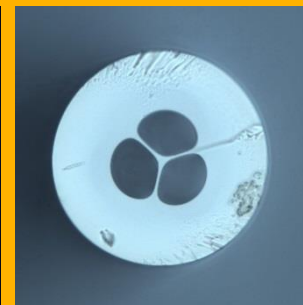
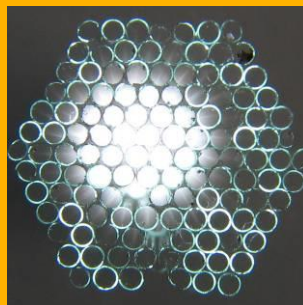




ÚFE

Kouzlo optických vláken a vláknových laserů

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



ÚFE



www.ufe.cz

Institute of Photonics and Electronics



*Assoc. Prof. Pavel
Peterka, PhD.*

**Academy
of
Sciences**



*Dr. Ing. Pavel
Honzátka*

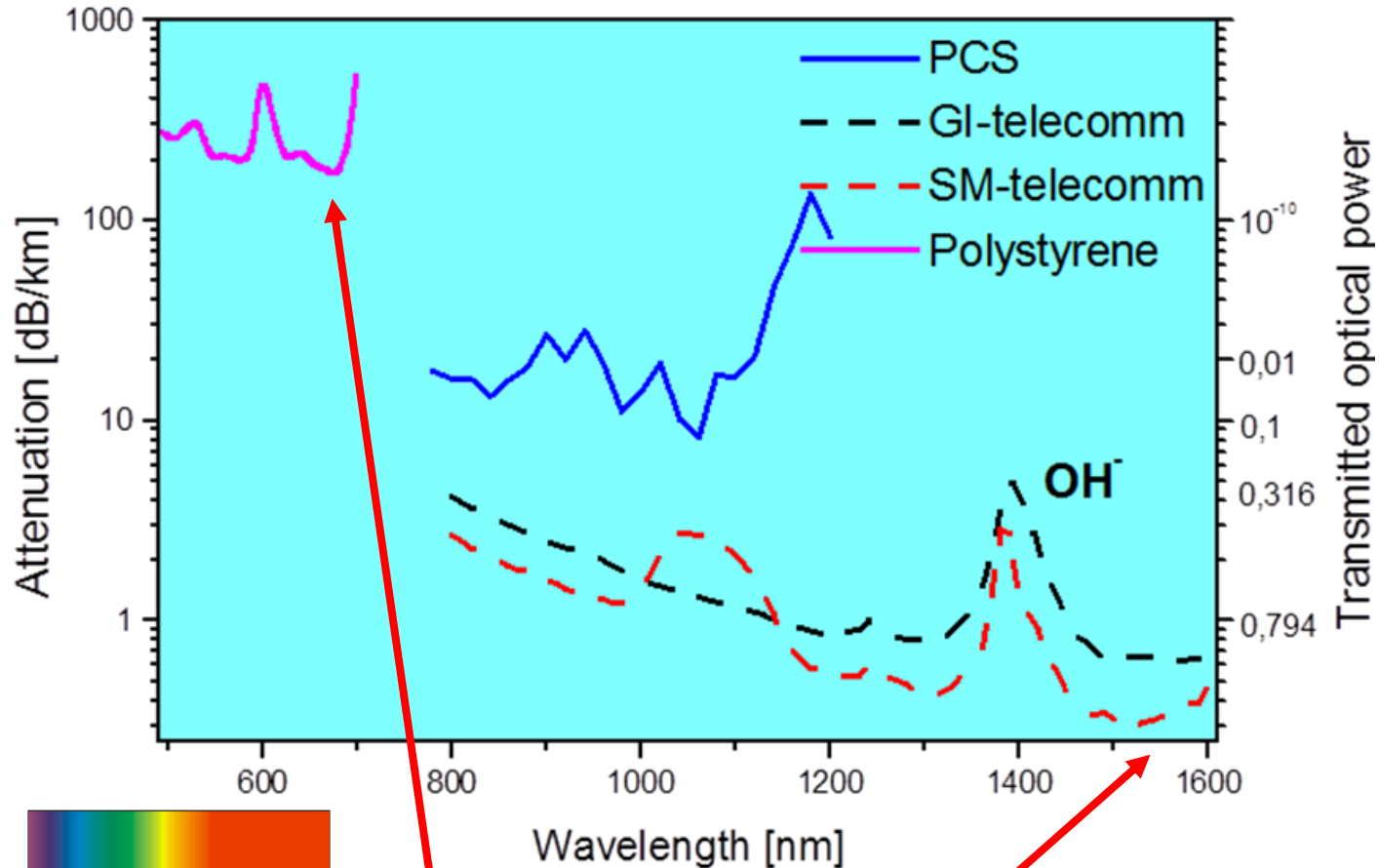
Fiber Lasers and Non-linear Optics = FILANO – 15-22 FTE

Optical fiber

Opakování je matka moudrosti ☺

Dielectric structure, $L \gg r$, $n_{\text{core}} > n_{\text{cladd}}$

Total reflection

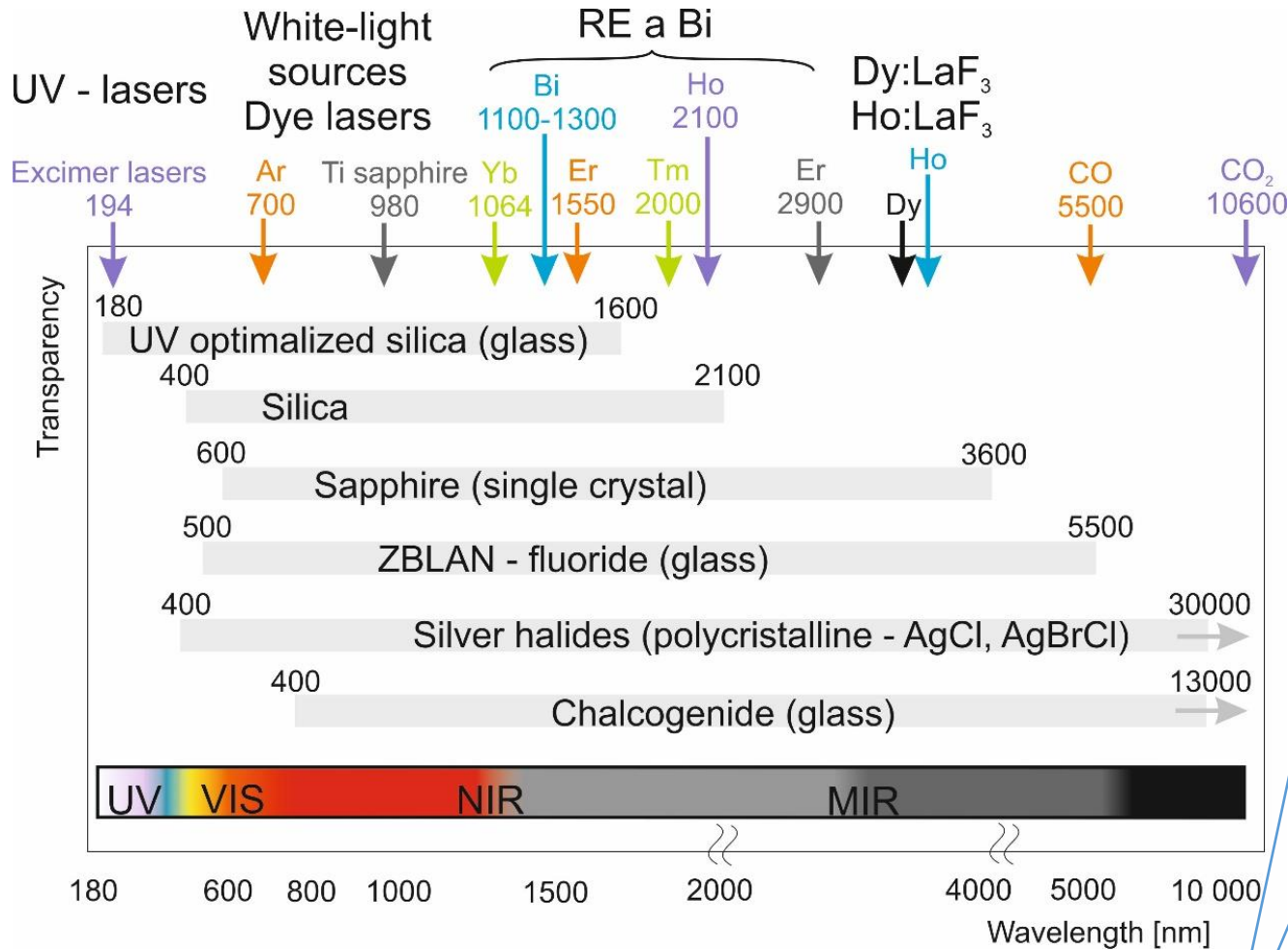


Intrinsic losses

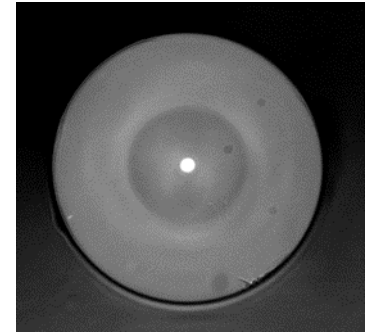
Silica RI = 1,457

Optical fibers

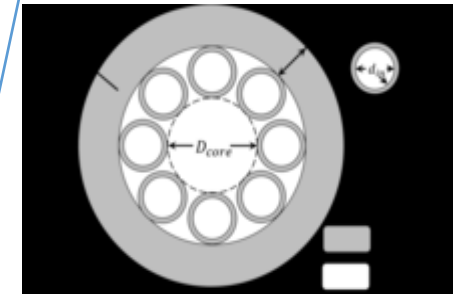
Opakování je matka moudrosti ☺



Solid core



Hollow core



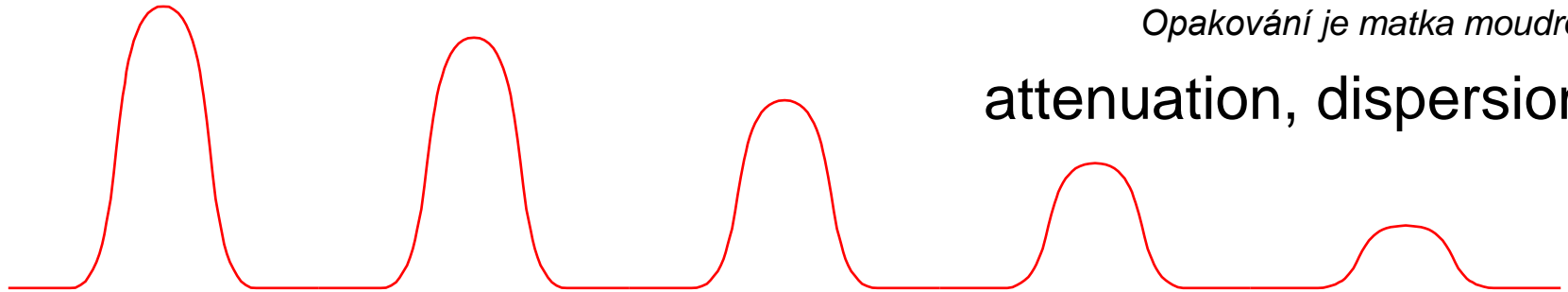
[Komsomol]



Optical fiber : material of high purity

Opakování je matka moudrosti ☺

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})



