AKADEMIE VĚD ČESKÉ REPUBLIKY
TÝDEN VĚDY A TECHNIKY

INTERNATIONAL YEAR OF LIGHT 2015

ÚFE

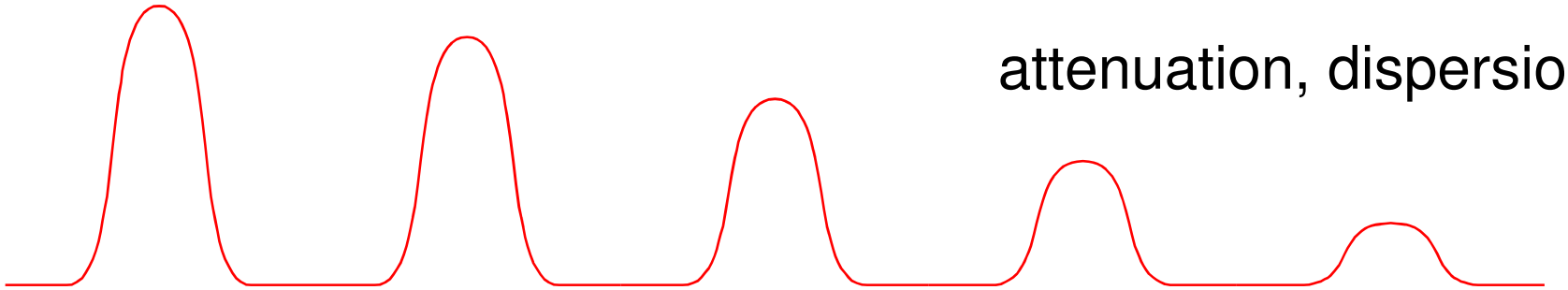
Kouzlo optických vláken a vláknových laserů

Ústav fotoniky a elektroniky, AVČR, v.v.i.

www.ufe.cz/en/ivan-kasik

Optical fiber : material of high purity

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



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

ppm Ti^{3+} in SiO_2

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

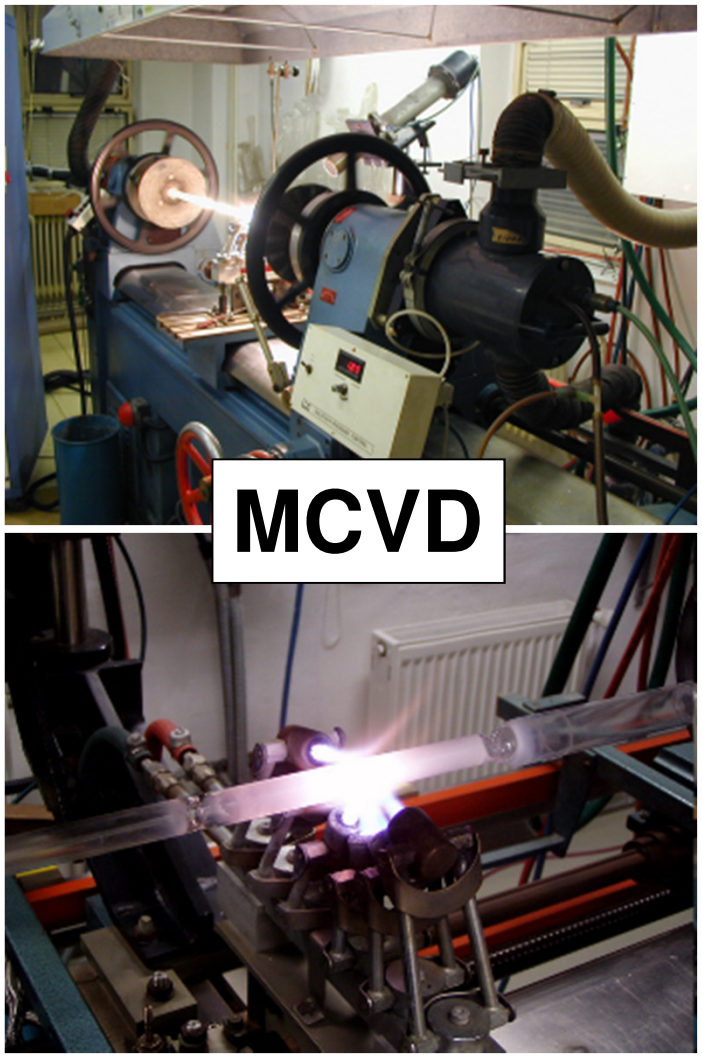
% – 10^{-2}

ppm – 10^{-6} (parts per million)

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

Ultra-pure technologies - CVD !

