



UFE

**Academy of Sciences
Institute of Photonics and Electronics v.v.i.**

TECHNOLOGY OF OPTICAL FIBERS

Ivan Kašík, www.UFE.cz

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

Optical losses in optical fibers (extrinsic, intrinsic)

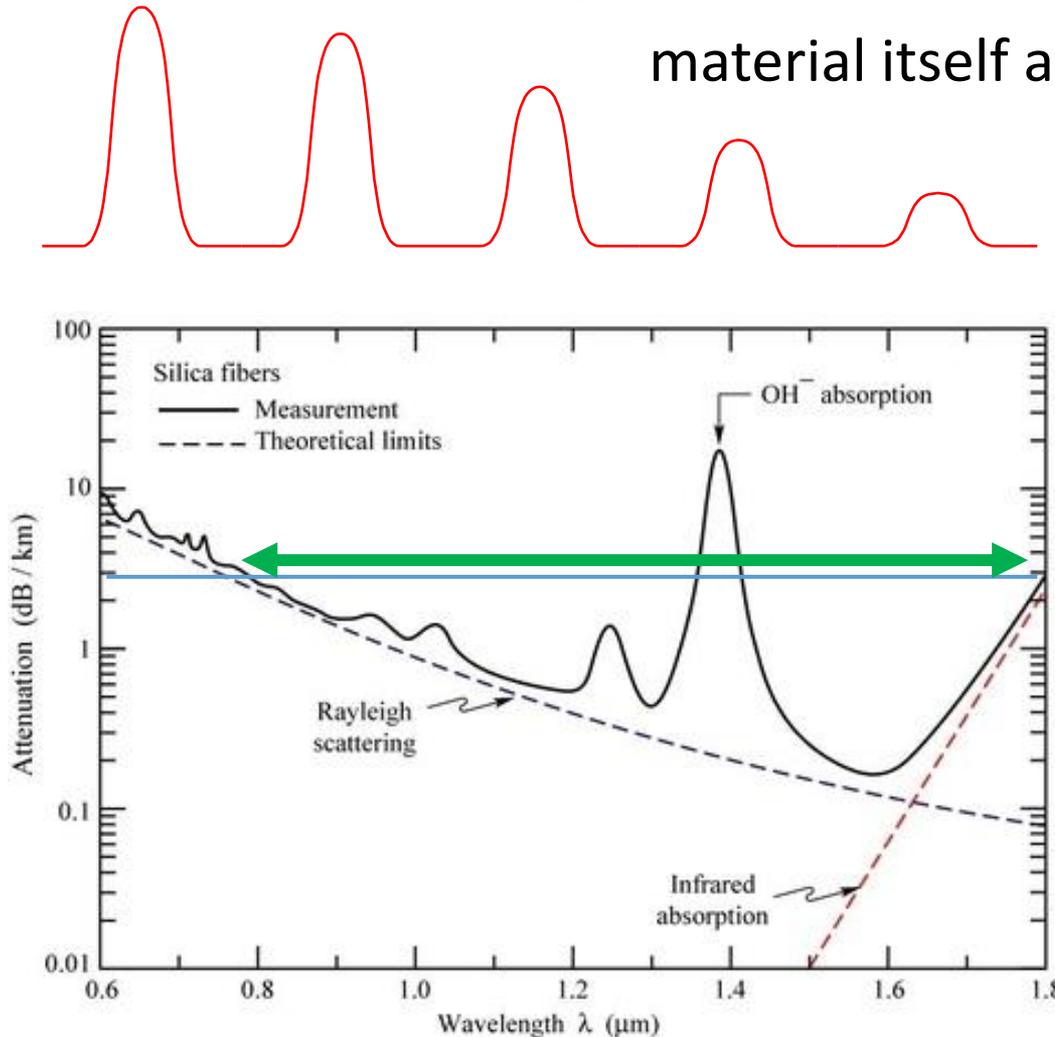
material itself and its purity

Example:

SILICA

20 dB/km

1% transmitted

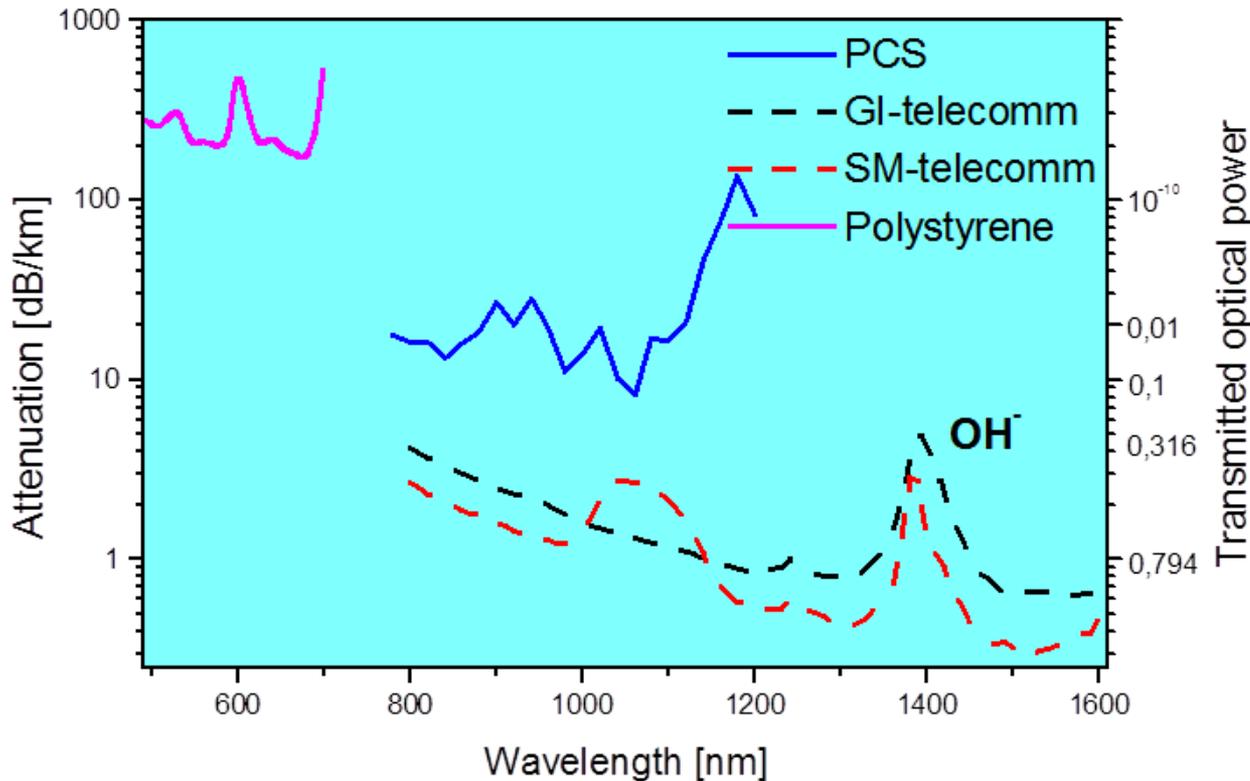


Transmission



Optical fibers (solid core)

Optical losses in optical fibers (intrinsic, **extrinsic**)



max. impurities
acceptable in ppb
(10⁻⁹)



Nobel prize
2009 Ch.K.Kao

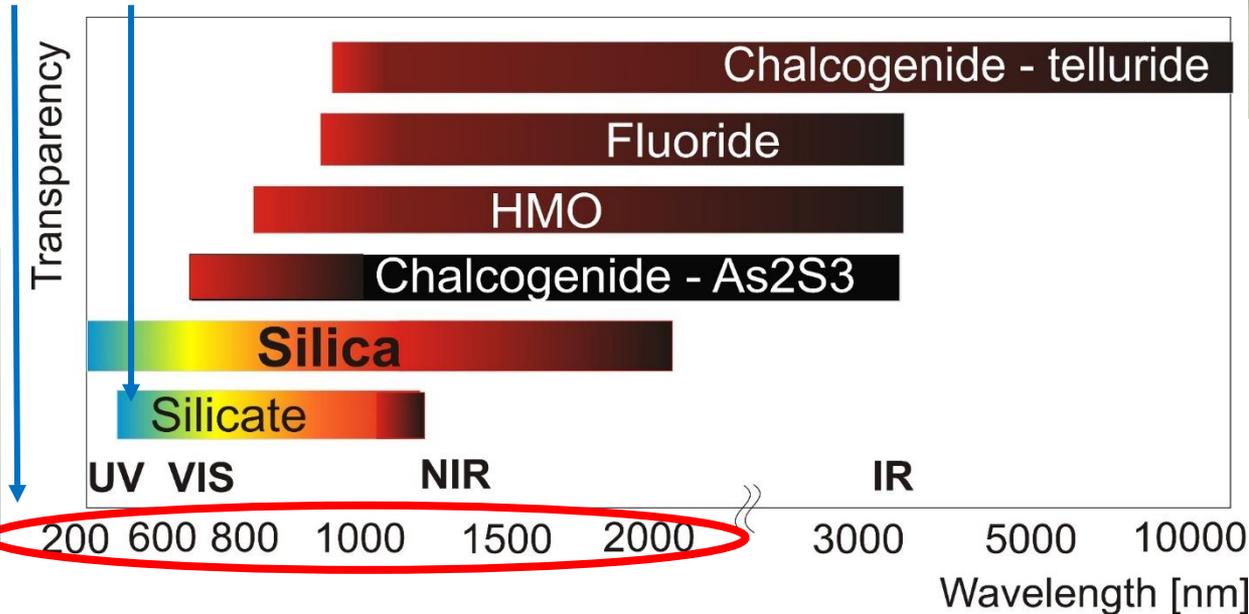


ULTRA-PURE TECHNOLOGIES

Optical fibers

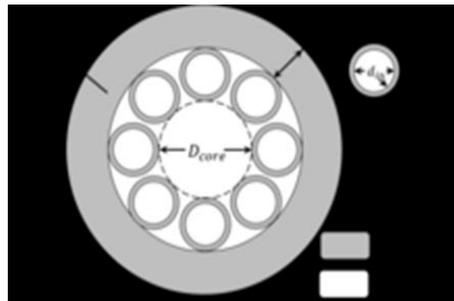
Optical losses in optical fibers (intrinsic, extrinsic)

SILICA OPTICAL FIBRES



- ☺ **SILICA :**
- ☺ glassforming
- ☺ transparency
- ☺ purity
- ☺ expansion 10^{-7}
- ☺ durability

