



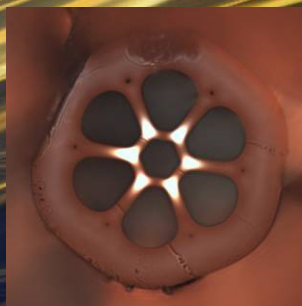
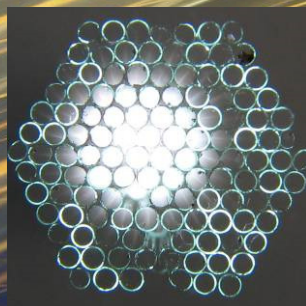
INTERNATIONAL
YEAR OF LIGHT
2015

ÚFE

Kouzlo optických vláken a vláknových laserů

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

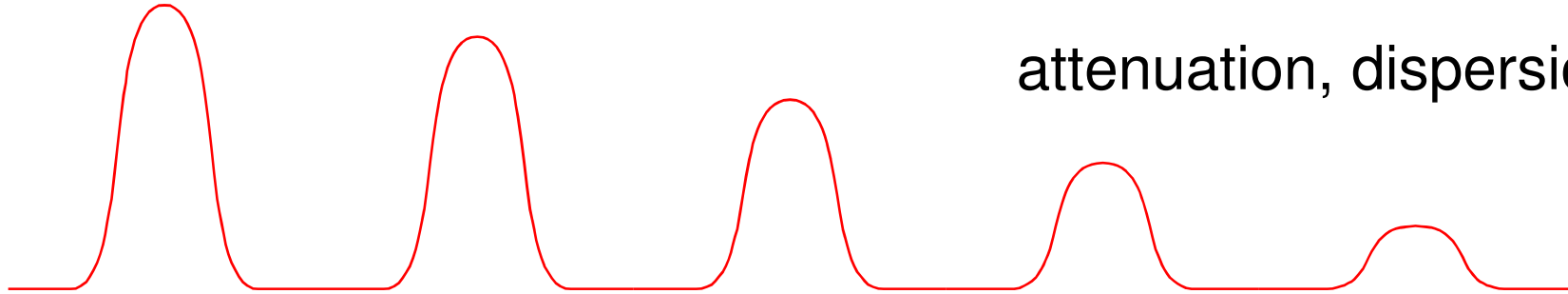
www.ufe.cz/en/ivan-kasik



Optical fiber : material of **high purity**

Optical fiber : dielectric structure, $L \ll r$, $n_{\text{core}} > n_{\text{clad}}$

attenuation, dispersion



Optical losses in optical fibers

- transparency of 3 mm of window-glass $\approx$ 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 %) ppm Ti³⁺ in SiO₂
3. **Ultra-pure - FO Optipur / for trace analysis [ppb]**

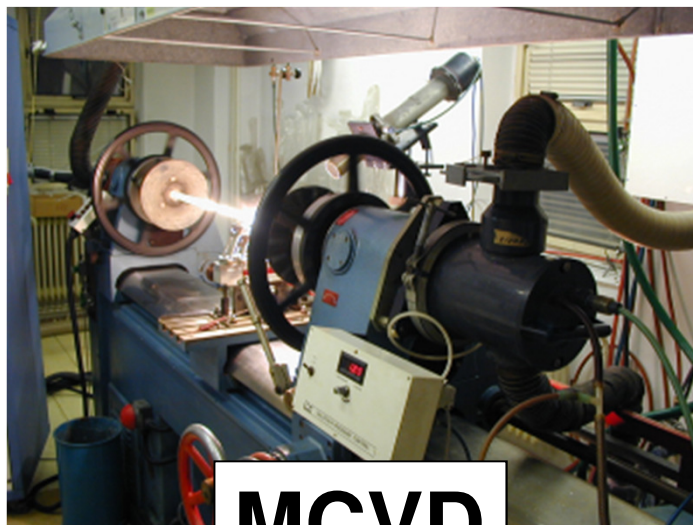
% – 10⁻²

ppm – 10⁻⁶ (parts per million)

ppb – 10⁻⁹ (parts per billion) : **content of impurities
acceptable in FO Optipur materials**

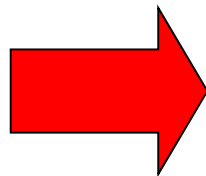
Ultra-pure technologies - CVD !

Optical fiber **technology**

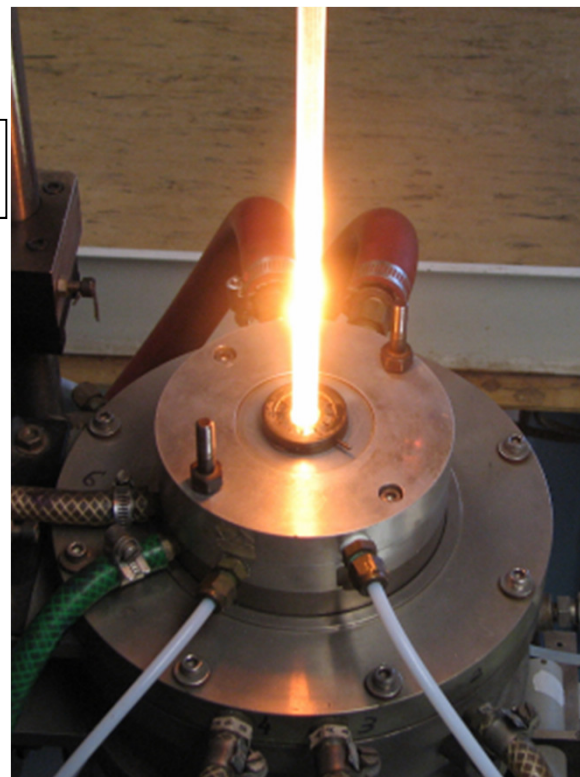


MCVD

1. Preform

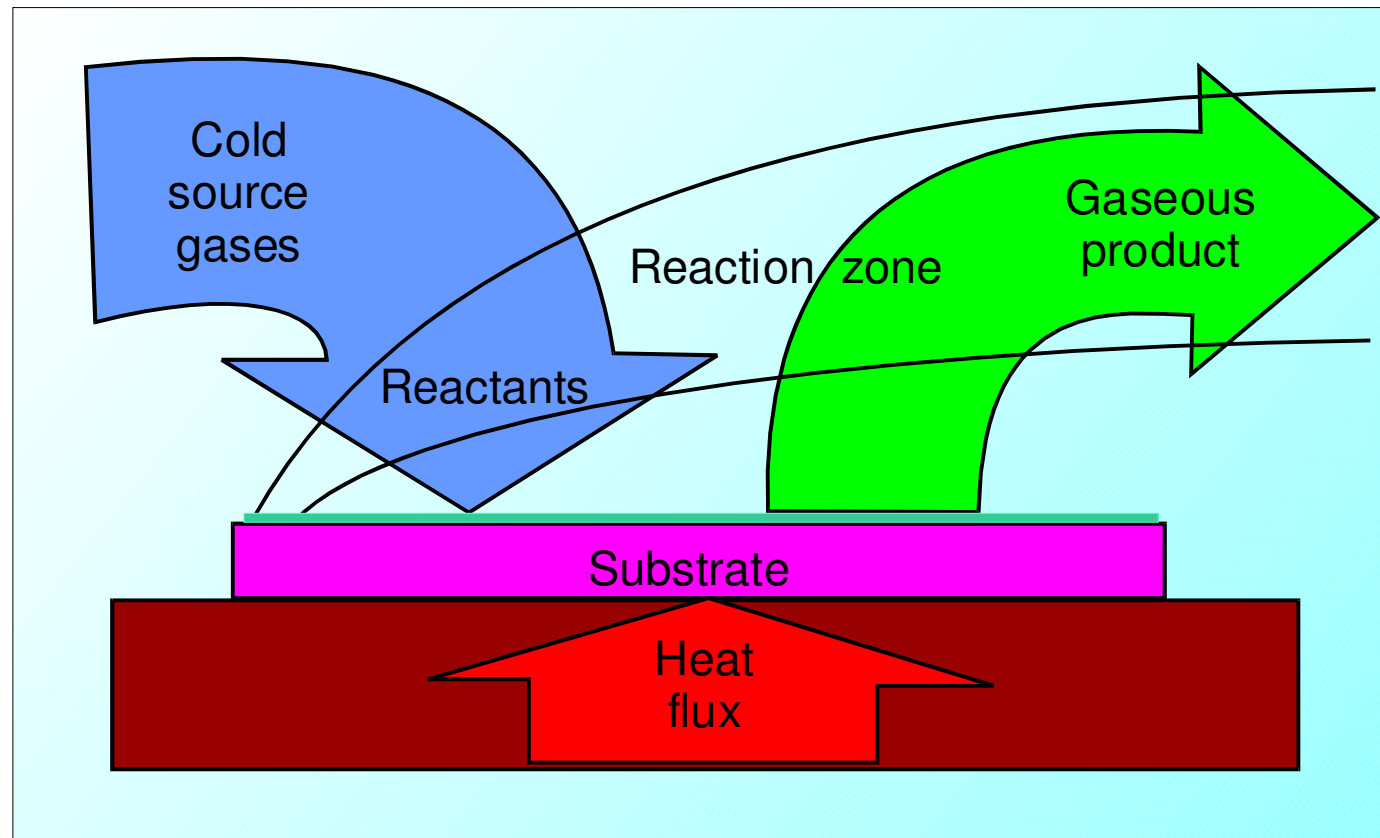
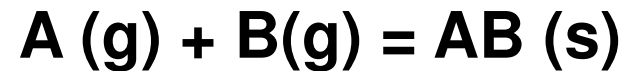


