INTERNATIONAL YEAR OF LIGHT 2015

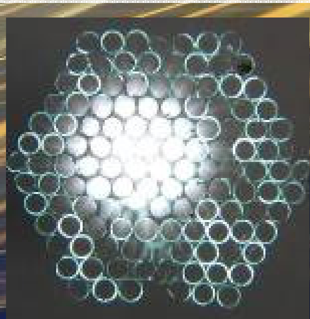
ÚFE

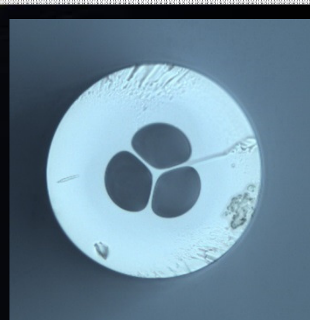
Academy of Sciences

Institute of Photonics and Electronics v.v.i.

Technology of Optical Fibers

I.Kašík, www.ufe.cz

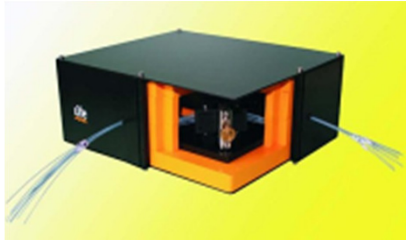



Institute of Photonics and Electronics

ÚFE

Prof. Jiří Homola
Head of UFE

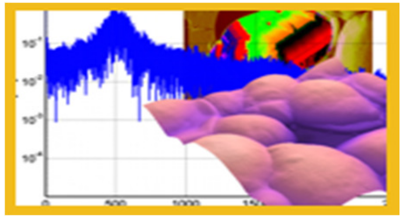


FUNDAMENTAL RESEARCH

Optical Biosensors (SPR Homola)

Fiber Lasers and Non-linear Optics (Honzatko)

Nanomaterials (SIMS Lorincik)



Bioelectrodynamics (Cifra)

National Time and Frequency Standard (Kuna)

Outline

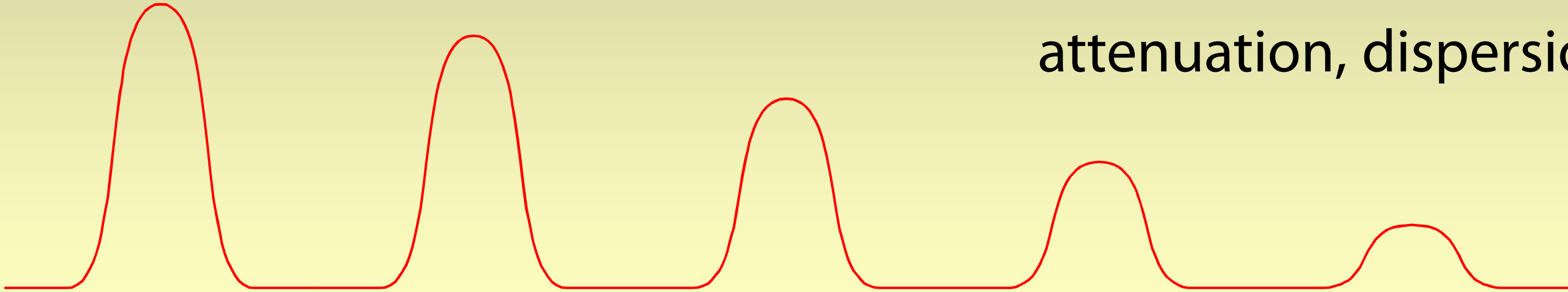
- Intro

- **Optical fiber purity & technologies**
- Application : - telecommunications
  - fiber amplifiers and lasers
  - fiber sensors
- Optical fibers - materials and structures
  - processing and accessories

Summary

Optical fiber

Optical fiber : dielectric structure, L<< r, $n_{core} > n_{clad}$



attenuation, dispersion

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 material

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

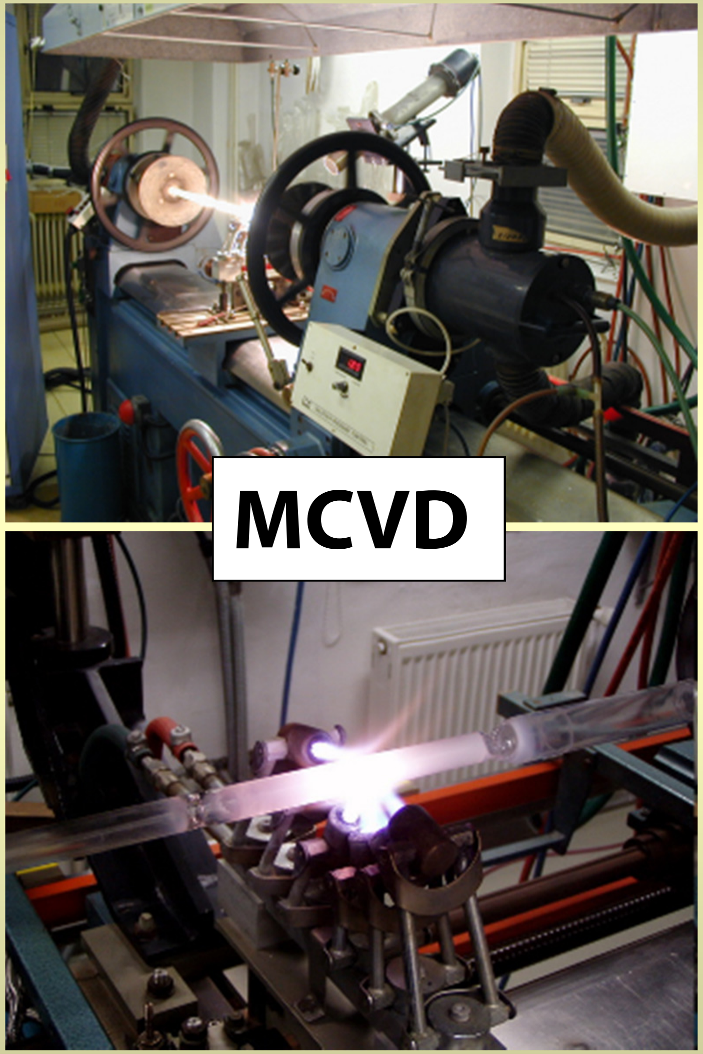
% – 10^{-2}

ppm – 10^{-6} (parts per million)

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

Ultra-pure technologies - CVD !

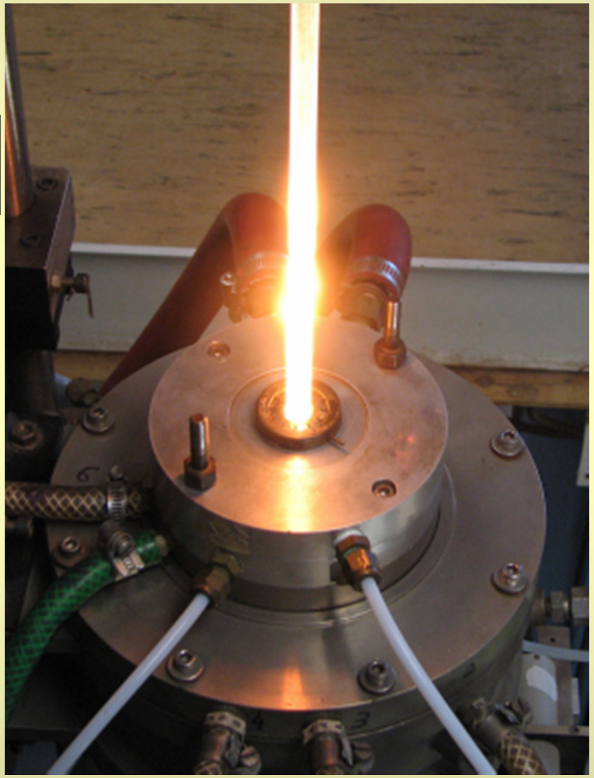
Optical fiber preparation



MCVD

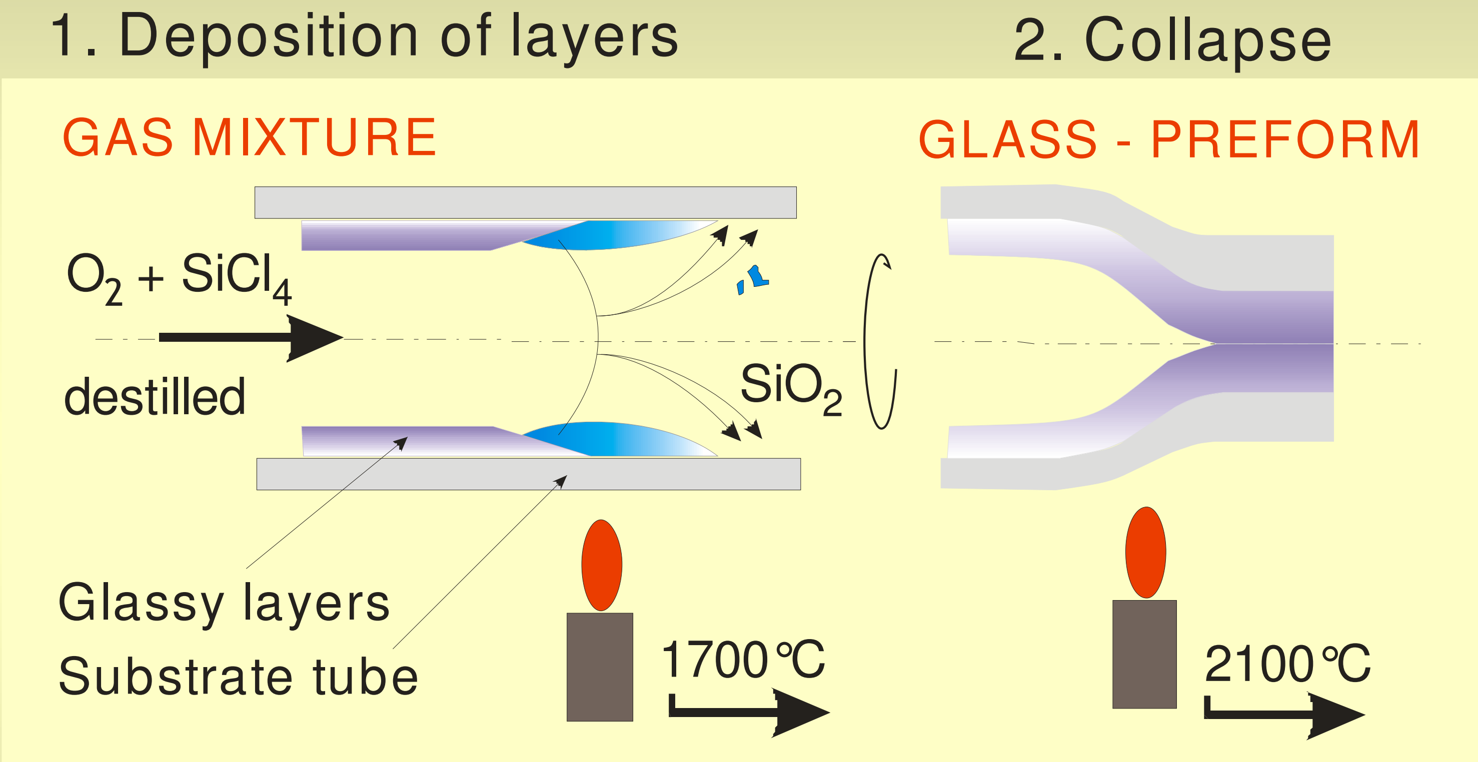
1. Preform

2. Fiber drawing



Preform preparation

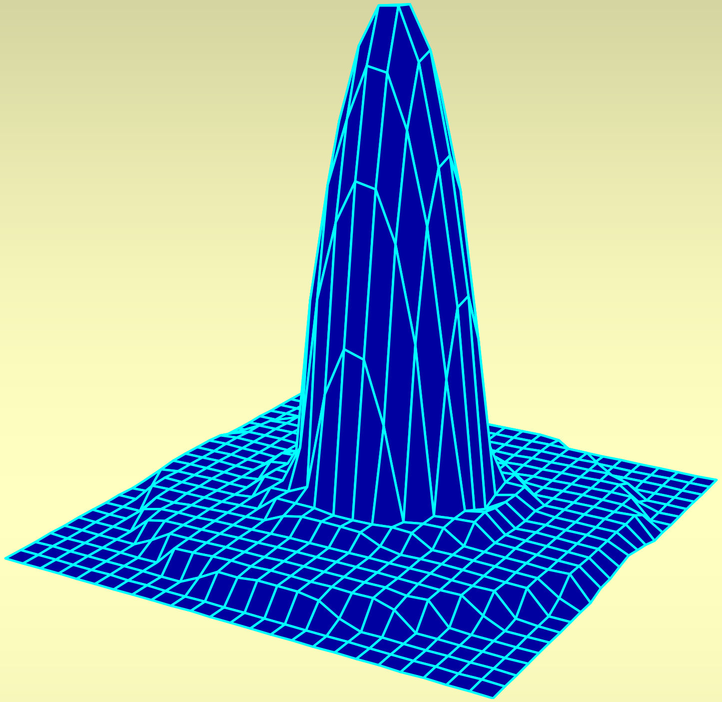
MCVD – (Modified) Chemical Vapor Deposition



- 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 %)