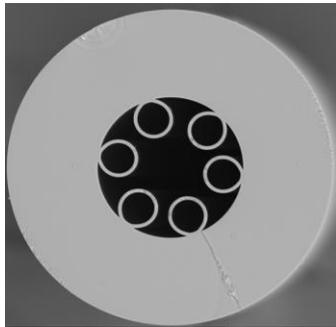
NIR => IR →



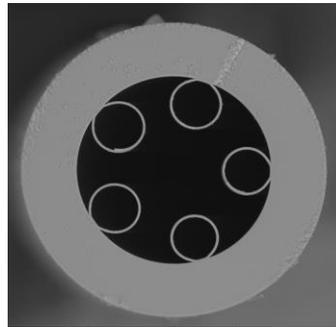
SOLID CORE
↓
HOLLOW CORE

Hollow-core optical fibers

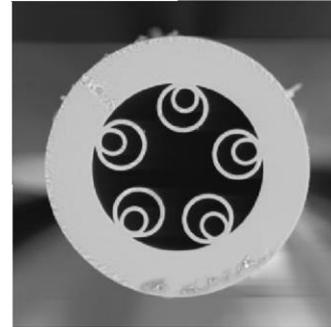
NCHCF125



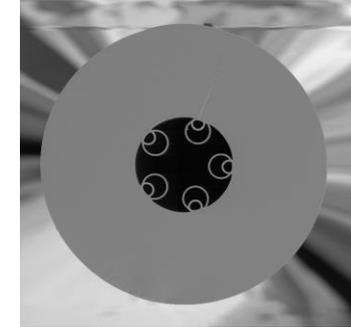
NCHCF100



NANF80



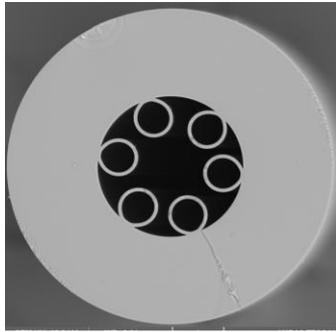
NANF200



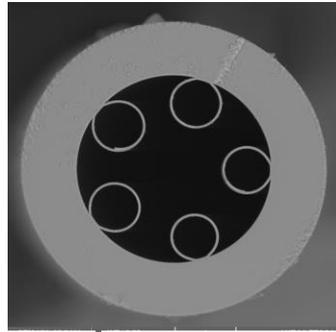
Fiber	NCHCF125	NCHCF100	NANF80	NANF200
Cladding diameter, μm	125	100	80	200
Core diameter, μm	24.3	30.5	21.1	32
Cladding wall thickness, μm	34.5	18	14	66
Capillary outer diameter, μm	14.8	17	15.3	8.6
Capillary wall thickness, μm	1.29	0.84	1.26	1.29
Mode field diameter, μm	19	24	16.3	25.9

Hollow-core optical fibers

NCHCF125



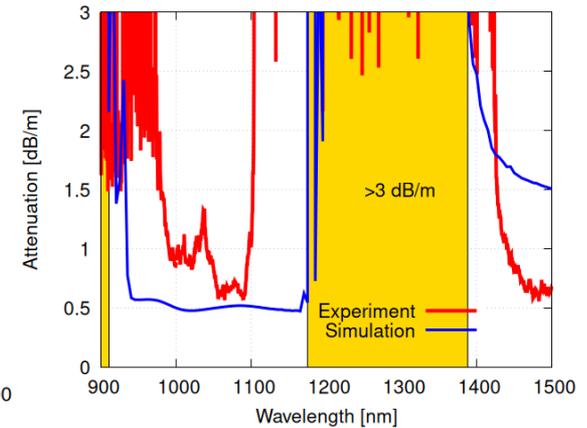
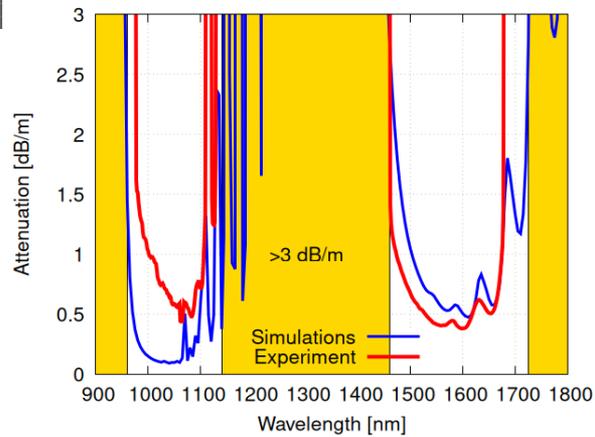
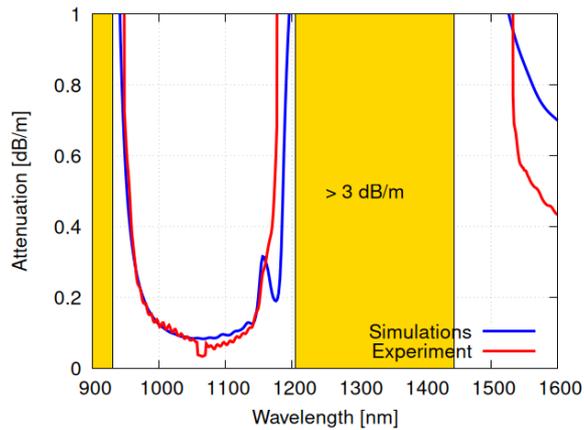
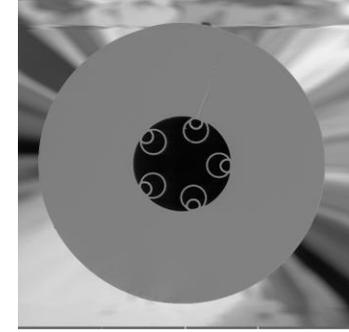
NCHCF100



NANF80



NANF200

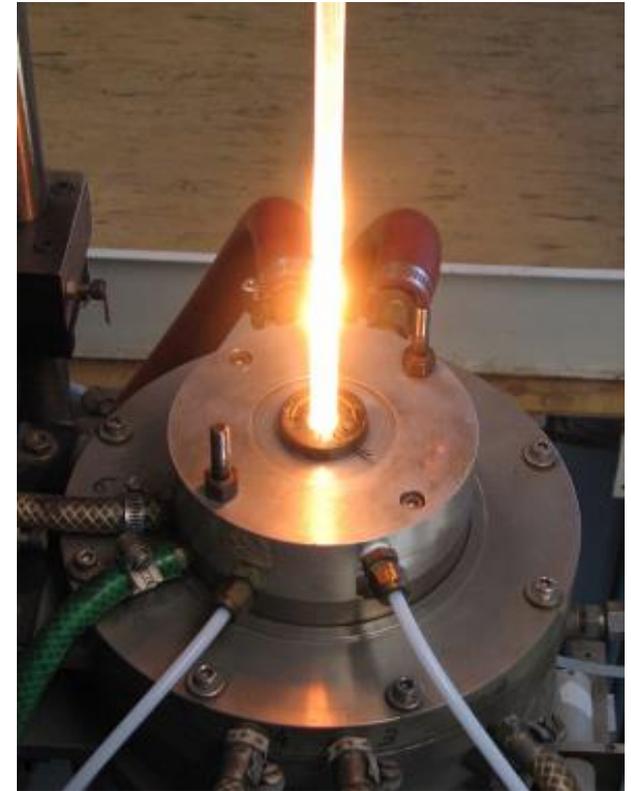


Optical fiber technology

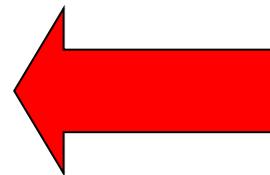
1. Preform



2. Fiber drawing



PURITY



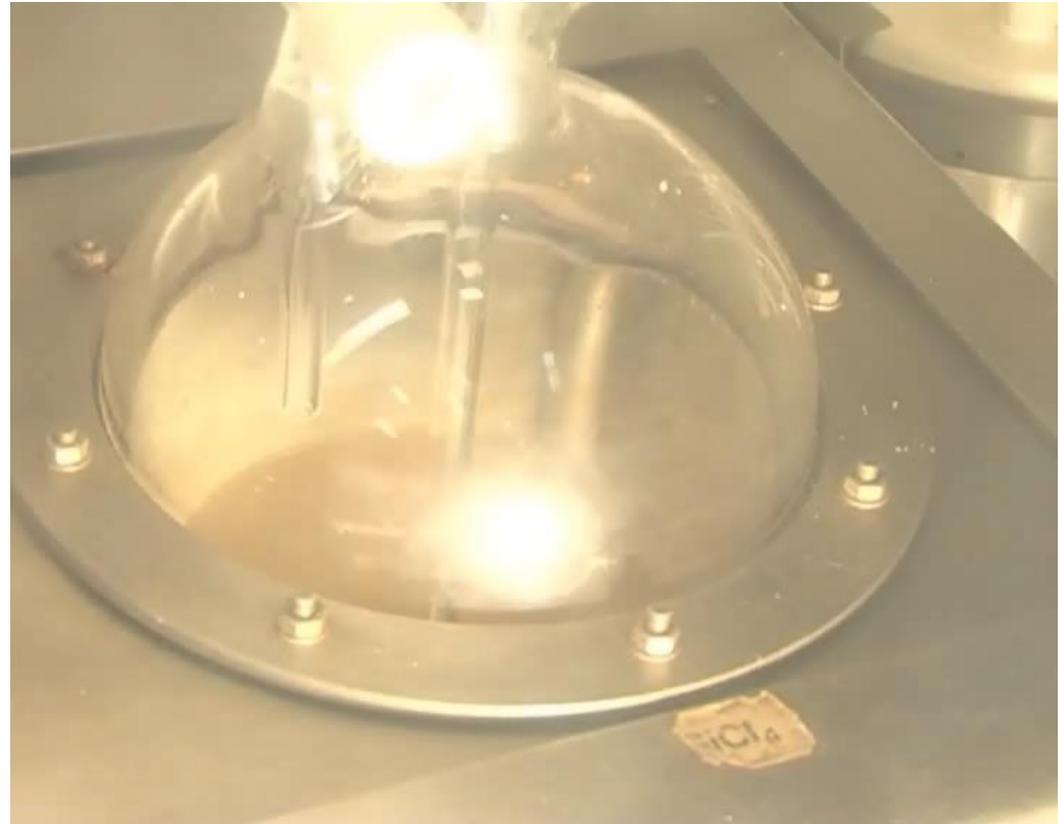
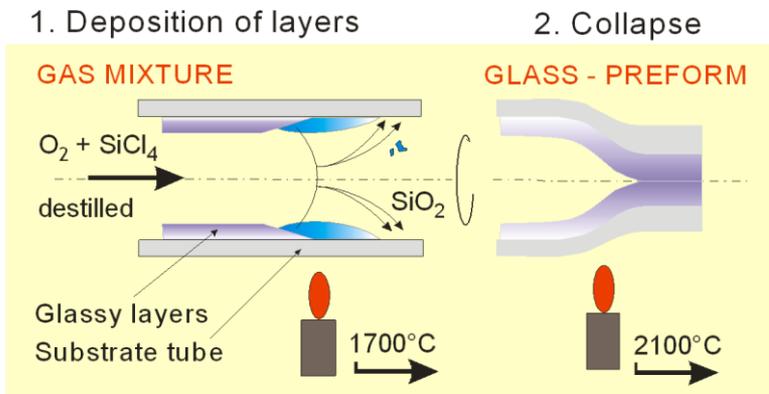
Optical fiber technology – solid core

