Optical Fiber Technology

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The Czech Academy of Sciences

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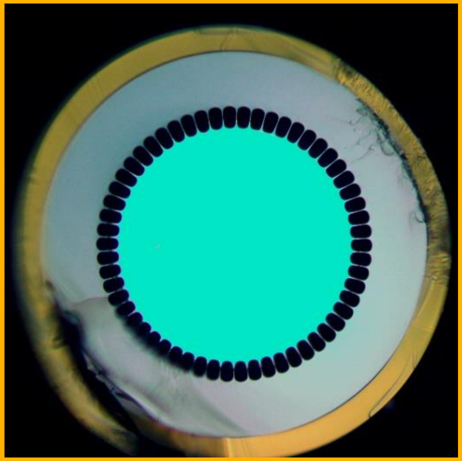
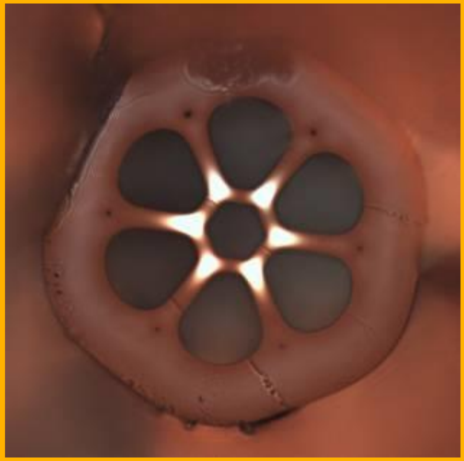
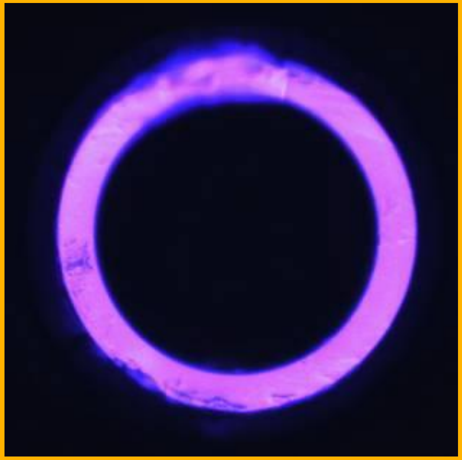
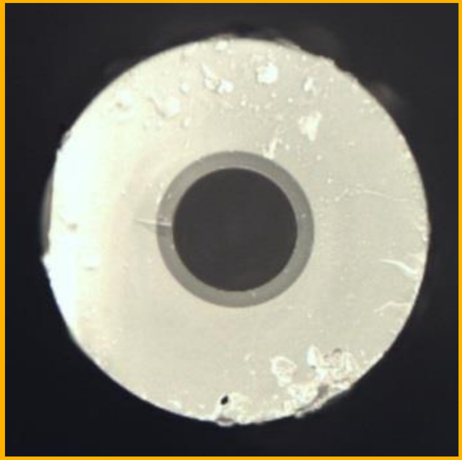
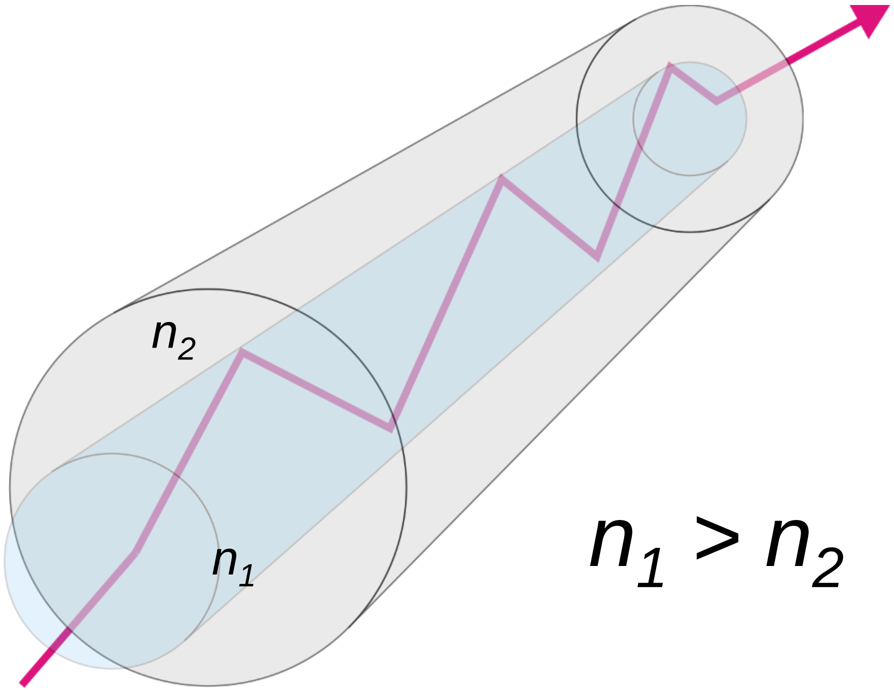






Content

Waveguiding principle → optical fiber

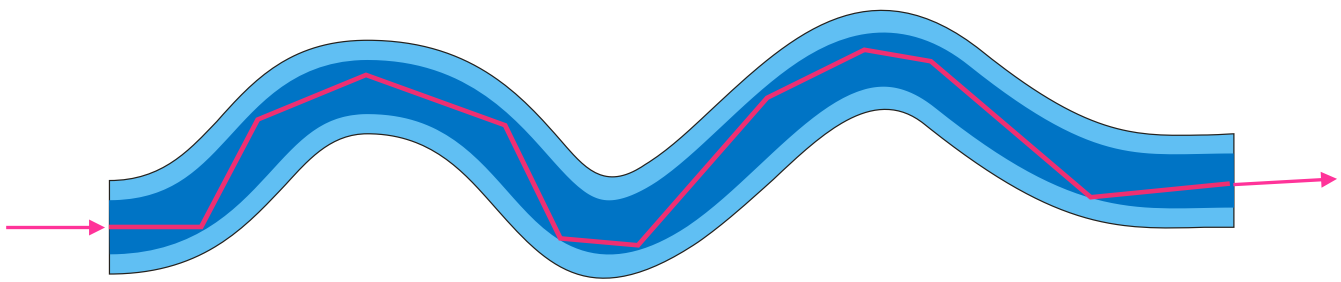


$$n_1 > n_2$$

W. Snell (~1620) : total reflection

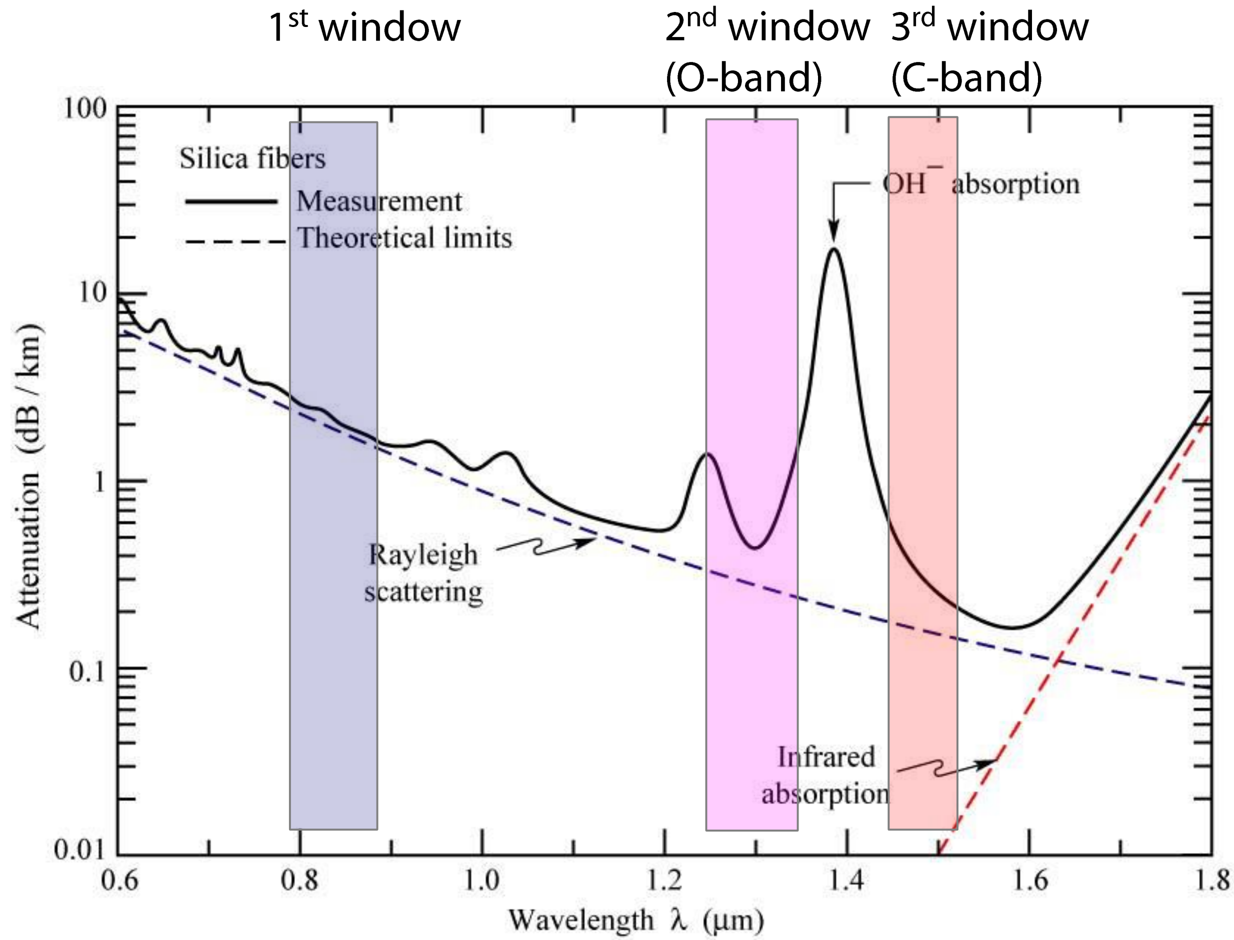
J. Tyndall (1853) : **waveguide**

$\mathbf{n}_{\text{water, glass, plexi}} > \mathbf{n}_{\text{cladding, surroundings}}$