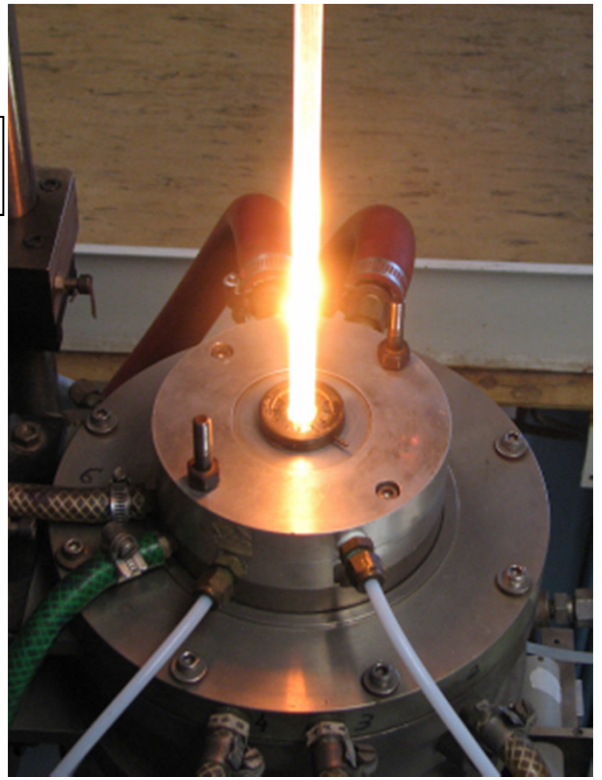
Optical fiber technology



MCVD

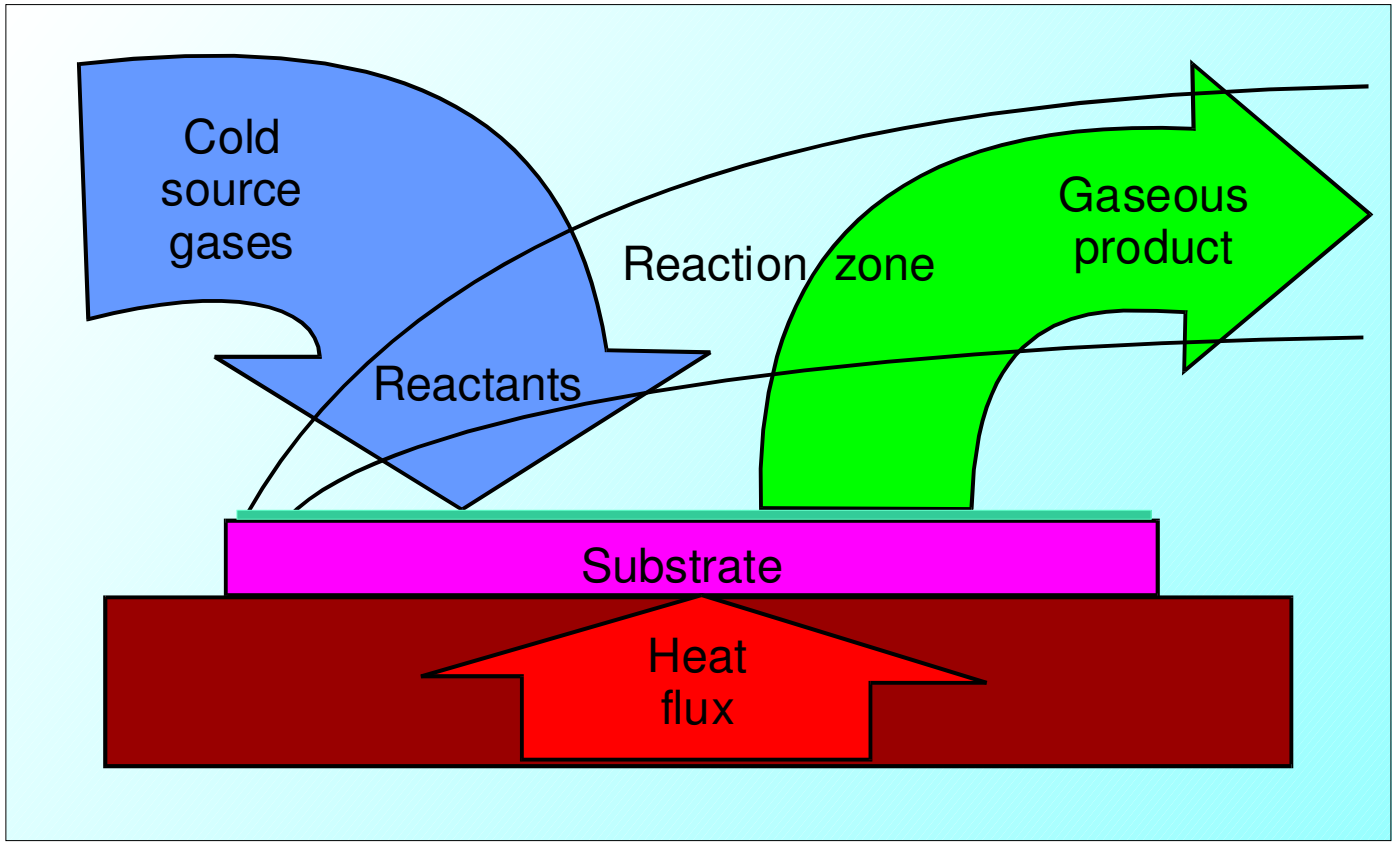
1. Preform

2. Fiber drawing



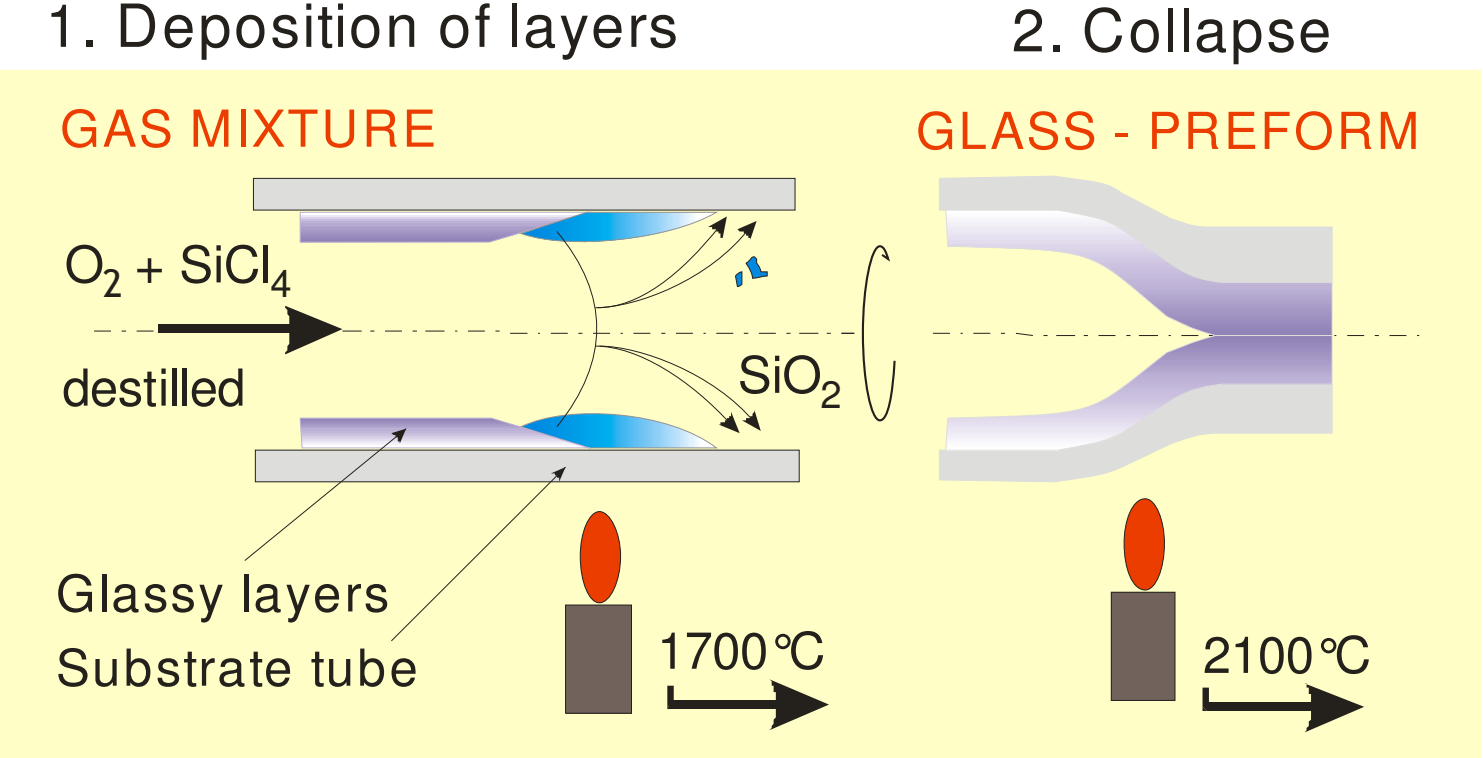
Ultra-pure technologies
CVD - Chemical Vapor Deposition

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



Preform preparation

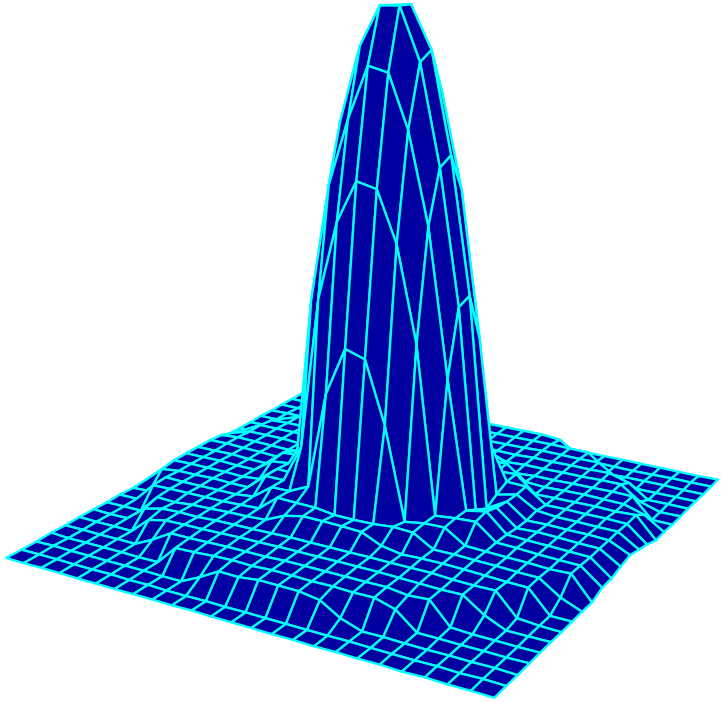
MCVD – (Modified) Chemical Vapor Deposition



- 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

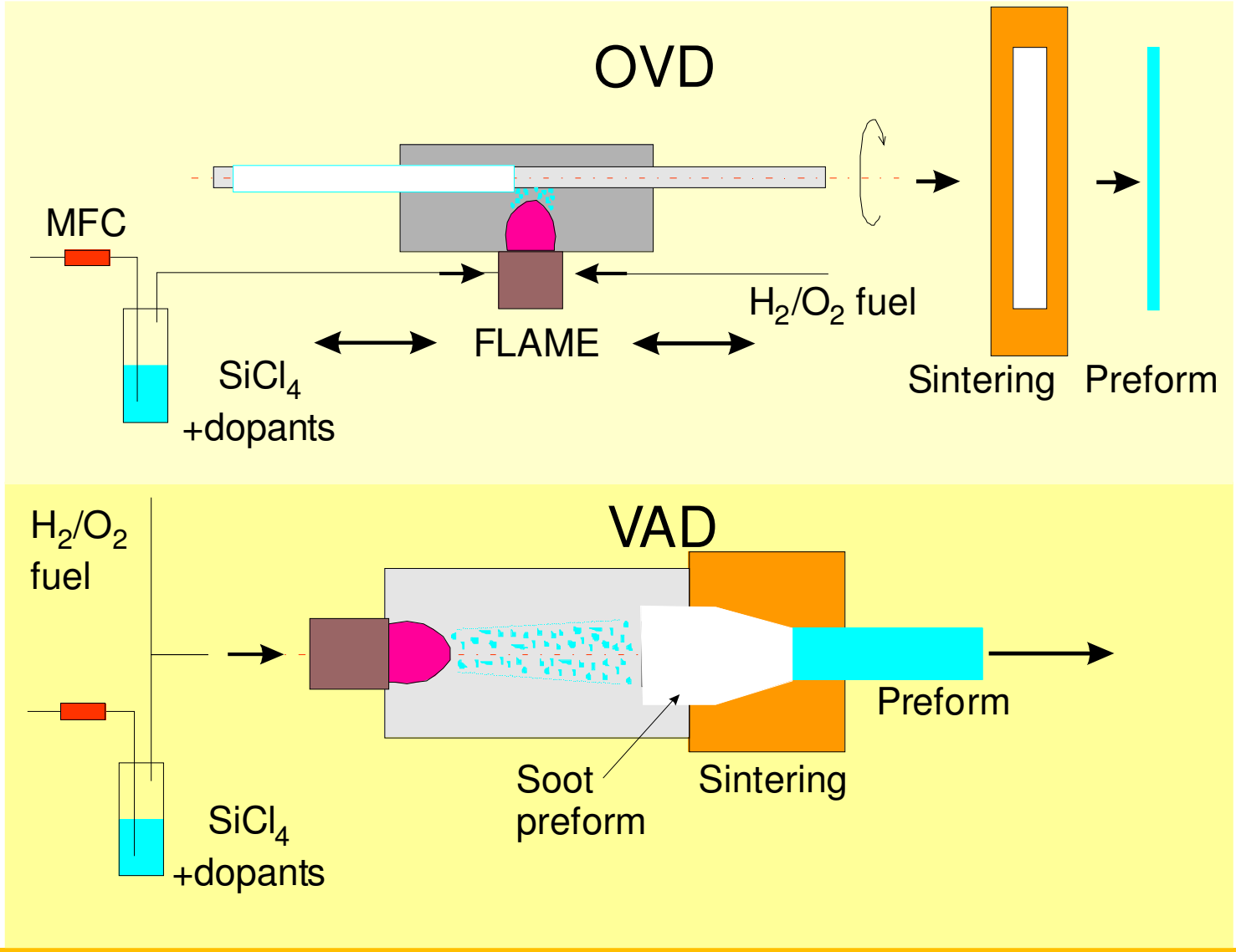
Microphoto of cross section of produced preform