2. Fiber drawing



Ultra-pure technologies

CVD - Chemical Vapor Deposition

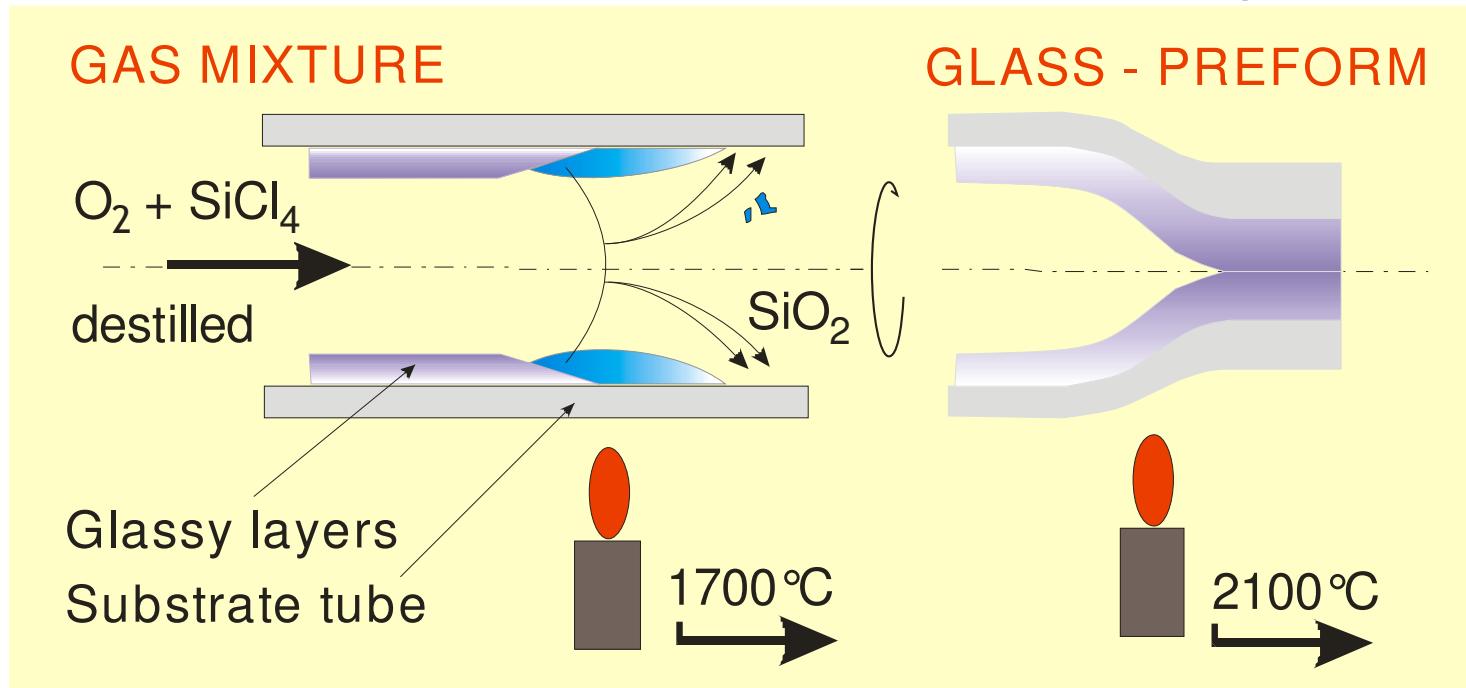


Preform preparation

MCVD – (Modified) Chemical Vapor Deposition

1. Deposition of layers

2. Collapse

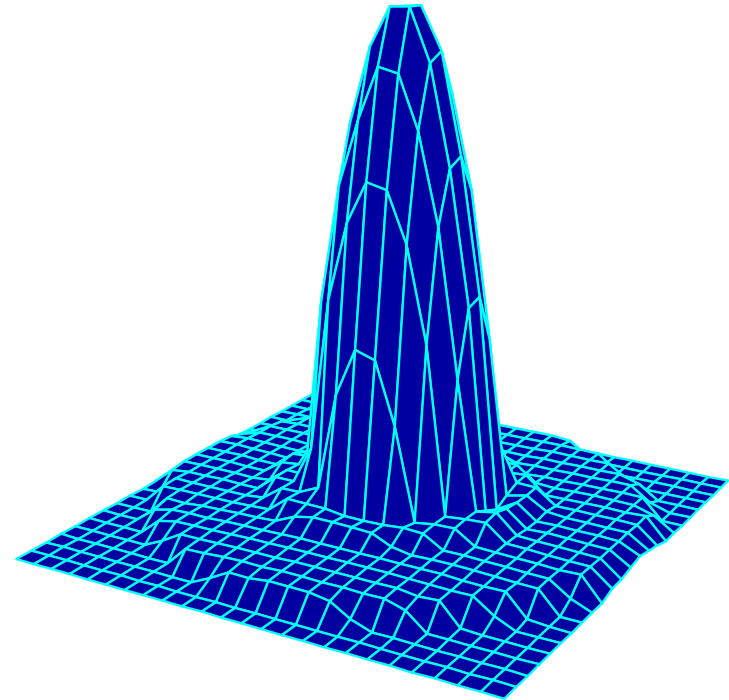


- Sequential sintering of **thin glassy layers** (of thickness 1-20 μm) onto inner wall of silica substrate **resulting in bulk material – preform**
- **high purity** ($\sim 10^1$ ppb) **high preciseness** (better than 1 %)

Preform preparation



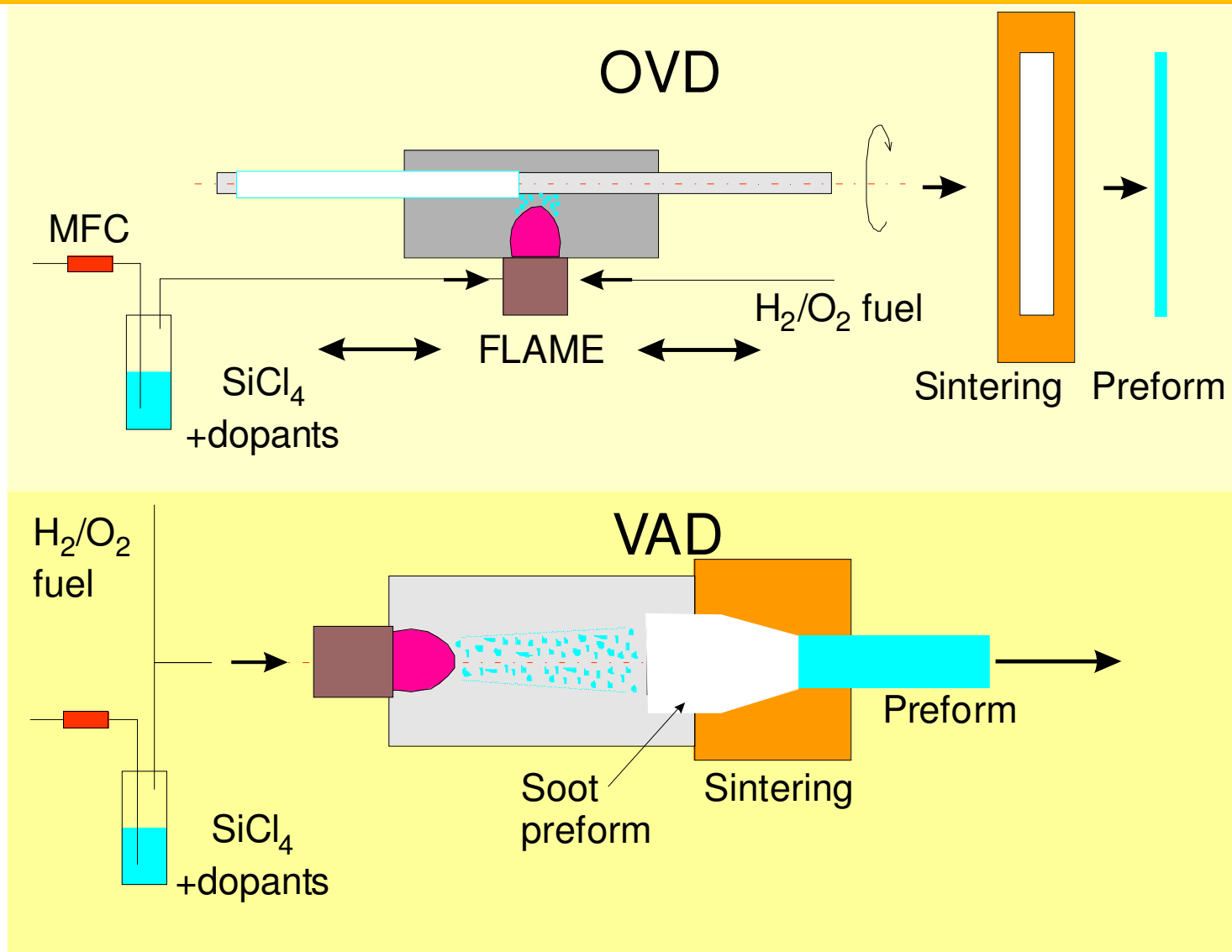
Microphoto of cross section
of produced preform



