Academy of Sciences

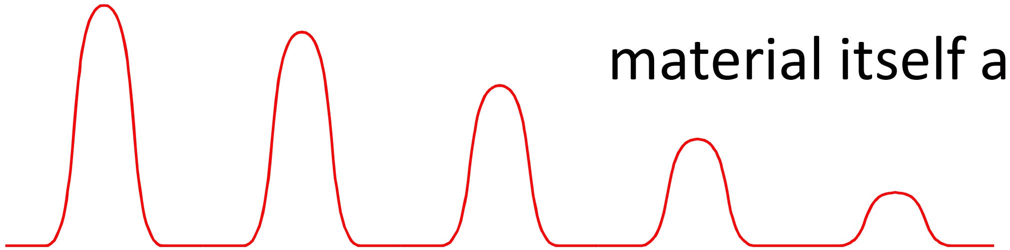
Institute of Photonics and Electronics v.v.i.

Technology of Optical Fibers

I.Kašík, www.ufe.cz

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

Optical losses in optical fibers (extrinsic, intrinsic)



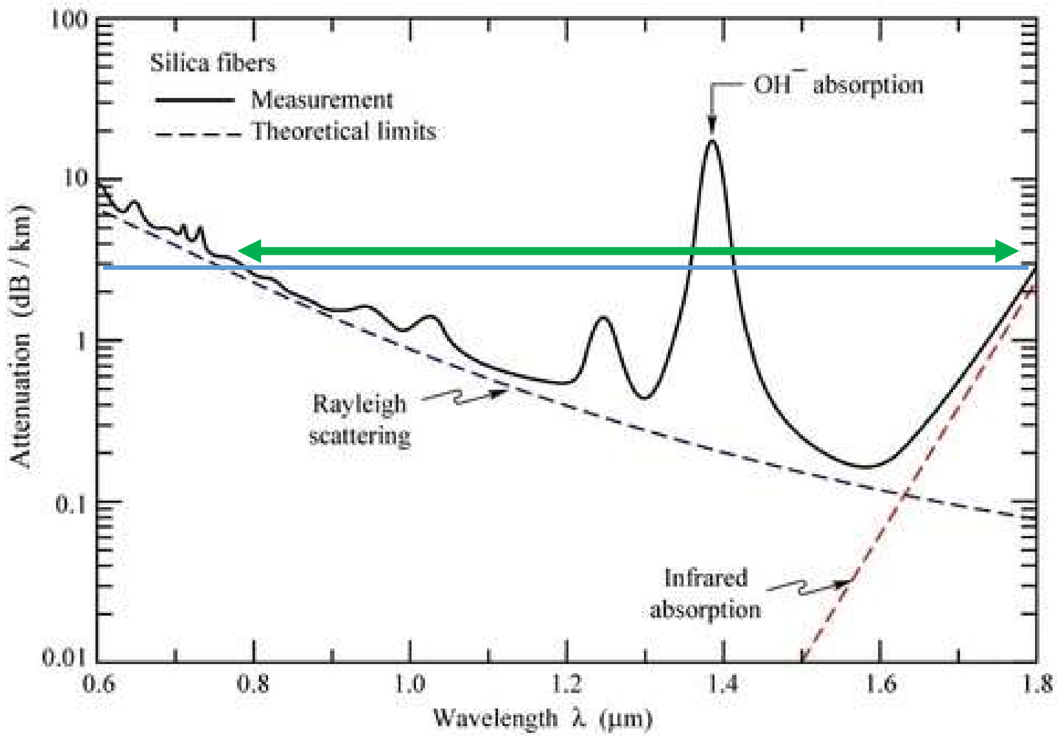
material itself and its purity

Example:

SILICA

20 dB/km

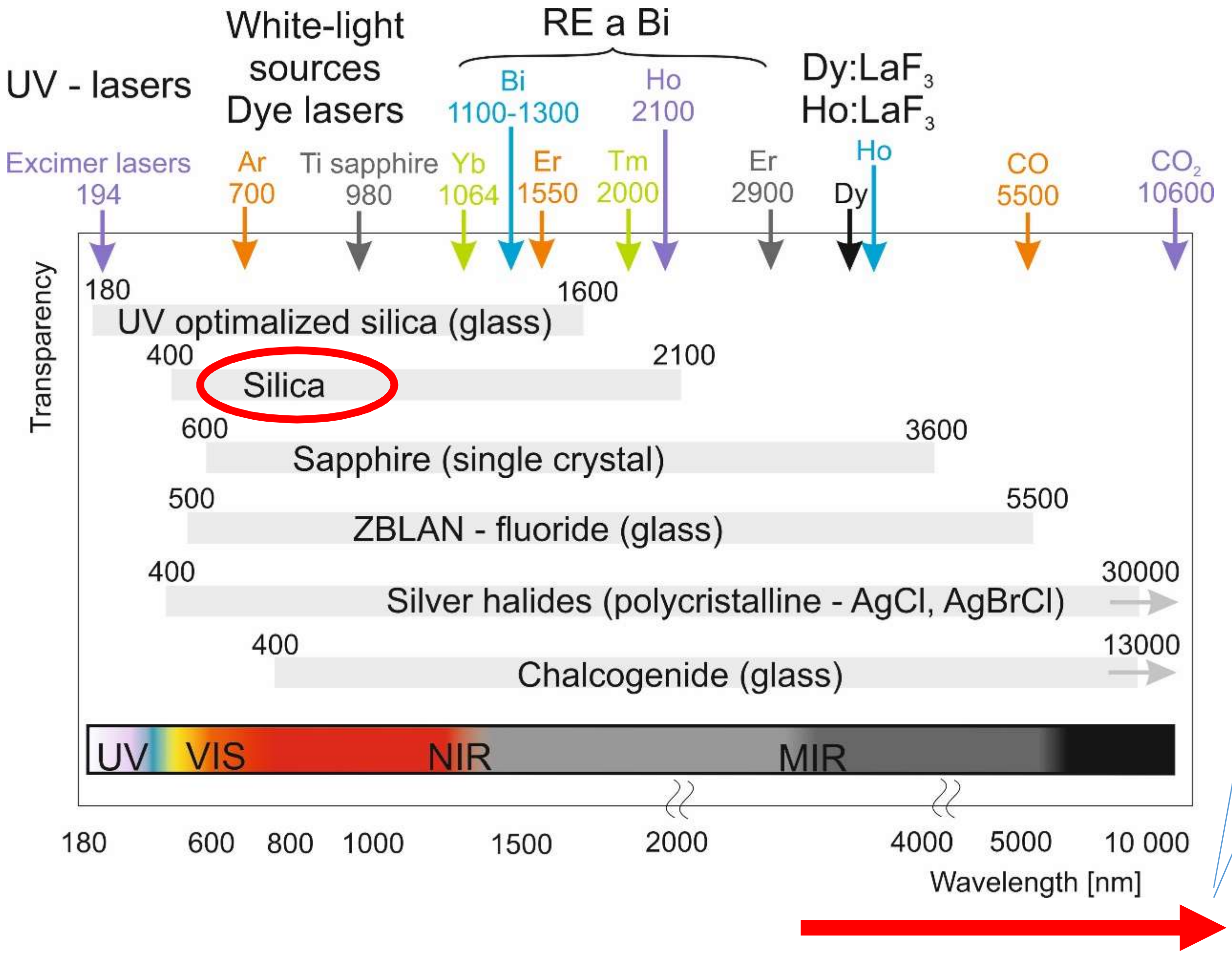
1% transmited



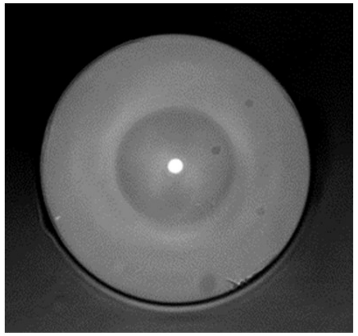
Transmission

Optical fibers

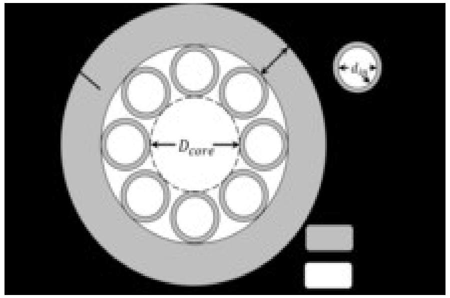
Optical losses in optical fibers (intrinsic, extrinsic)



Solid core



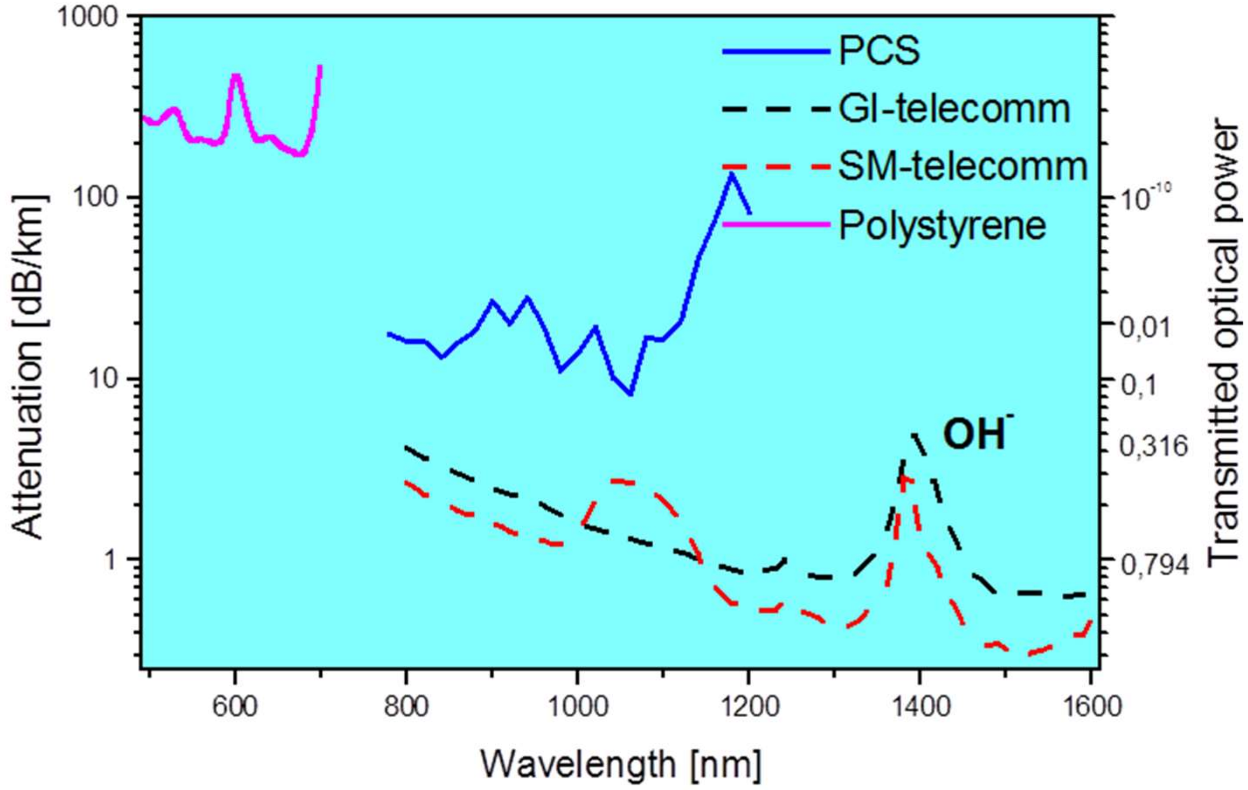
Hollow core



[Komsomol]