Optical fiber : dielectric structure, L >> d, $n_{core} > n_{cladd}$

Transmission and attenuation



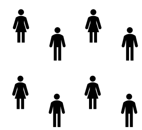
Credit: http://LightEmittingDiodes.org

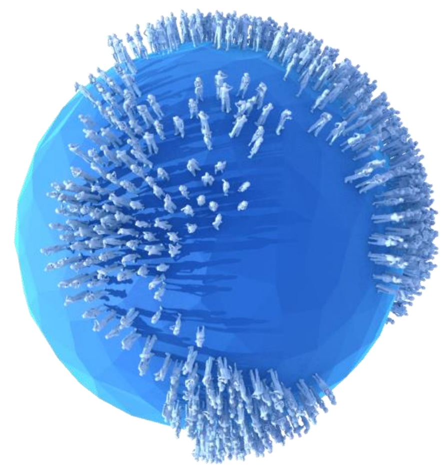
Purity of material

Charles K. Kao
1966

½ Nobel prize
in 2009

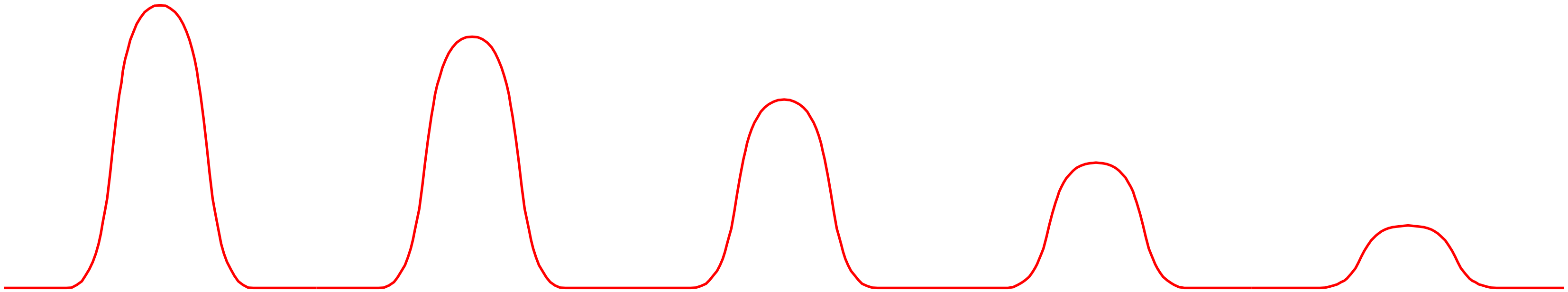
ultra pure materials
impurities in order of ppb = 10^{-9}





ULTRA PURE TECHNOLOGIES

Purity of material



<u>Attenuation in optical fibers</u>

1966 ~ 1000 dB/km (meters)

1970 < 20 dB/km (hundreds of meters)

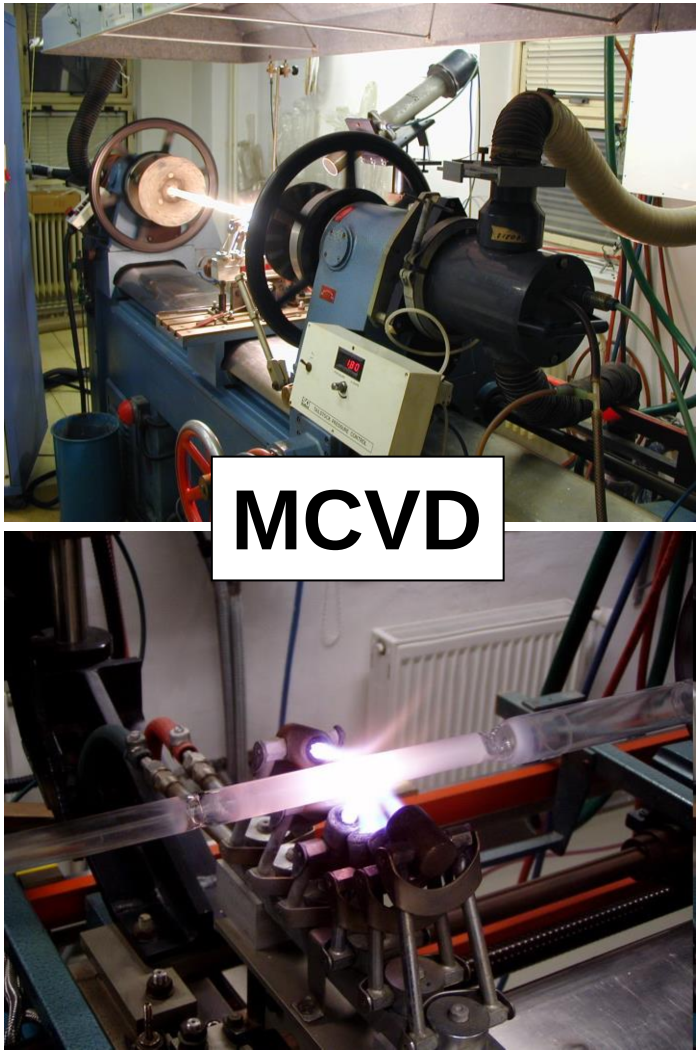
1987 ~ 0,2 dB/km (~100 km)

Corning SMF28ULL - 0,17 dB/km (@1550 nm)

~ Only 4% of the input power is lost in 1 km of the fiber

~ 2 km of optical fiber has the same transparency as 3 mm of window glass

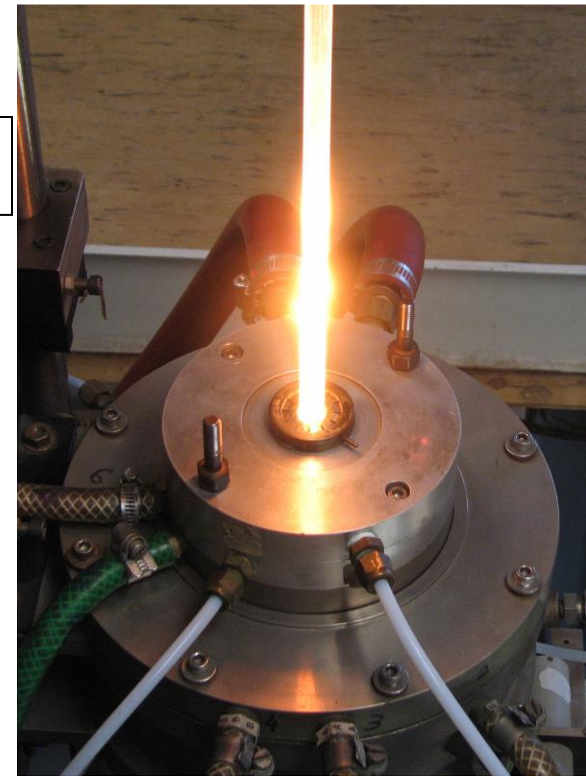
Optical fiber preparation



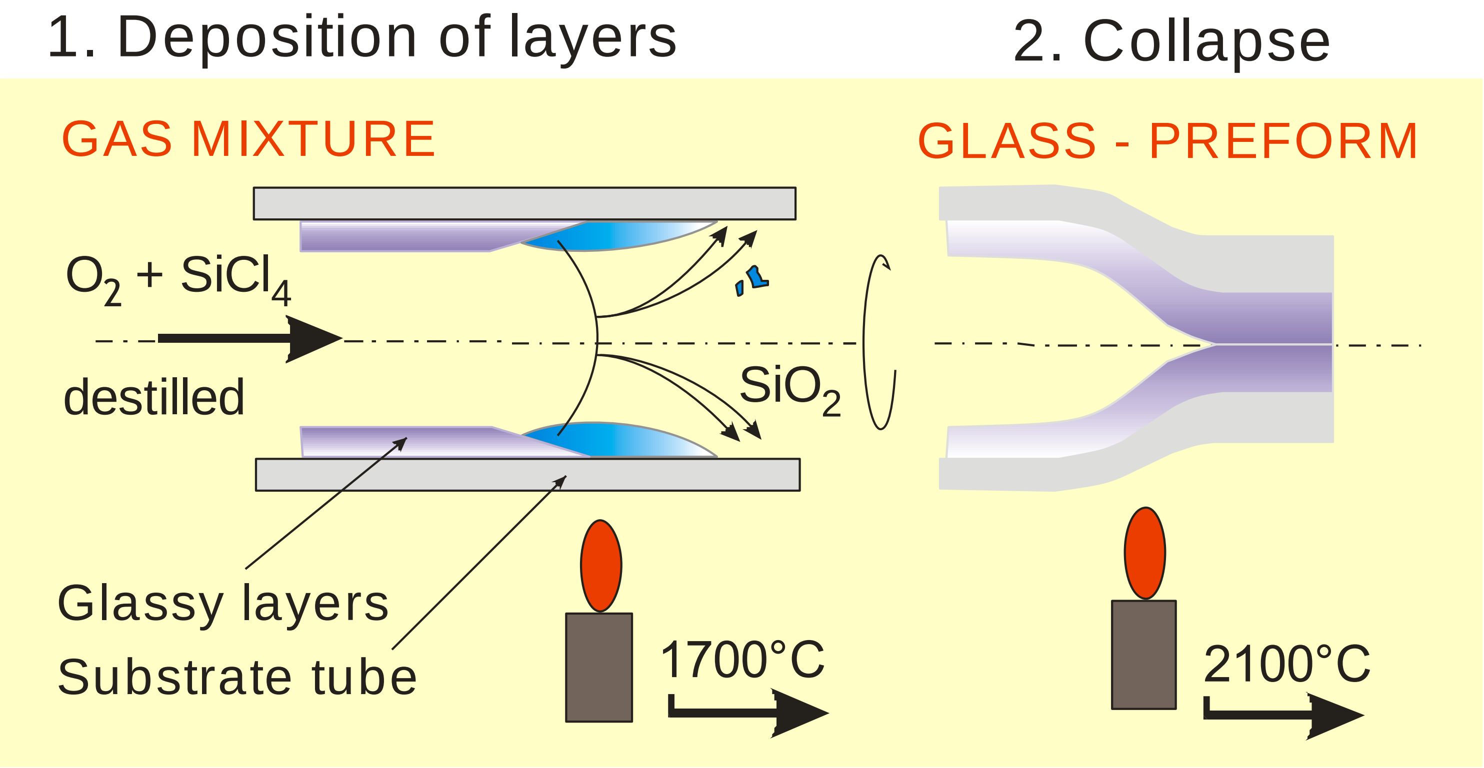
MCVD

1. Preform

2. Fiber drawing



Preform preparation:
MCVD – Modified Chemical Vapor Deposition



- Sequential deposition of thin (~ 1-20 µm) glassy layers onto inner wall of silica tube => preform (rod)
- high purity (ppb impurities), high precision (>1 %) material

