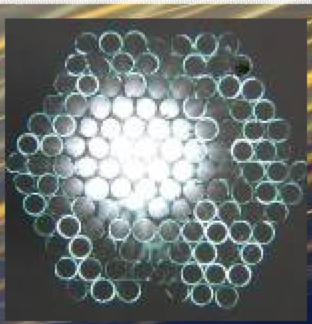
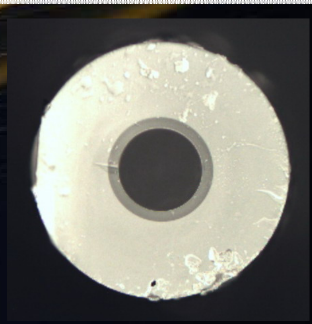
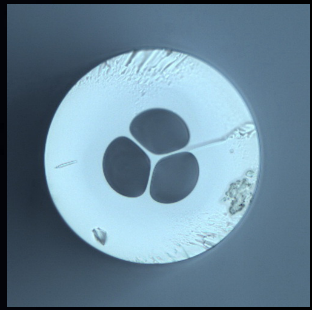
Academy of Sciences

Institute of Photonics and Electronics v.v.i.

Technology of Optical Fibers

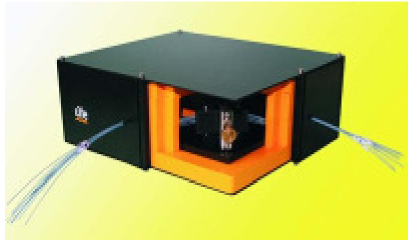
www.ufe.cz

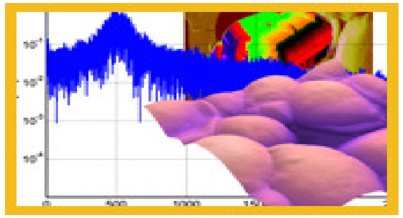



Institute of Photonics and Electronics

Prof. Jiří Homola
Head of UFE





<u>FUNDAMENTAL RESEARCH</u>

Optical Biosensors (SPR Homola)

Fiber Lasers and Non-linear Optics (Honzatko)

Nanomaterials (SIMS Lorincik)

Bioelectrodynamics (Cifra)

National Time and Frequency Standard (Kuna)

Outline

- Intro

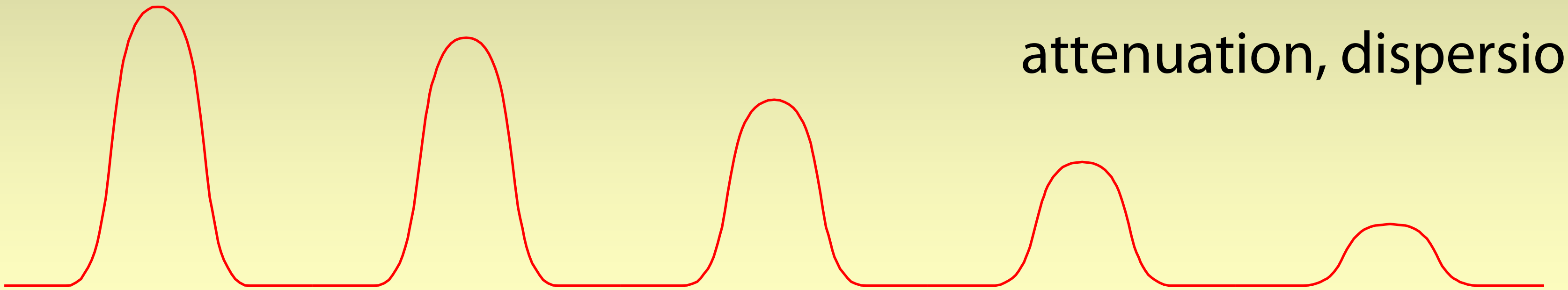
- **Optical fiber purity & technologies**
- Application : - telecommunications
  - fiber amplifiers and lasers
  - fiber sensors
- Optical fibers - materials and structures
  - processing and accessories

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]

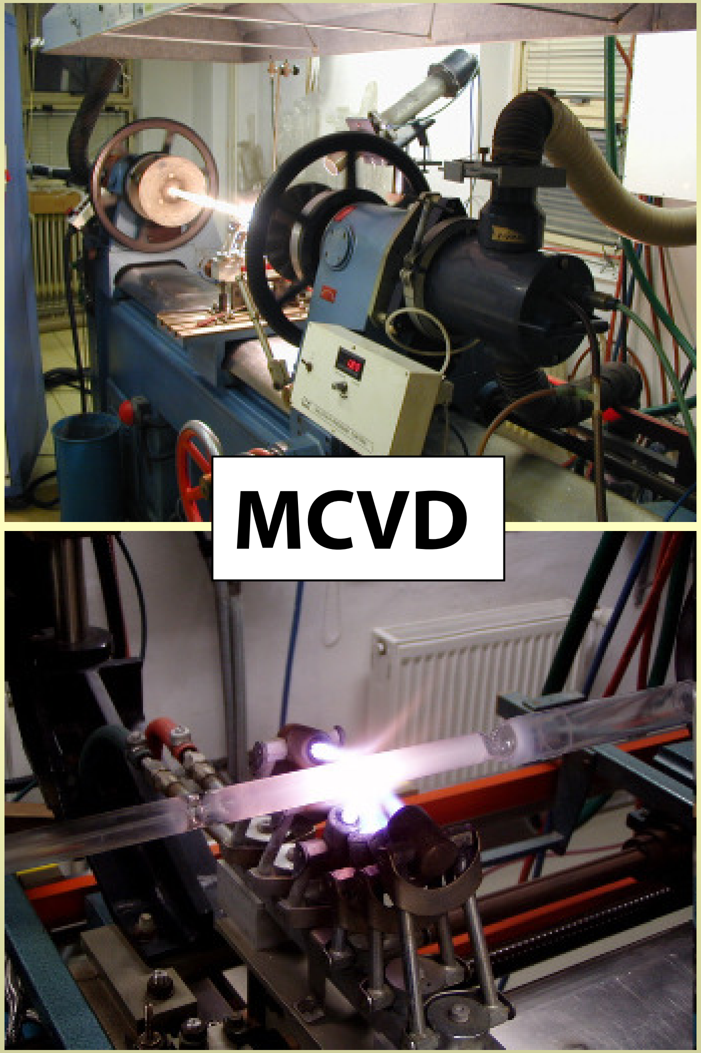
% – 10^{-2}

ppm – 10^{-6} (parts per million)

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

Ultra-pure technologies - CVD !

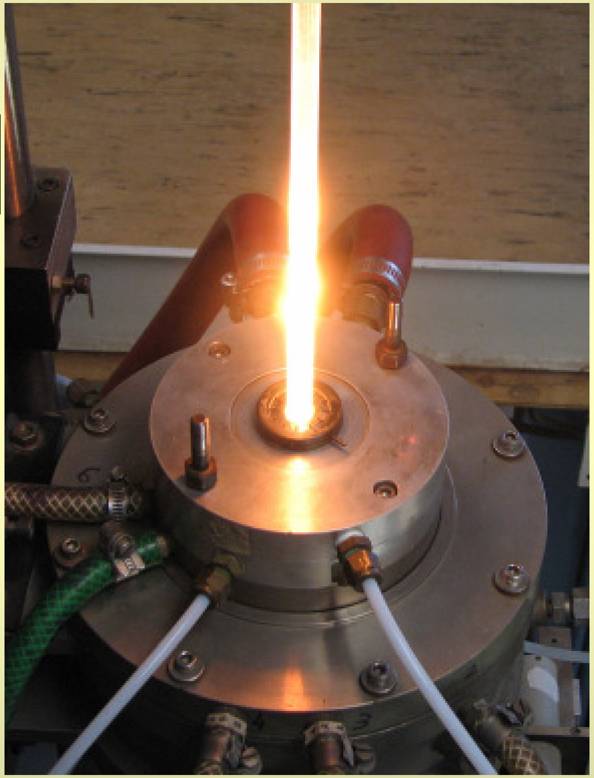
Optical fiber preparation



MCVD

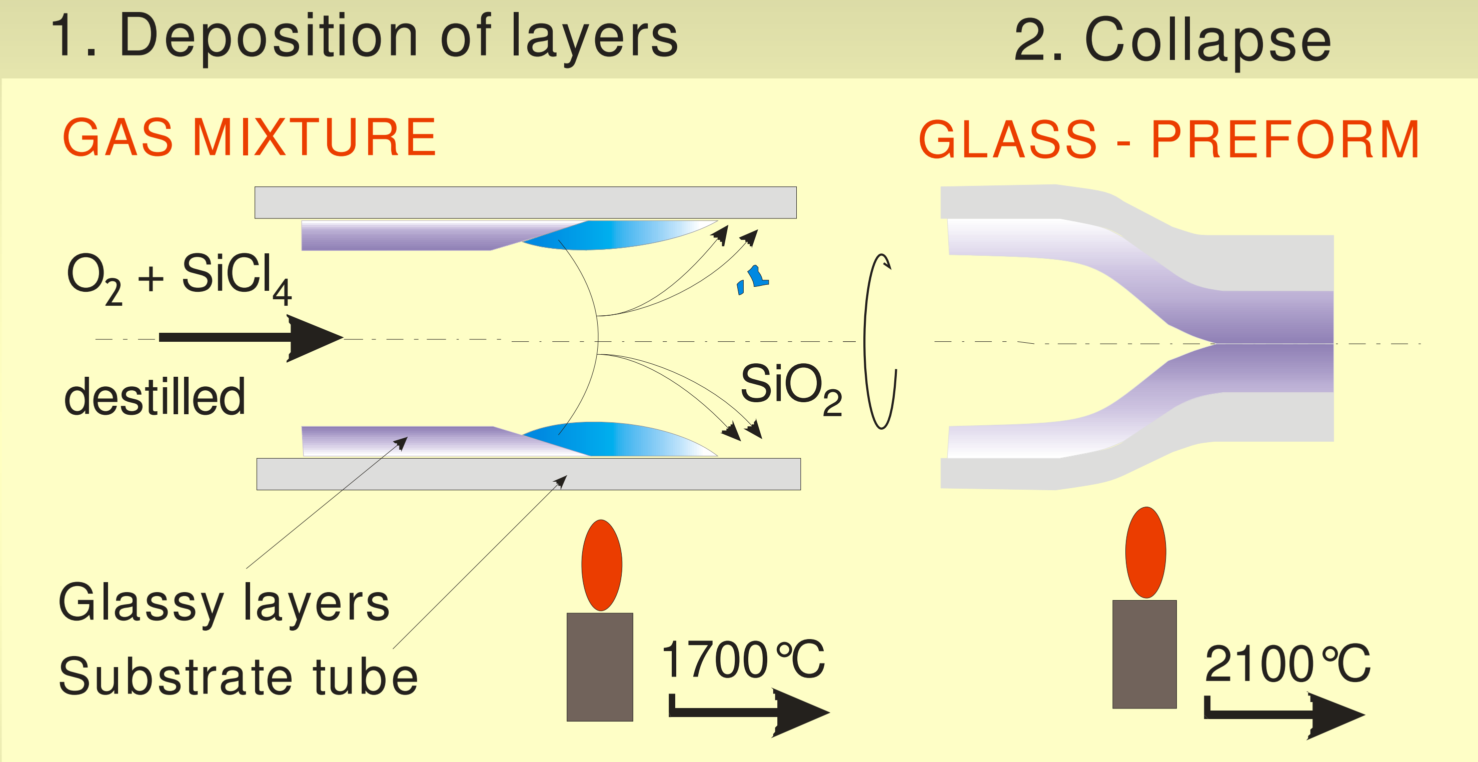
1. Preform

2. Fiber drawing



Preform preparation

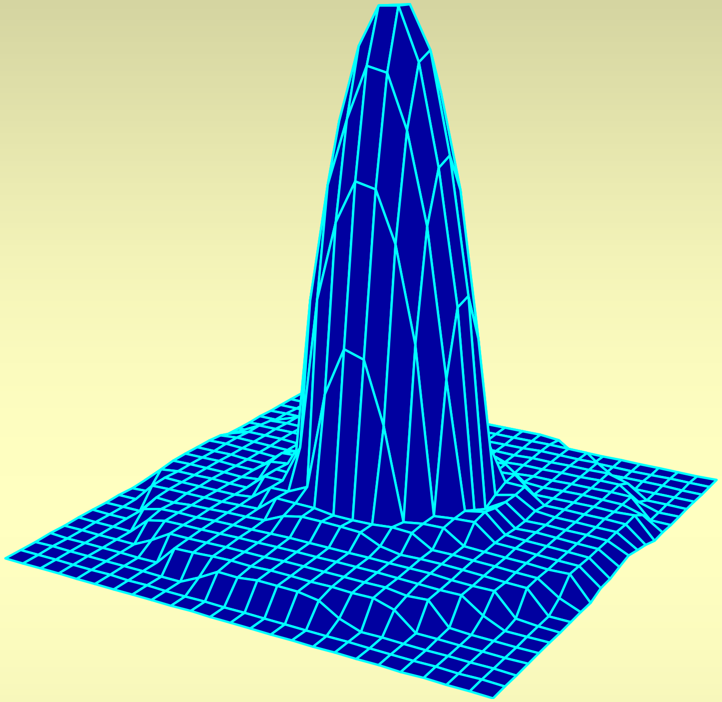
MCVD – (Modified) Chemical Vapor Deposition