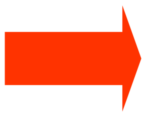
Optical fibers

Optical losses in optical fibers (intrinsic, extrinsic)



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

Nobel prize
2009 Ch.K.Kao



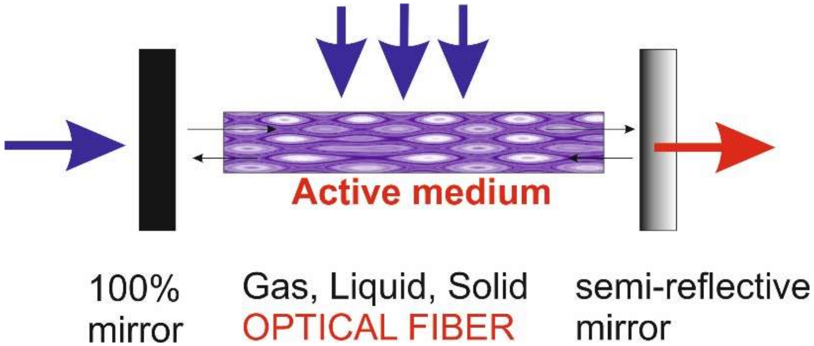
ULTRA-PURE TECHNOLOGIES

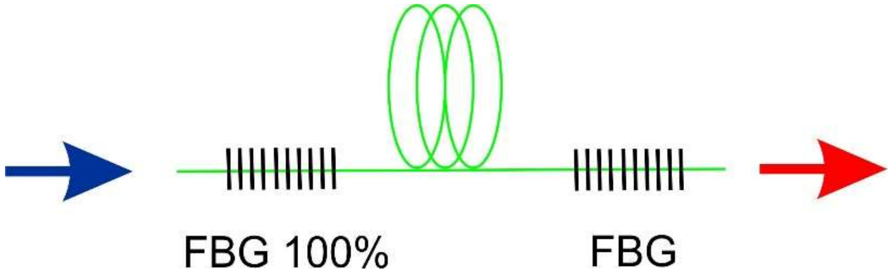
Optical fibers – fiber lasers

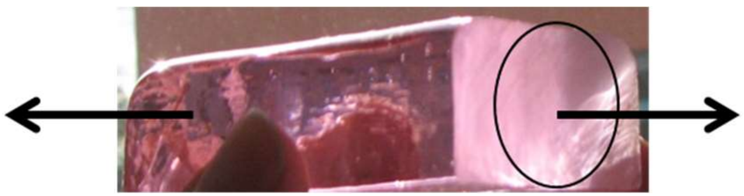
PASSIVE optical fibers (telecom)

x ACTIVE optical fibers => for fiber lasers

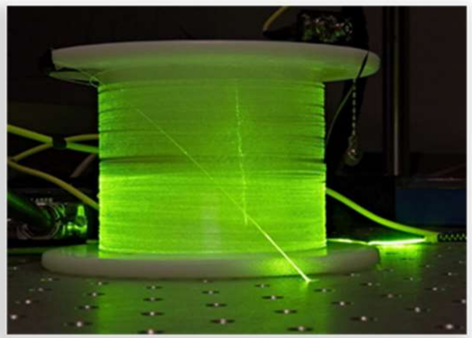
ACTIVE : (usually) RE^{3+} -doped



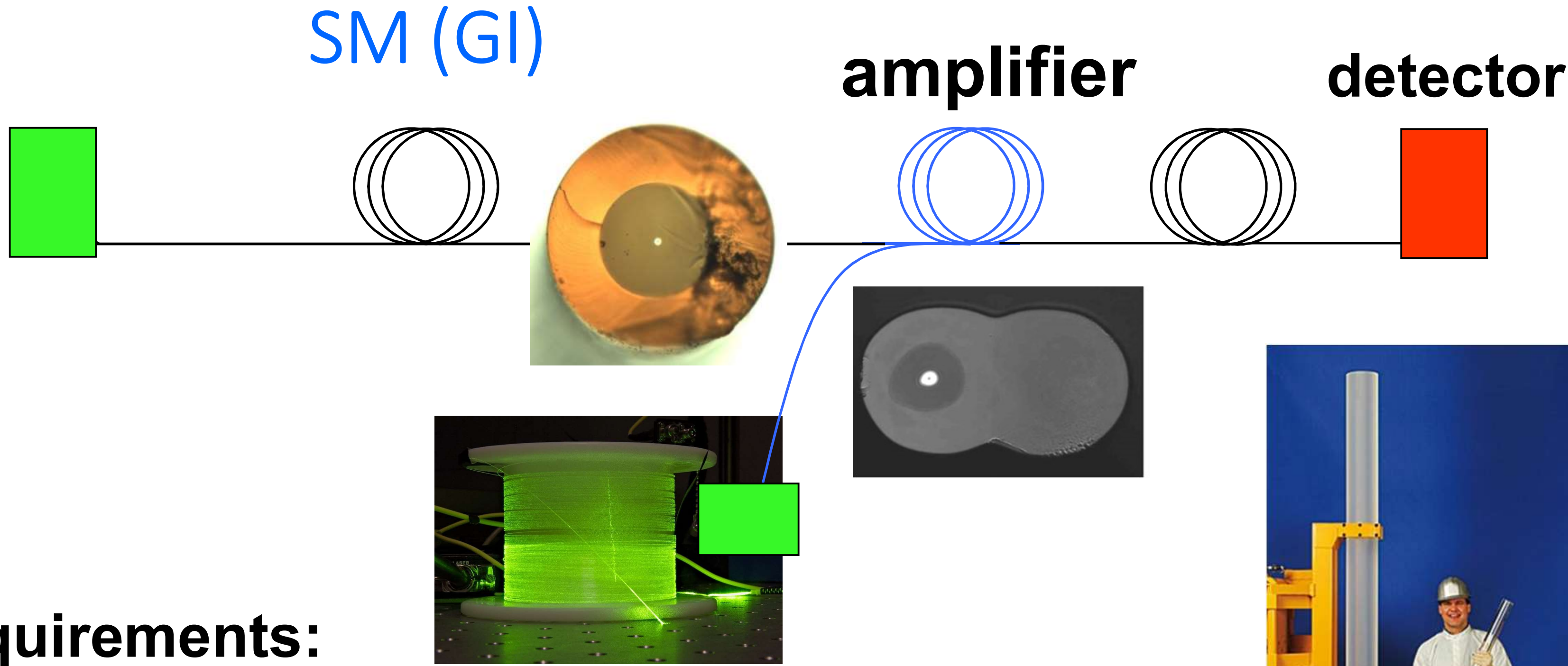




Er^{3+}



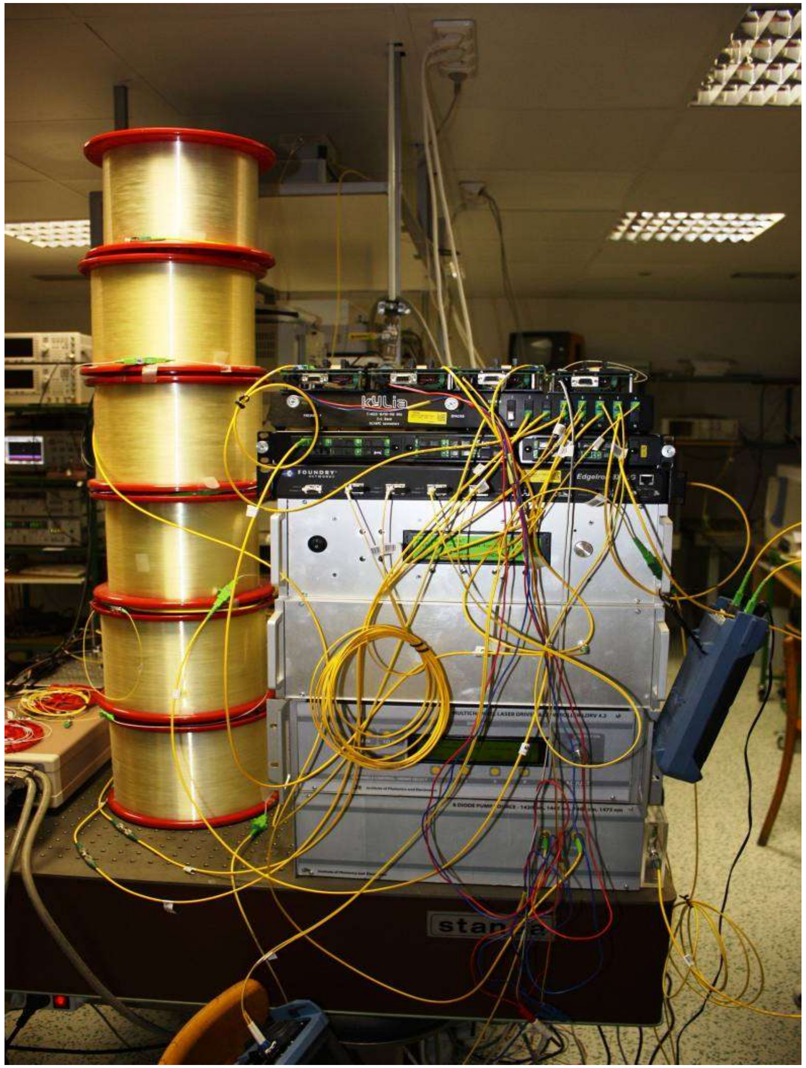
PASSIVE optical fibers for telecom

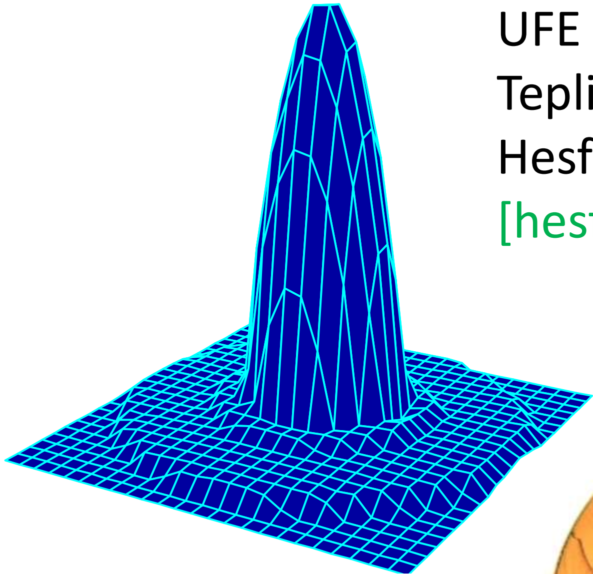


Requirements:

- Low attenuation, low dispersion
- Durability (temperature, pressure, EM field...)
- Low price (<< 1 USD/m)

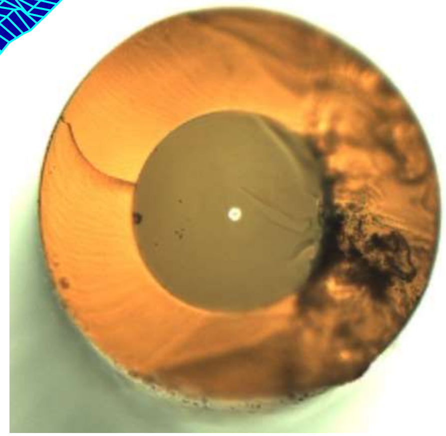
PASSIVE optical fibers for telecom





UFE Prague =>
Teplice, CR =>
Hesfibel, TR
[hesfibel.com.tr]

GI - multimode

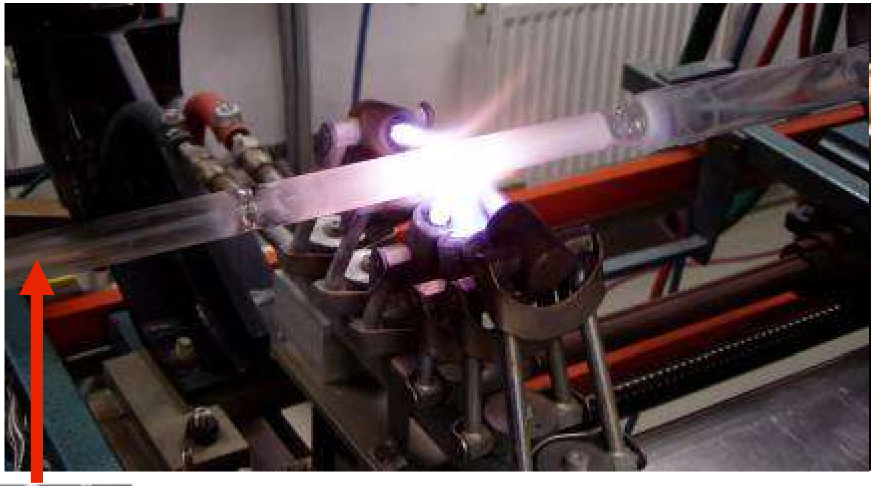


SM - singlemode

200 km telecom line - test

Optical fiber technology

I. **Silica optical fibers (solid core)** – 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

I. **Silica optical fibers (solid core)** – preform fabrication

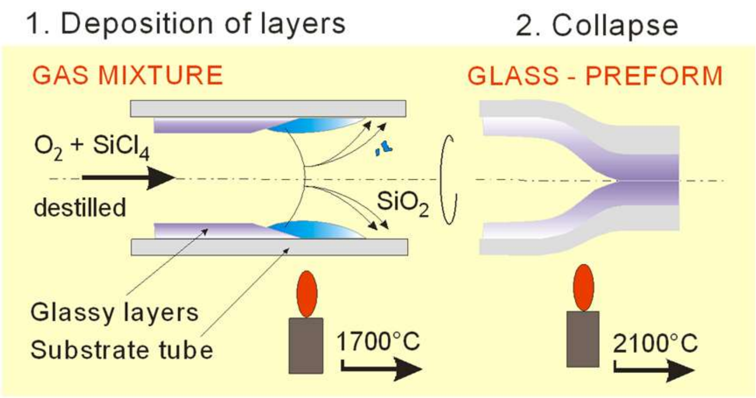
Chemical Vapor Deposition - CVD - Modified CVD (MCVD)

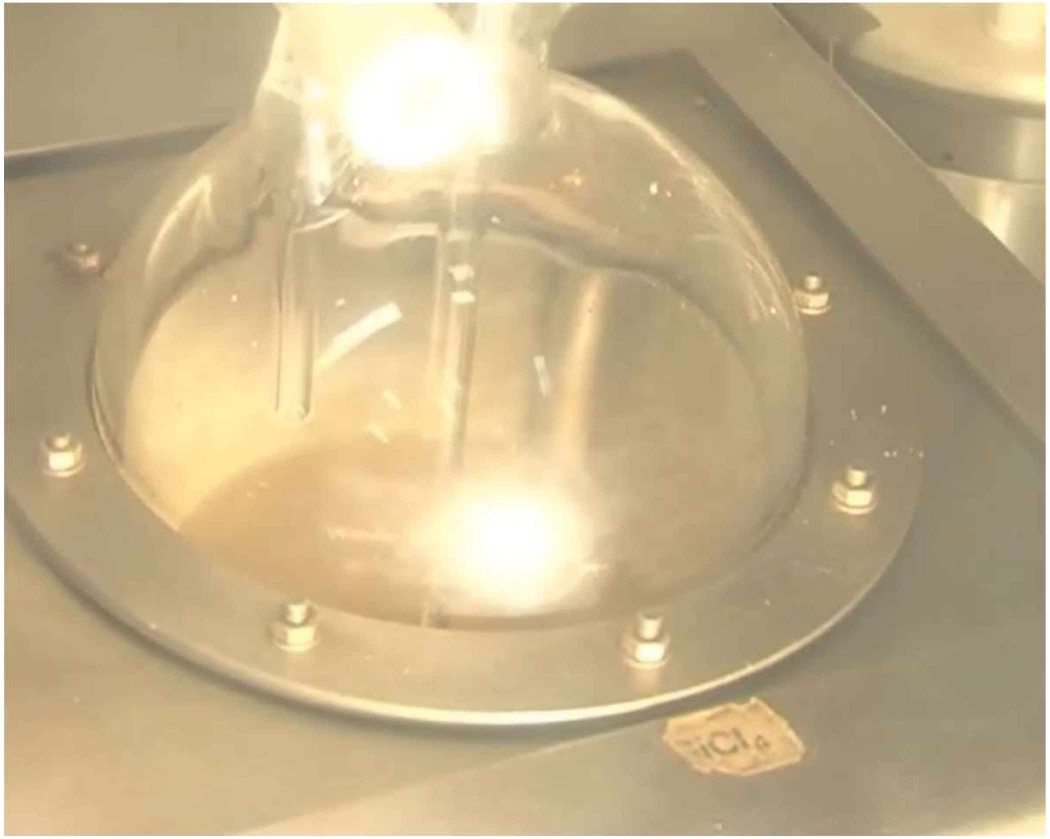
Deposition of solid-state SiO_2 glass layers from gaseous $SiCl_4$+O_2

Precursors – liquid/gas

Ultra-pure (distillation)

PASSIVE (modif. ACTIVE)



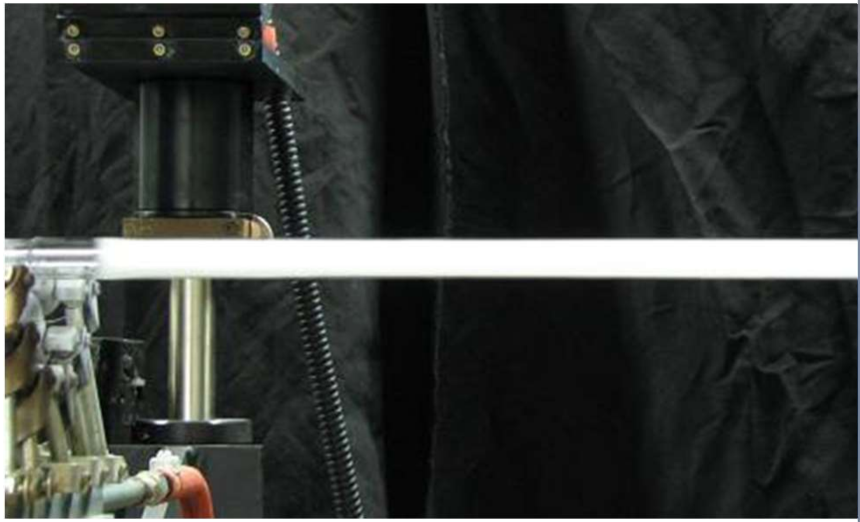


Optical fiber technology

I. Silica optical fibers (solid core) – preform fabrication

RE starting materials solid-state => modification of technology

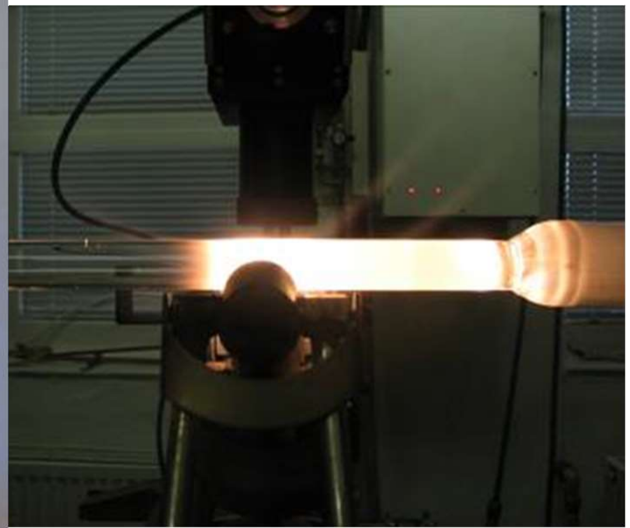
Solution doping, Sol-gel **ACTIVE**



Porous layer

(SiO_2, GeO_2-SiO_2 …)