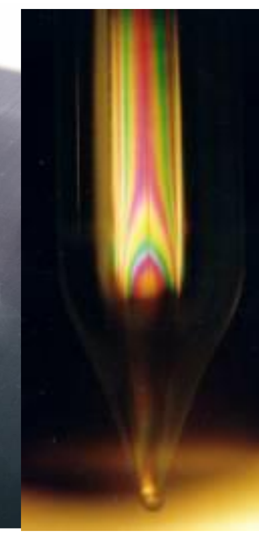
MCVD → Preform

Deposition
of layers

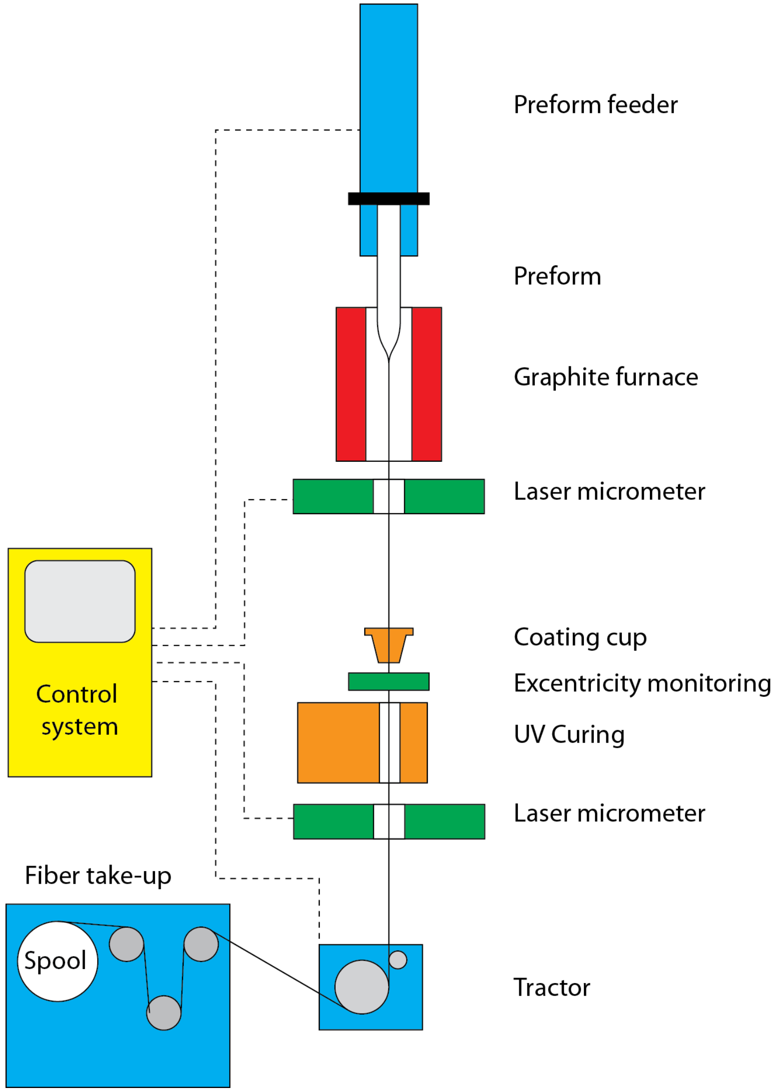
Preform
collapse

Destilation
(halogenides)

Preforms



Drawing of Optical Fibers



- Fiber diameter 80-1000 µm
- Temperature 1800-2000°C
- Drawing speeds:
  - UFE: 0.1-0.5 m/s
  - Industry: 20-30 m/s

Optical fiber preparation

Industrial scale

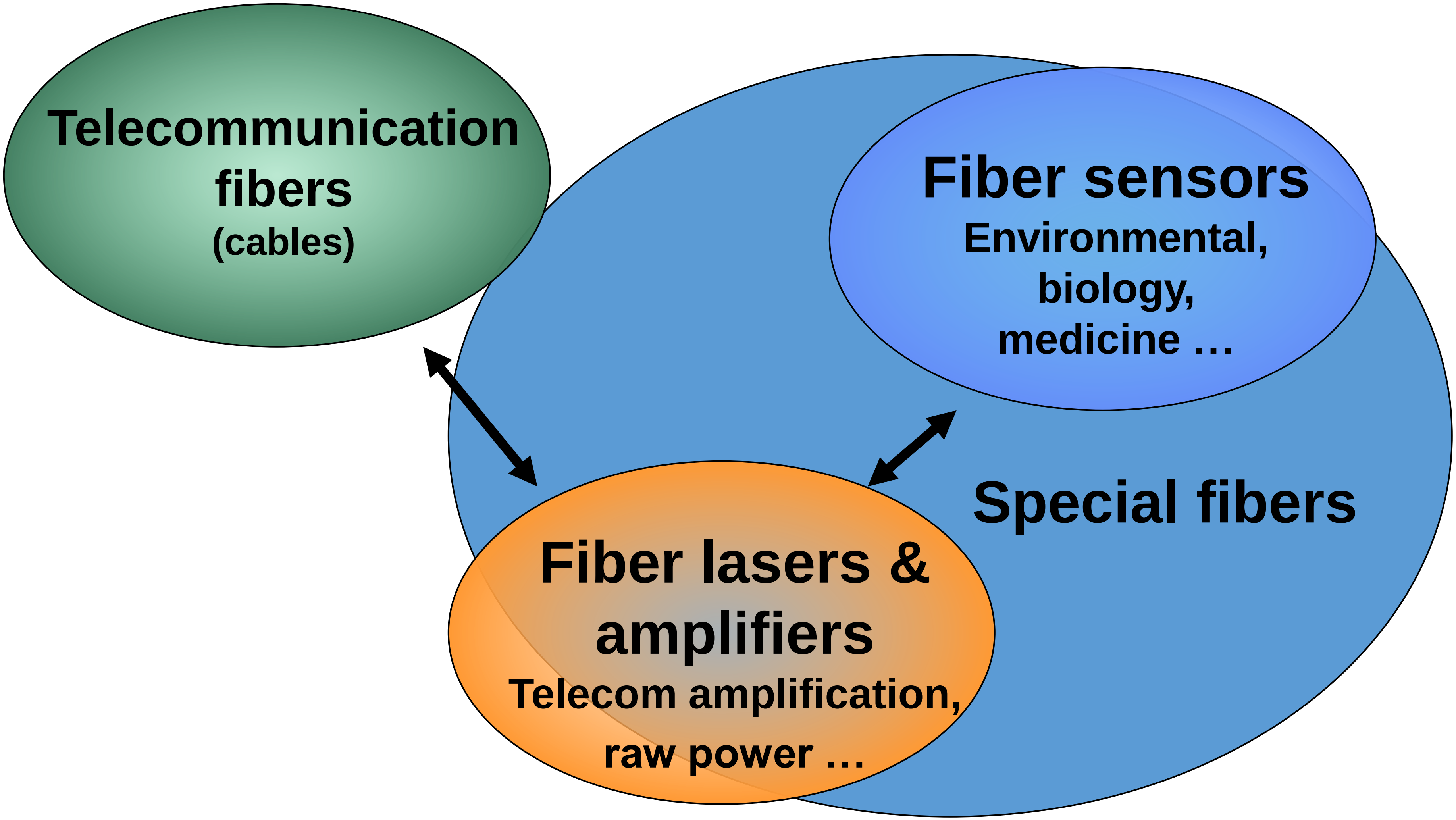
https://rosendahlnextrom.com/fiber/products/telecom-preform-fiber/

Industrial scale

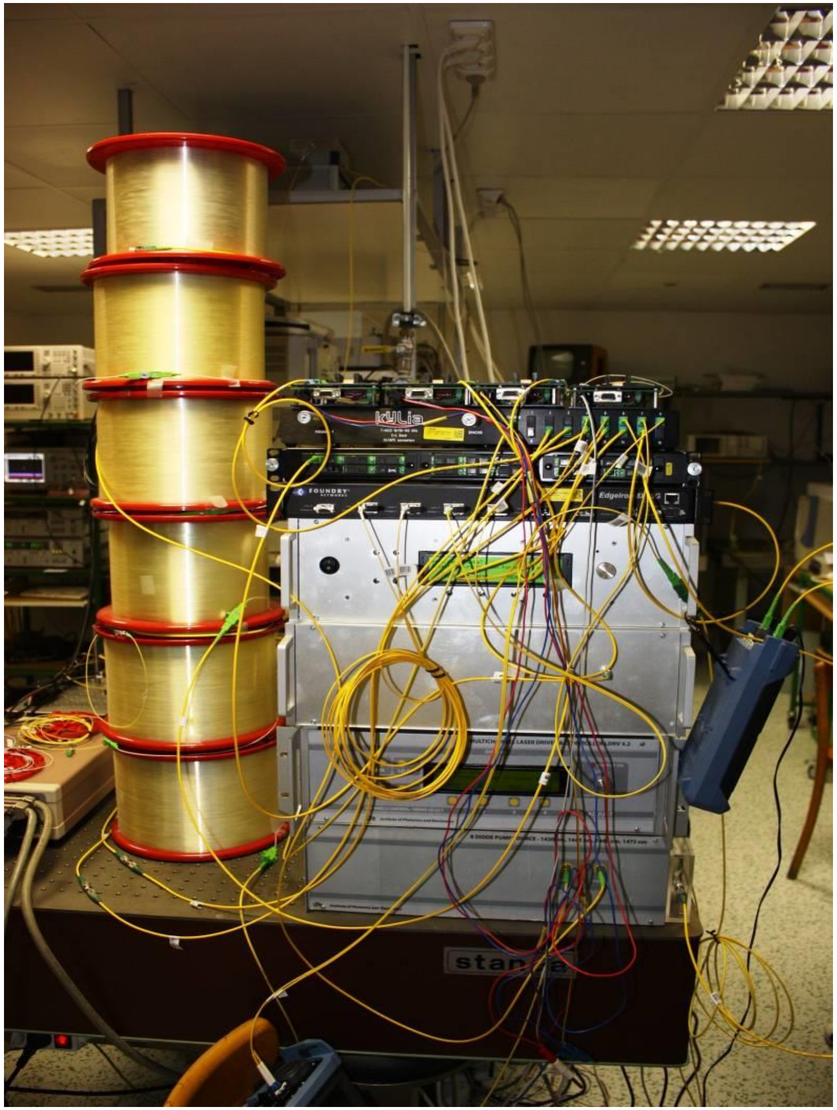
- Preform diameter ~ 230 mm
- Drawing speed ~ 1-2,5 km/min !
- Fiber length ~ 10 000 km !
- Price <0,05 USD/m