- 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

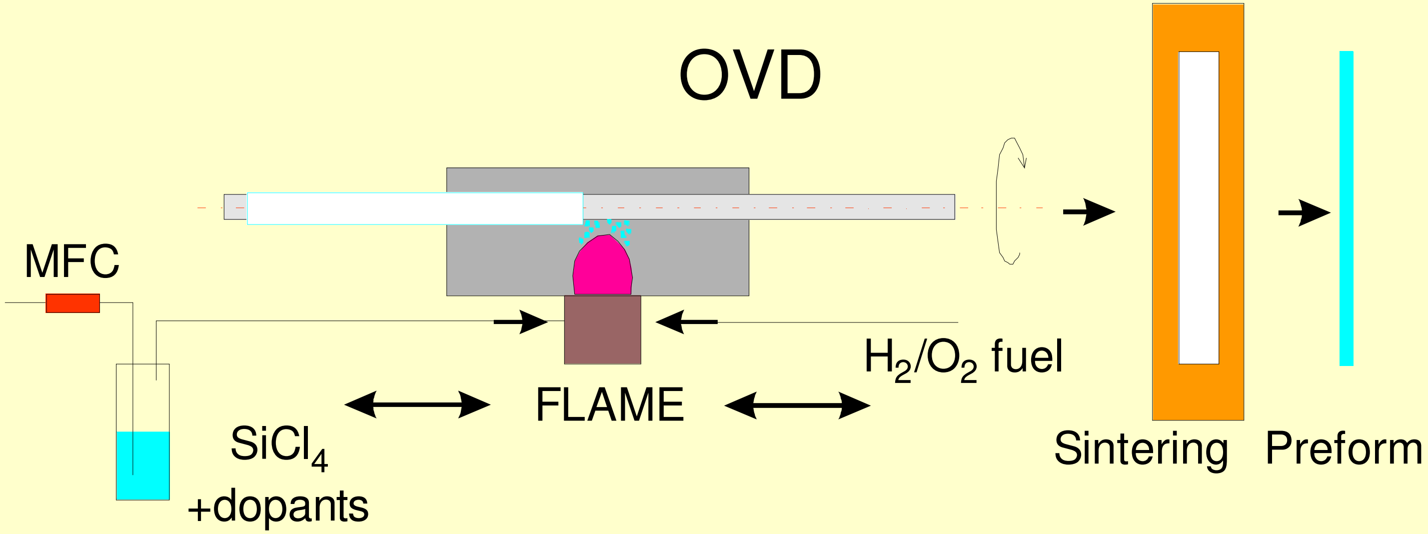
Microphoto of cross section of produced preform

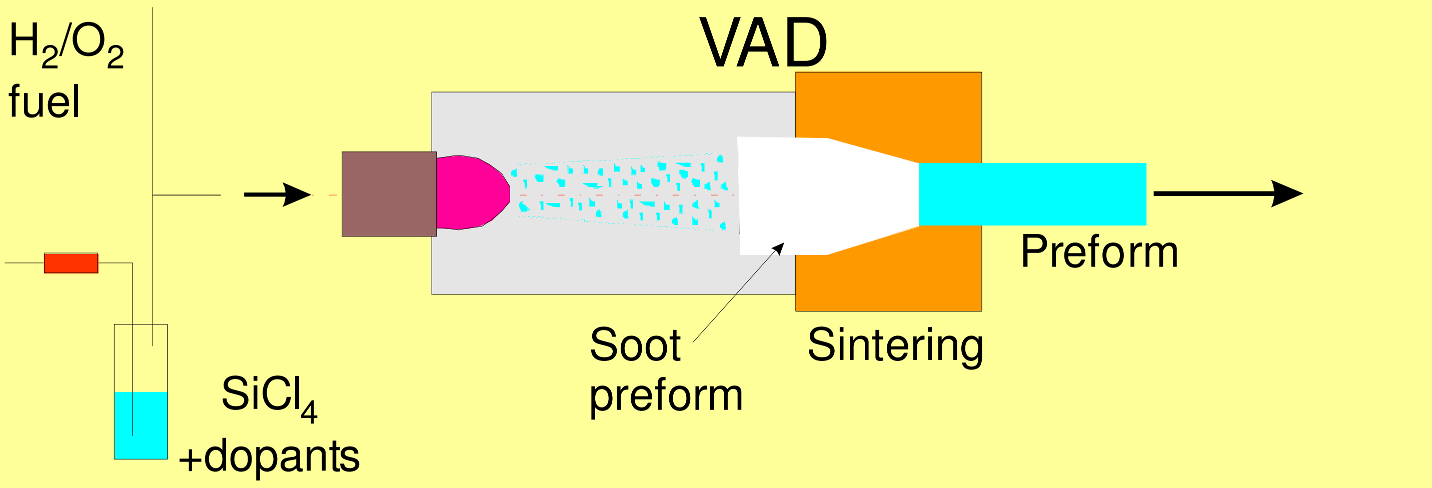


Tomography of the refractive-index profile of preform

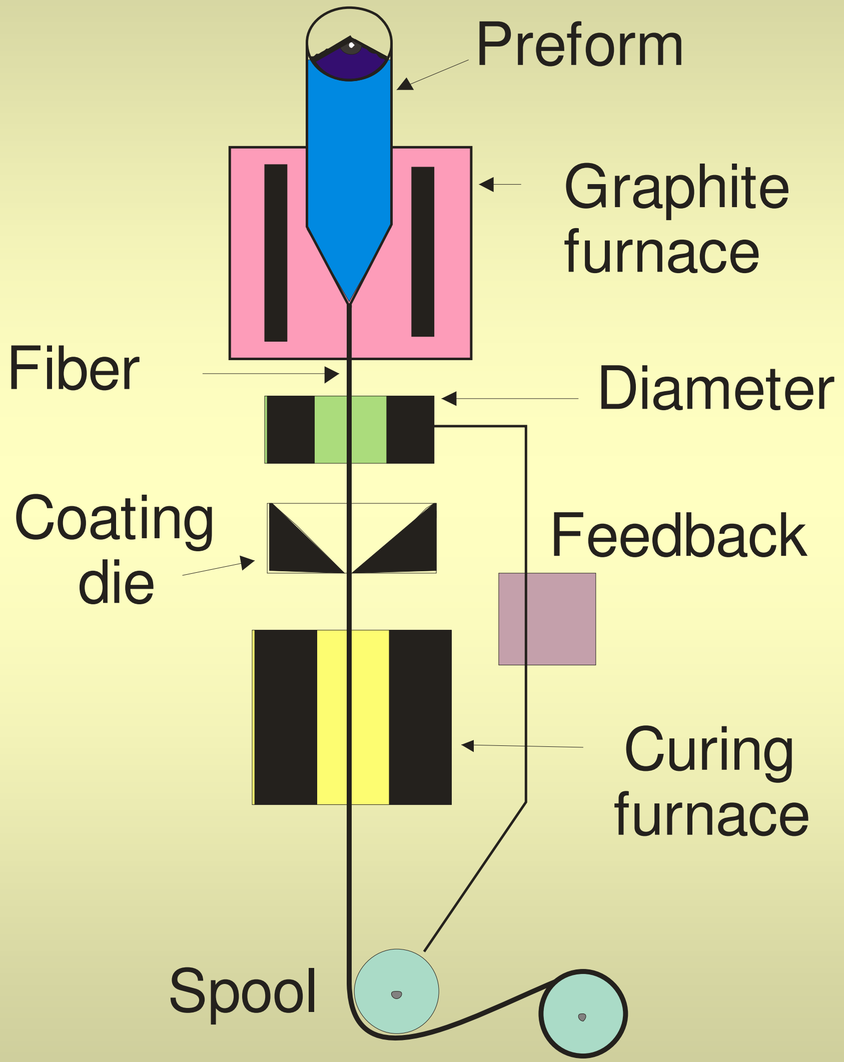
- High purity material due to FO-Optipur purity starting materials.
- High quenching rate ranging from 10^2 to 10^3 °C/s.

