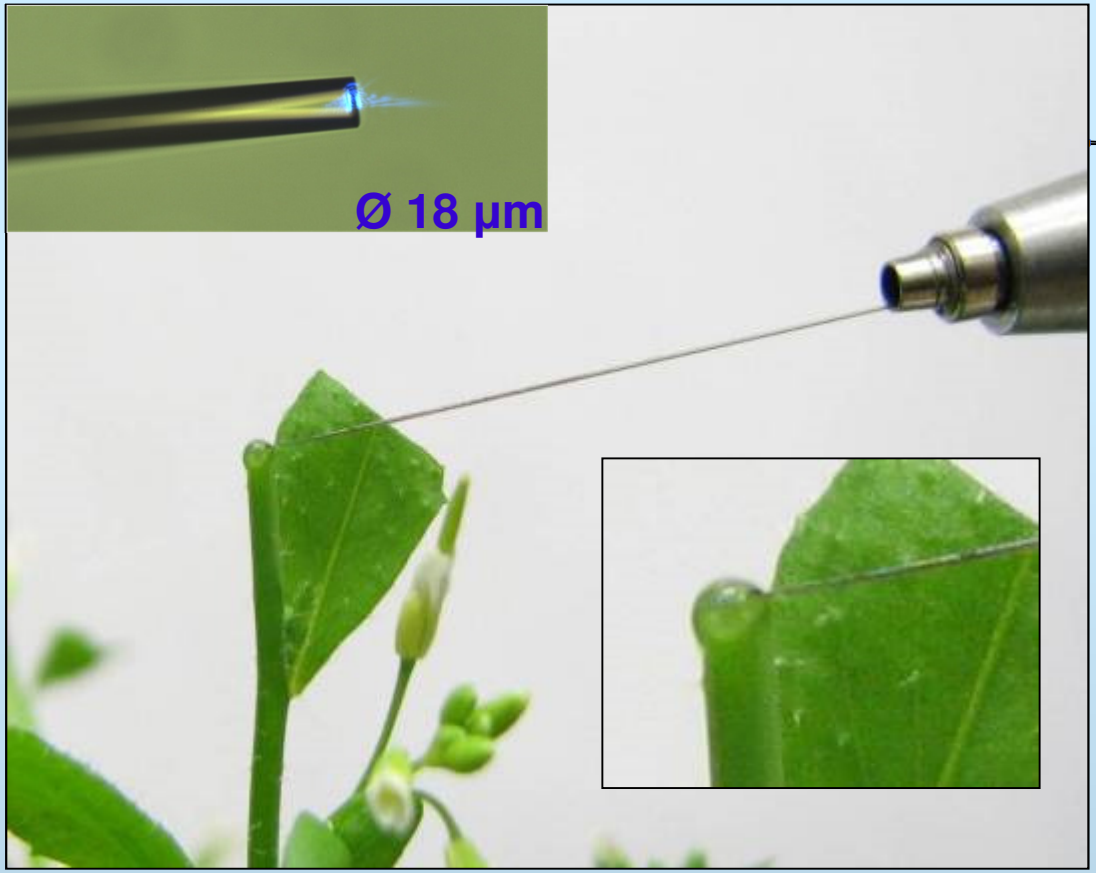


Suitable for :