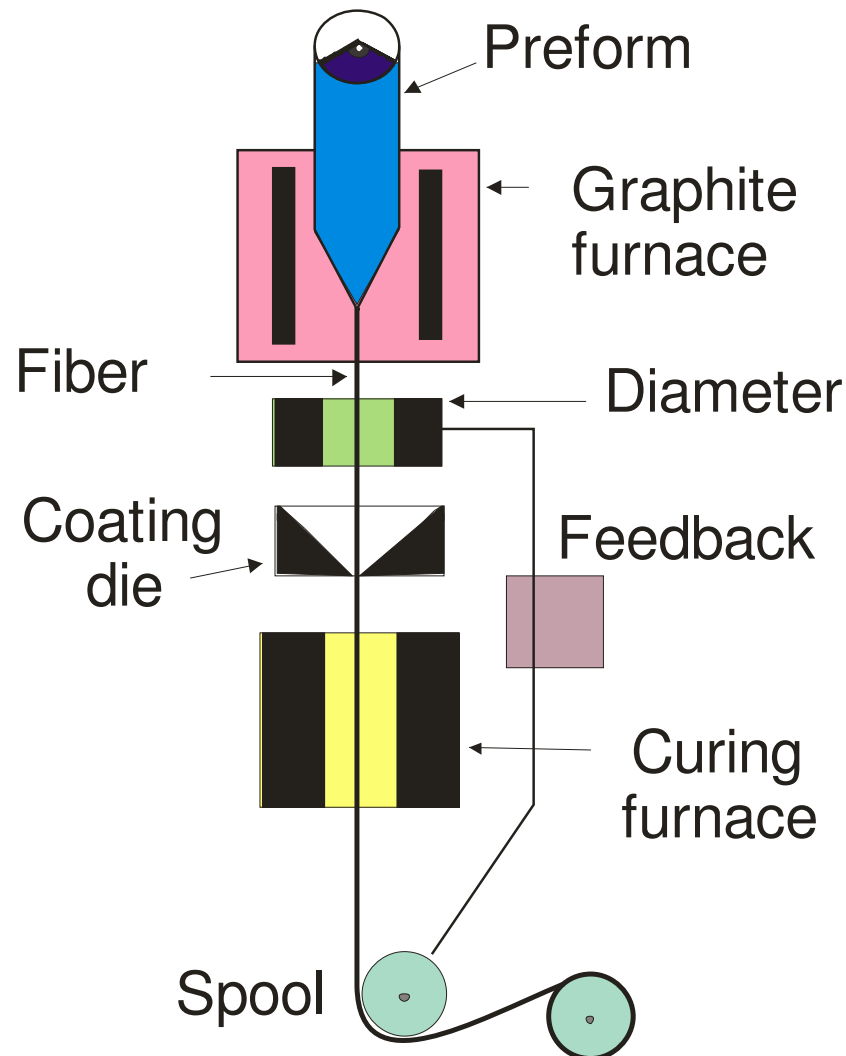
Tomography of the refractive-
index profile of preform

- 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

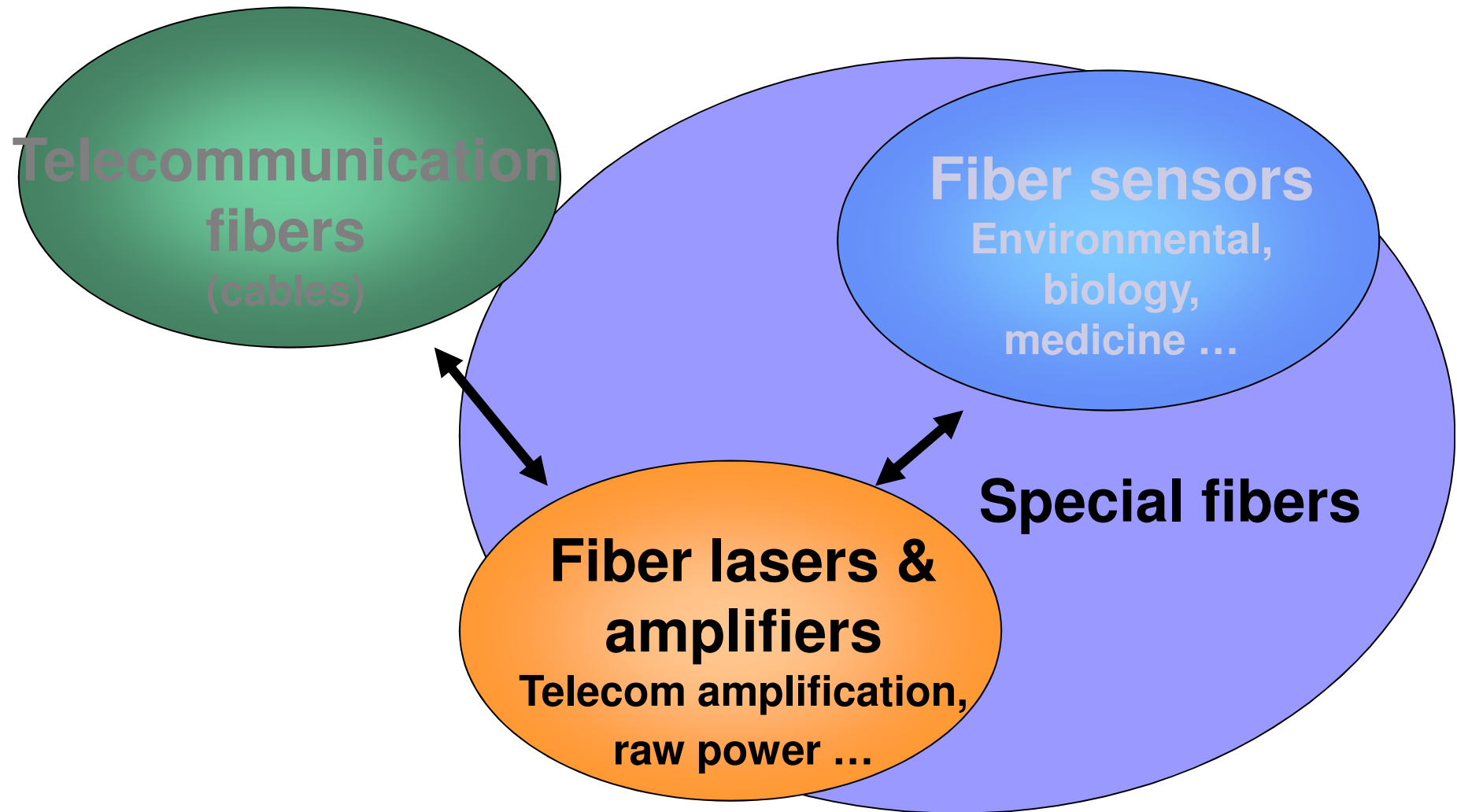


Drawing of optical fibers from preforms

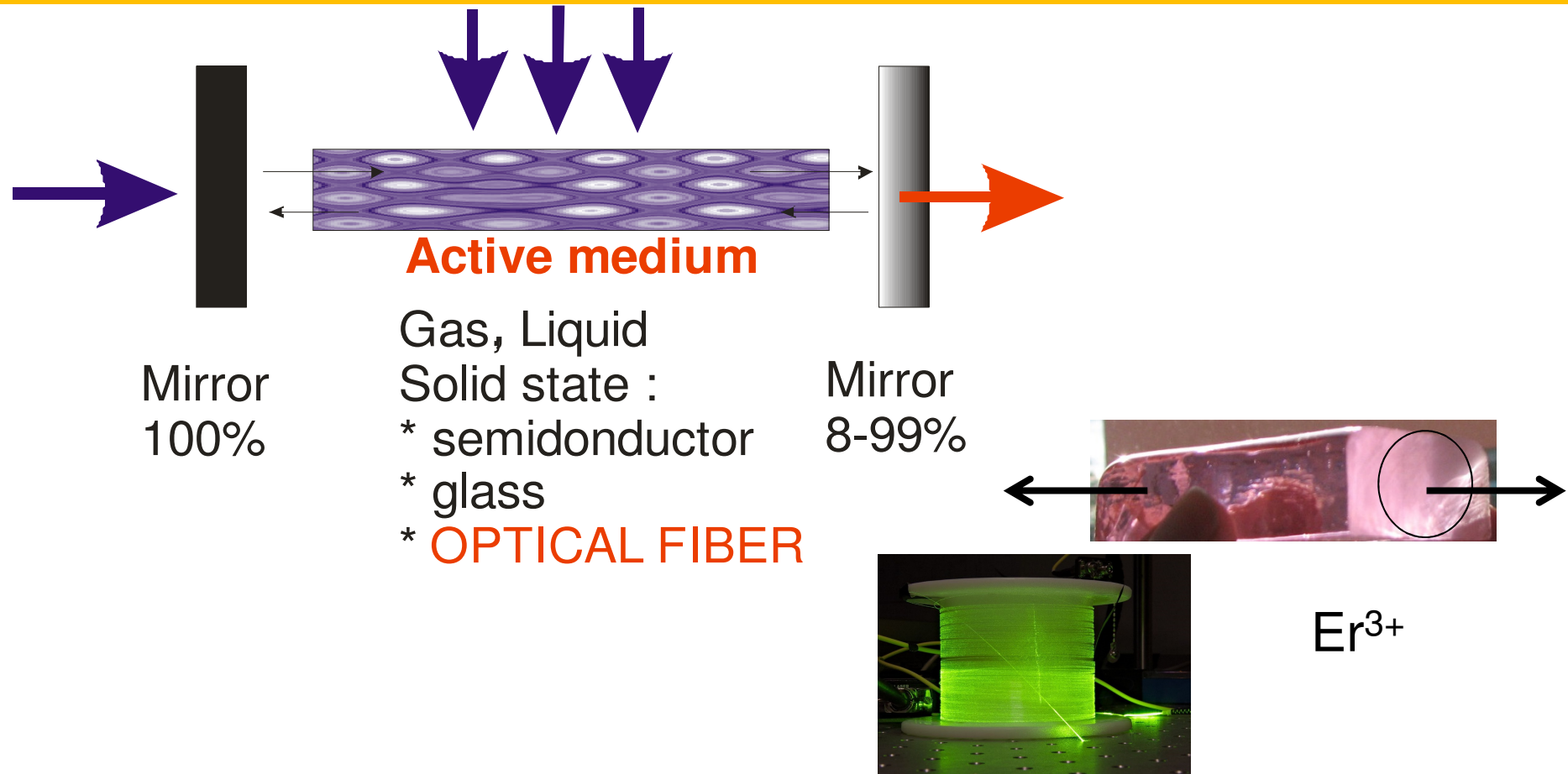


- Diameter
80-1000 μm
- Temperature
1800-2100°C
- No textile
- No thermo-insulation