Silica optical fibers – preform fabrication

Chemical Vapor Deposition - CVD - Modified CVD (MCVD)

Deposition of **solid-state** SiO_2 glass layers **from gaseous** $\text{SiCl}_4 + \text{O}_2$

Precursors – liquid/gas
Ultra-pure (distillation)



Optical fiber technology – solid core

Silica optical fibers – preform fabrication

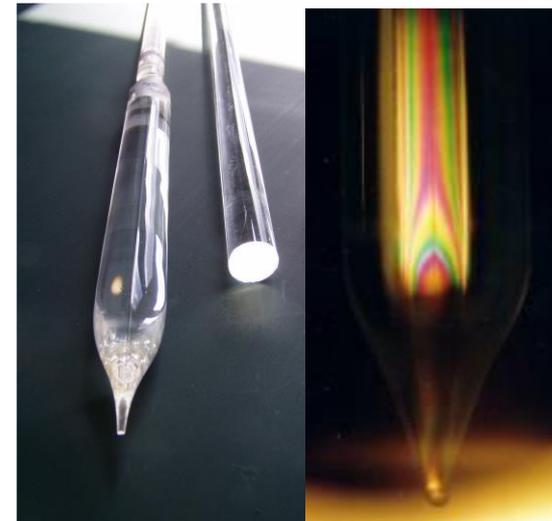


Deposition
of layers

Raw materials
halogenides (SiCl_4)

Colapse of
preform

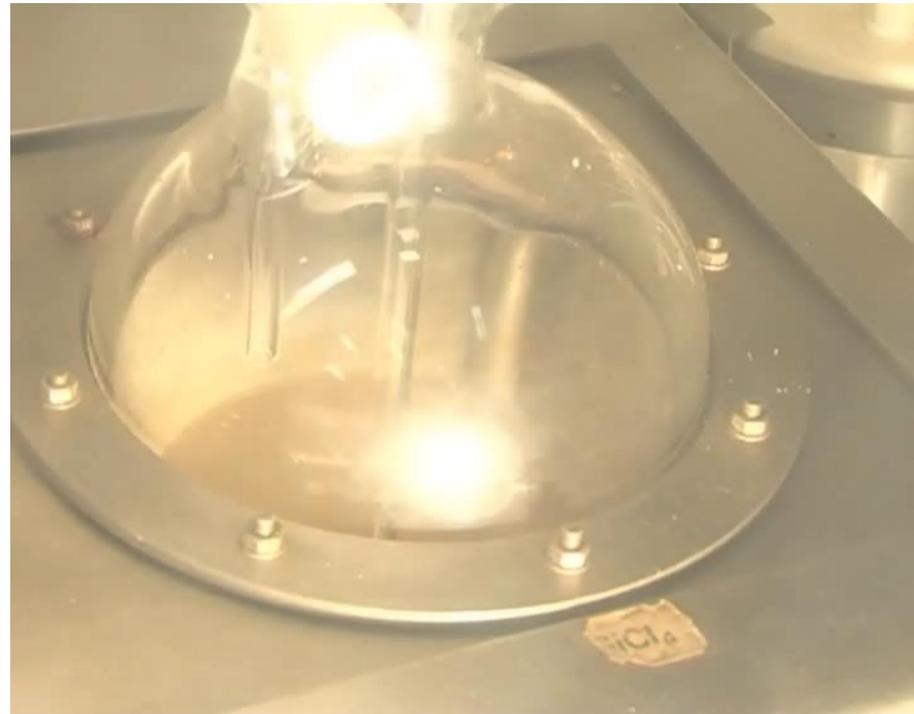
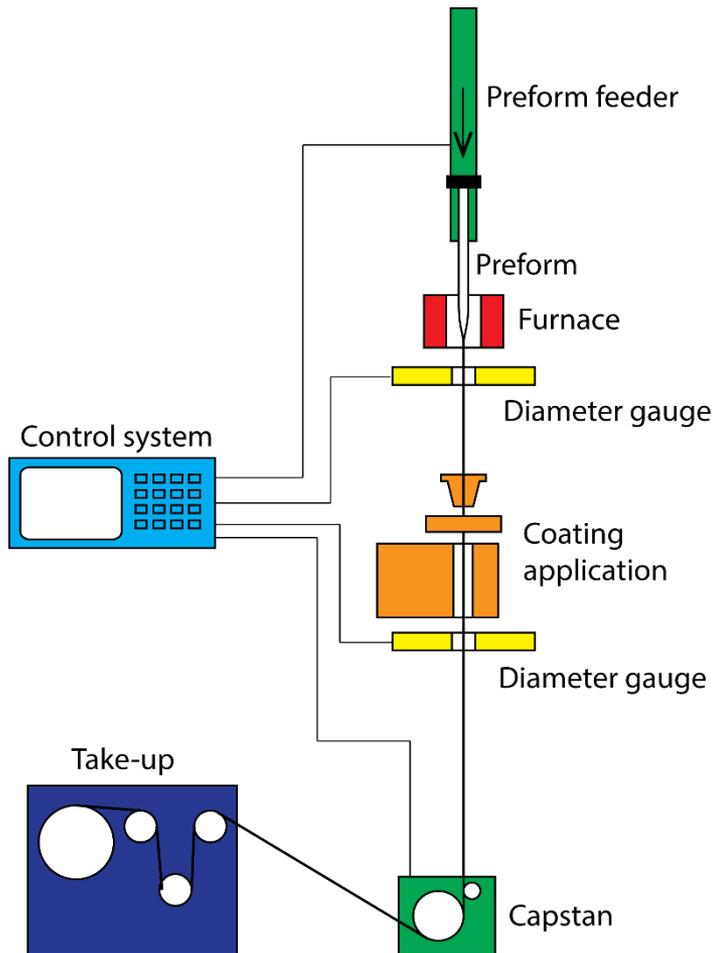
Preforms



Optical fiber technology – solid/hollow

Silica fiber drawing

- Temperature 1800-2000°C
- Fiber diameter 80-1000 μm
- Drawing speeds (industrial) 20-30 m/s

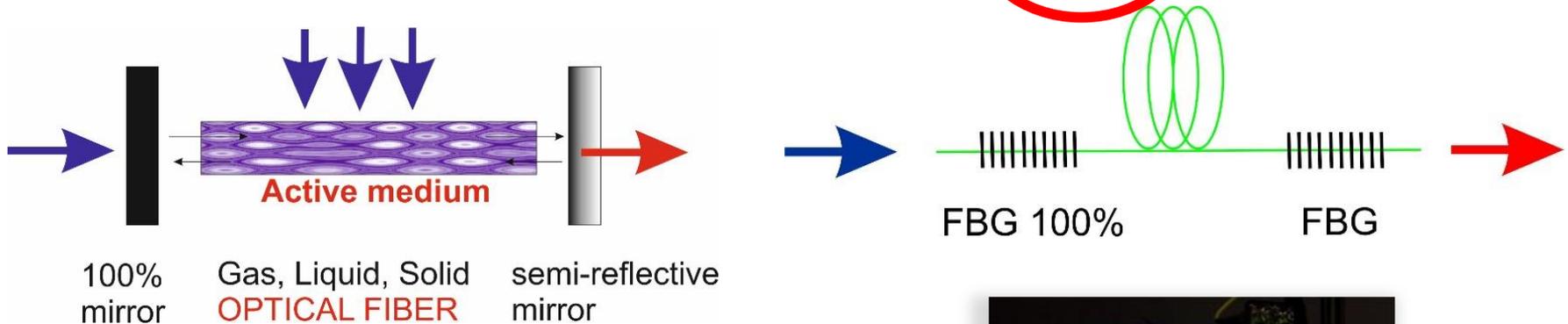


Optical fibers & fiber lasers

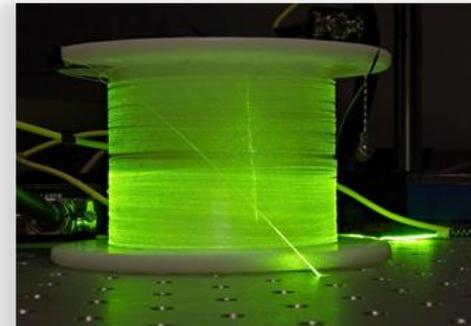
PASSIVE optical fibers (telecom)

x ACTIVE optical fibers => for fiber lasers

ACTIVE : (usually) **RE³⁺**-doped



Er³⁺



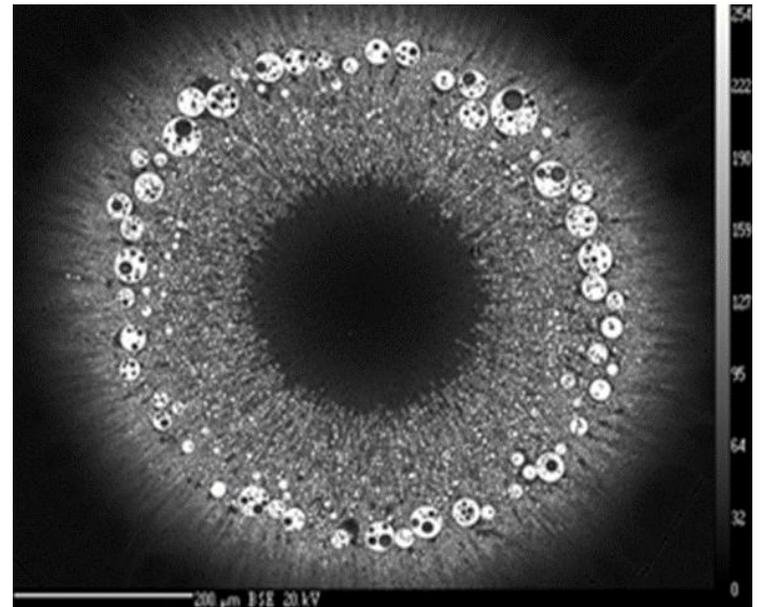
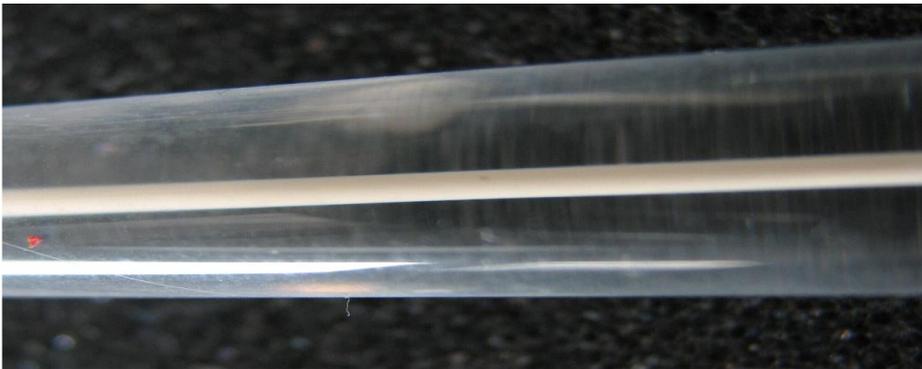
RE-doped silica MATERIALS for lasers

