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

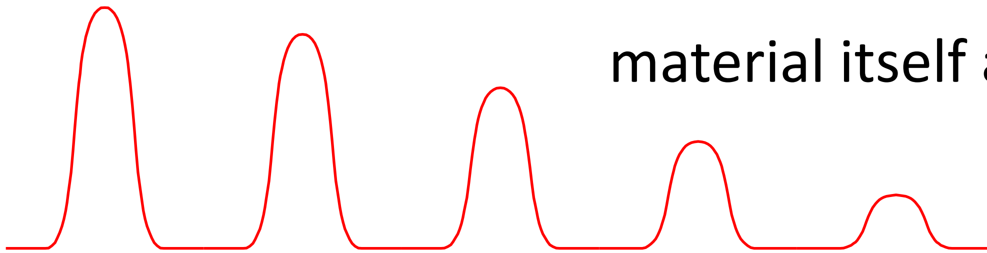
TECHNOLOGY OF OPTICAL FIBERS

Ivan Kašík, www.UFE.cz

03/ 2025

Optical fibers: dielectric, L<< r, n_{core}> n_{clad}

Optical losses in optical fibers (extrinsic, intrinsic)



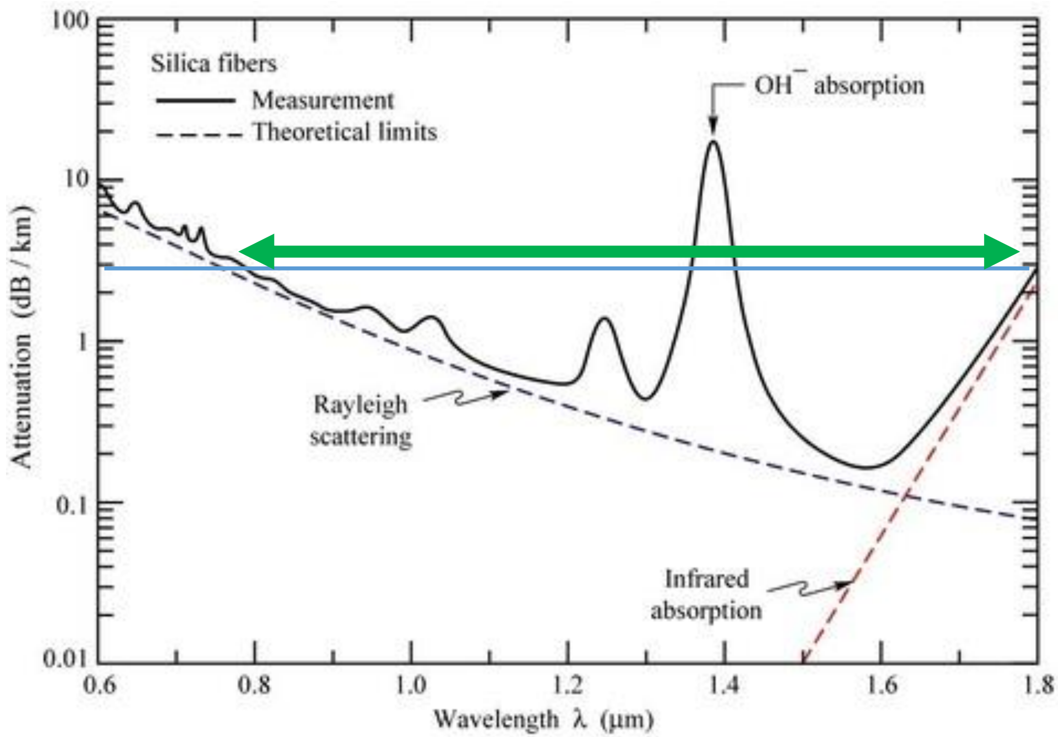
material itself and its purity

Example:

SILICA

20 dB/km

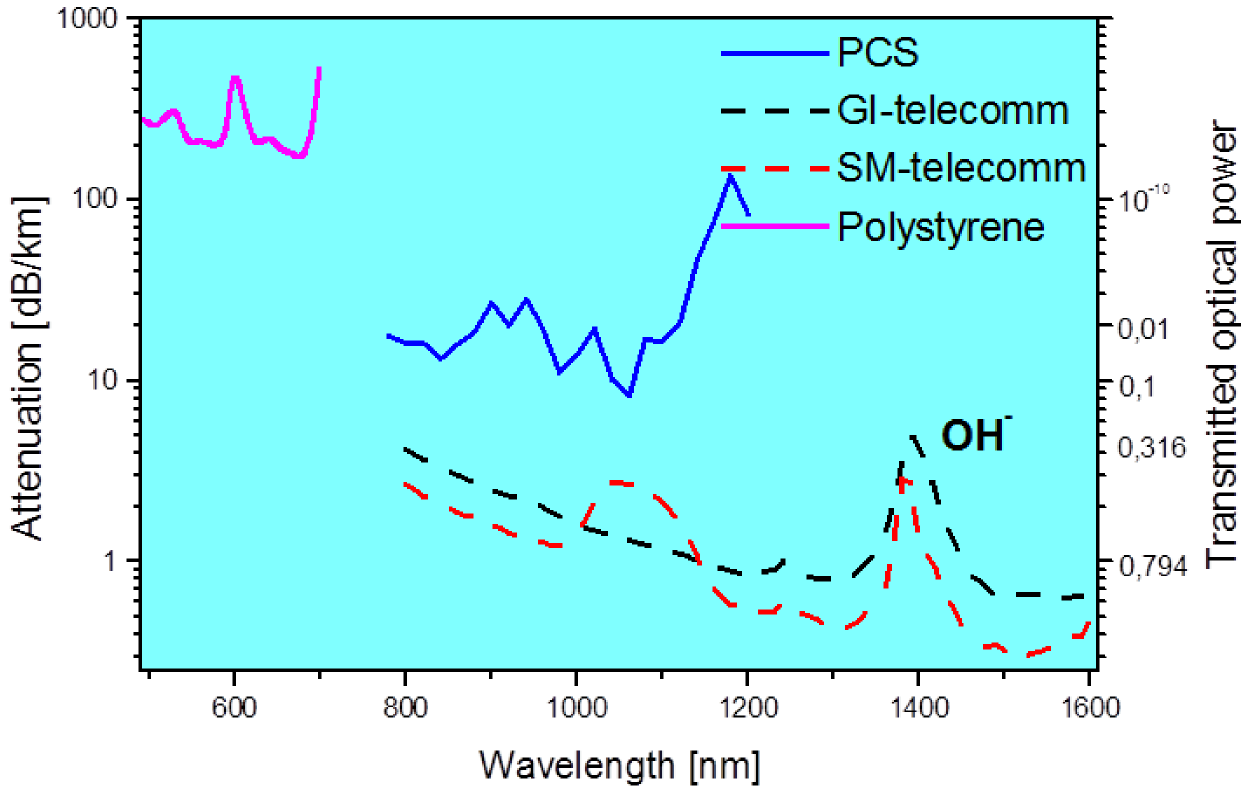
1% transmited



Transmission

Optical fibers

Optical losses in optical fibers (intrinsic, extrinsic)



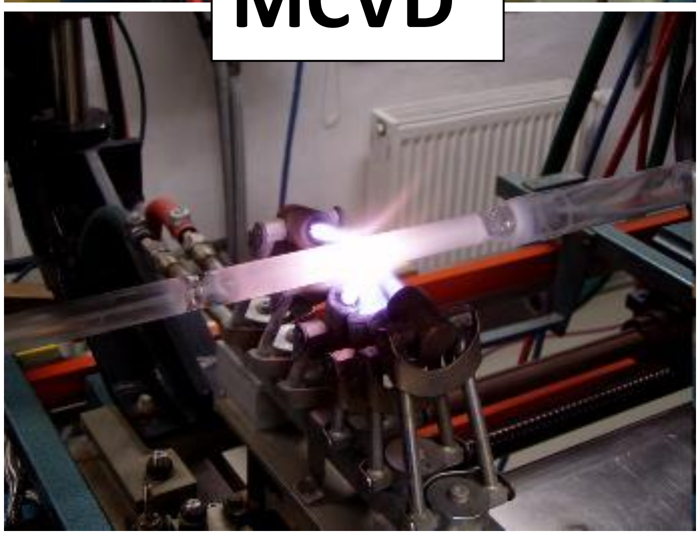
max. impurities acceptable in ppb (10^{-9})