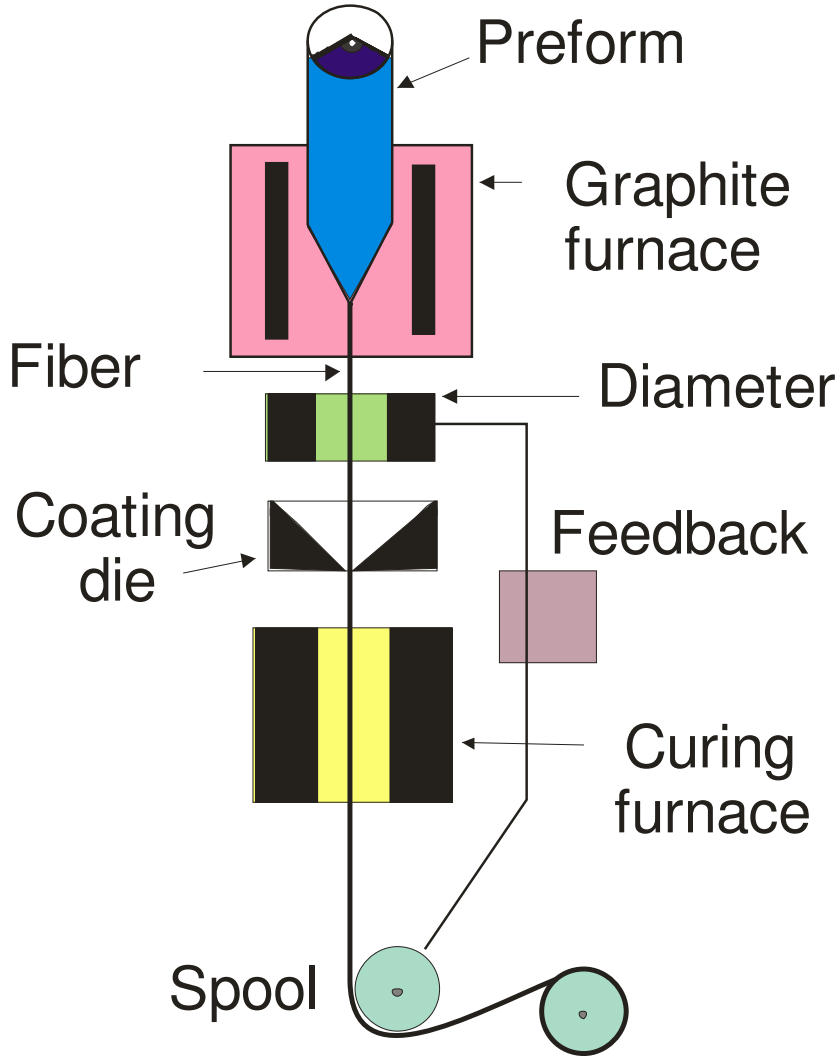
Tomography of the refractive-index profile of preform

- 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



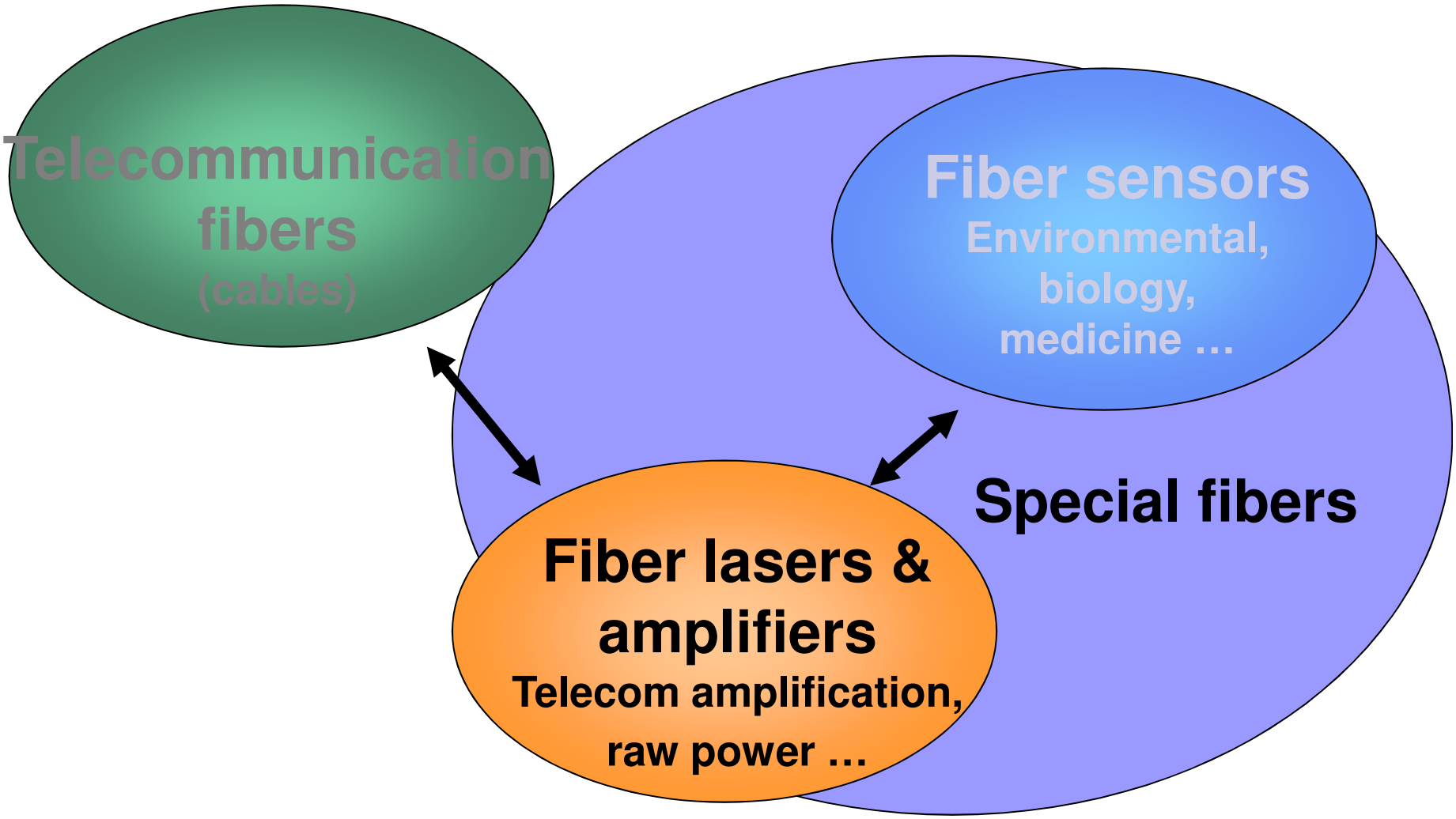
Drawing of optical fibers from preforms



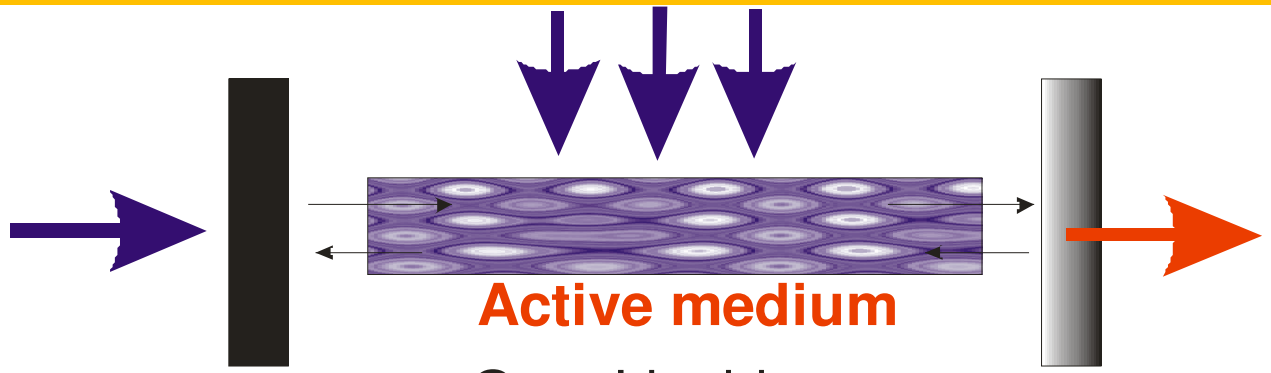
- Diameter
  80-1000 µm
- Temperature
  1800-2100°C

- No textile
- No thermo-insulation

Application



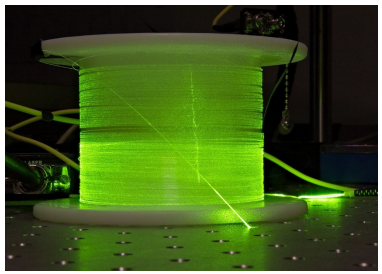
Silica specialty optical fibers for fiber lasers and amplifiers



Mirror
100%

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

Mirror
8-99%



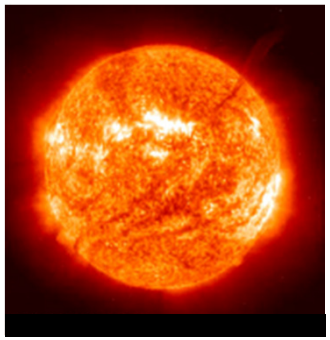
Er^{3+}

[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]

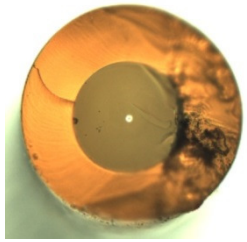
Fiber lasers mW → kW

* **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)