Other CVD Technologies





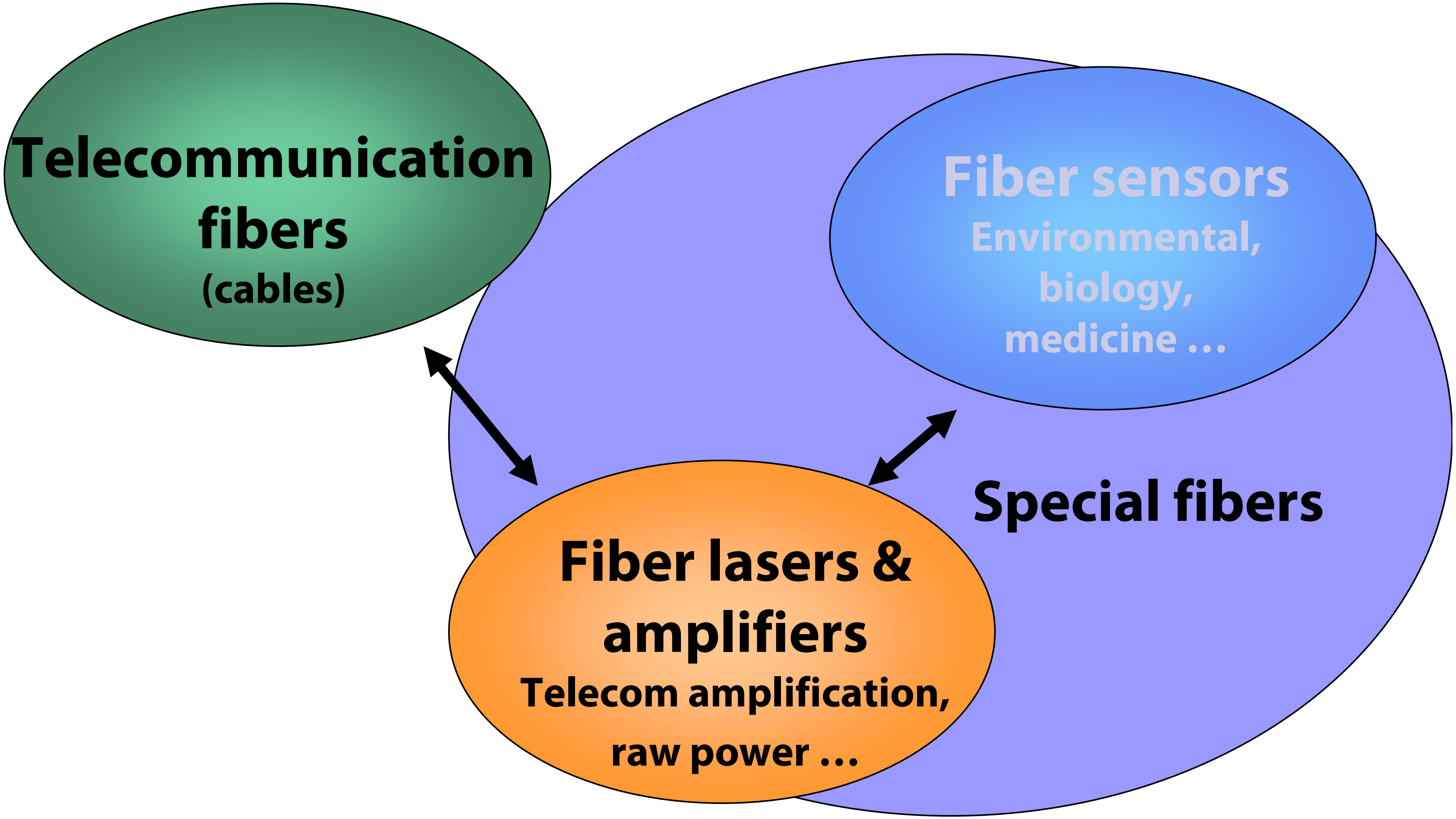
Drawing of optical fiber from preforms



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

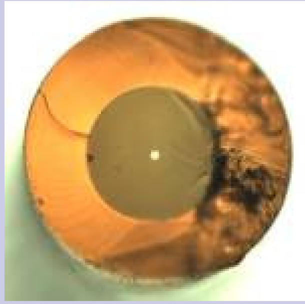
- No textile
- No thermo-insulation

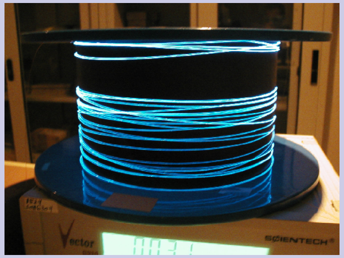
Application

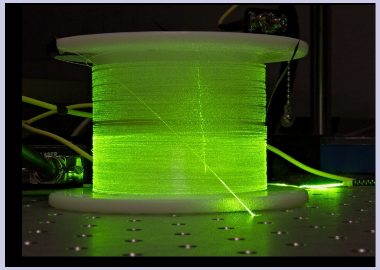


Telecommunication optical fibers

Fiber lasers and amplifiers

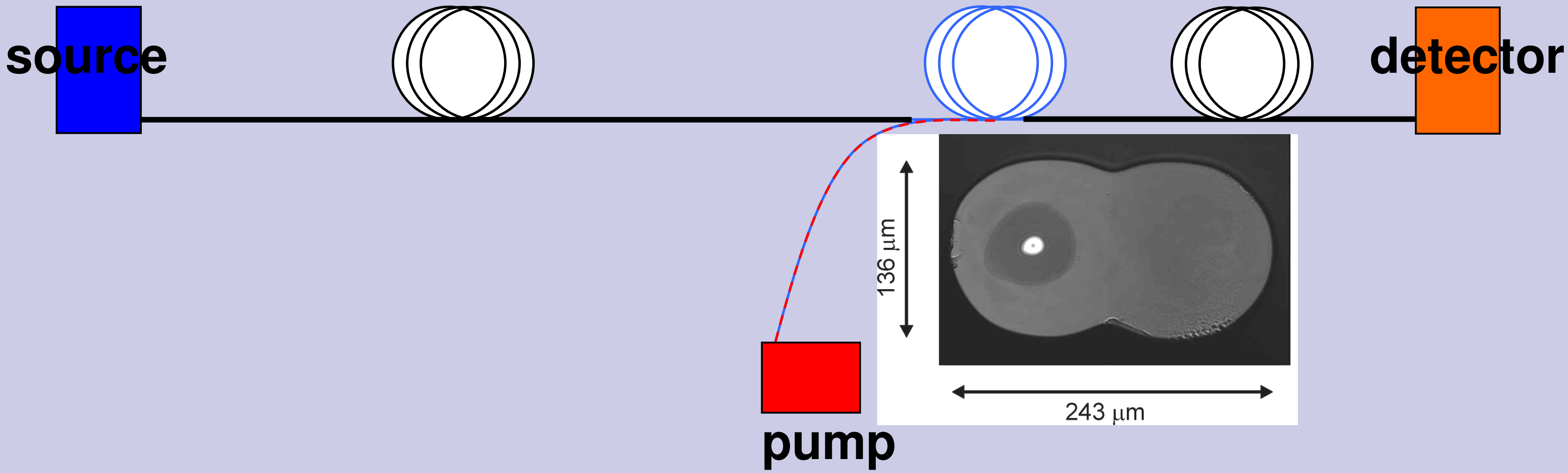






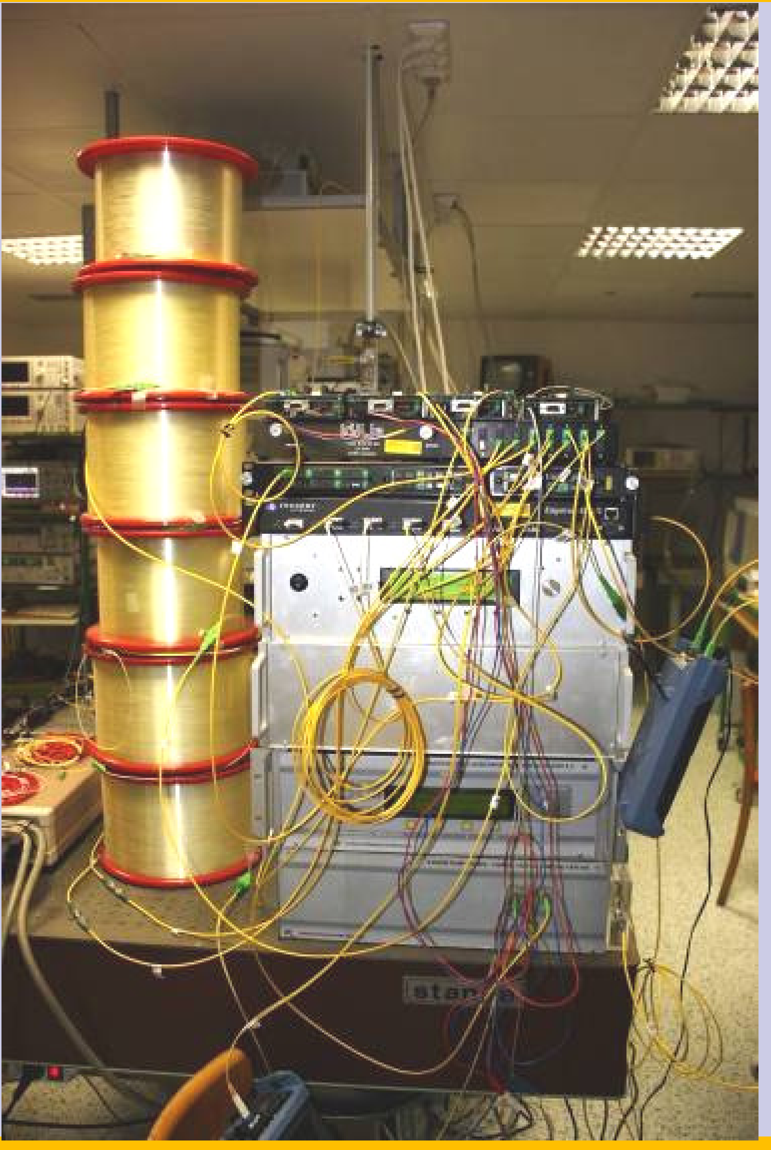
100 km fiber

Fiber amplifier



Increasing requirements on speed and ammount of info.

Telecommunication & fiber amplifiers

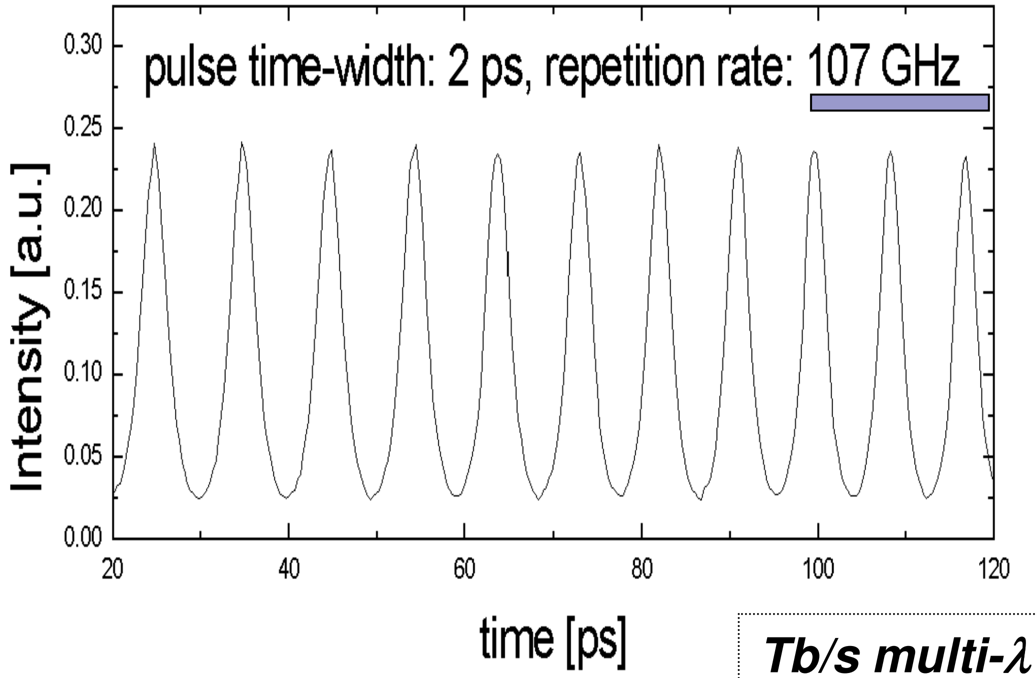


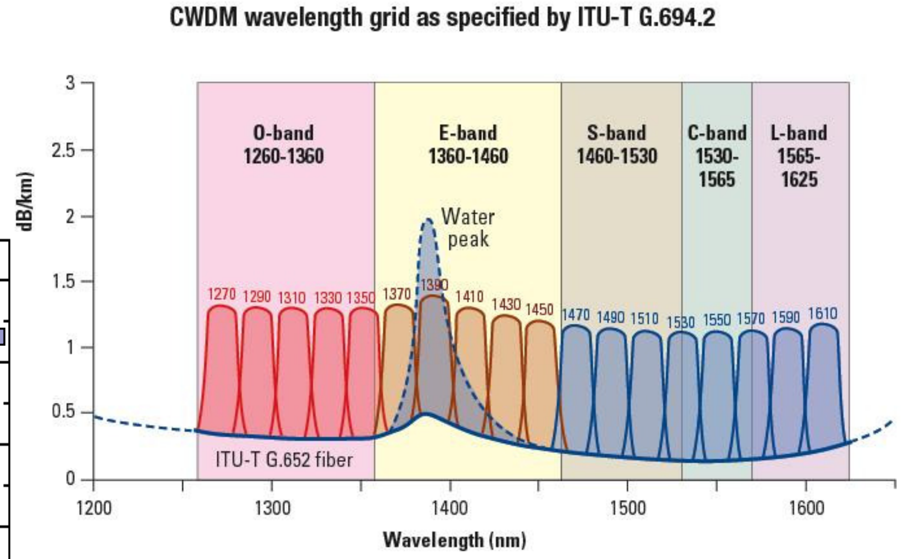
in collaboration with Cesnet : testing 200 km line

TDM

WDM

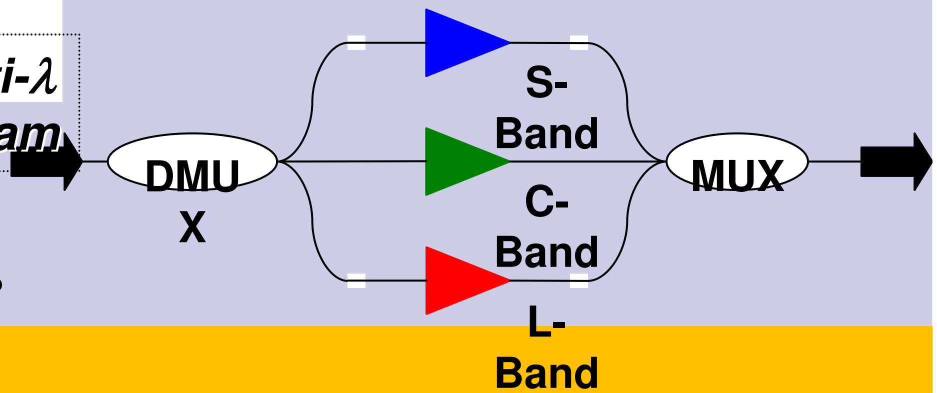
Time Division Multiplexing (TDM)





Wavelength Division Multiplexing (WDM)