Nobel prize 2009 Ch.K.Kao

ULTRA-PURE TECHNOLOGIES

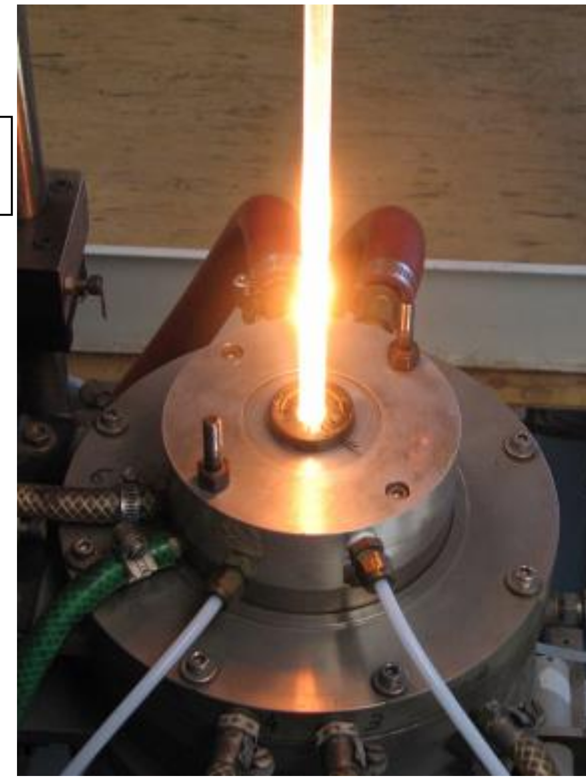
Optical fiber technology

MCVD



1. Preform

2. Fiber drawing



Optical fiber technology

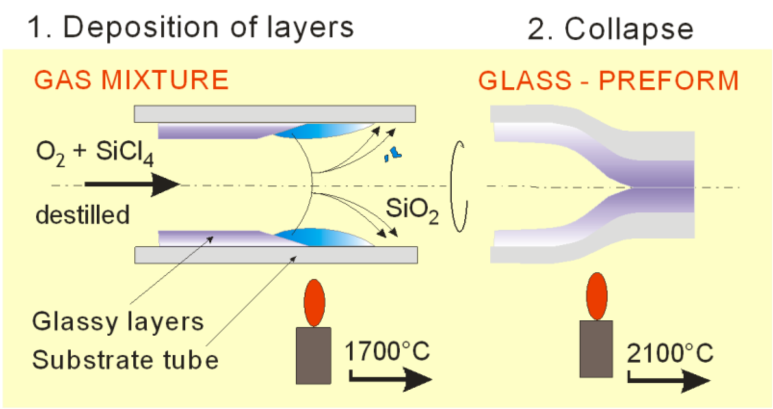
Silica optical fibers – preform fabrication

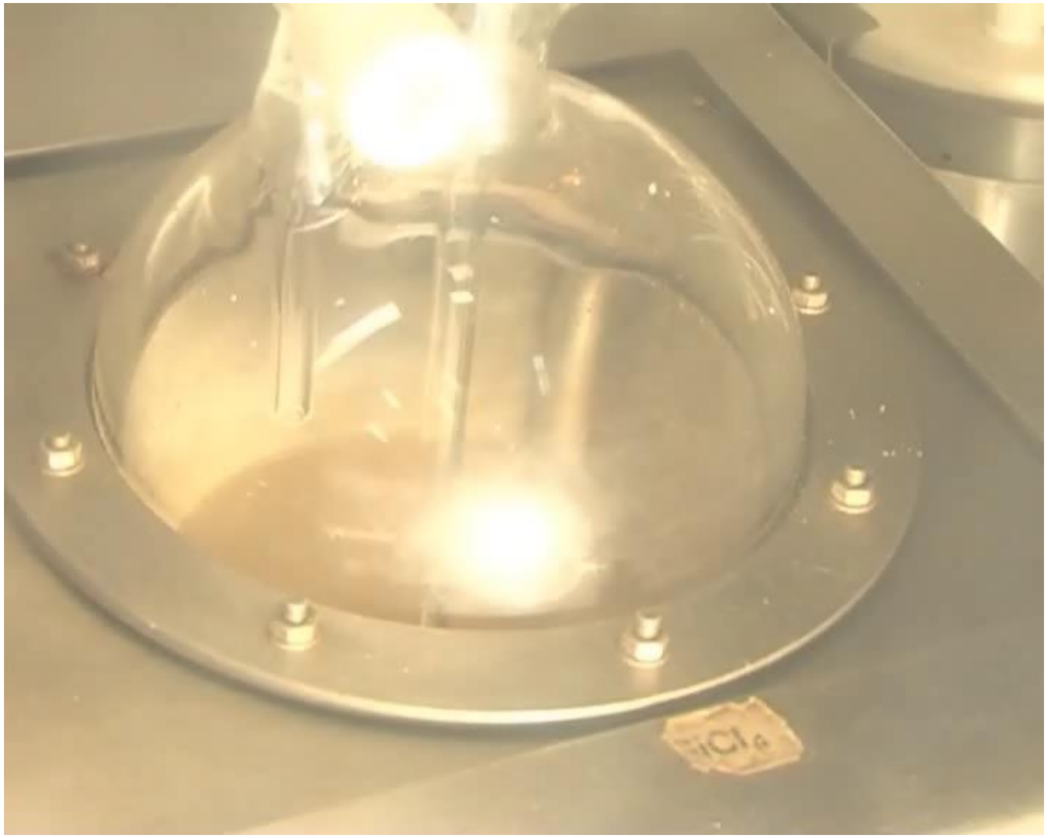
Chemical Vapor Deposition - CVD - Modified CVD (MCVD)

Deposition of solid-state SiO_2 glass layers from gaseous $SiCl_4$+O_2

Precursors – liquid/gas

Ultra-pure (distillation)





Optical fiber technology

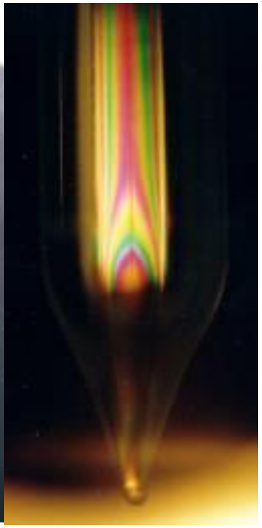
Silica optical fibers – preform fabrication

Deposition of layers

Colapse of preform

Raw materials halogenides ($SiCl_4$)