Preform preparation

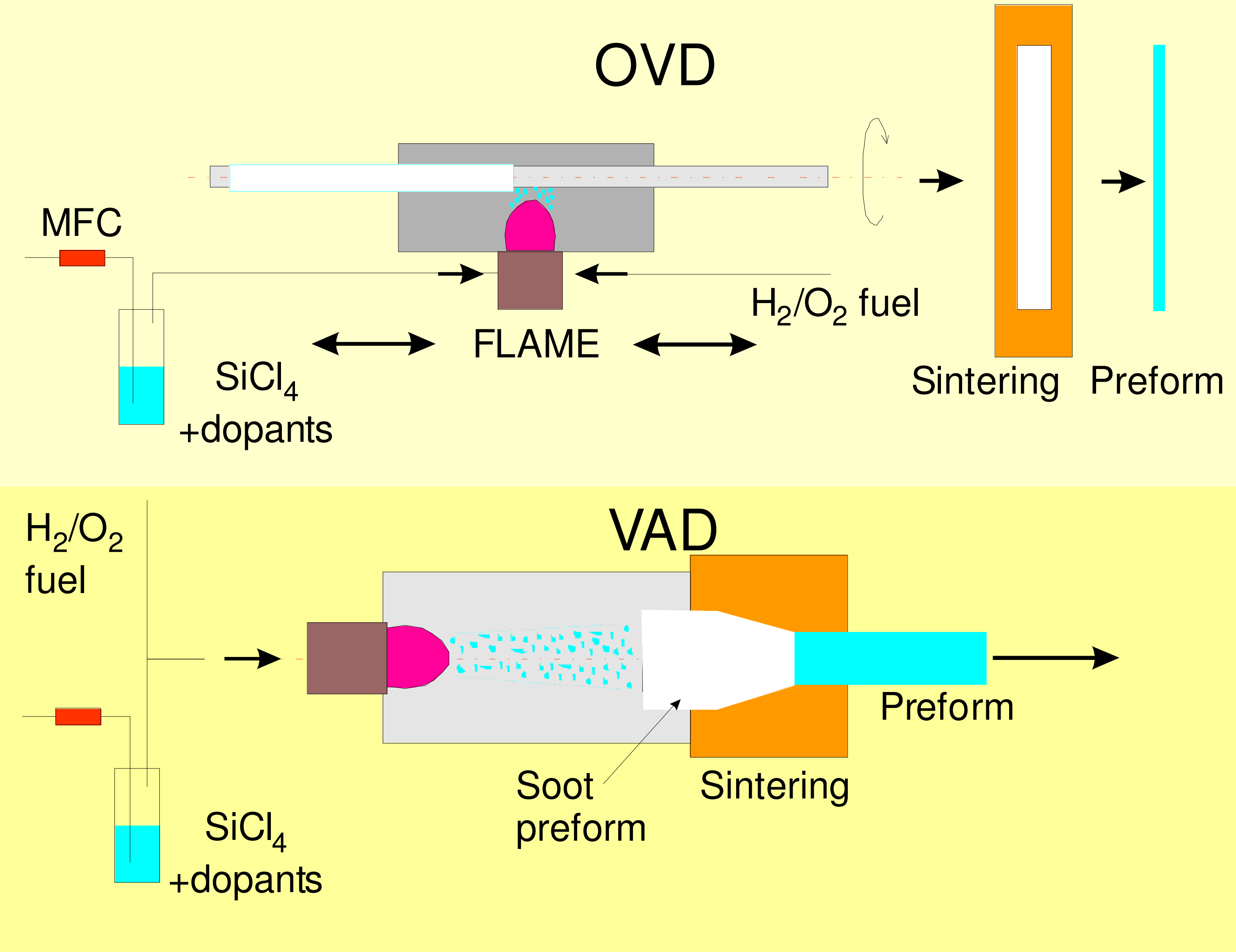
Microphoto of cross section of produced preform



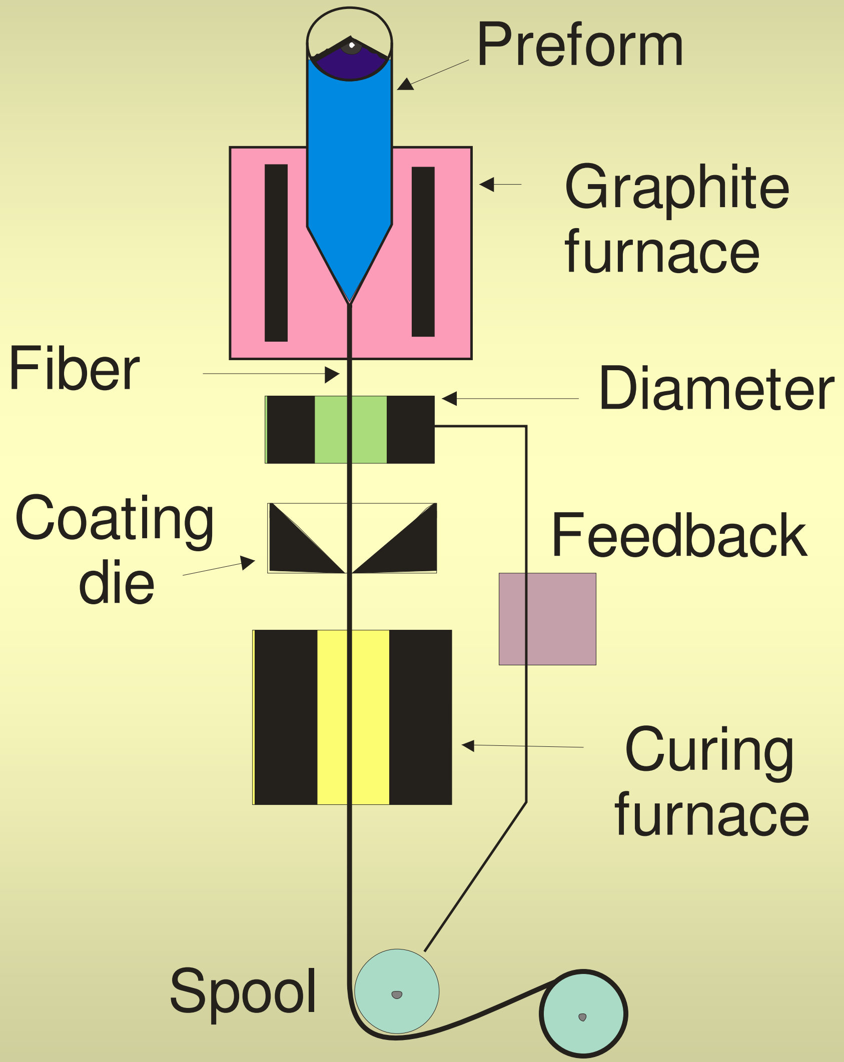
Tomography of the refractive-index profile of preform

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

Other CVD Technologies

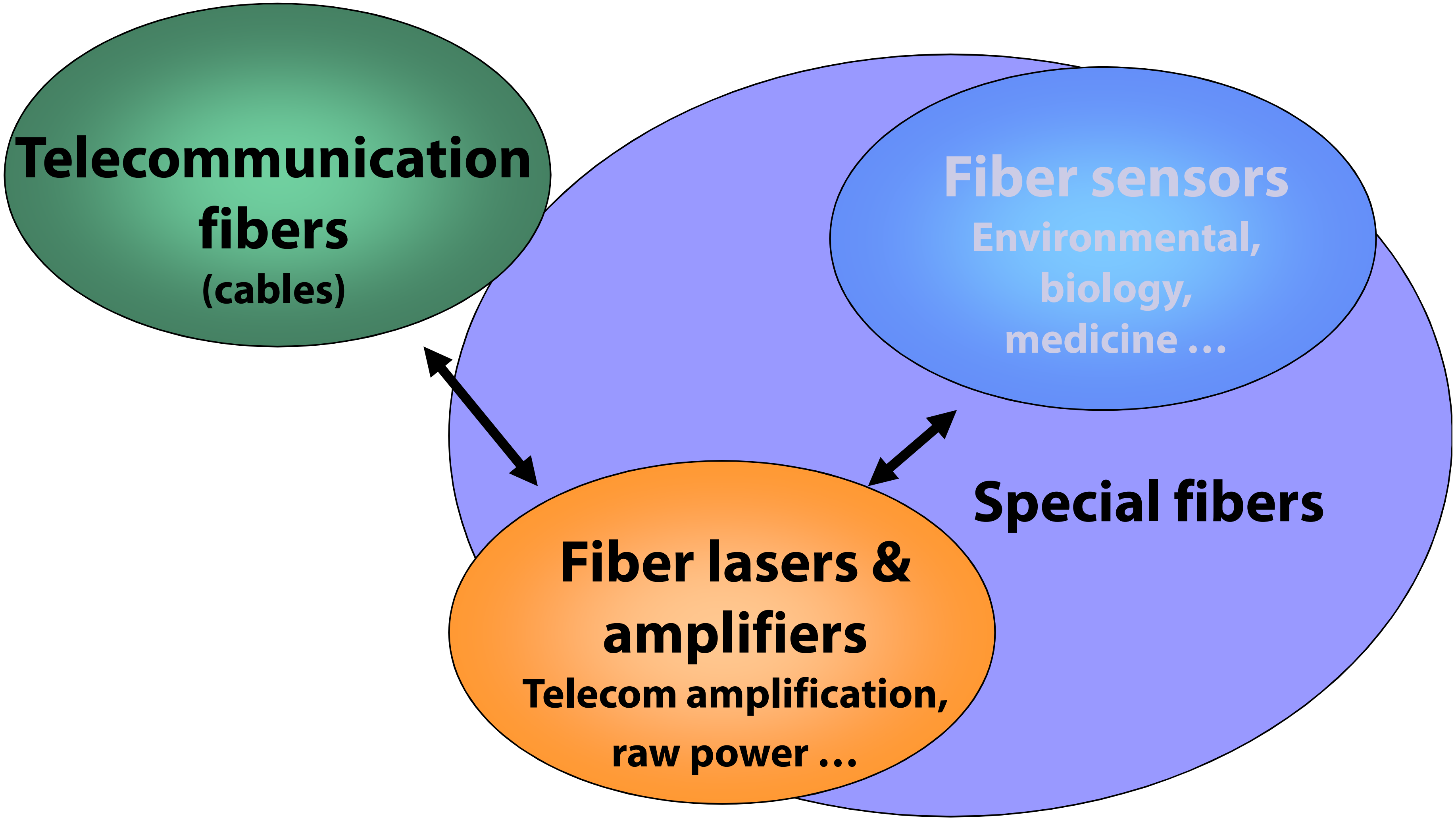


Drawing of optical fiber from preforms

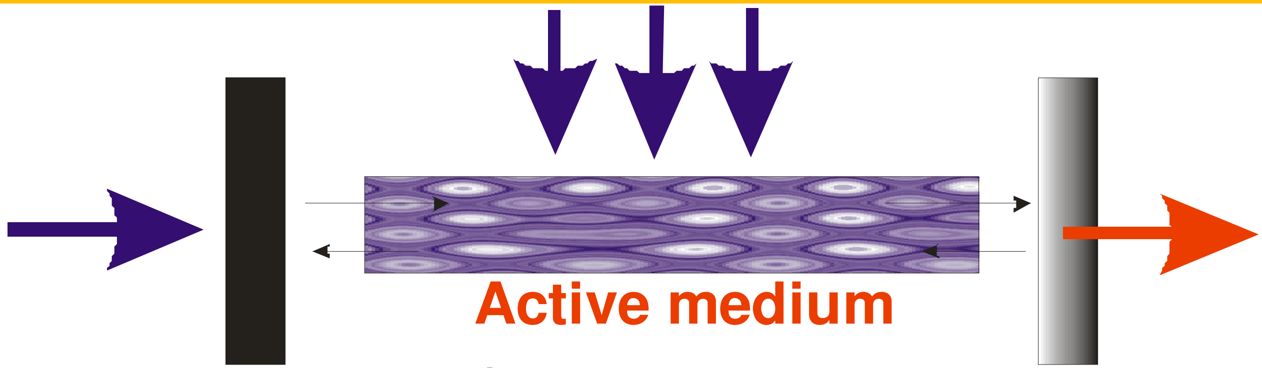


- Diameter
  80-1000 µm
- Temperature
  1800-2100°C
- No textile
- No thermo-insulation

Application



Silica specialty optical fibers for fiber lasers and amplifiers

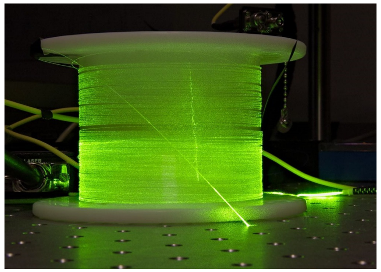


Active medium

Mirror
100%

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

Mirror
8-99%



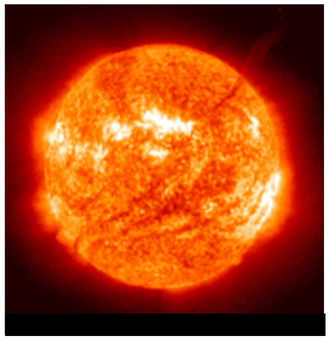
Er^{3+}

[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]

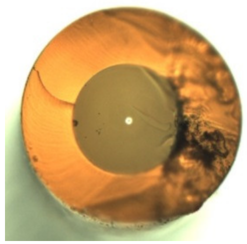
Fiber lasers mW → kW

* **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)