☺ low optical losses, wide transmission window, durability...

☹ **low miscibility of RE with silica**

→ clusterring, phase separation

→ unacceptable attenuation



=> **MODIFICATION OF MATRIX** with (GeO_2) , Al_2O_3 , P_2O_5 ...

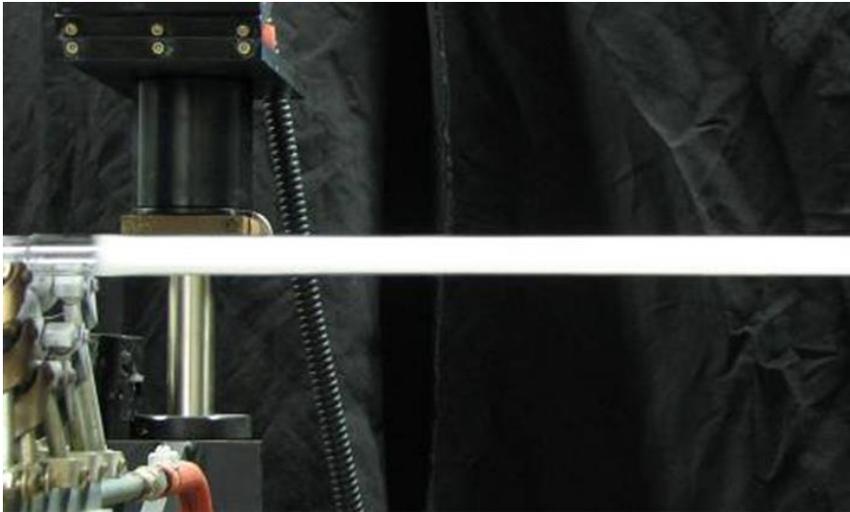
= **dissolving of RE in glass matrix**

=> **MODIFICATIONS OF METHODS** (starting materials-solids)

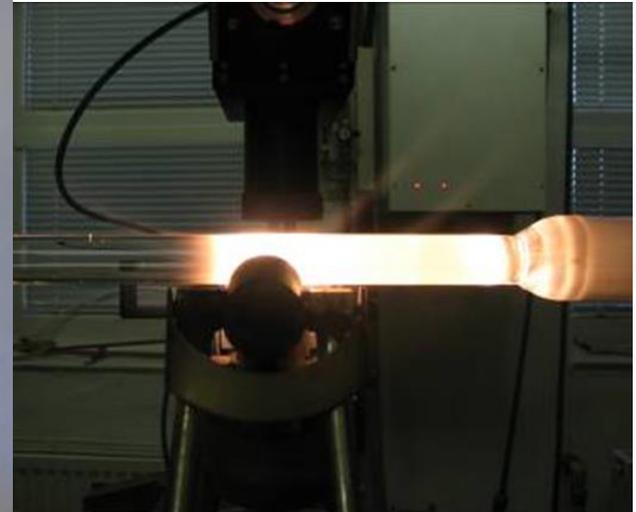
Optical fiber technology – RE doped

Preform fabrication

RE starting materials solid-state => modification of technology + matrix modifiers : Solution doping, Sol-gel



Porous layer
(SiO_2 , GeO_2 - SiO_2 ...)



Oxidation, drying,
sintering

Soaking – solution, sol, nanoparticles

[Townsend, *El. Lett.* **23**, 329, 1987] [Sysala, *Ceramics*, **35**, 361, 1991], [Podrazky, *IEEE LEOS*, 1-2, 246, 2007]

Optical fiber technology – RE doped

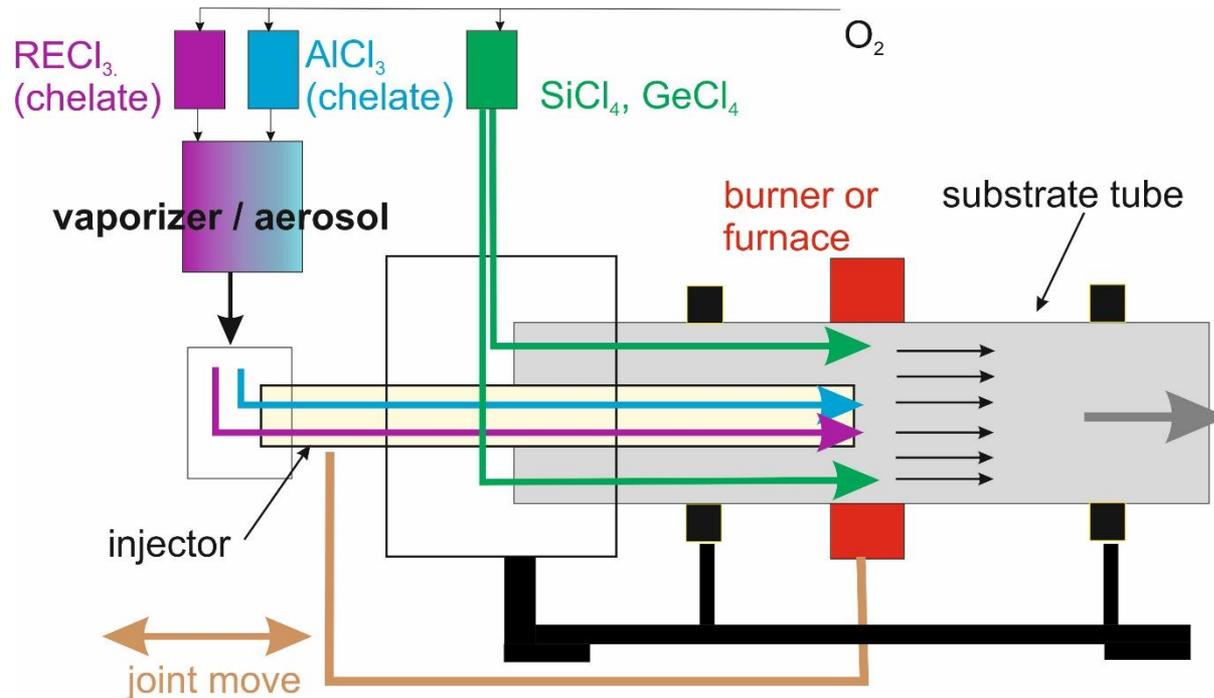
Preform fabrication

RE starting materials **solid-state** => **modification** of technology

Chelate-delivery MCVD, Flash vaporization

(~200 C)

(~ 700-900 C)



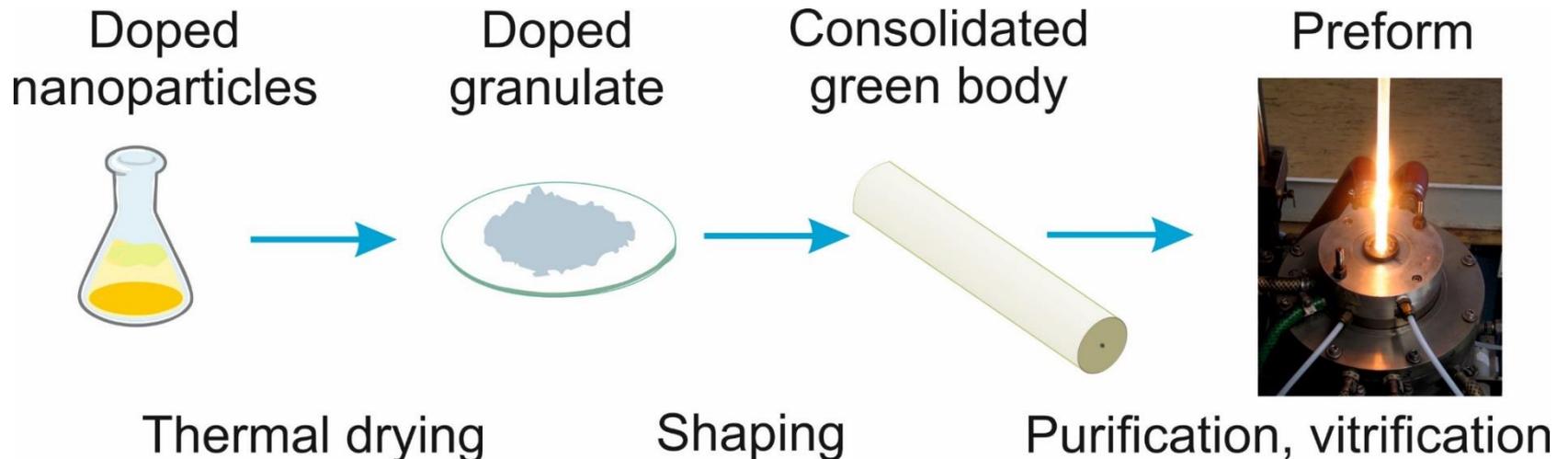
[Lenardic & Optacore, Sen& Dhar & Nextrom/ Optogear]

Optical fiber technology – RE doped

Preform fabrication by REPUSIL

Conventional glass melting, forming, quenching, annealing :

Precursors - solid state; optical purity suitable for fiber lasers



[Schuster & IPHT]

