Academy of Sciences

Institute of Photonics and Electronics v.v.i.

Technology of Optical Fibers

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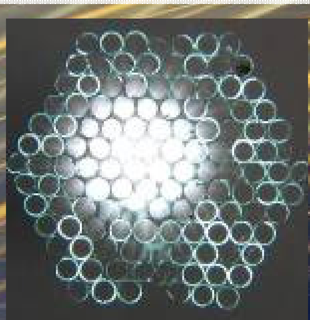
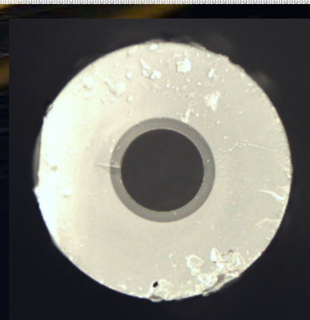
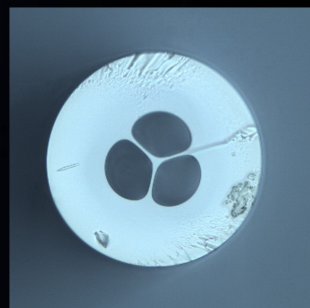
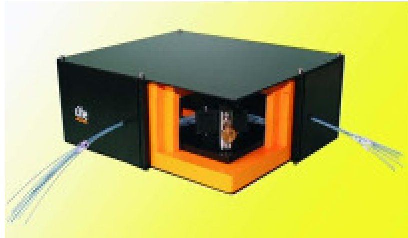
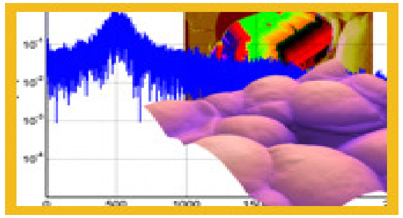


Institute of Photonics and Electronics

Prof. Jiří Homola
Head of UFE





FUNDAMENTAL RESEARCH

Optical Biosensors (SPR Homola)

Fiber Lasers and Non-linear Optics (Honzatko)

Nanomaterials (SIMS Lorincik)

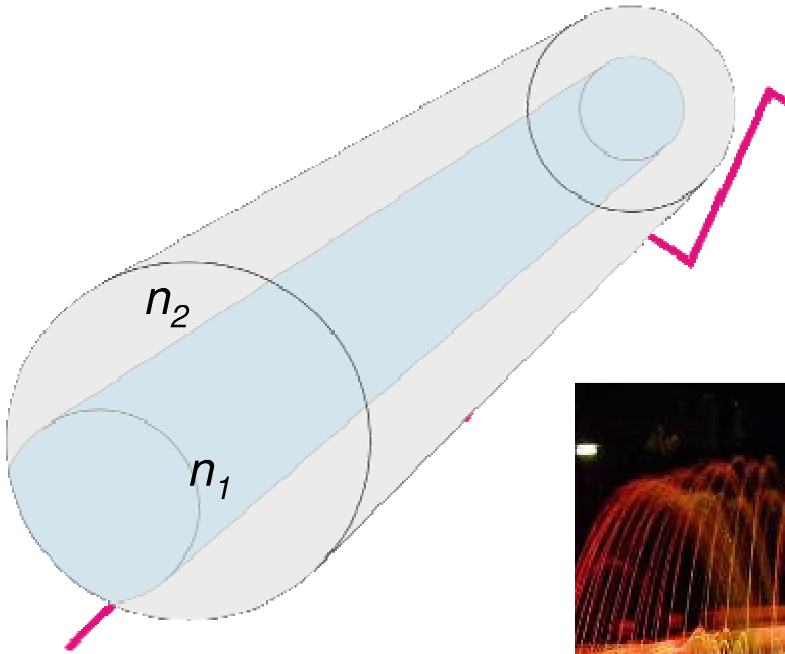
Bioelectrodynamics (Cifra)

National Time and Frequency Standard (Kuna)

Outline

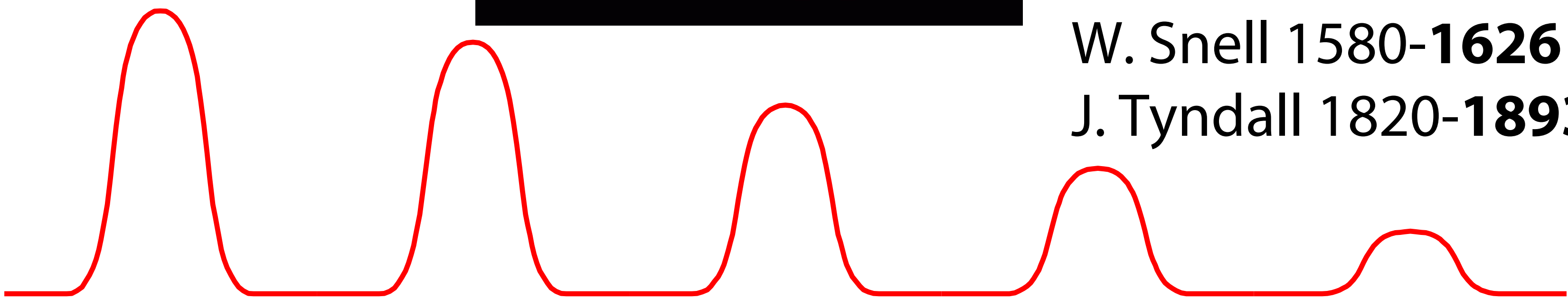
Intro	optical fibers
Technologies	MCVD preform preparation fiber drawing
Application	telecommunications fiber lasers (sensors)
Summary	& Invitation ICPF
LABO	MCVD, fiber drawing, sol-gel, magnetron sputtering

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

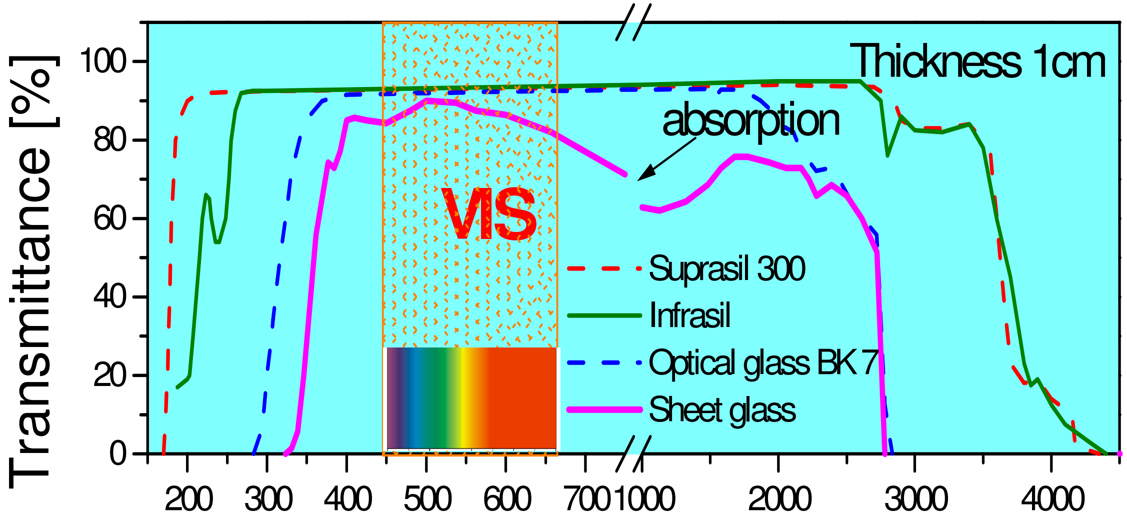
Charles K. Kao

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]

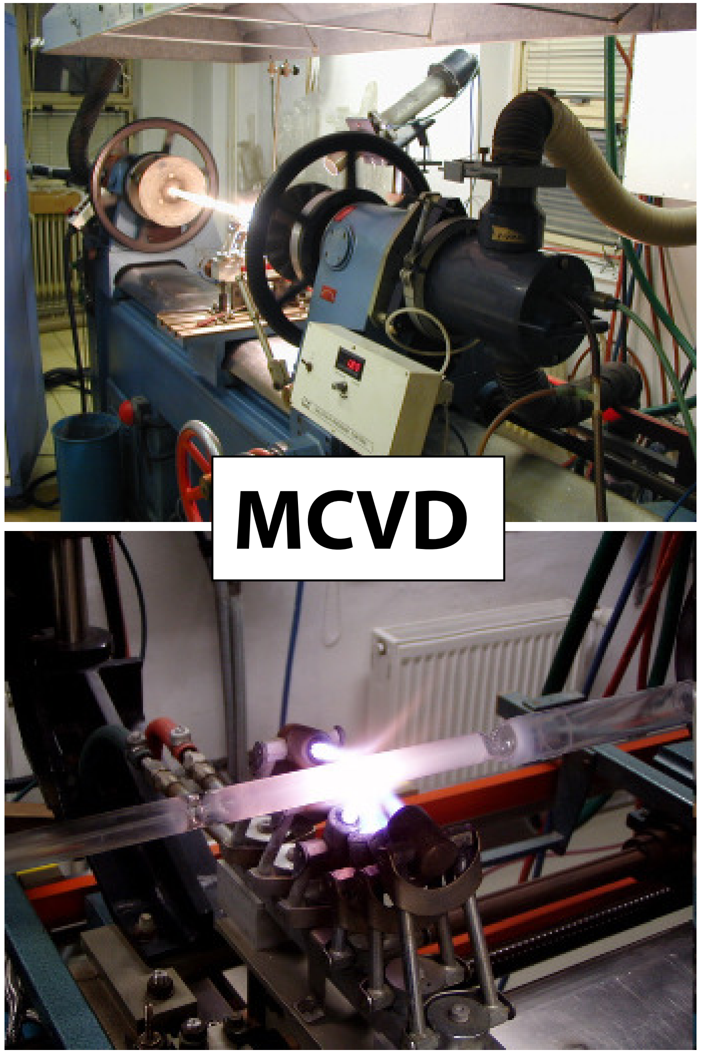
% – 10^{-2}

ppm – 10^{-6} (parts per million)

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

Ultra-pure technologies - CVD !