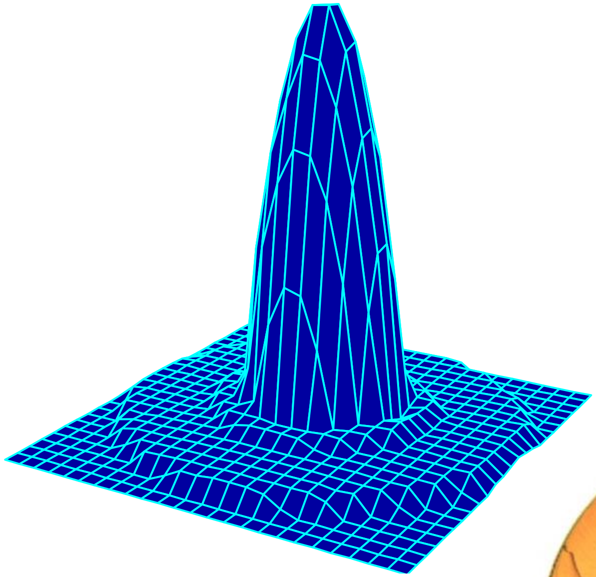
https://rosendahlnextrom.com/fiber/products/telecom-preform-fiber/
https://www.heraeus.com/en/hcv/products_and_solutions_1/ric/ric_cylinders/ric_cylinders_1.html

Application

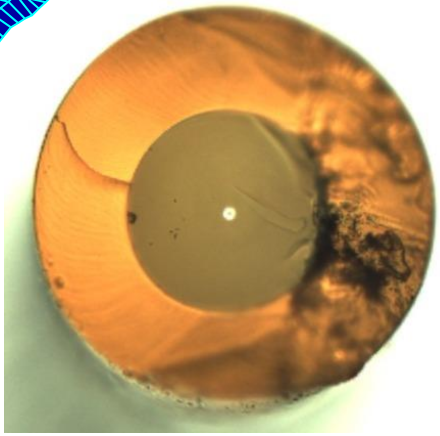


Optical fibers for telecommunications (passive)





GI - multimode



SM - singlemode

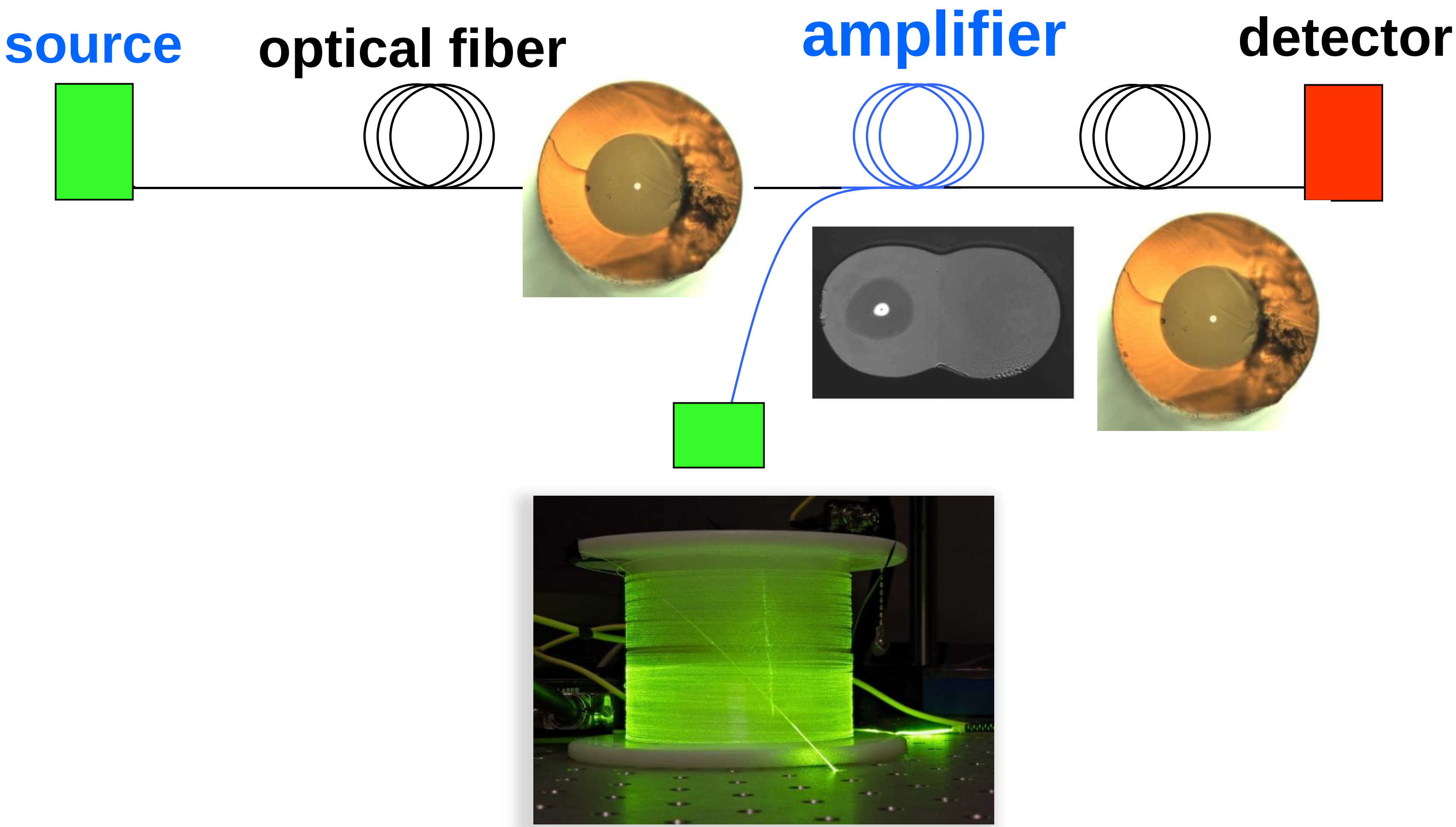
ŪFE

Optical fibers for telecommunications

Requirements:

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

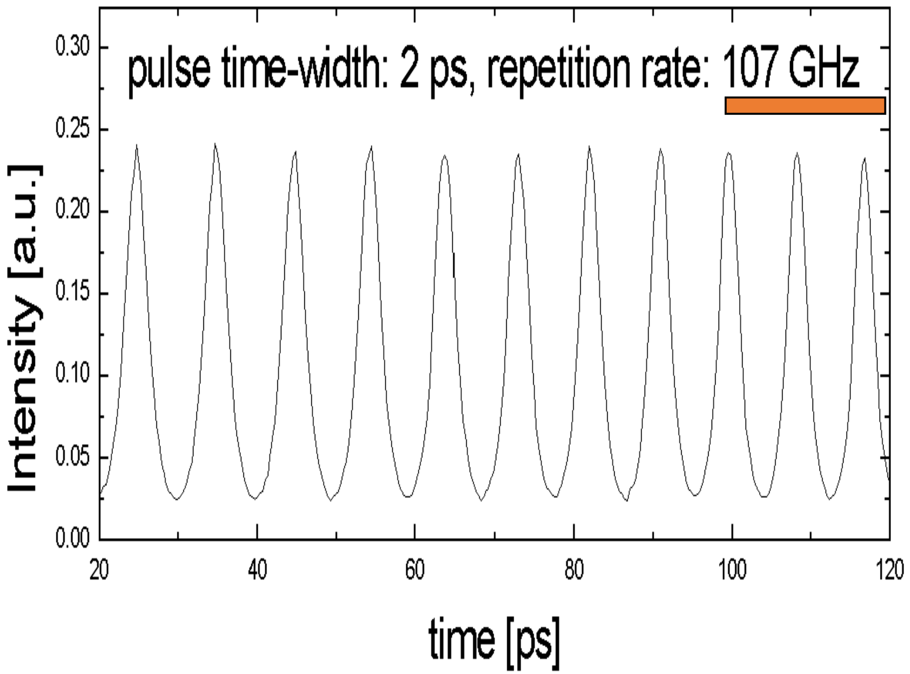
Specialty optical fibers for communications (active)

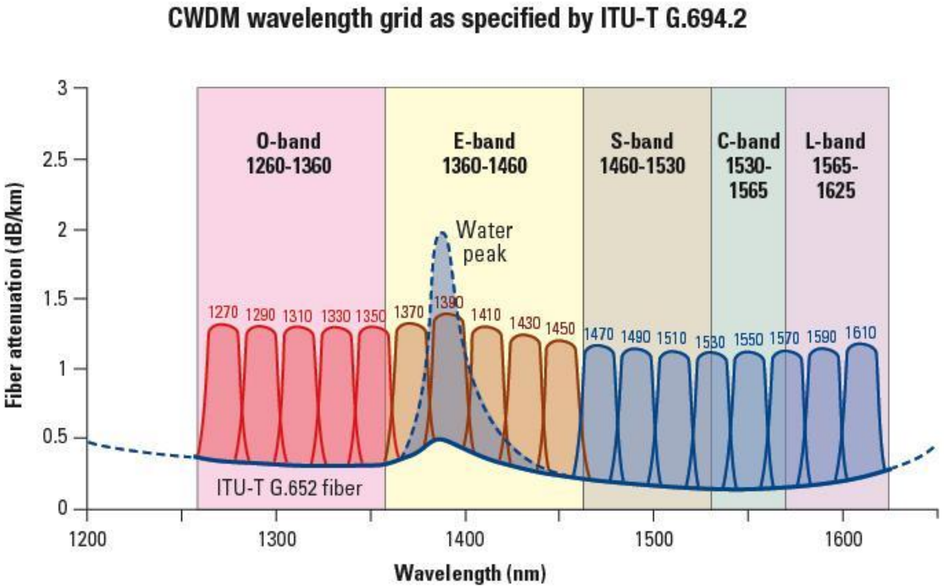


Multiplexing

Time Division Multiplexing (TDM)