Optical fiber technology

RE-doped silica **DC** optical fibers – **preform shaping**

Mechanical grinding - diamond tools

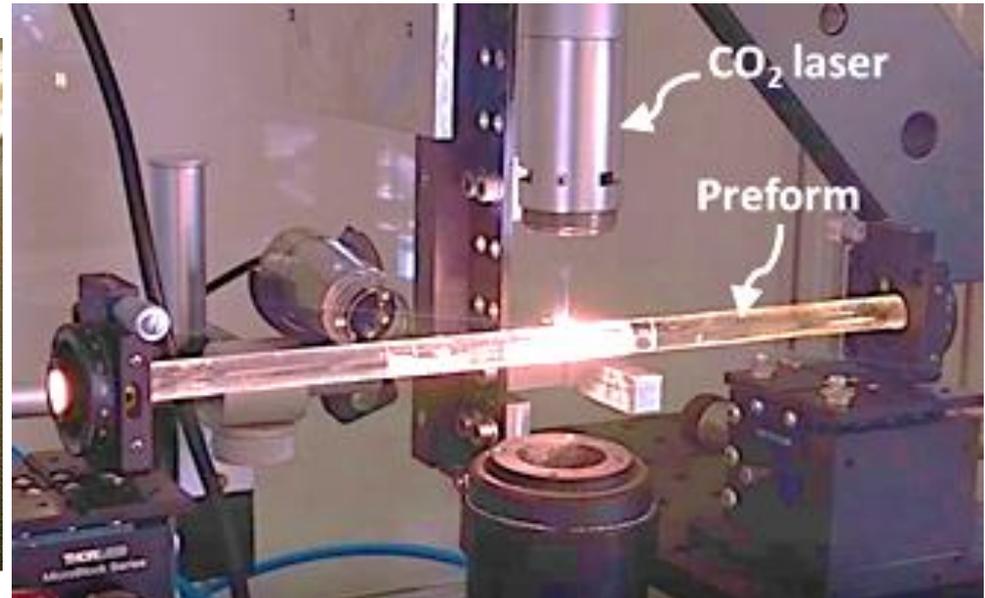
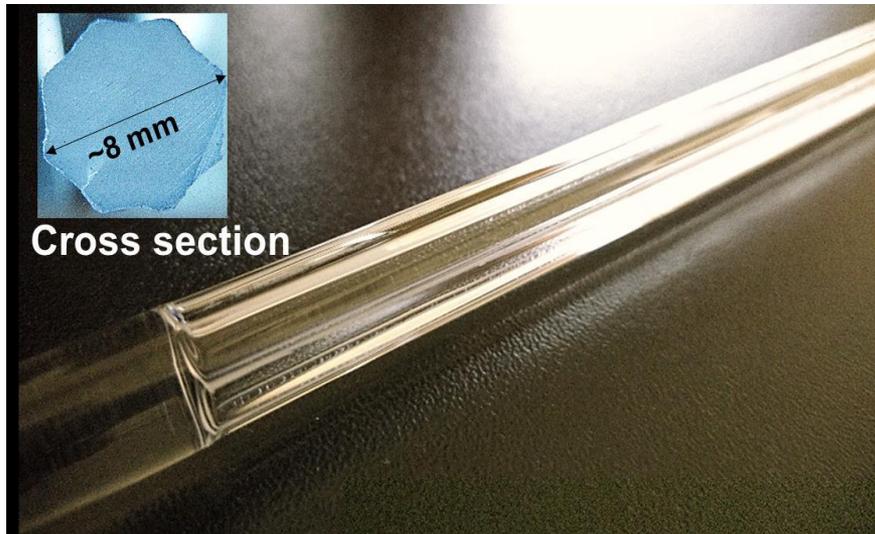


Optical fiber technology

RE-doped silica **DC** optical fibers – preform shaping

Laser processing

CO₂ laser setup (30 W)

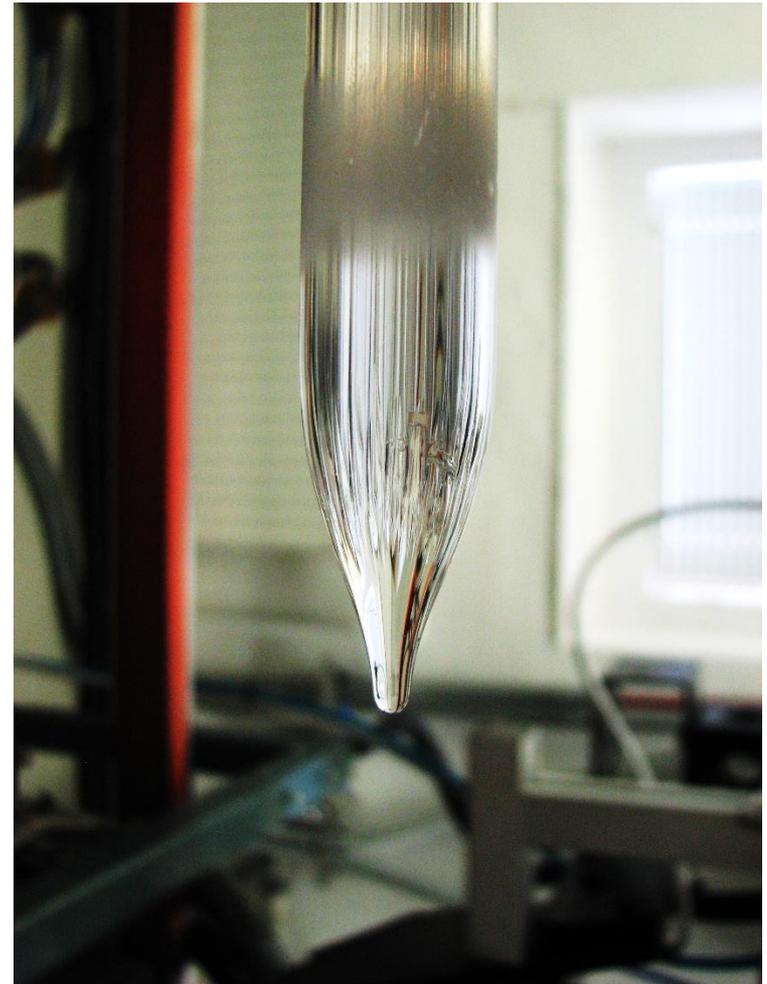
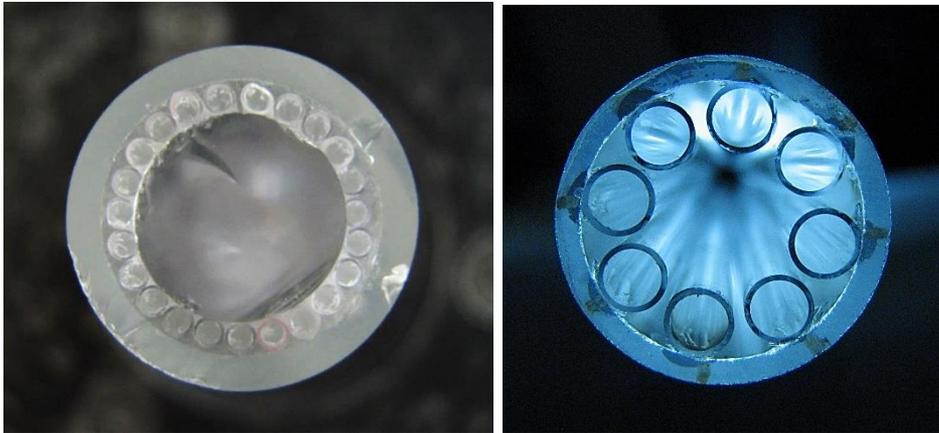


Optical fiber technology – hollow core

Microstructured silica optical fibers - preform fabrication

Silica **microstructure** fibers

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



Optical fiber technology - soft glass

Solid core - (non-silica) optical fibers

PREFORM fabrication

Germanate, chalcogenide (silicate, phosphate) + RE³⁺

Conventional glass melting, forming, quenching, annealing

Precursors - solid state

Processing ~500-1500 C (Super/Kanthal)



Er³⁺ silicate, As₂S₃, PbO-GeO₂ preforms

Optical fiber technology

Soft glass

■ +

Variety of composition

=> Variety of optical properties

=> Variety of RE concentration

Mass production

Good miscibility Glass + RE

Sometimes low phonon energy

■ -

Low purity

=> Higher optical losses

=> Lower output power FL

Silica glass

High purity

=> Low optical losses

=> Lower overheating

=> High output power FL

Low miscibility Silica + RE

=> co-doping with Al_2O_3 , P_2O_5 ...

=> Technology !



RESULTS

**Specialty optical fibers for
fiber lasers, amplifier, ASE
sources and their properties**

Fiber lasers

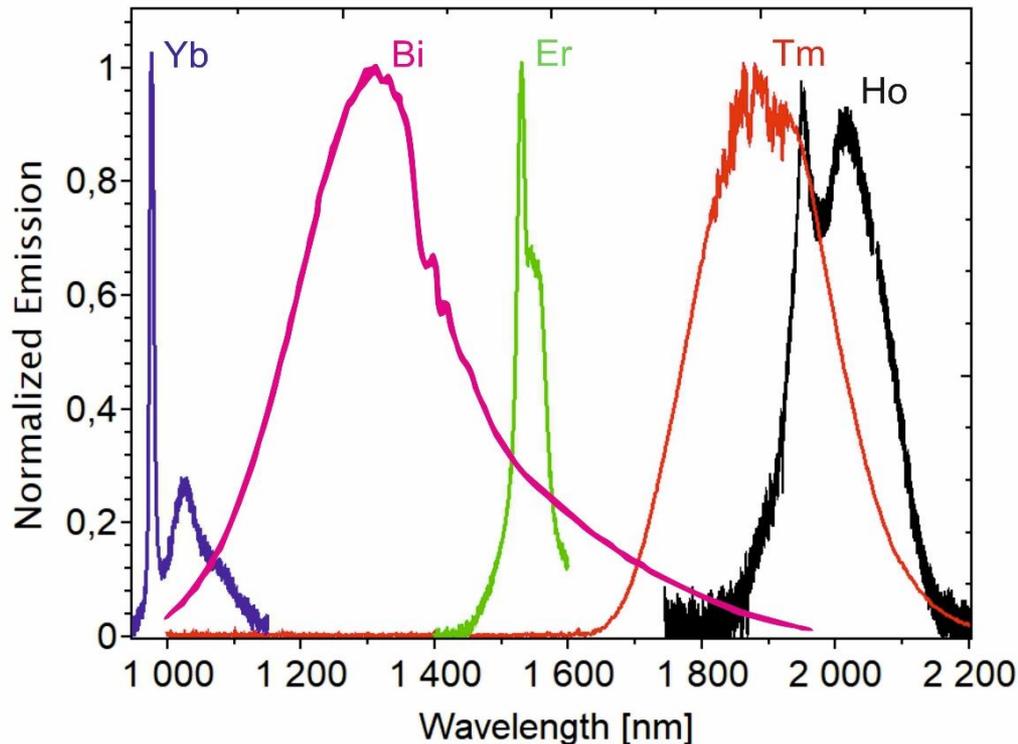
- * **high conversion efficiency** (fiber lasers ~70-90%) - savings
- * **high quality beam** (nearly Gaussian, low divergency)
- * **high brightness** (high concentration of power)
- * **good thermal management** (cooling)
- * effective pumping
- * tunability
- * compactness
- * size (long resonator in small space)