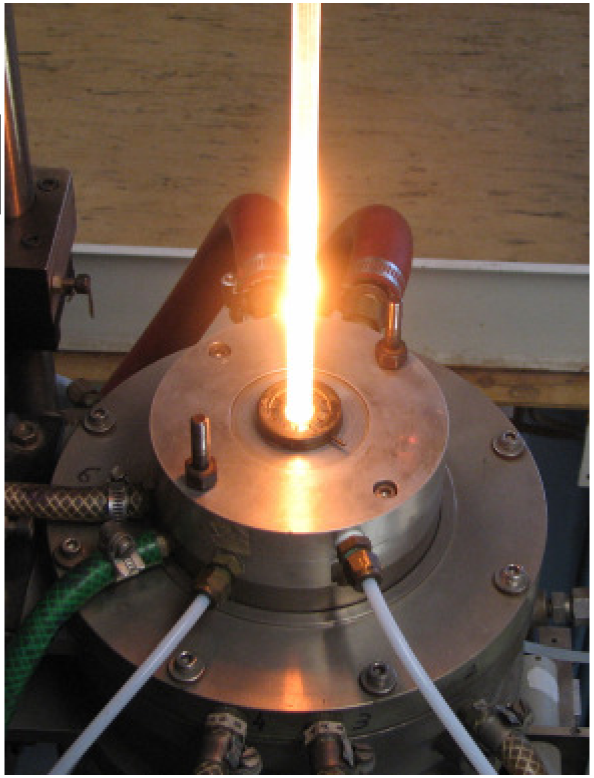
Optical fiber preparation - technology



MCVD

1. Preform

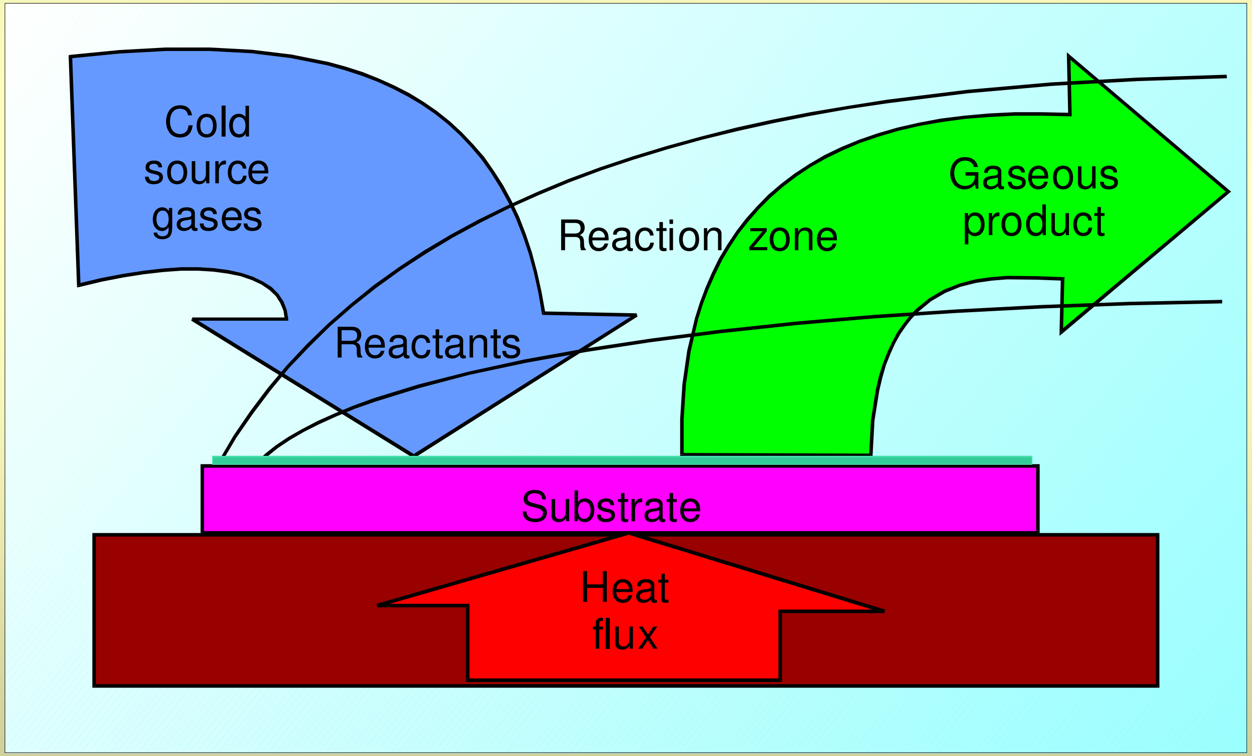
2. Fiber drawing



CVD - Chemical Vapor Deposition
TECHNOLOGIES

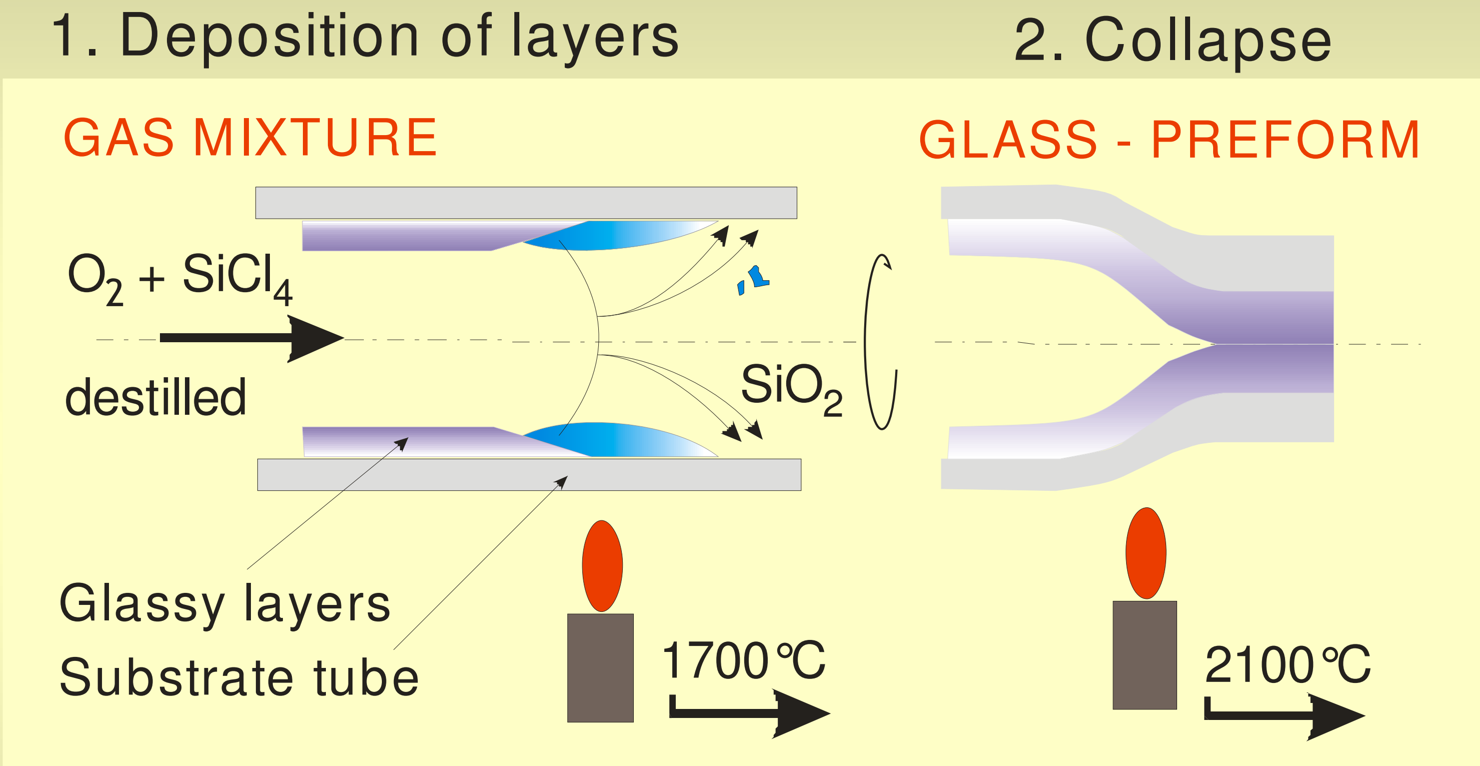
Production and deposition of material in solid state from starting materials in gaseous state through a chemical reaction :

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



Preform preparation - MCVD

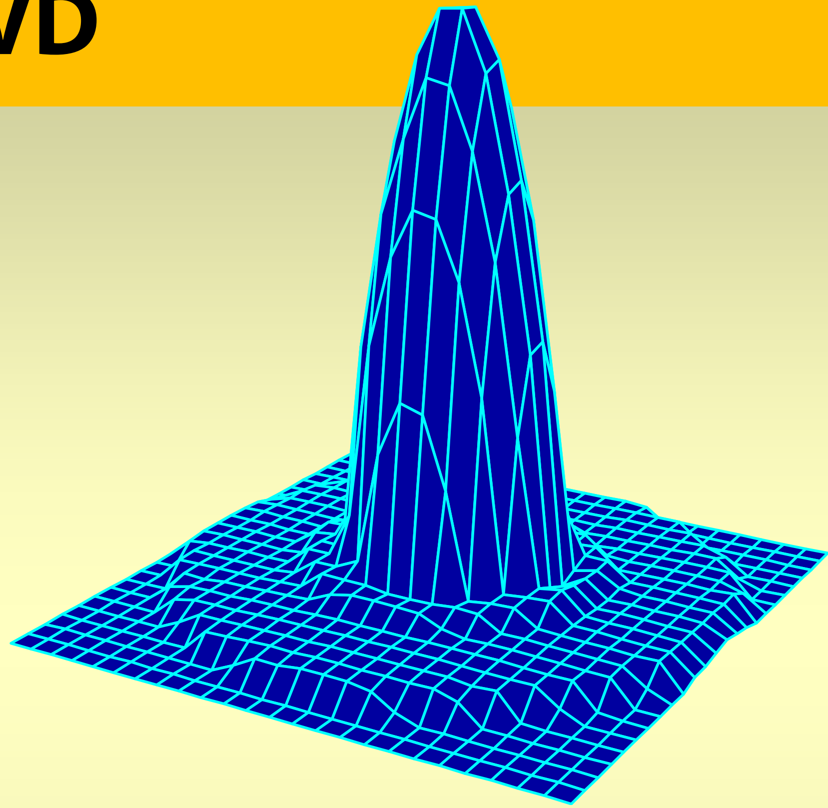
MCVD – (Modified) Chemical Vapor Deposition



- 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 preciseness** (better than 1 %)

MCVD

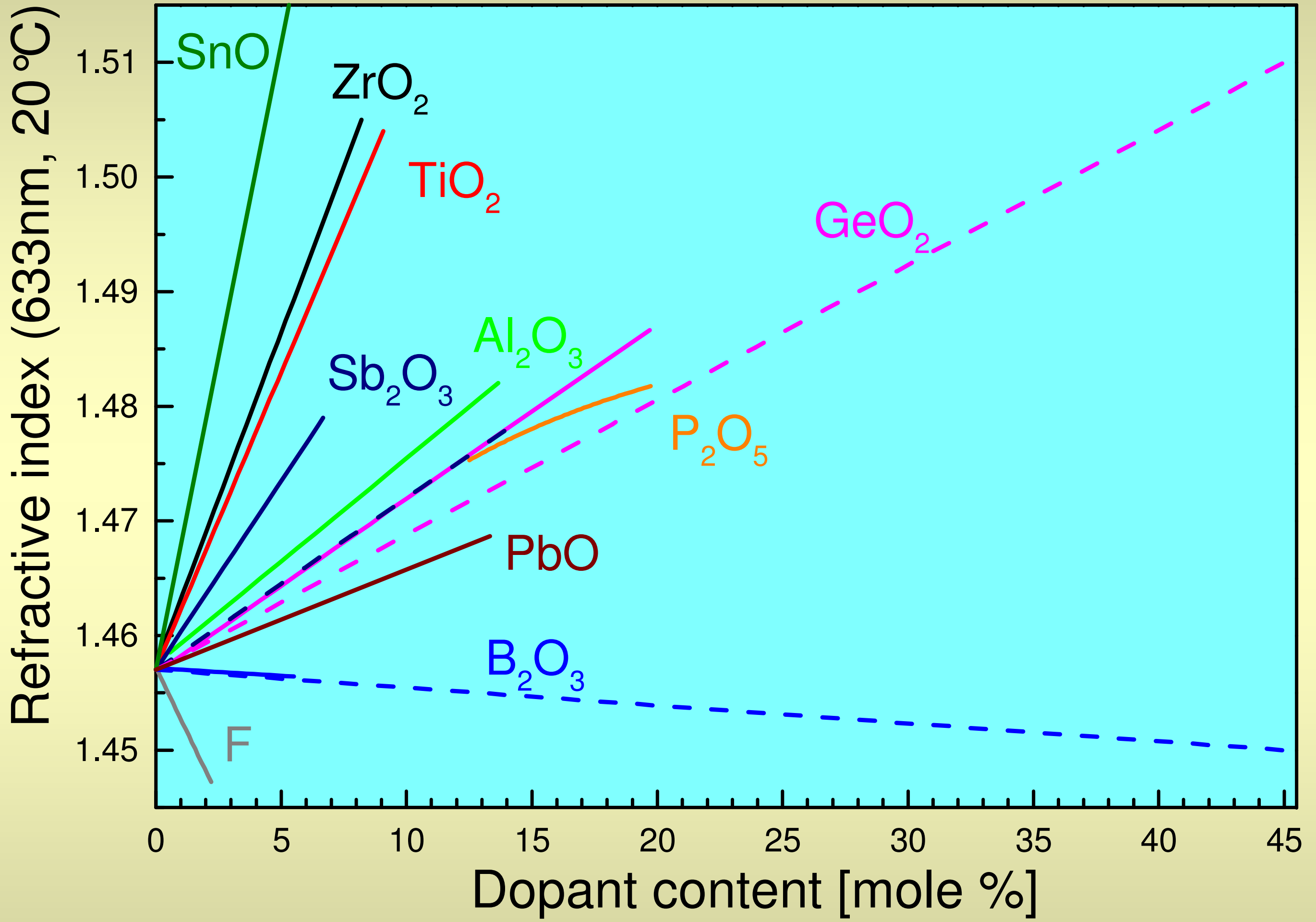
Microphoto of cross section of produced preform