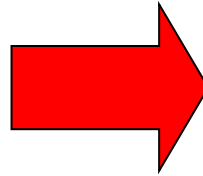
ULTRA-PURE TECHNOLOGIES

Optical fiber technology

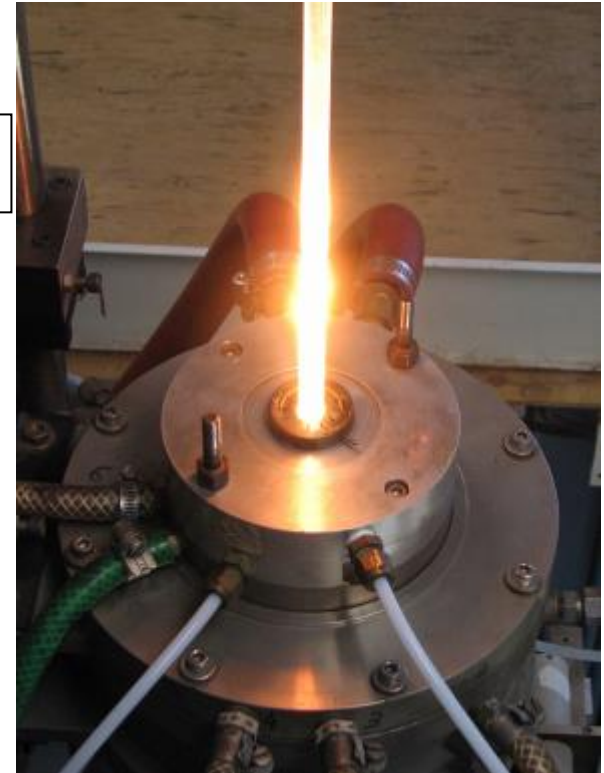


MCVD

1. Preform



2. Fiber drawing

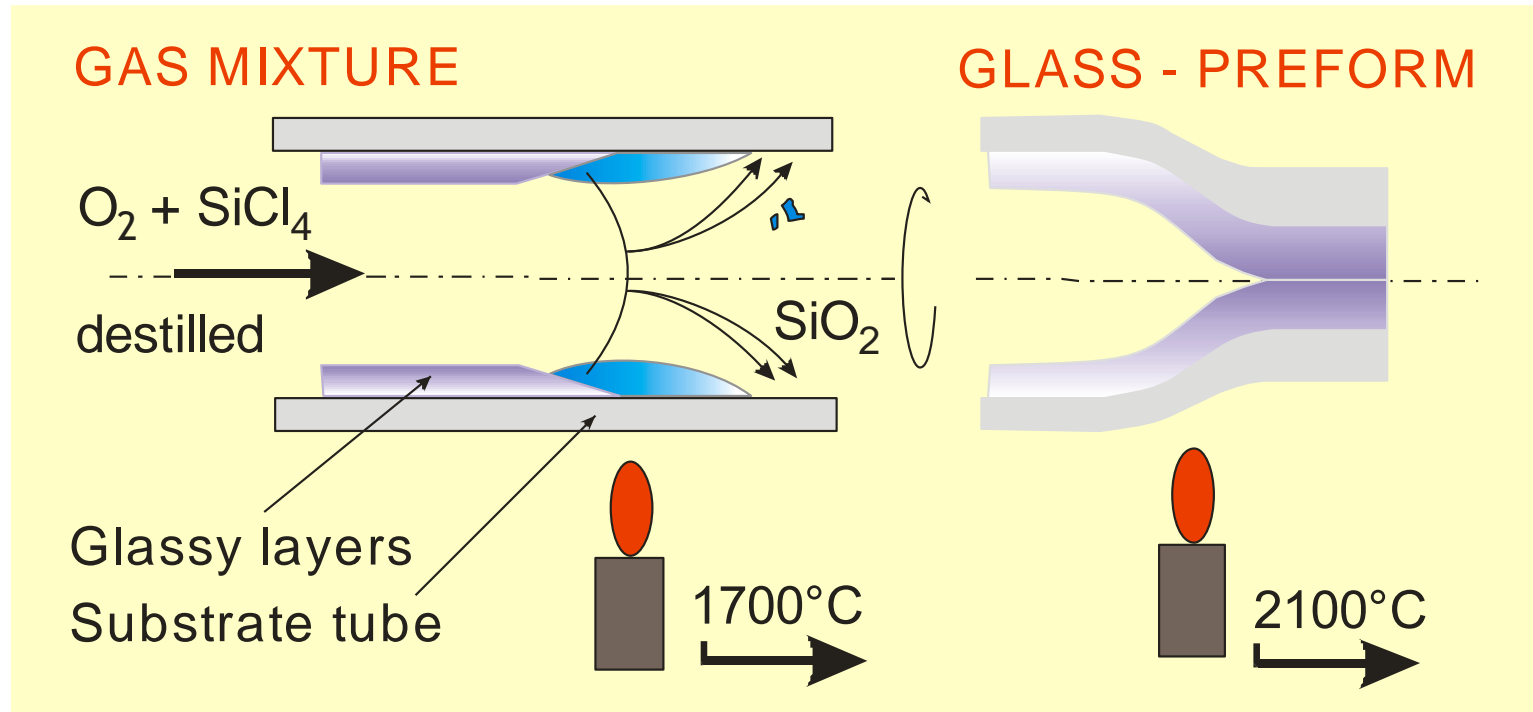


Preform fabrication

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 %)

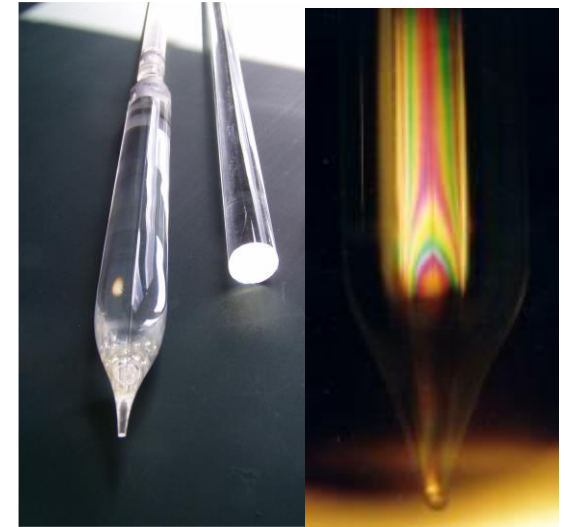
Preform fabrication



Distilled
halogenides

Deposition
of layers

Preform
collapse

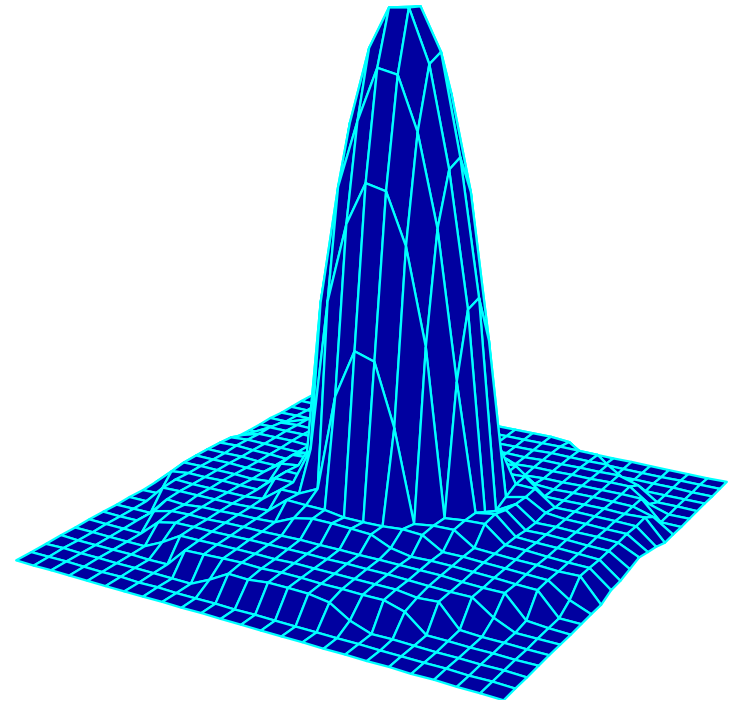


Preforms

Preform fabrication



Microphoto of cross section of produced preform



Tomography of the refractive-index profile of preform

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

Industrial preform fabrication

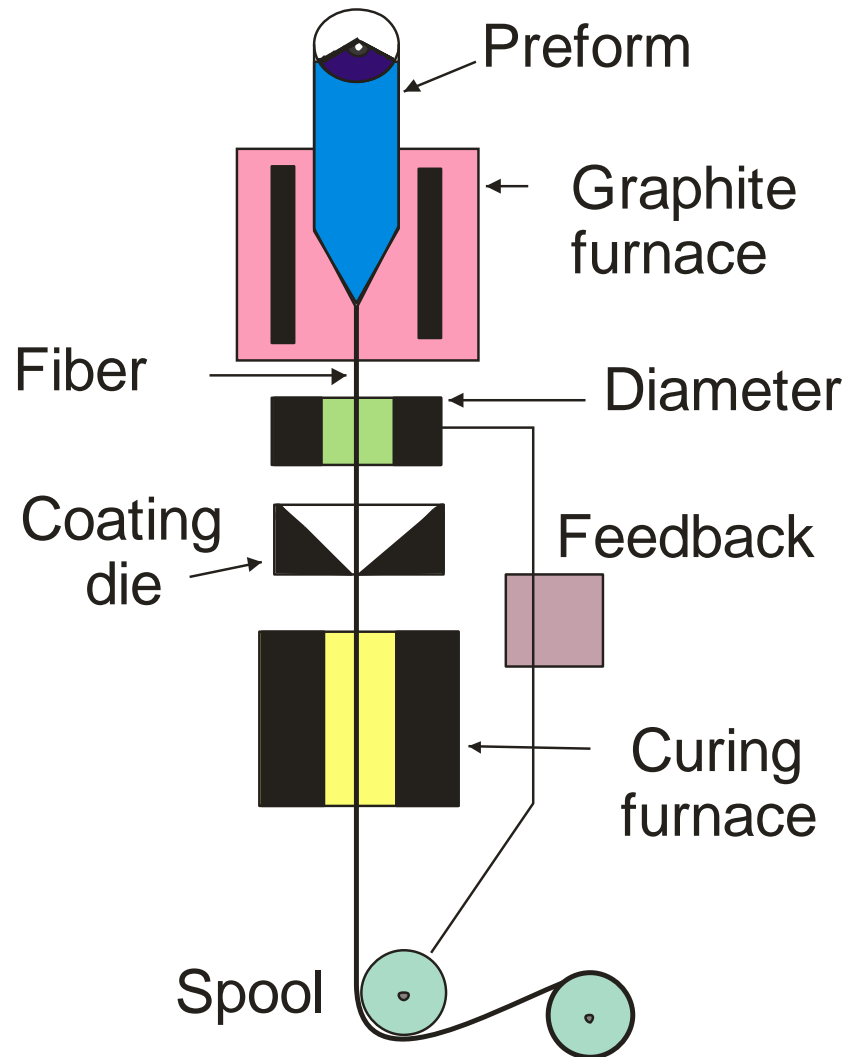


- Preform diameter
~ 230 mm
- Drawing speed
~ 1-2,5 km/min !
- Fiber length
~ 10 000 km !
- Price
<0,05 USD/m