Optical fibers for lasers

Silica RE doped, (Bi –doped)

Task of technology: to avoid clusterring of **RE³⁺**

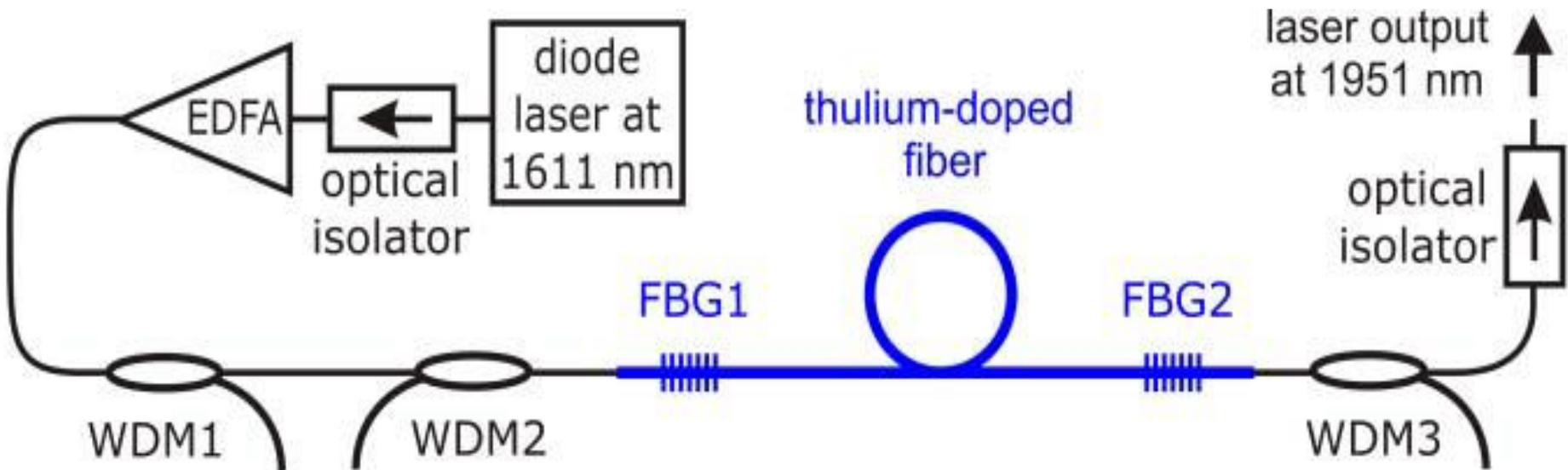


Commercial RE-doped: Nufern, NKT, Corning, ADValue photonics

Experimental Bi-doped: E.M.Dianov, J.K.Sahu: FORC Moscow, ORC Southampton

Tm fiber laser at 1951 nm

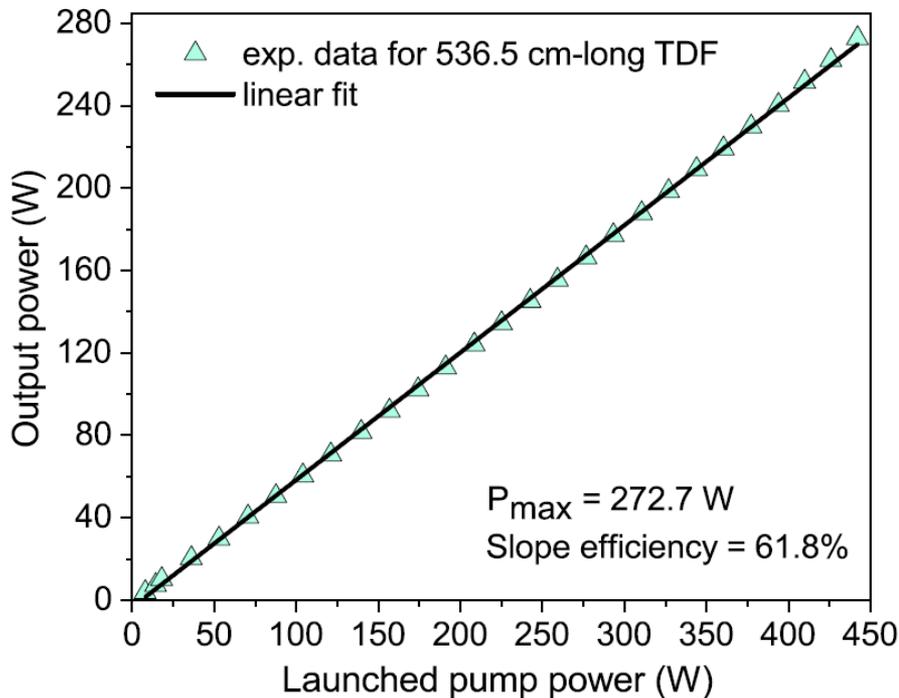
Eye-safe spectral region (\neq 1550 nm)



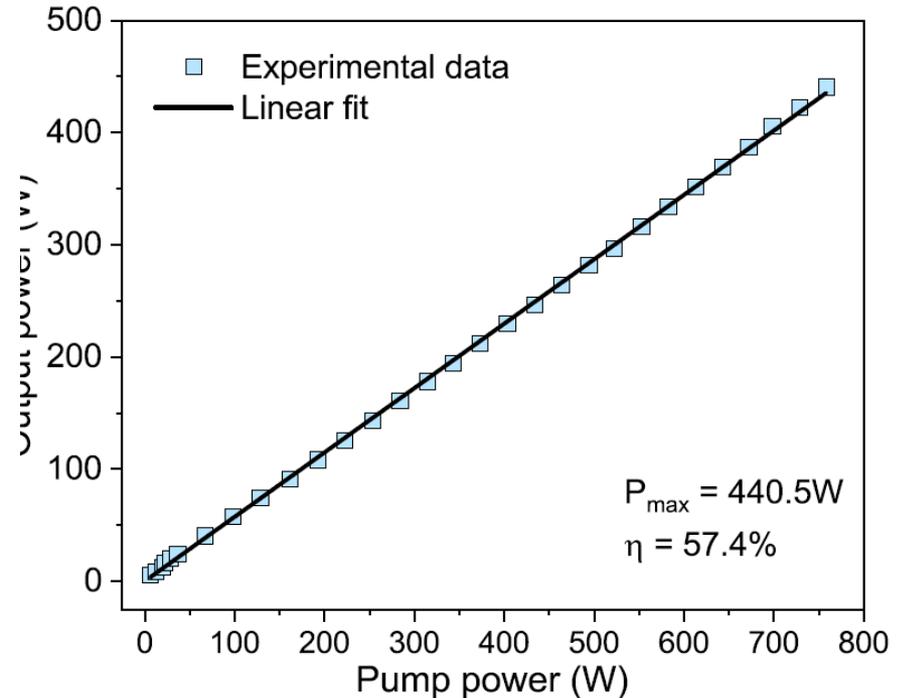
- 1000 ppm Tm^{3+} , 11mol% Al_2O_3 , 0 mol% P_2O_5 or GeO_2
- Inscription of FBG into GeO_2 -free fiber (!)
- Nowadays TDFL up to 65% SLE, up to 400 W

[P.Peterka, Photonic Technol Lett, 25, 2013, 1623, Michalska_JLT_2024]

1940- and 2034-nm TDFL



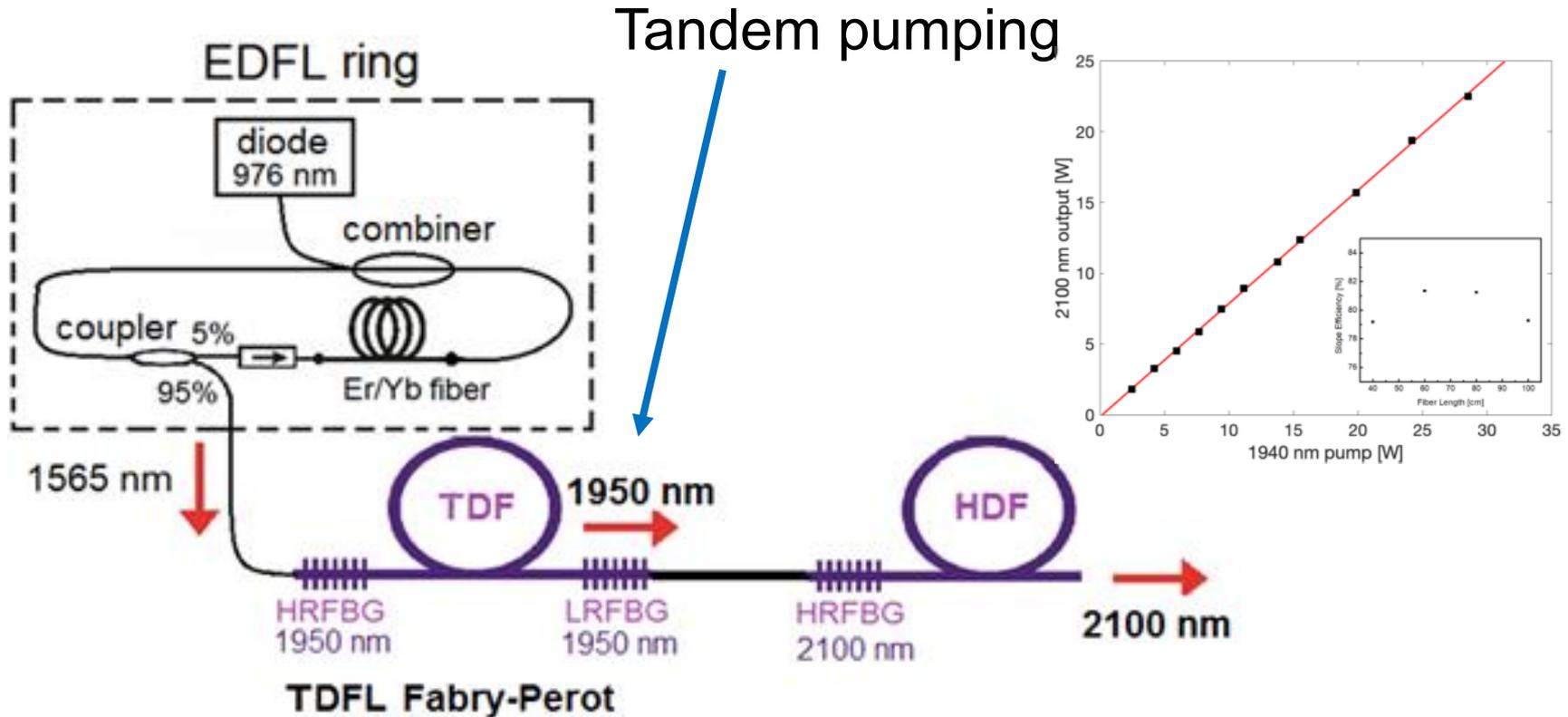
Pump 793 nm
Output_1940 nm:
272.7 W, 61.8 % SLE