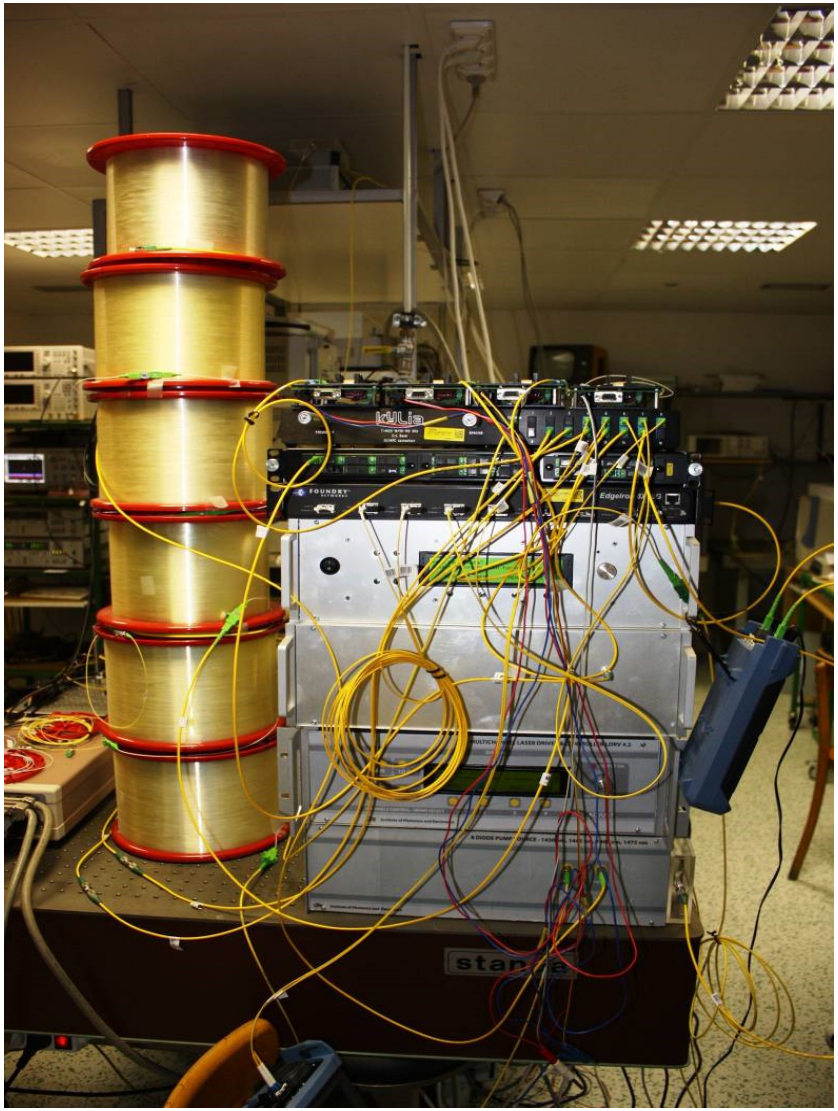
[IPG]

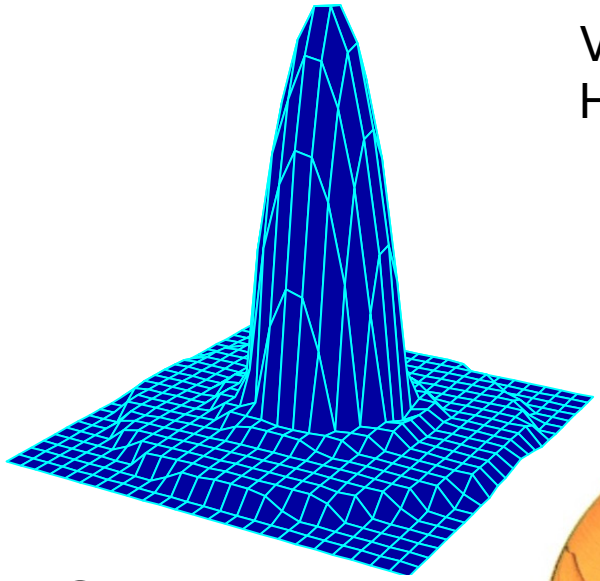


sun	63 MW/m^2
fiber laser	12.7 GW/m^2



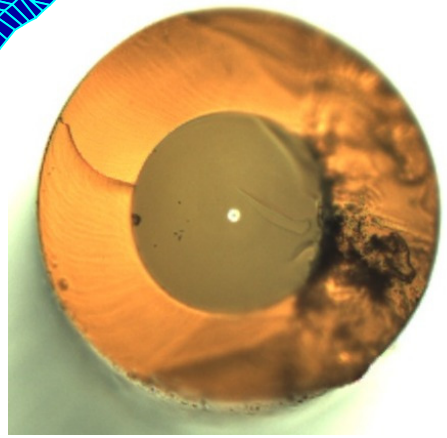
Telecommunications [mW]





VÚSU Teplice,
Hesfibel - TR

GI - multimode



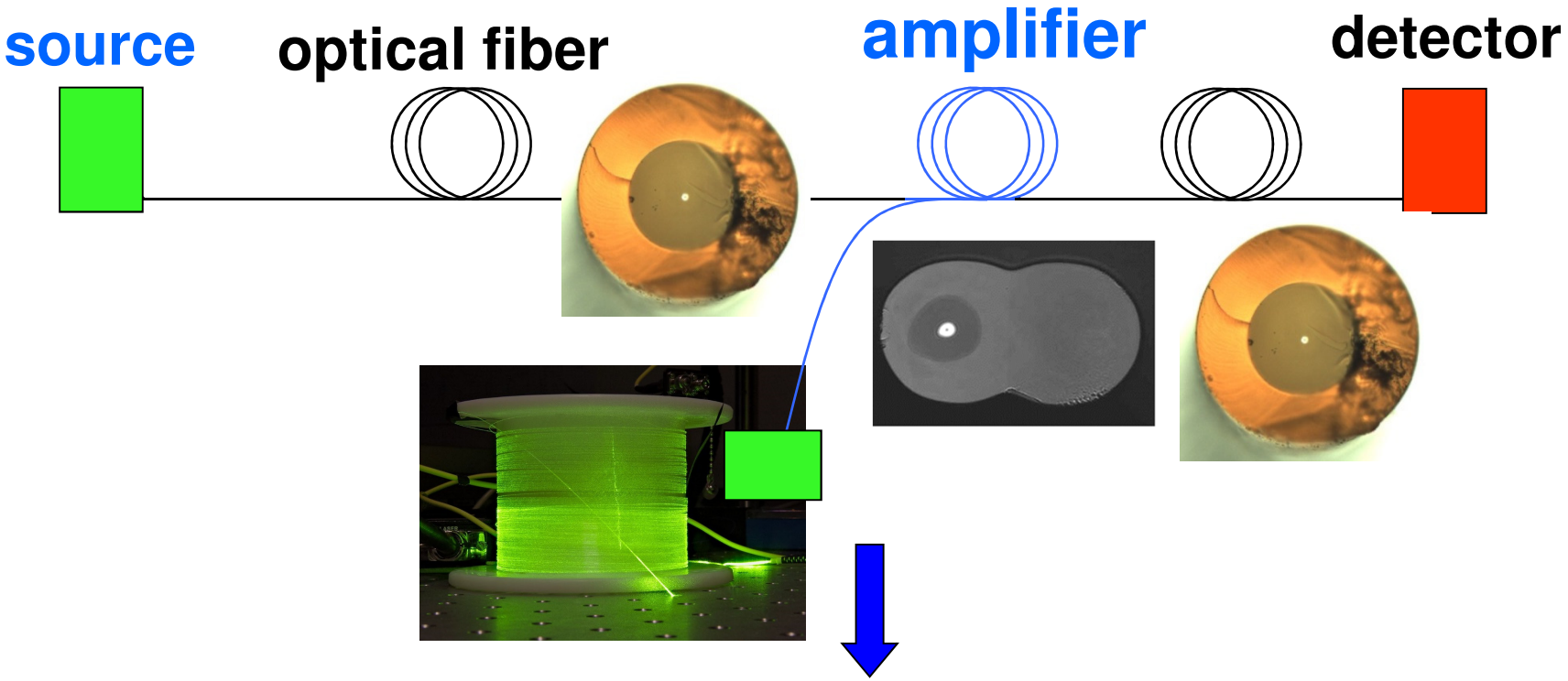
SM - singlemode

200 km telecom line - test

Telecommunications

Internet connection : 8.1 MB/s (7)
Fix line: EU 95% towns, 82 % countryside
CR 97% towns, 90 % countryside
FTTx 210 tis users = 7%
Strategy: each municipality <200 inhabitants optical connection