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

1. Vaporization of starting materials

- $V_{XCl4} = V_{Ox} * P^o_{XCl4} / (P - P^o_{XCl4})$ … boiling point $SiCl_4$=56°C

2. Oxidation

- 1[st] -order kinetics, $t = 0.02$ s
- Chemical equilibrium :
- $SiCl_4 (g) + O_2 \rightarrow SiO_2 (s) + 2Cl_2$

  conversion ~ 0.95 – 0.99 (1500 °C)
- $GeCl_4 (g) + O_2 \rightarrow GeO_2 (s) + 2Cl_2$

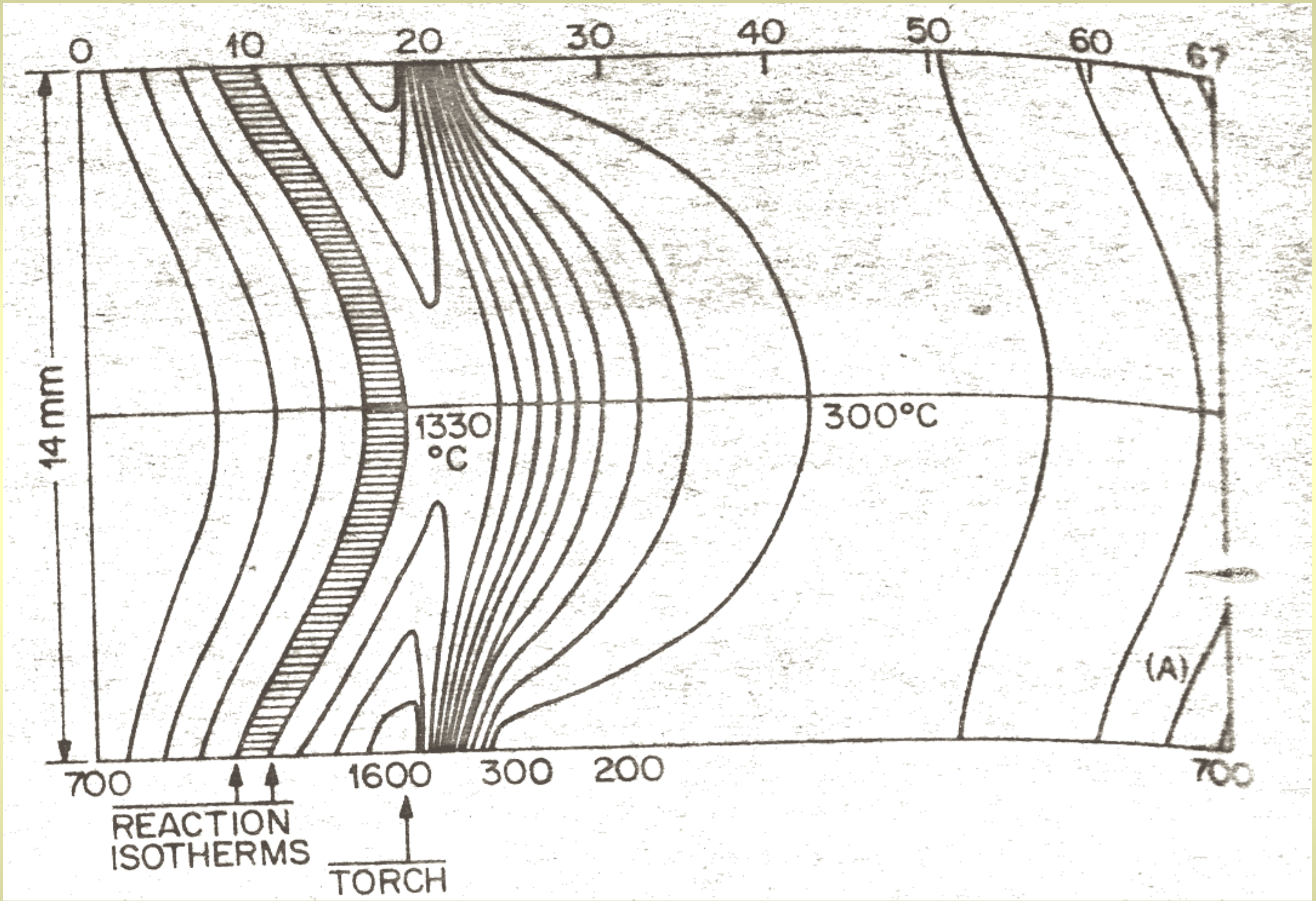
  conversion ~0.5 – 0.6 (1600 °C), $f(t, x_{SiCl4}/x_{GeCl4})$

3. Deposition

- Thermophoretic efficiency

  $E = K . (1 - T_{cool\ surface} / T_{reaction}) \sim 0.6$

MCVD model



Temperature field during deposition

MCVD model

Process parameters :

Variable :

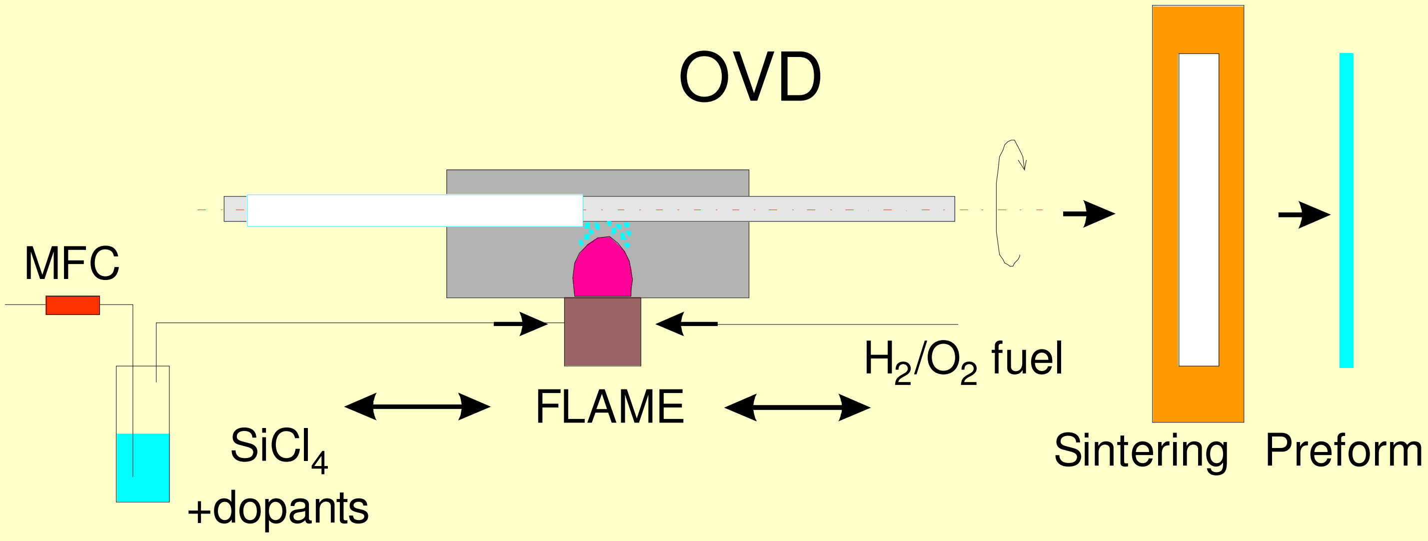
- flow rates (Si, Ge, P, B, F, Ox …)
- deposition temperature

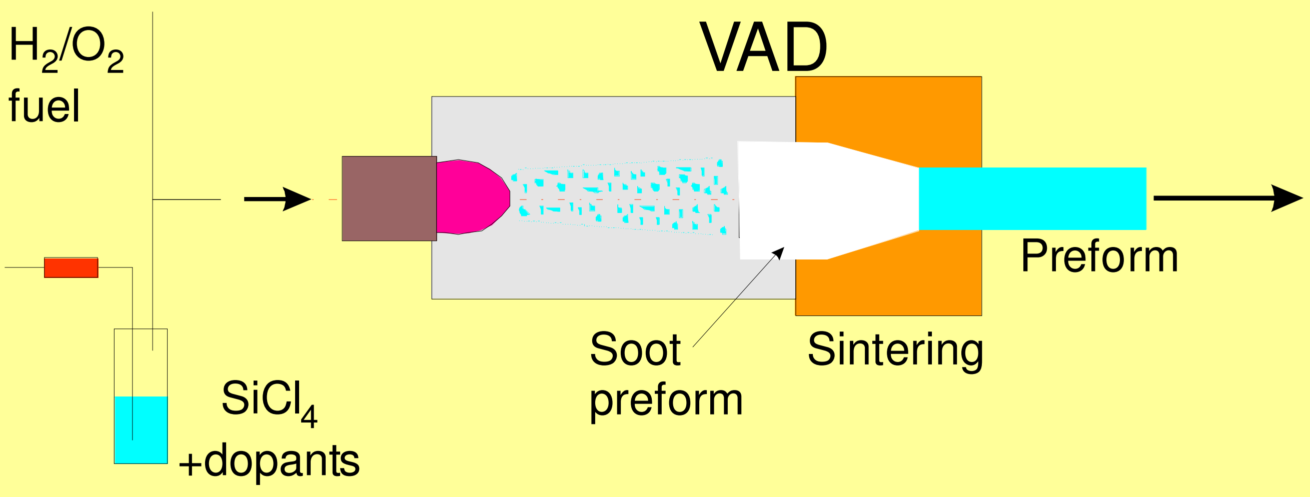
Adjustable :

- 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





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

(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

Comparison

(M)CVD x conventional

Process

(M)CVD	conventional
Deposition of layers = oxidation+deposition+sintering (NO MELTING)	Melting
Collapsing of preform (MELTING)	Forming
-	Annealing