Application



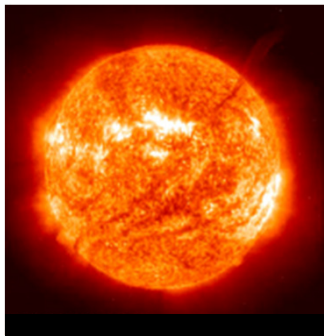
Silica specialty optical fibers for **fiber lasers and amplifiers**



[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)

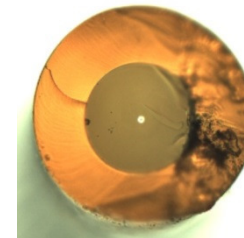


sun
fiber laser

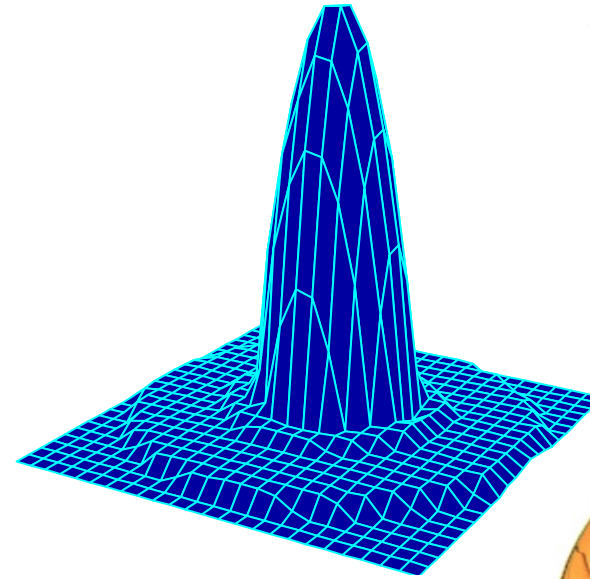
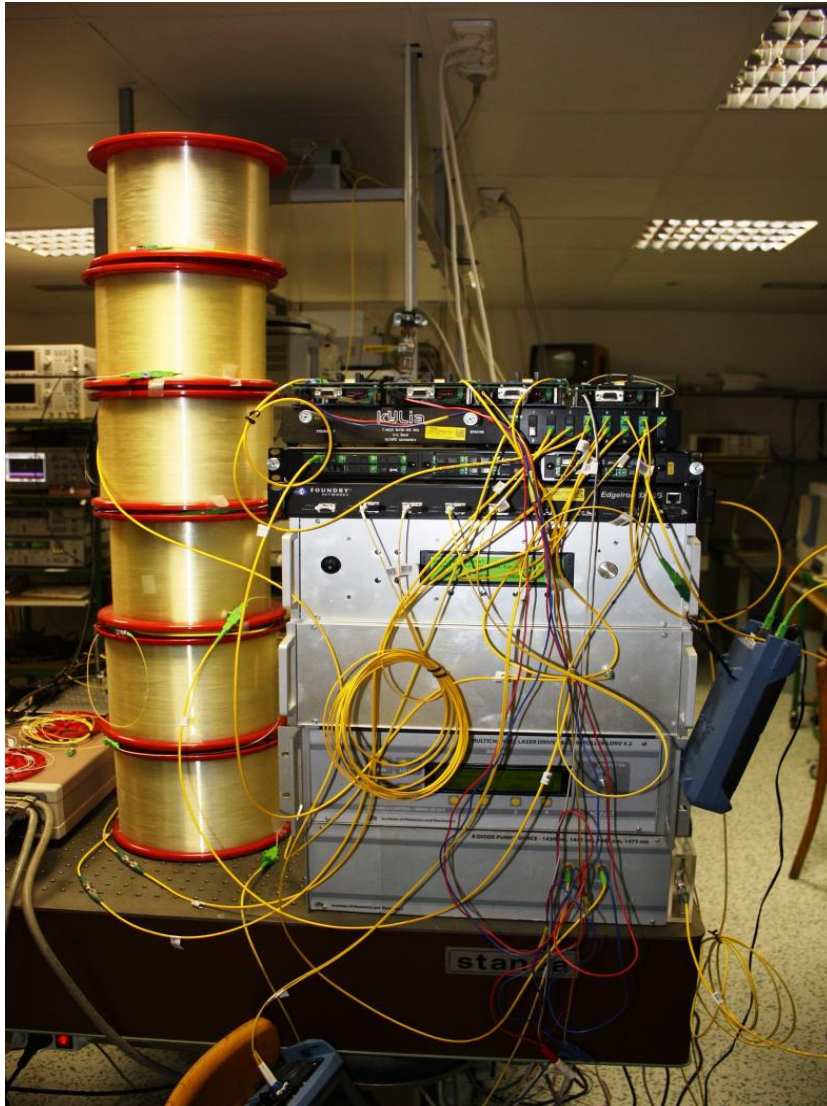
63 MW/m²
12.7 GW/m²



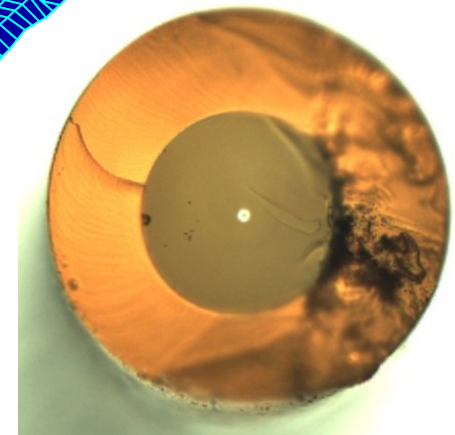
[IPG]



Telecommunications [mW]