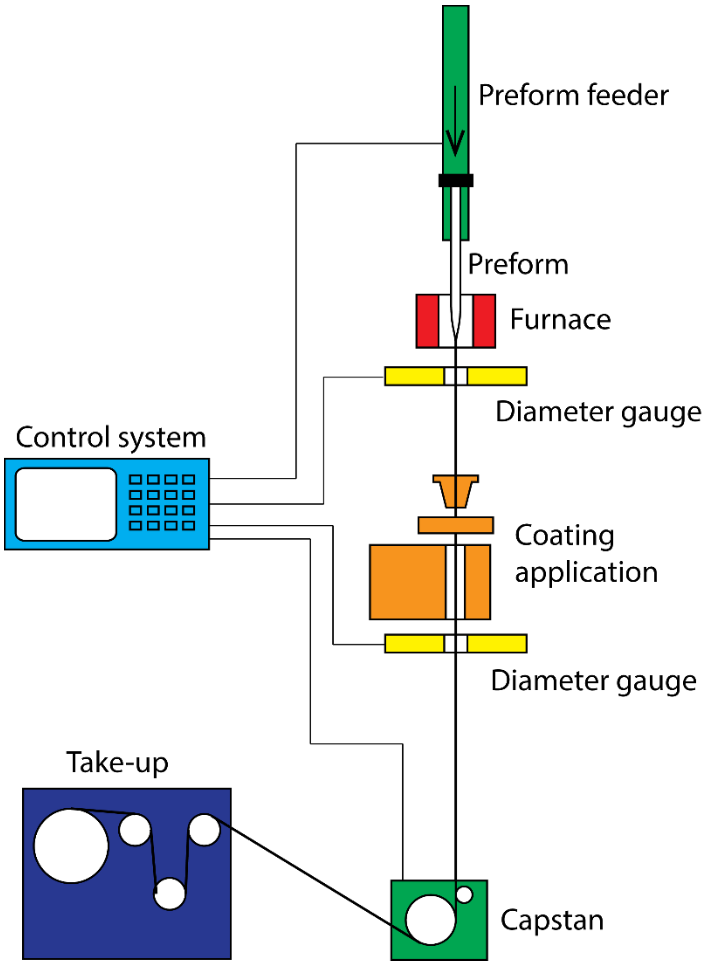
Preforms



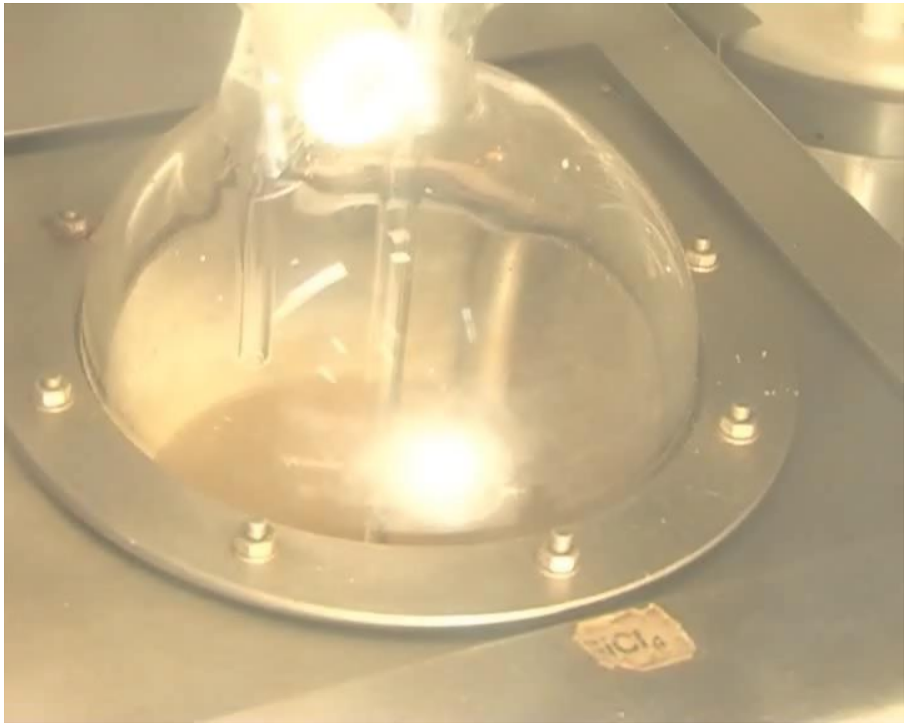
[Nagel et.al., IEEE JQE, QE-18, 459, 1982]

Optical fiber technology

Silica fiber drawing



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

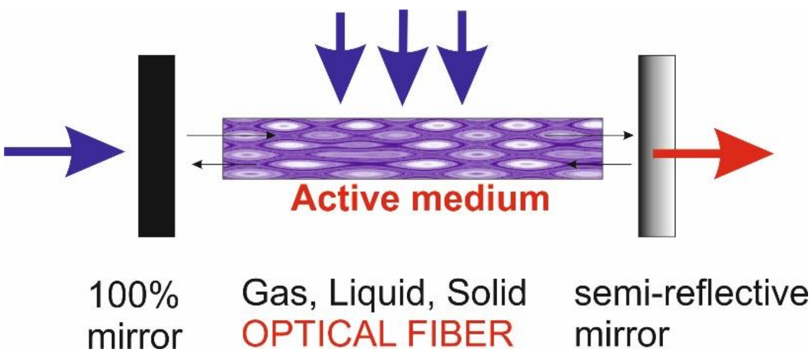


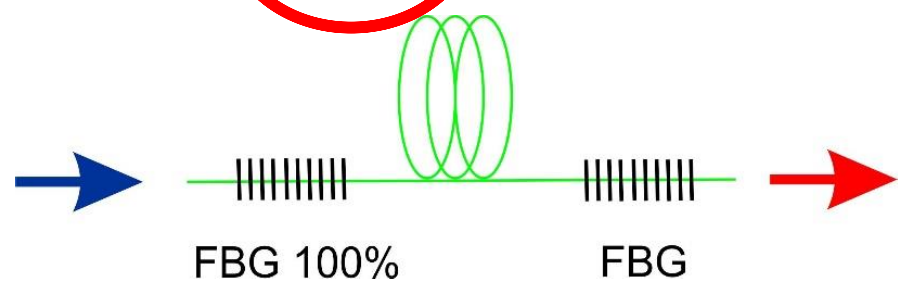
Optical fibers & fiber lasers

PASSIVE optical fibers (telecom)

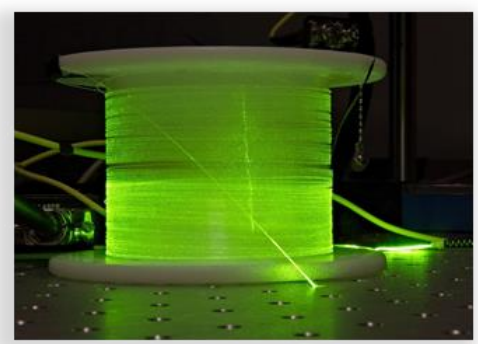
x ACTIVE optical fibers => for fiber lasers

ACTIVE : (usually) RE^{3+}-doped





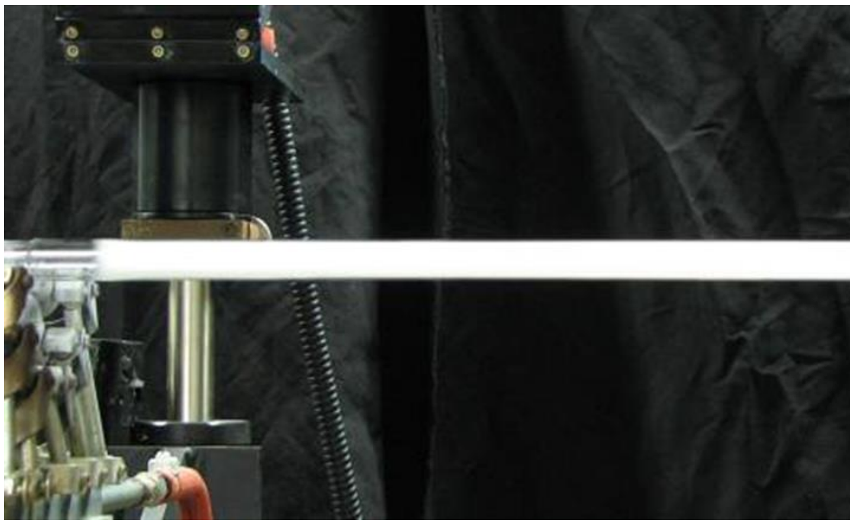
Er^{3+}



Optical fiber technology

RE-doped silica optical fibers – preform fabrication

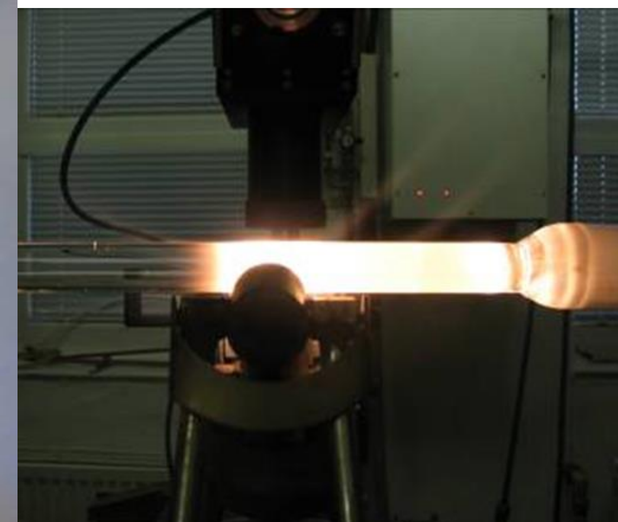
RE starting materials solid-state => modification of technology + matrix modifiers : **Solution doping, Sol-gel**



Porous layer

(SiO_2, GeO_2-SiO_2 …)