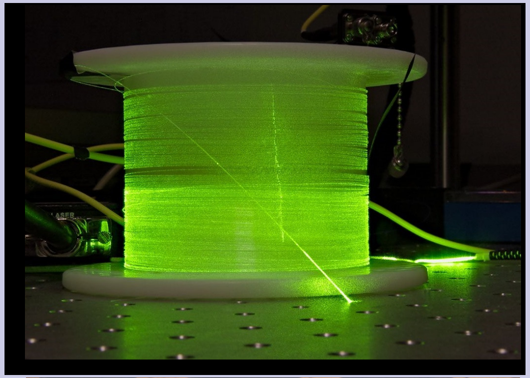
Tb/s multi-λ Data stream

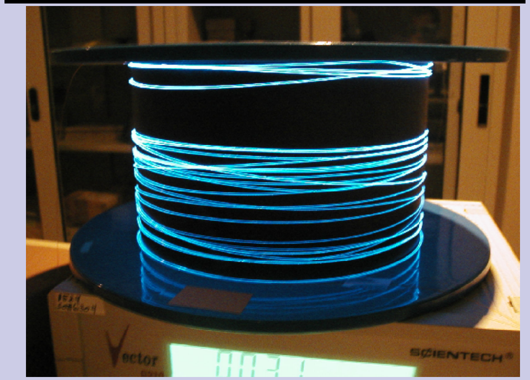


in collaboration with CTU-FJFI, LPMC Nice

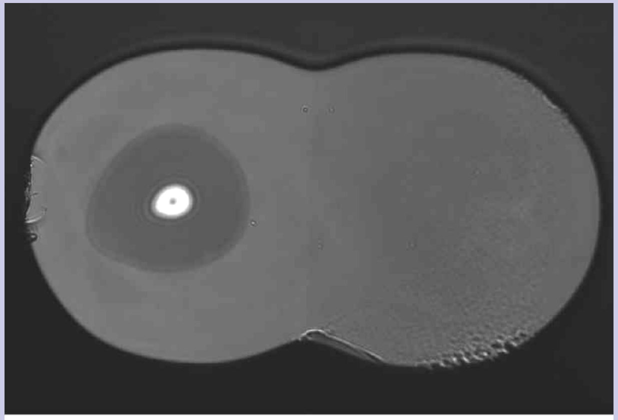
ufe

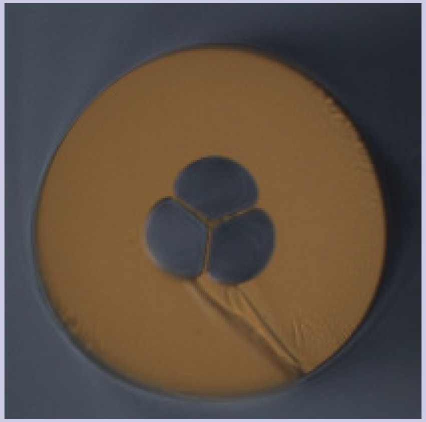
SPECIAL OPTICAL FIBERS
for fiber lasers & amplifiers





Yb/Er, Tm -doped

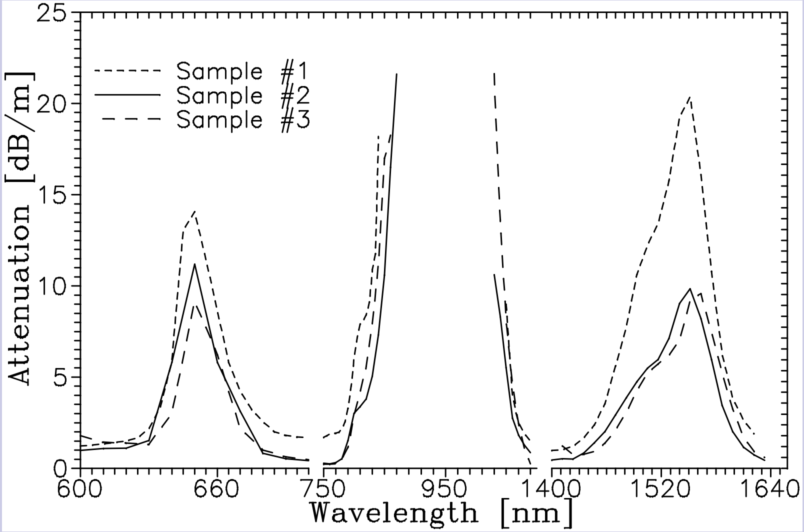


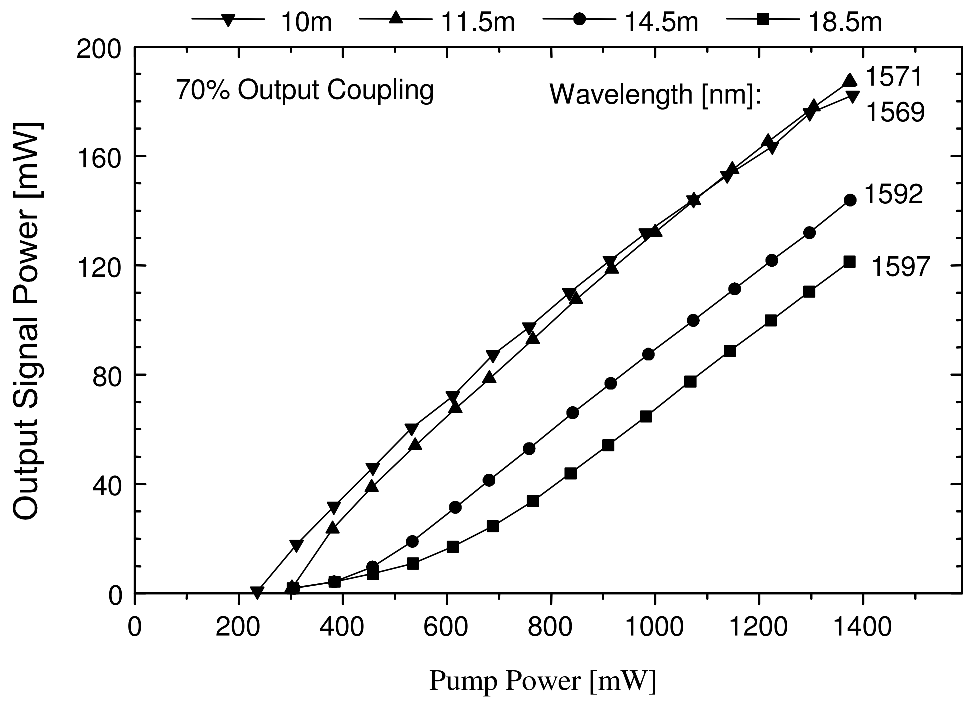


Double-clad (DC)
Twin-core (TCF)
Microstructure (MSF)

Er/Yb -doped fibers for soliton fiber lasers

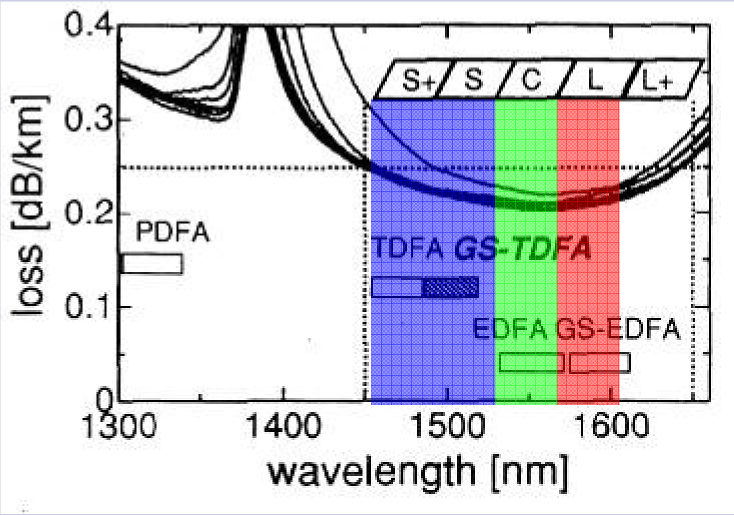
- Technol. challenge : special optical fiber efficiently operating at ~1550 nm and suitable for pumping at 1064 nm (mini-YAG). Er/Yb-P_2O_5-Al_2O_3-SiO_2 fiber

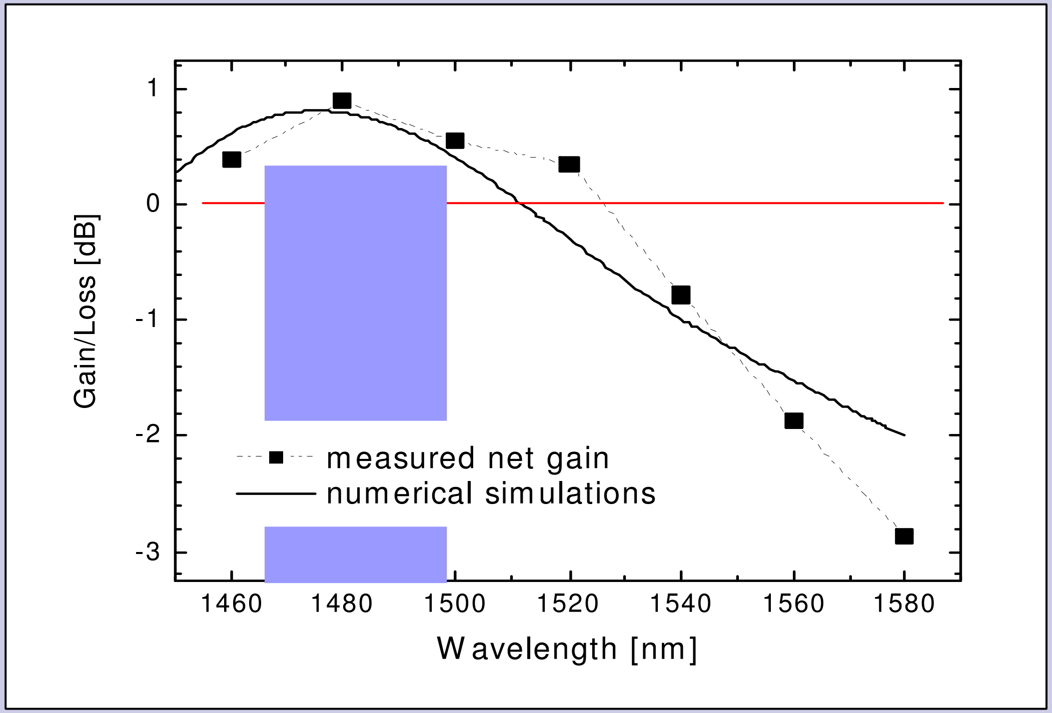




[I. Kasik, Pure Appl. Opt. **7** (1998) 457-465], [I. Kasik, Proc. **SPIE 2777** (1995) 71-79]