Soaking – solution, sol, nanoparticles



Oxidation, drying, sintering

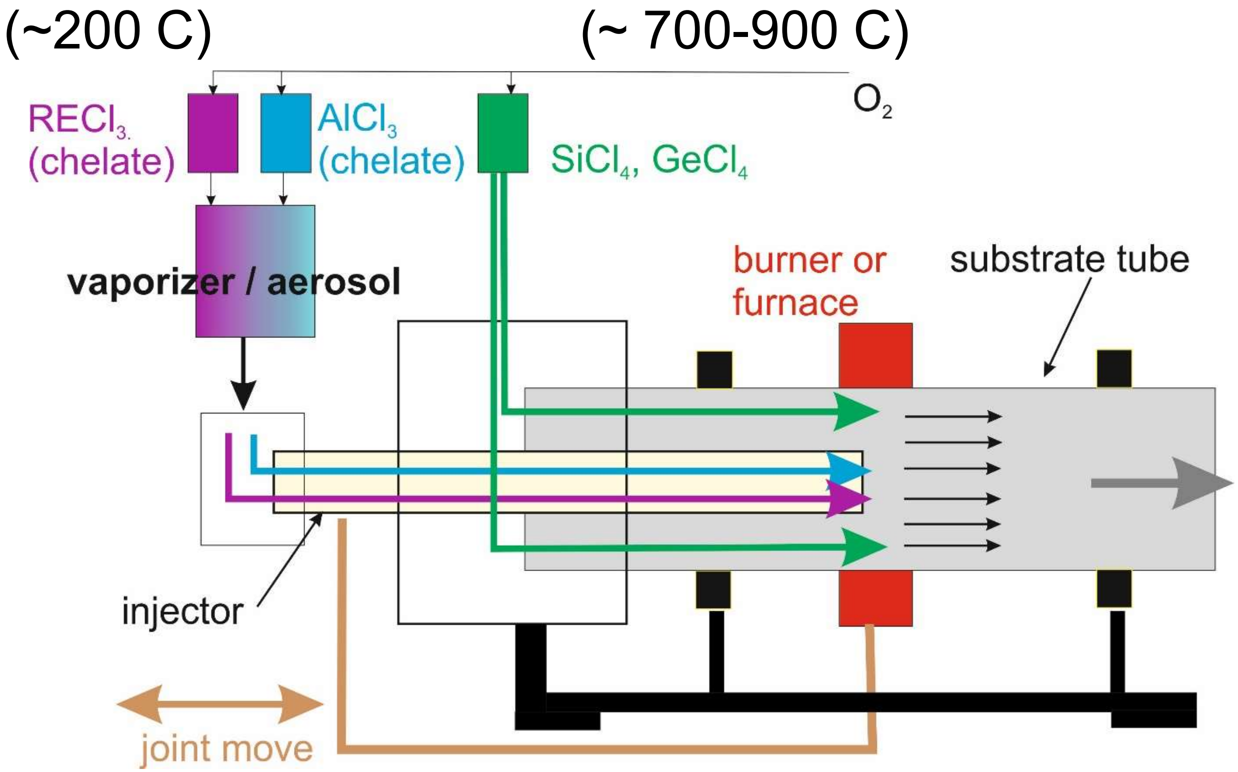
Towndsend, El. Lett. **23**, 329, 1987] [Sysala, Ceramics, **35**, 361, 1991], [Podrazky, IEEE LEOS, 1-2, 246, 2007]

Optical fiber technology

I. Silica optical fibers (solid core) – preform fabrication

RE starting materials solid-state => modification of technology

Chelate-delivery MCVD, Flash vaporization **ACTIVE**



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

Optical fiber technology

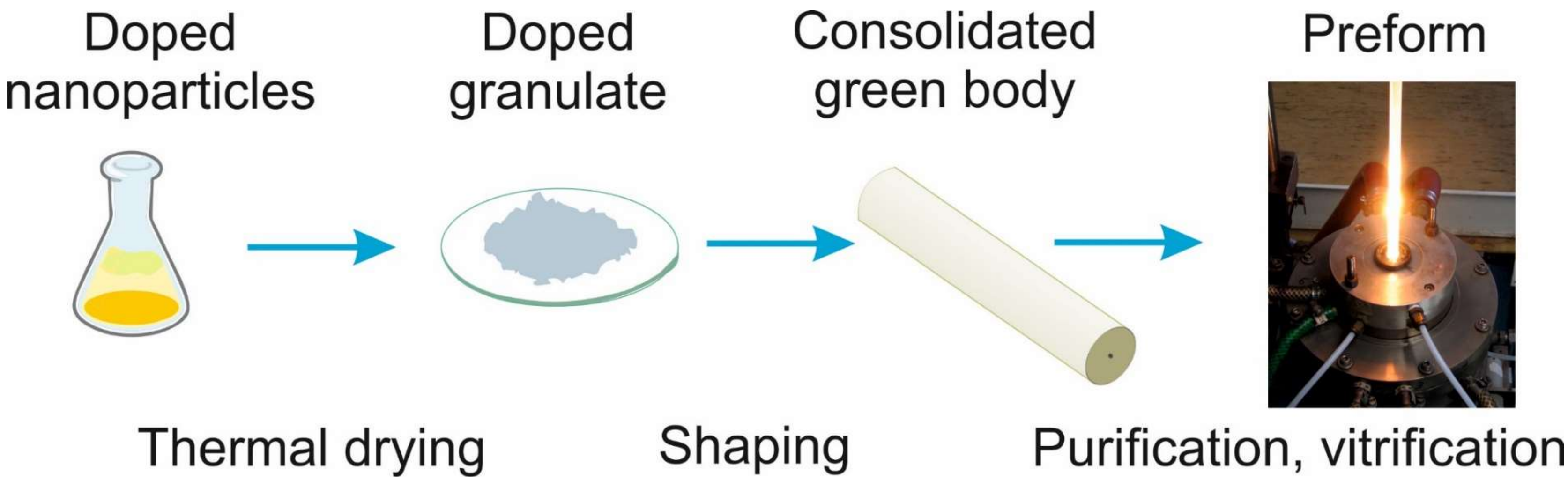
I. Silica optical fibers (solid core) – preform fabrication by

REPUSIL

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

Precursors - solid state; optical purity suitable for fiber lasers

ACTIVE

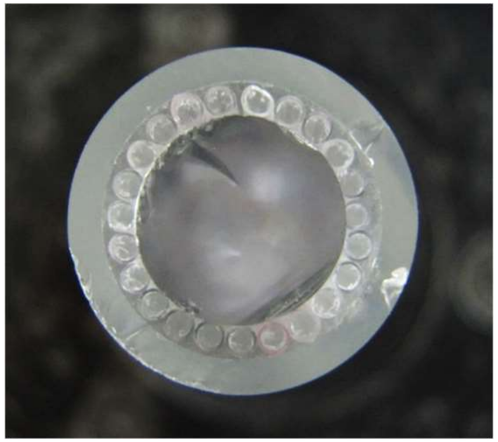


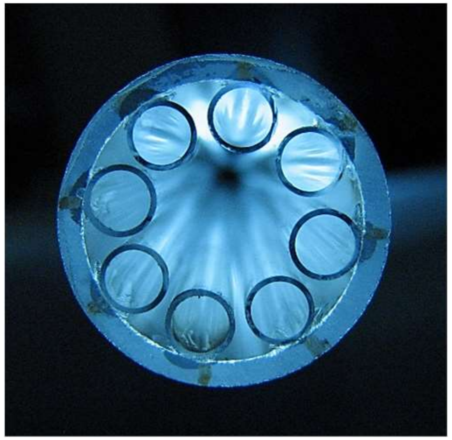
[Schuster & IPHT]

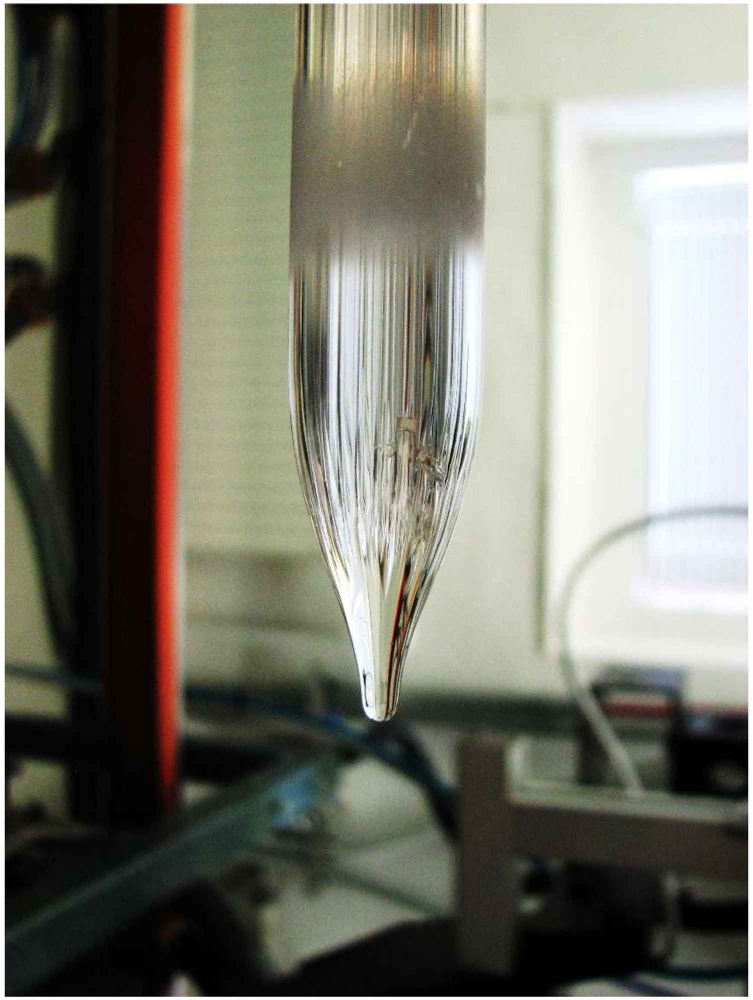
Optical fiber technology

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

Silica microstructure fibers
Design + stack & draw ~2000 C







Optical fiber technology

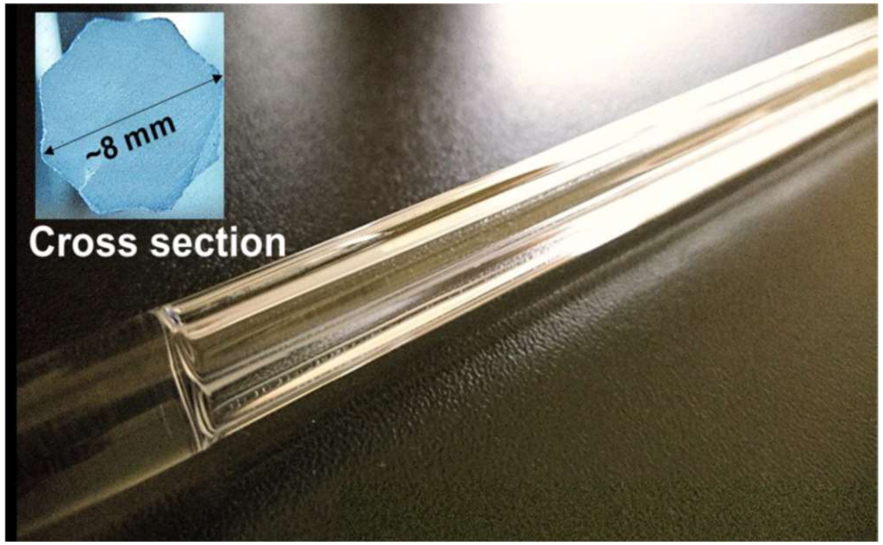
Silica DC optical fibers – preform shaping