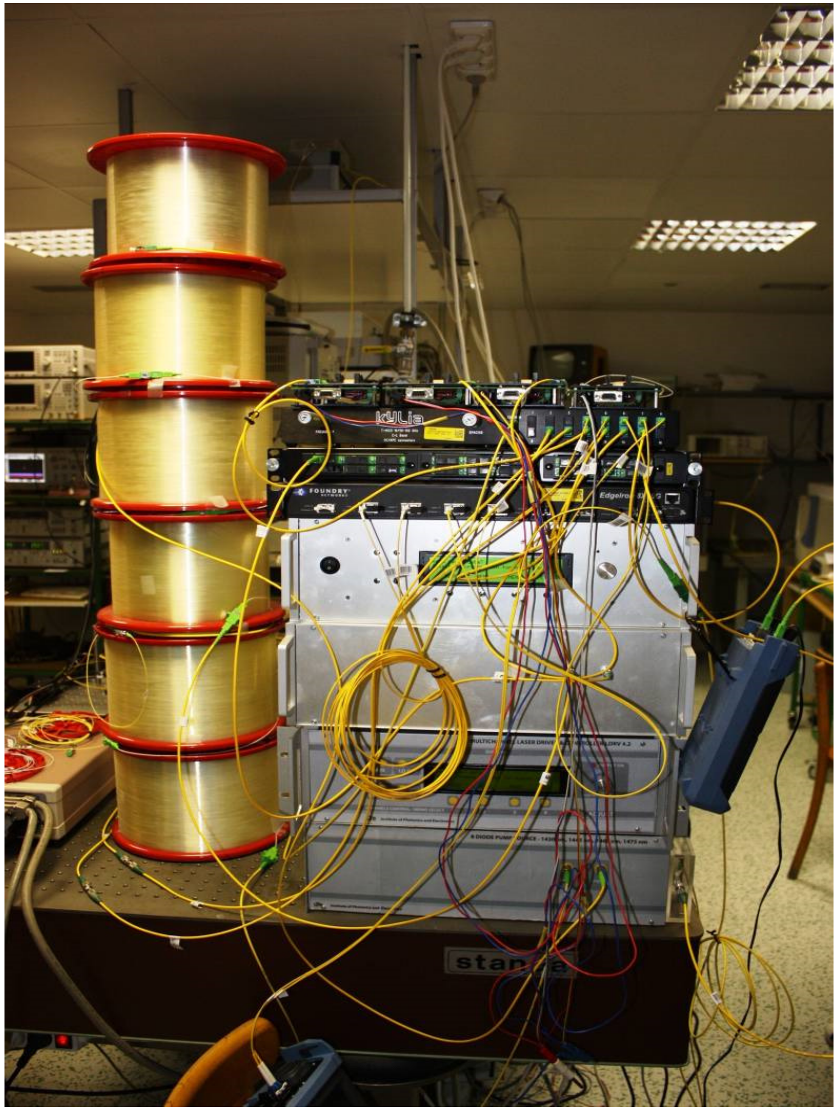
[IPG]

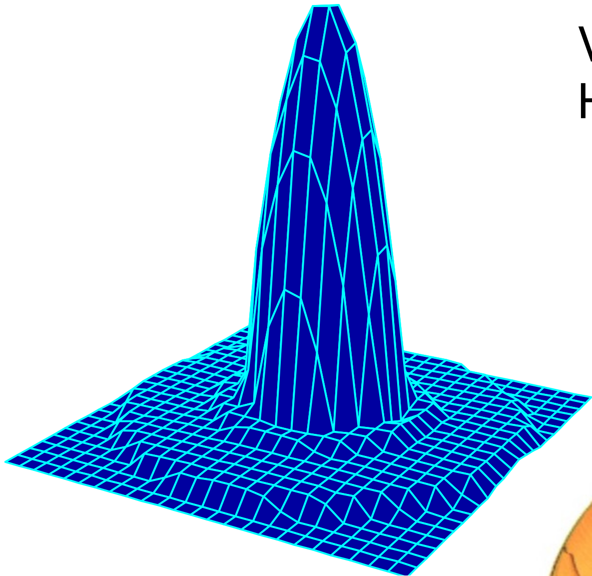


sun	63 MW/m^2
fiber laser	12.7 GW/m^2



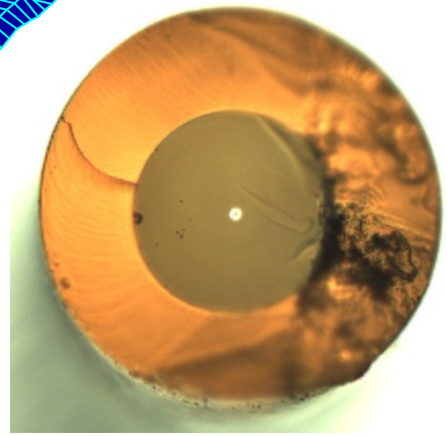
Telecommunications [mW]





VÚSU Teplice,
Hesfibel - TR

GI - multimode



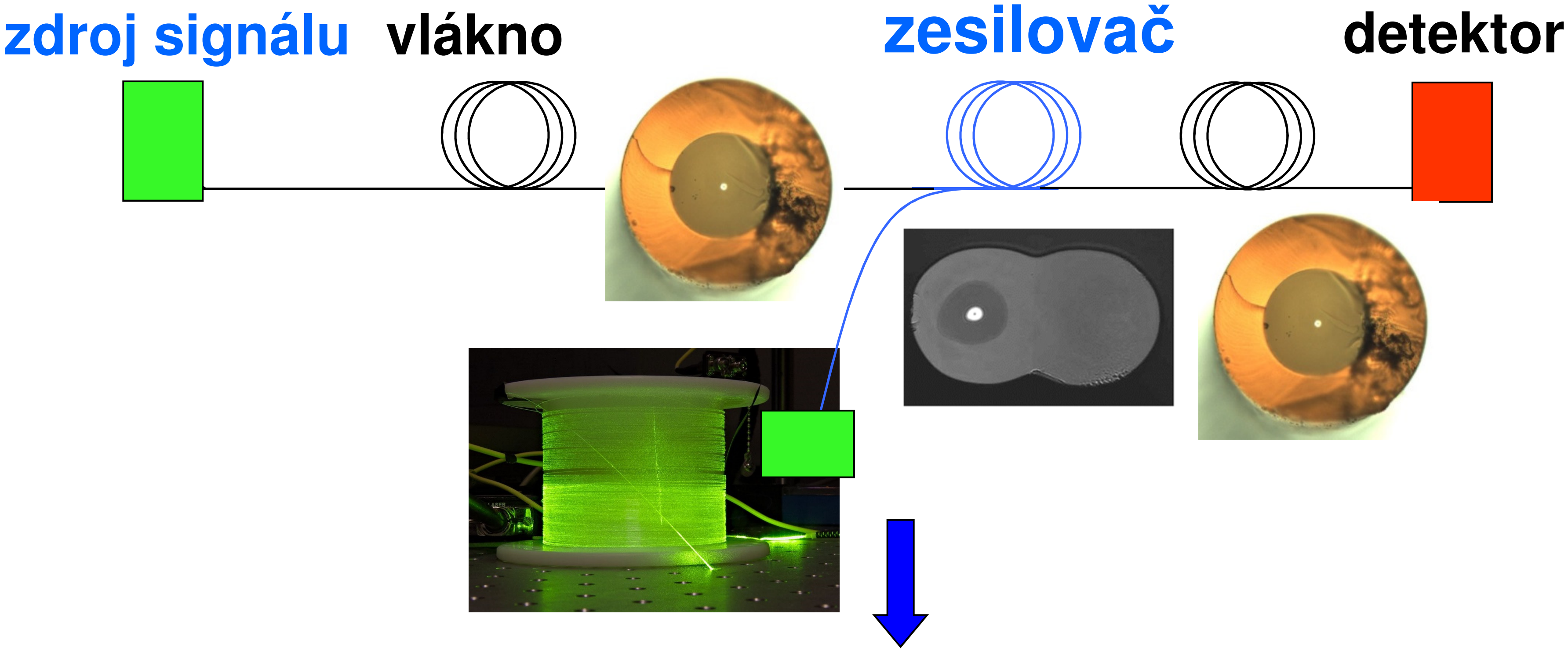
SM - singlemode

200 km telecom line - test

Telecommunications

Internet – připojení : 8.1 MB/s (7. místo)
Pevné připojení : EU 95% města, 82 % venkov
ČR 97% města, 90 % venkov
Optika FTTx 210 tis uživatelů = 7%
Každá obec nad 200 obyv. má optické připojení

Speciální vlákna pro telekomunikace : Vláknové lasery a zesilovače

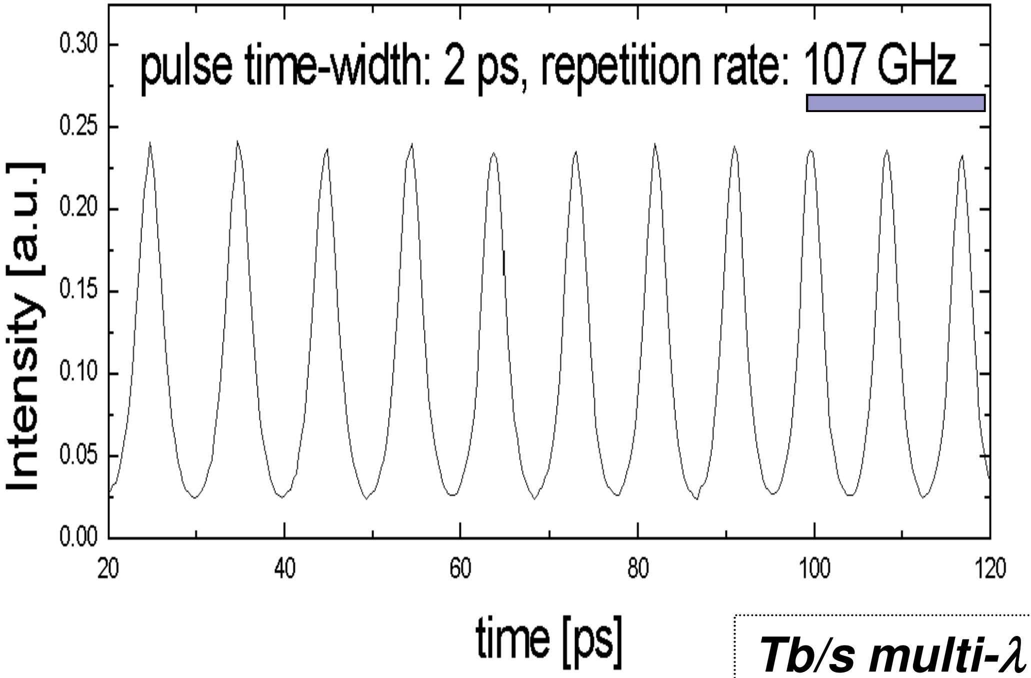


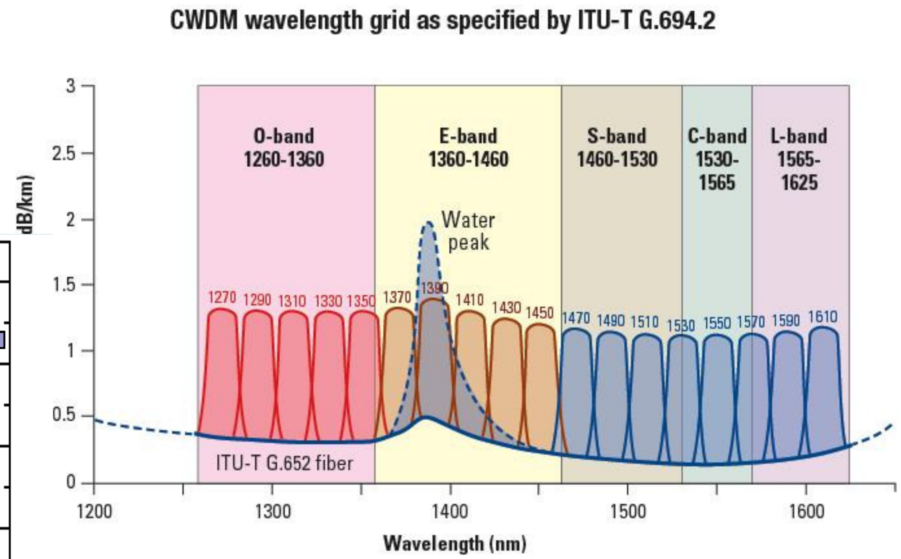
Vláknový zesilovač, laser

TDM

WDM

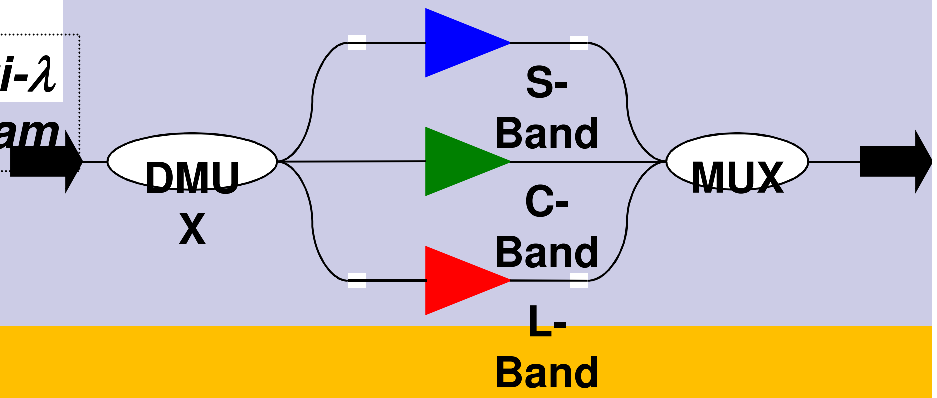
Time Division Multiplexing (TDM)





Wavelength Division Multiplexing (WDM)

Tb/s multi-λ
Data stream



in collaboration with CTU-FJFI, LPMC Nice

Fiber lasers mW → kW

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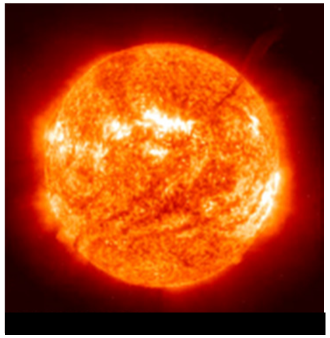
[IPG]