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

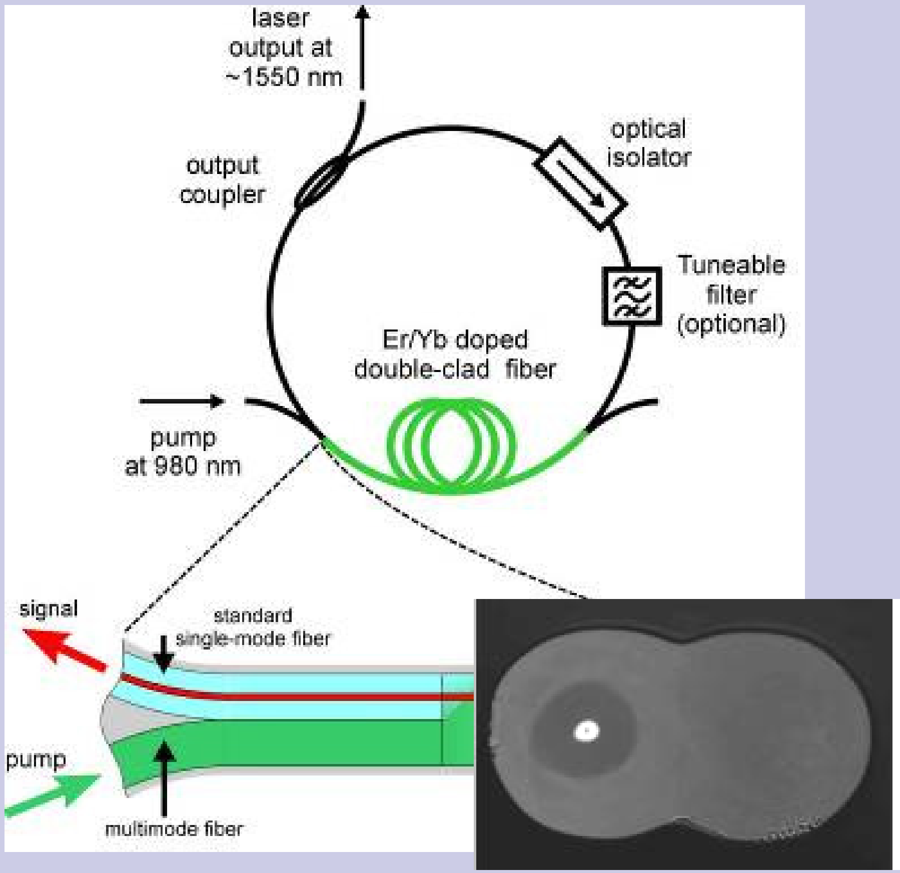


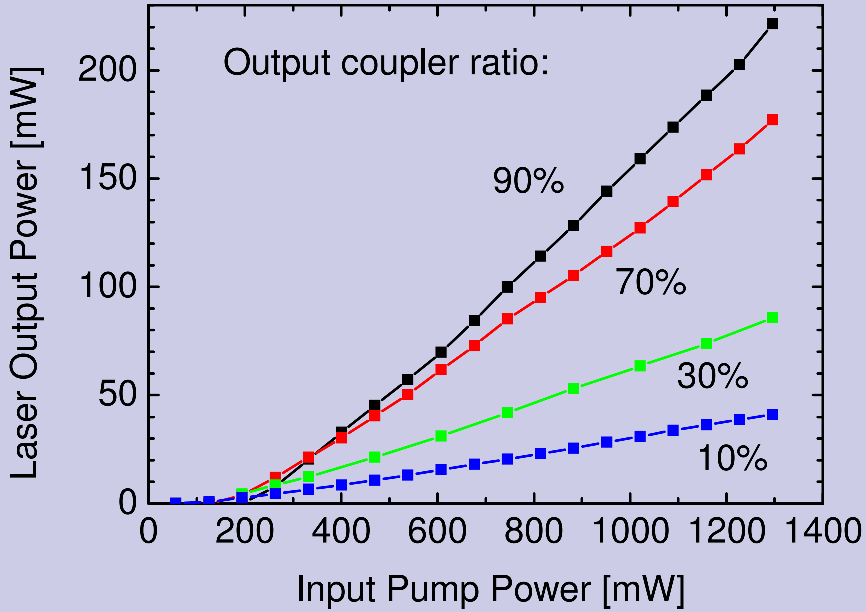


Non-optimized fiber parameters (low NA, low Tm^{3+} concentration), longer lifetime required.

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

Er/Yb -doped DC fibers

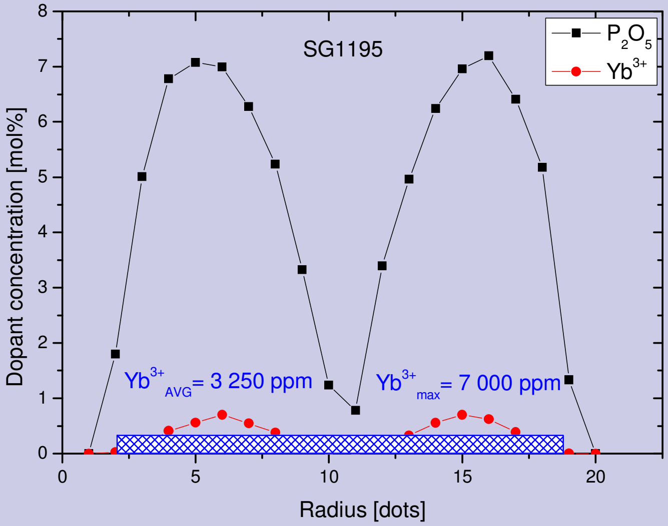


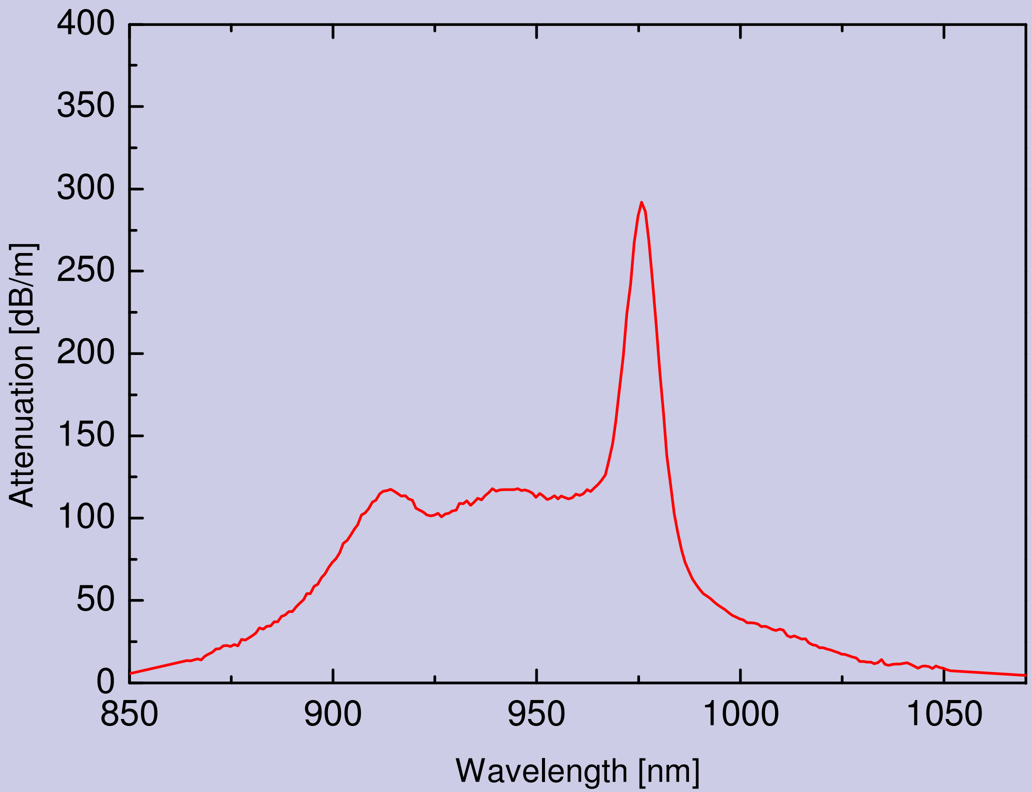


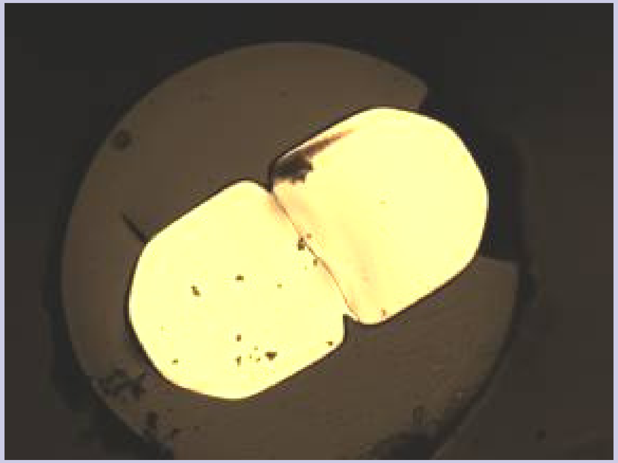
PCE 19 $\longrightarrow$ 40%

[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 fibers : Yb^{3+}-P_2O_5-SiO_2





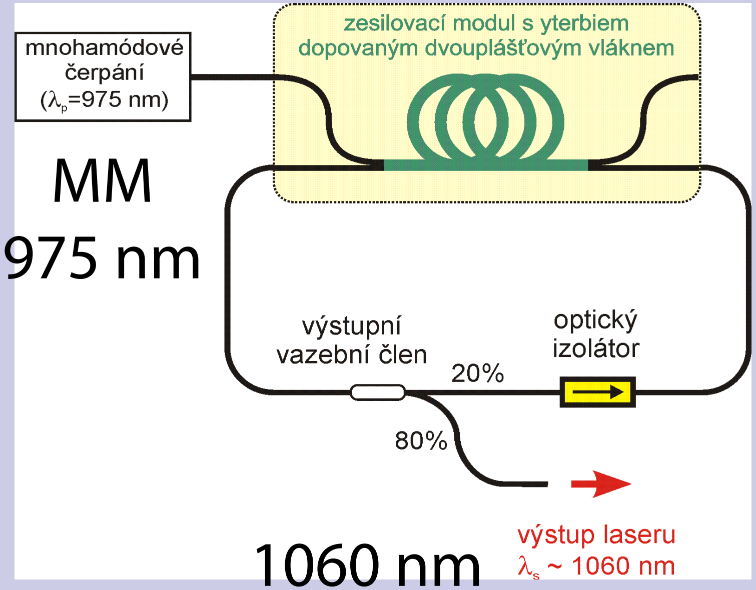


Technol. challenge : high Yb and P_2O_5 conc.;