Soaking – solution, sol, nanoparticles



Oxidation, drying, sintering

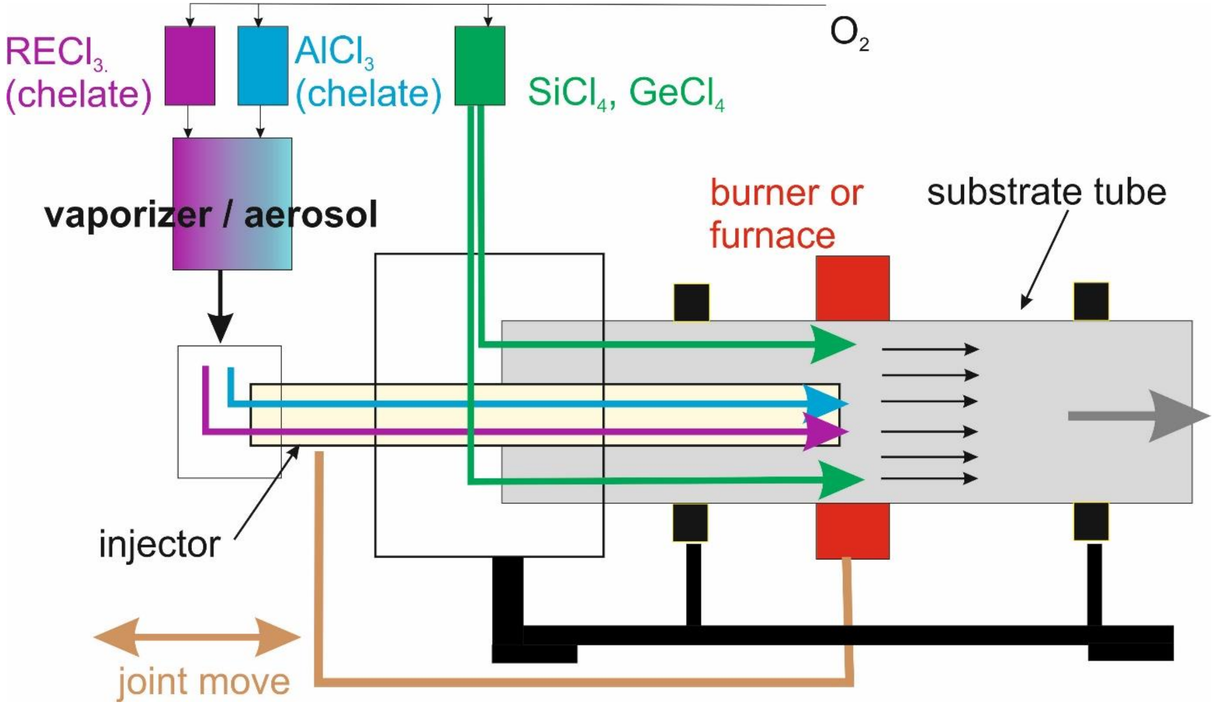
Towndsend, El. Lett. **23**, 329, 1987] [Sysala, Ceramics, **35**, 361, 1991], [Podrazky, IEEE LEOS, 1-2, 246, 2007]

Optical fiber technology

RE-doped silica optical fibers – 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]

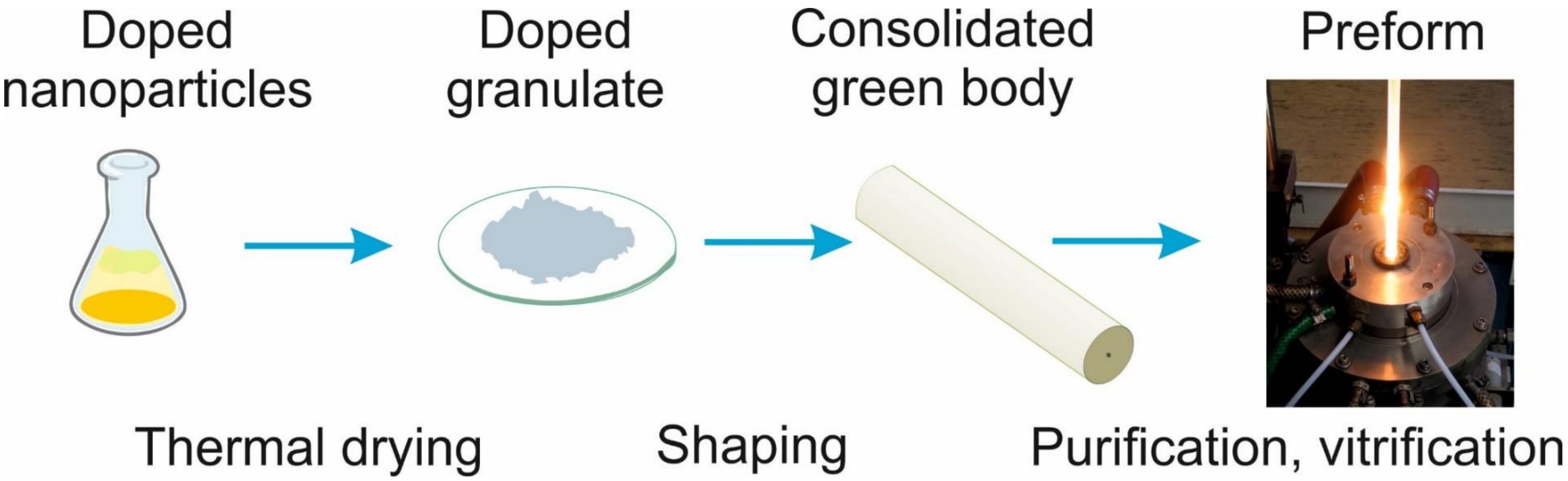
Optical fiber technology

RE-doped silica optical fibers – preform fabrication by

REPUSIL

Conventional glass melting, forming, quenching, ~~annealing~~ :

Precursors - solid state; optical purity suitable for fiber lasers



[Schuster & IPHT]

Optical fiber technology

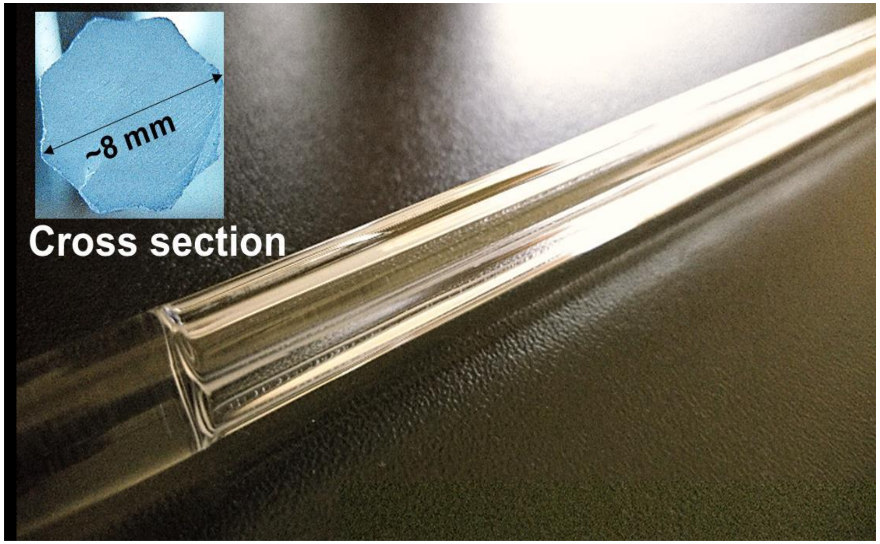
RE-doped silica DC optical fibers – **preform shaping**

Mechanical grinding - diamond tolls

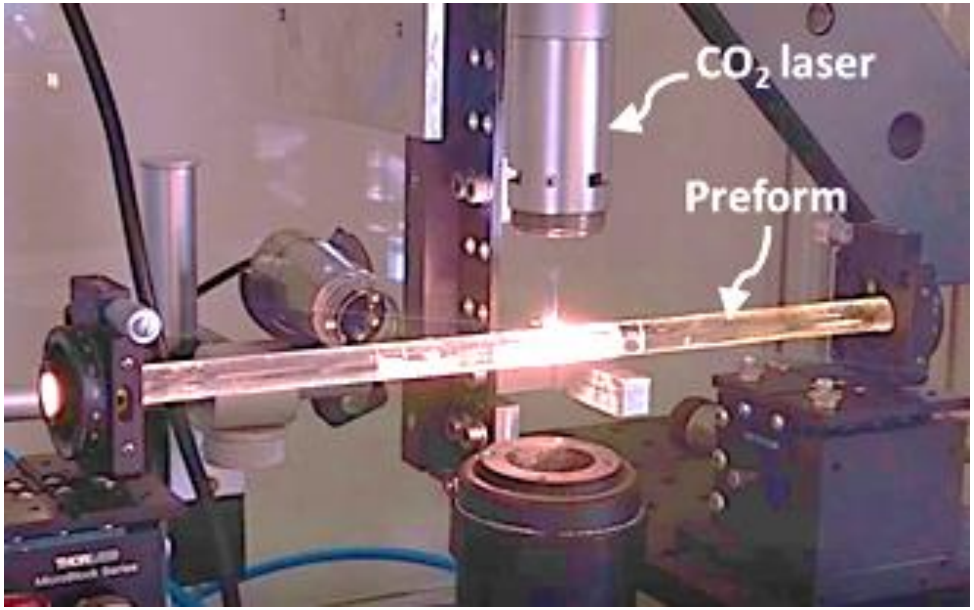
Optical fiber technology

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

Laser processing



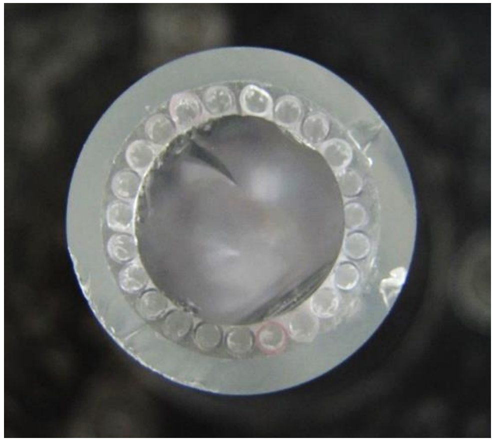
CO_2 laser setup (30 W)