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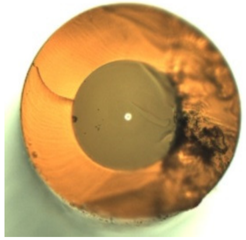
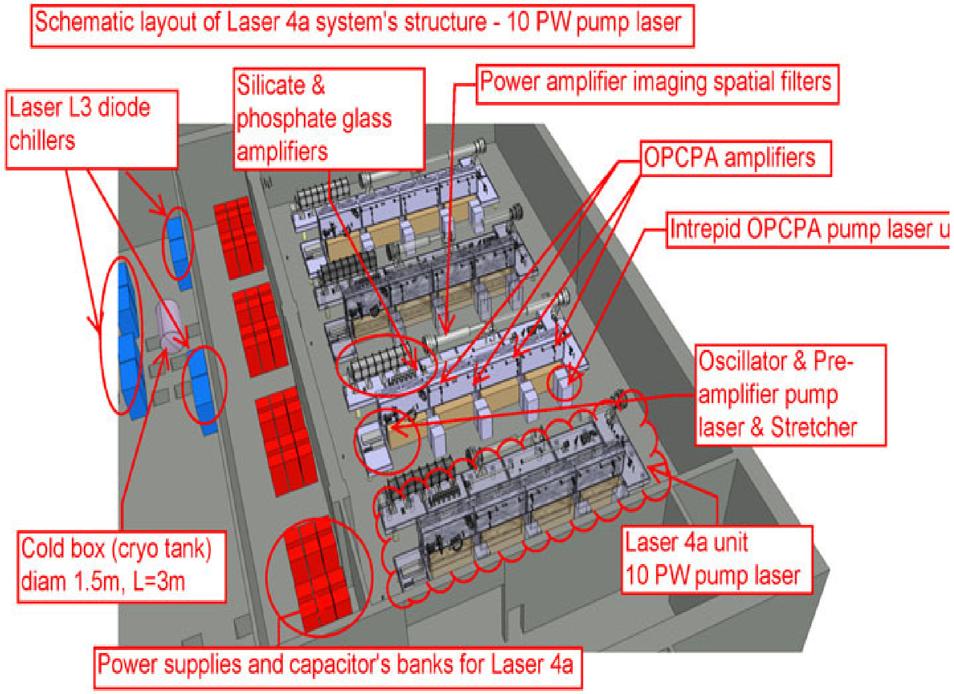


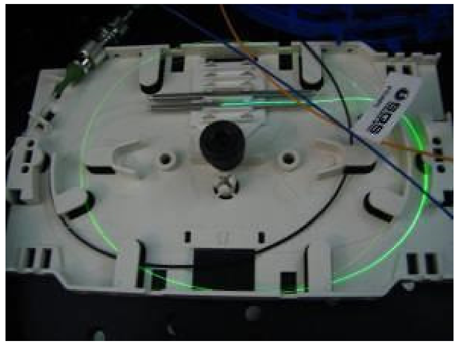
Fiber lasers vers. solid state lasers (SSL)

- **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]





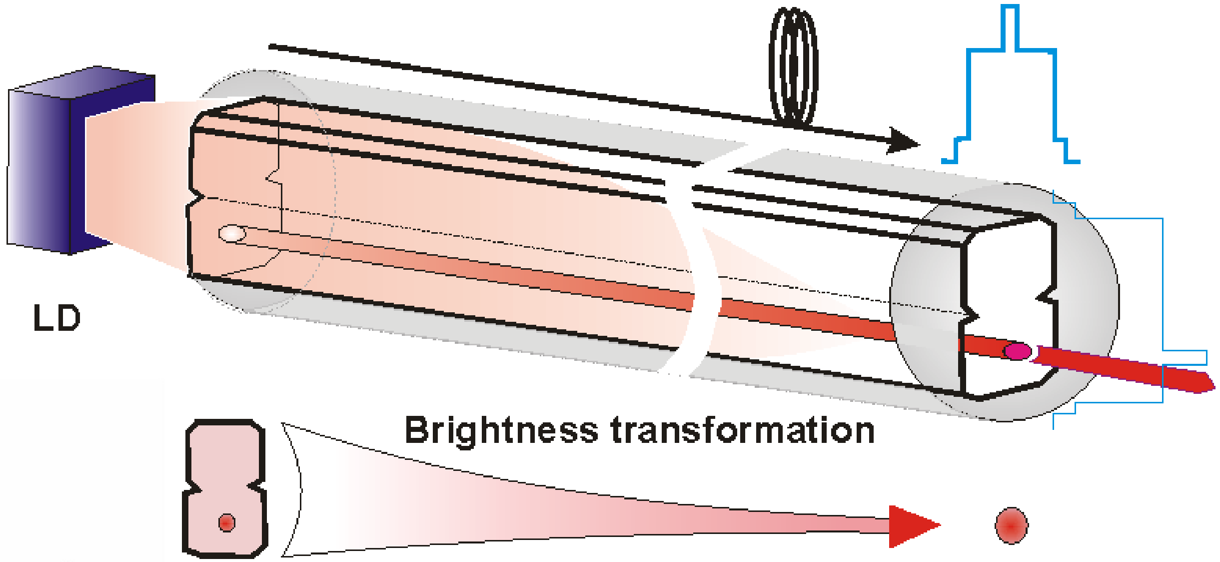
100 m

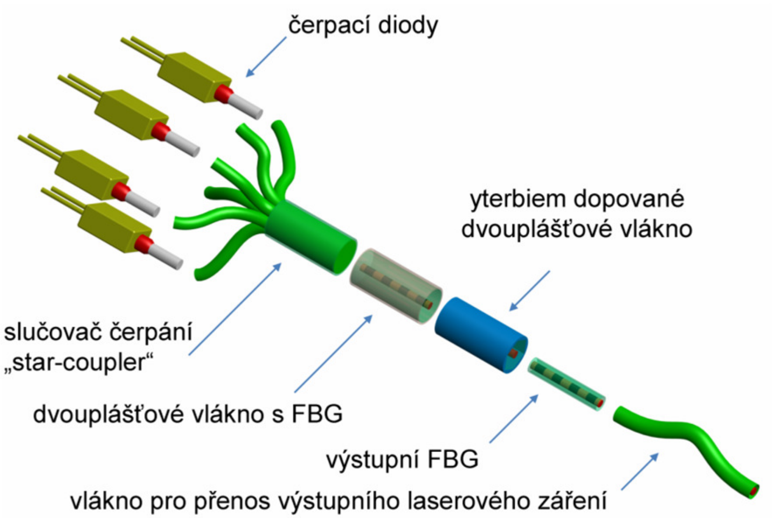
1 m

0.1 m

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

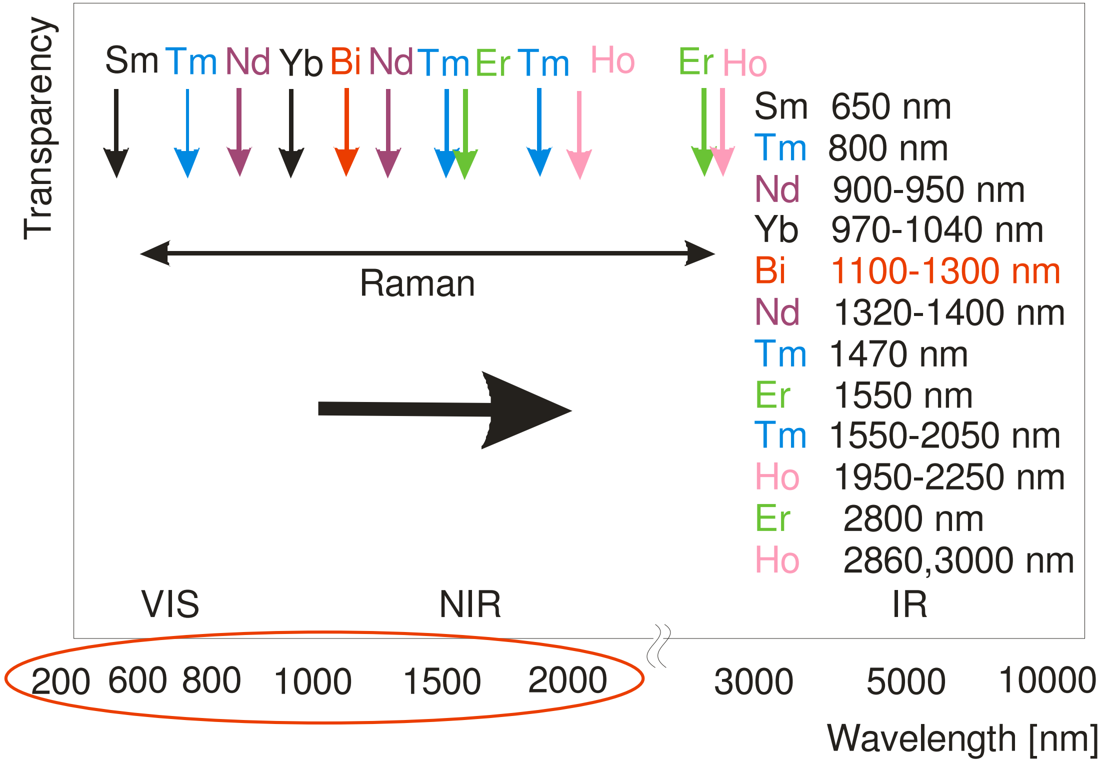
DC structures, beam combining ..





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

Dopants



Dopant combination : effective pumping due to energy transfer

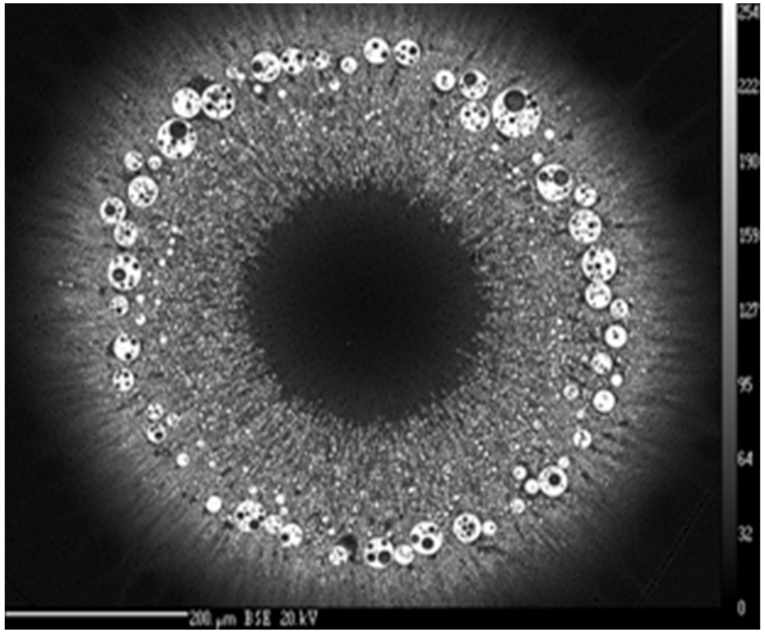
High-power lasers : Er (1.5 um), Yb (1.1 um), Tm (1,9 um)

RE-doped SILICA

+ low optical losses in wide transmission window

+ good thermal durability and stability

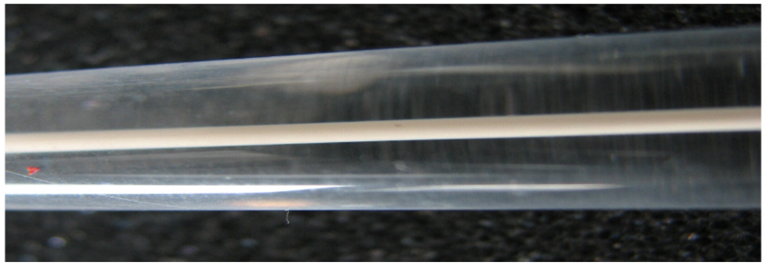
- low miscibility of RE with silica



Increase of RE doping + Mixing of RE

→ phase separation

→ unacceptable attenuation

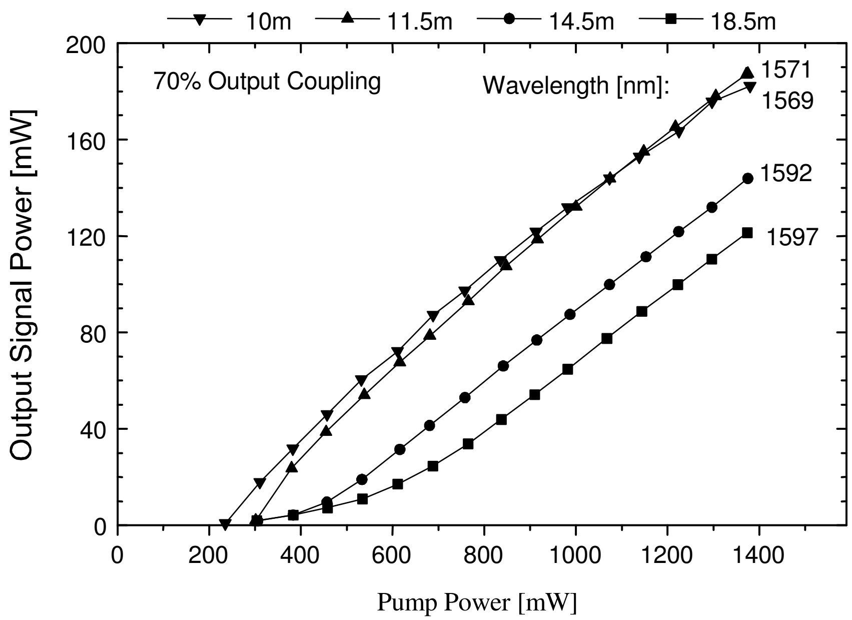


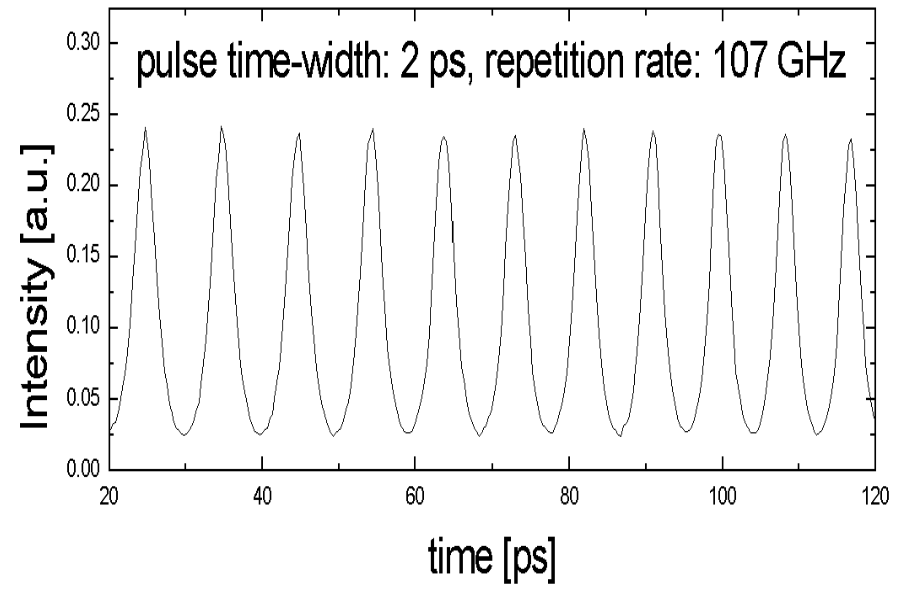
=> modification of matrix with (GeO_2), Al_2O_3, P_2O_5 … Sb_2O_3