Specialty optical fibers for communications
Fiber lasers and amplifiers

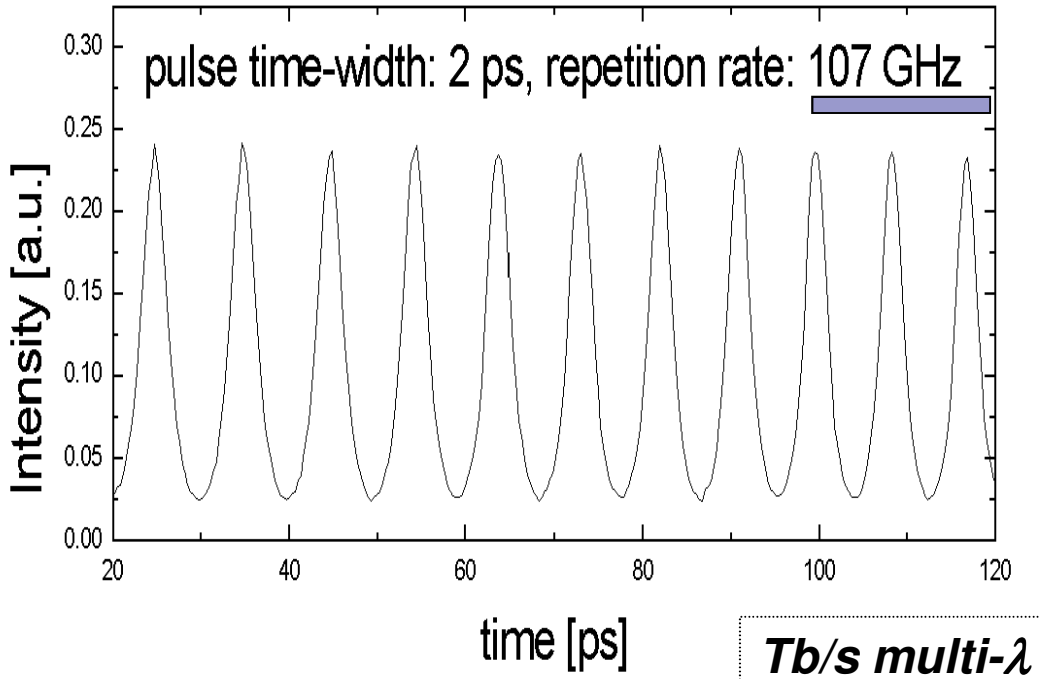


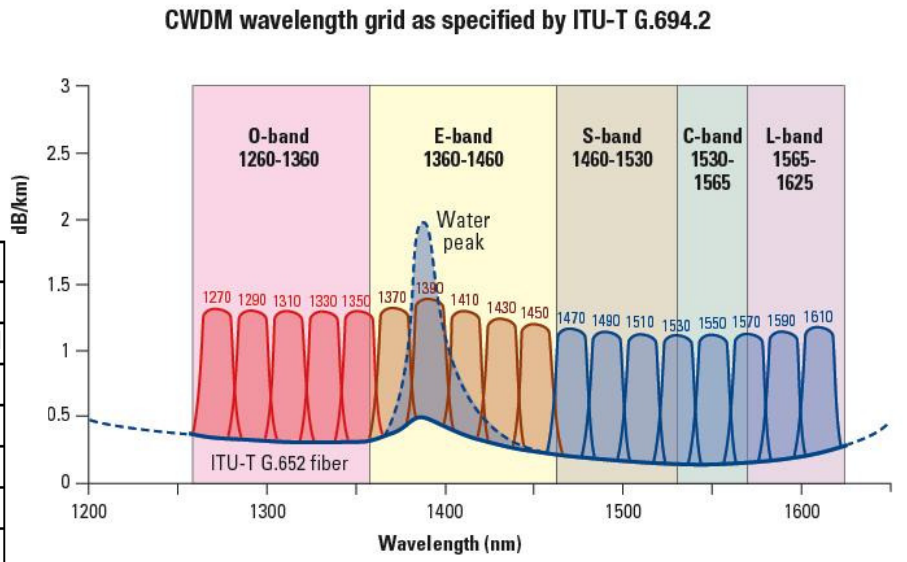
Fiber amplifier, laser

TDM

WDM

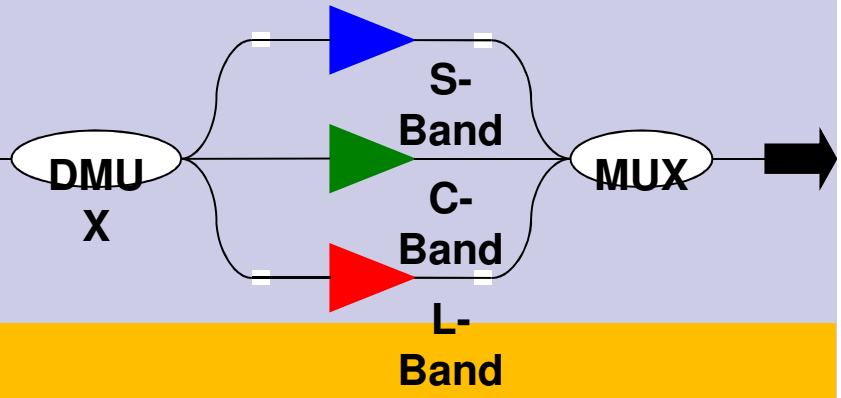
Time Division Multiplexing (TDM)



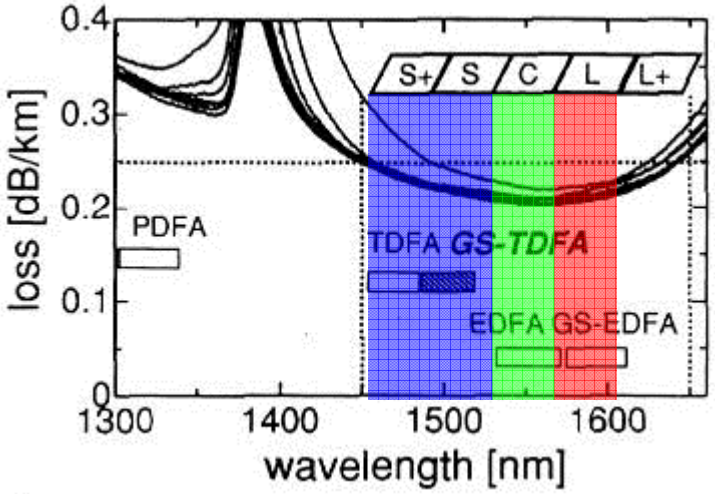


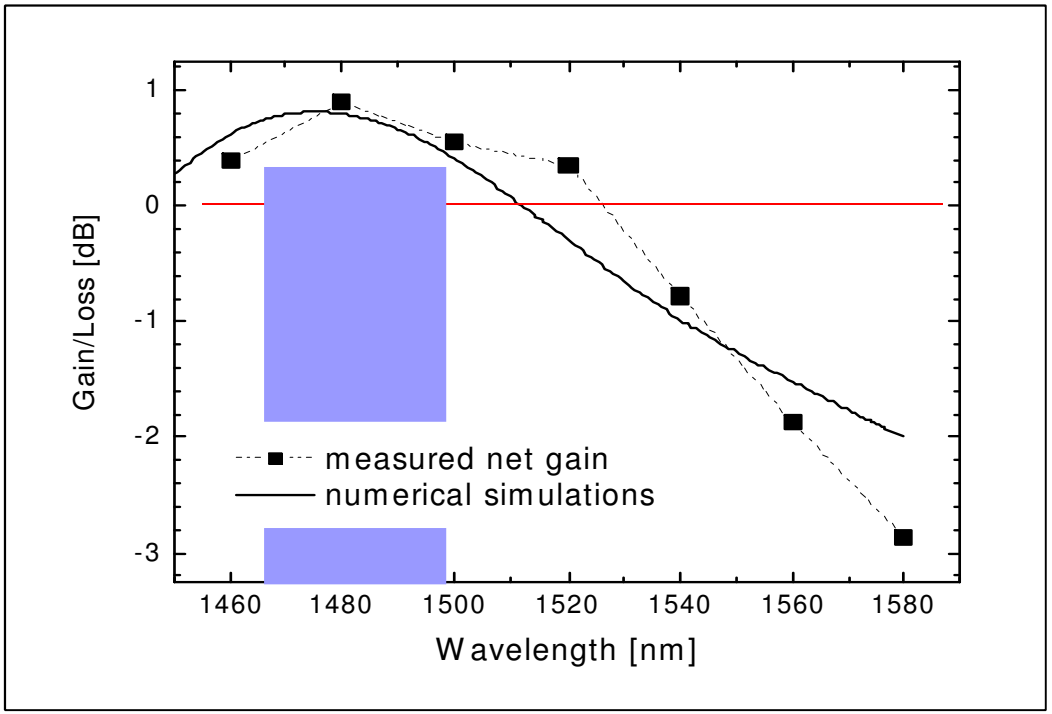
Wavelength Division Multiplexing (WDM)