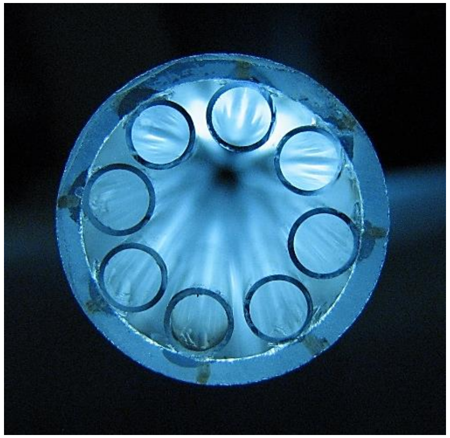


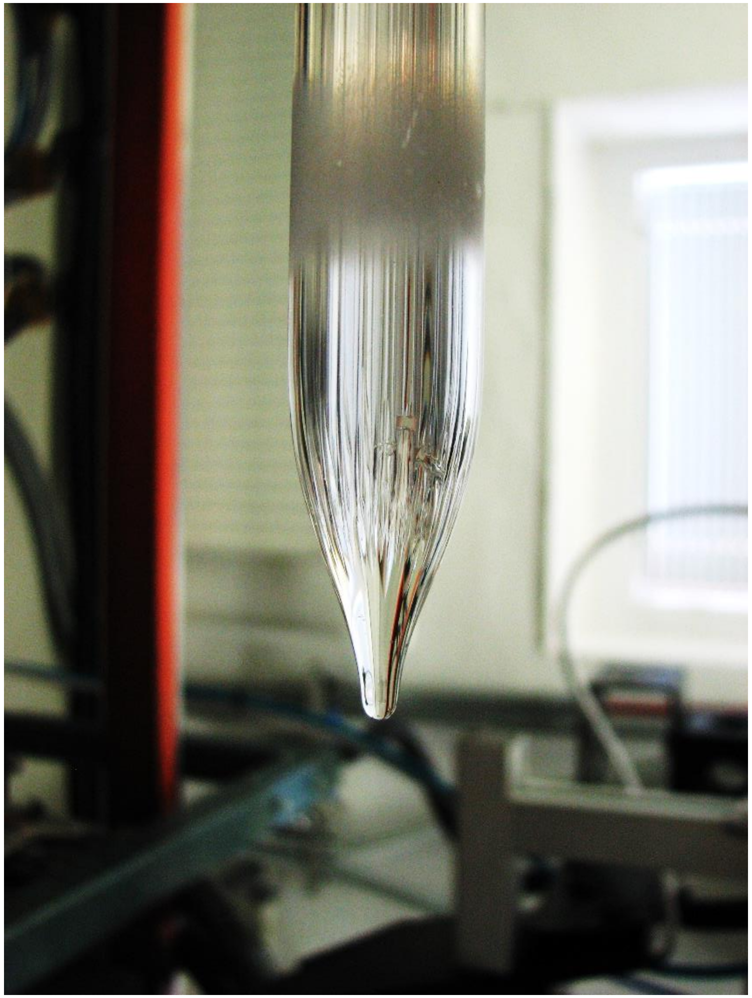
Optical fiber technology

Microstructured silica optical fibers - preform fabrication

Silica microstructure fibers
Design + stack & draw ~2000C







Optical fiber technology

Soft glass (non-silica) optical fibers

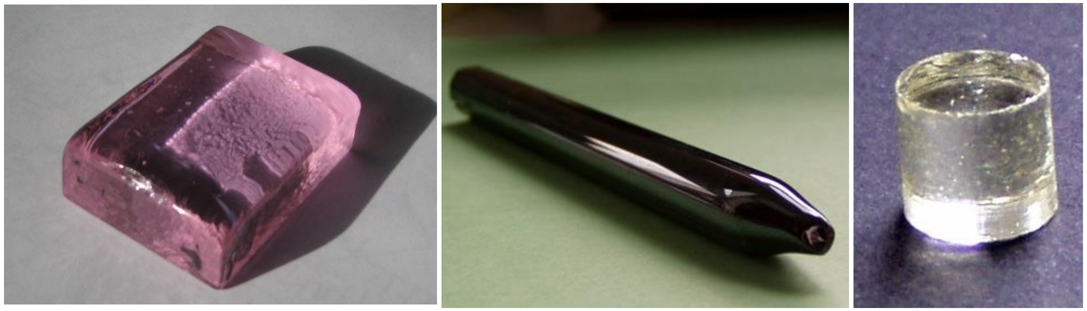
PREFORM fabrication

Germanate, chalcogenide (silicate, phosphate) ….. **+ RE^{3+}**

Conventional glass **melting, forming, quenching, annealing**

Precursors - solid state

Processing ~500-1500 C (Super/Kanthal)



Er^{3+} silicate, As_2S_3, $PbO-GeO_2$ 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

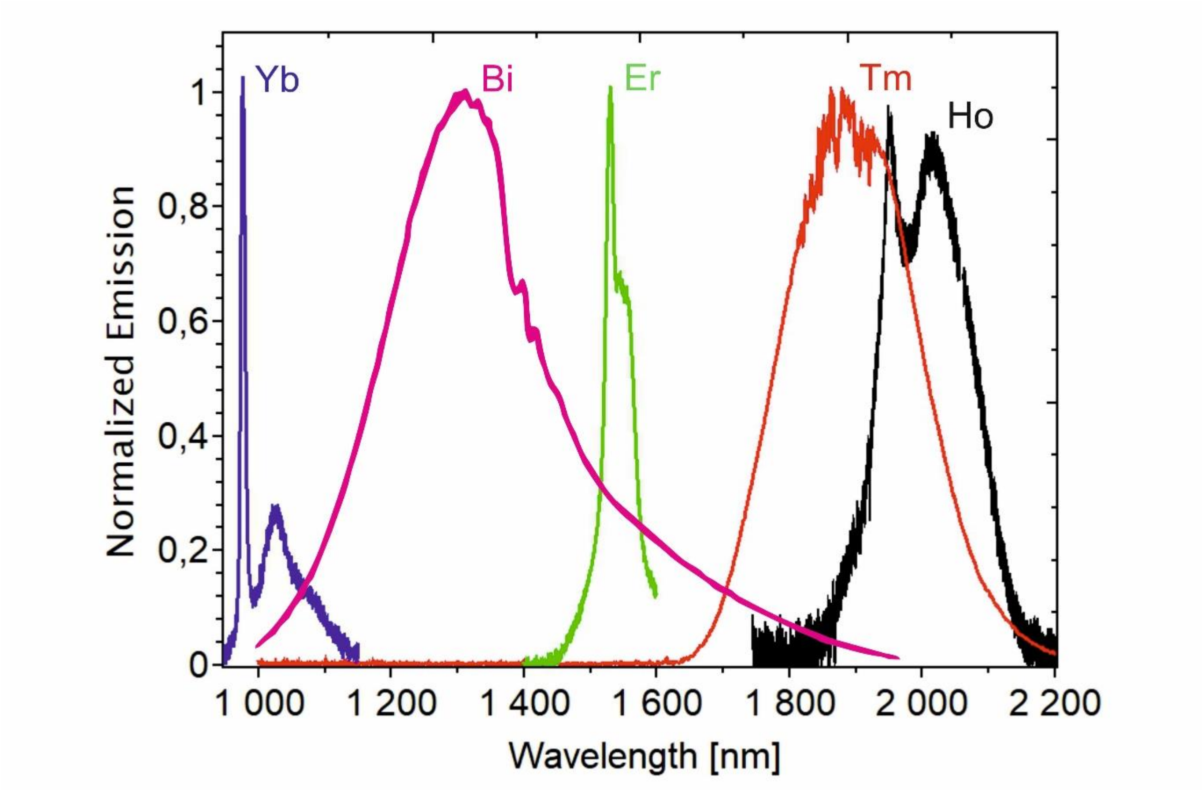
* high conversion efficiency (fiber lasers ~70-90%) - savings
* high quality beam (nearly Gaussian, low divergency)
* **high brightness** (high concentration of power)
* good thermal management (cooling)
* effective pumping
* tunability
* compactness
* size (long resonator in small space)

[IPG]