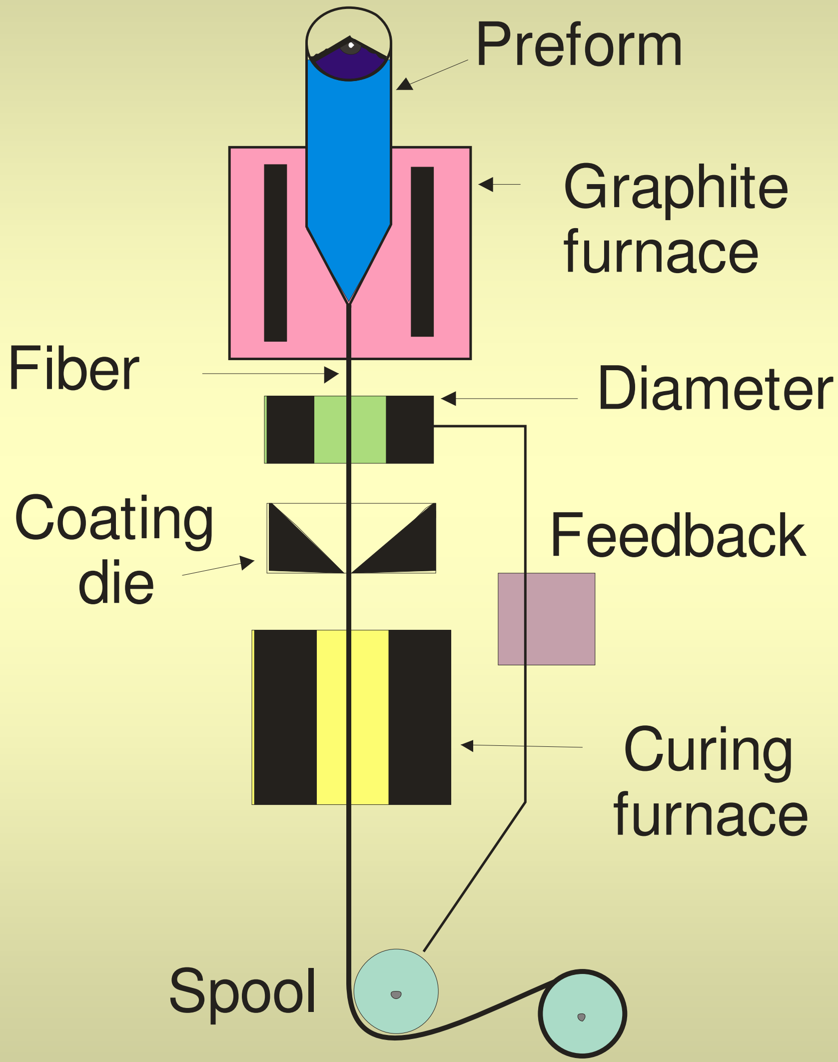
Structure of products

(M)CVD	conventional
Graded - profiles	Homogeneous

Material purity

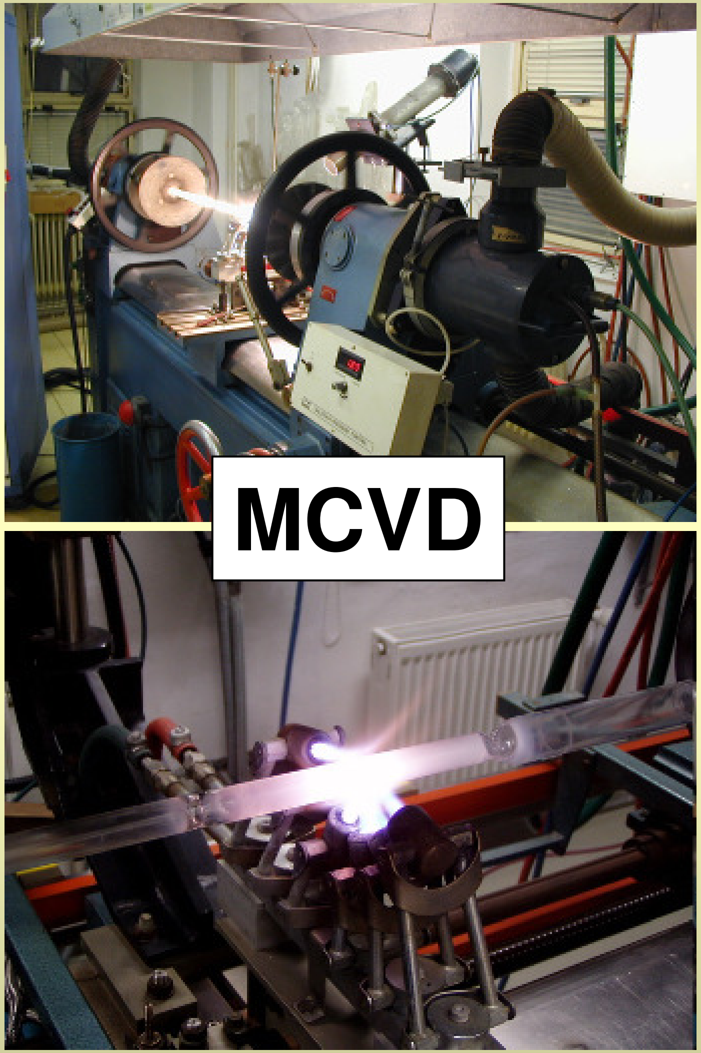
(M)CVD	conventional
ppb (10^{-9}, i.e. 10^{-7} mol%)	10^{-3} mol% (99,999%)

Drawing of optical fiber from preforms



- Diameter
  80-1000 µm
- Temperature
  1800-2100°C
- No textile
- No thermo-insulation

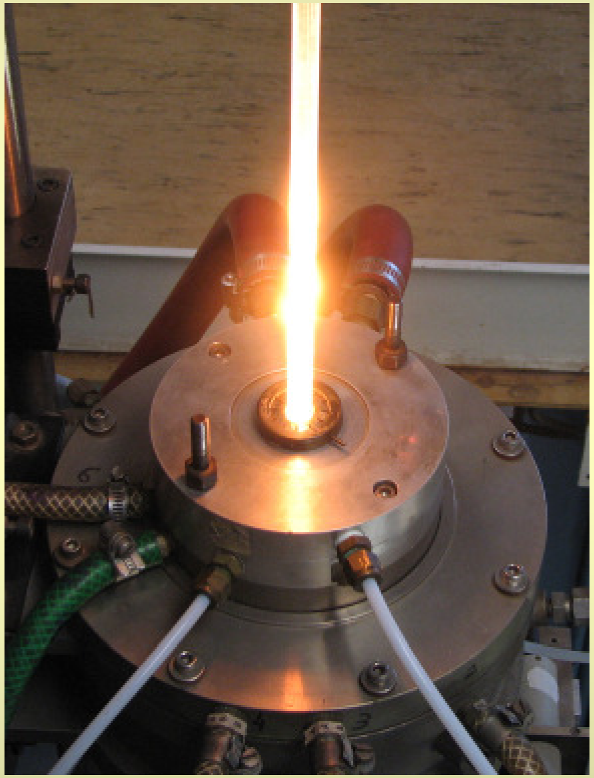
Preparation of optical fibers



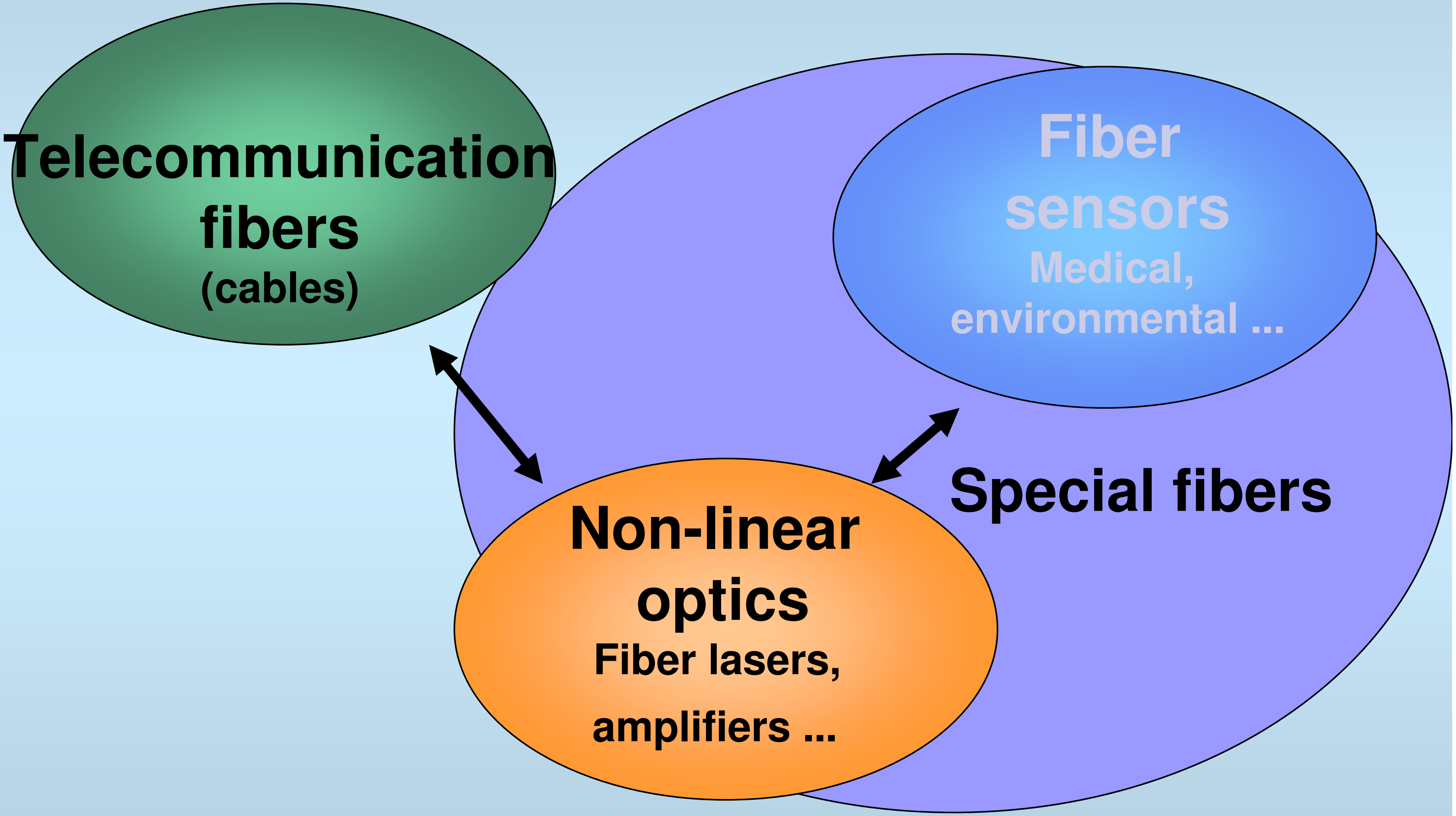
MCVD

preform

Drawing

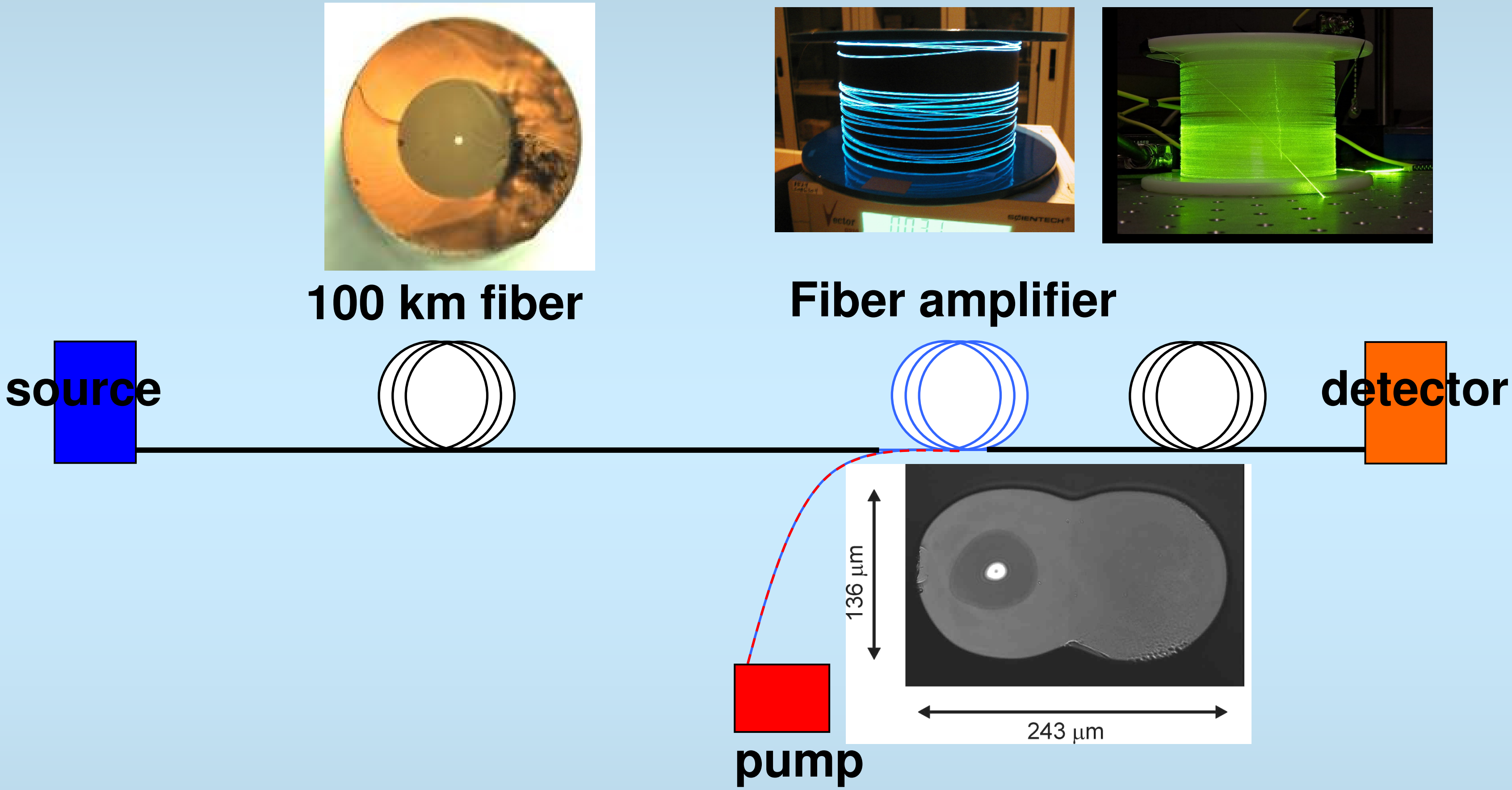


Application



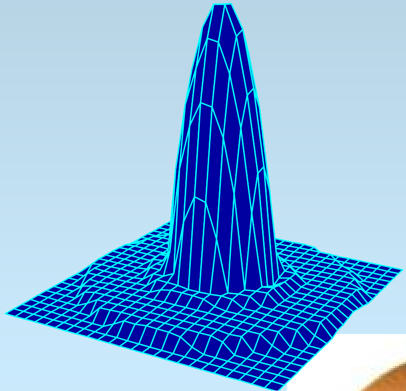
Telecommunication optical fibers

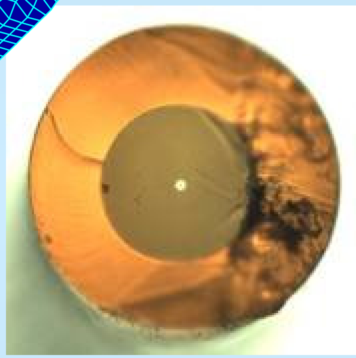
Fiber lasers and amplifiers



Increasing requirements on speed and ammount of info.