<https://rosendahlnextrom.com/fiber/products/telecom-preform-fiber/>

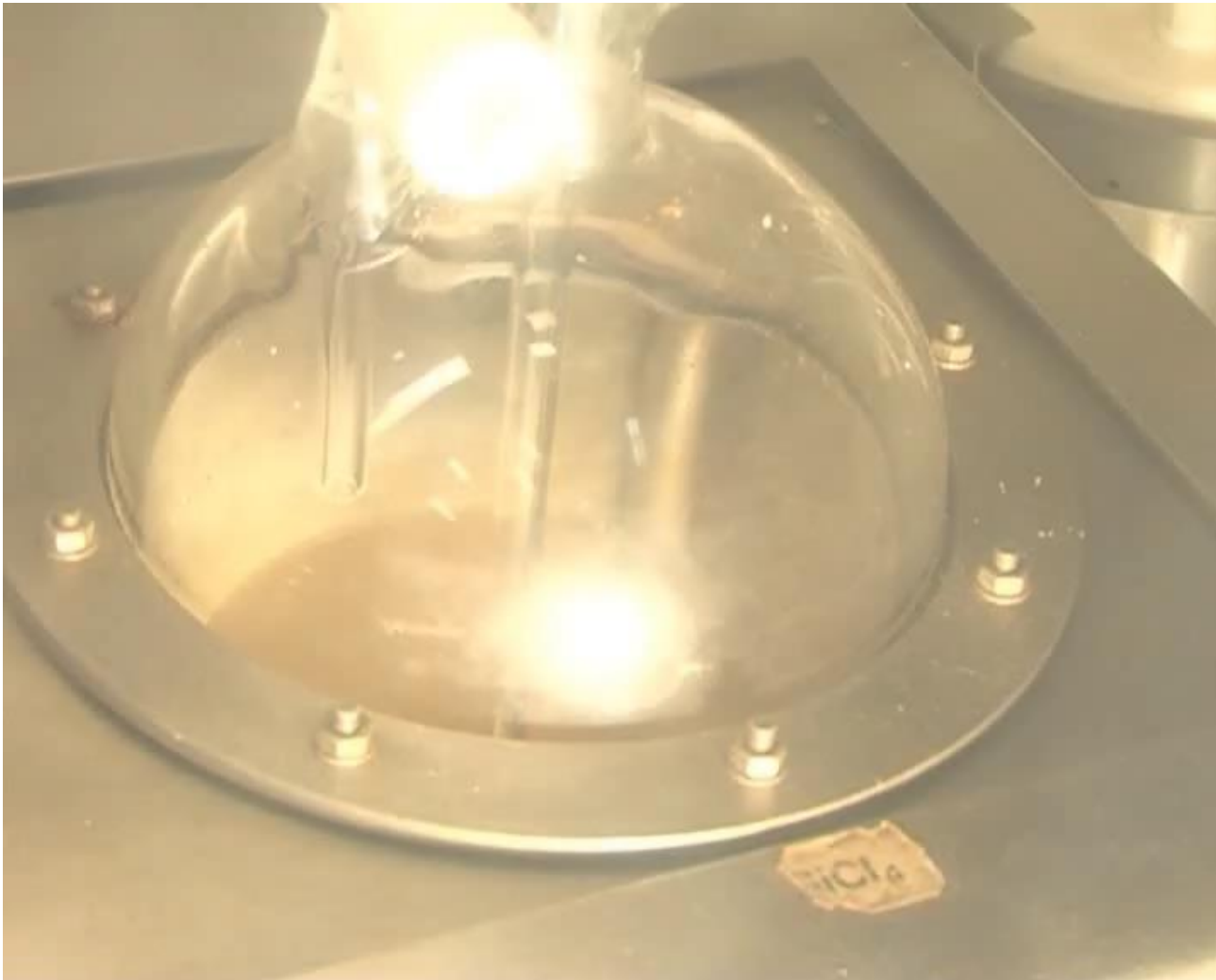
https://www.heraeus.com/en/hcv/products_and_solutions_1/ric/ric_cylinders/ric_cylinders_1.html

Drawing of optical fibers from preforms



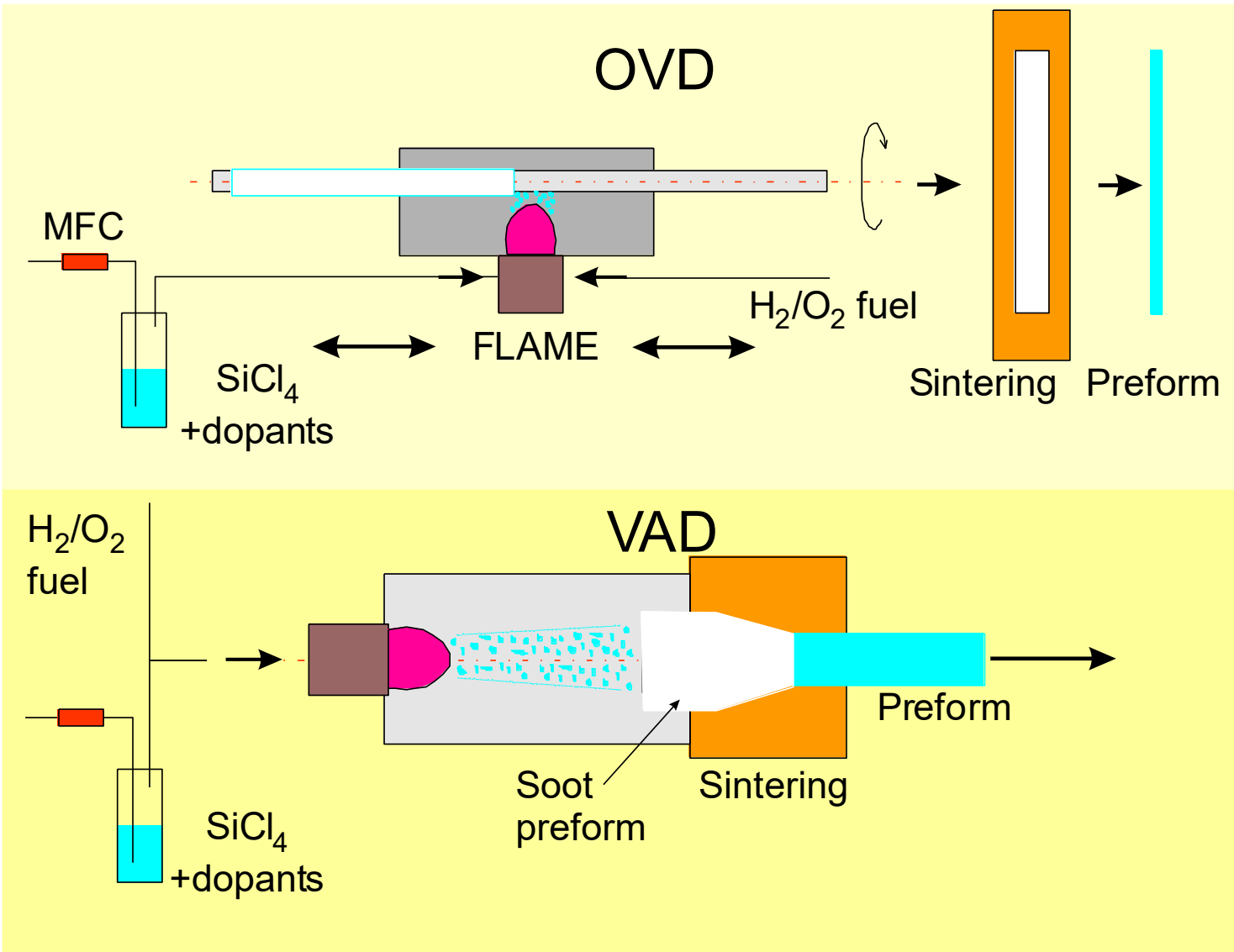
- Diameter
 - 80-1000 μm
- Temperature
 - 1800-2100 $^{\circ}\text{C}$
- No textile
- No thermo-insulation

Optical fiber drawing

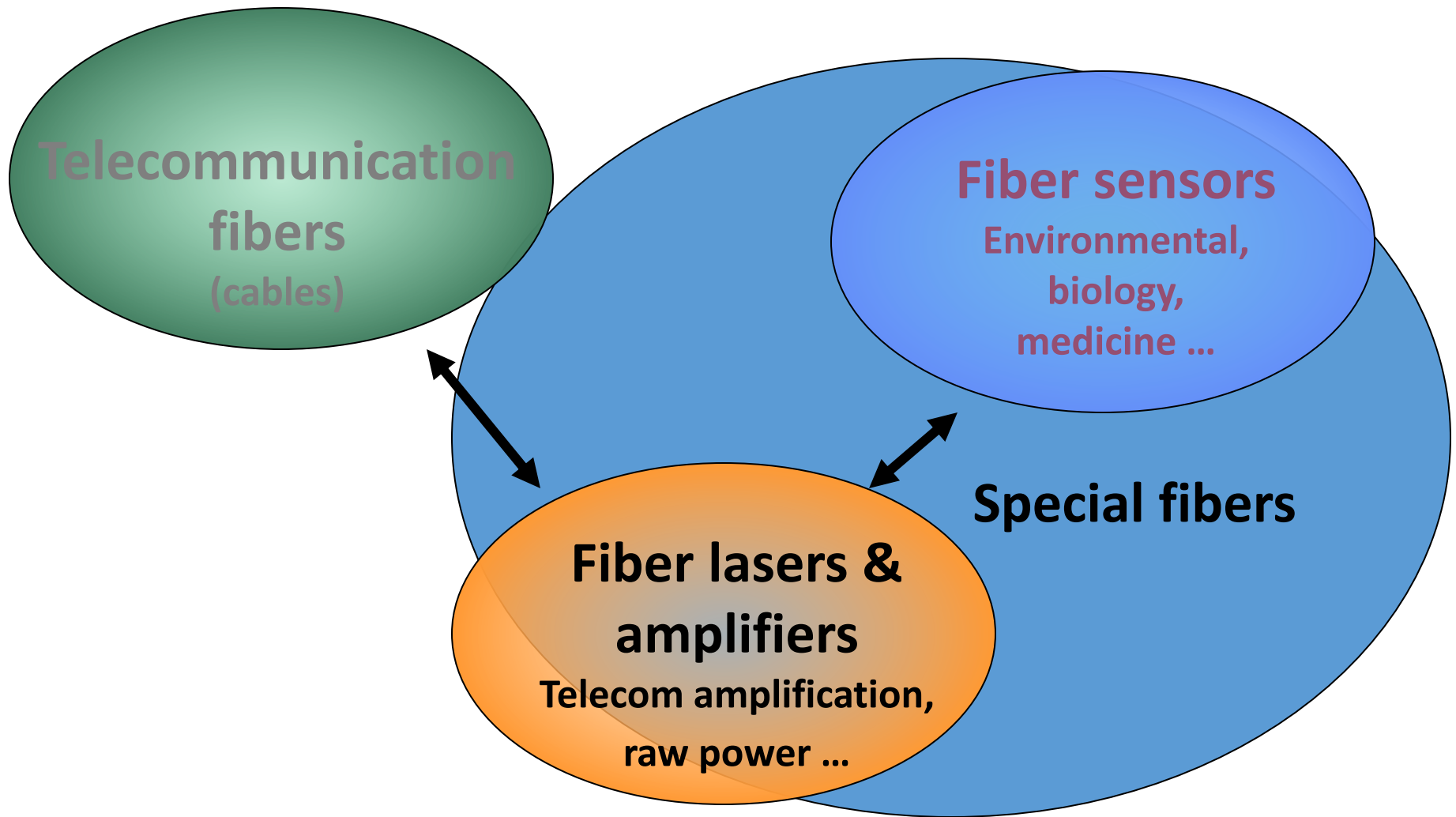


[J. Šerých & students of SPS SD Panska]