Optical fibers for lasers

Silica RE doped, (Bi –doped)

Task of technology: to avoid clusterring of **RE^{3+}**

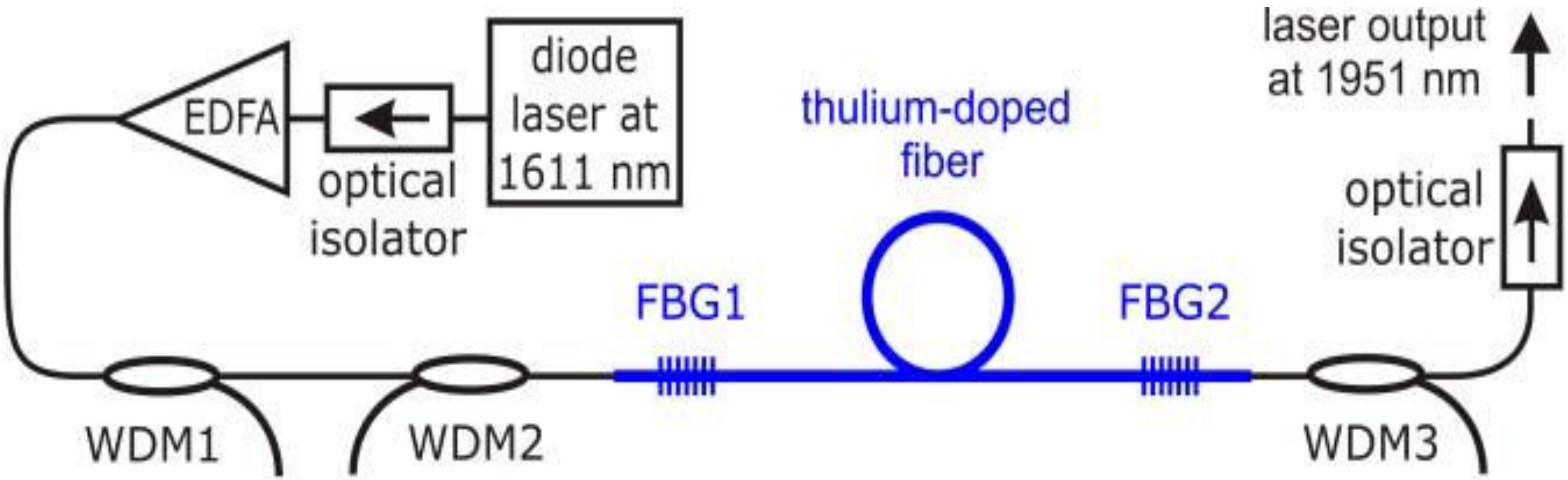


Commercial RE-doped: Nufern, NKT, Corning, ADValue photonics ….

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

Tm fiber laser at 1951 nm

Eye-safe spectral region (≠ 1550 nm)

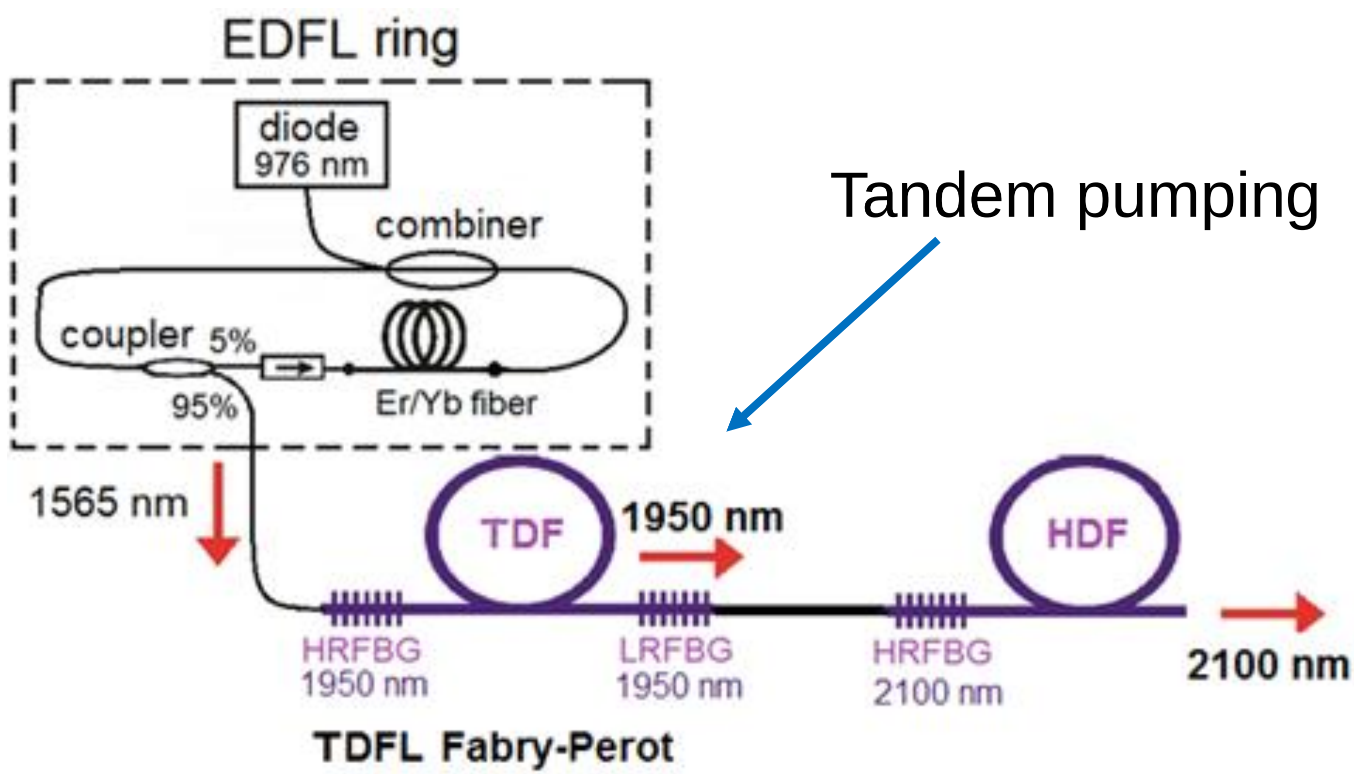


- 1000 ppm Tm^{3+}, 11mol% Al_2O_3, 0 mol% P_2O_5 or GeO_2
- Inscription of FBG into GeO_2-free fiber (!)
- Nowadays TDFL up to 65% SLE, up to 400 W

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

Ho fiber laser at 2100 nm

Eye-safe spectral region (≠ 1550 nm)



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

[Kamradek_OC_2025, Pokorny_OPEX_2025]

Dual wavelenght fiber laser

Conventional Yb-Er-doped fiber laser [Peterka, Kanka, 1997]

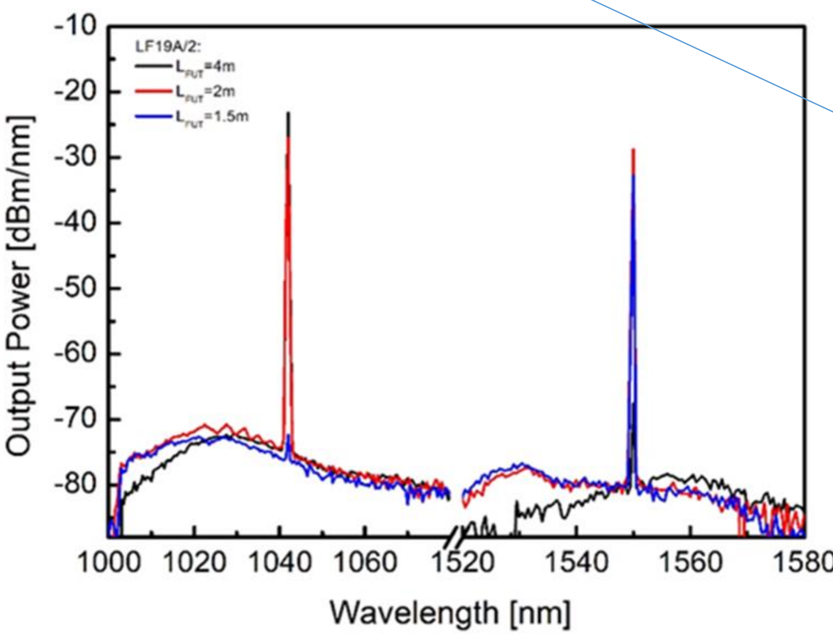
Method solution doping – solution of $ErCl_3$ + $YbCl_3$