Telecommunication & **fiber amplifiers**





1981 – 1st CZ optical fiber

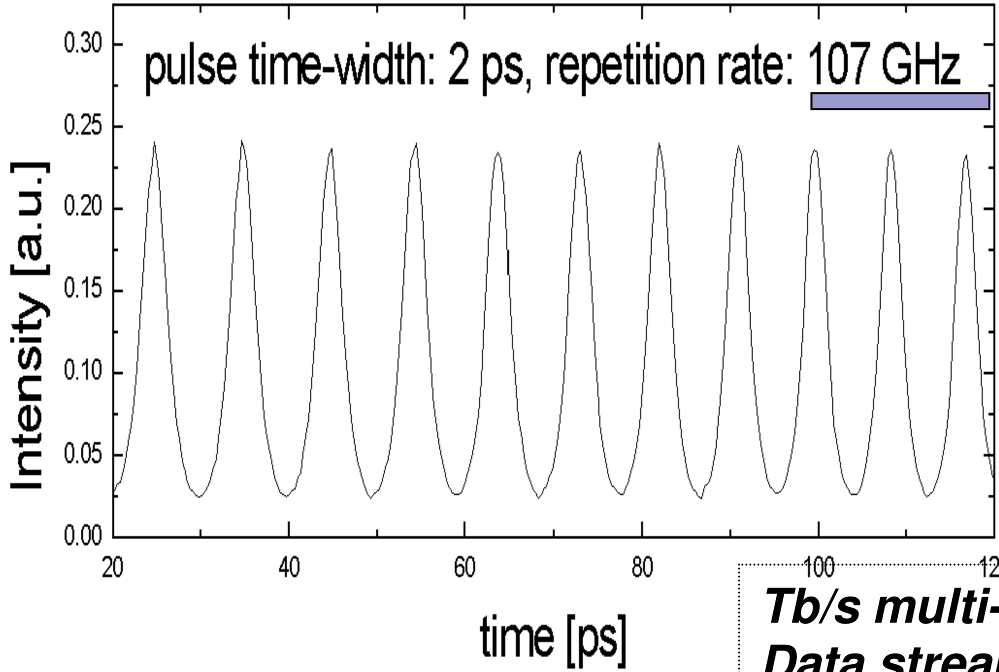
GI - technology transfer VÚSU Teplice, Hesfibel

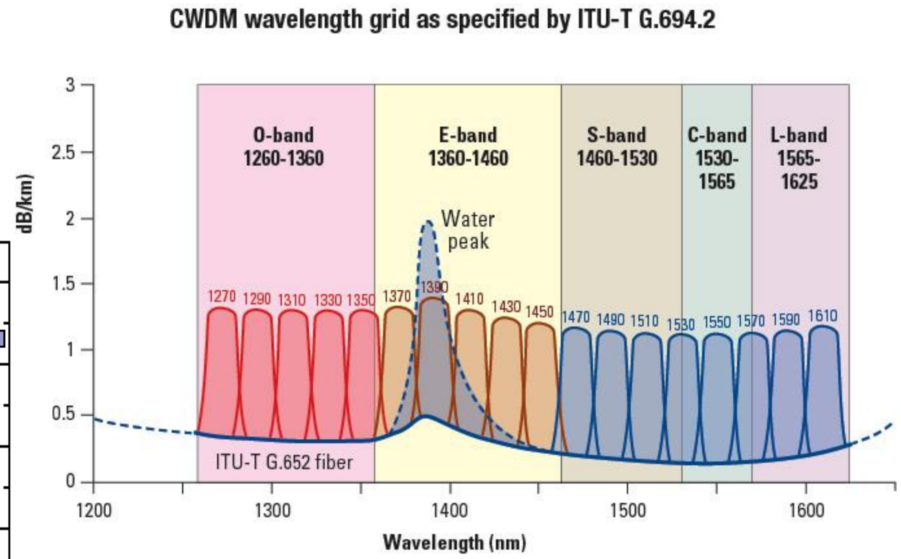
in collaboration with Cesnet : testing 200 km line

TDM WDM

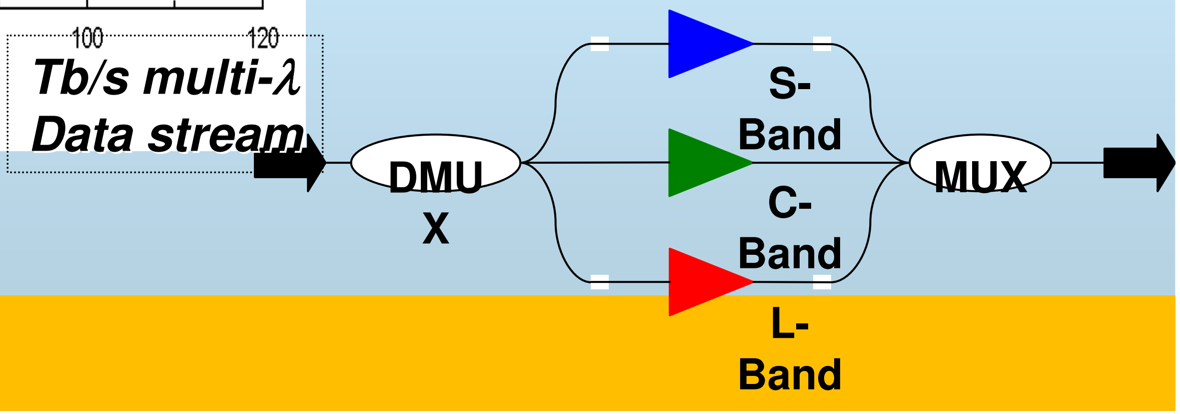
All optical info processing

Time Division Multiplexing (TDM)

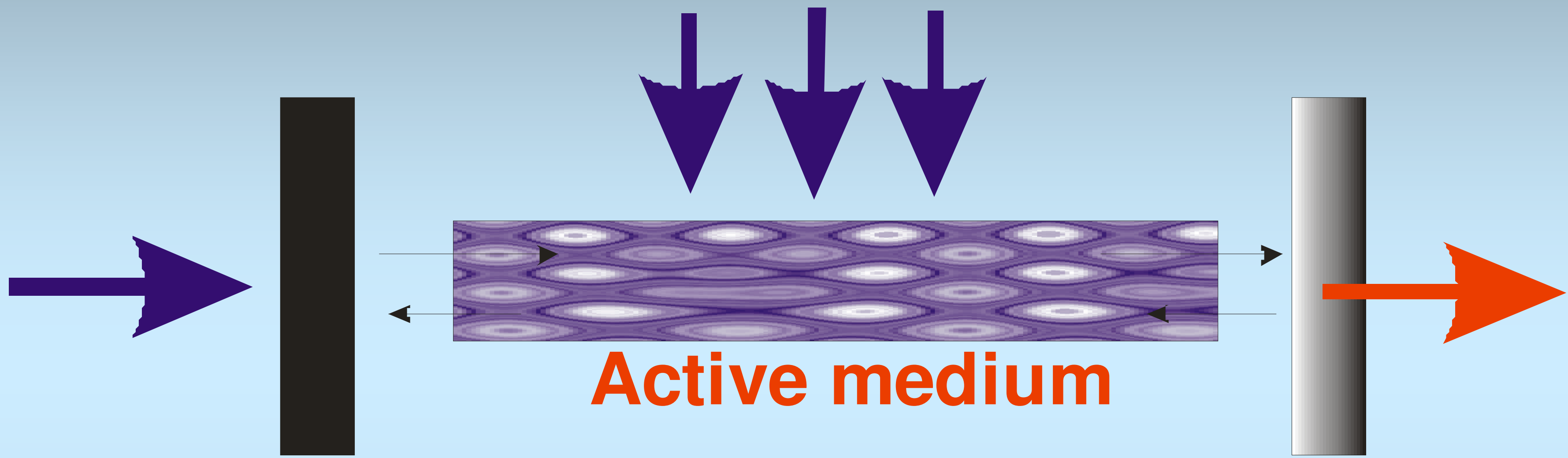




Wavelength Division Multiplexing (WDM)



Fiber lasers (amplifiers)



