

Optical Fiber Technology

Ondřej Podrazký

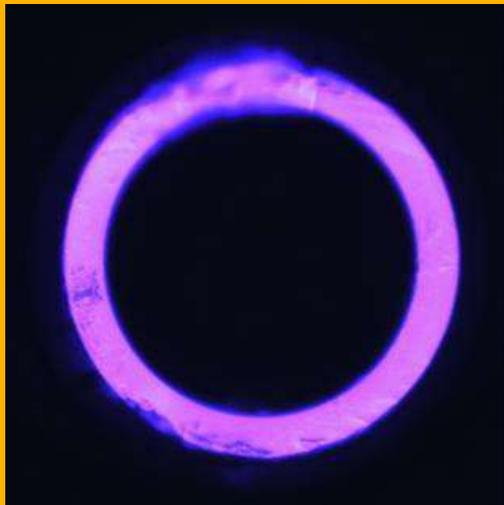
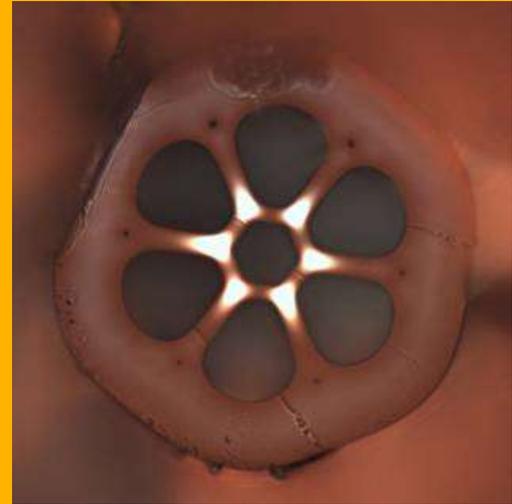
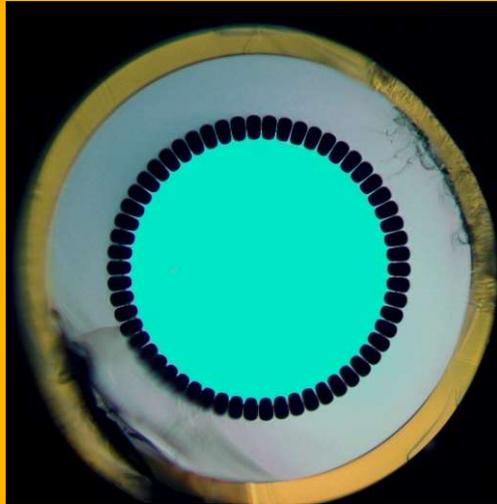
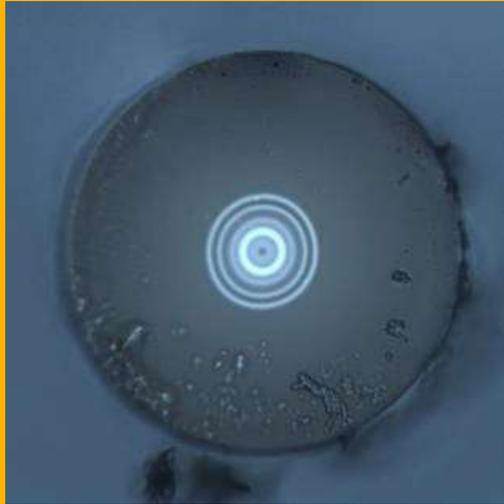
**Institute of Photonics and Electronics
The Czech Academy of Sciences**