Tb/s multi-λ Data stream



Tm- doped fiber for amplifier at 1470 nm

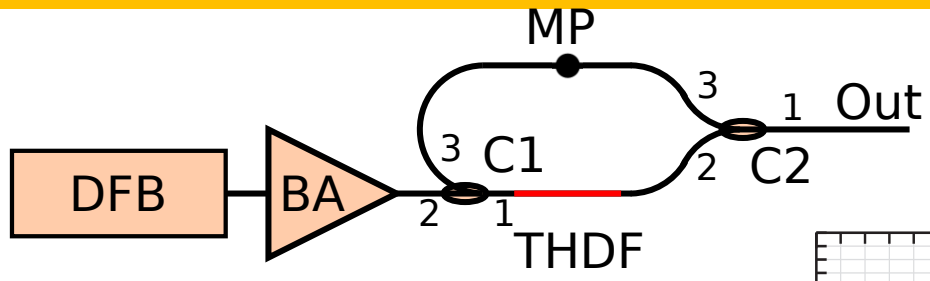


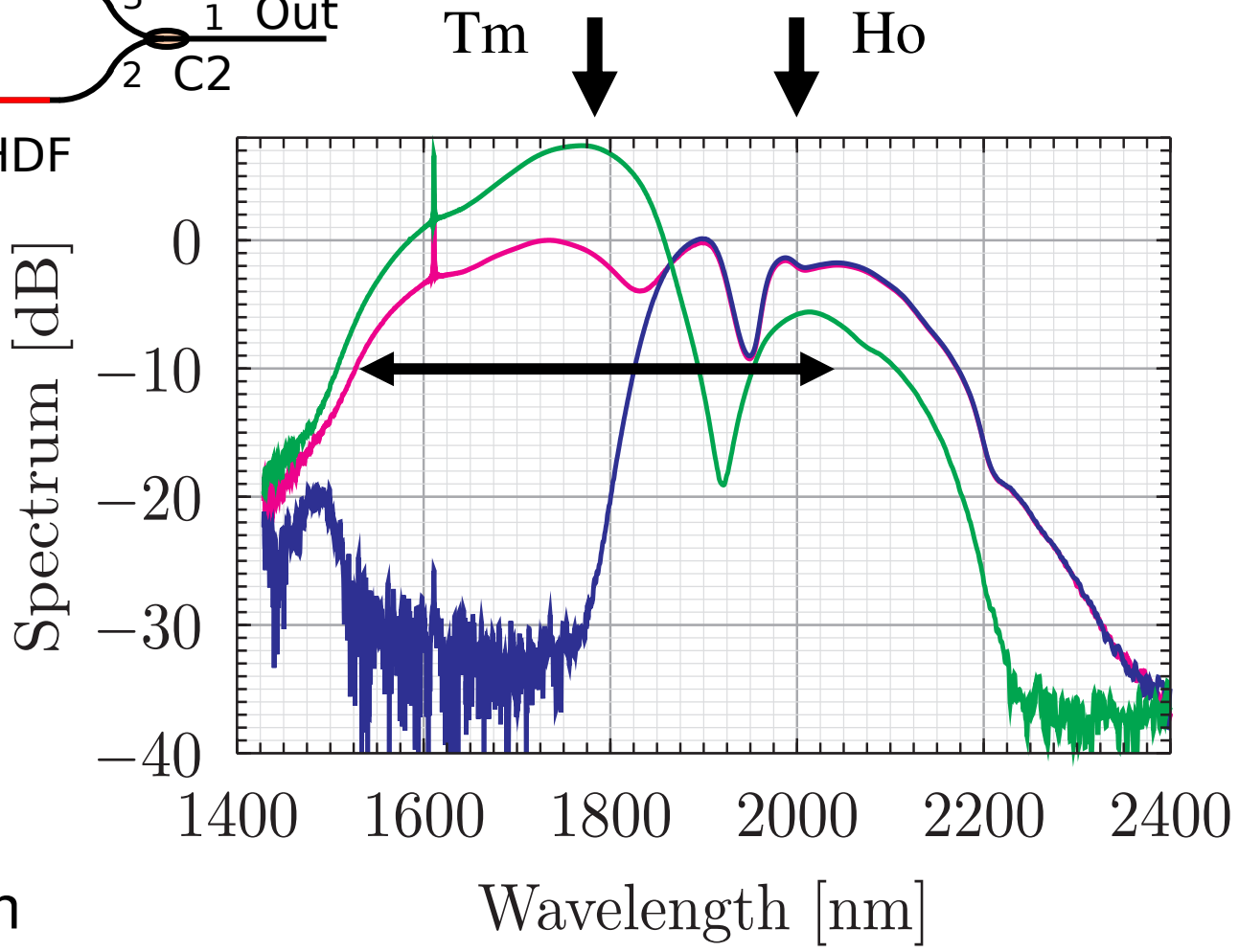


Non-optimized fiber parameters (low NA, low Tm^{3+} concentration), longer lifetime required.

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

Tm/Ho – fiber for ASE source





GOAL: wide fluorescence

Fiber: 1800 ppm Tm / 360 ppm Ho

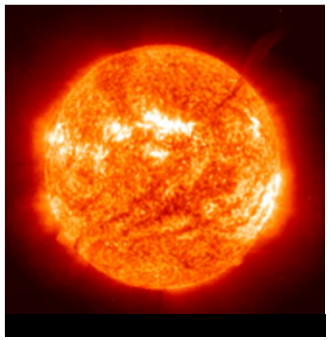
Backward emission 1550 – 2050 nm

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

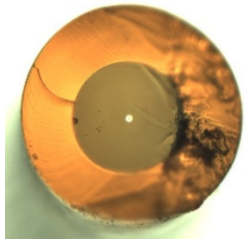
Fiber lasers mW → kW

* **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

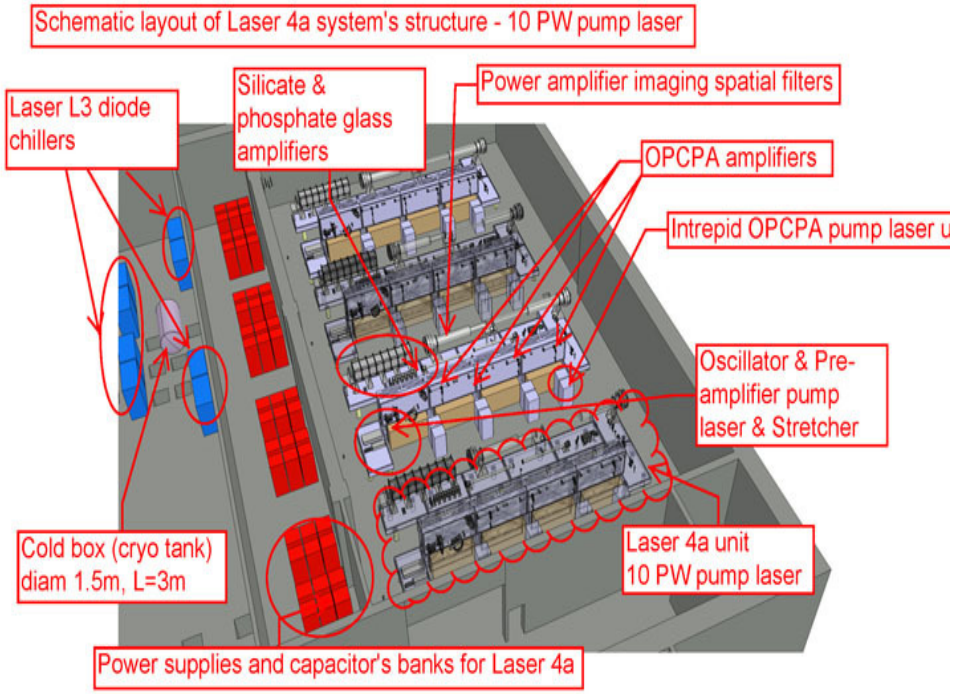


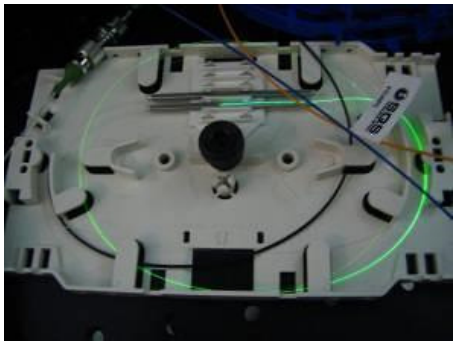
Fiber lasers vers. solid state lasers (SSL)

- **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]