Pump 793 nm
Output_2034 nm:
440.5 W, 57.4 % SLE

Ho fiber laser at 2100 nm

Eye-safe spectral region ($\neq 1550$ nm)



Nowadays HDFL up to **35 W** of output power and up to **86% SLE**

[Kamradek_OC_2025, Pokorny_OPEX_2025]

Dual wavelength fiber laser

Conventional Yb-Er-doped fiber laser

[Peterka, Kanka, 1997]

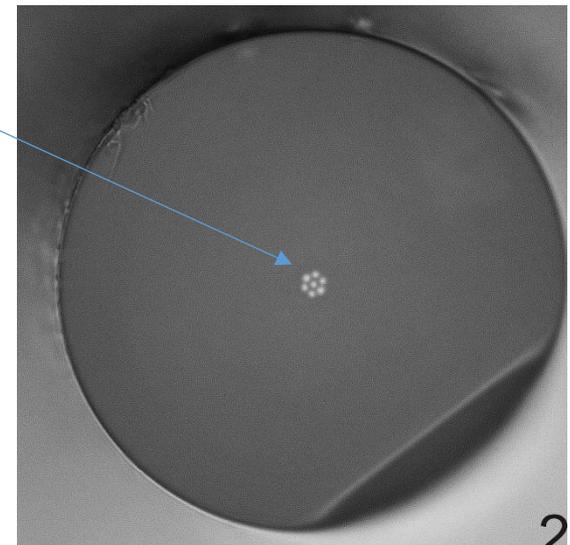
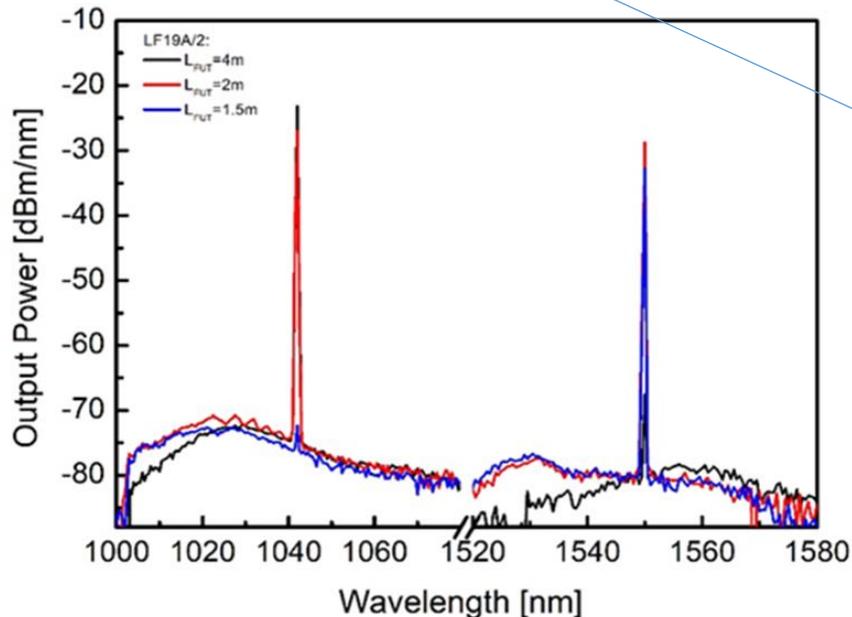
Method solution doping – solution of $\text{ErCl}_3 + \text{YbCl}_3$

Emission 1550 nm (thanks to energy transfer $\text{Yb}^{3+} \Rightarrow \text{Er}^{3+}$)

Structured-core fiber Yb + Er –doped fiber laser [Kasik, OC, 2025]

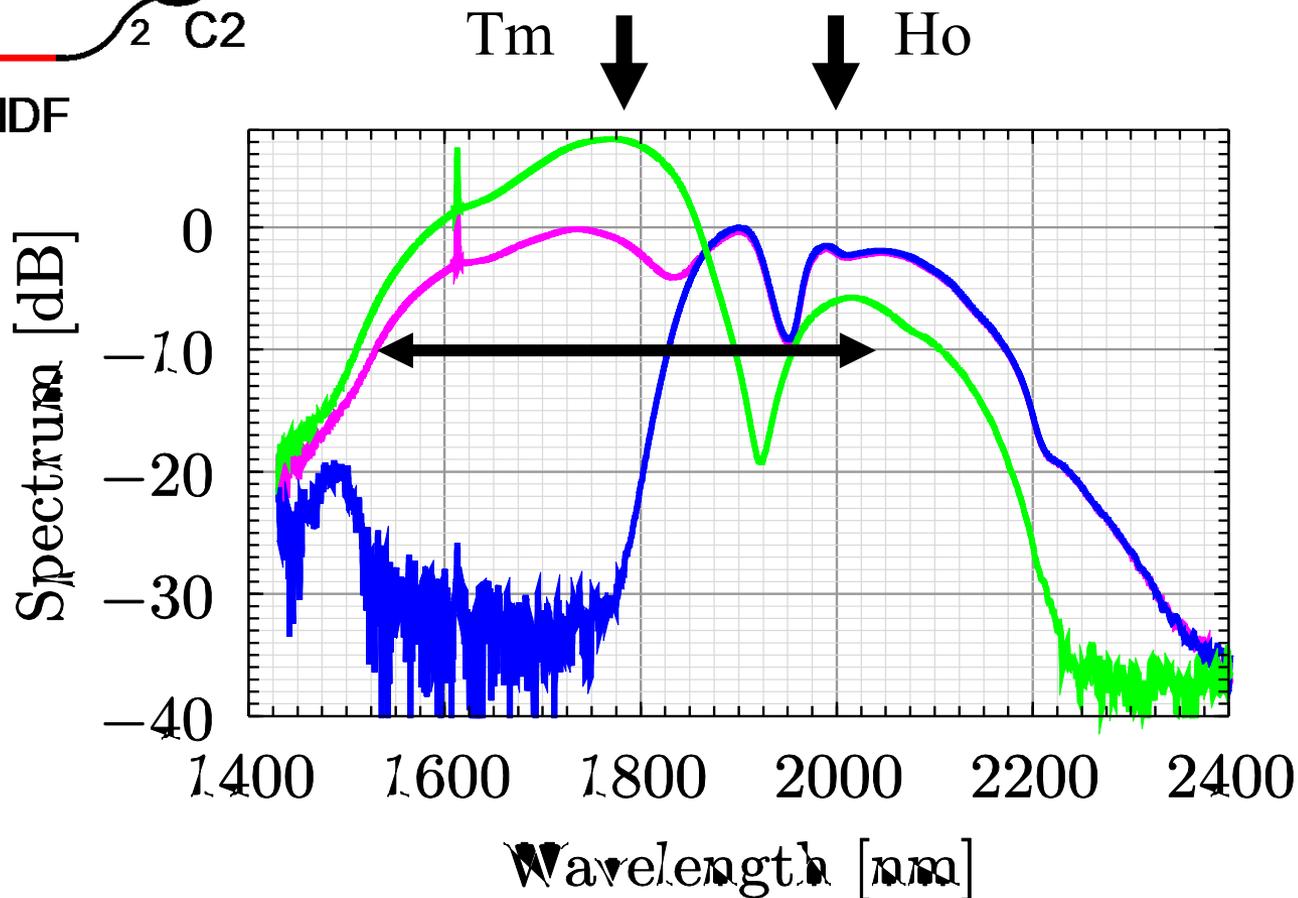
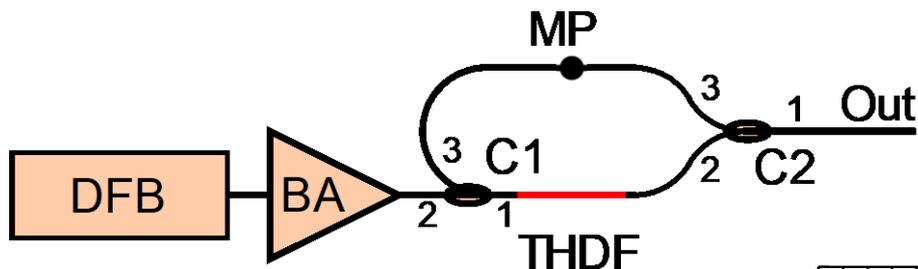
Method : assembling from 7 rods („sub-cores“)

Emission 1550 nm (telecom) and 1060 nm



Tm/Ho fiber for ASE (1550-2050 nm) source

(≠ 1550 nm)