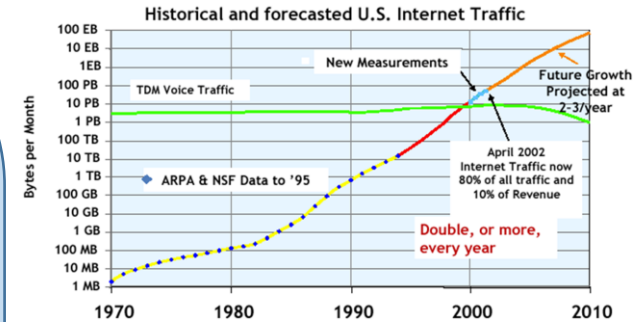
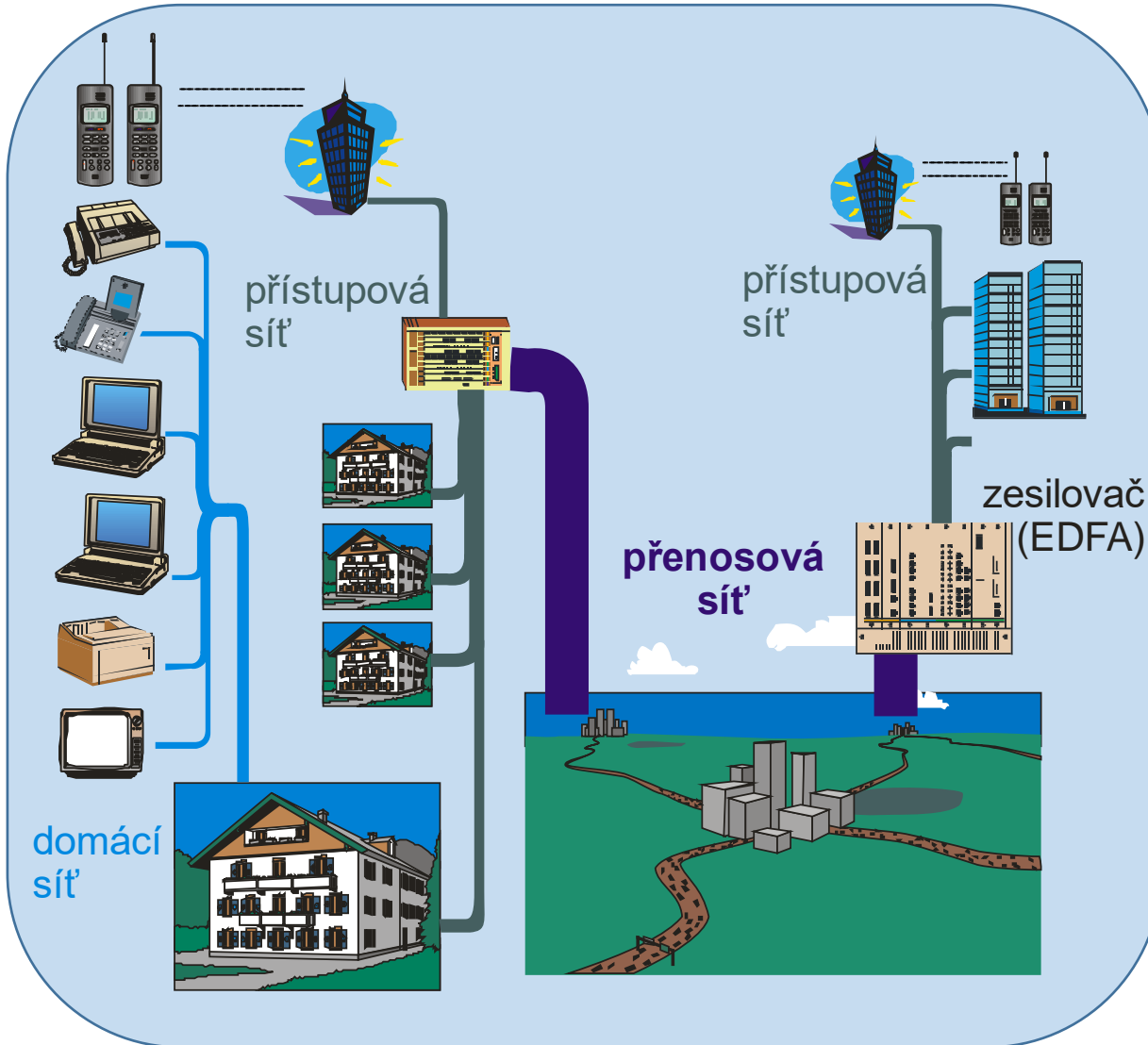
Other CVD technologies



Application



Telecomm – optical communication



Y axis = Log

~2017 O₂ 40Mbps

~2022 O₂ 1Gbps

vers.

Sat 2021 O₂
3000Kc/month

=> Full optical
processing

Telecomm – hi story



[P. Peterka, JMO, 2015]

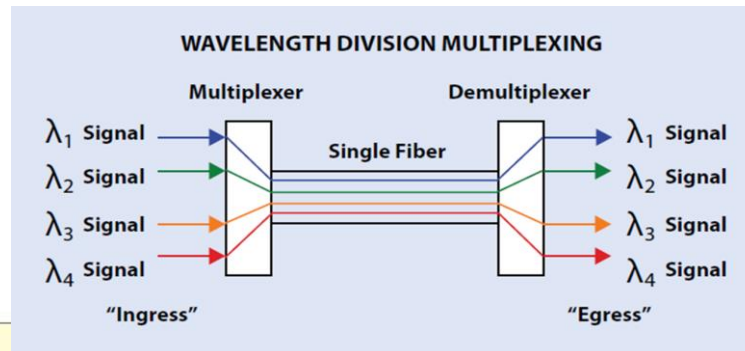
1966 : free space optical transmission
Kobylisy (ÚRE) – Novodvorská (VÚST)
1983 : **optical fiber** transmission
Karlův most (Česká televize)



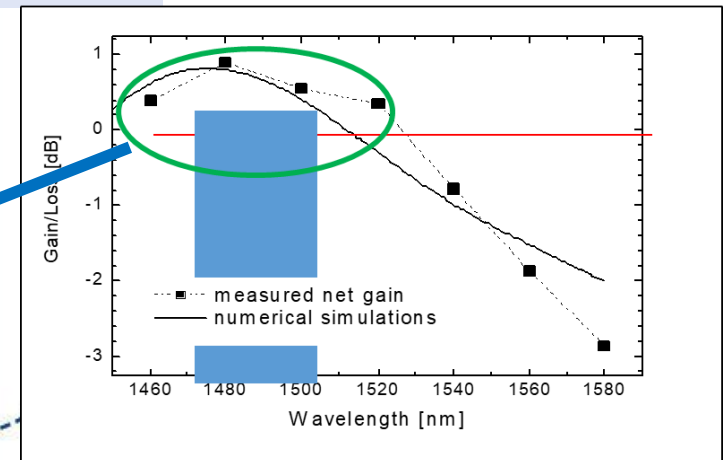
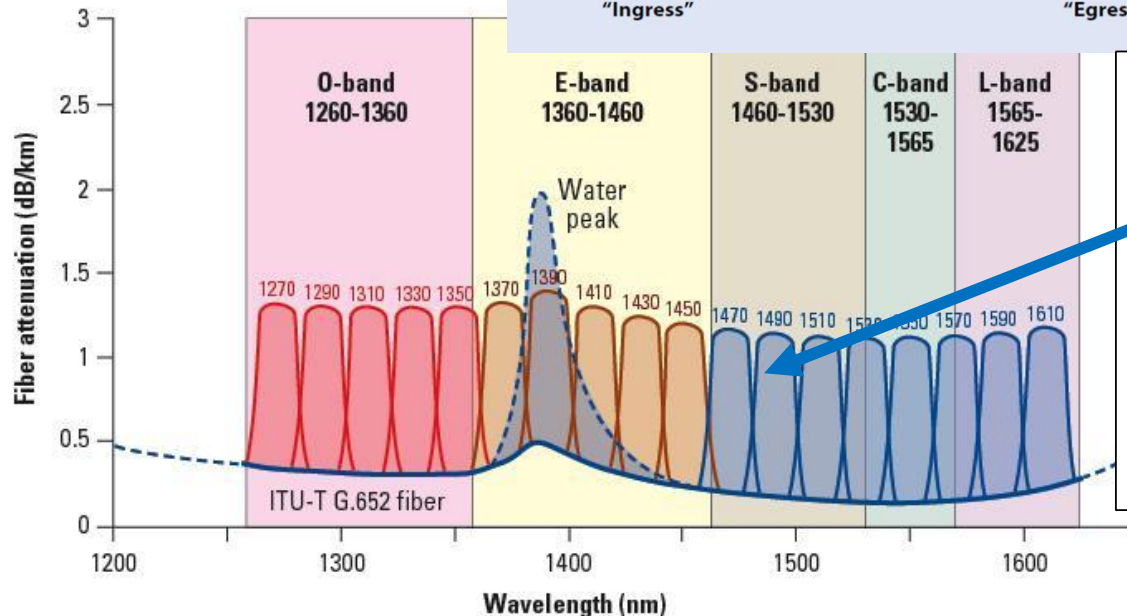
36 [kB/s] => [TB/s]
Full optical transmission & processing

Fiber amplifiers (telecomm [mW]) => Full optical processing

Wavelength Division Multiplexing (WDM)

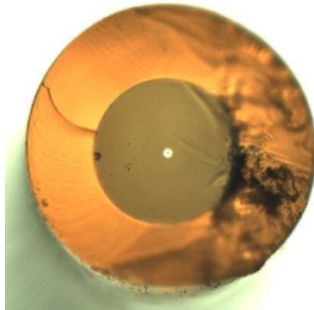
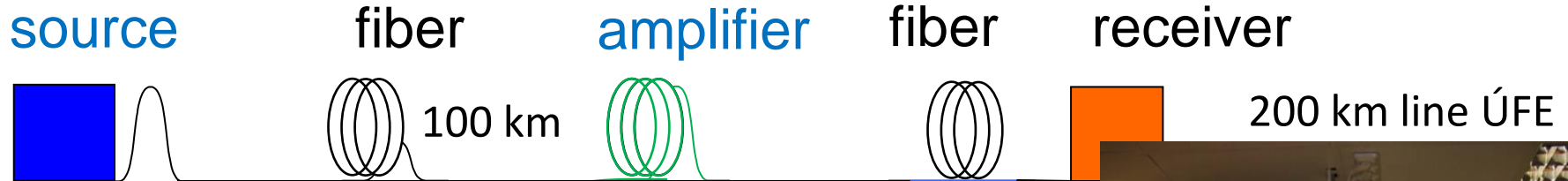


Tm^{3+} TDFA



Telecomm – optical communication

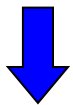
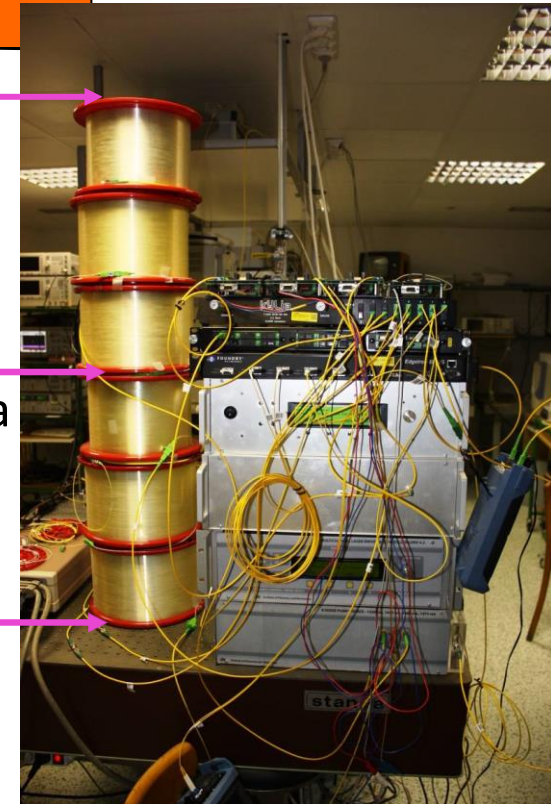
Passive (transmission) & **active** (amplification, sources) fibers