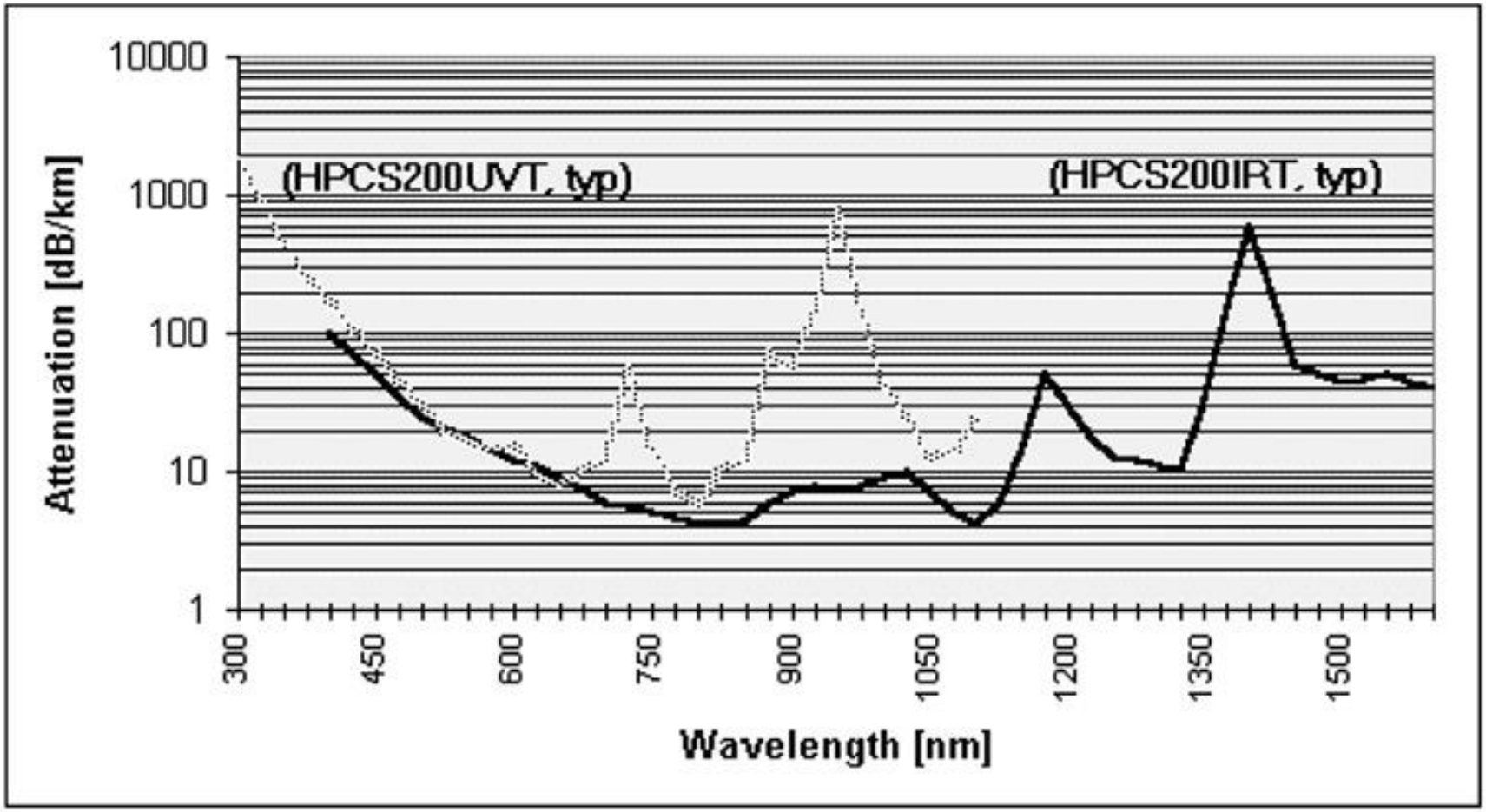
- remote sensing
- distributed sensing
  flammable or explosives
- in high-voltage areas
- human body