P_2O_5 or P_2O_5 - Al_2O_3 good photodarkening

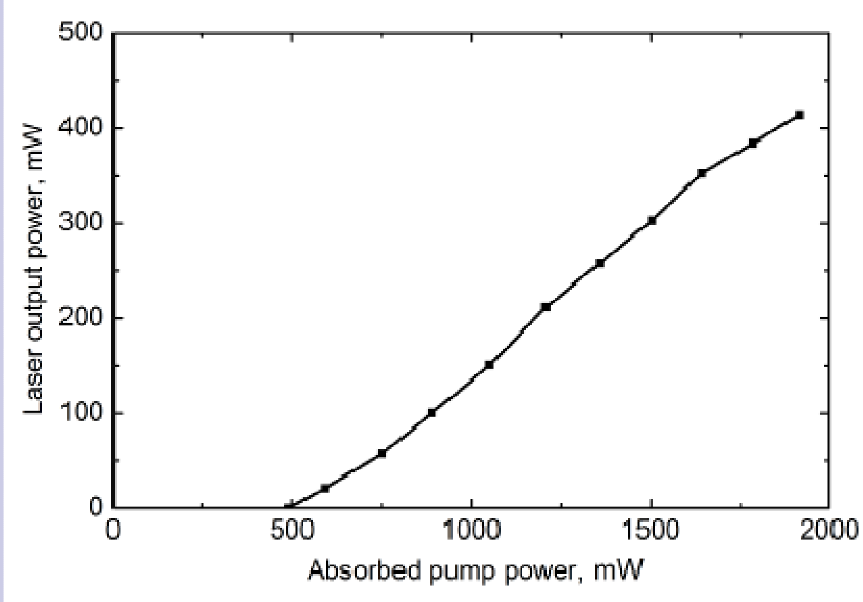
P_2O_5 max 7 mol%, Yb^{3+} 3 250 ppm

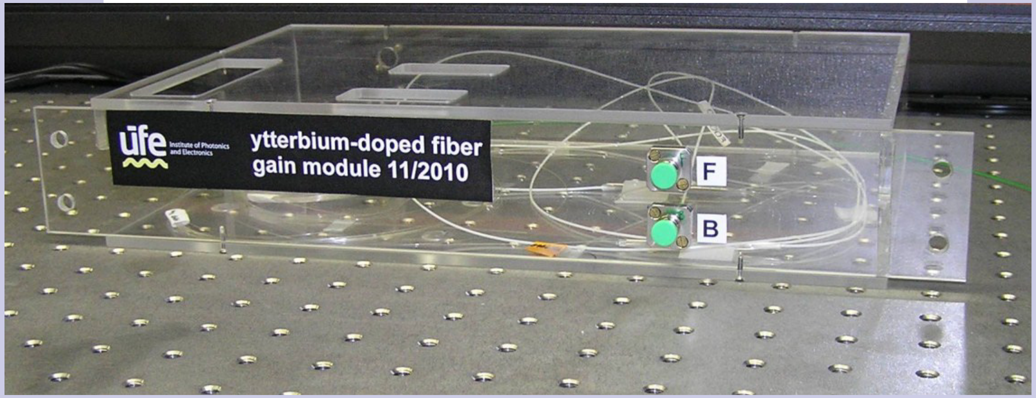
Yb -doped DC fiber amplification module



MM
975 nm

1060 nm



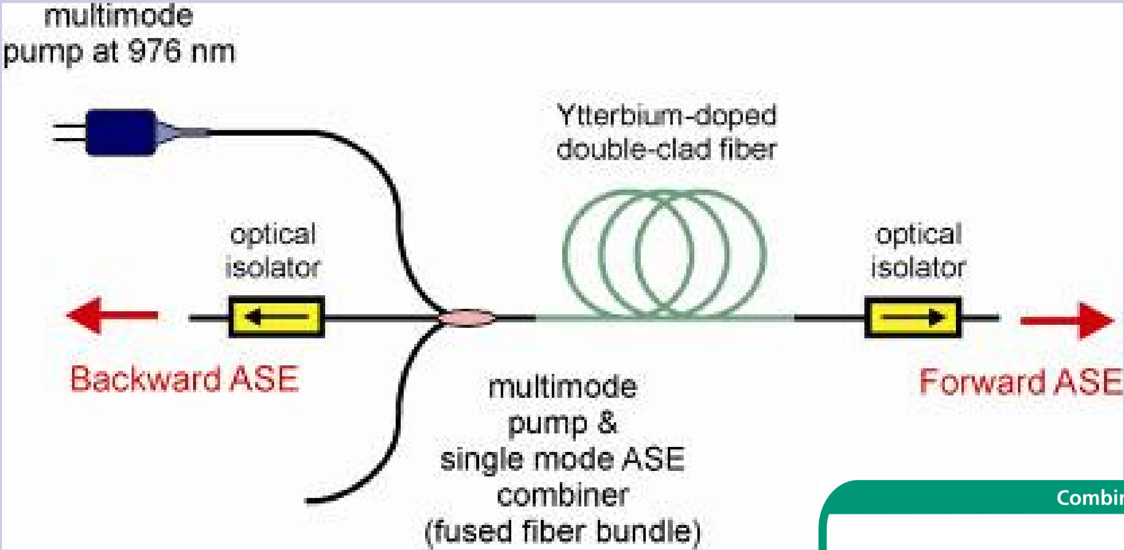


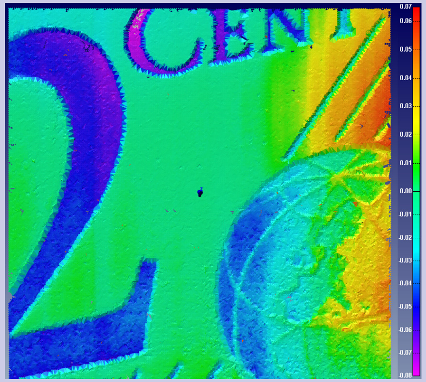
[A. Novozamsky, Proc. SPIE 7746, 2010, 77461O], [Schmitt, Proc. SPIE 8082, 2011, 808228]

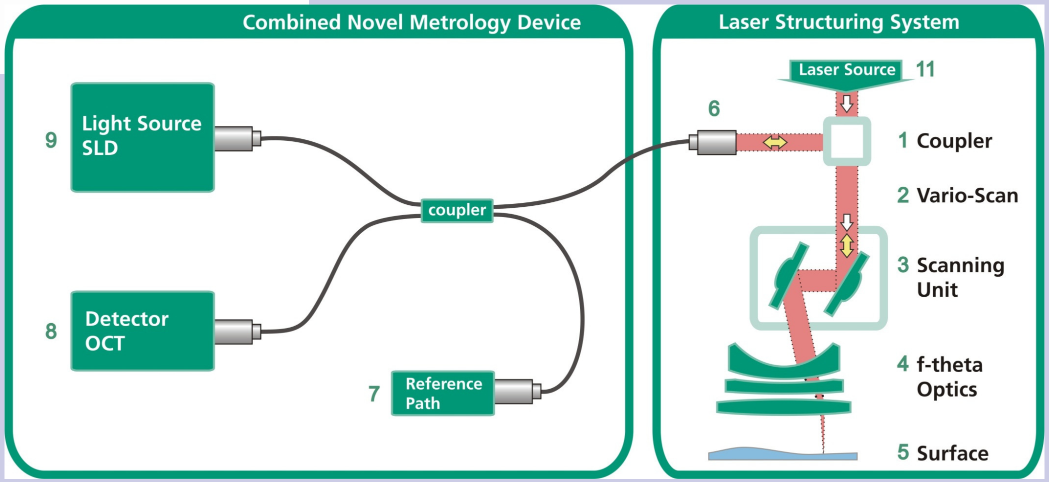
Yb –doped DC fiber ASE source

Fiber lasers in delicate applications

- **metrology of fine surfaces**

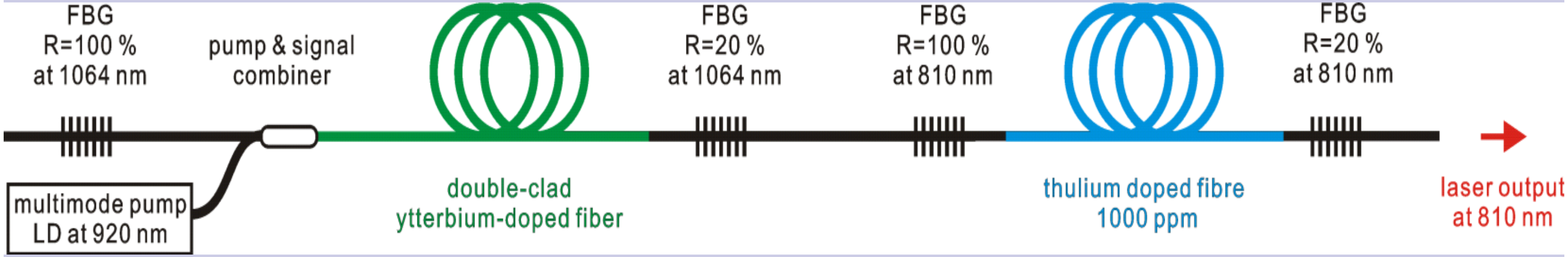


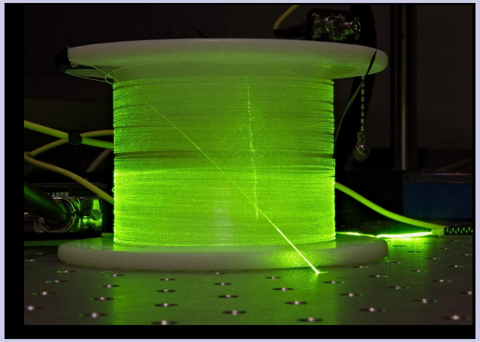


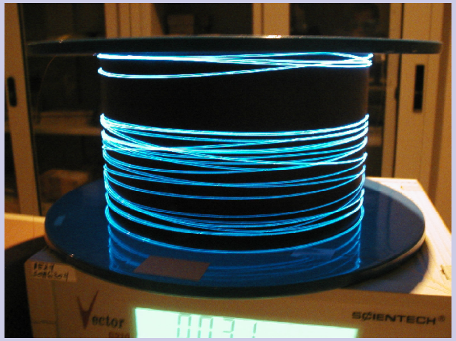


[Peterka, Proc. SPIE 8697, 2012, 869718]

Yb -doped DC fibers amplification module for Tm -doped fiber laser at 810 nm





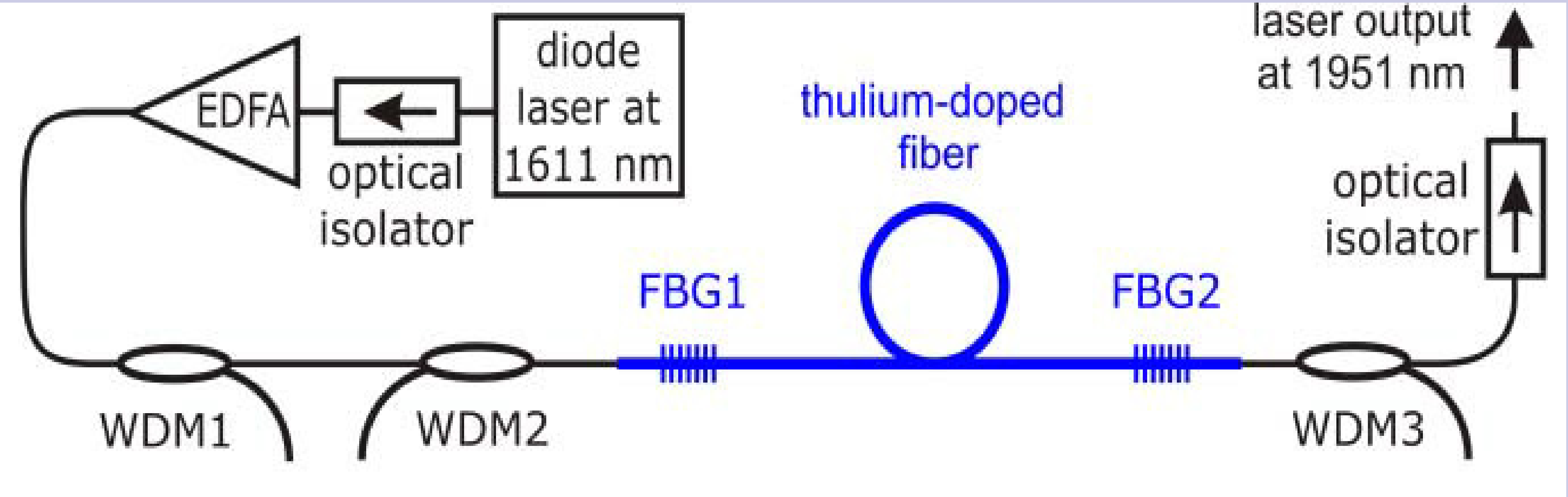


Theoretical modelling

[P.Peterka, *OPEX* **19,** 2773, 2011], [P.Peterka, Proc.SPIE **7843**, 2010, 78430A]

Monolitic Tm -doped fiber laser at 1951 nm

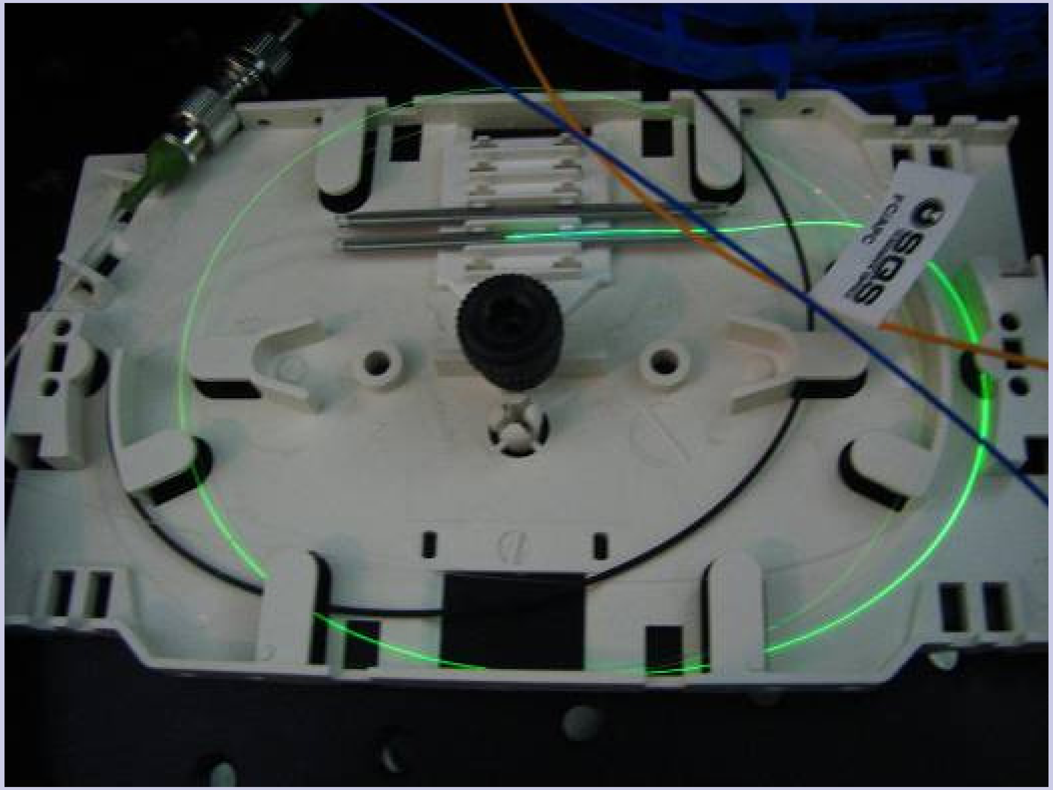
Eye-safe spectral region



* 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]