Praha

Jihlava

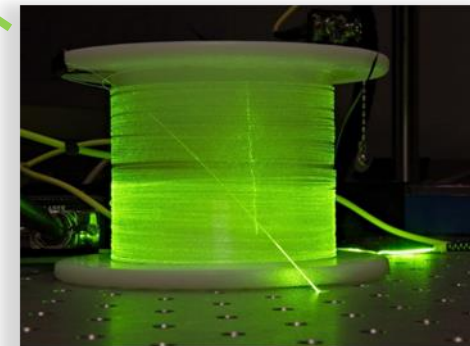
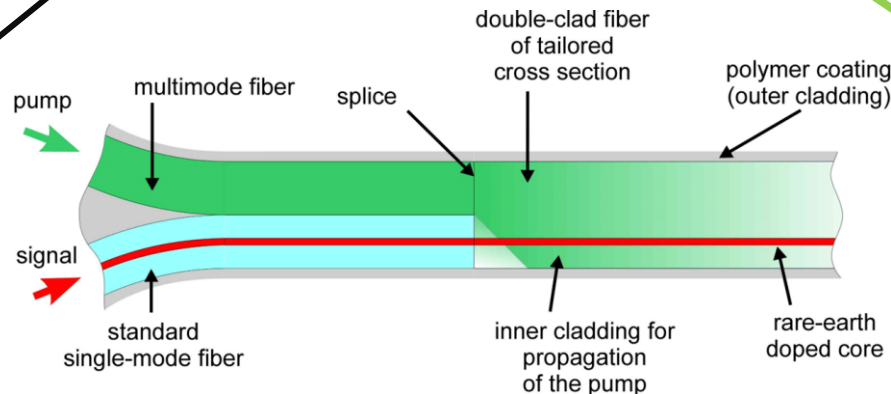
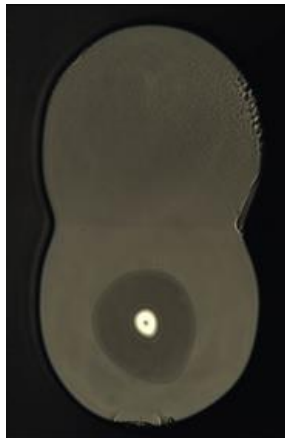
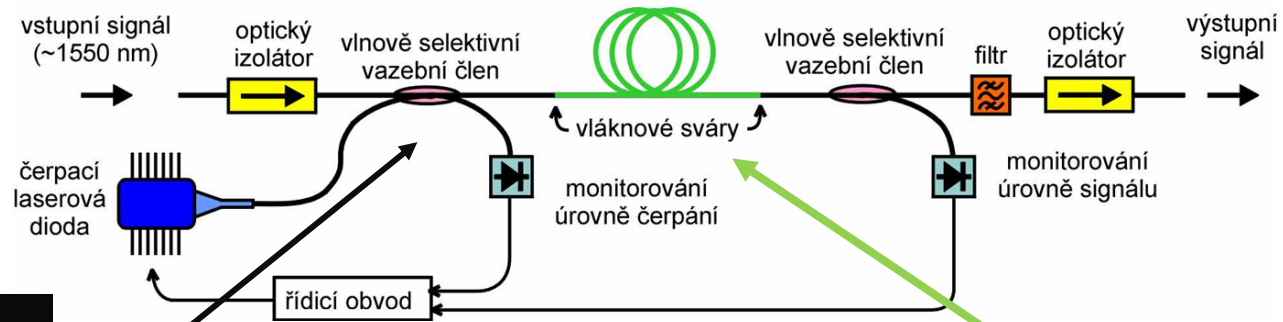
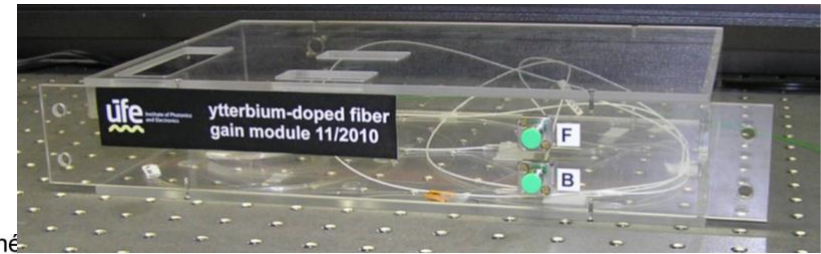
Brno



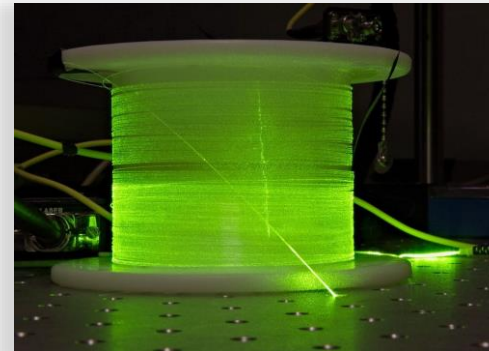
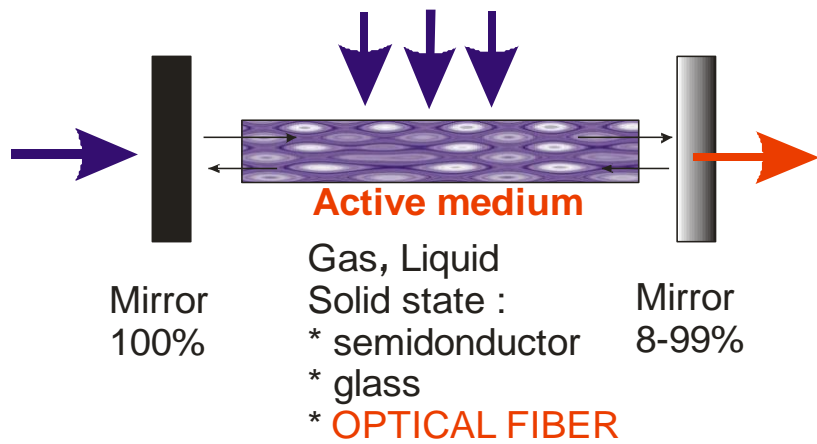
Fiber amplifier (FA)
Fiber laser (FL)

Fiber amplifiers (EDFA - Telecomm) [mW]

1550 nm



Fiber lasers (& amplifiers)

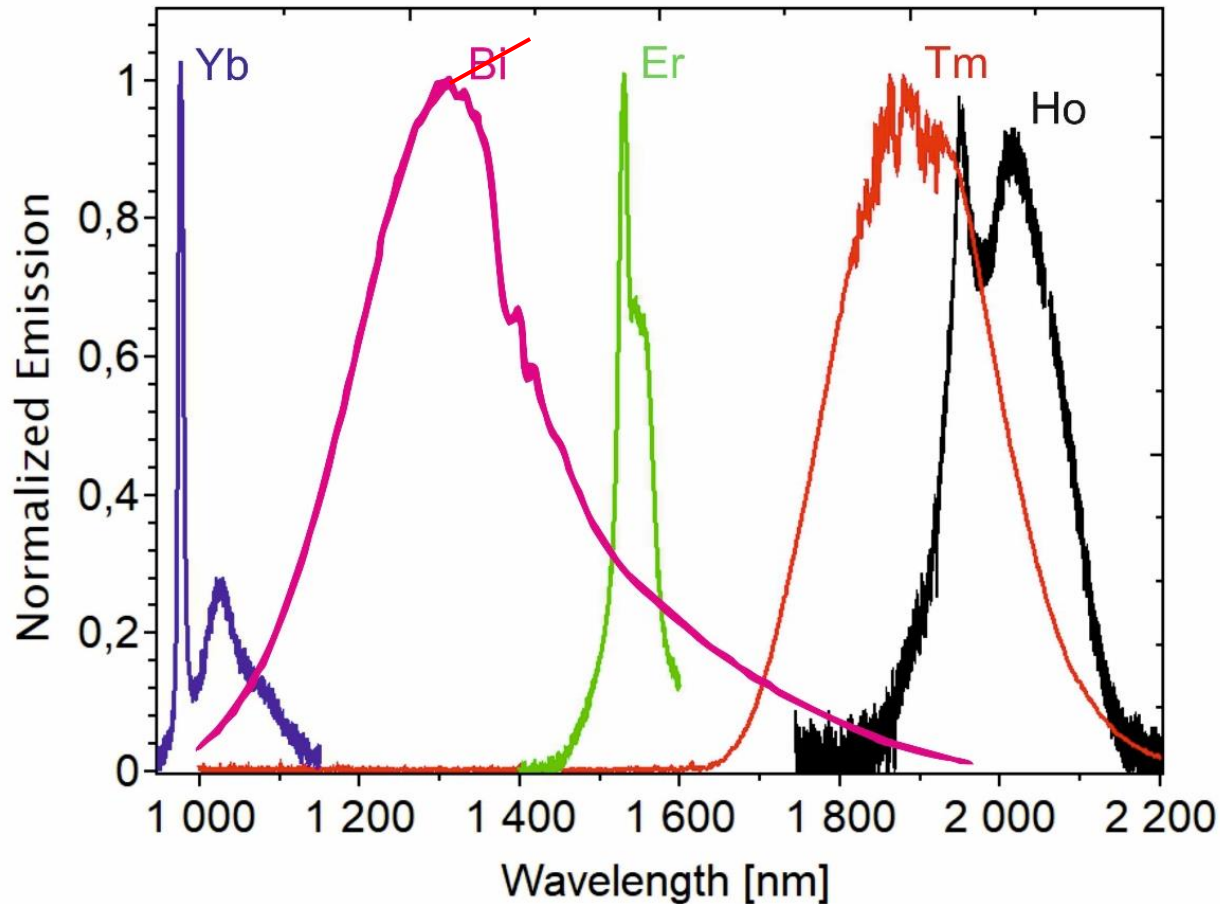


Er³⁺ 1550 nm
RARE EARTHS
Stimulated emission

[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]