Mechanical grinding - diamond tolls

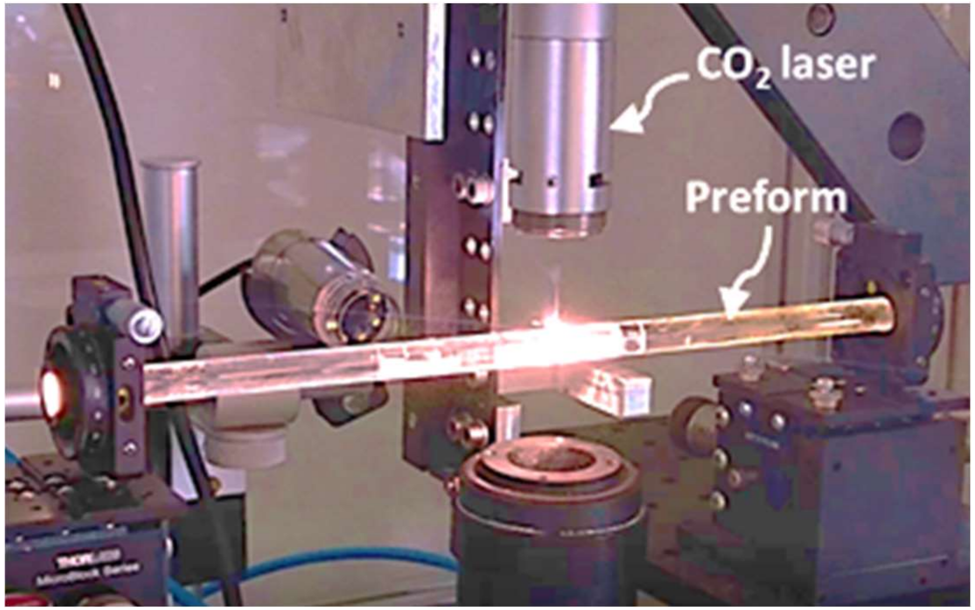
Optical fiber technology

Silica DC optical fibers – preform shaping

Laser processing

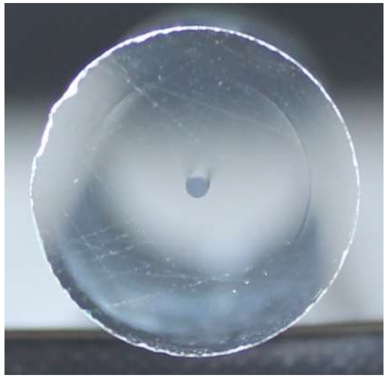


CO_2 laser setup (30 W)



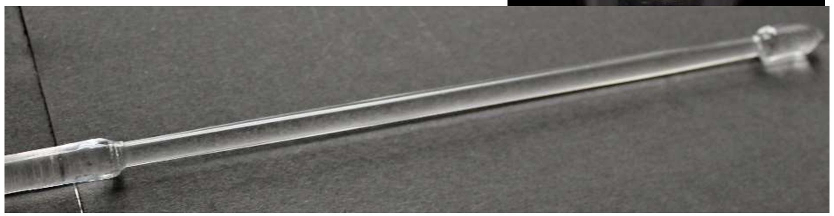
Optical fiber technology

Silica PM – PANDA optical fibers – preform drilling (ultrasonic,mechanical)



Doped preform

+



B_2O_3 doped Preform - etched

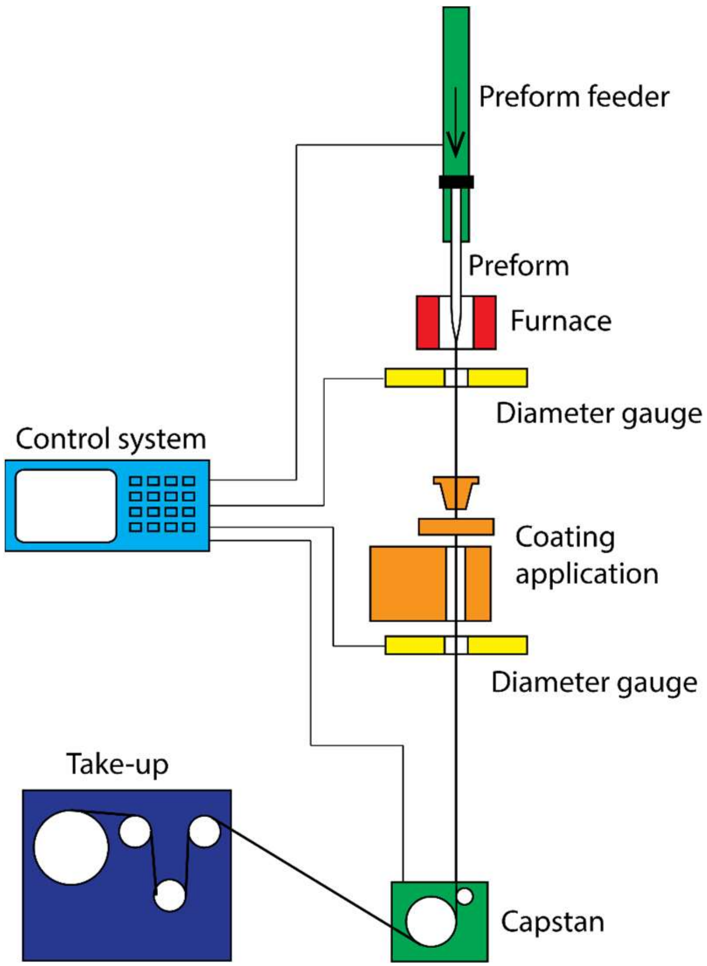
Preform drilling

Drilled & polished prf

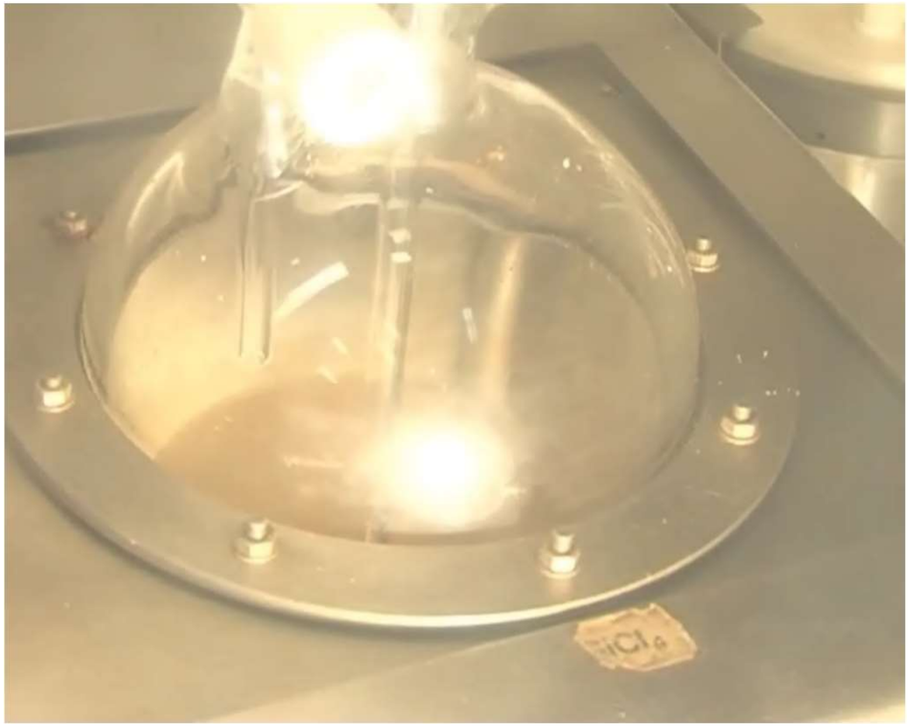
Assembled preform

Optical fiber technology

Silica fiber drawing



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



Optical fiber technology

Soft glass (non-silica) optical fibers (**solid core**)

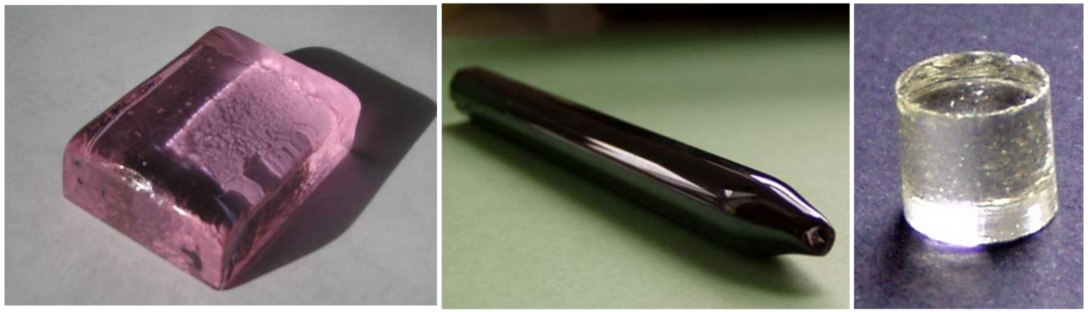
PREFORM fabrication **ACTIVE**

Germanate, chalcogenide (silicate, phosphate) ….. **+ RE**

Conventional glass melting, forming, quenching, annealing

Precursors - solid state

Processing ~500-1500 C (Super/Kanthal)



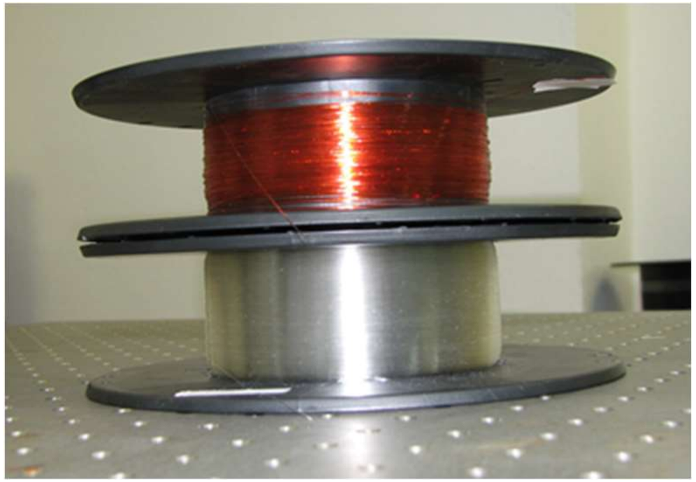
Er^{3+} silicate, As_2S_3, $PbO\text{-}GeO_2$ preforms

ÚFE

Optical fiber technology

Soft glass FIBER drawing

- Temperature : ~Littleton
- Coated/uncoated



Coatings :
acrylates (100 C)
polysiloxanes (180 C)
metals (1000 C)

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 !