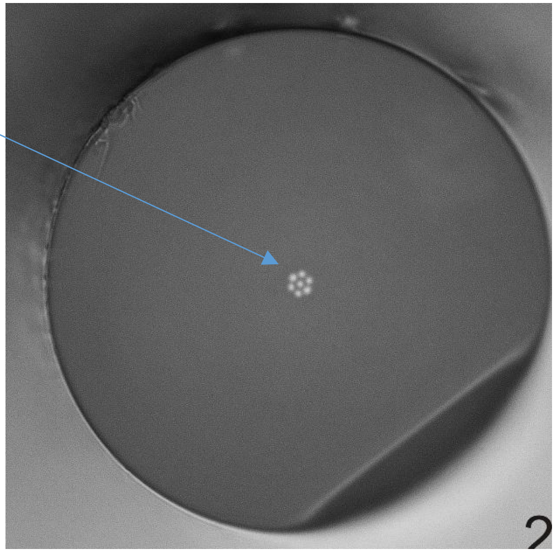
Emission 1550 nm (thanks to energy transfer Yb^{3+} => Er^{3+})

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

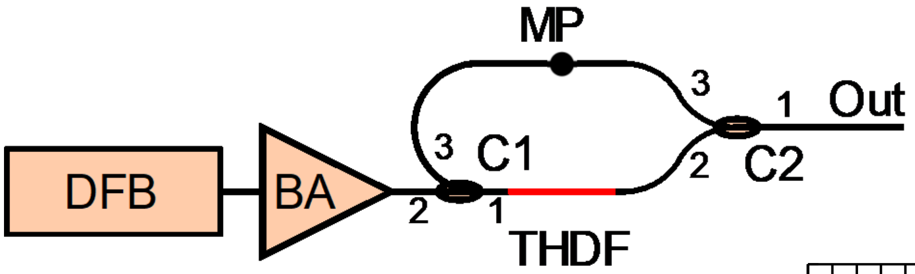
Method : assembling from 7 rods („sub-cores“)

Emission 1550 nm (telecom) and 1060 nm

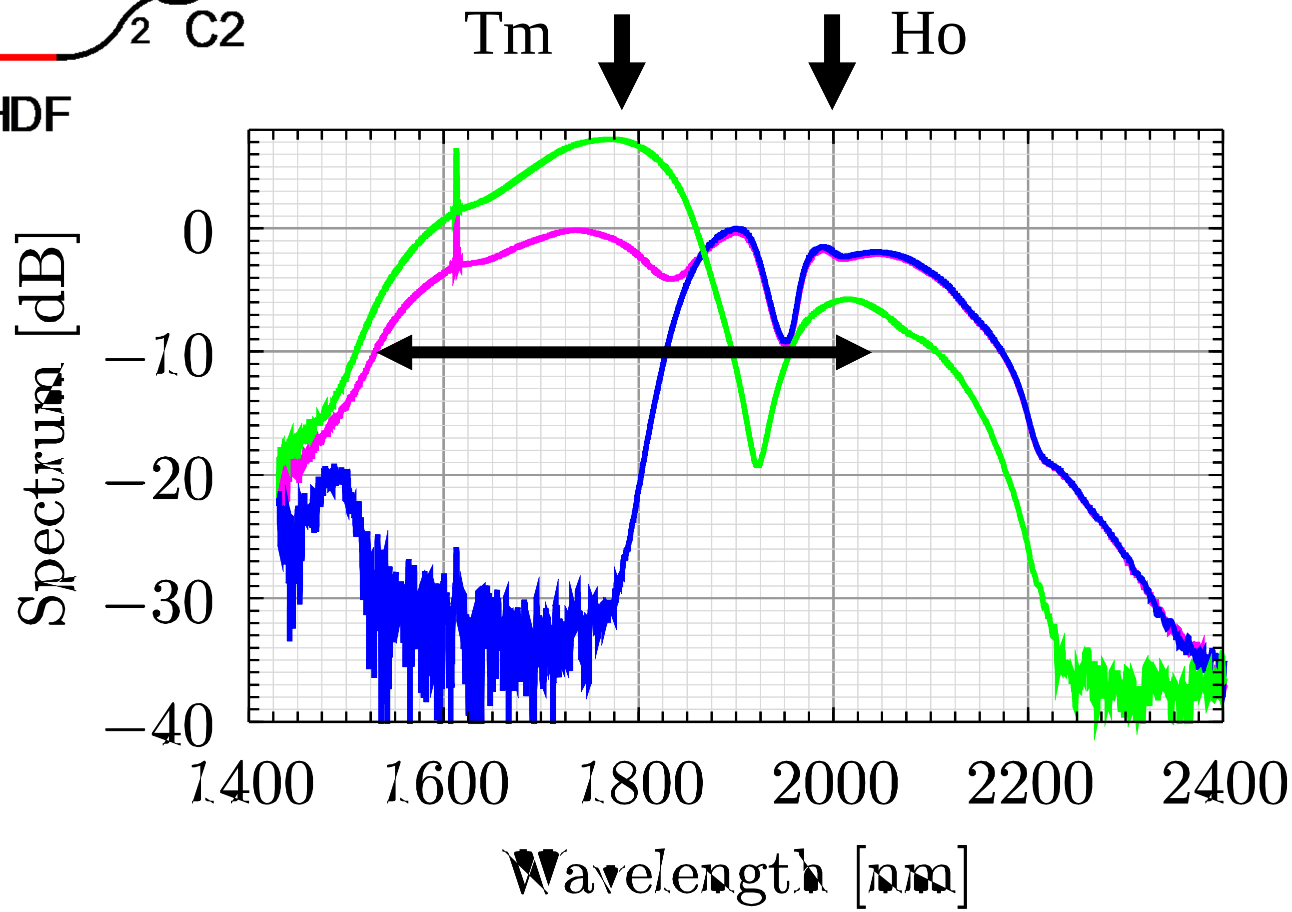




Tm/Ho fiber for ASE (1550-2050 nm) source



(≠ 1550 nm)

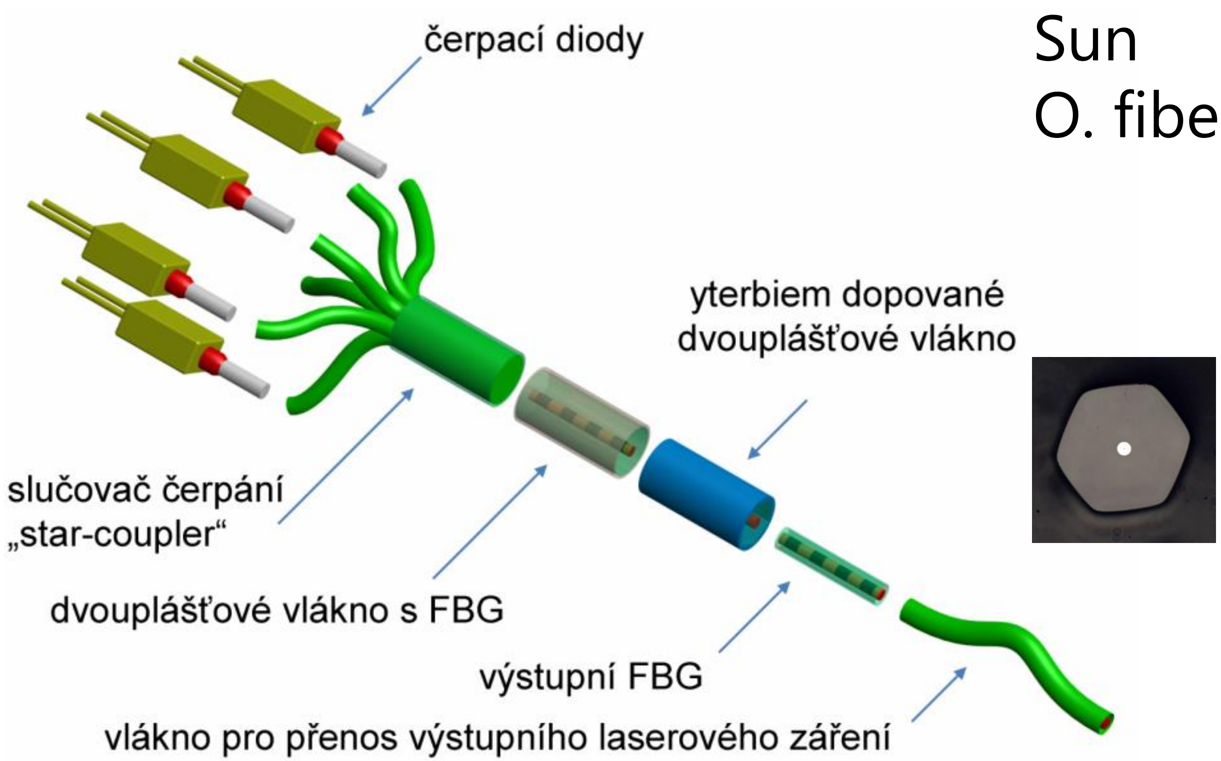


1800 ppm Tm^{3+} /
360 ppm Ho^{3+}

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

Fiber lasers mW → **kW**

DC*



Intenzity of light

Sun	63 MW/m2
O. fiber	12.7 GW/m2

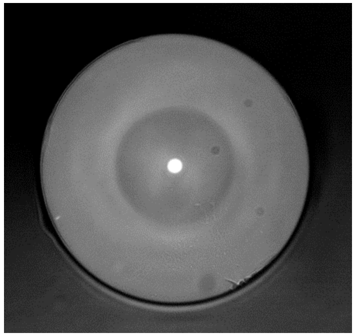
[P.Peterka, Eysafe, 2015]

Beam combining, double-clad structures ....