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Content

1 Basics

- Waveguide principle
- Transmission, attenuation and material purity

2 Optical fiber preparation

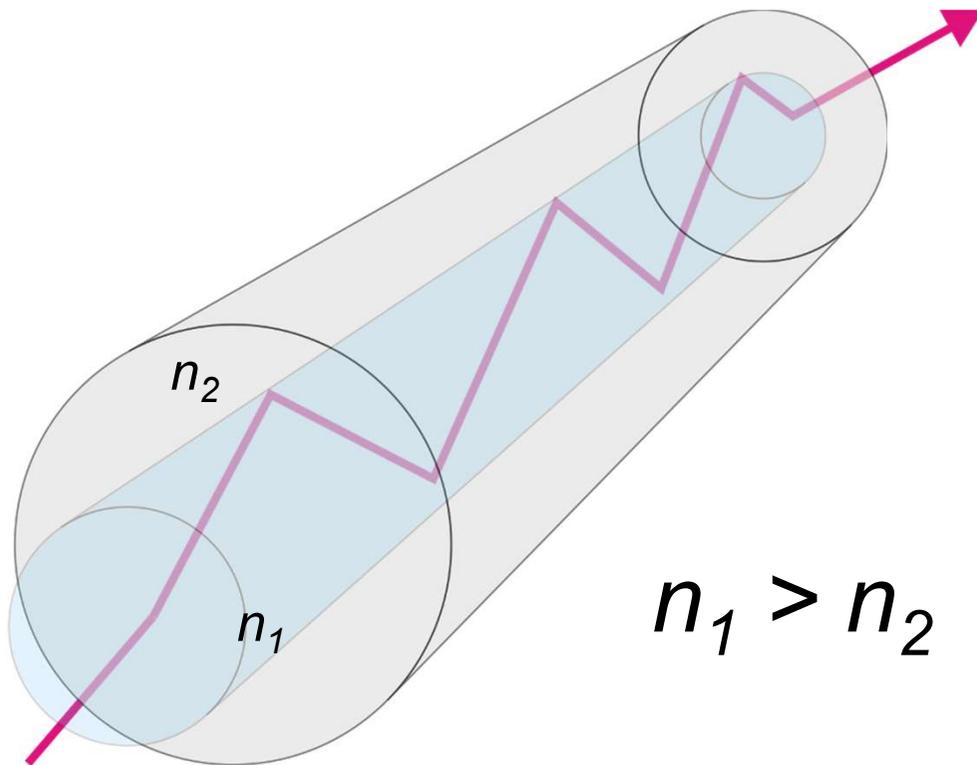
- MCVD
- Fiber drawing

3 Applications

- Telecommunications
- Lasers
- Sensors

4 Summary

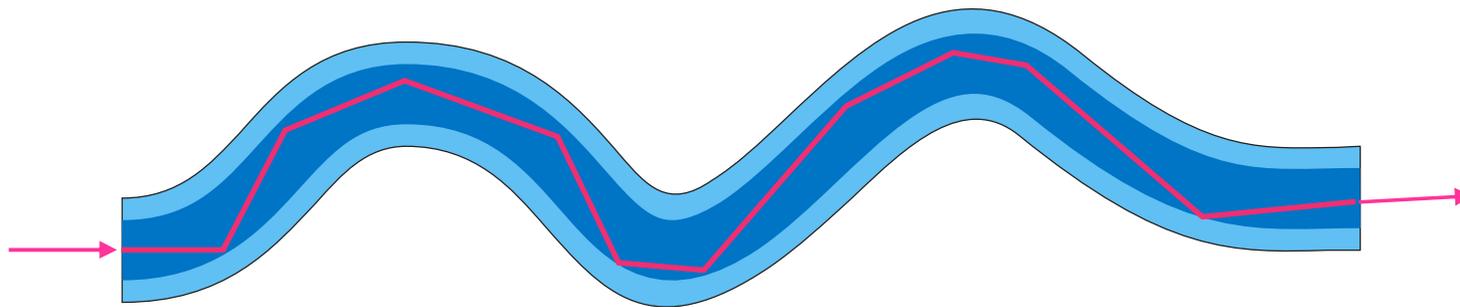
Waveguiding principle → optical fiber



W. Snell (~1620) : total reflection