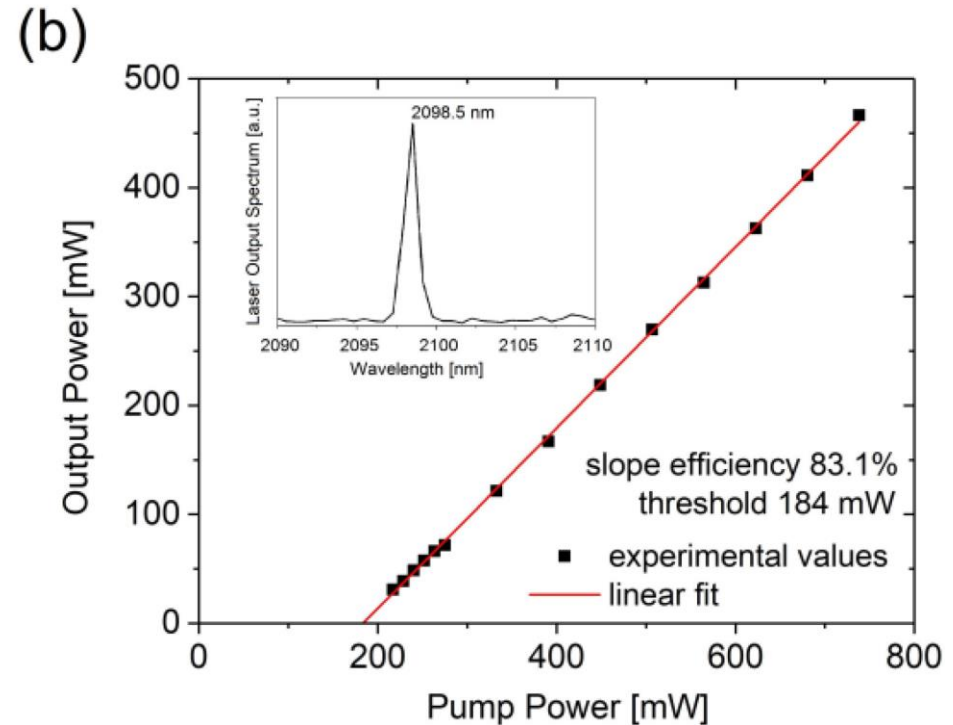
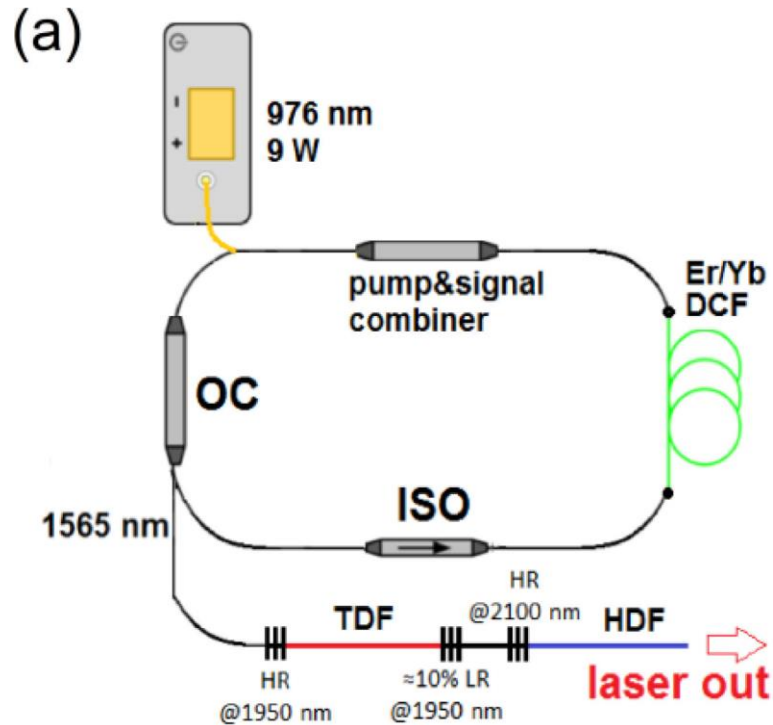
Optical fibers for fiber lasers

RE³⁺ -doped silica glass



Ho fiber laser

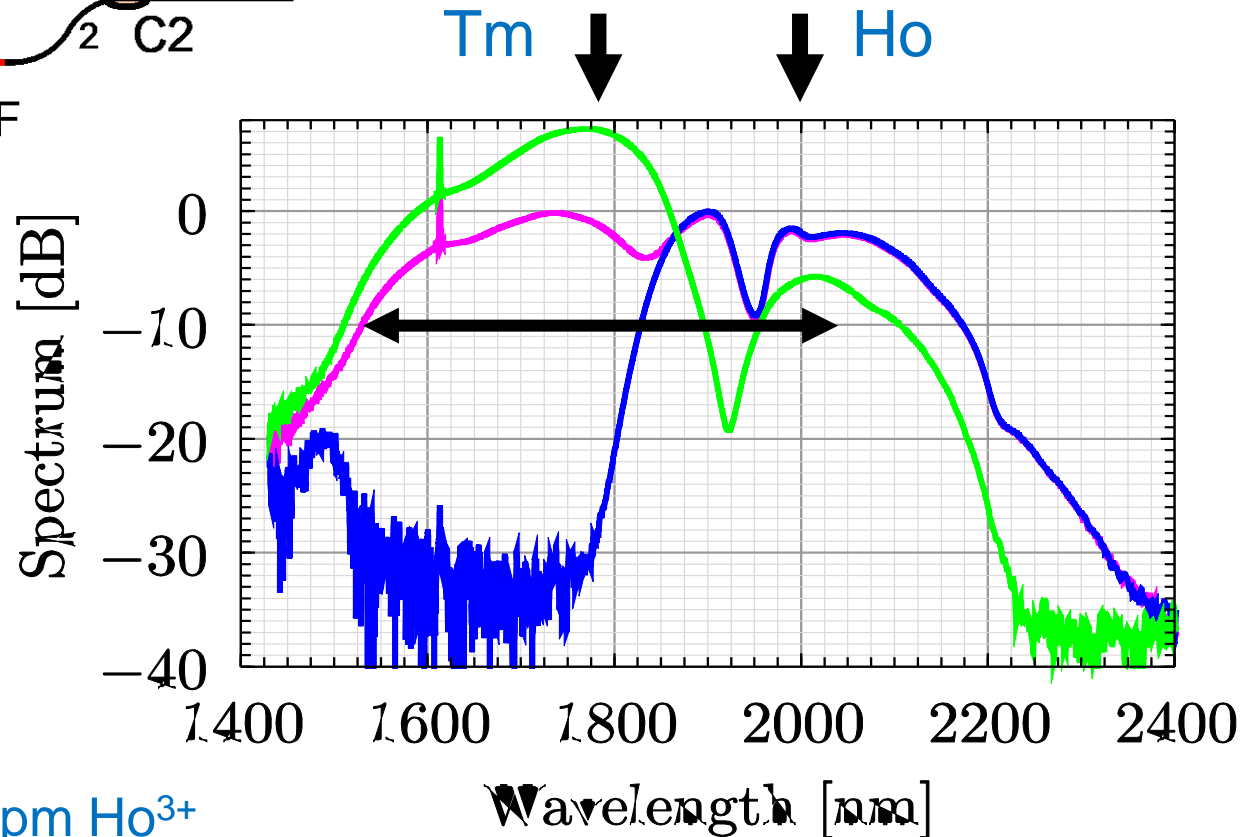
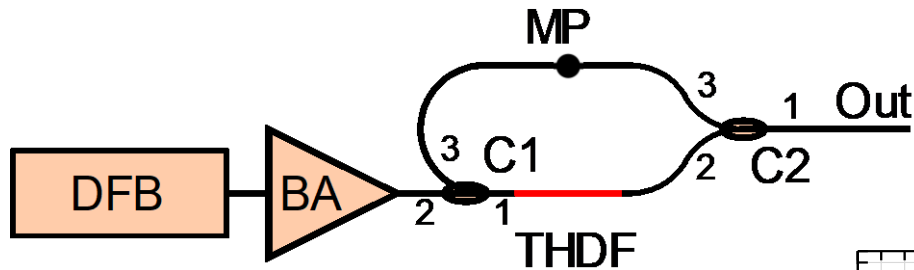
2098 nm



M. Kamrádek, I. Kašík, J. Aubrecht, J. Mrázek, O. Podrazký, J. Cajzl, P. Vařák, V. Kubeček, „Ceramic nanoparticle-doping implementation into MCVD method for fabrication of holmium-doped fibers for fiber lasers, IEEE Photonics J. 11 (2019)

Tm/Ho ASE source (1550-2050 nm)

(≠ 1550 nm)



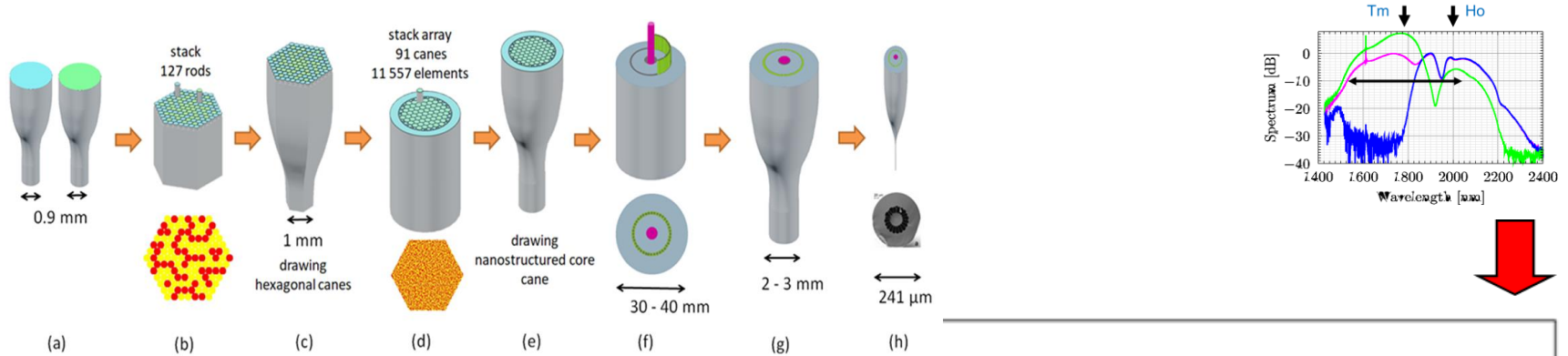
Optical fiber

1800 ppm Tm^{3+} / 360 ppm Ho^{3+}

P. Honzátko, Y. Baravets, I. Kašík, O. Podrazký: „Wideband thulium-holmium-doped fiber source with combined forward and backward ASE at 1600-2300 nm spectral band“, Optics Letters 39 (2014) 3650-3653

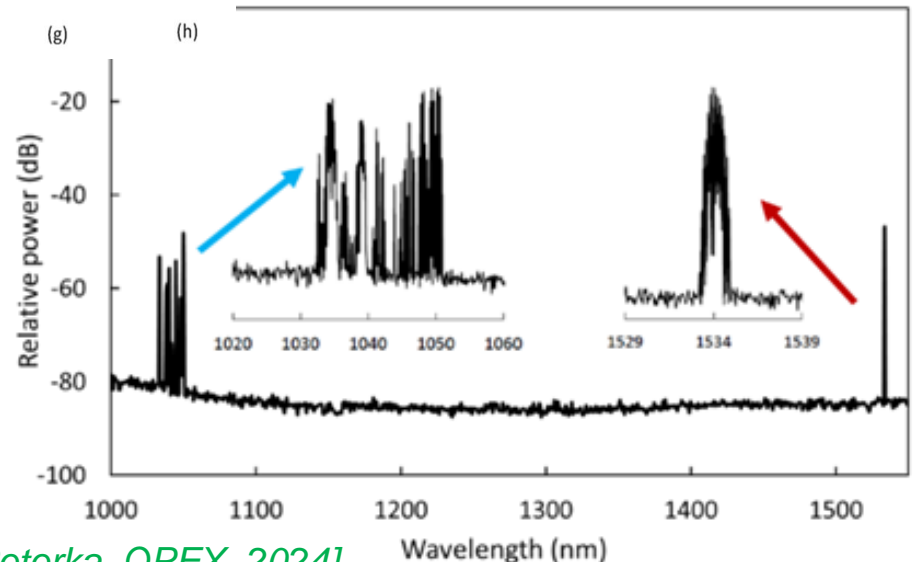
Nanostructured Er–Yb fibers for dual-wavelength fiber lasers

Stack and draw – well defined nanostructurization



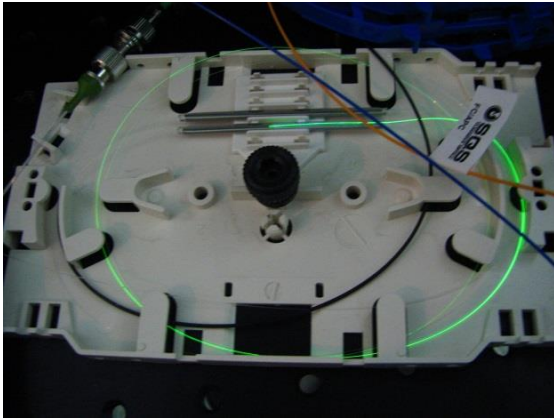
+ Alternative to

- * nano-engineering phase separation (M.Paul, W. Blanc)
- * NP condensation (B. Coole)
- * Direct NP doping (Tammela)