= **dissolving of RE in glass matrix** + increase of RI

Er/Yb -doped fiber for soliton laser

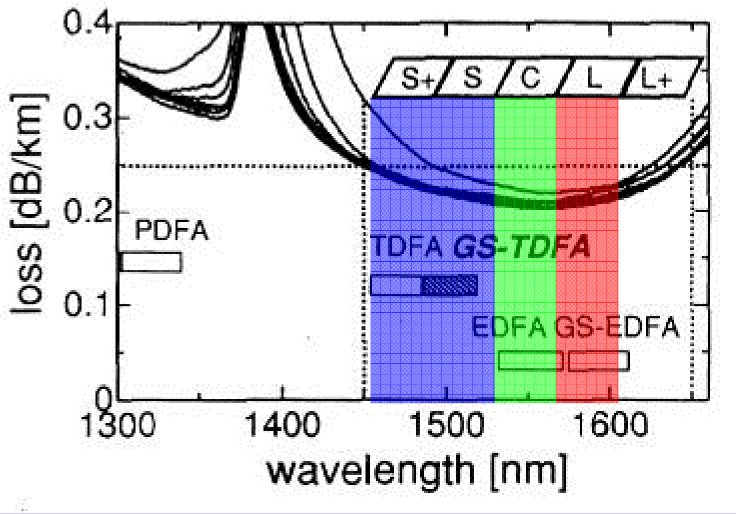
- GOAL: 1 W soliton source of 1-2 ps pulse trains operating at ~1550 nm when pumped at 1064 nm (mini-YAG)
- Fiber: 1 000 ppm Er / 10 000 ppm Yb + 10 mol% Al_2O_3

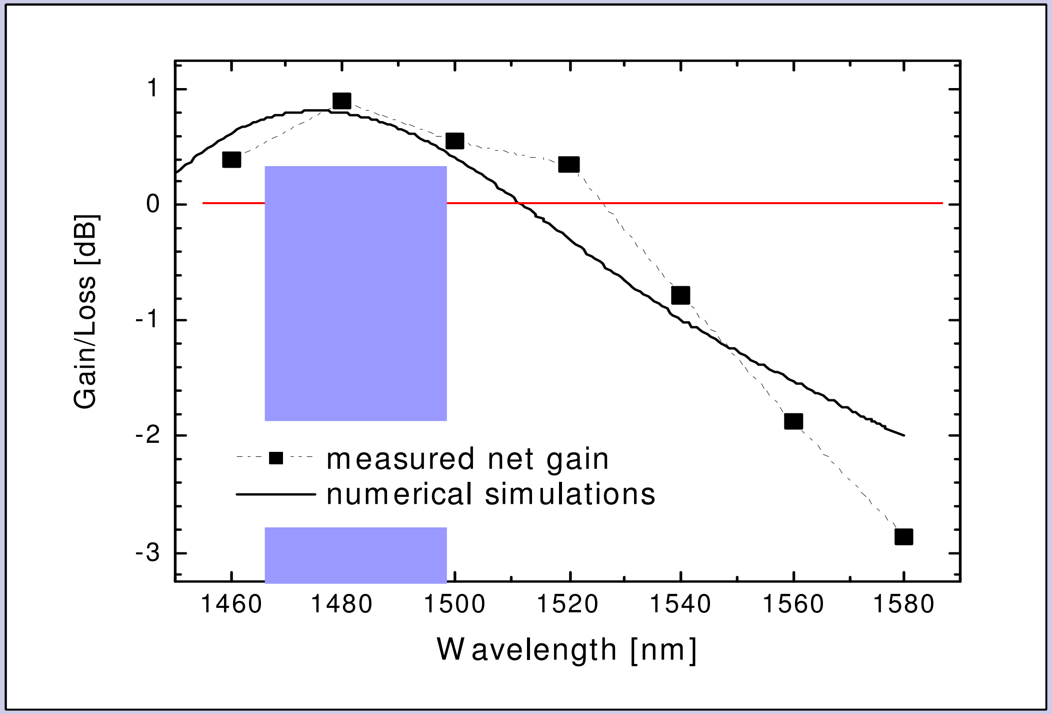




[Kasik, V. Matejec, J. Kanka, P. Honzatko : Pure and Appl. Opt. **7** (1998) 457-465]
[I. Kasik, V. Matejec, M. Pospisilova, J. Kanka, J. Hora : Proc. **SPIE 2777** (1995) 71-79]

Tm- doped fiber for amplifier at 1470 nm



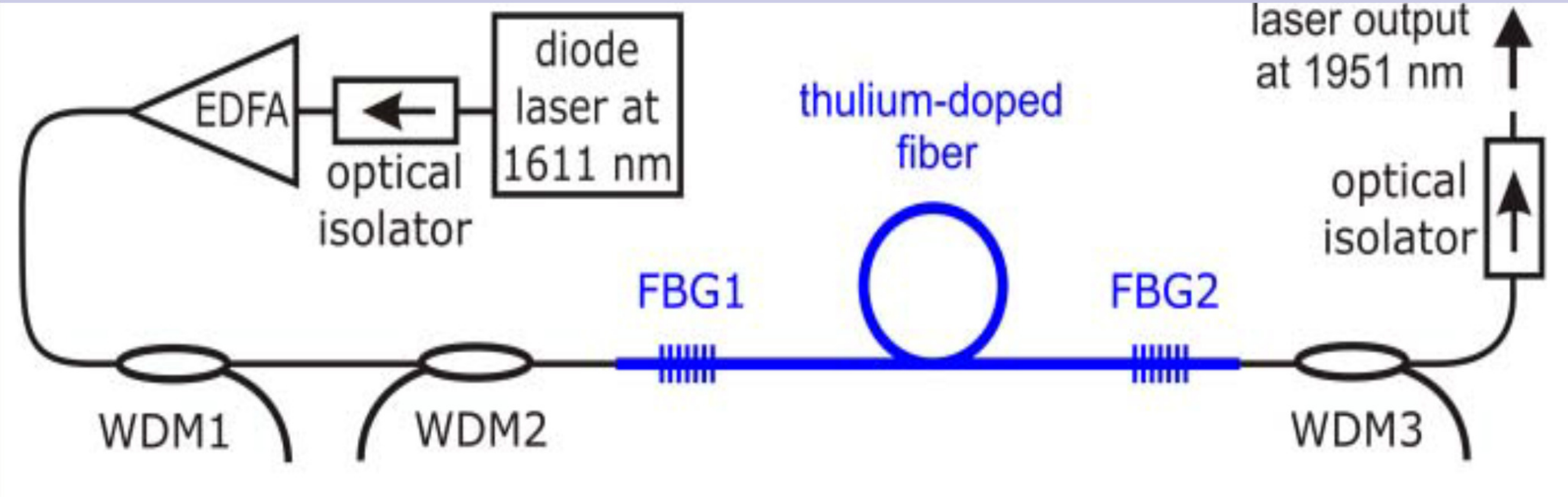


Non-optimized fiber parameters (low NA, low Tm^{3+} concentration), longer lifetime required.

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

Monolitic Tm- doped fiber laser at 1951 nm

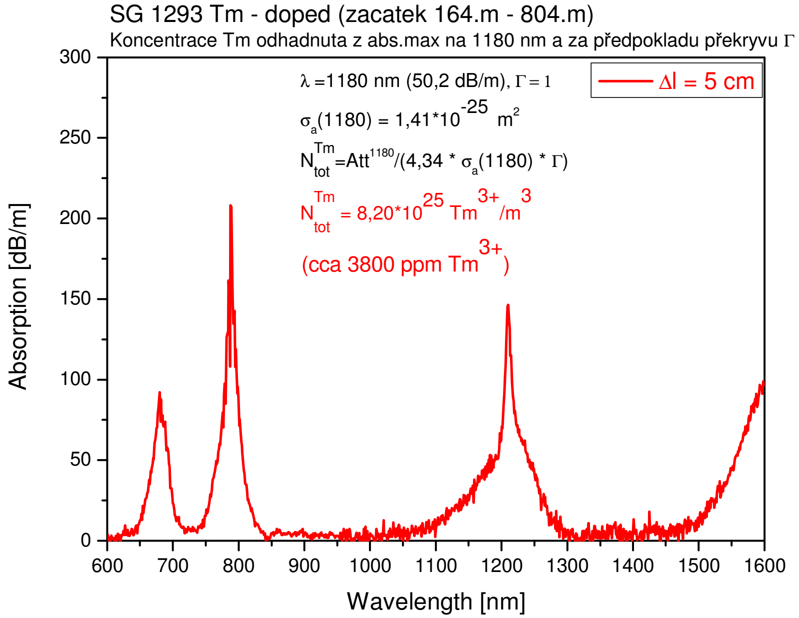
Eye-safe spectral region

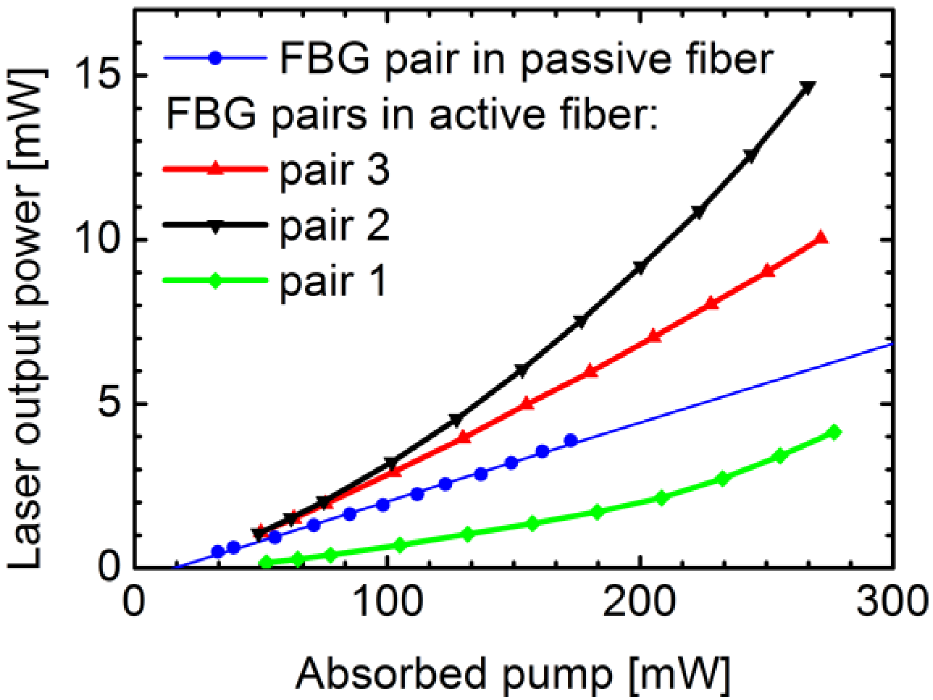


* Tm^{3+} - Al_2O_3-SiO_2 core (Al_2O_3 nanoparticles),
* 1000 ppm Tm^{3+}, 11mol% Al_2O_3, 0 mol% P_2O_5 or GeO_2,
* **deep-UV inscription of FBG**