High-power fiber lasers

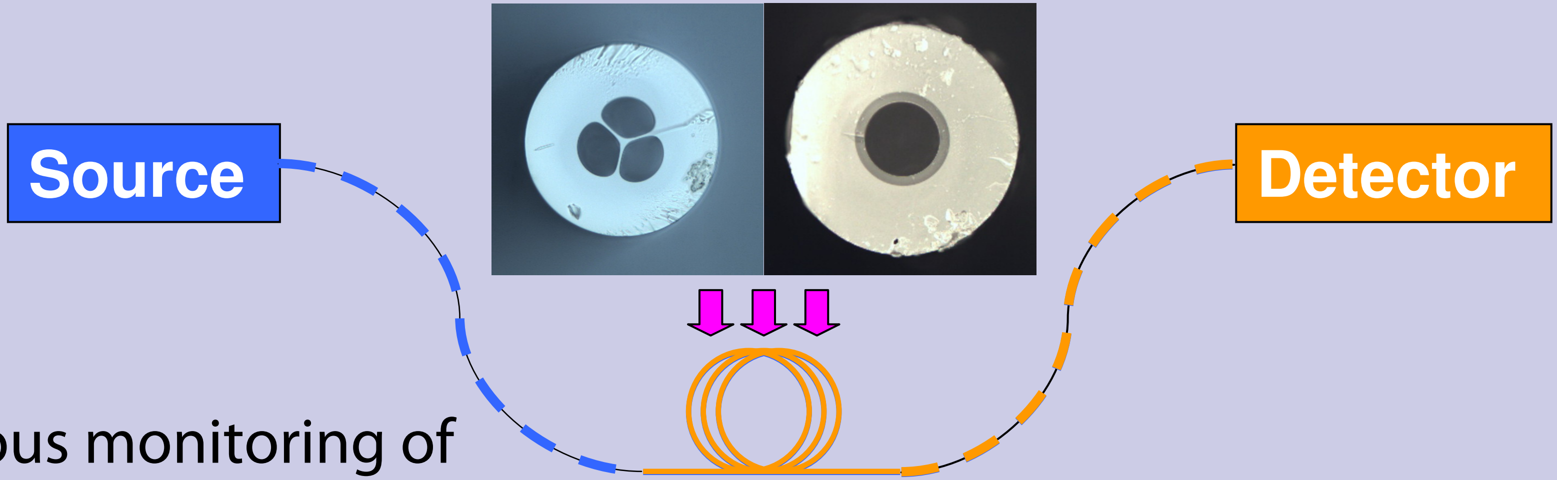


Er- fiber laser,
pulsed 197 fs,
5m rezonator
Liekki

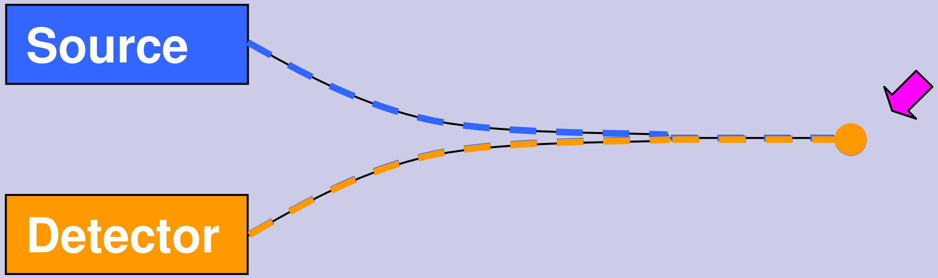
Ligth intensity	
Sun	63 MW/m2
Optical fiber	12.7 GW/m2

Welding, cutting < 2kW

Optical fiber sensors



Continuous monitoring of (bio)chemicals and their concentration.

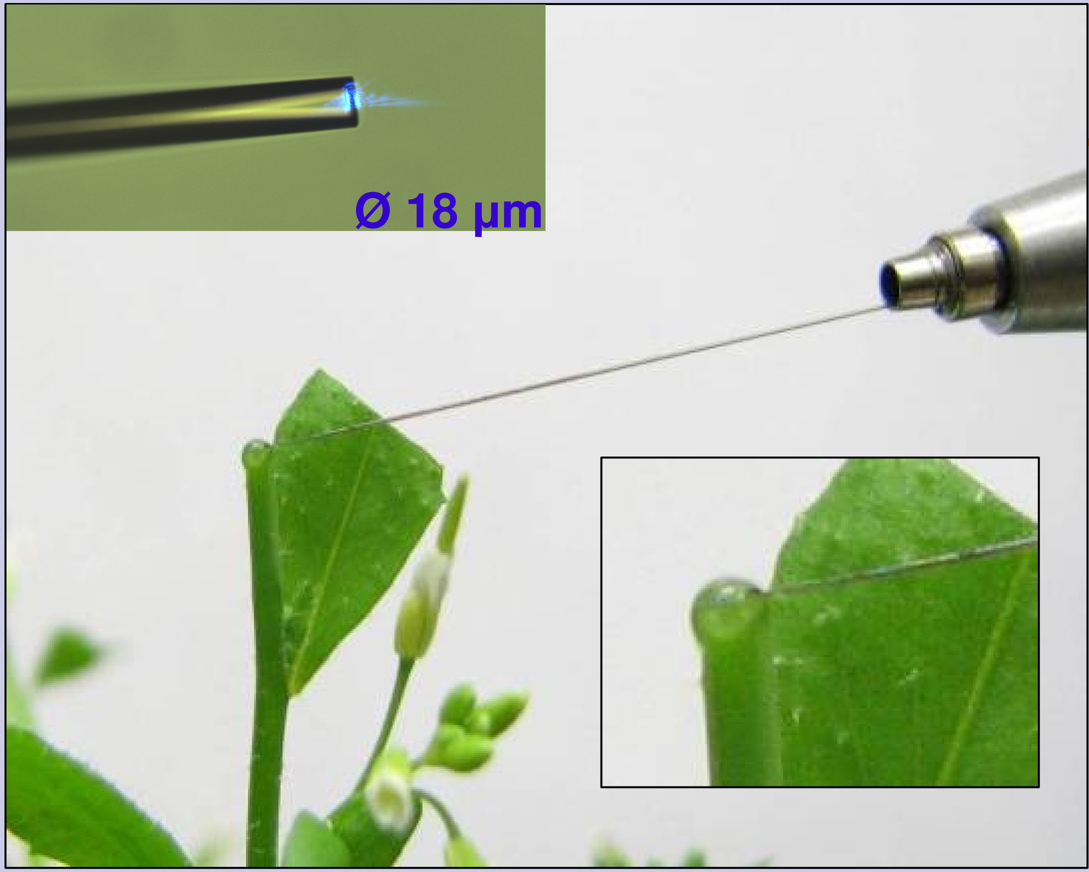


Suitable for :

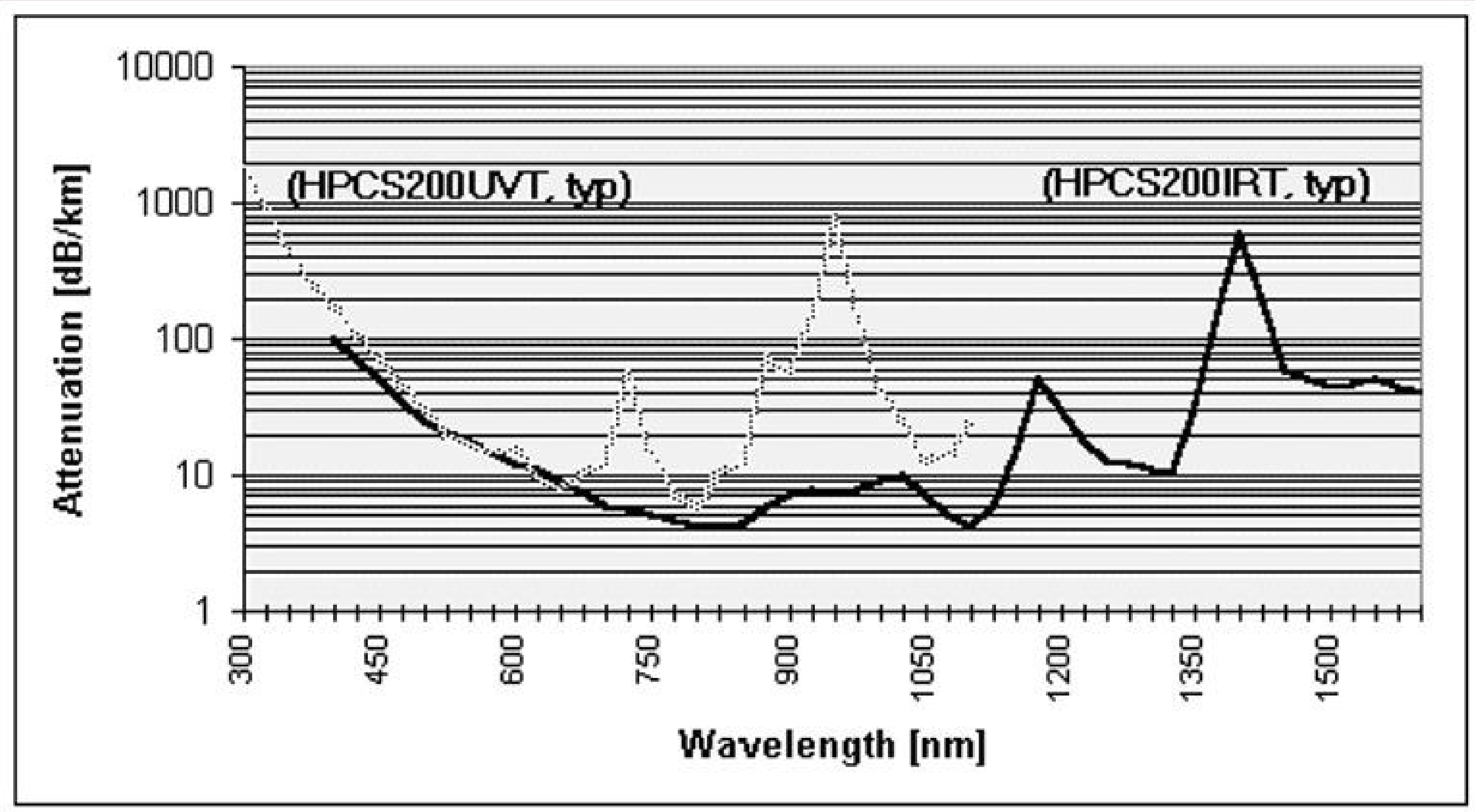
- remote sensing
- distributed sensing
- flammable or explosives
- in high-voltage areas
- human body