Q-switched FL

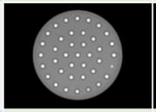
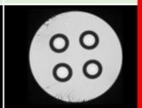
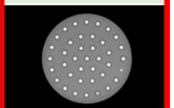




Wavelength Division Multiplexing (WDM)

Fastest data transmission over single OF

World Record Optical Fiber Transmission Capacity Doubles to 22.9 Petabits per Second

			This study
Fiber type	38 core, 3 mode	4 core	38 core, 3 mode
	Mar. 2020	May 2022	Oct. 2023
Fiber cross section			
Spatial channels	114	4	114
Data rate (Pb/s)	10.66	1.02	22.9
Transmission distance (km)	13	51.7	13
Bandwidth (THz), Wavelength band	9.2 C, L	20 S, C, L	18.8 S, C, L
QAM order	64 /256	256	256

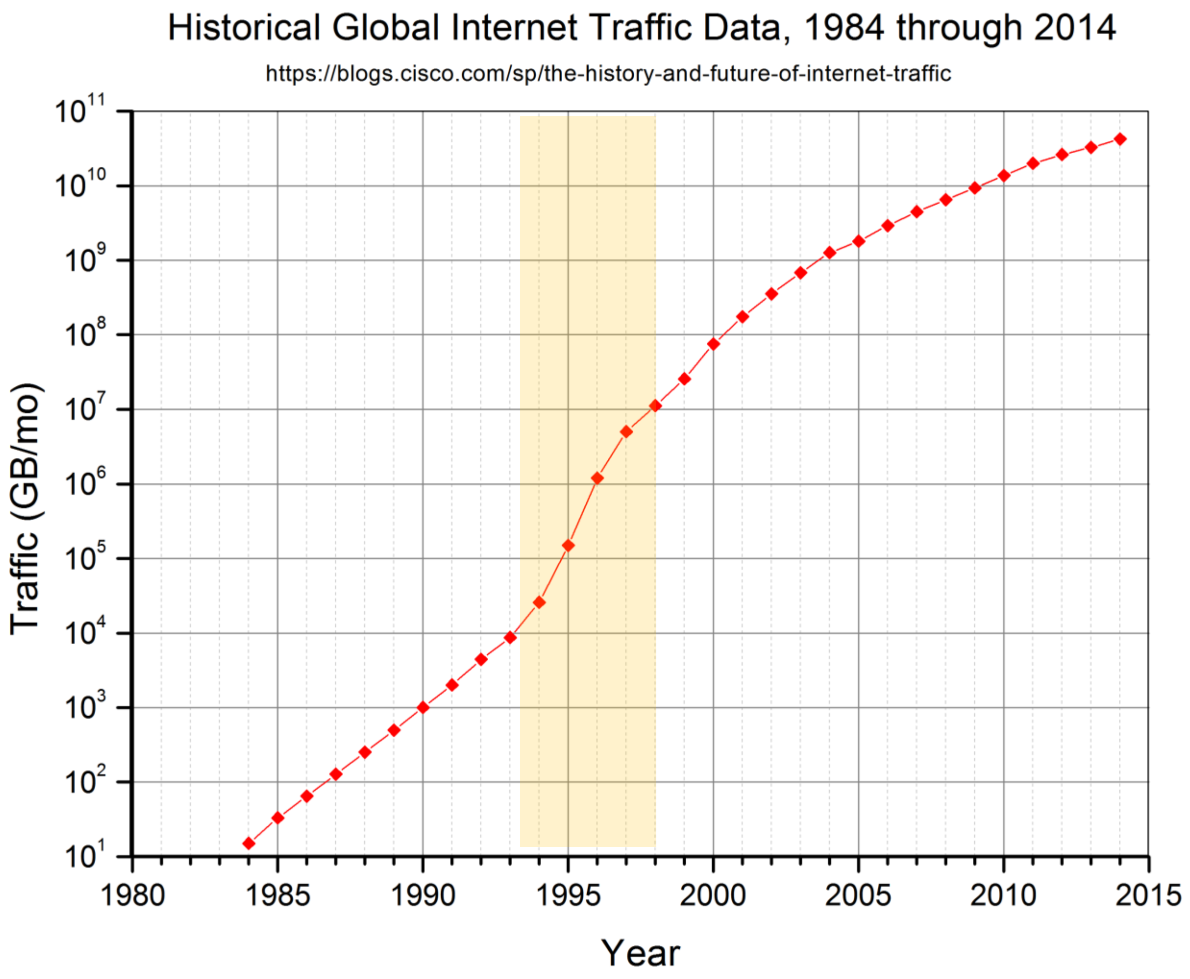
https://www.nict.go.jp/en/press/2023/11/30-1.html

National Institute of Information and Communications Technology

World Record 301 Tb/s Transmission in a Standard Commercially Available Optical Fiber

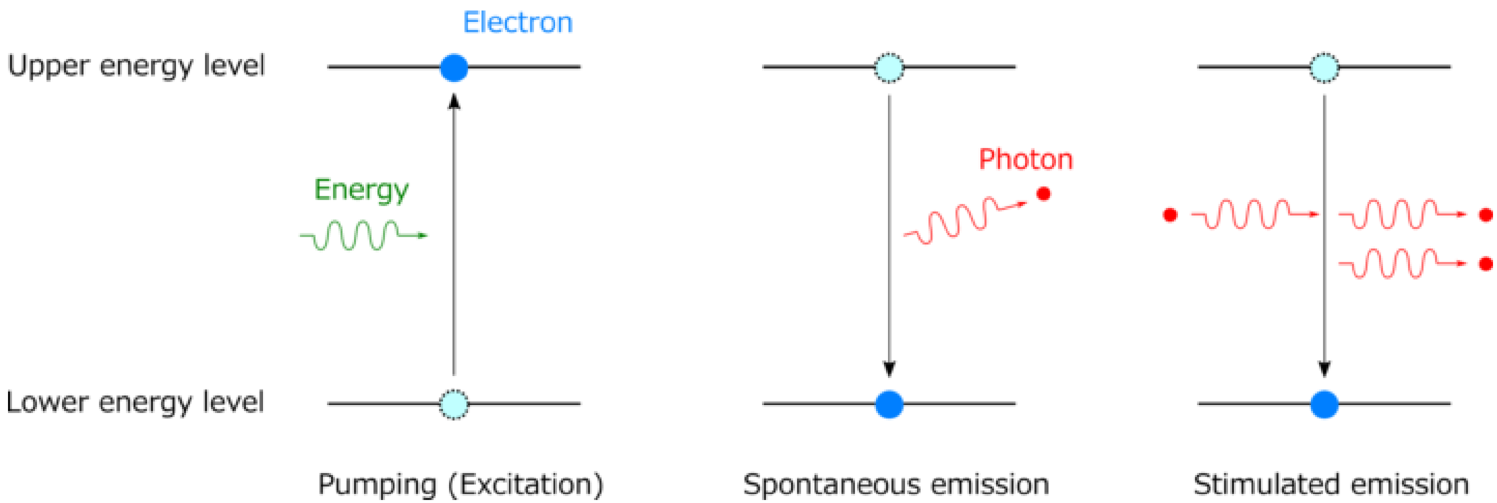
https://www.nict.go.jp/en/press/2024/01/29-1.html