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

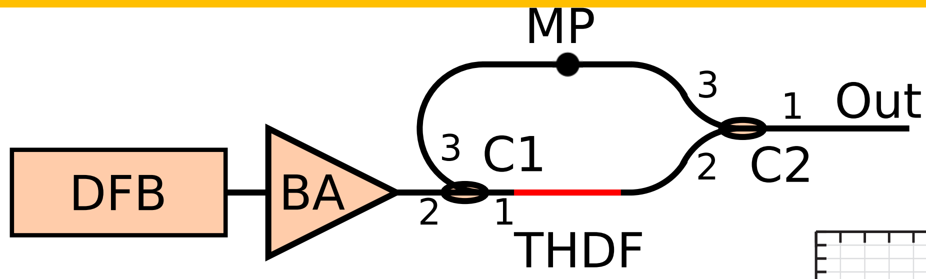
Tm -doped fiber for laser at 1951 nm

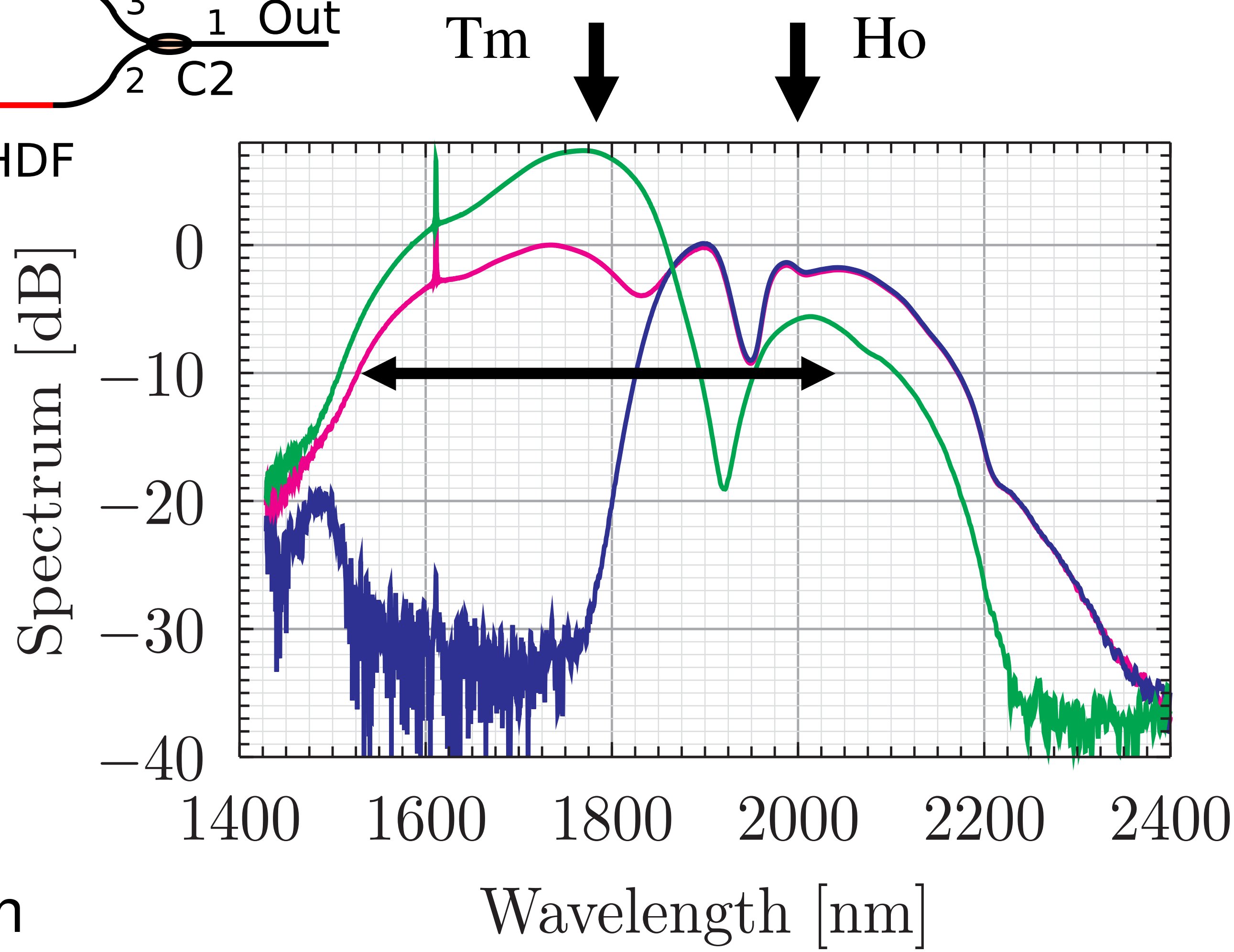




Fiber: Δn ~ 0.008, NA ~ 0.15, symmetric, Al_2O_3 ~4 mol%
attenuation_1180 nm = 50,2 dB/m; Tm ~ 4000 ppm
background losses ~0.01-0,04 dB/km

Tm/Ho – fiber for ASE source





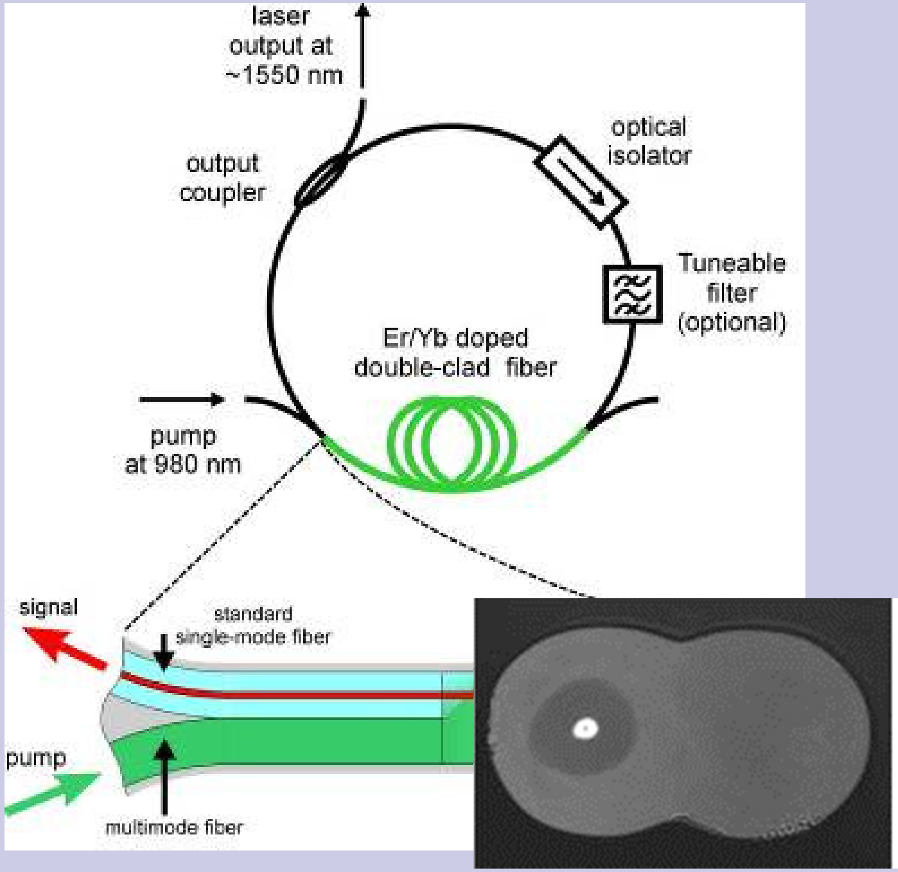
GOAL: wide fluorescence

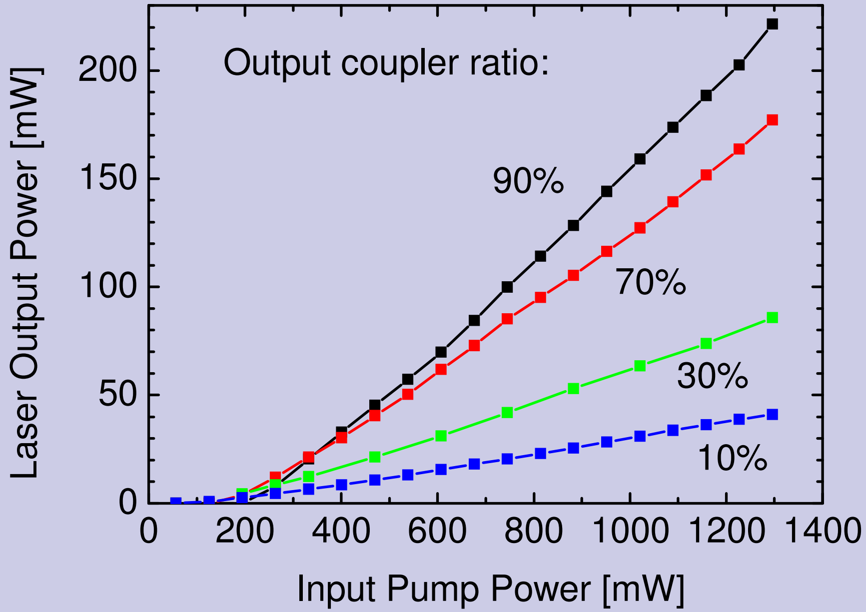
Fiber: 1800 ppm Tm / 360 ppm Ho

Backward emission 1550 – 2050 nm

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

Er/Yb -doped DC fiber

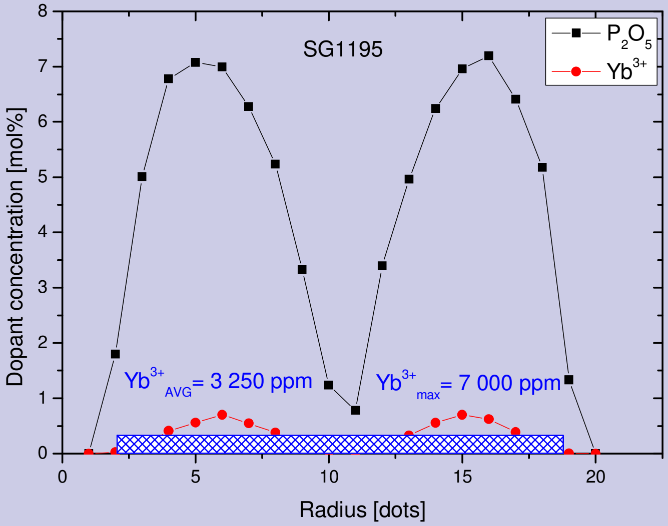


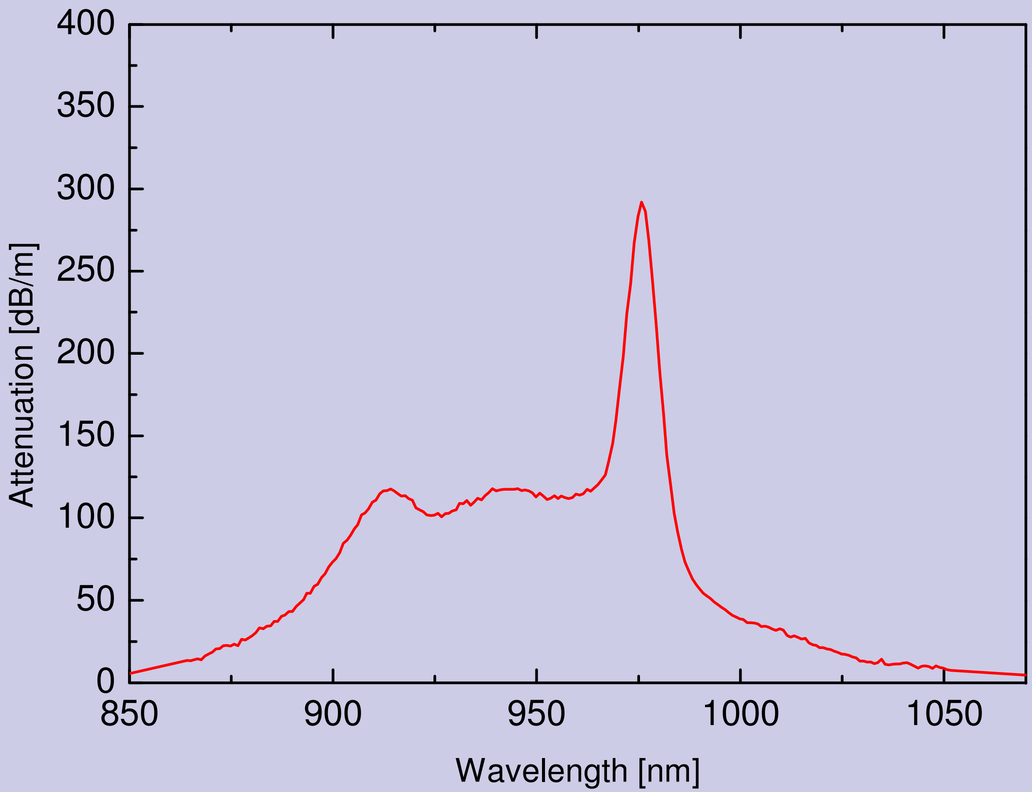


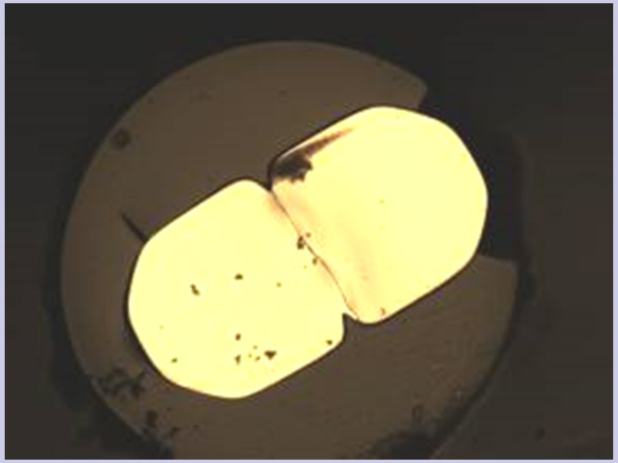
PCE 19 ⟶ 40%

[P.Peterka, Opt. Lett. **31** (2006), 3240], [P.Peterka, Proc. SPIE **6180**, 2006, 618010], [P.Peterka, Proc.CLEO/QELS'06 & PhAST 2006, CTuQ7.pdf], [Peterka, CZ Pat. 301215, 2009]

Yb- doped DC fiber





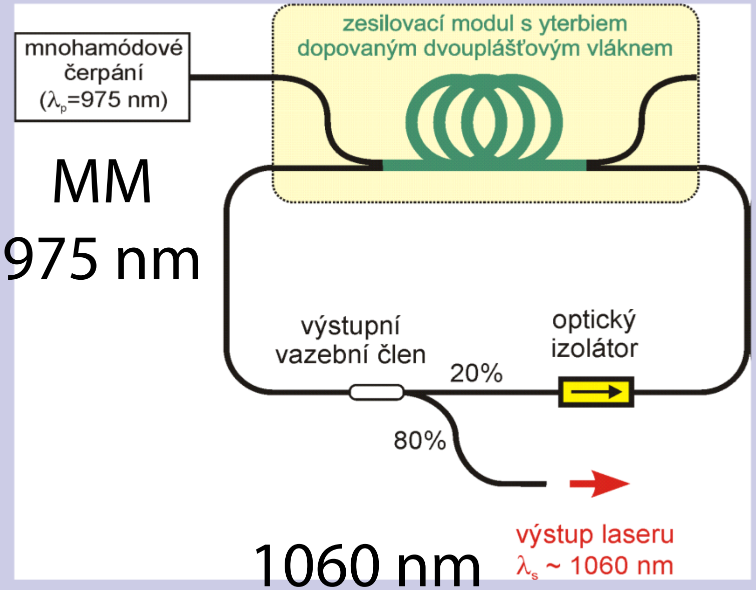


Technol. challenge : high Yb and P_2O_5 conc.;