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

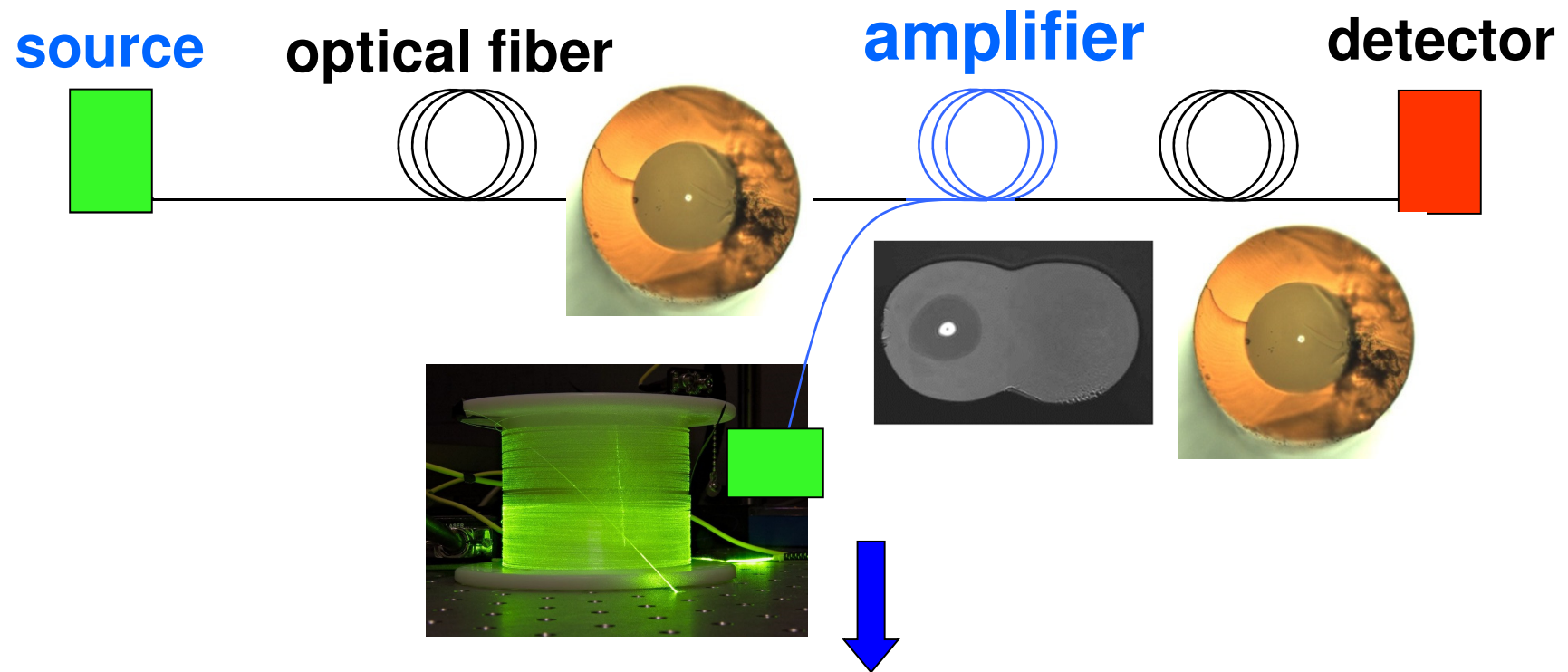
FTTx 210 tis users = 7%

Strategy: each municipality <200 inhabitants
optical connection



Specialty optical fibers for communications

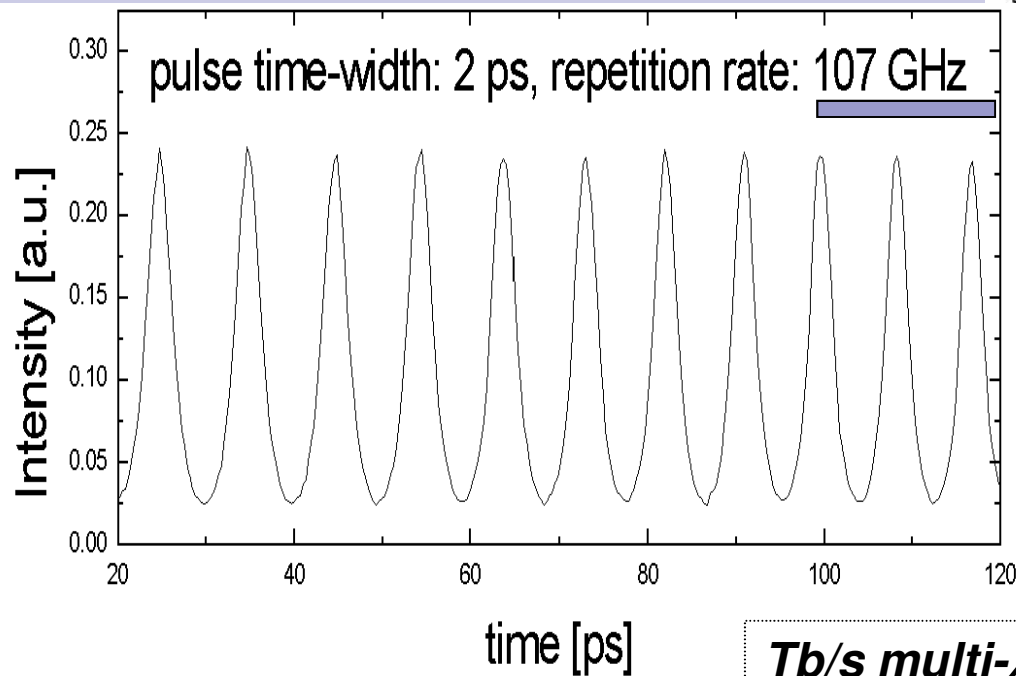
Fiber lasers and amplifiers



Fiber amplifier, laser

TDM

Time Division Multiplexing (TDM)



*Tb/s multi- λ
Data stream*

DMU
X

S-
Band

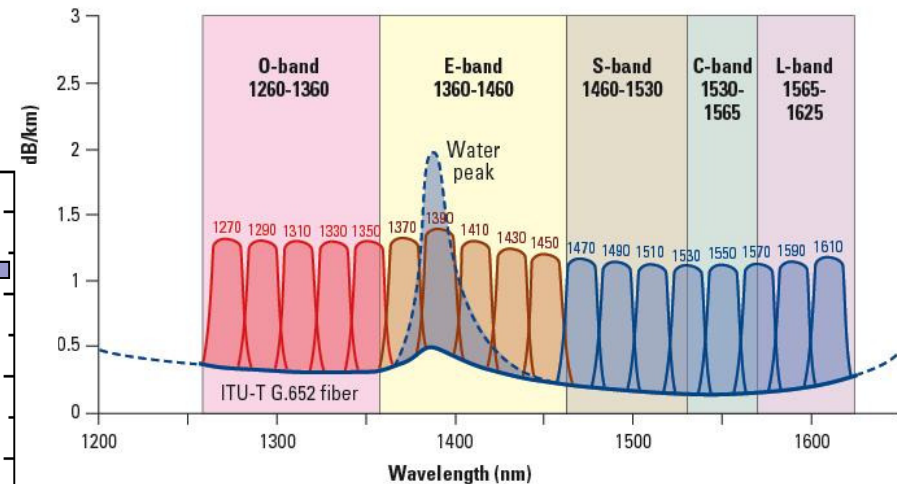
C-
Band

L-
Band

MUX

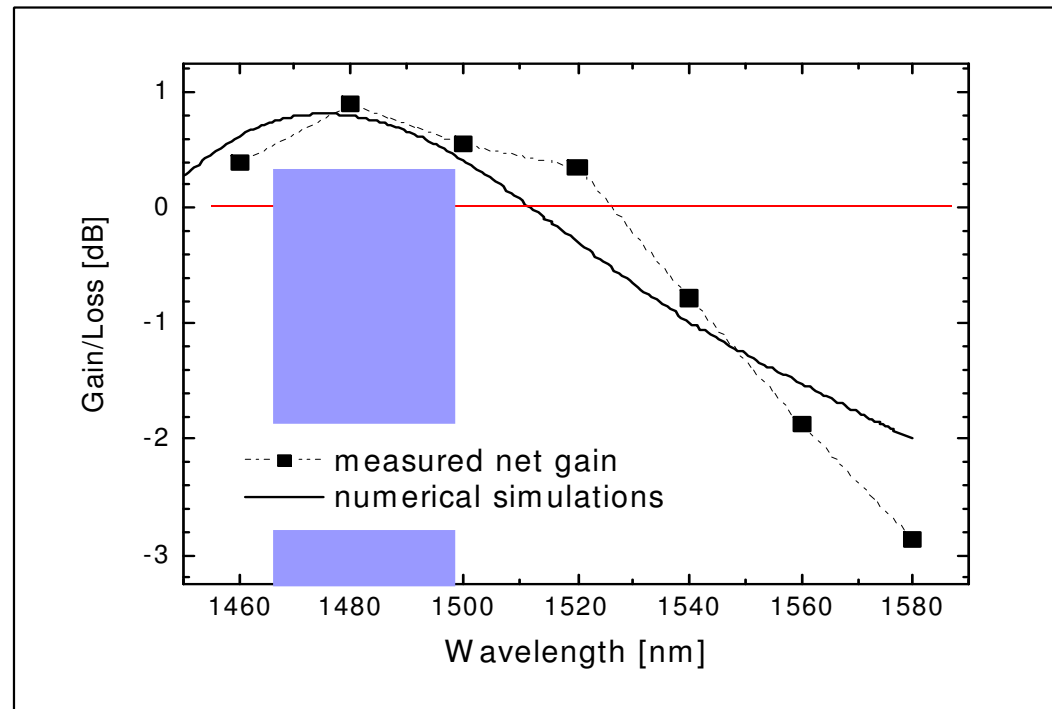
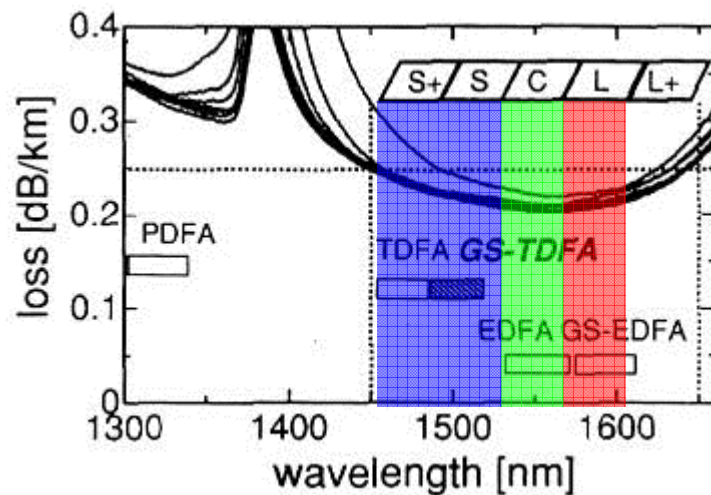
WDM

CWDM wavelength grid as specified by ITU-T G.694.2



Wavelength Division Multiplexing (WDM)

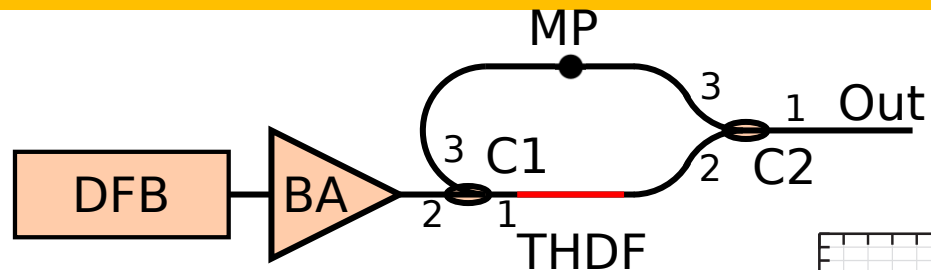
Tm³⁺-doped fiber for amplifier at 1470 nm



Non-optimized fiber parameters (low NA, low Tm³⁺ 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]