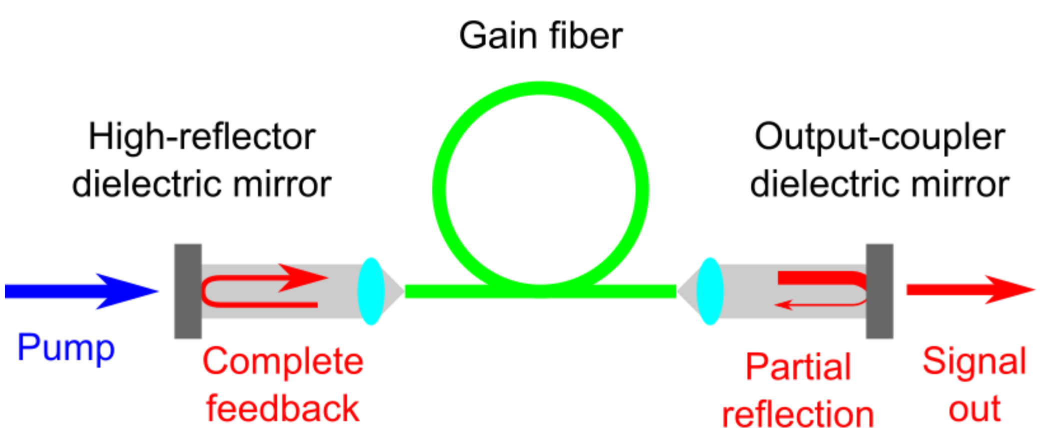
Importance of fiber amplifiers



EDFA+Dispersion management=>WDM

Light **A**mplification of **S**timulated **E**mission of **R**adiation

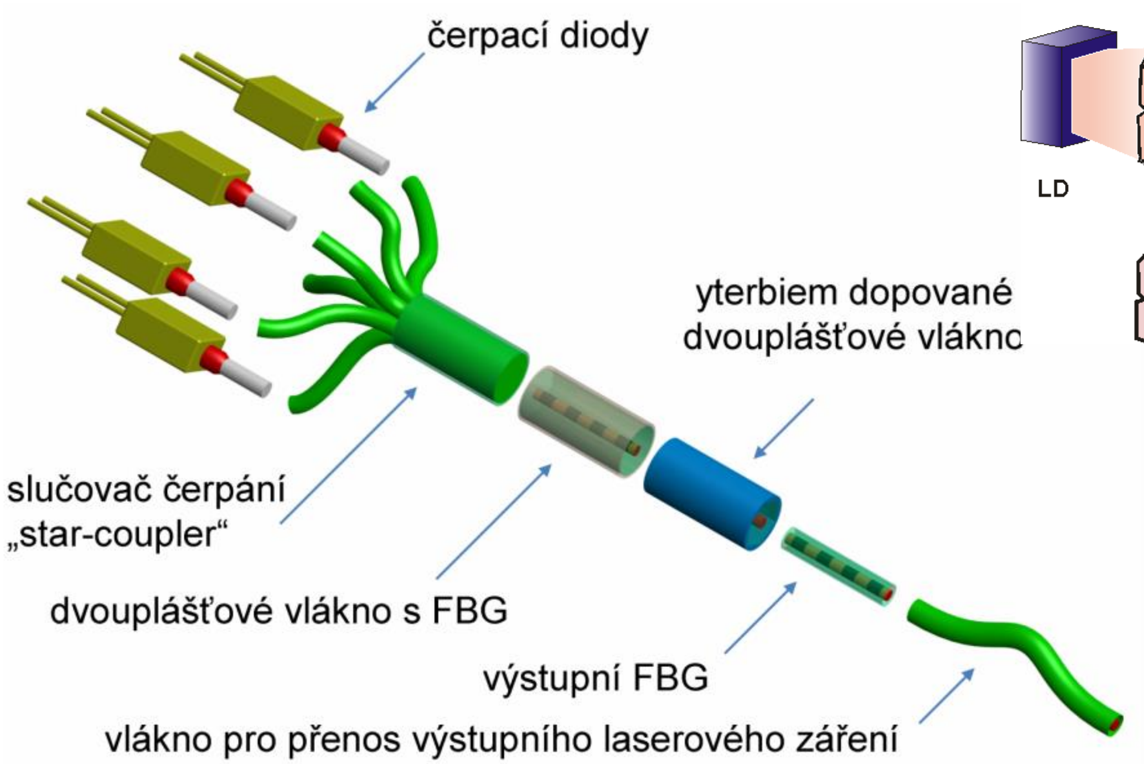


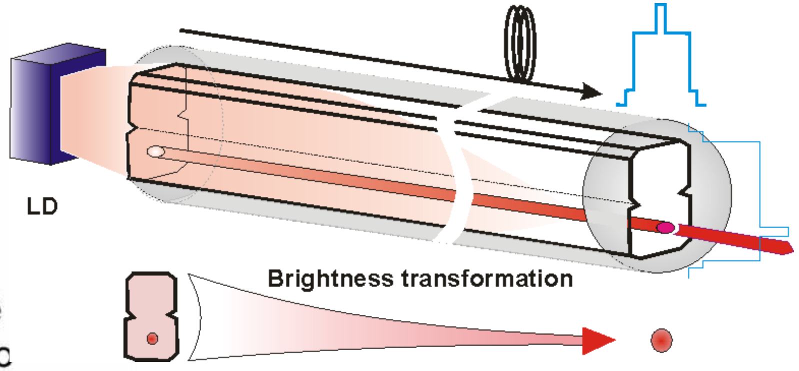


Credit: http://fiberlabs.com

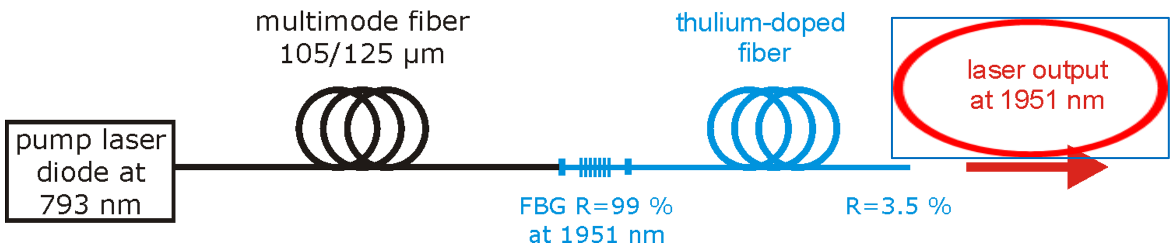
Silica specialty optical fibers for fiber lasers and amplifiers in VIS-NIR spectral range

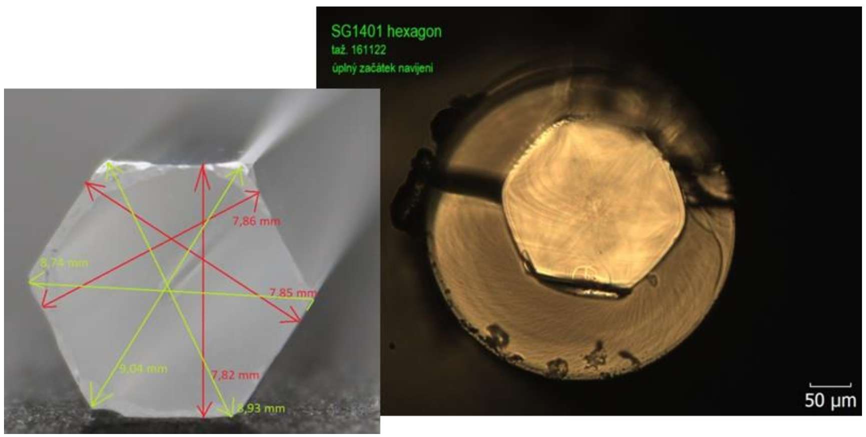
DC structures, beam combining ..

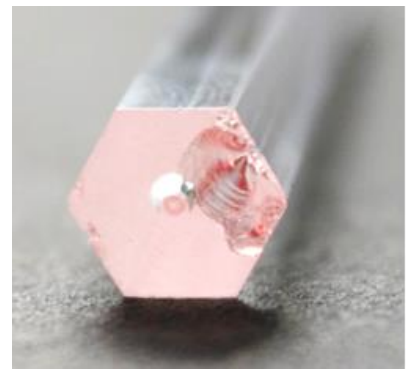


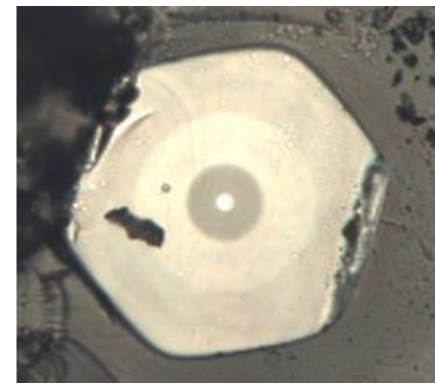


Core-pumped active fibers







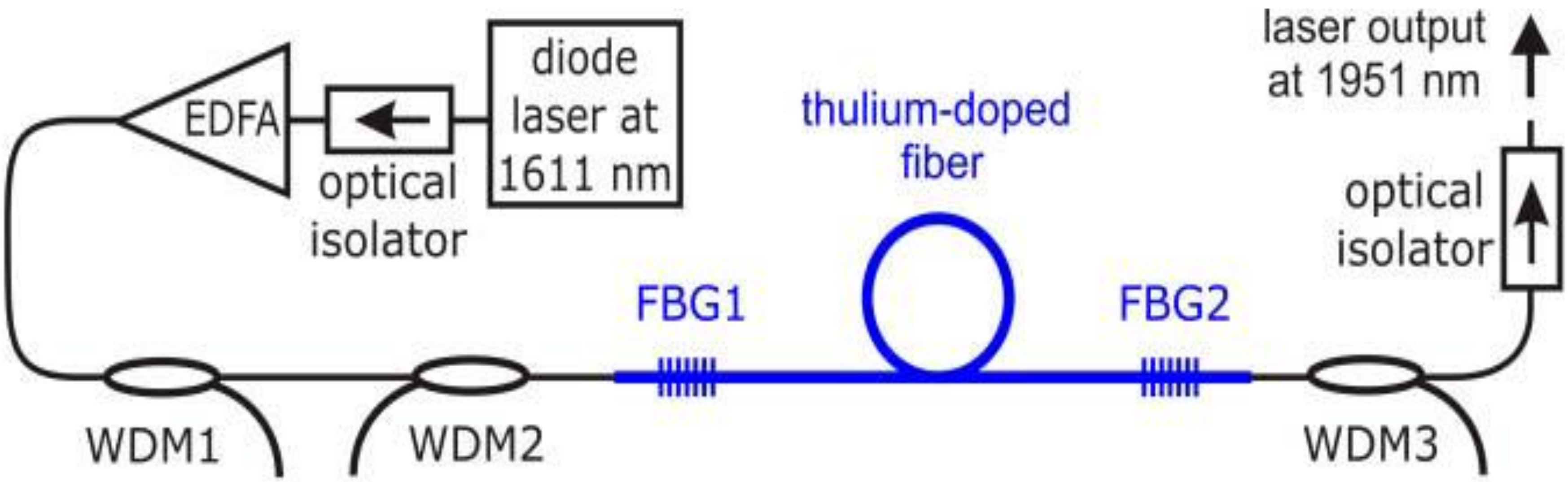


Preform /
20 µm / 250 µm fiber
NA_{max}=0.077 (LMA), hot-twist

Preform /
12 µm /130 µm fiber
NA_{max}=0.22, cold-twist

Monolitic Tm- doped fiber laser at 1951 nm

Eye-safe spectral region

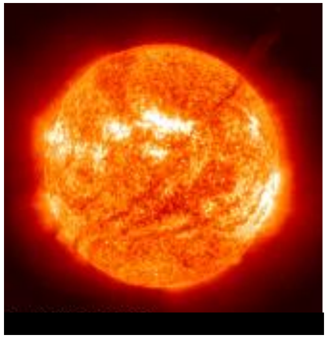


* Tm^{3+} - Al_2O_3-SiO_2 core (Al_2O_3 nanoparticles),
* 1000 ppm Tm^{3+}, 11mol% Al_2O_3, 0 mol% P_2O_5 or GeO_2,
* **deep-UV inscription of FBG**

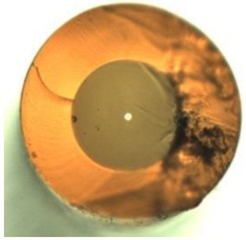
[P.Peterka, Photonic Technol Lett, 25, 2013, 1623]