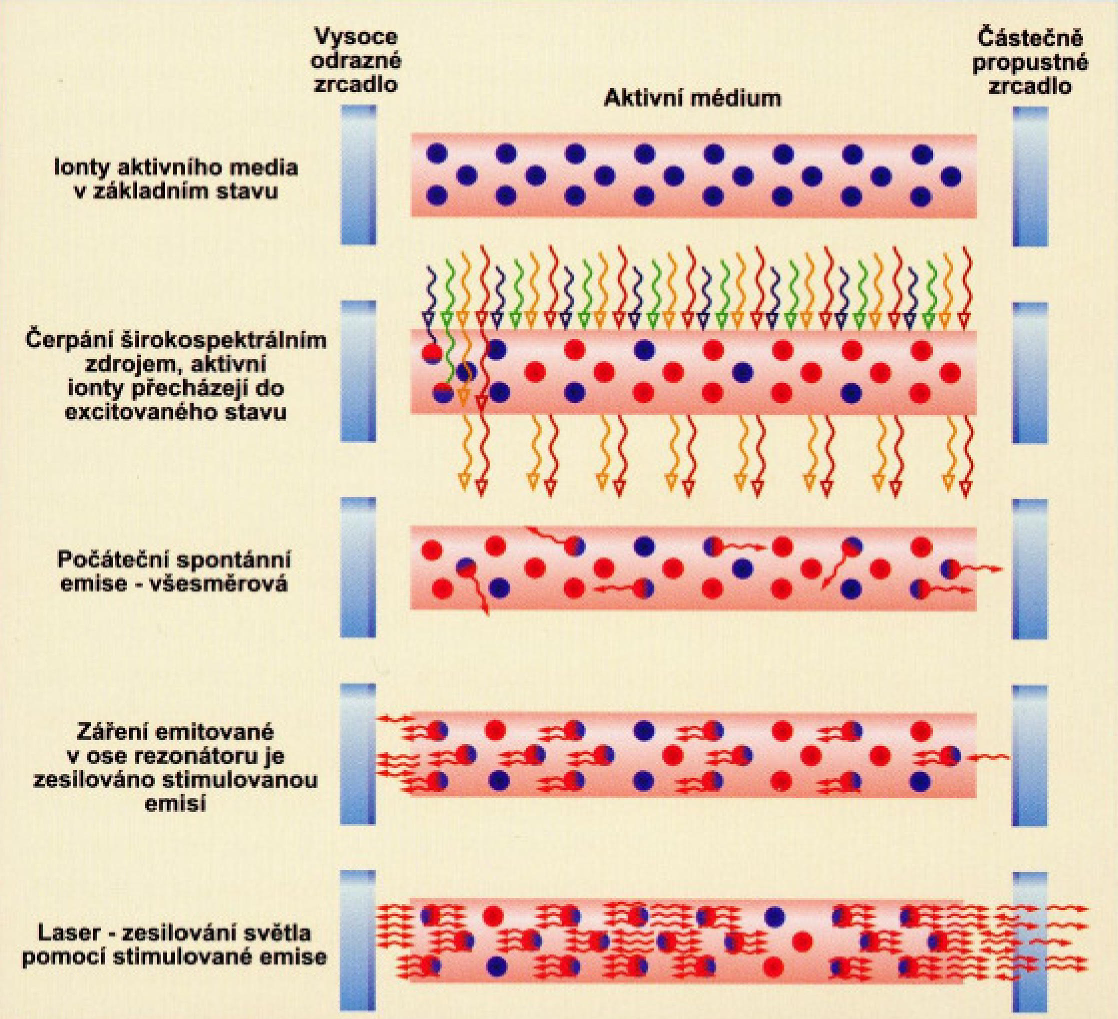
Mirror
100%

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

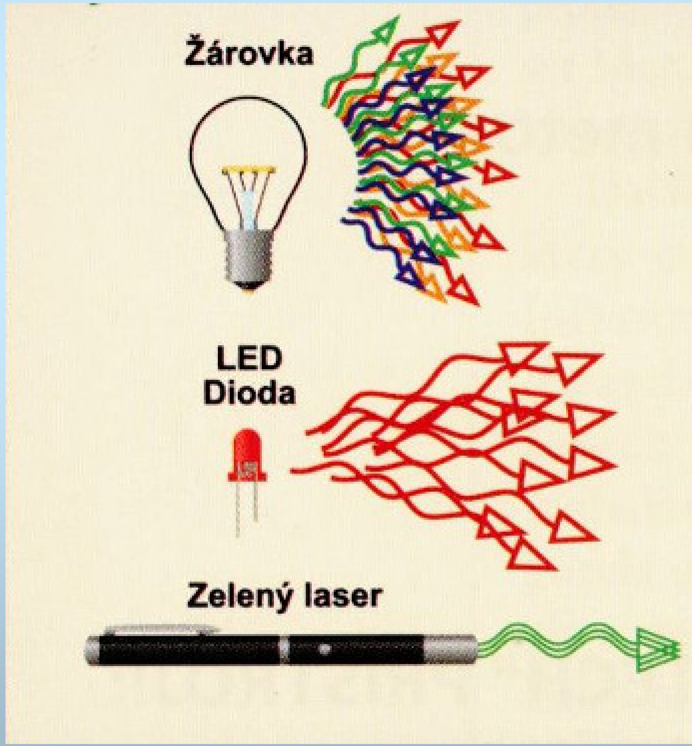
Mirror
8-99%

Stimulated emission → laser

Amplification by Stimulated Emission of Radiation

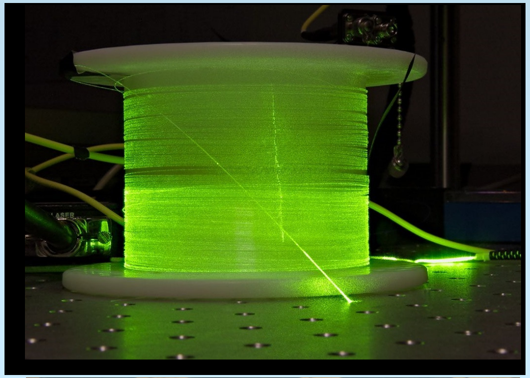


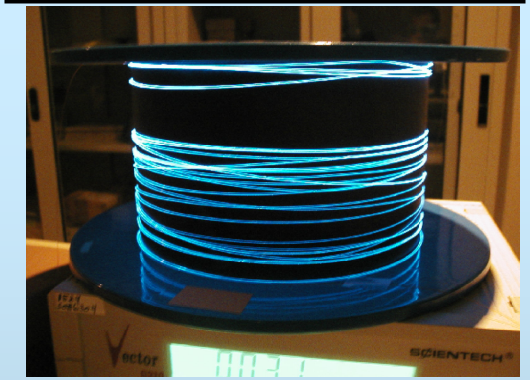
tyč (preforma) →
dopované vlákno →
vláknový laser



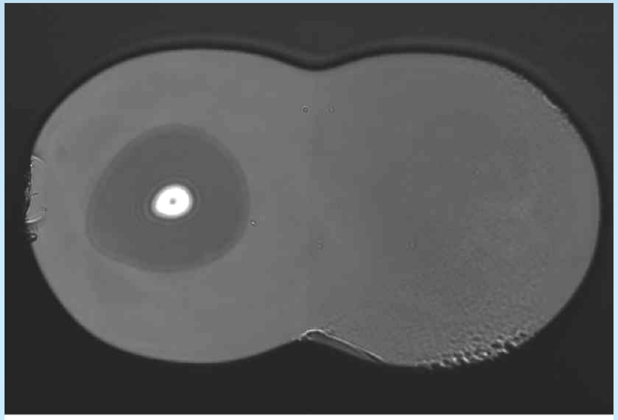
* H. Jelínková, Čs. Časopis pro fyziku, No. 4-5, 2011

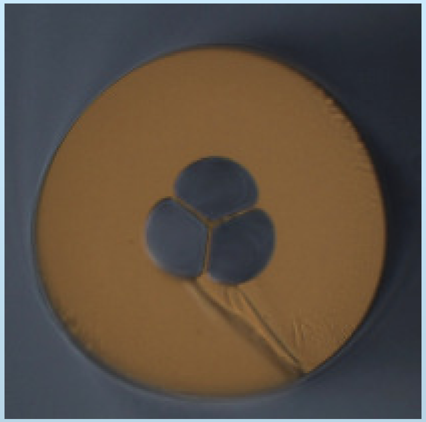
SPECIAL OPTICAL FIBERS
for fiber lasers & amplifiers





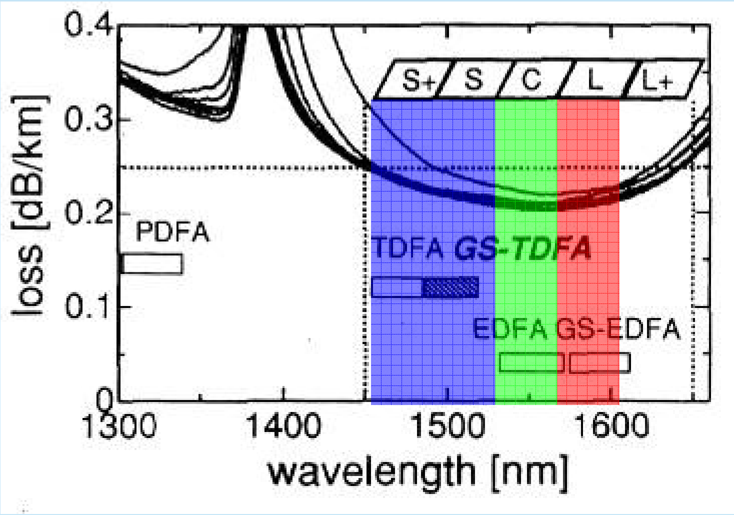
Yb/Er, Tm -doped

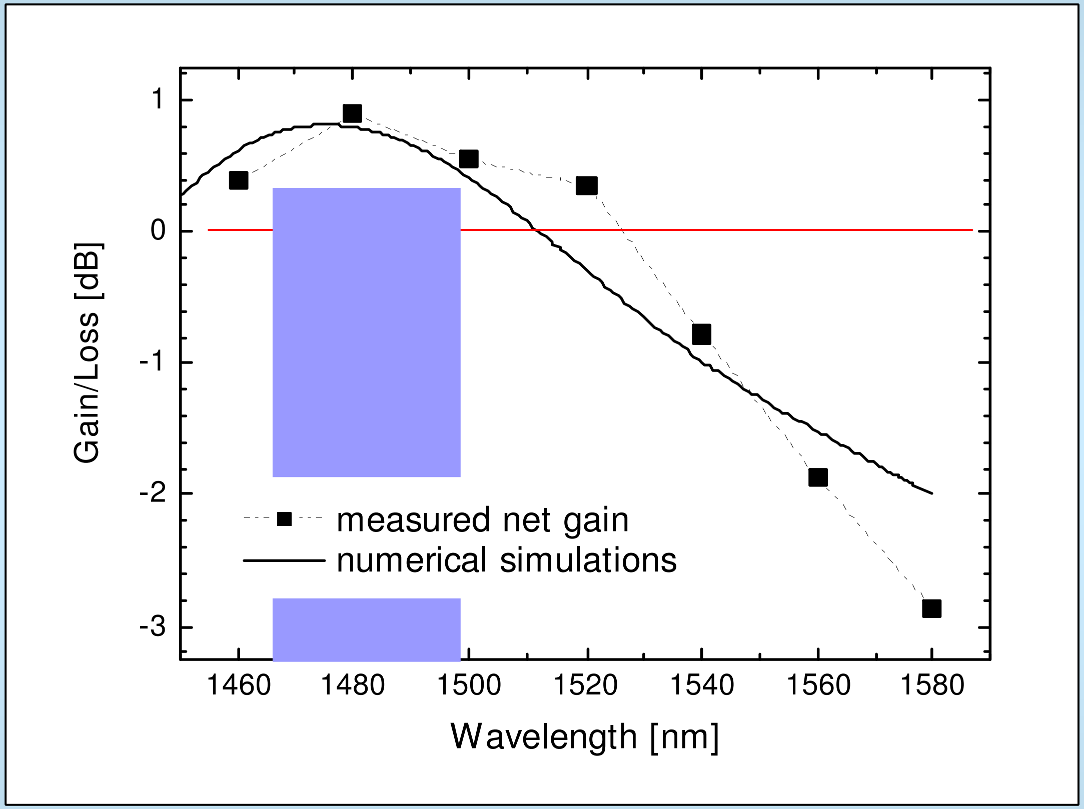




Double-clad (DC)
Twin-core (TCF)
Microstructure (MSF)

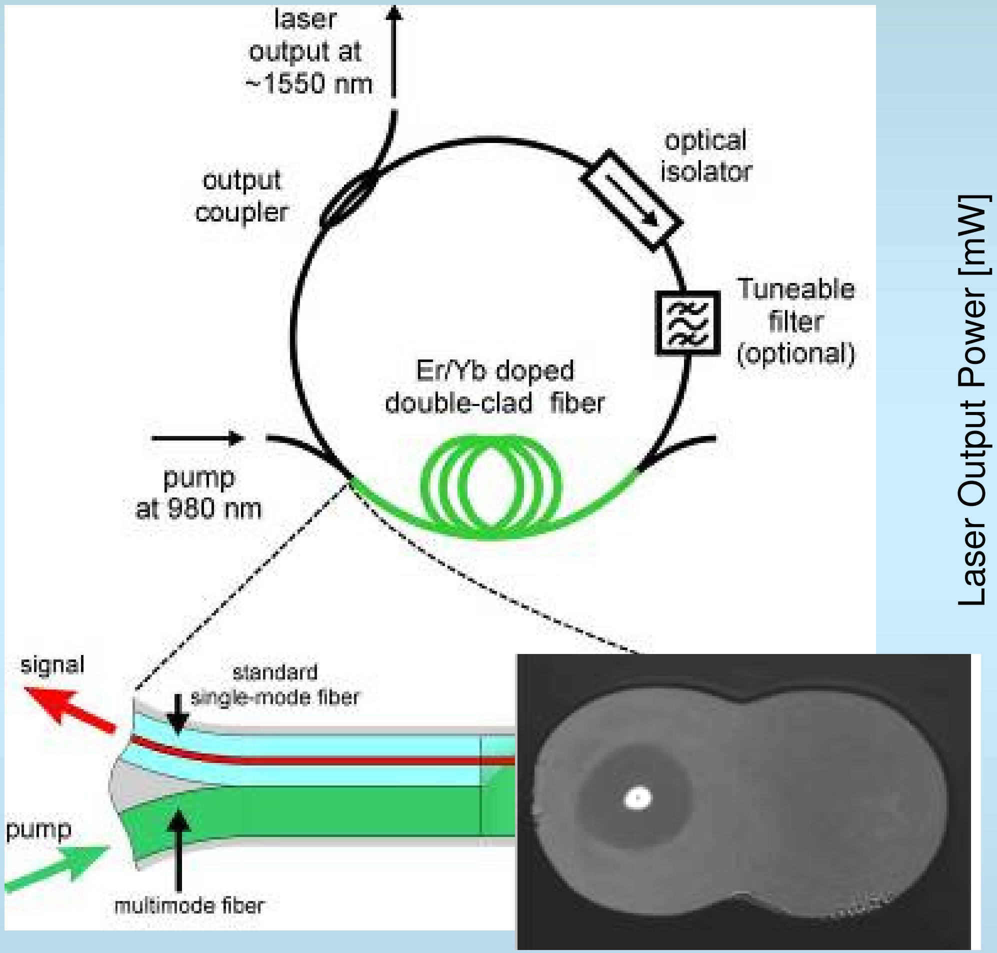
Tm^{3+}-Al_2O_3-SiO_2 fibers for Tm -doped fiber amplifier at 1470 nm