Optical fiber sensors

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

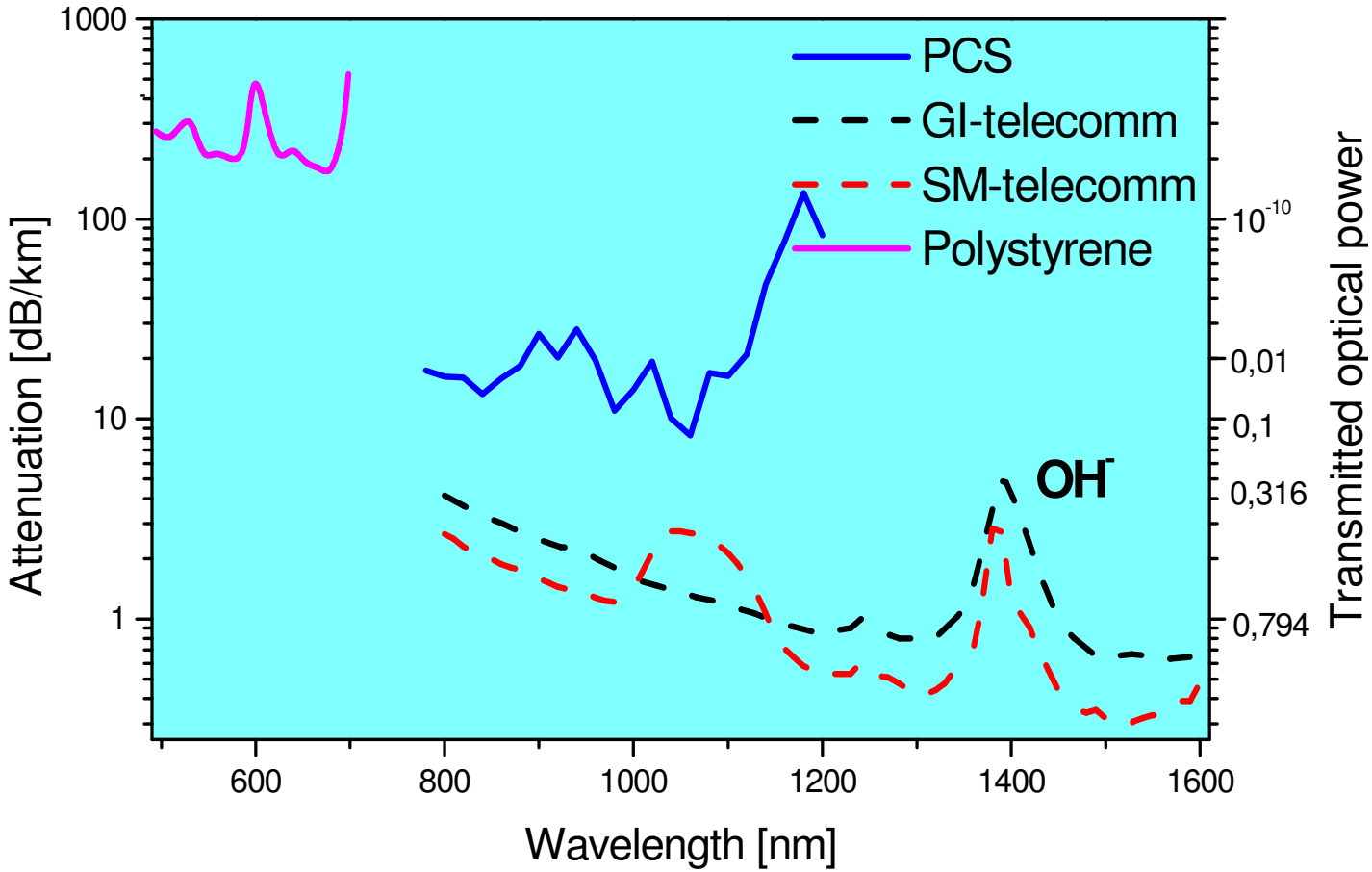


OPTICAL FIBERS – Materials - UV



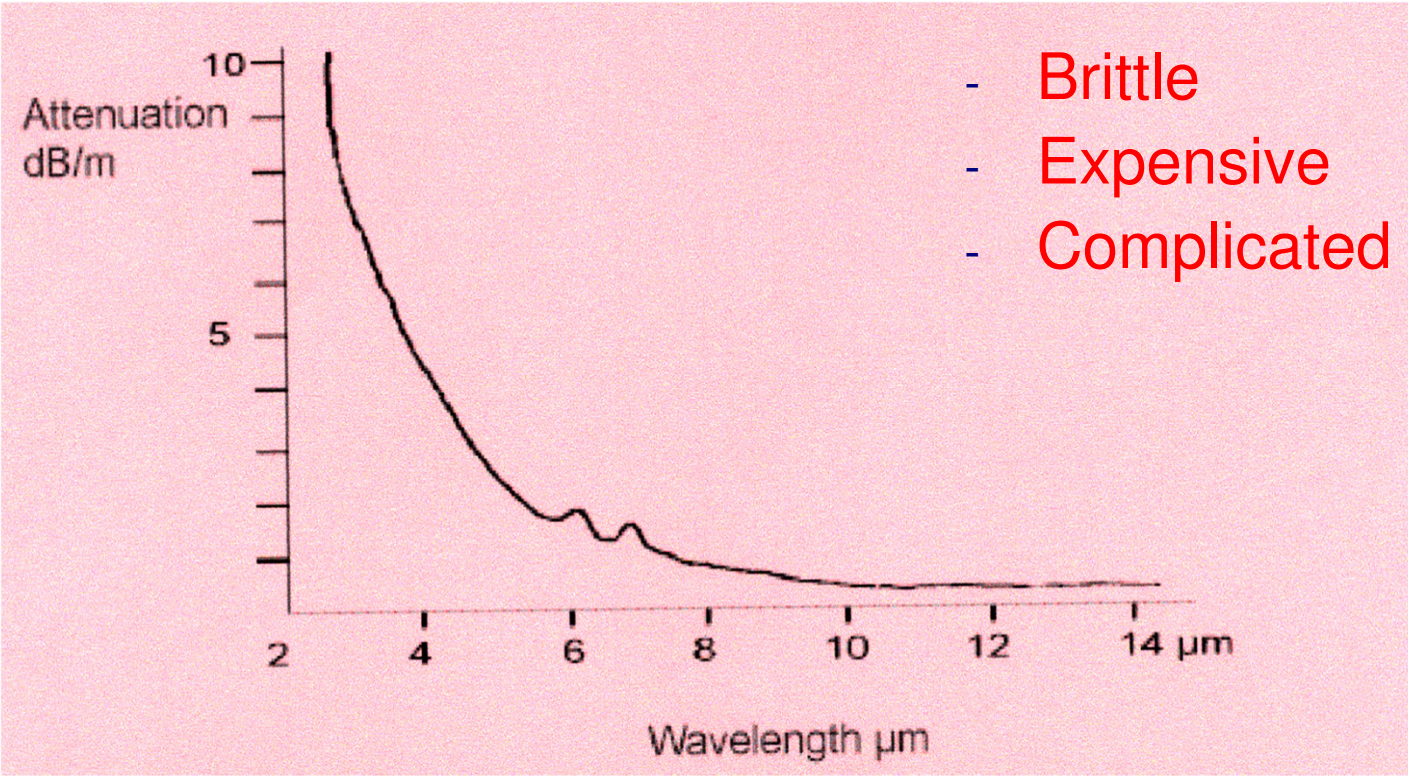
- silica fibers - SUPRASIL $n_{200\,nm} = 1.55$ [ceramoptec.de, OceanO, IPE …]
- planar silica, crystalline CaF_2 (MgF_2) – [edmundoptics, technicalglass …]

OPTICAL FIBERS – Materials – VIS/NIR



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…]

OPTICAL FIBERS – Materials - IR



- 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 55 (2010)
- Sdělovací technika 3/2011