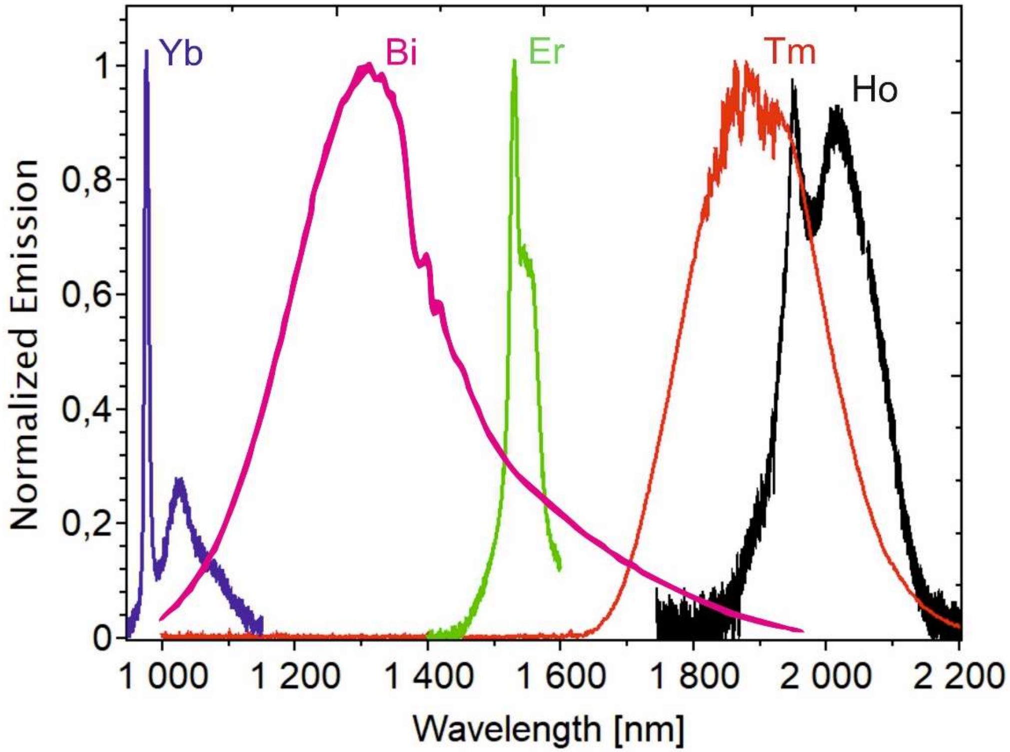
RESULTS

optical fibers and their properties

Optical fibers for lasers

Silica (solid core): RE doped, Bi –doped

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



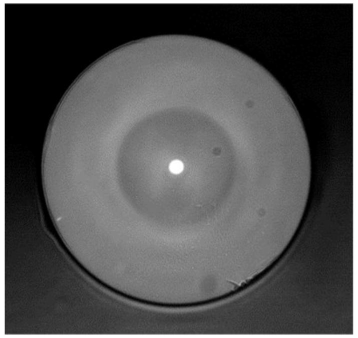
Commercial RE-doped: Nufern, NKT, Corning, ADValue photonics ….

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

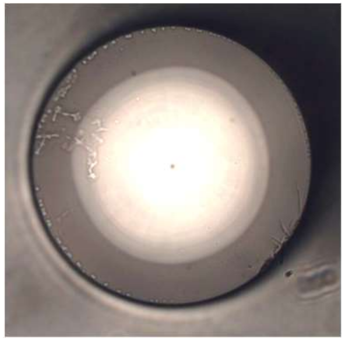
Optical fibers for lasers

Solid core

SM & LMA

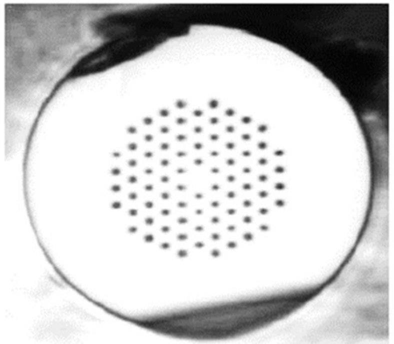


SM 125/10



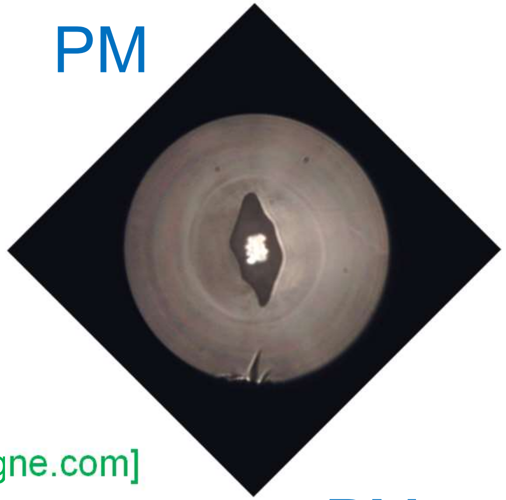
TDF 125/65

PCF

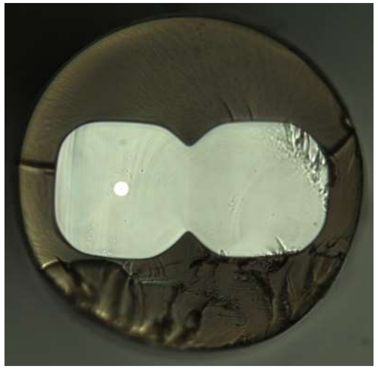


[www.photonics-bretagne.com]

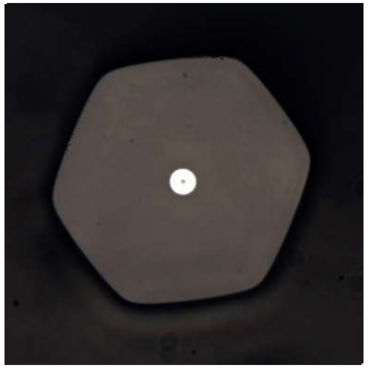
PM



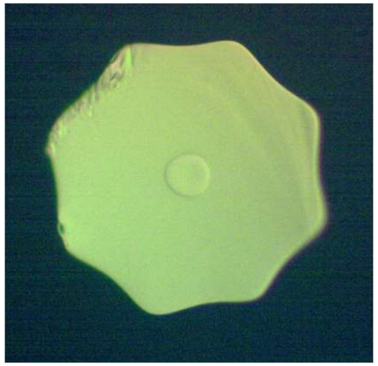
DC*



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]

Optical fibers for lasers

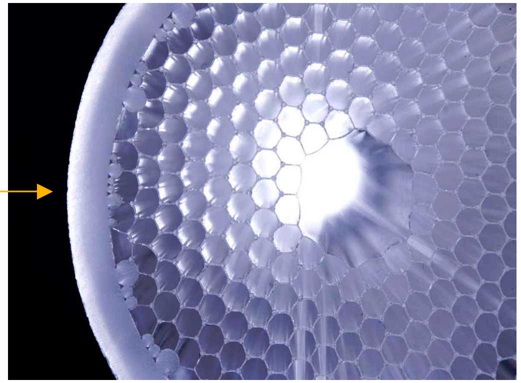
Silica fibers (hollow core)

Transmission dependent upon the fiber structure

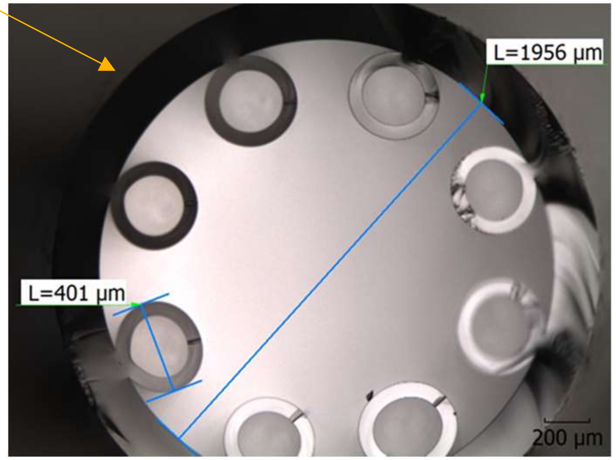
=> operating spectral window

Hollow-core photonic bangap (air-guiding)

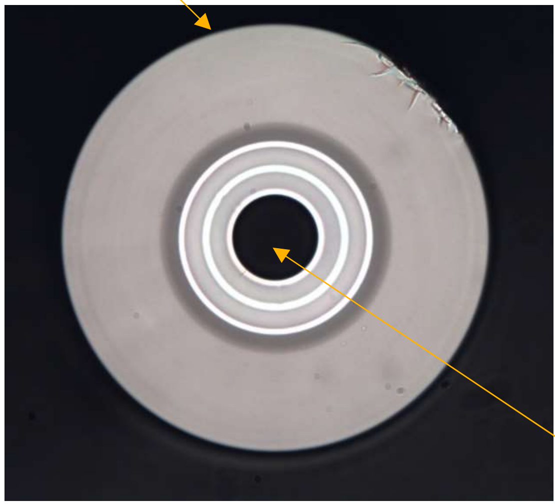
[Paschota, www.rp-photonics.com]; [Benabid, Opt.Lett. **42**, 3363, 2017]



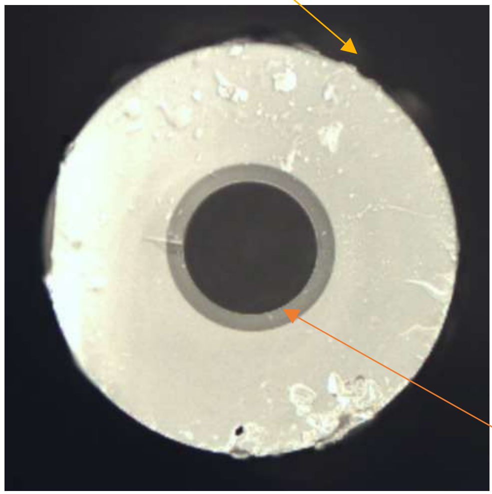
Negative curvature (NCF) [Jasim, 2021]



Omnidirectional (Bragg)