Optical fiber sensors

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

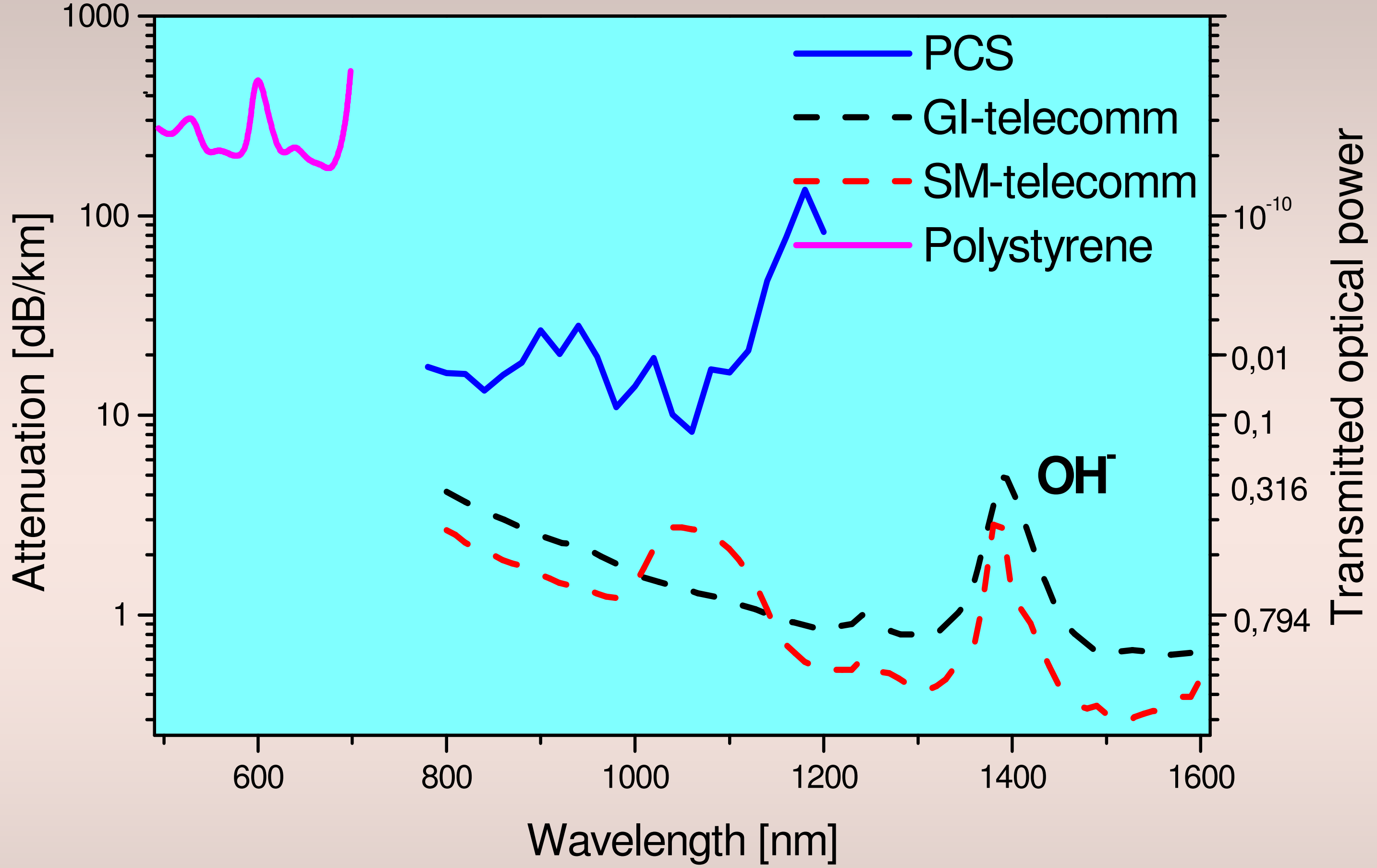


OPTICAL FIBERS – Materials - UV



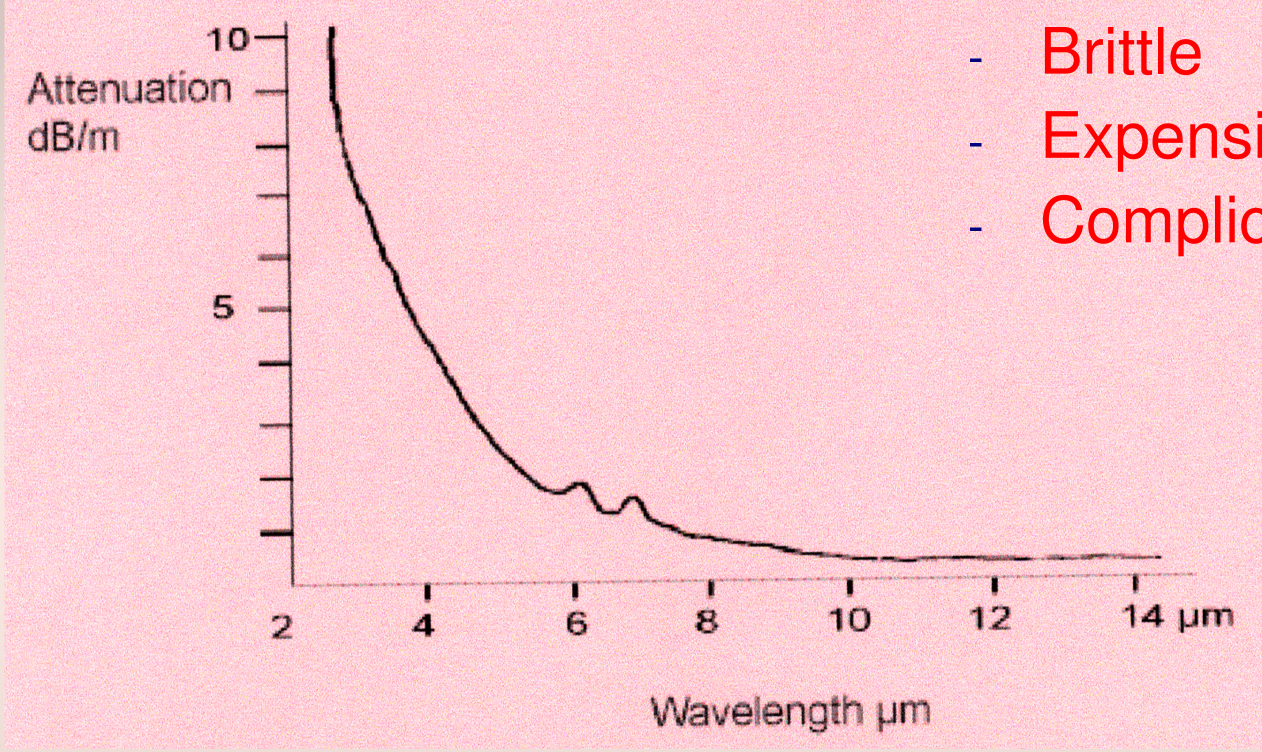
- silica fibers - SUPRASIL $n_{200\,nm} = 1.55$ [ceramoptec.de, OceanO, IPE …]
- planar silica, crystalline CaF_2 (MgF_2) – [edmundoptics, technicalglass …]

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

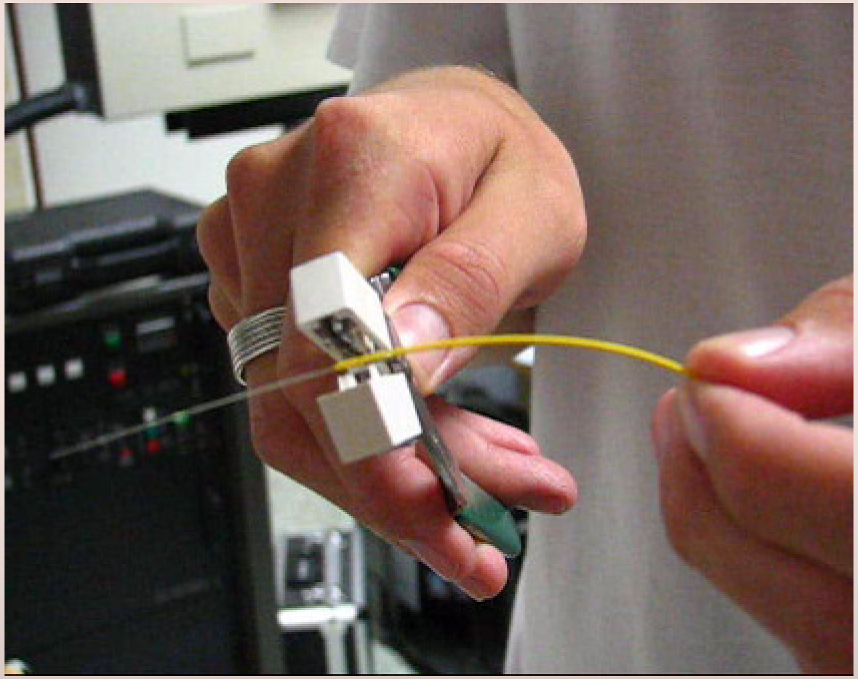


- Brittle
- Expensive
- Complicated

- 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]

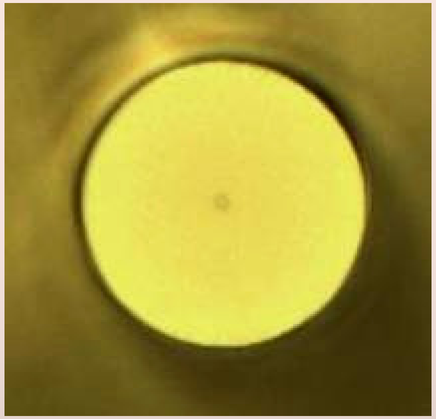
Optical fiber decladding

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



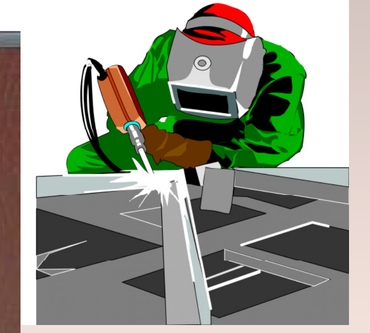
Optical fiber cleaving

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



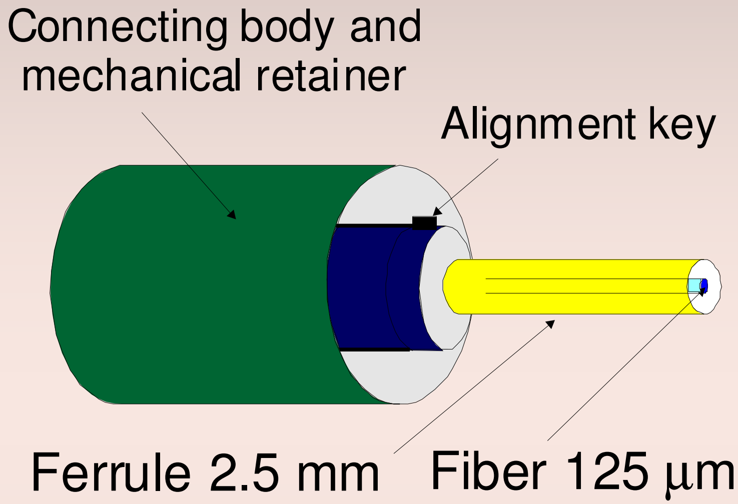
- correctly :
  - **fiber cleaver** FK11
    (York Tech, Ericsson)

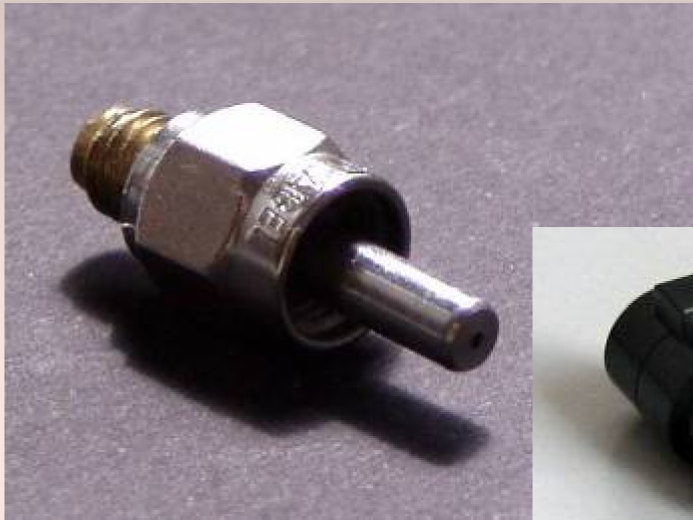
Optical fiber splicing



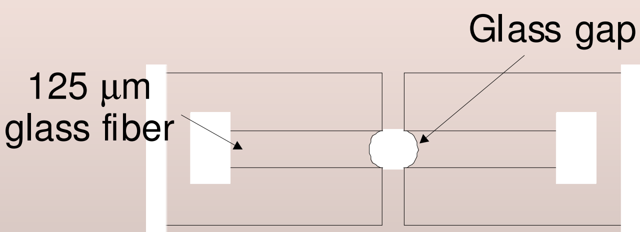
Splicing device (Fujikura, Ericsson), losses ~0.1-0.2 dB

Optical fiber connectoring

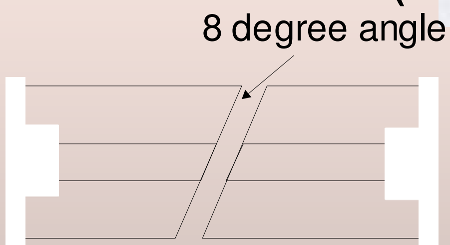




Fiber Connection (FC)



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

- **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