P_2O_5 or P_2O_5 - Al_2O_3 good photodarkening

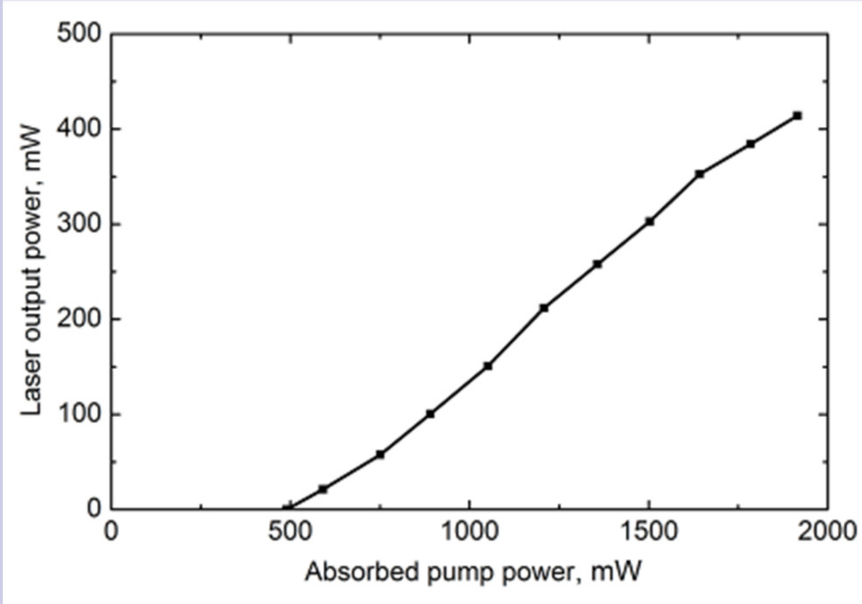
P_2O_5 max 7 mol%, Yb^{3+} 3 250 ppm

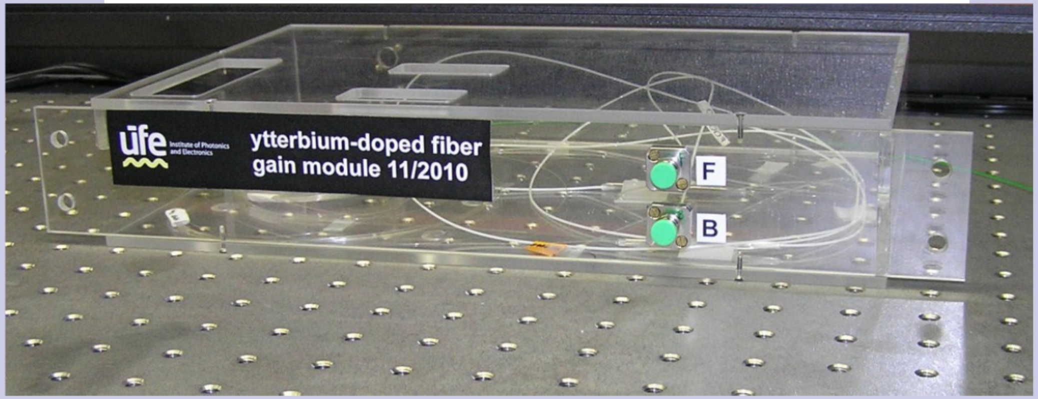
Yb- doped DC fiber amplification module



MM
975 nm

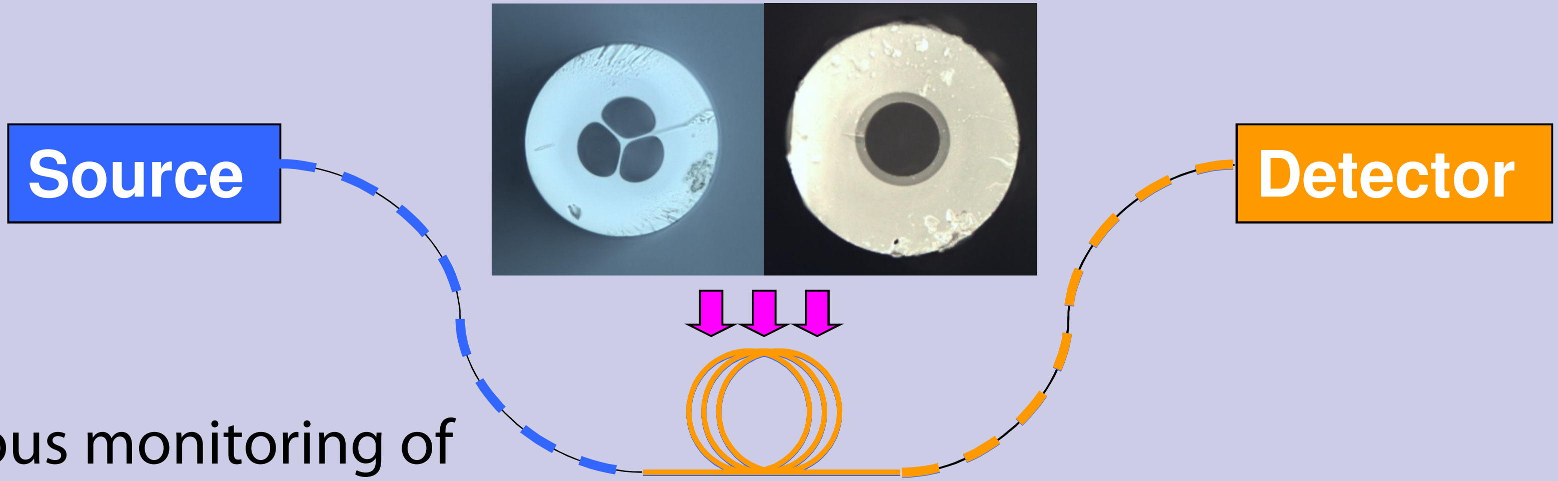
1060 nm



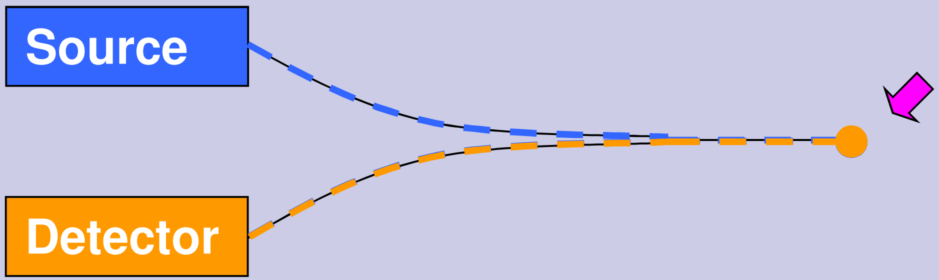


[A. Novozamsky, Proc. SPIE 7746, 2010, 77461O], [Schmitt, Proc. SPIE 8082, 2011, 808228]

Optical fiber sensors



Continuous monitoring of (bio)chemicals and their concentration.



Suitable for :