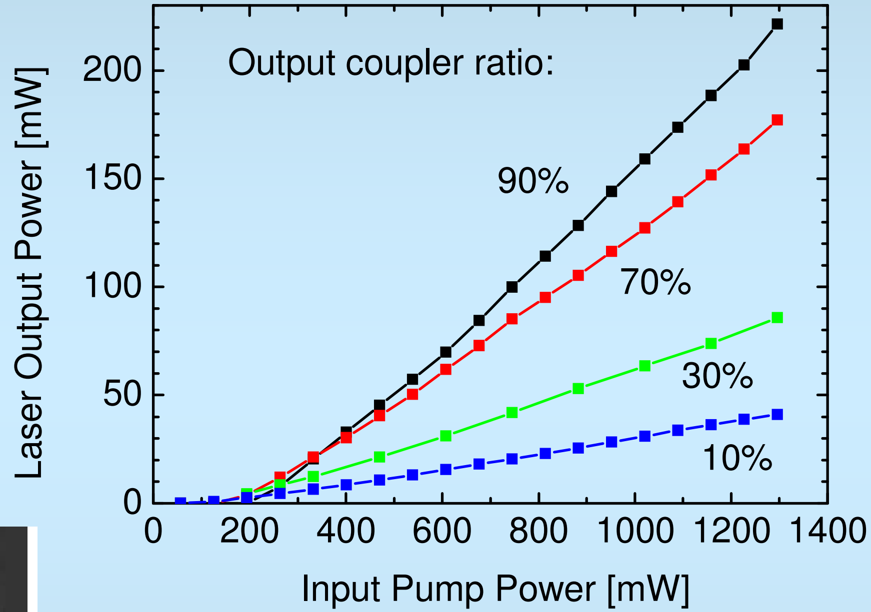




Non-optimized fiber parameters (low NA, low Tm^{3+} concentration), longer lifetime required.

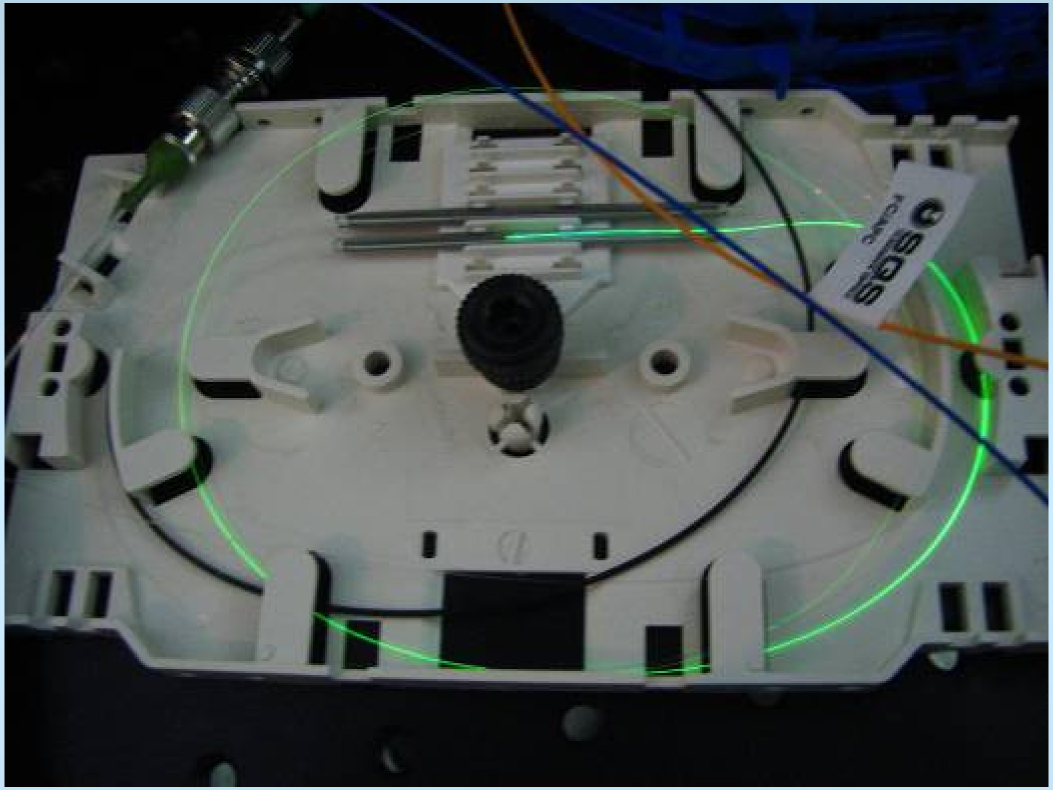
Er/Yb -doped DC fibers





PCE 19 → 40%

High-power fiber lasers



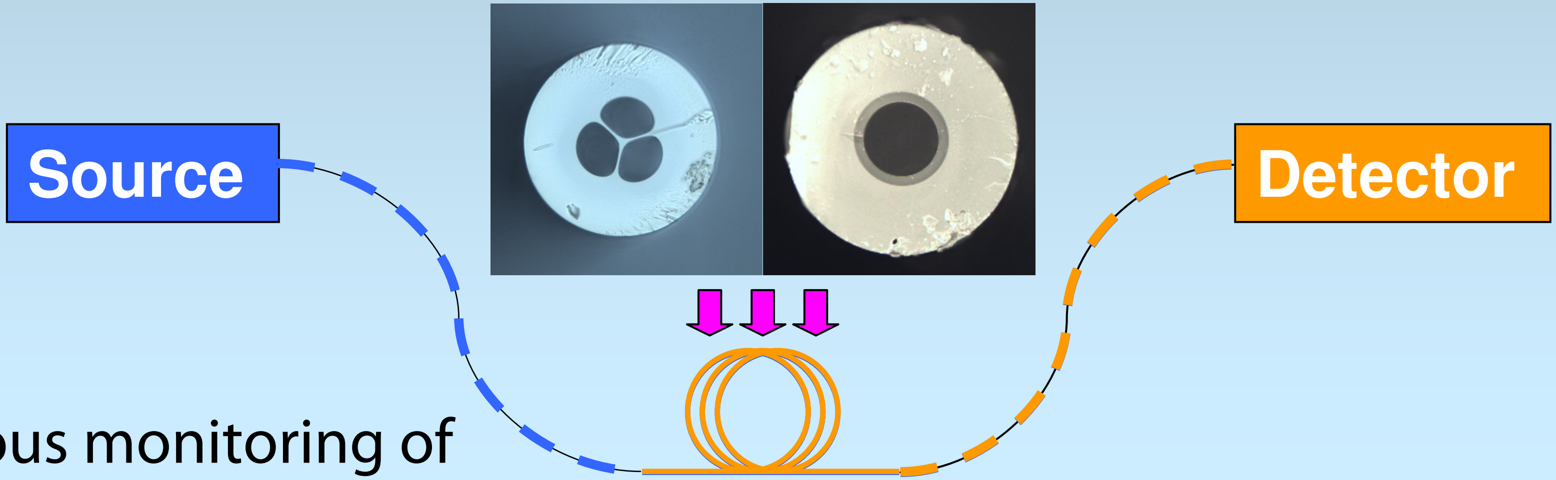
Ligth intensity

Sun	63 MW/m^2
Optical fiber	12.7 GW/m^2

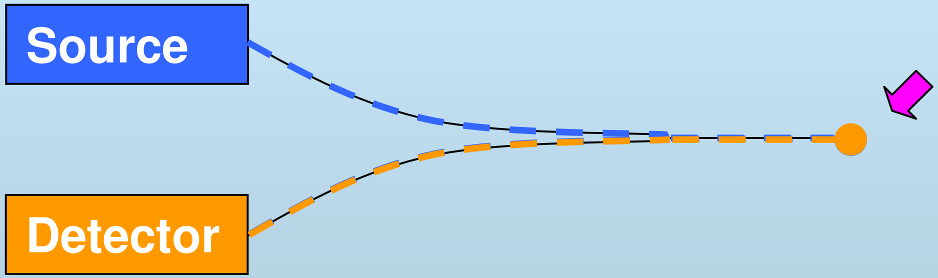
Er- fiber laser,
pulsed 197 fs,
5m rezonator
Liekki

Welding, cutting < 2kW

Optical fiber sensors



Continuous monitoring of (bio)chemicals and their concentration.

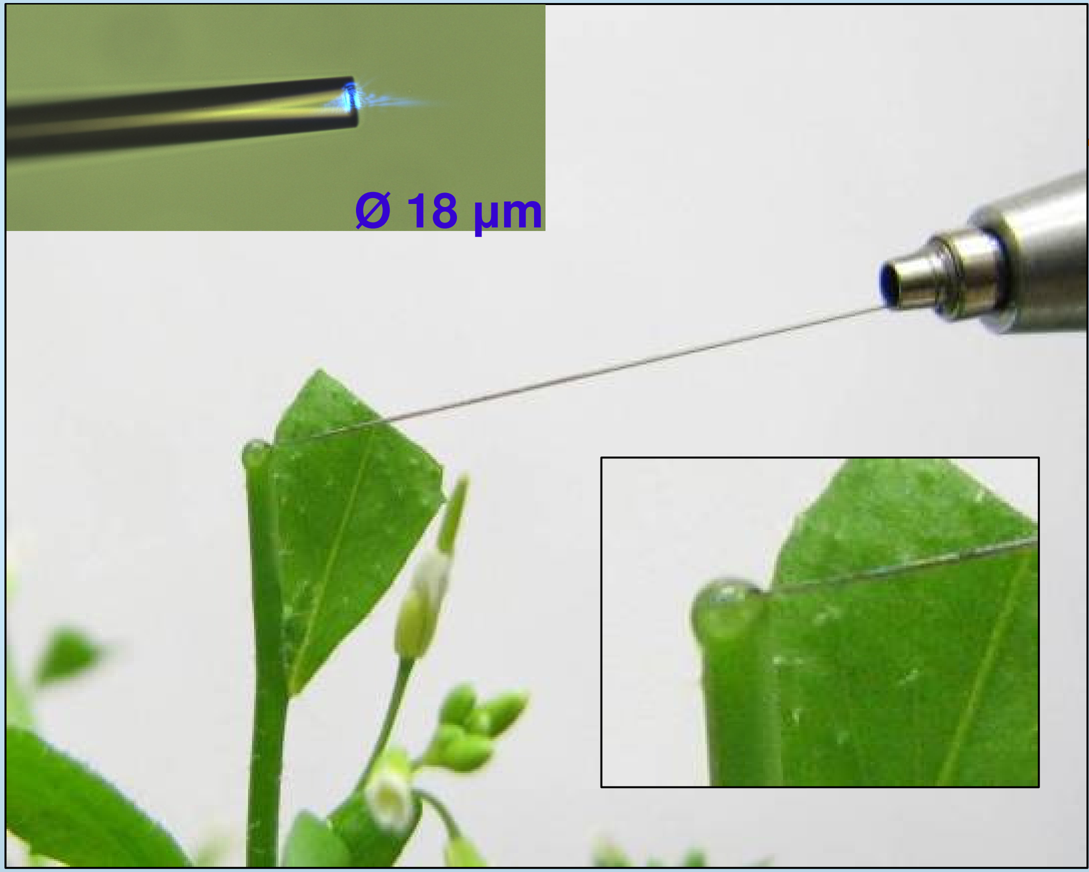


Suitable for :