[M. Franczyk, R. Buczynski et. al., JLT, 2022], [P.Peterka, OPEX, 2024]

Fiber lasers [mW] → [kW]



Er/Yb - fiber laser \leftrightarrow 10 cm



[IPG photonics.com]

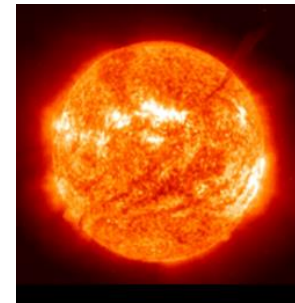
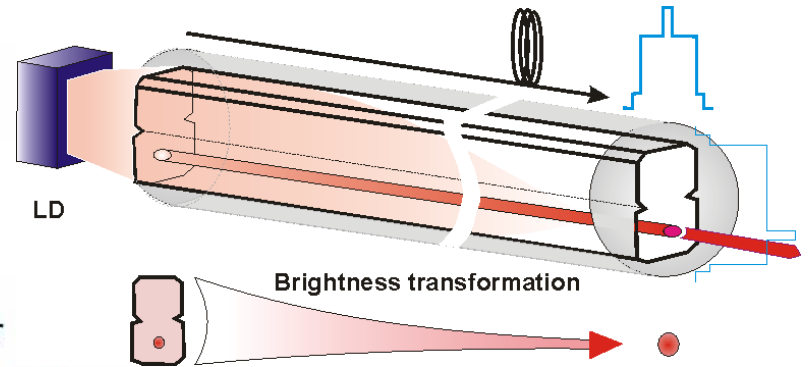
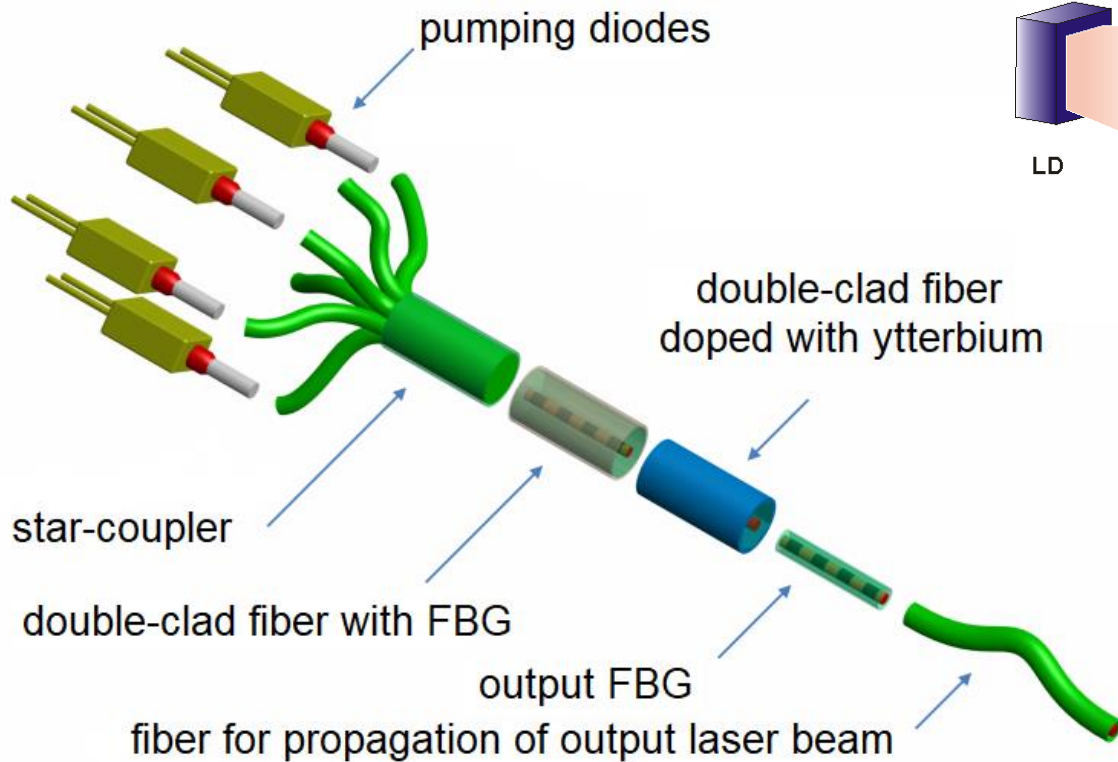
Welding, cutting ~ 2kW

IPG Photonics CW 40- 100 kW / 10 μm^2

~ ELI Beamlines



Fiber lasers - specialty (DC) optical fibers

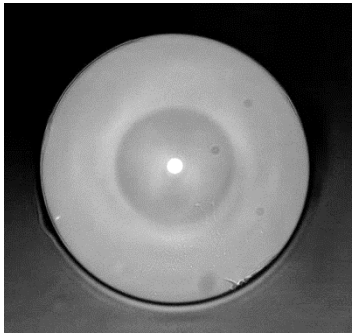


sun
fiber laser

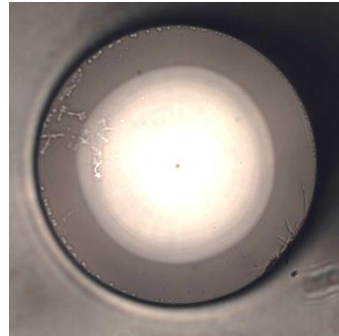
63 MW/m²
12.7 GW/m²

Optical fibers for high-power FL

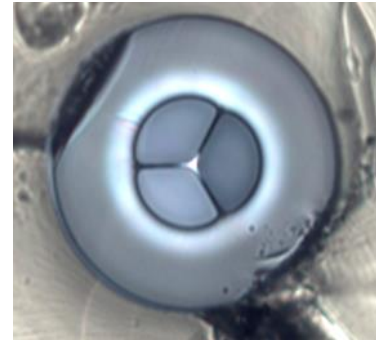
Single-Mode Large Mode Area Microstructure Polarization (PM)



SM 125/10

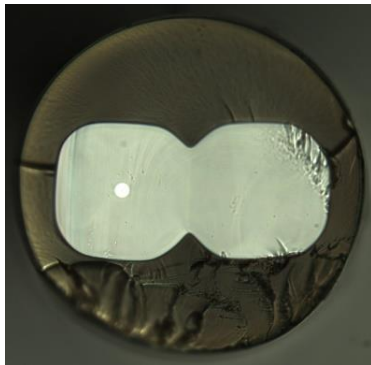


TDF 125/65

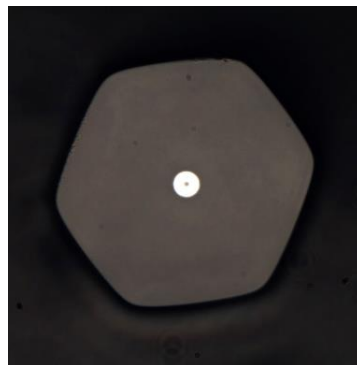


TDF PANDA 125/8

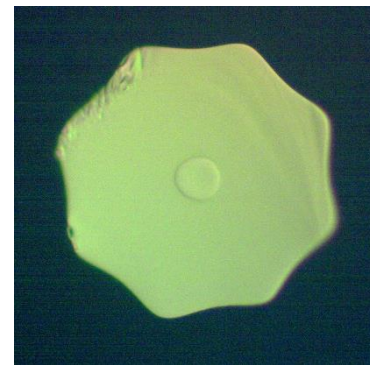
Double-Clad (DC)



EDF 250x125/7



TDF 130/12

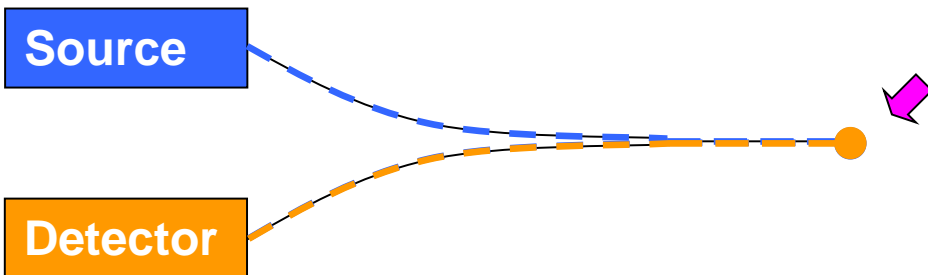
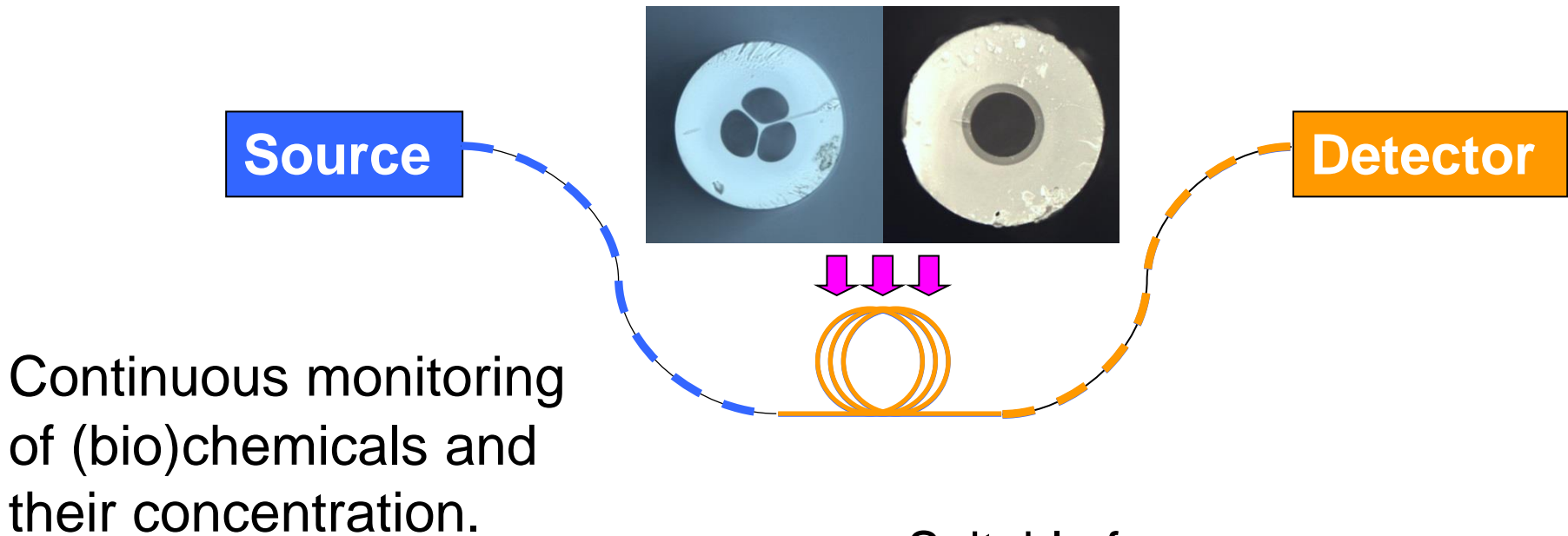


TDF 130/15



[Peterka et.al., *Opt. Lett.*, **31**, 3240, 2006], [Koska et.al., *Op.Ex.* **24**, 102, 2016], [Jasim et.al., *Op.Ex.* **28**, 13601, 2020, Honzatko et.al., *Cena TACR 2020*]