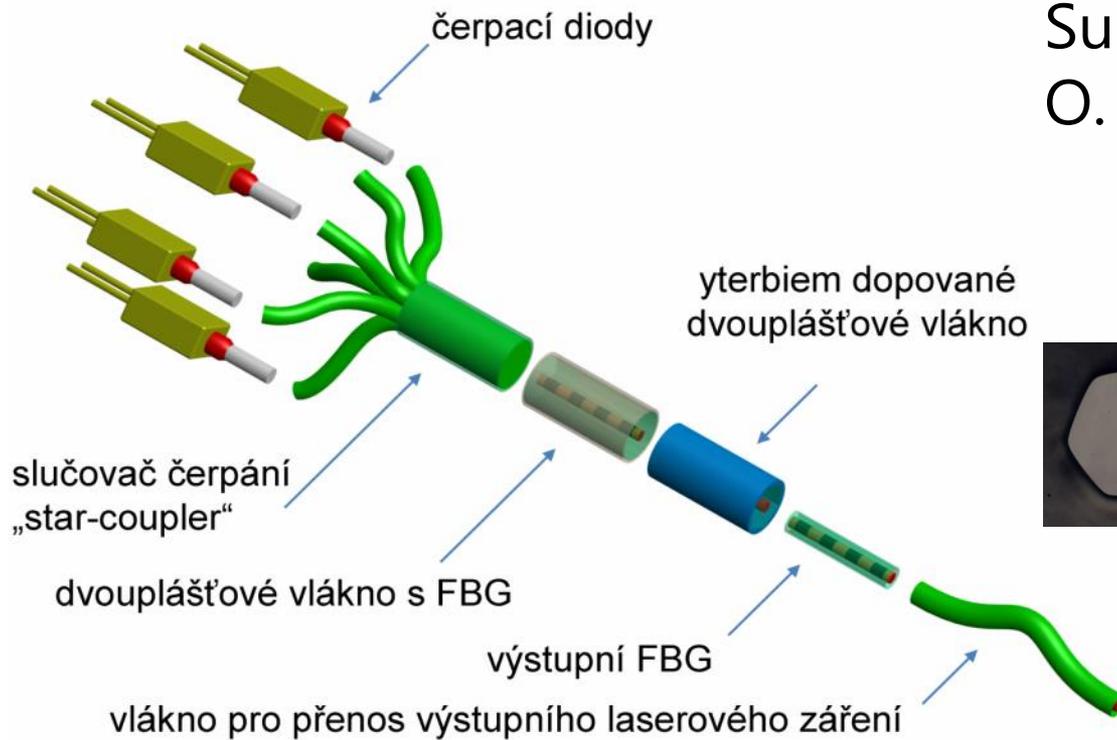


1800 ppm Tm^{3+} /
360 ppm Ho^{3+}

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

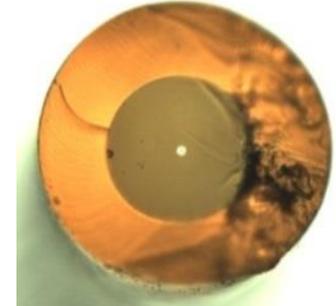
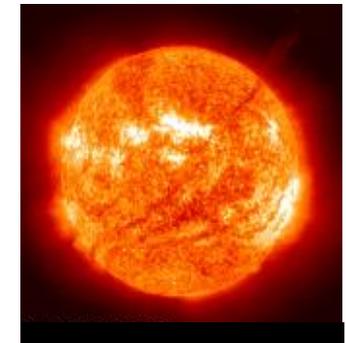
Fiber lasers $mW \rightarrow kW$

DC*



Intenzity of light

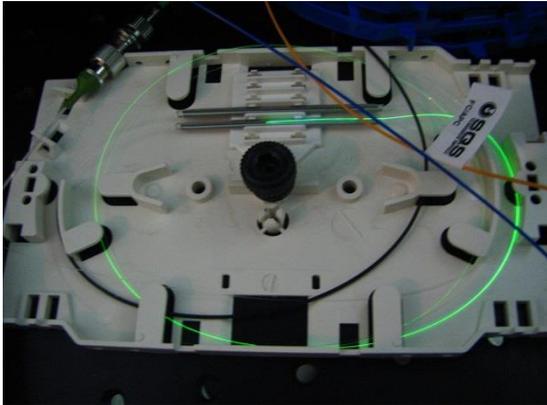
Sun	63 MW/m ²
O. fiber	12.7 GW/m ²



[P.Peterka, Eysafe, 2015]

Beam combining, double-clad structures

Fiber lasers $mW \rightarrow kW$



Er/Yb - fiber laser $\leftrightarrow 10$ cm



Welding/cutting
YDFL $< 2kW$

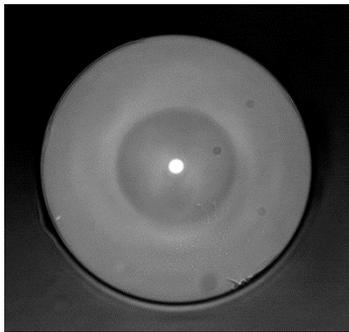
[IPG]



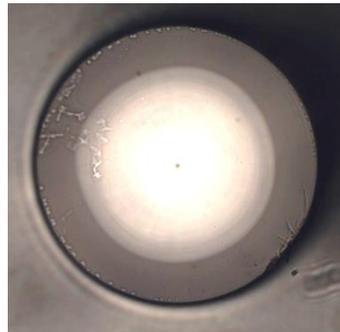
Silica optical fibers for lasers

STRUCTURES

SM & LMA

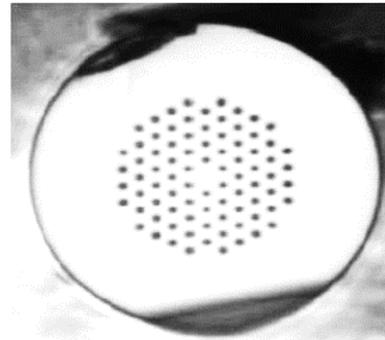


SM 125/10



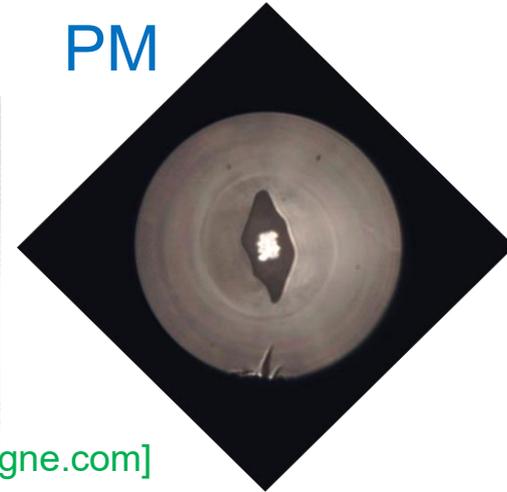
TDF 125/65

PCF

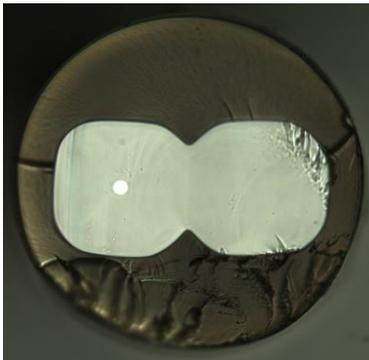


[www.photonics-bretagne.com]

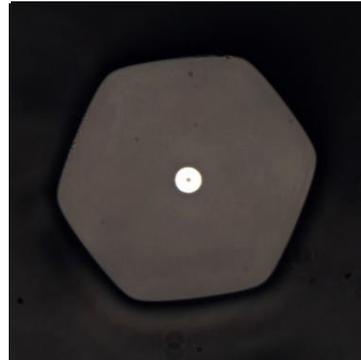
PM



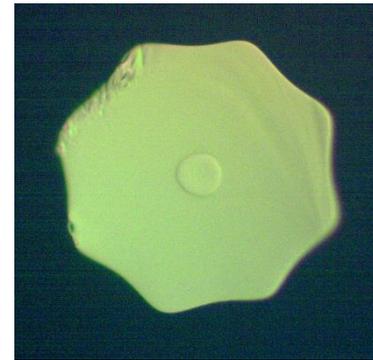
DC*



EDF 250x125/7

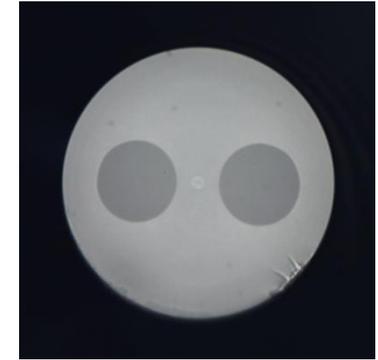


TDF 130/12



TDF 130/15

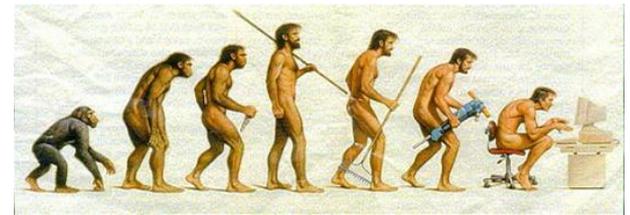
PM



TDF PANDA 125/8

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

SUMMARY



1. **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.**
2. **Fiber technology : preparation of structures of high preciseness (<1%) from materials of ultra-high purity (impurities in ppbs only) – (M)CVD.**
3. **Fibers conventional (passive) and specialty (active). Fiber lasers competitive with Solid State Lasers (SSL).**
4. **Fibers – silica (silica-based), soft optical glass, chalcognide, phosphate ...**
5. **Research of optical fibers & fiber lasers**

References

- **A. Mendez, F.T. Morse** : [Specialty optical fibers handbook](#), Elsevier Science & Technol, USA, 2006.
- **J. M. Senior** : [Optical fiber communications](#) - Principle and practise, Pearson Education Limited, Harlow, England, 2009.
- **Saaleh**, [Fotonika](#) (1 - 4), Matfyzpres
- **J. Schrofel, K. Novotný** : [Optické vlnovody](#), SNTL, 1986
- **P. Peterka, J. Vojtěch**, Optical amplification, in [Handbook of radio and optical networks convergence](#), Springer, 2023. https://doi.org/10.107/978-981-33-4999-5_20-1
- **S. R. Nagel, J. B. McChesney, K. L. Walker** : An overview of the [MCVD](#) process and performance, IEEE J. Quantum El. QE-18 (1982) 459-477
- **Peterka - Vláknové lasery**
- Československý časopis pro fyziku 1/2010, 4-5/2010, 1/2011
- **Jemná mechanika a optika (5-6/2025)**

Be UFE !

- STUDIUM (MS, PGS)

ČVUT – FJFI, FEL ...

fyzikální elektronika,
elektromagnetické pole,
mikro/opto elektronika,



UK – MFF

chemická fyzika a optika,
fyzika



VŠCHT

Sklo – anorganické nekovové
materiály



Studentské projekty

Diplomové práce

Doktorské práce



Be careful !



EXCURSION

1. Preform preparation (MCVD) + 2. Fiber drawing
3. Preform characterization

Thank you for attention

ICTON 2026 - INVITATION