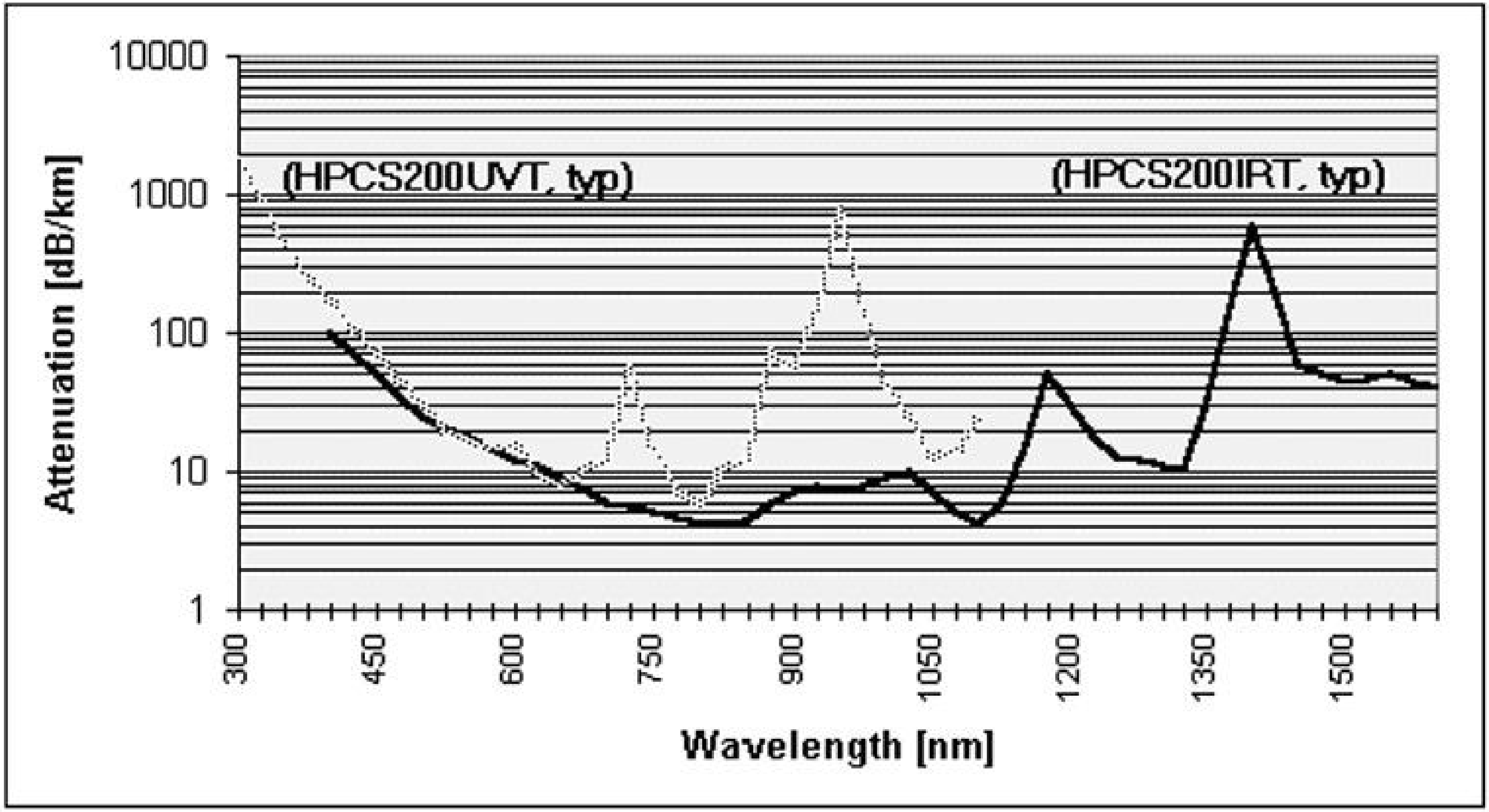
- remote sensing
- distributed sensing
- flammable or explosives
- in high-voltage areas
- human body

Optical fiber sensors

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

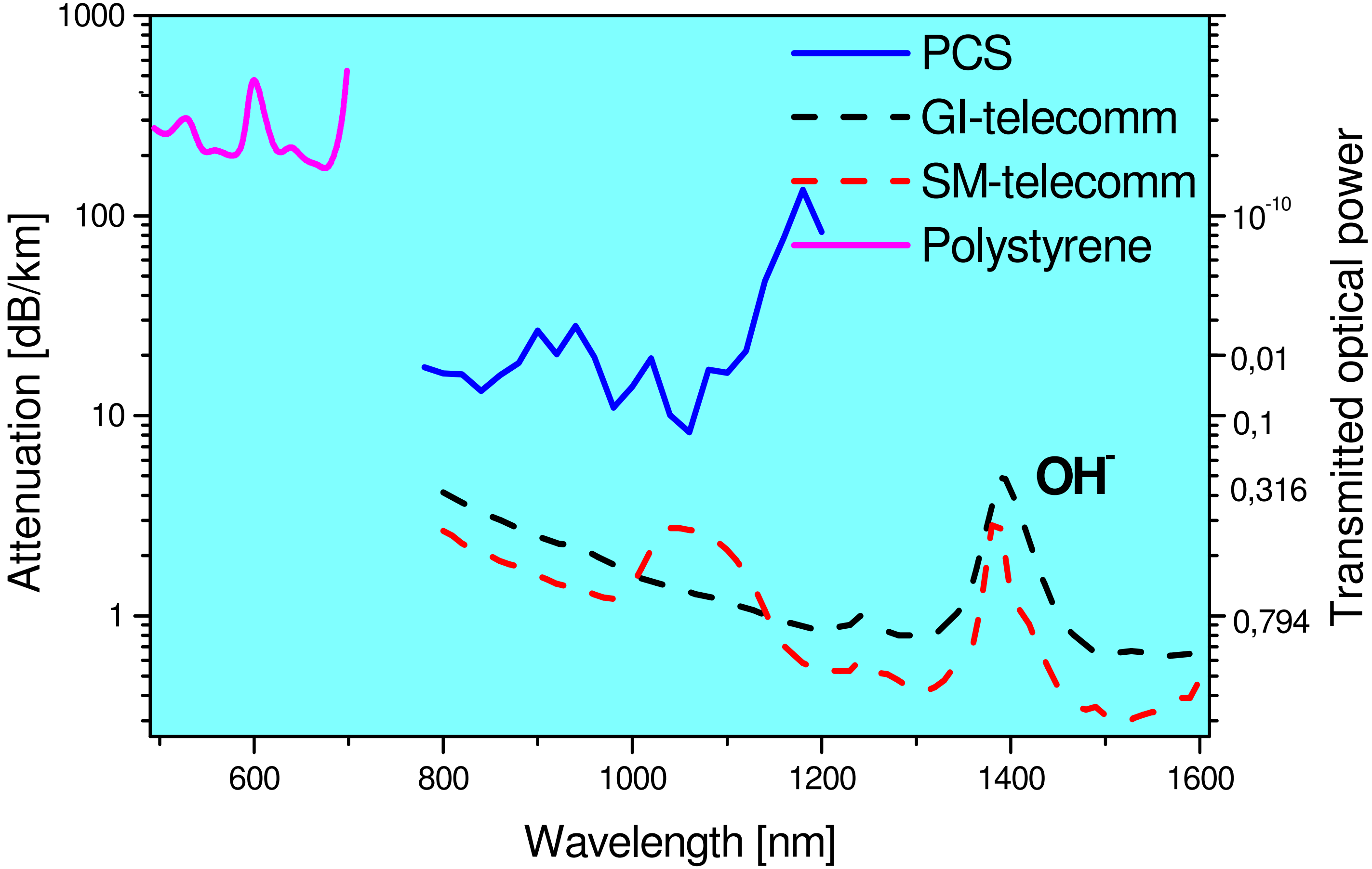


OPTICAL FIBERS – Materials - UV



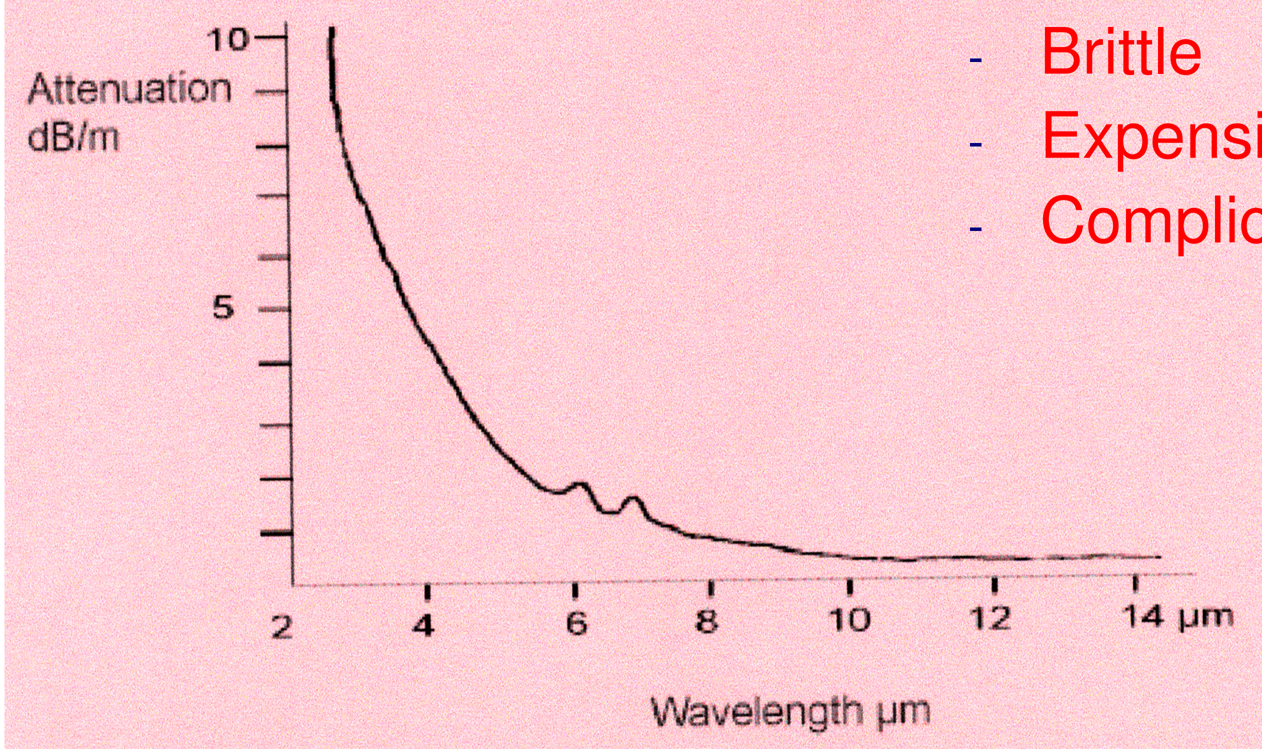
- silica fibers - SUPRASIL $n_{200\ nm} = 1.55$ [ceramoptec.de, OceanO, IPE …]
- planar silica, crystalline CaF_2 (MgF_2) – [edmundoptics, technicalglass …]

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



- Brittle
- Expensive
- Complicated

- 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 preciseness 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

- Československý časopis pro fyziku 1/2010, 4-5/2010, 1/2011
- Jemná mechanika a optika 55 (2010)
- Sdělovací technika 3/2011

Uplatnění v oboru

- **ÚCHP : Laboratoř chemie a fyziky aerosolů**
- Aerosols, Clouds, and Trace gases Research InfraStructure Network
- Thermophysical properties of water in unexplored, technologically significant regions
- Study of transport of inhaled nano-sized particles (Pb, Cd) and their allocation in organs
- Laser chemistry **-** příprava tenkých vrstev, nanočástic, nanodestiček a dalších objektů technikami laserové ablace, laserové depozice z plynné fáze, CVD a MAPLE (Matrix Assisted Pulsed Laser Evaporation).