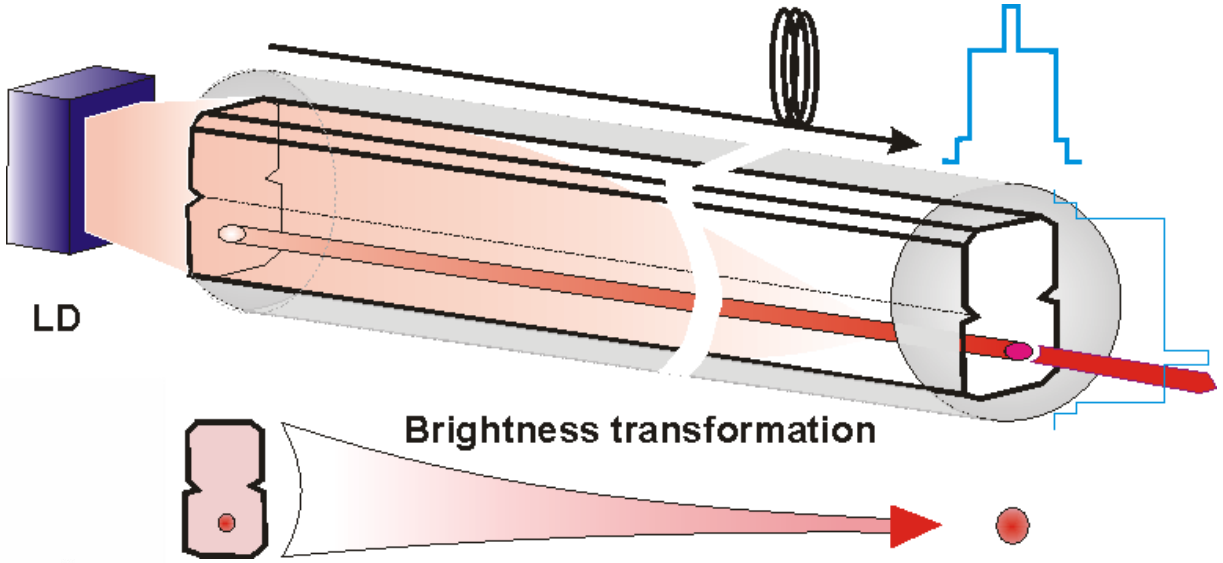
100 m

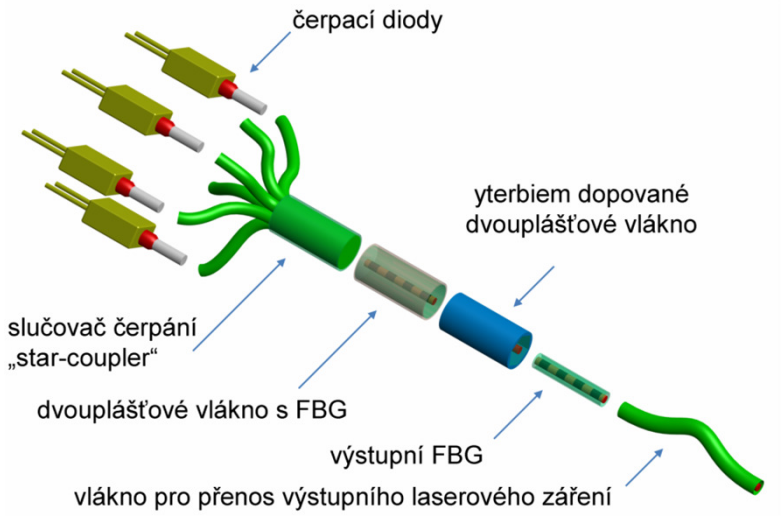
1 m

0.1 m

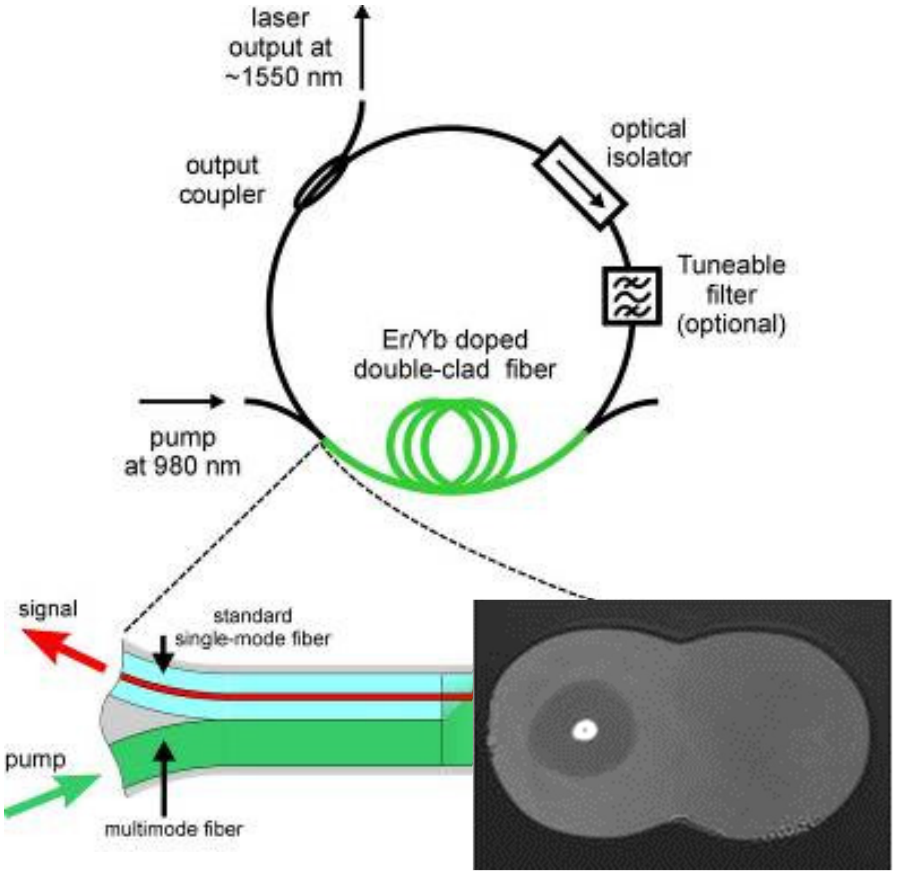
Silica (VIS-NIR) specialty optical fibers for fiber lasers and amplifiers

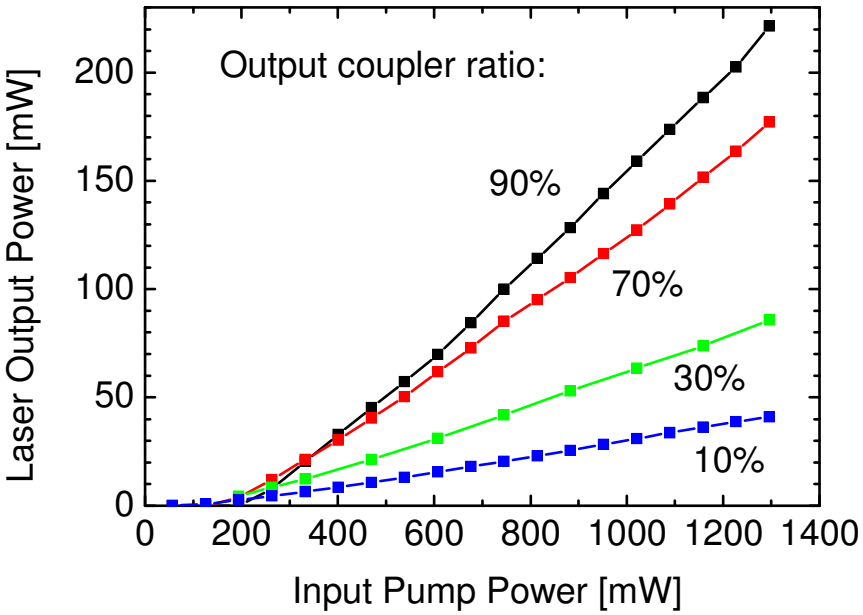
DC structures, beam combining ..





Er/Yb -doped DC fiber



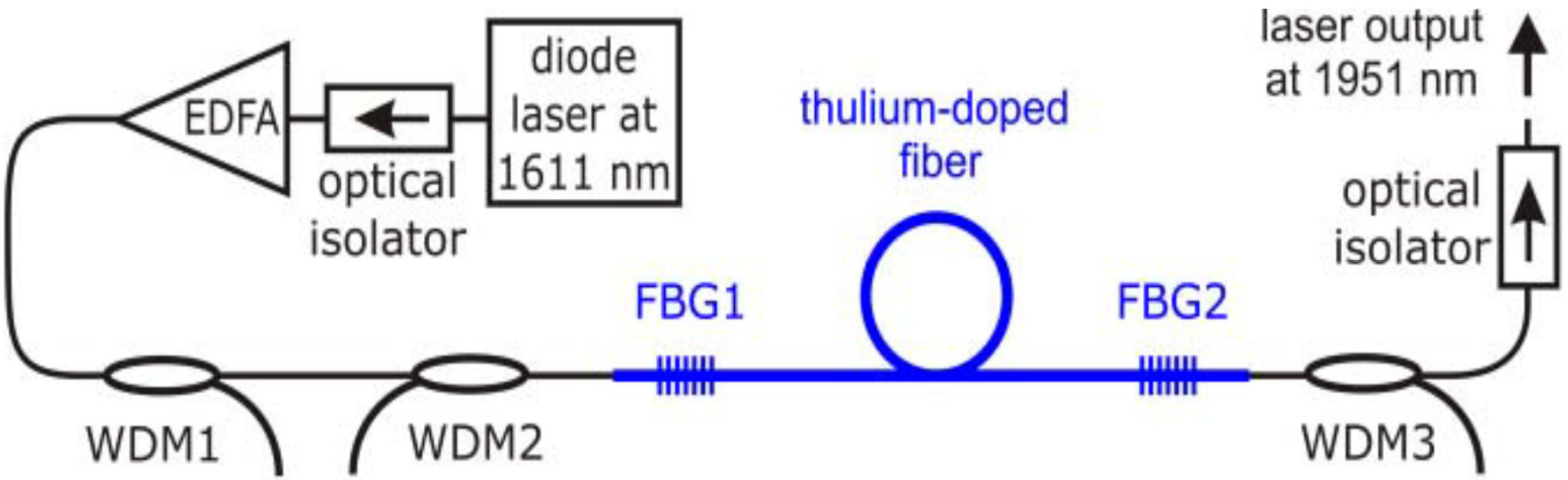


PCE 19 → 40%

[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]