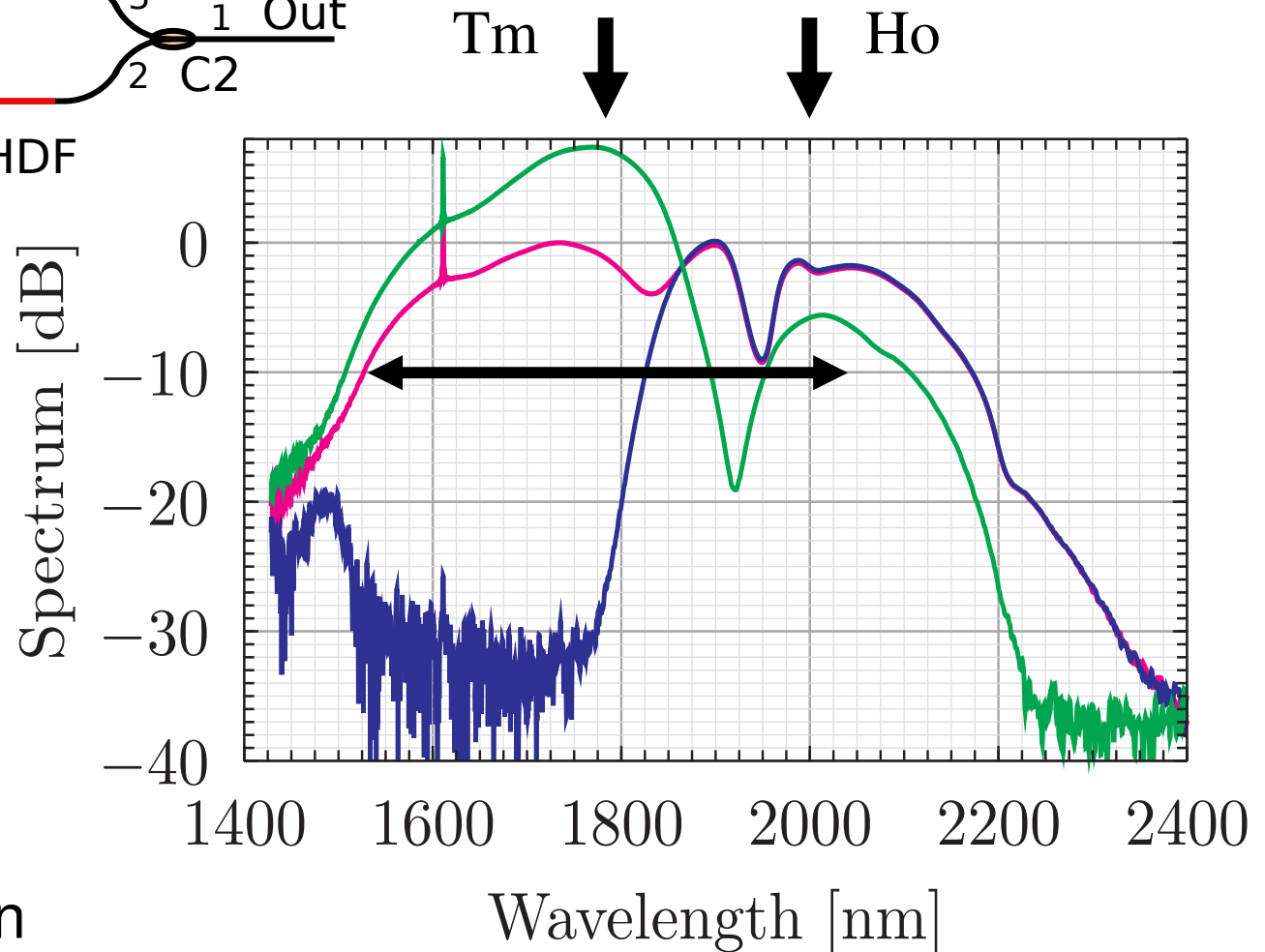
Tm/Ho – fiber for ASE source



GOAL: wide
fluorescence

Fiber: 1800 ppm
Tm / 360 ppm Ho

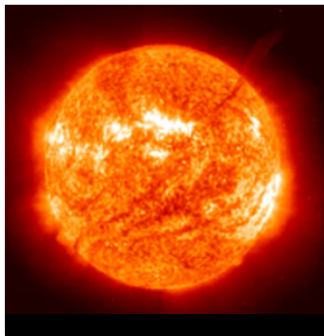
Backward emission
1550 – 2050 nm



[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)

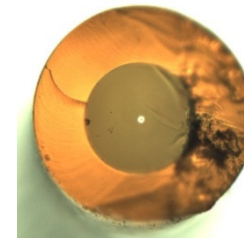


sun
fiber laser

63 MW/m²
12.7 GW/m²



[IPG]

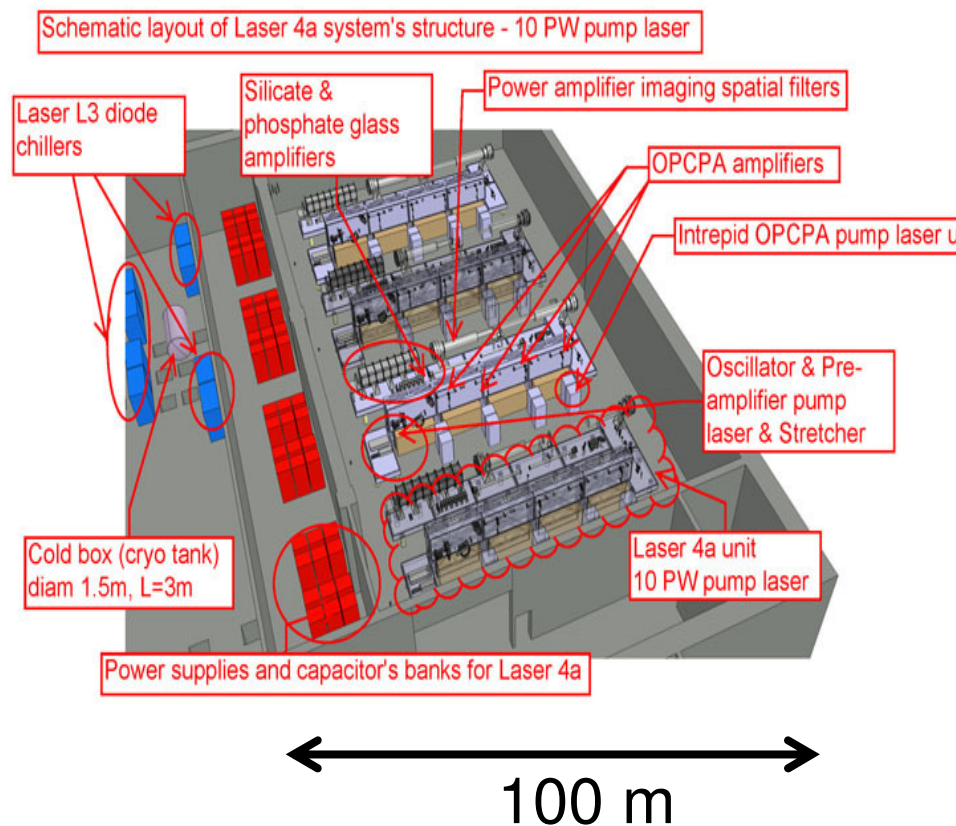


Fiber lasers vers. solid state lasers (SSL)