remote sensing

distributed sensing

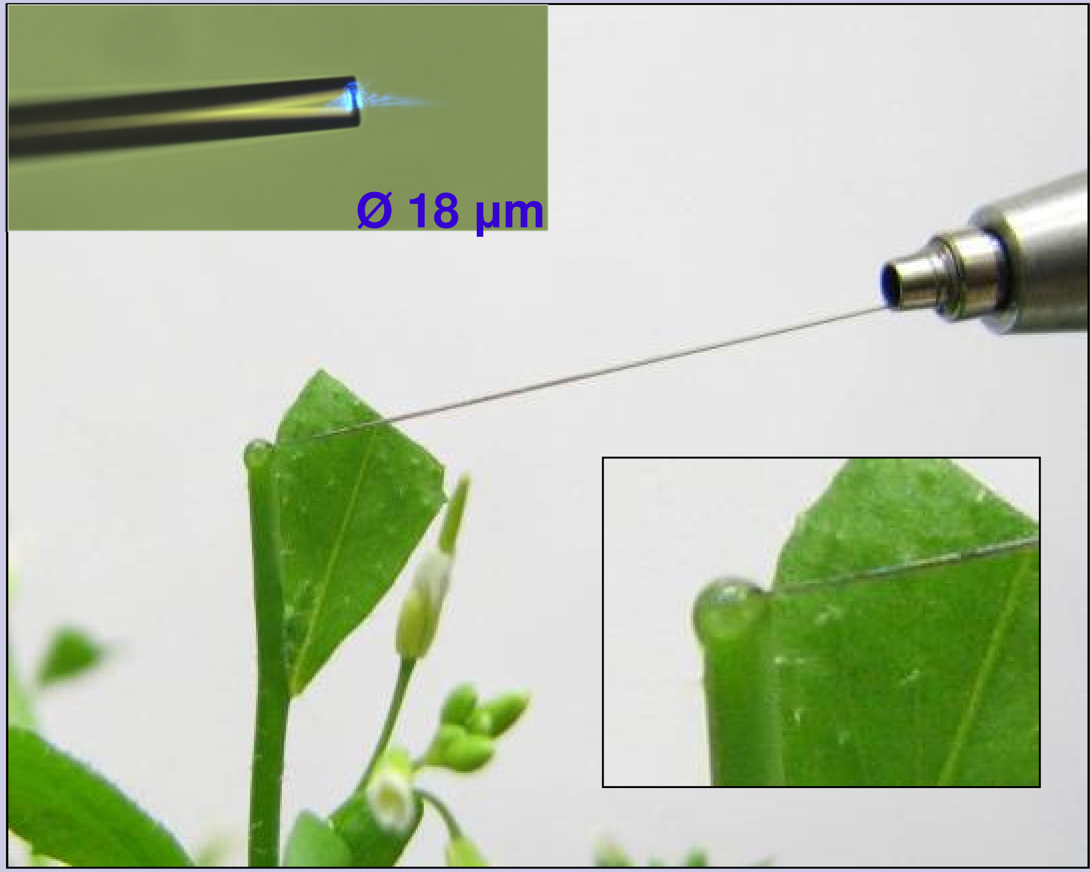
flammable or explosives

in high-voltage areas

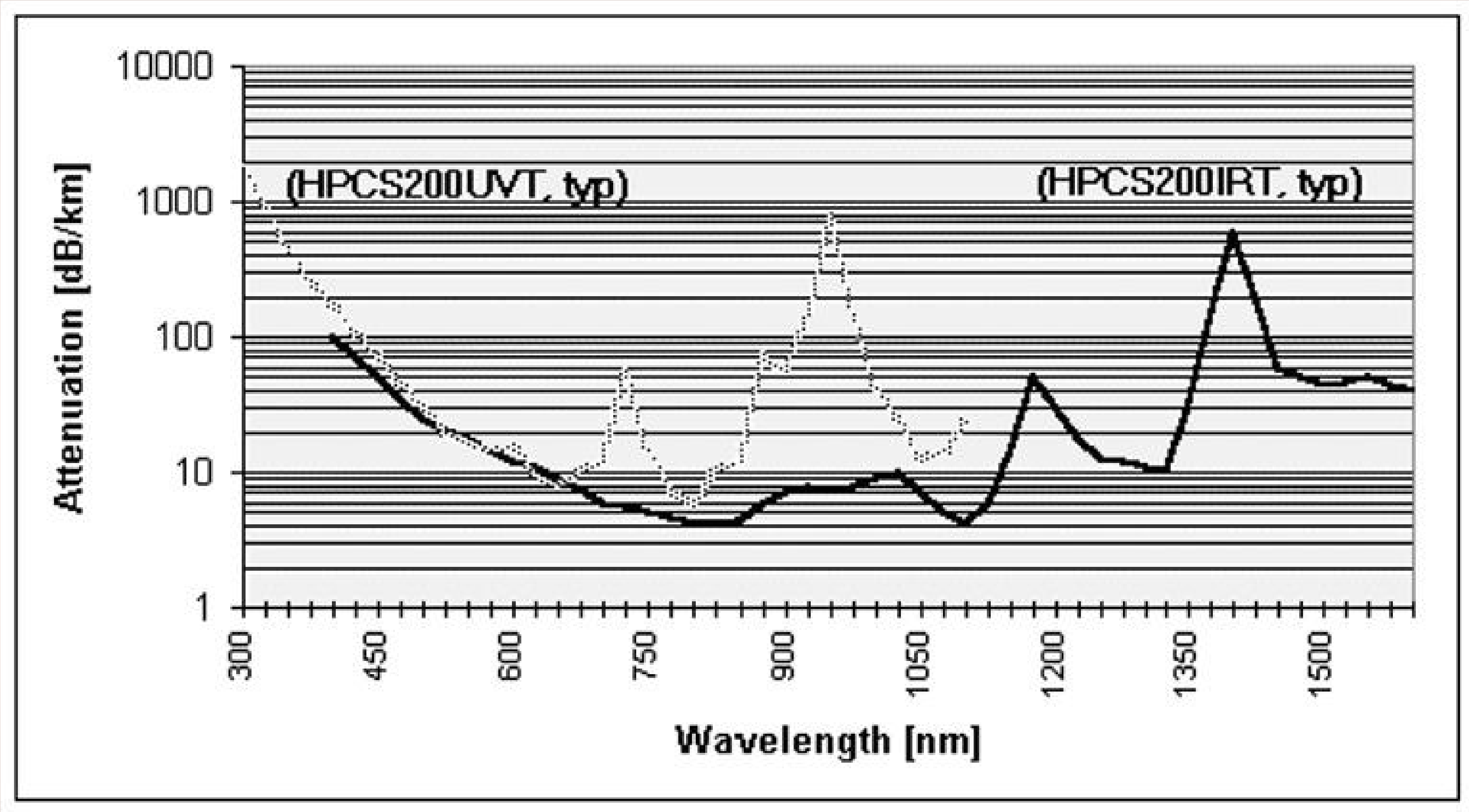
human body

Optical fiber sensors

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

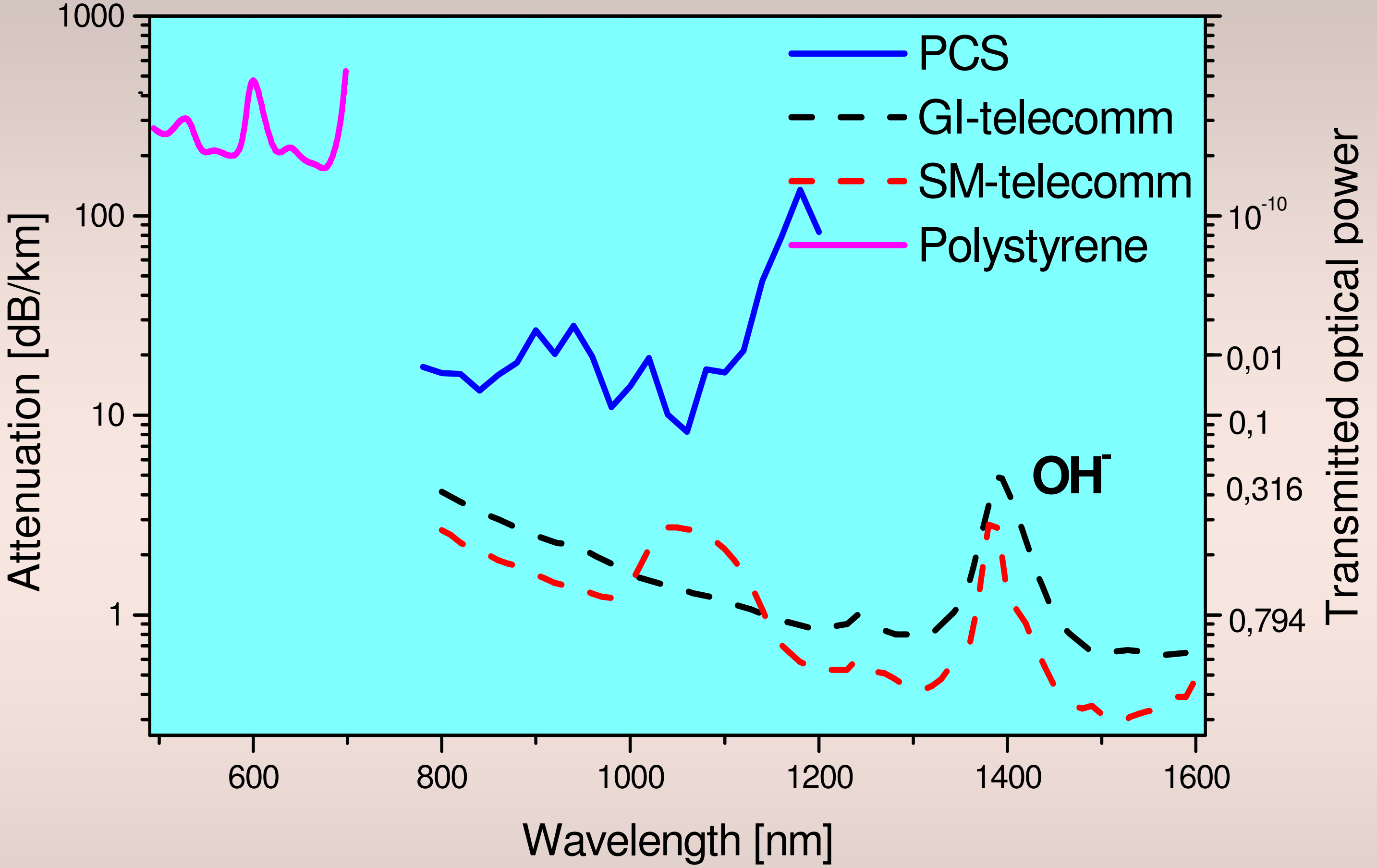


OPTICAL FIBERS – Materials - UV



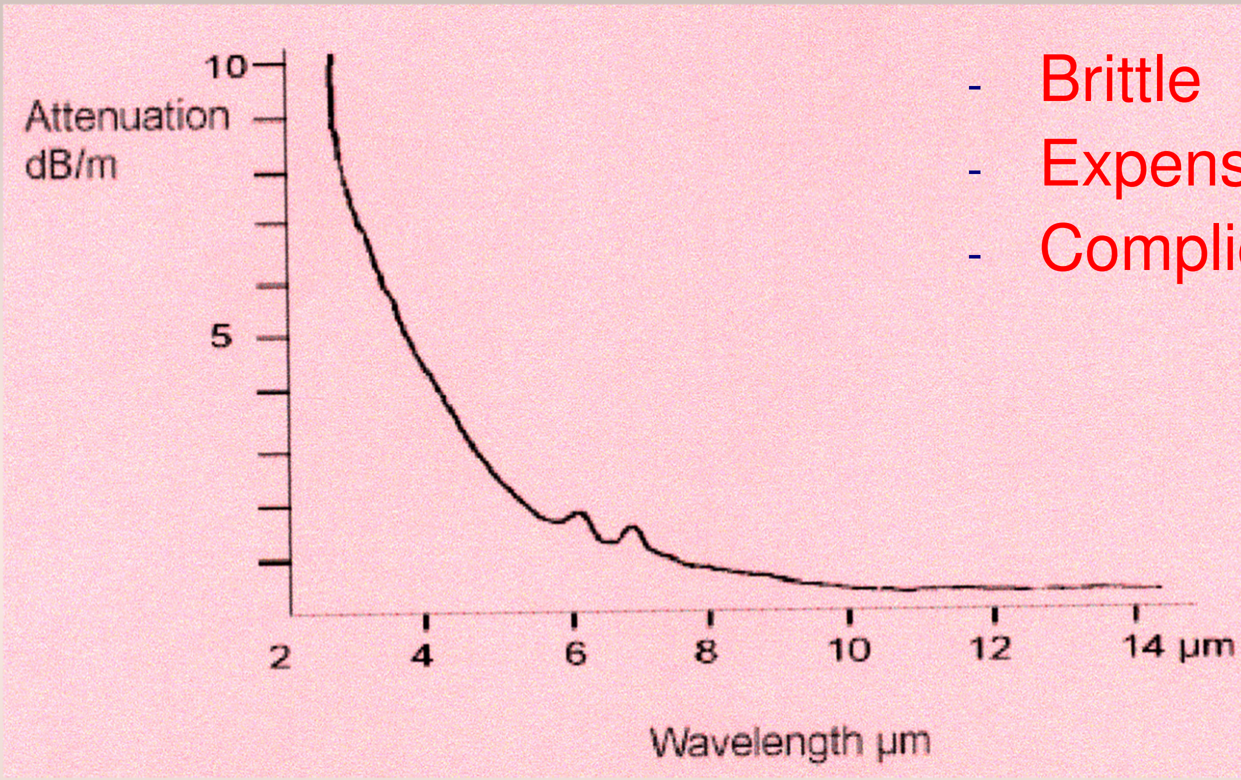
- silica fibers - SUPRASIL $n_{200\ nm} = 1.55$ [ceramoptec.de, OceanO, IPE …]
- planar silica, crystalline CaF_2 (MgF_2) – [edmundoptics, technicalglass …]

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

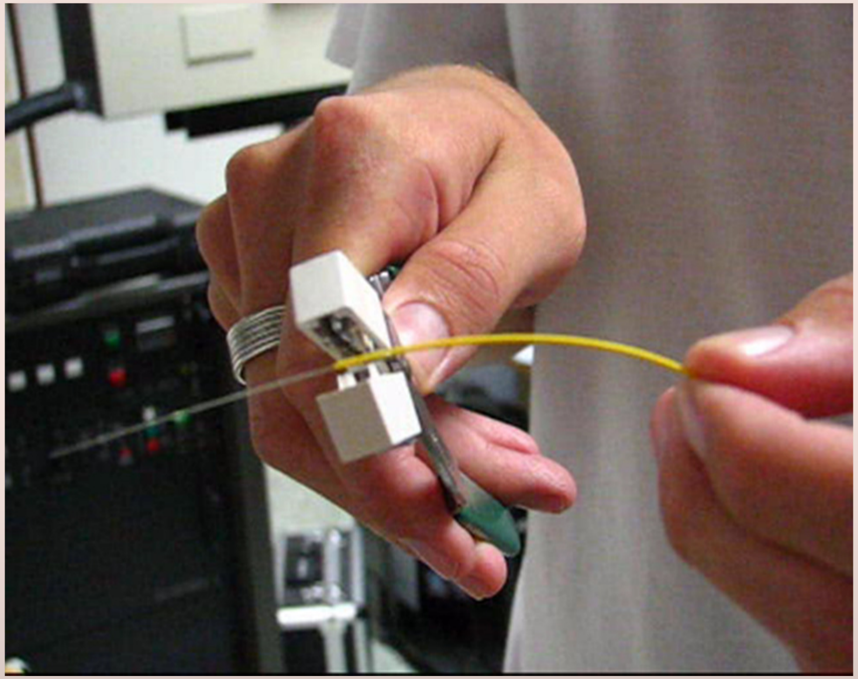


- Brittle
- Expensive
- Complicated

- 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]

Optical fiber decladding

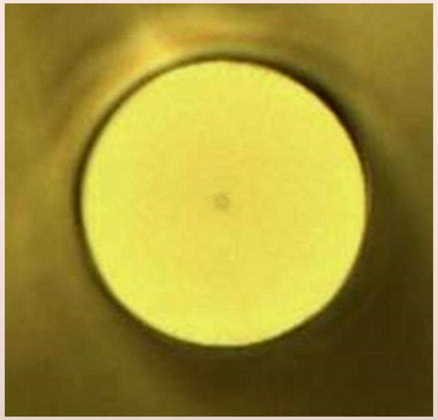
- mechanically
  – stripping tool (pliers) :
- chemically - leaching
  - trichloethylene (acrylates)
  - HF acid (siloxanes)
  - exposition – seconds-minute



Optical fiber cleaving

- primitively :
  scissors, knife, razor blade (suitable for POF)

- more primitively: fire

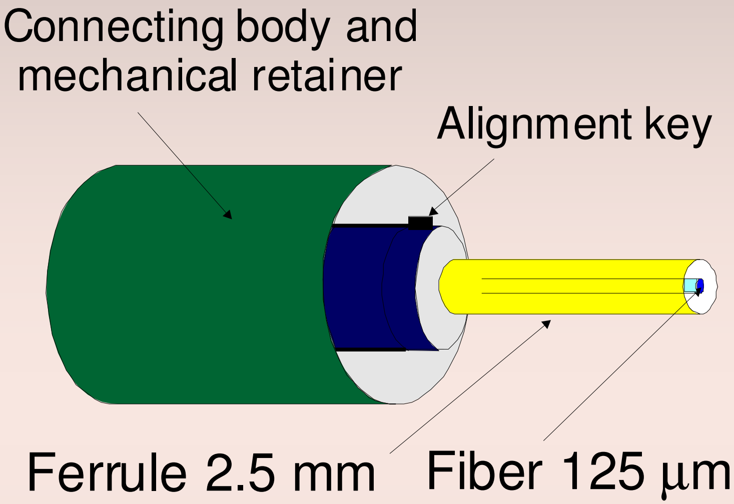


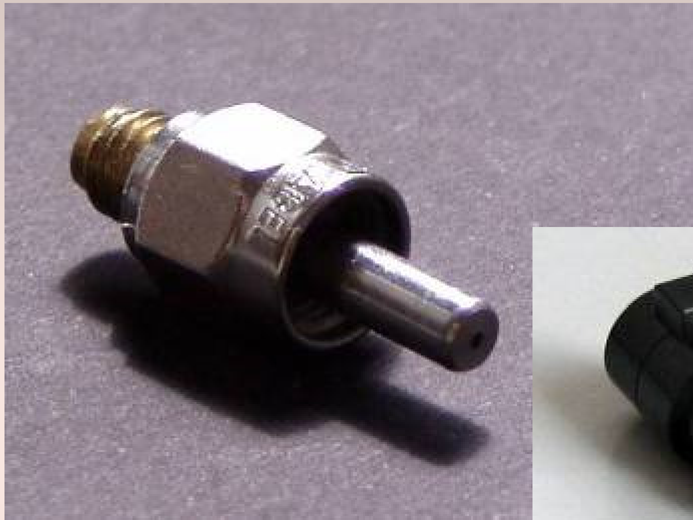
- correctly :
  - **fiber cleaver** FK11 (York Tech, Ericsson)

Optical fiber splicing

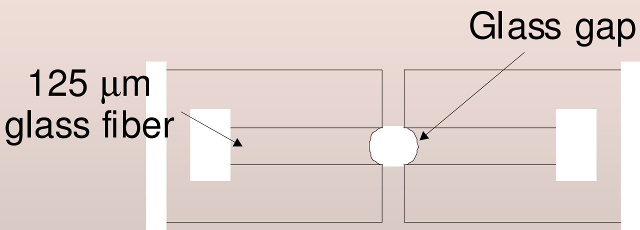
Splicing device (Fujikura, Ericsson), losses ~0.1-0.2 dB

Optical fiber connectoring

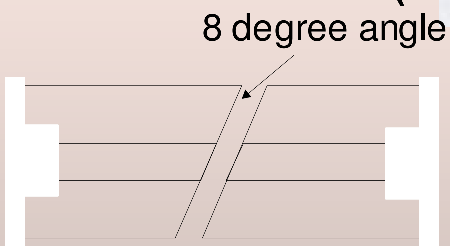




Fiber Connection (FC)



Angled Fiber Connection (APC)



- Types : FC, SMA, APC …; losses ~0.2 dB

Optical fiber connectoring

Types : SMA, FC, APC (Angled Physical Contact)

SUMMARY

1. Fiber technology : preparation of structures of high preciseness from materials of ultra-high purity (impurities in ppbs only).
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

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