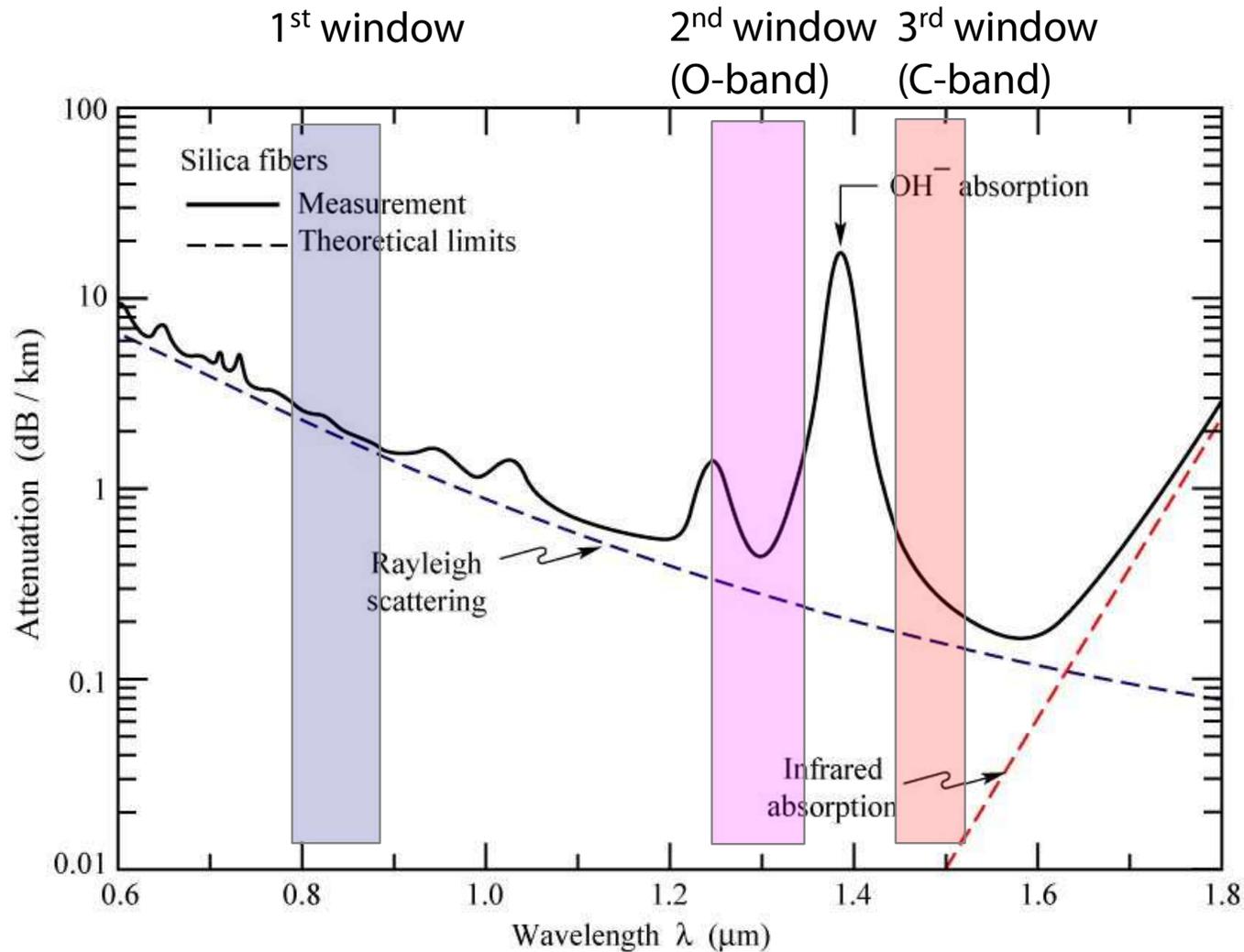
J. Tyndall (1853) : **waveguide**

$n_{\text{water, glass, plexi}} > n_{\text{cladding, surroundings}}$



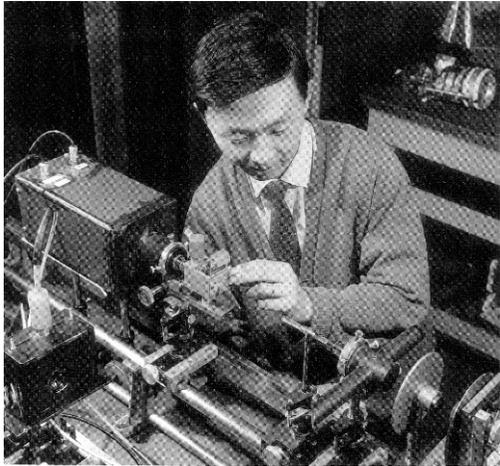
Optical fiber : dielectric structure, $L \gg d$, $n_{\text{core}} > n_{\text{cladd}}$

Transmission and attenuation



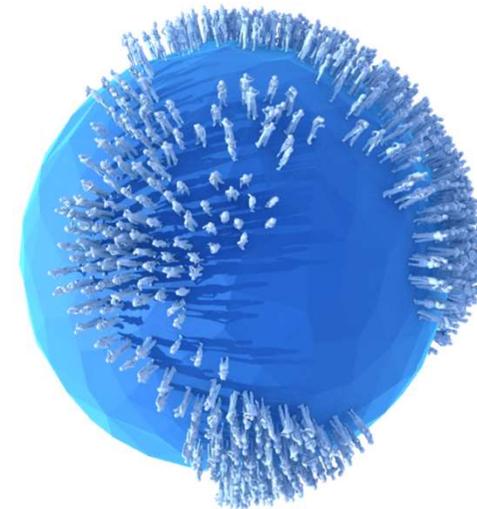
Credit: <http://LightEmittingDiodes.org>