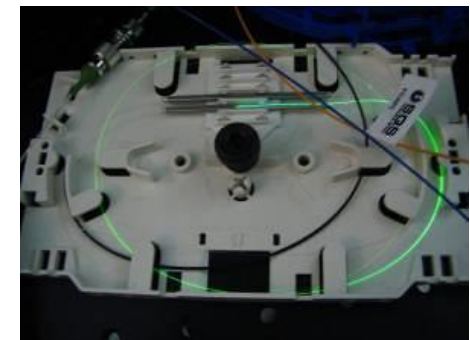
- High brightness + flexibility

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

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



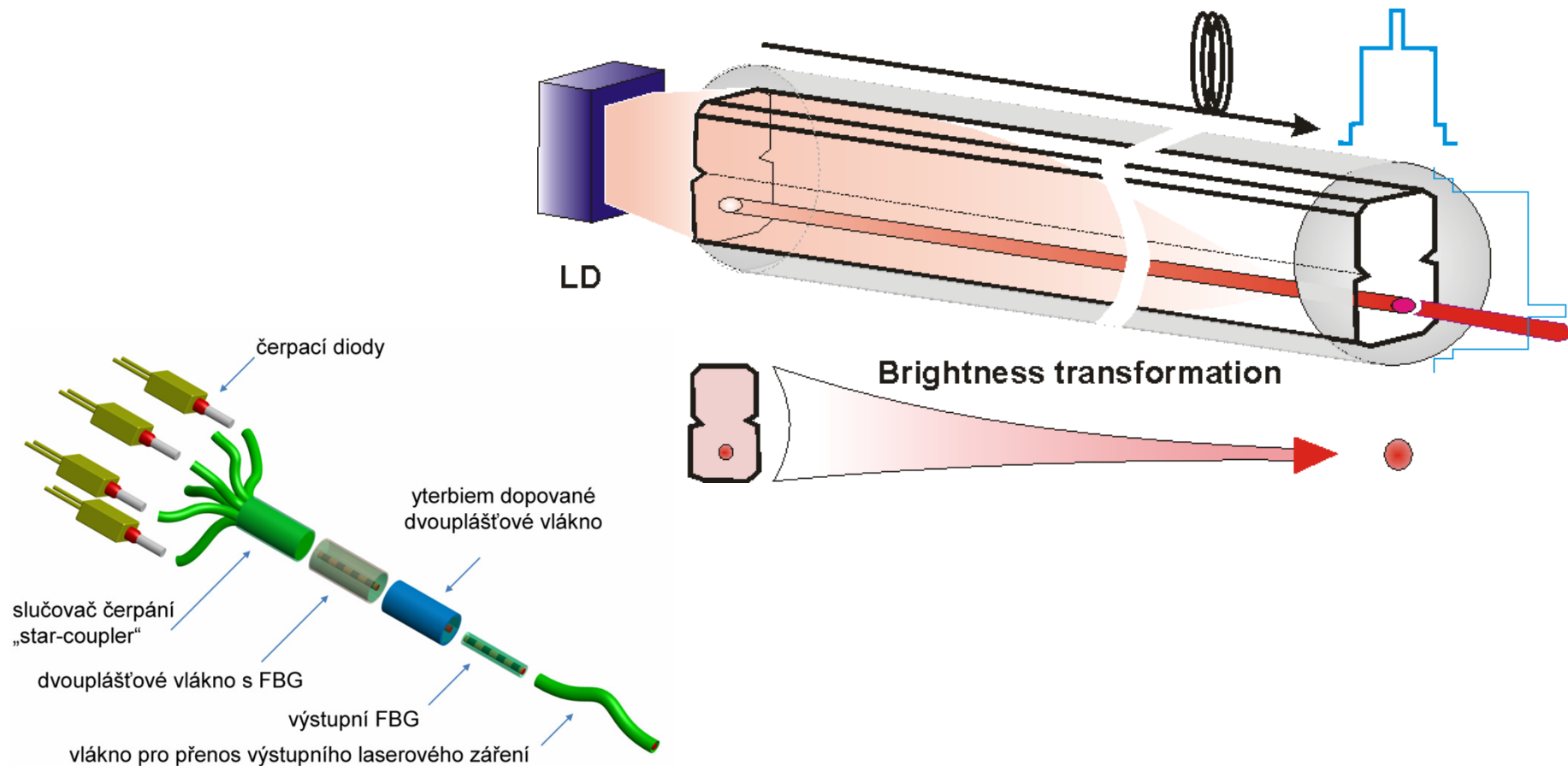
1 m



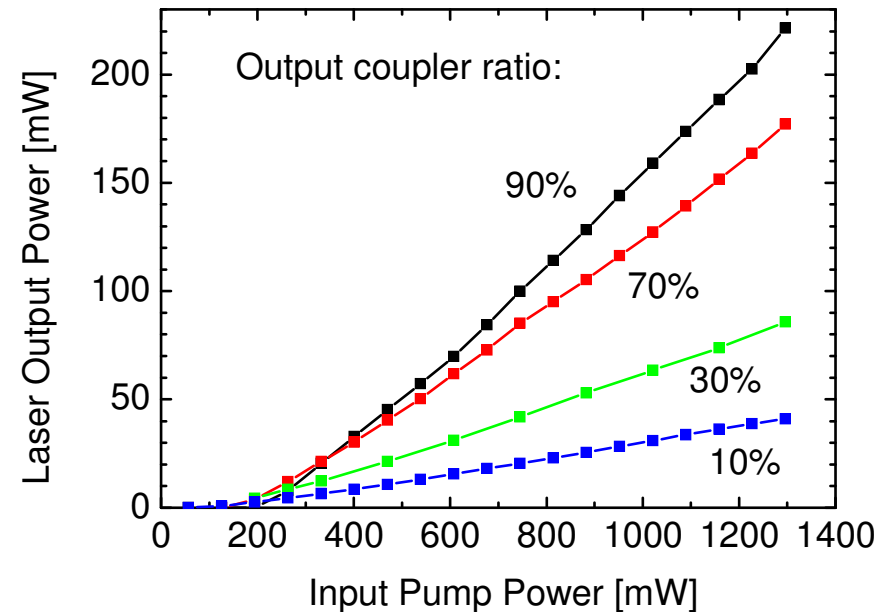
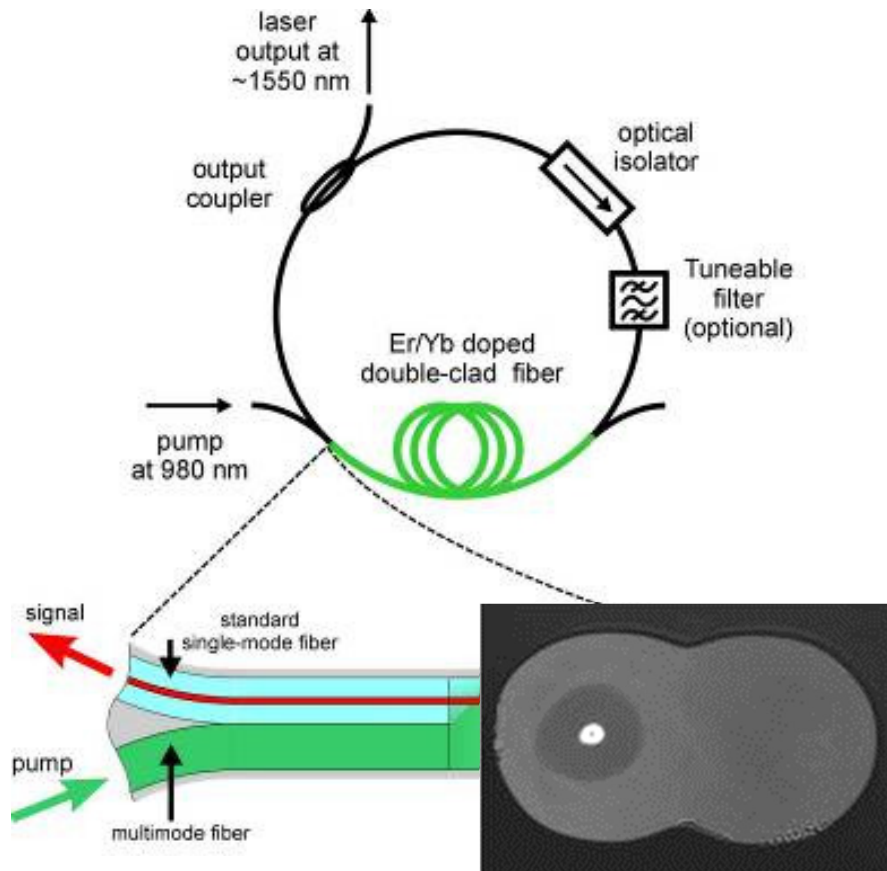
0.1 m

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

DC structures, beam combining ..



Er/Yb -doped DC fiber



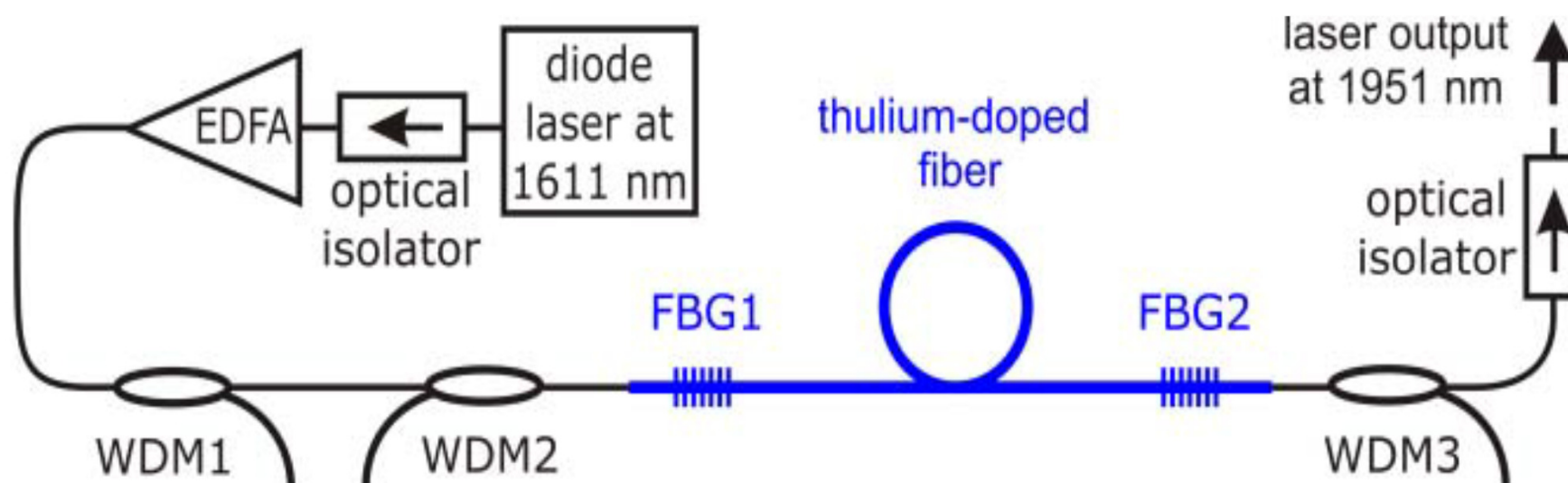
PCE 19 → 40%

[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]

Kouzlo optických vláken a ...