Fiber lasers – from mW to kW

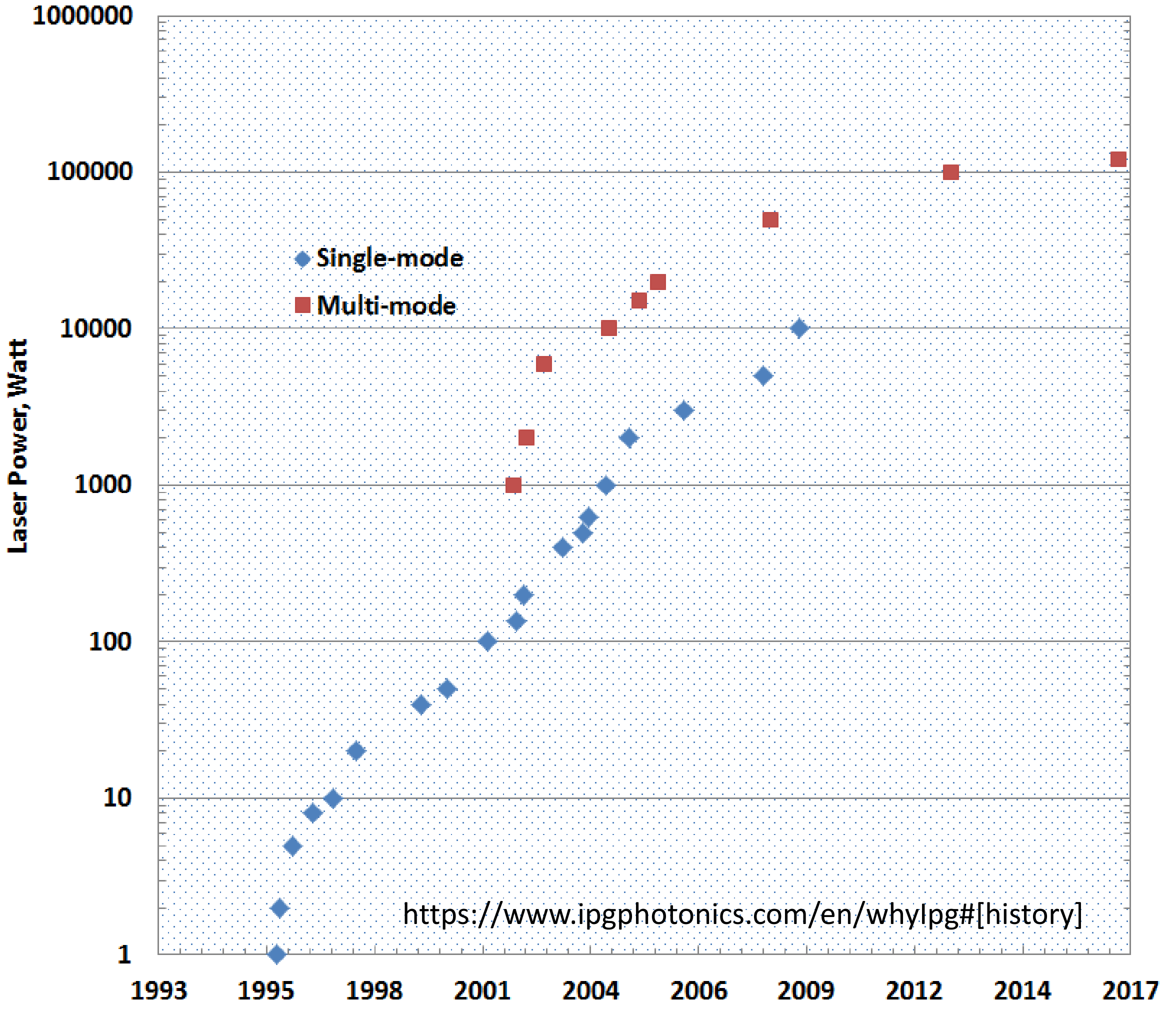
* **high conversion efficiency** (fiber lasers ~70-90%) - savings
* **high quality beam** (nearly Gaussian, low divergency)
* **high brightness** (high concentration of power)
* **good thermal management** (cooling)
* effective pumping
* tunability
* compactness
* size (long resonator in small space)



sun	63 MW/m^2
fiber laser	12.7 GW/m^2



Fiber lasers – from mW to kW



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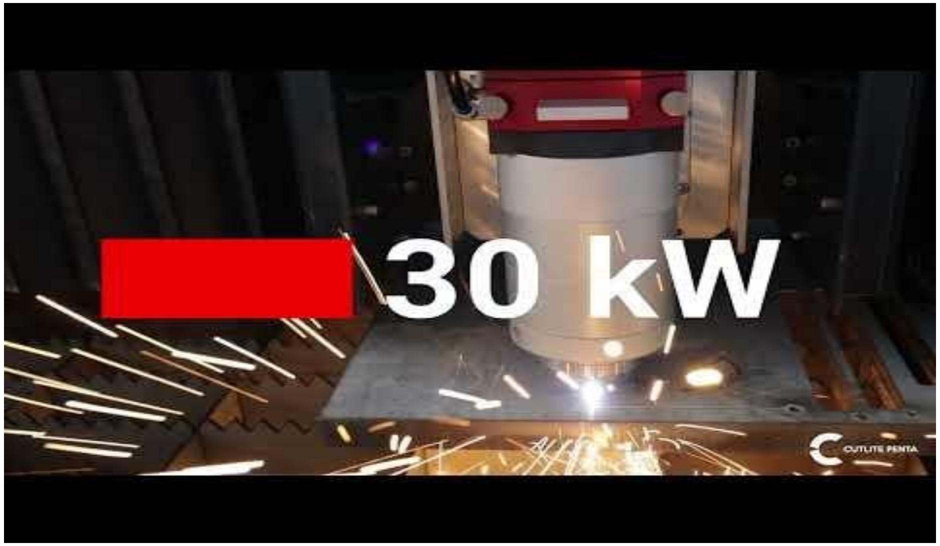
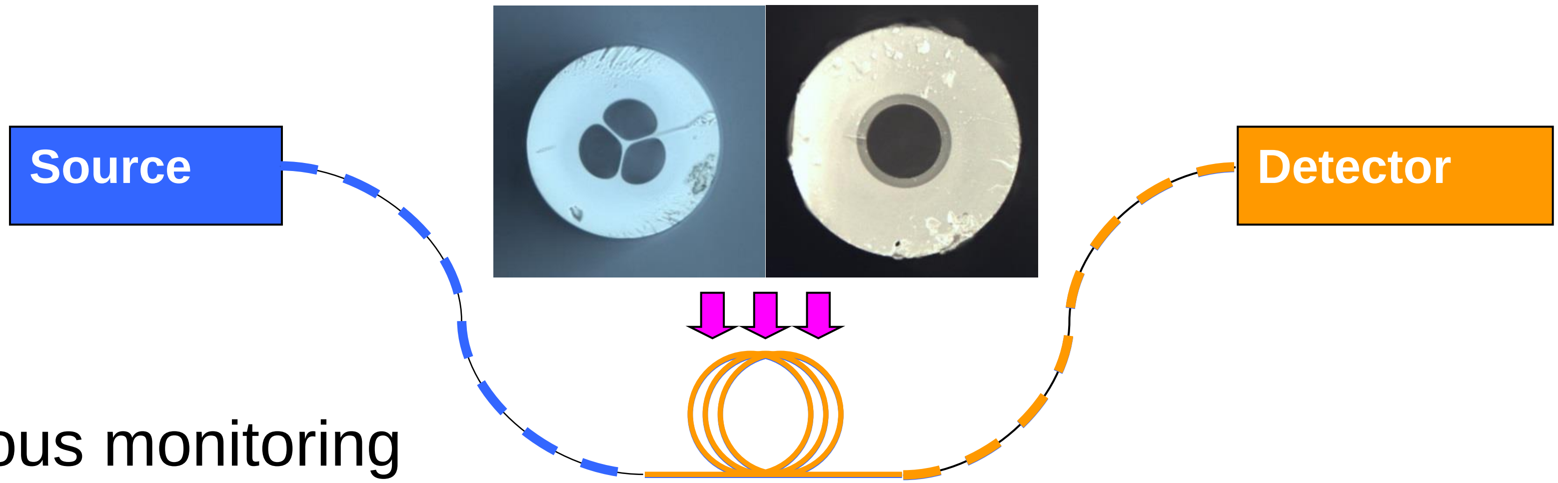
Fiber lasers - videos

https://www.youtube.com/@NarranCzlaser

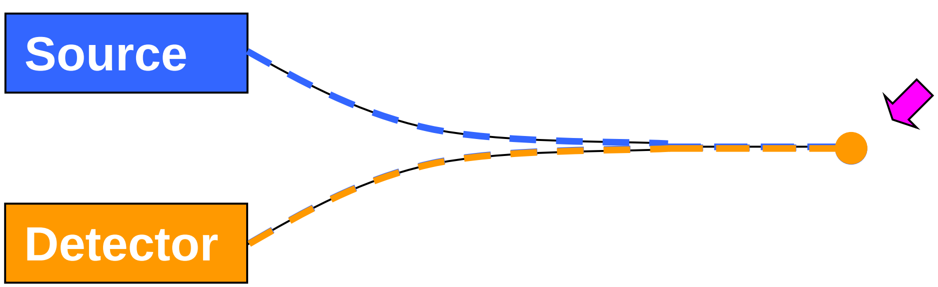


https://www.youtube.com/watch?v=7J-nhEnHWbM

Optical fiber sensors



Continuous monitoring of (bio)chemicals and their concentration.