Monolitic Tm- doped fiber laser at 1951 nm

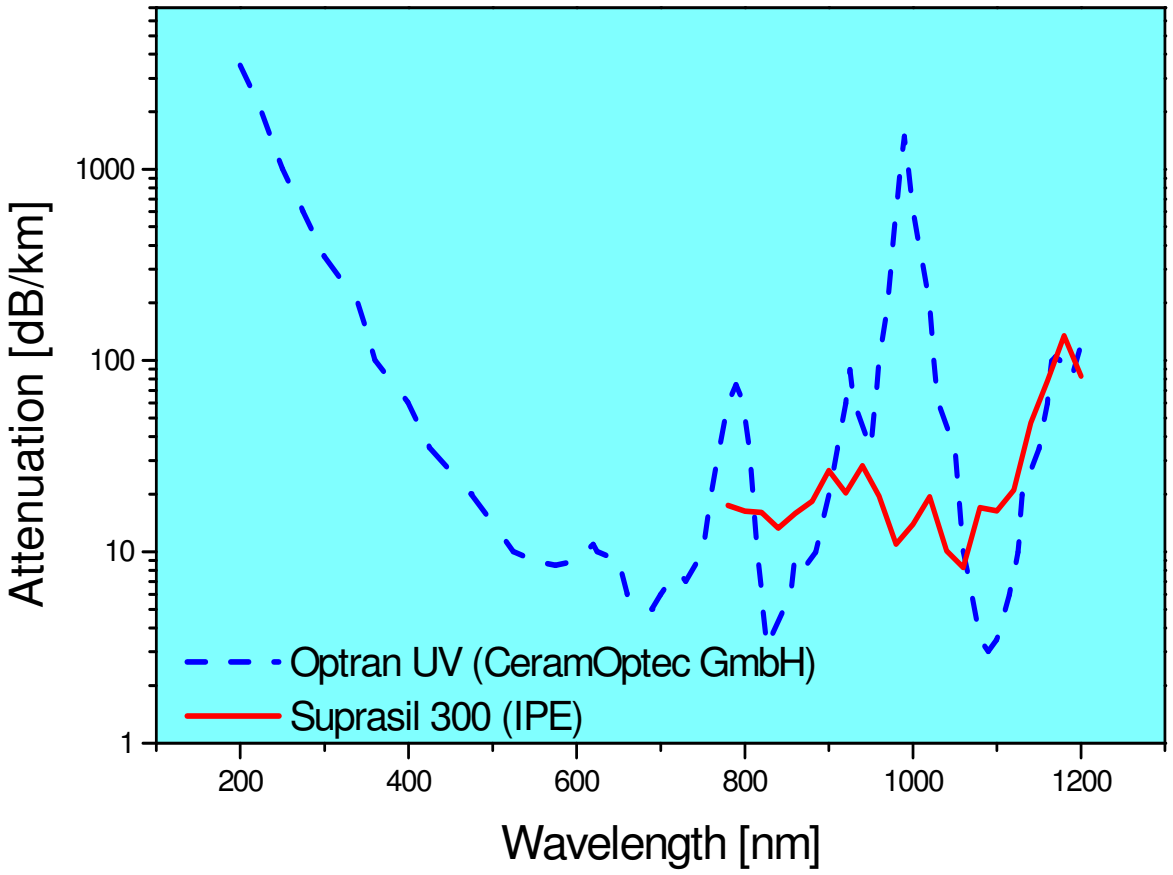
Eye-safe spectral region



* 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**

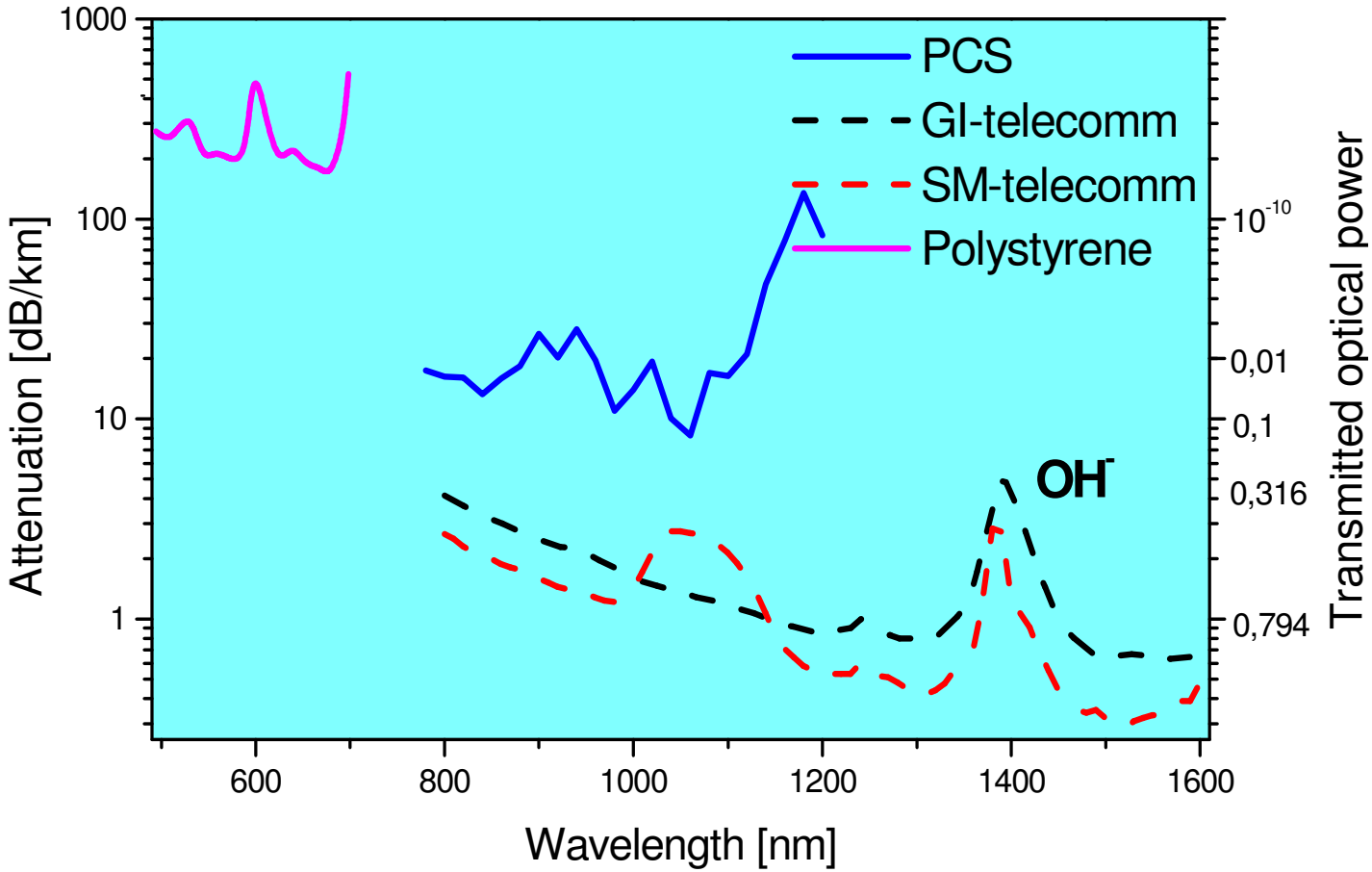
[P.Peterka, Photonic Technol Lett, 25, 2013, 1623]

Reminder:
OPTICAL FIBRES – Materials - UV



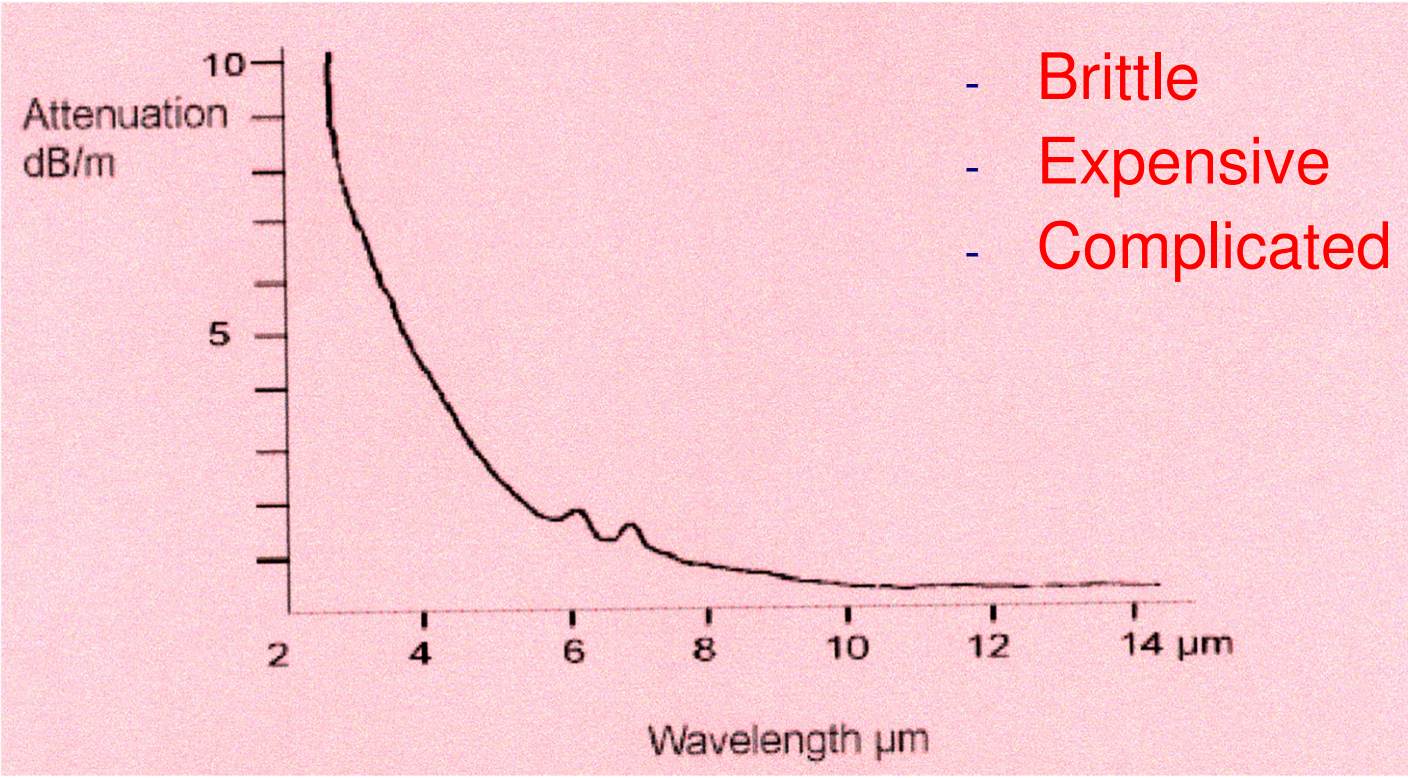
- silica fibres - SUPRASIL $n_{200\ nm} = 1.55$ [ceramoptec.de, OceanO, IPE …]
- planar silica, crystalline CaF_2 (MgF_2) – [edmundoptics, technicalglass …]

Reminder: OPTICAL FIBRES – 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…]

Reminder : OPTICAL FIBRES – 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 preciseness (<1%) 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 specialty (active). Fiber lasers : special case of Solid State Lasers (SSL).
4. Research of optical fibers & fiber lasers

ÚFE

Literatura

- **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 5-6/2015
- Sdělovací technika 3/2011

Ústav fotoniky a elektroniky AV ČR, v.v.i.

Prof. Jiří Homola
Česká hlava 2009

<u>ZÁKLADNÍ VÝZKUM:</u> **Fotonika**

- **vláknové lasery & optická vlákna**
- **optické biosenzory**
- **státní etalon času, detekce pole buněk**