Monolithic **Tm**-doped fiber laser at 1951 nm

Eye-safe spectral region

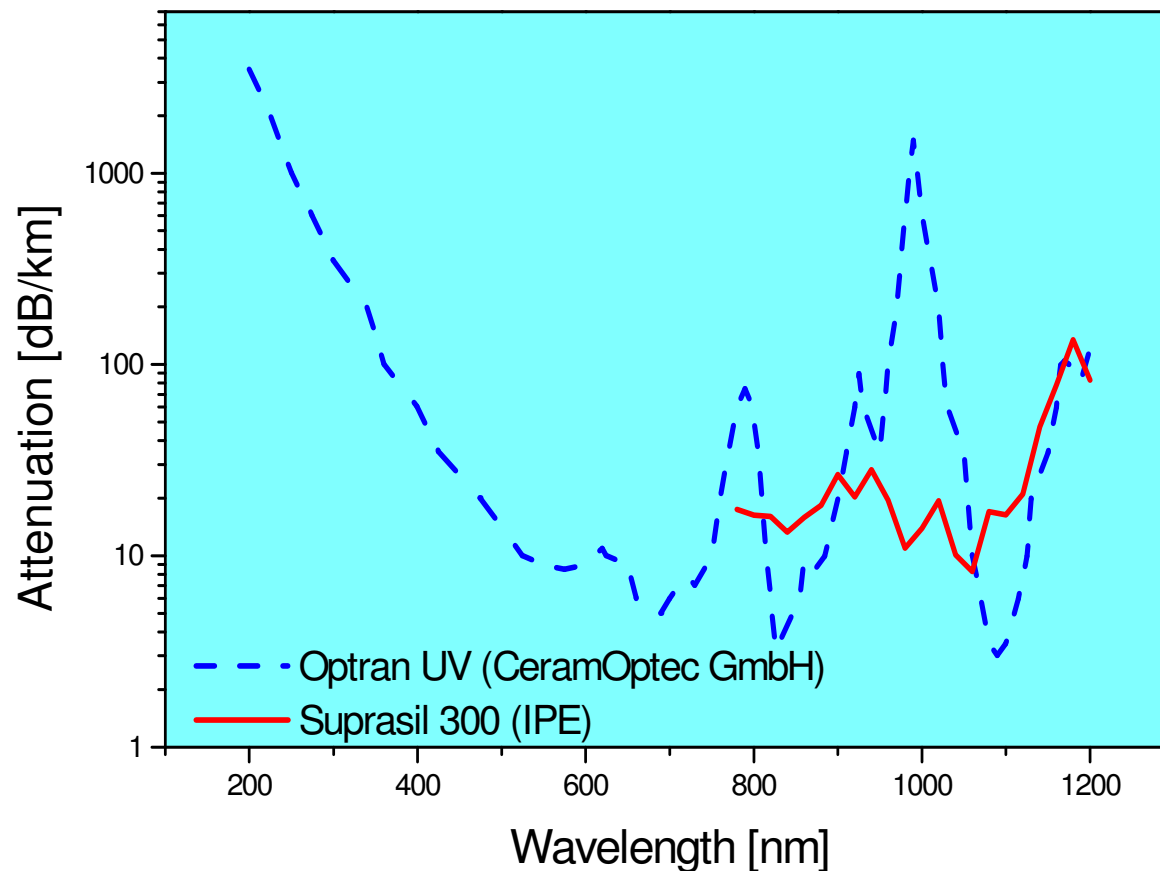


- * Tm^{3+} - Al_2O_3 - SiO_2 core (Al_2O_3 nanoparticles),
- * 1000 ppm Tm^{3+} , 11mol% Al_2O_3 , 0 mol% P_2O_5 or GeO_2 ,
- * **deep-UV inscription of FBG**

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

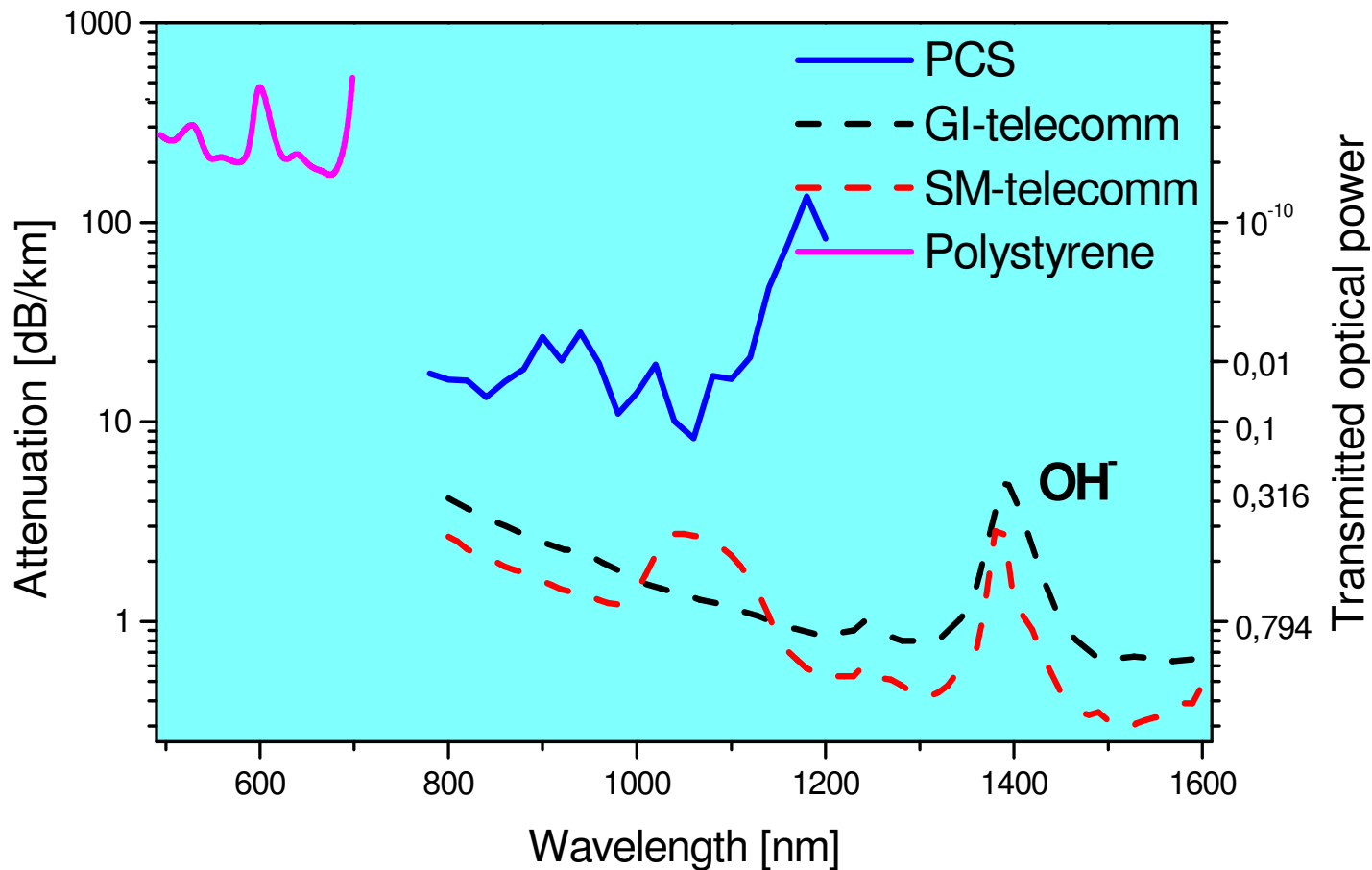
Reminder:

OPTICAL FIBRES – Materials - UV



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

Reminder: OPTICAL FIBRES – VIS/NIR

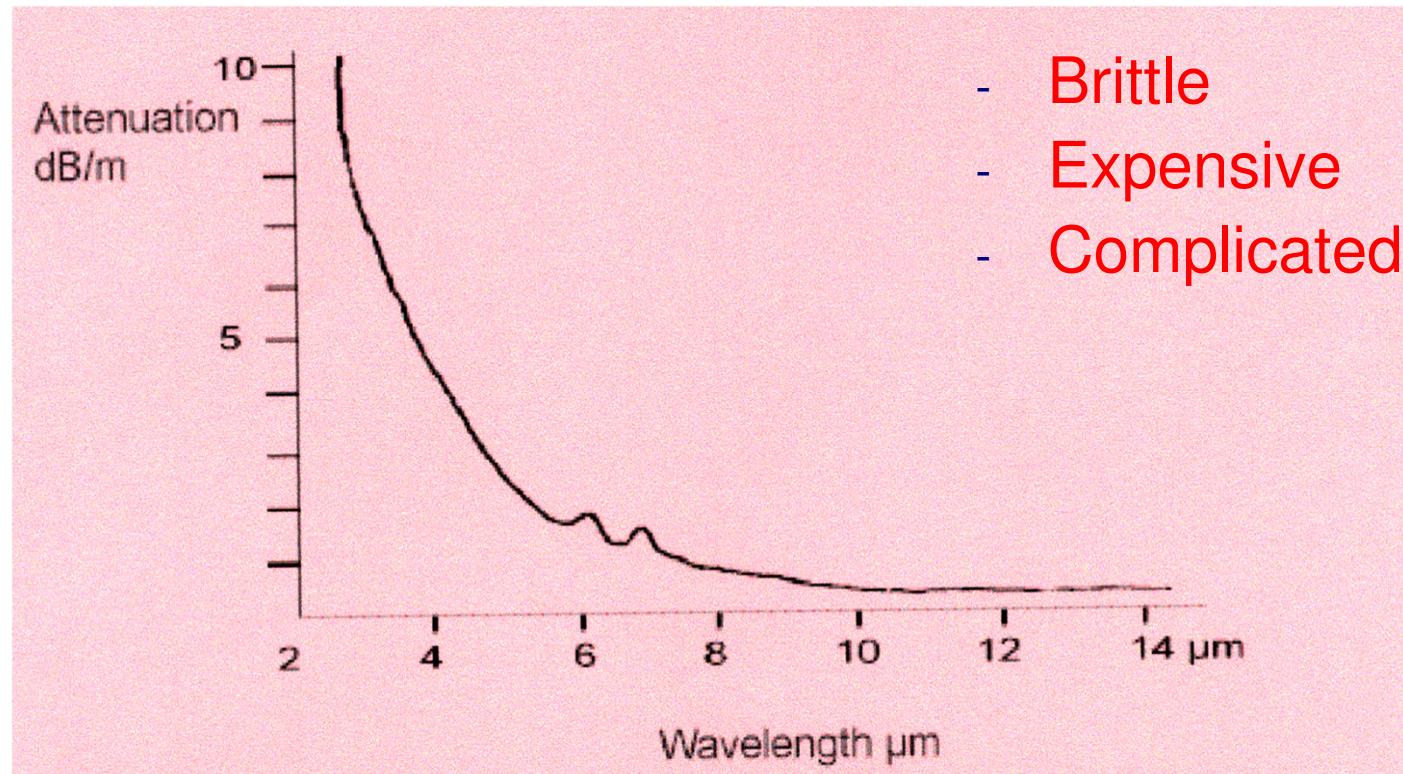


Silica $n_{633} = 1.457$ & doped silica $n_{633} = 1.45-1.50$ [corning, lucent, ocean_o, IPE]

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 $\text{AgCl}_x\text{Br}_{1-x}$ (up to 15 μm)
- chalcogen glasses (Se , As_2S_3 , As_2Se_3 ...) [[oxford-electronics](#), orc.soton.ac.uk] (< 20 μm)
- refractive indexes $_{2-20\mu\text{m}} \sim 2 - 2.5 \gg$ 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**

UFE

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*



ZÁKLADNÍ VÝZKUM: Fotonika

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