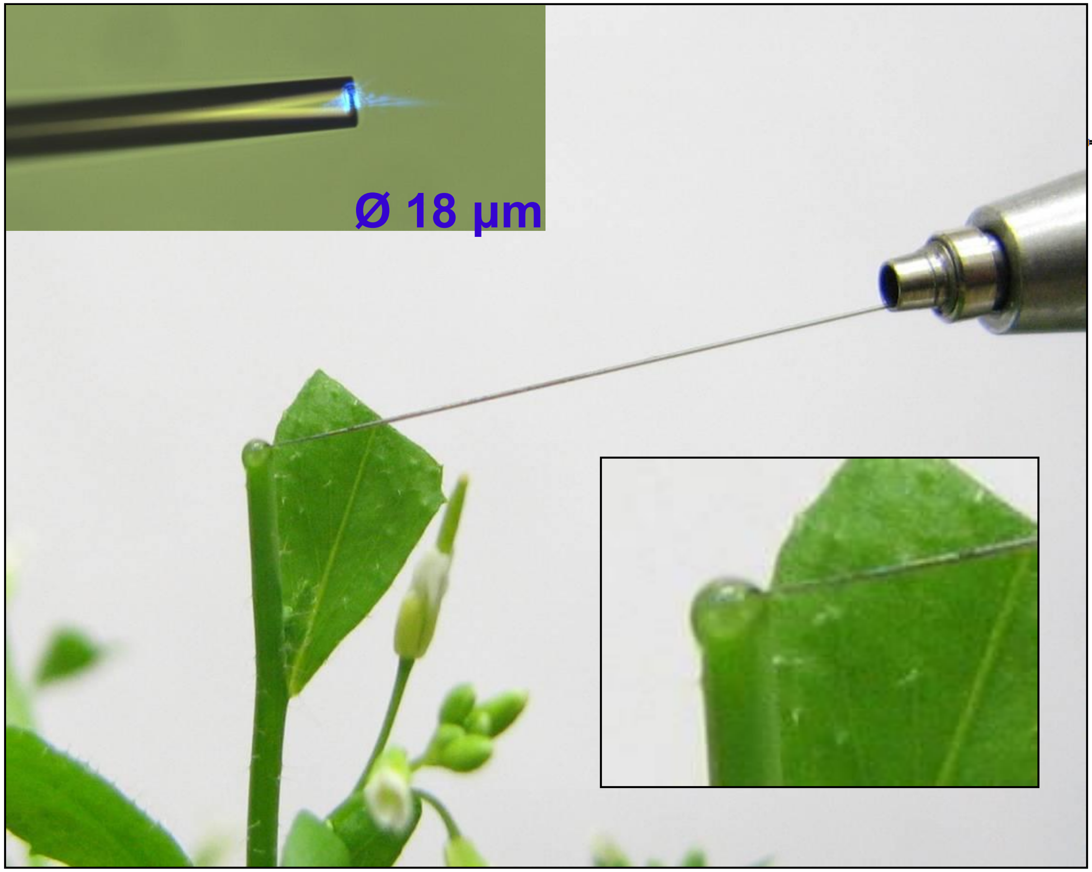


Suitable for :

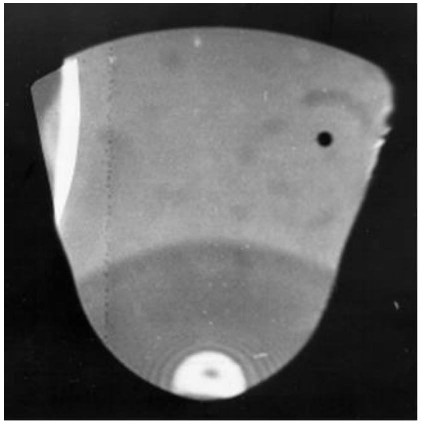
- remote sensing
- flammable or explosives
- in high-voltage areas
- human body
- distributed sensing

Optical fiber sensors

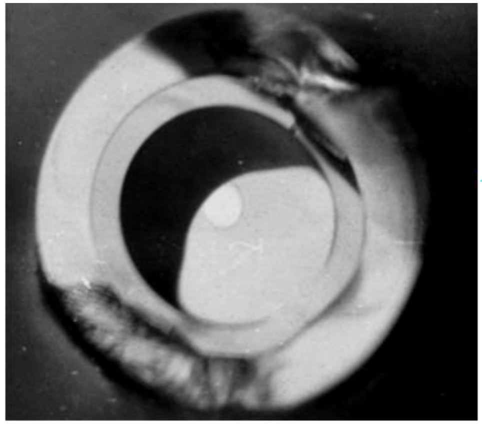
Detection of pH in small samples (droplets, cells)



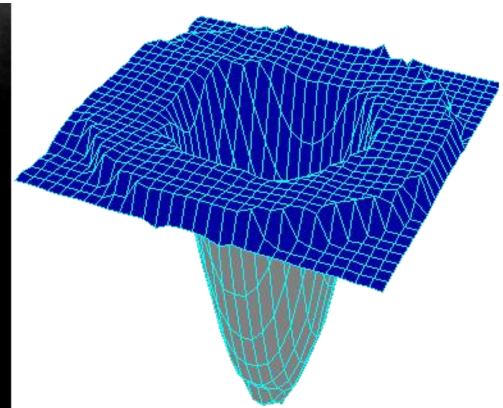
Optical fibers for sensors



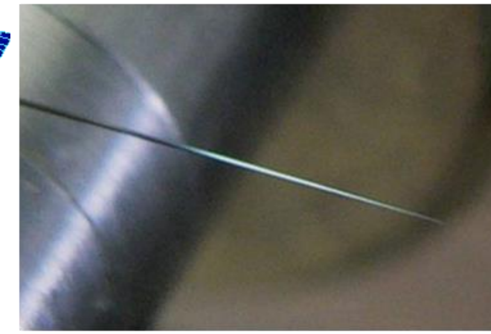
segment f.



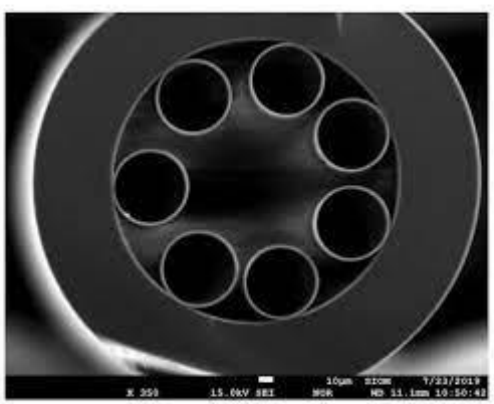
capillary seg. f.

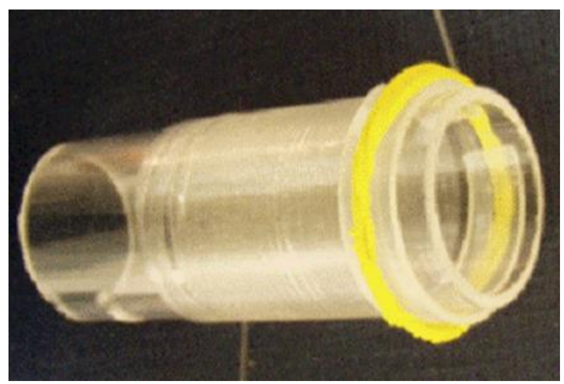


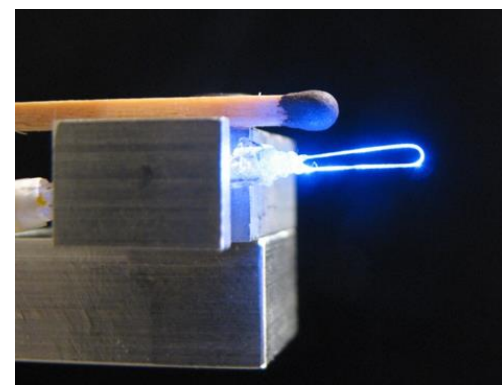
IGI fiber



fiber taper



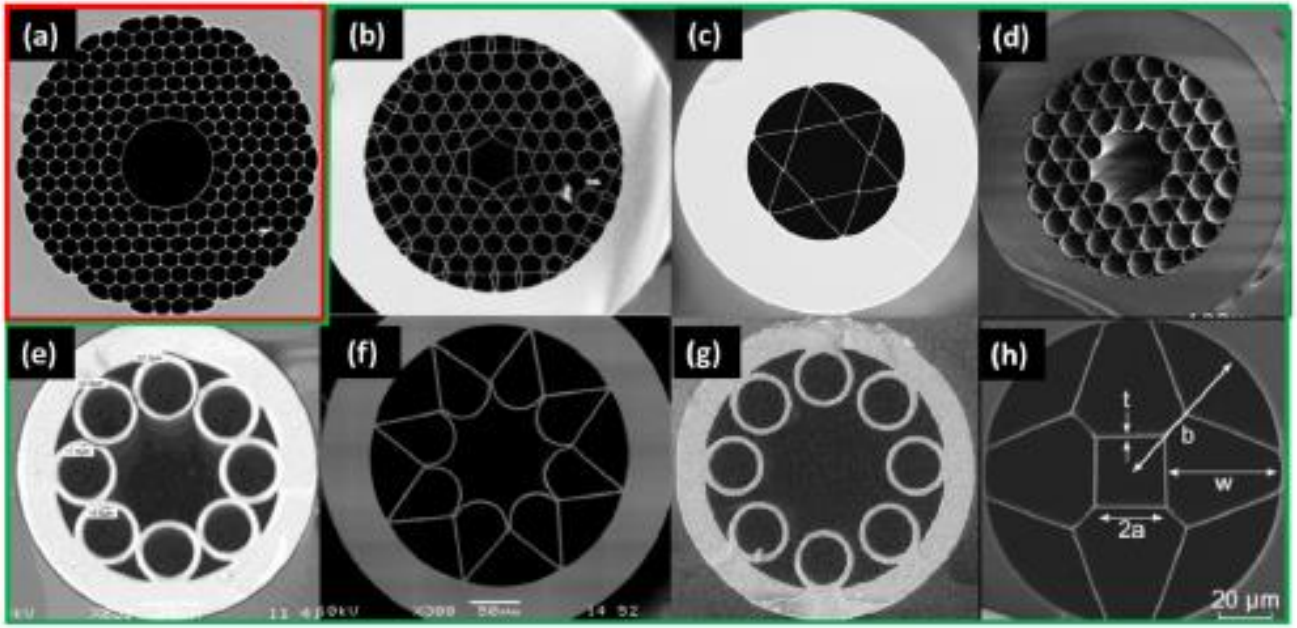


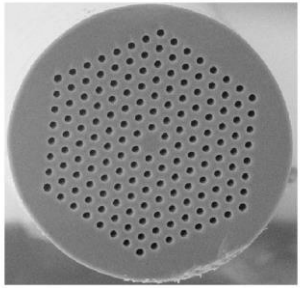


+ special coatings

Microstructured fibers

- Photonic band gap, anti-resonant fibers
- Higher attenuation, „unusual properties
  hollow core, non-linearity





F. Poletti, Opt. Express 22, 23807-23828 (2014);

Summary

1. **Fiber technology : preparation of structures with high precision (<1%) from materials of ultra-high purity (impurities in ppb).**
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 competitive with Solid State Lasers (SSL).**
4. **Fiber optic sensors – for special applications**
5. **Research of optical fibers & fiber lasers -> ŪFE**

References

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- **A. Mendez, F.T. Morse** : Specialty optical fibers handbook, Elsevier Science & Technol, USA, 2006.
- **Saleh B.E.A., Teich M.C.:** Fundamentals of Photonics 2nd Ed.,Wiley-VCH, 2007
- **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

www.ufe.cz

Be carefull !