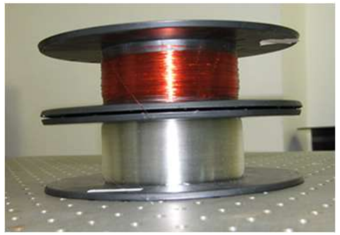
Capillary



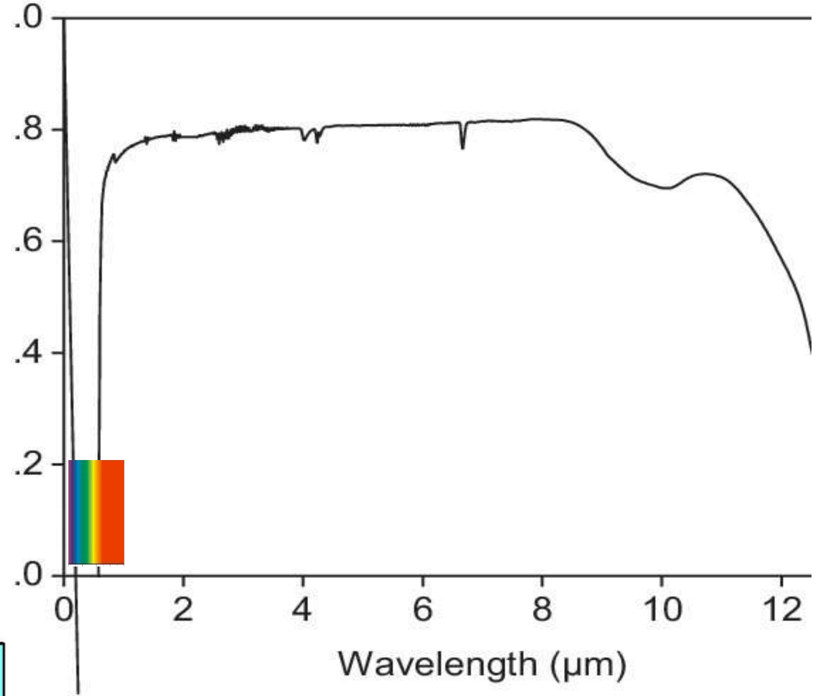
active layer

gas / liquid

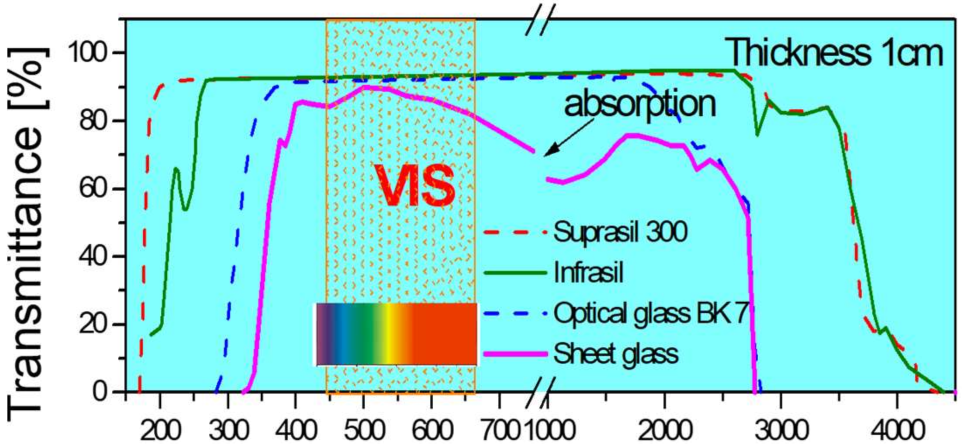
Soft glass fibers



Transmission spectra of As_2S_3 (right), silica and BK7 (bottom) - BULKs

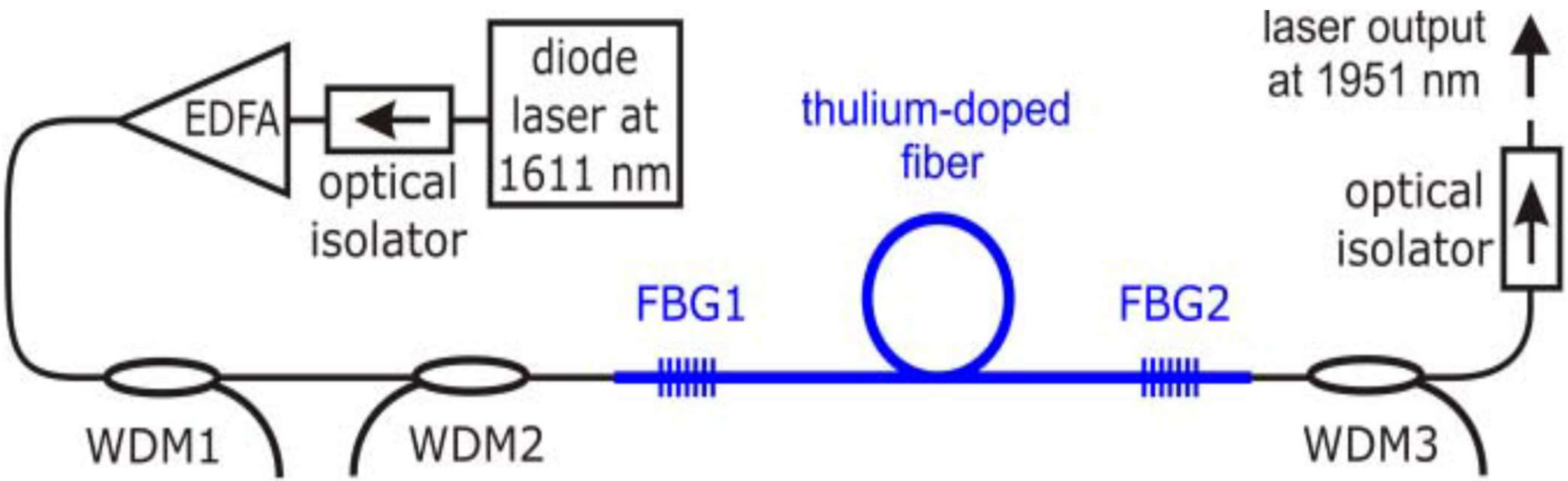


[A.Perrin]



Monolitic Tm fiber laser at 1951 nm

Eye-safe spectral region (≠ 1550 nm)

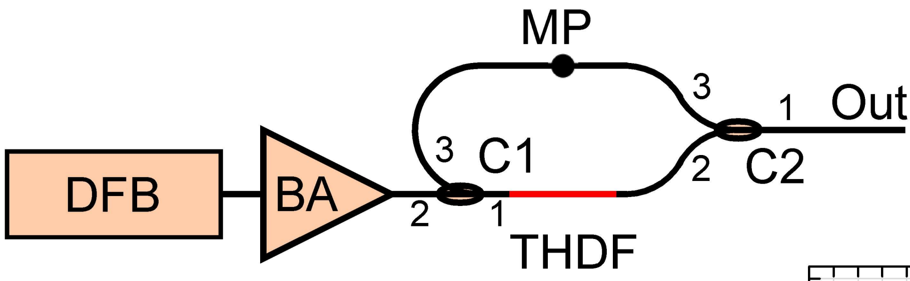


* 1000 ppm Tm^{3+}, 11mol% Al_2O_3, 0 mol% P_2O_5 or GeO_2,

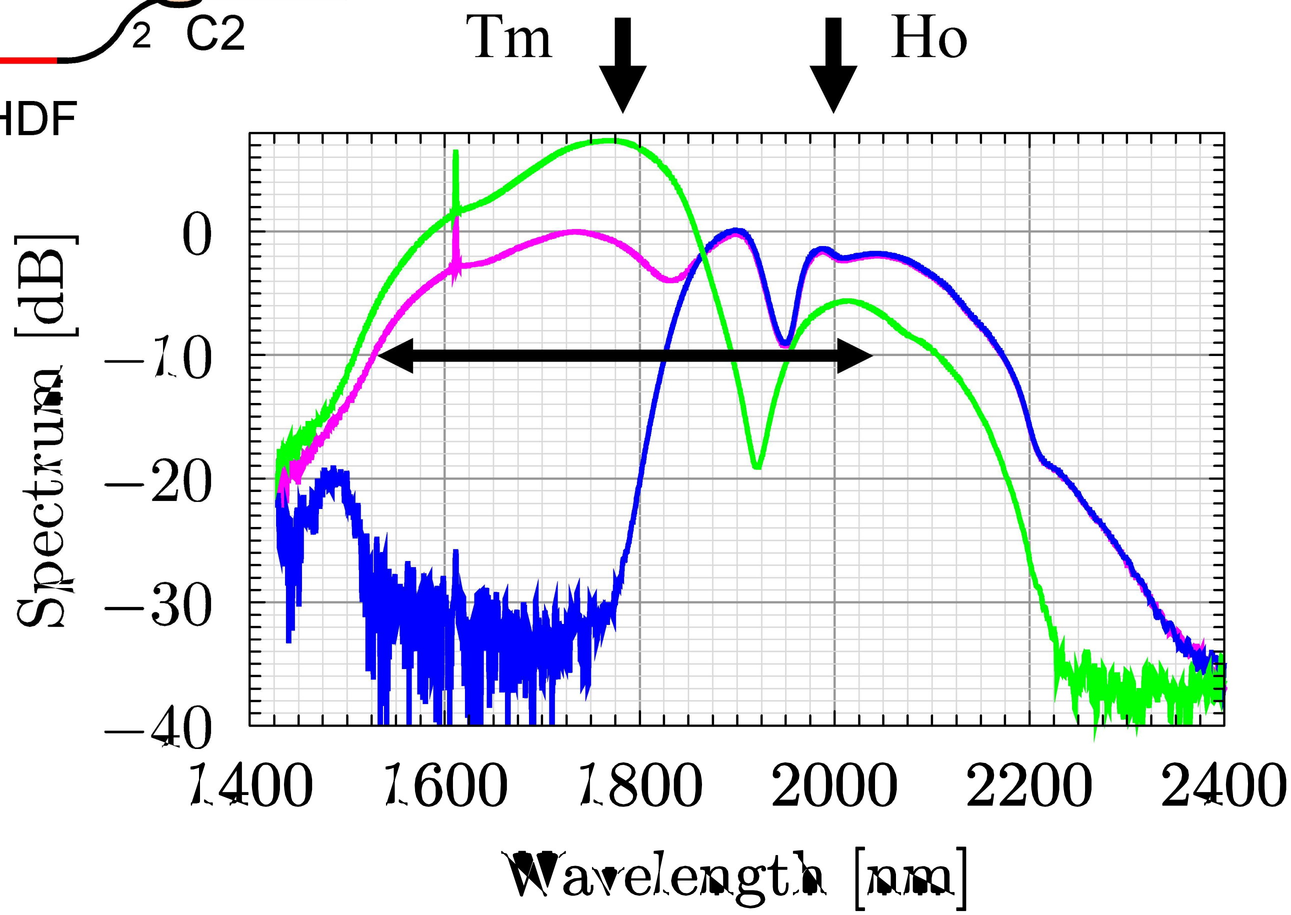
* **deep-UV inscription of FBG**

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

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



(≠ 1550 nm)