Purity of material



Charles K. Kao
1966

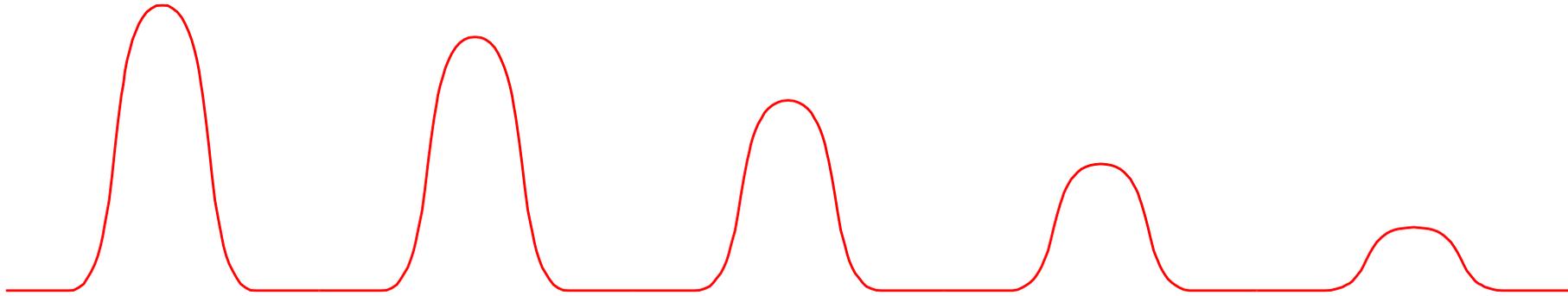
ultra pure materials
impurities in order of ppb = 10^{-9}



1/2 Nobel prize
in 2009

**ULTRA PURE
TECHNOLOGIES**

Purity of material



Attenuation in optical fibers

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

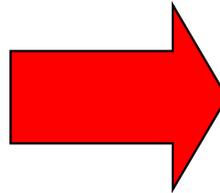
~ 2 km of optical fiber has the same transparency as 3 mm of window glass