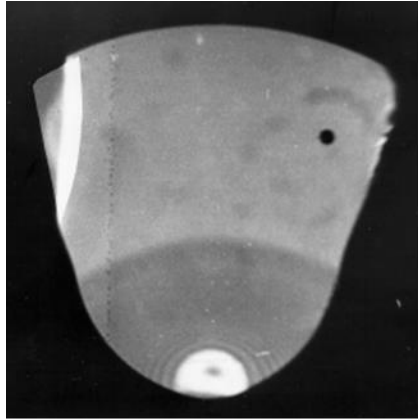
Optical fiber sensors



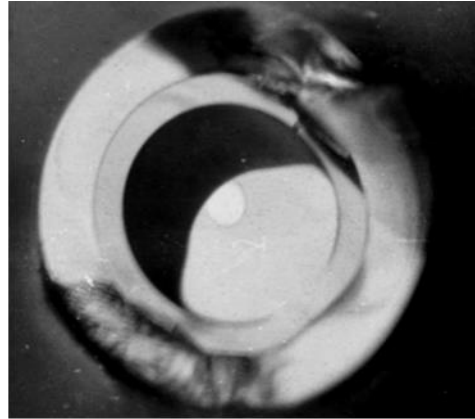
Suitable for :

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

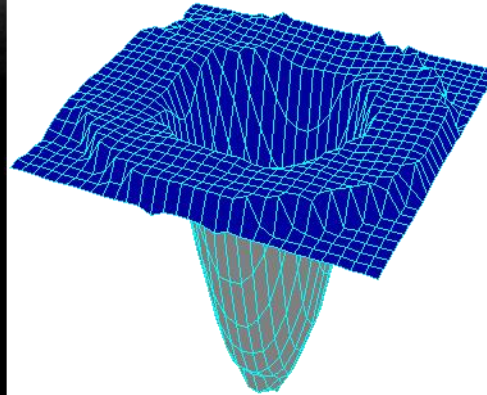
Optical fibers for fiber sensors



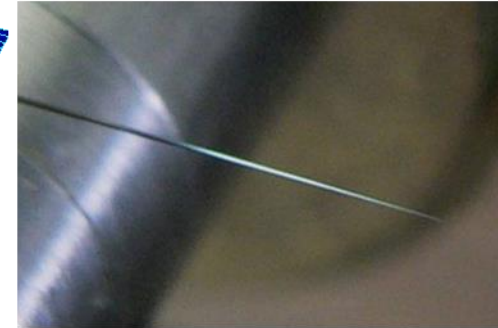
S -fiber



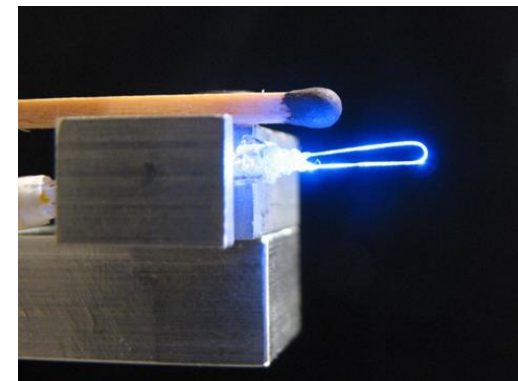
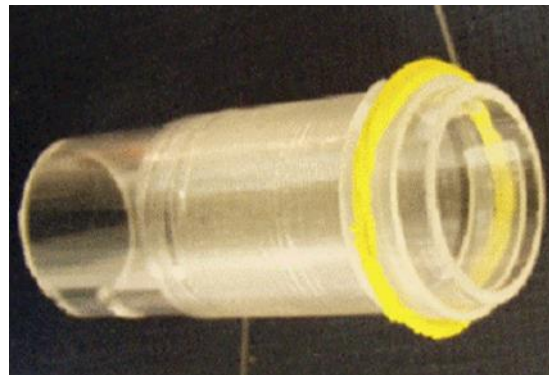
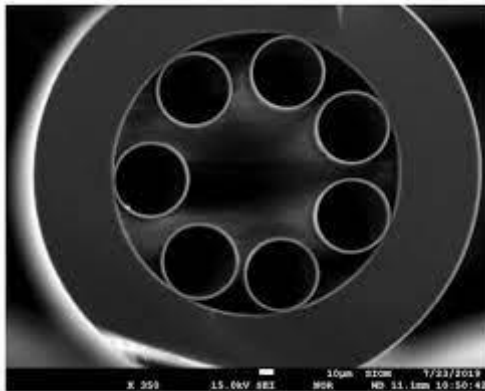
Capillary S-fiber



Inverted
graded-index fiber



fiber taper



+ special coatings

Refraktometric sensor of hydrocarbons

Early warning system of oil leakage



- Monitoring and warning
 - havárie
 - permanent leakage, eco-load
 - overheating, fire
- The higher the refractive index (concentration of detected substance)
 - the lower the transmitted light

Limit of detection ~ 3-5 mg/l (EU regulations),

Time response ~sec

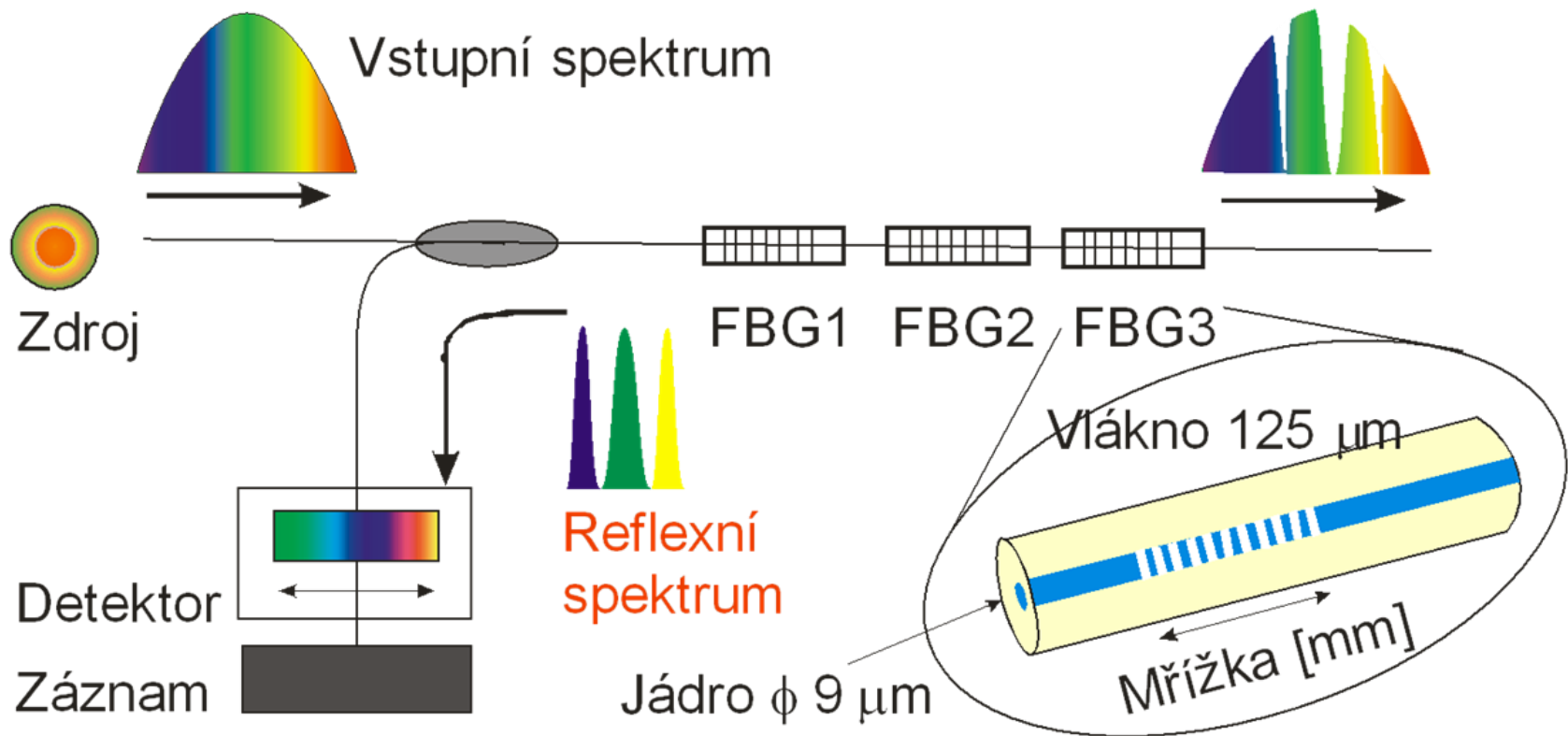
Instalation: Deno – Česká správa letišť, Shell, RWE, Škoda



[Cherif, Matejec: Sensors, 2], [Matejec: Mat. Sci. Eng. C-21], [Chomat: Sensors Act. B90], [Skokankova: Mat. Sci. Eng. C 26]

Fiber sensor of load

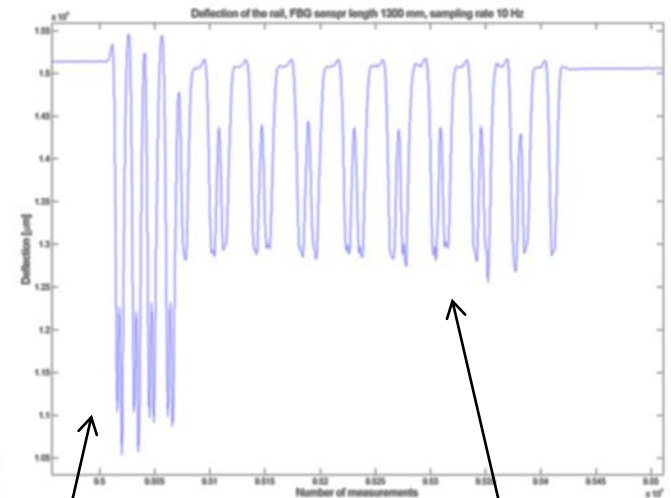
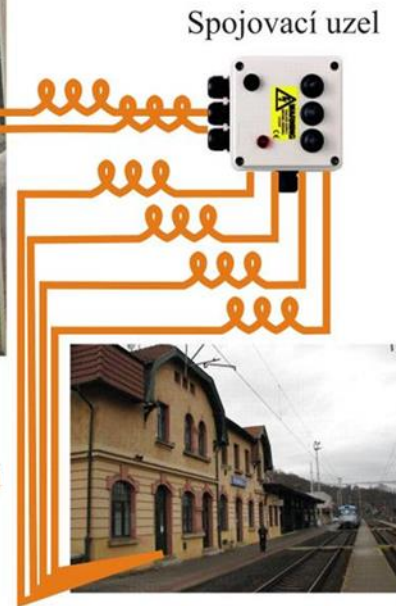
FBG/LPG systems of monitoring of critical infrastructures and homeland security



[I. Kašík, L. Šašek, Není tunel jako tunel, Panorama 21. Století 3/2012]

Fiber sensor of load

FBG/LPG systems of monitoring of critical infrastructures and homeland security



4 = 2x2 nápravy
(lokomotiva)

8 = 4x2
(vagony)

Instalation : Safibra - OBB Gmund

SUMMARY

1. **Fiber technology** : preparation of structures of **high preciseness (<1%)** from materials of **ultra-high purity (impurities in ppb 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).**

Be UFE !



& Be carefull !!



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
- [Peterka - Vlákňové lasery](#)
[Československý časopis pro fyziku](#) 1/2010, 4-5/2010, 1/2011
- [Jemná mechanika a optika](#) (2015)

Optical fiber technology

Silica optical fibers (solid/hollow core) – preform fabrication

Silica **microstructure** fibers

Design + **stack & draw** ~2000 C