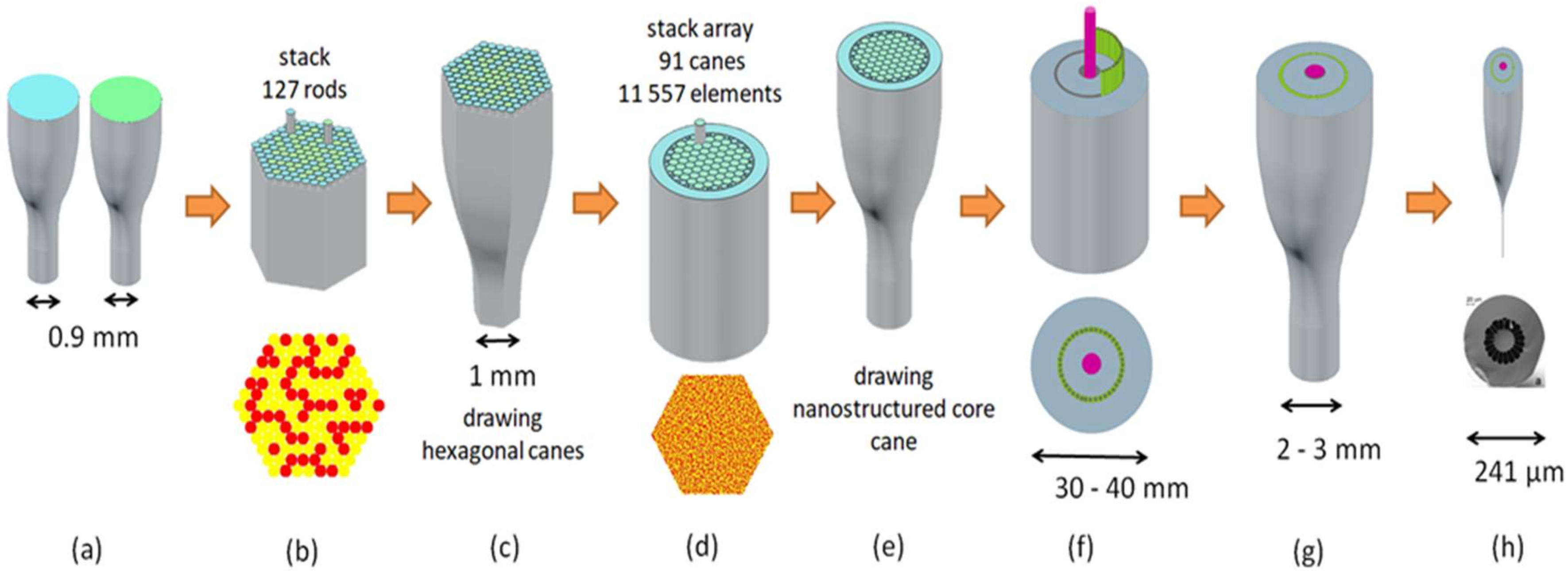


1800 ppm Tm^{3+} /
360 ppm Ho^{3+}

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

Dual wavelenght fiber laser

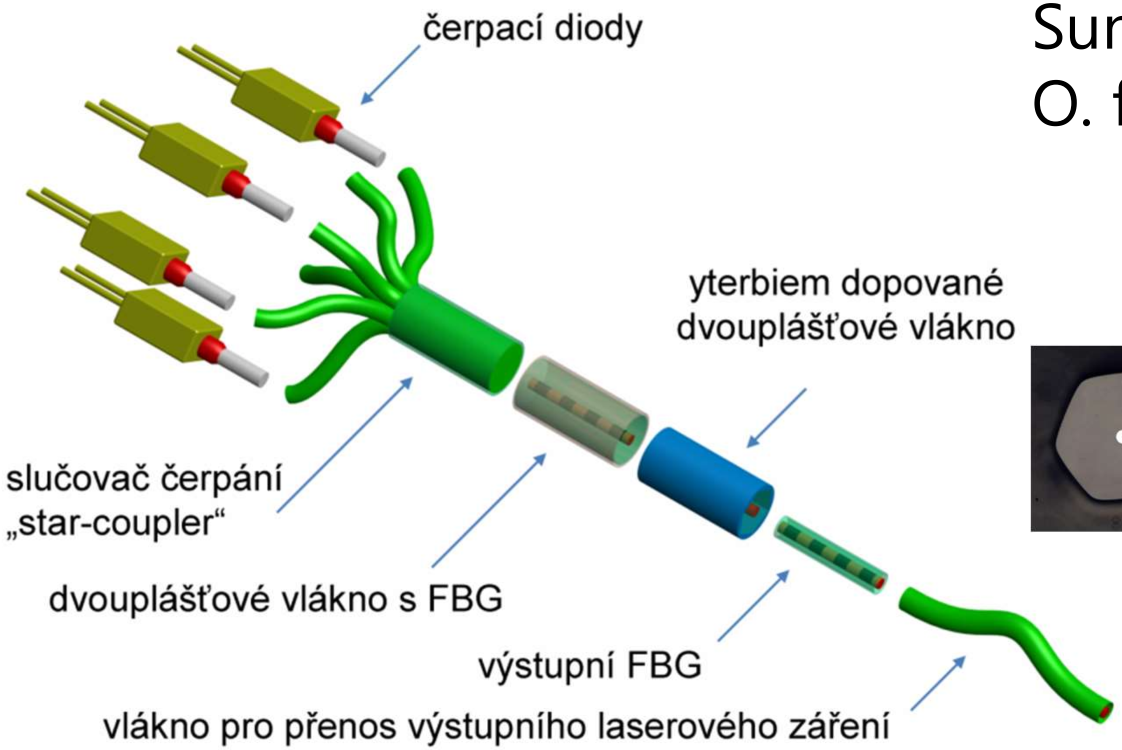
Er-Yb fiber laser operating at 1060 nm and 1550 nm

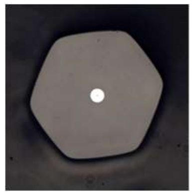


[R. Buczynski, M. Franczyk]

Fiber lasers mW → **kW**

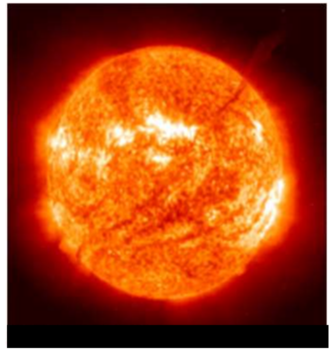
DC*

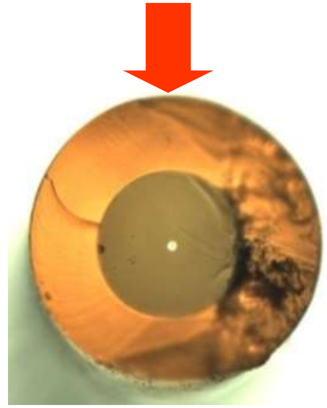




Intenzity of light

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



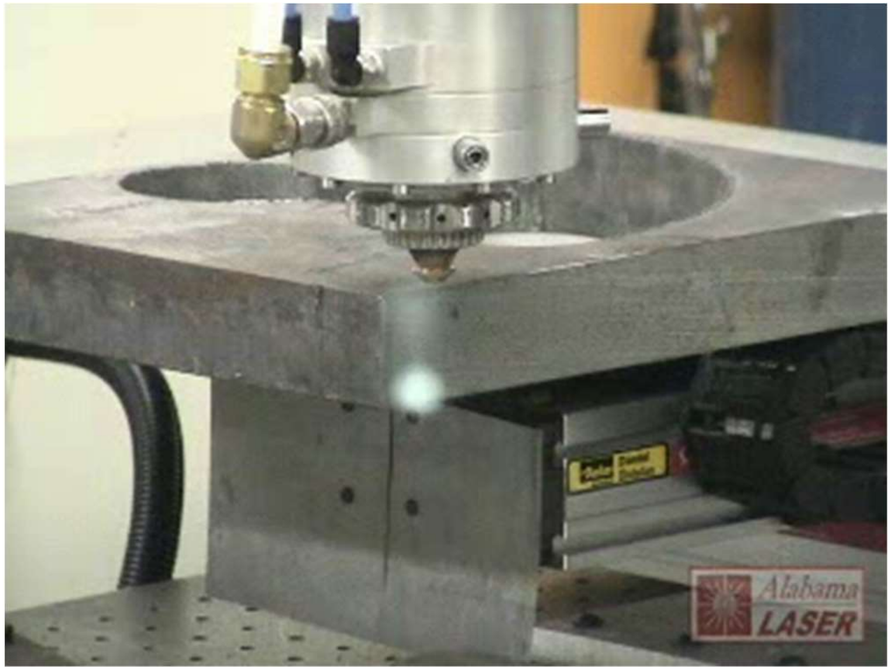


[P.Peterka, Eysafe, 2015]

Beam combining, double-clad structures ....

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)



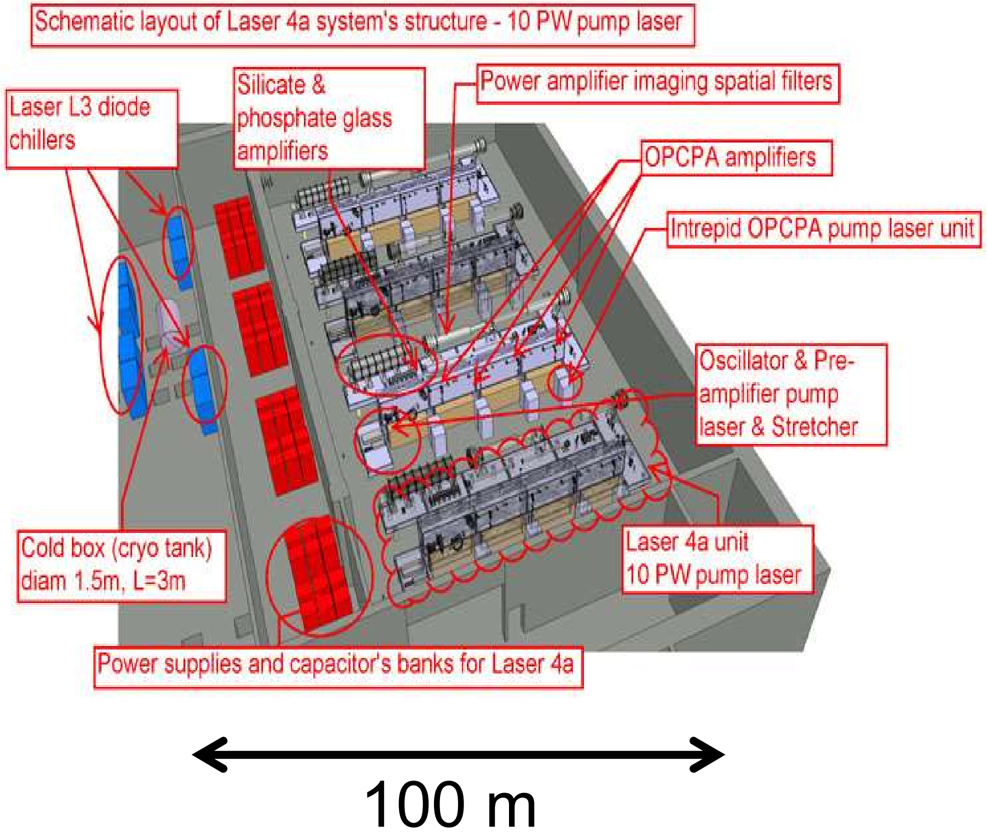
[IPG]

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

ŪFE

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

- **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)
- Sdělovací technika 3/2011

Be UFE !

- **STUDY** (diploma, thesis)

  Czech Technical University

  Charles University

  Institute of Chemical Technology

- **PROJECTS** - partners CZ

- **INTERNATIONAL** - collaboration

Be carefull !

EXCURSION

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

Thank you for attention