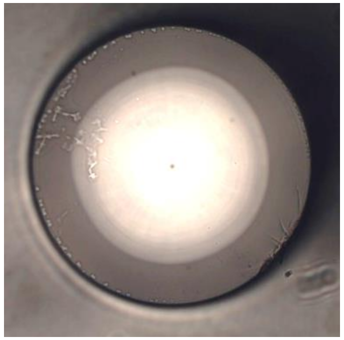
Silica optical fibers for lasers

STRUCTURES

SM & LMA

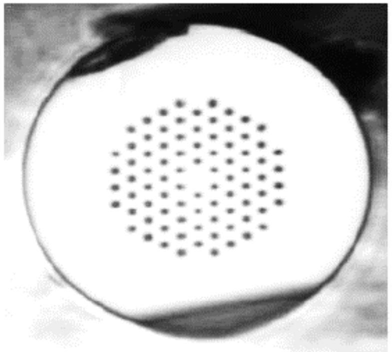


SM 125/10



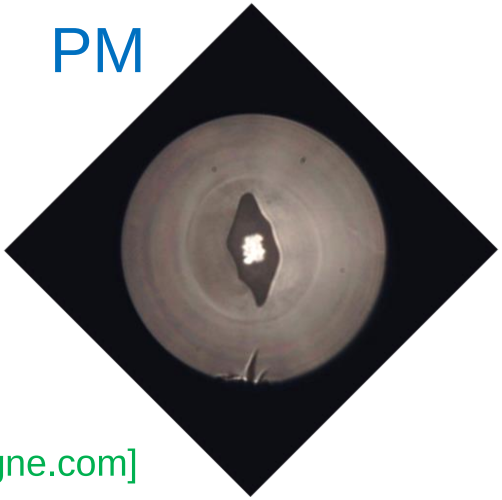
TDF 125/65

PCF

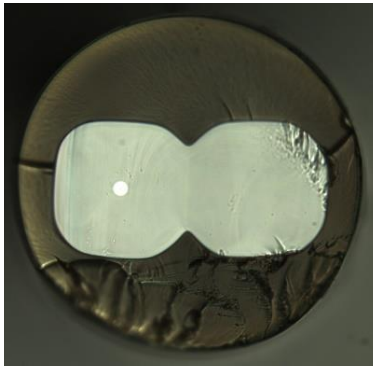


[www.photonics-bretagne.com]

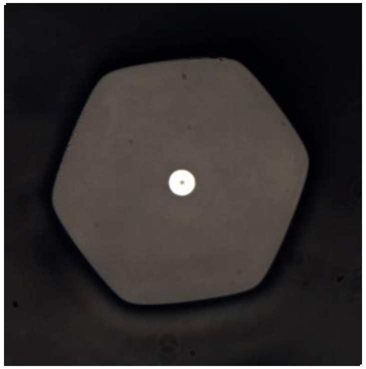
PM



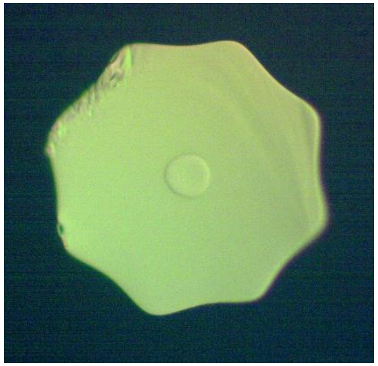
DC*



EDF 250x125/7



TDF 130/12



TDF 130/15

PM

TDF PANDA 125/8

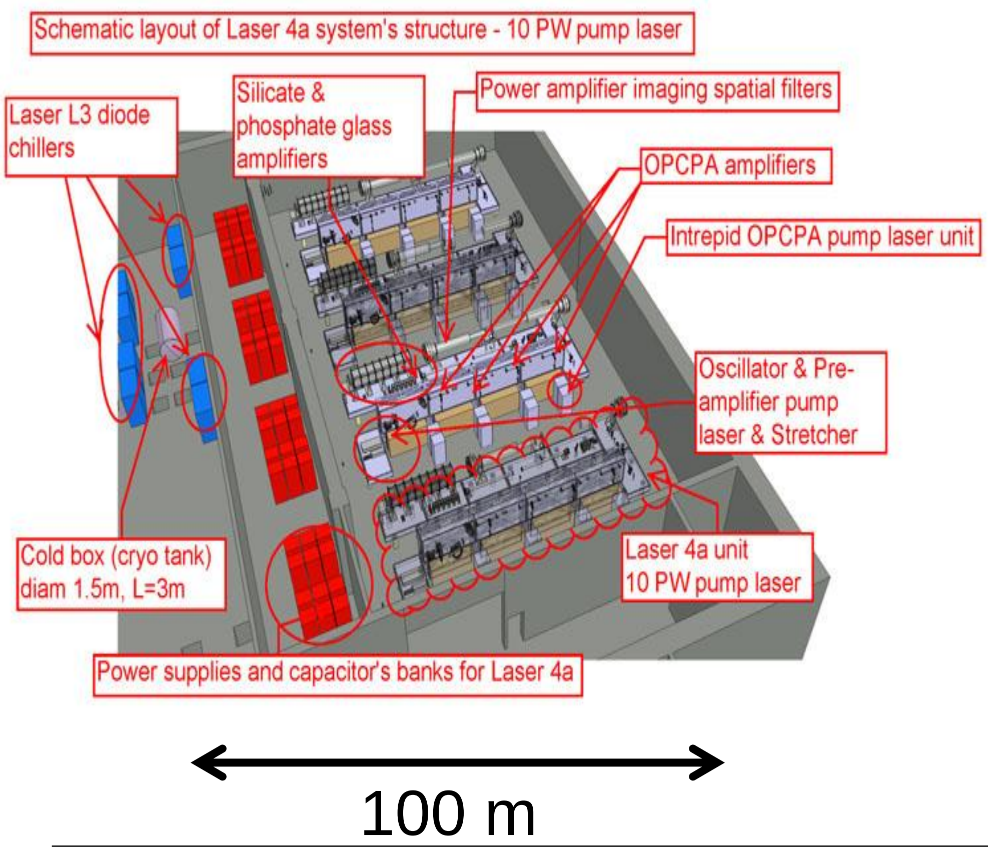
[Peterka et.al., Opt. Lett., **31**, 3240, 2006], [Koska et.al., Op.Ex. **24**, 102, 2016], [Jasim et.al., Op.Ex. **28**, 13601, 2020]

Fiber lasers & 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]



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).**
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**

ÚFE

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.
- **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 (2015)

Be UFE !

- STUDIUM

ČVUT – FJFI, FEL ...

fyzikální elektronika,

elektromagnetické pole,

mikro/opto elektronika,

UK – MFF

chemická fyzika a optika,

fyzika

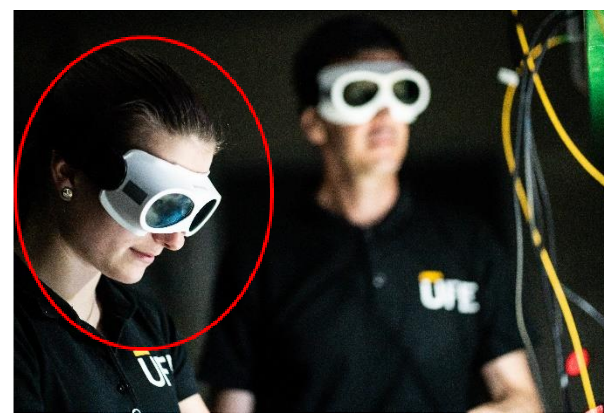
VŠCHT

Sklo – anorganické nekovové materiály

Studentské projekty

Diplomové práce

Doktorské práce



Be carefull !

EXCURSION

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

3. Preform characterization

Thank you for attention