Optical fiber preparation

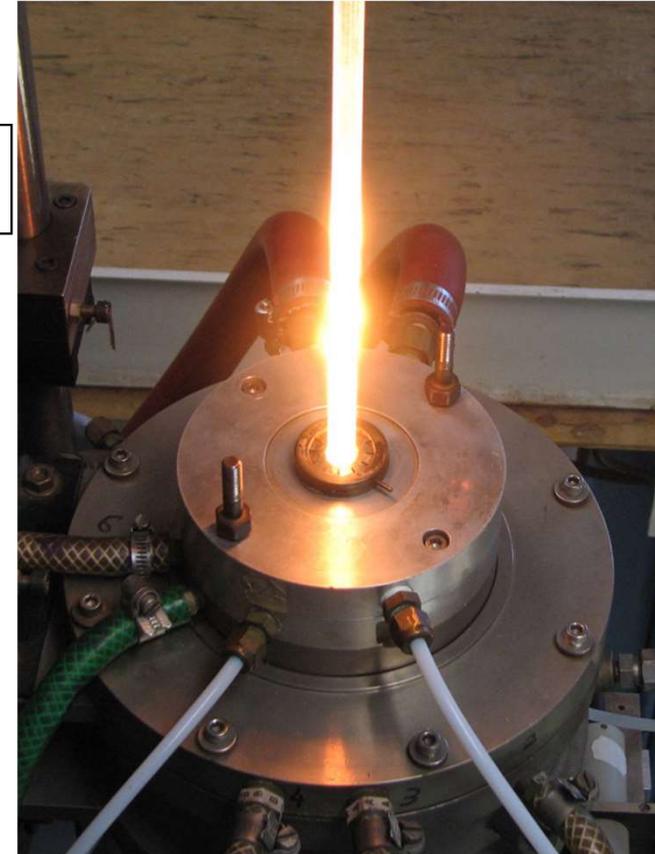


MCVD

1. Preform



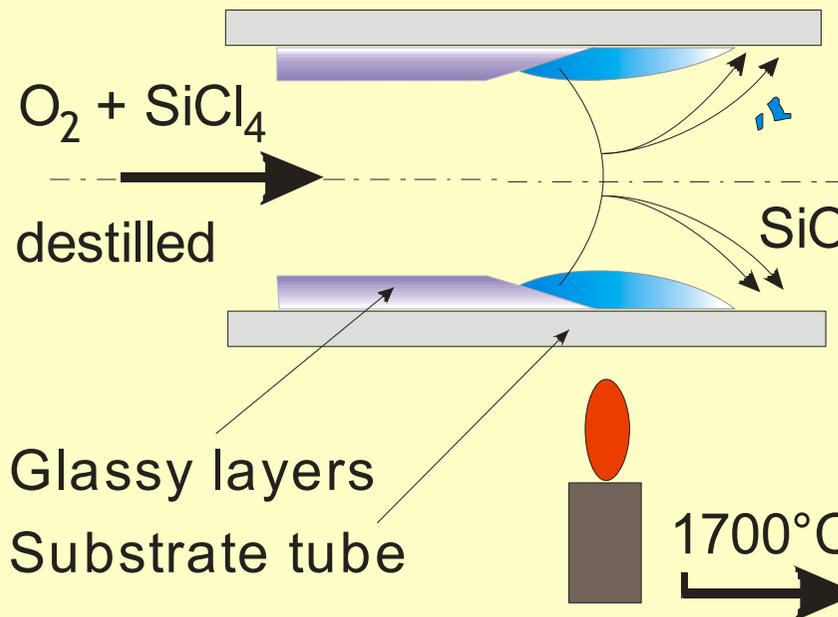
2. Fiber drawing



Preform preparation: MCVD – Modified Chemical Vapor Deposition

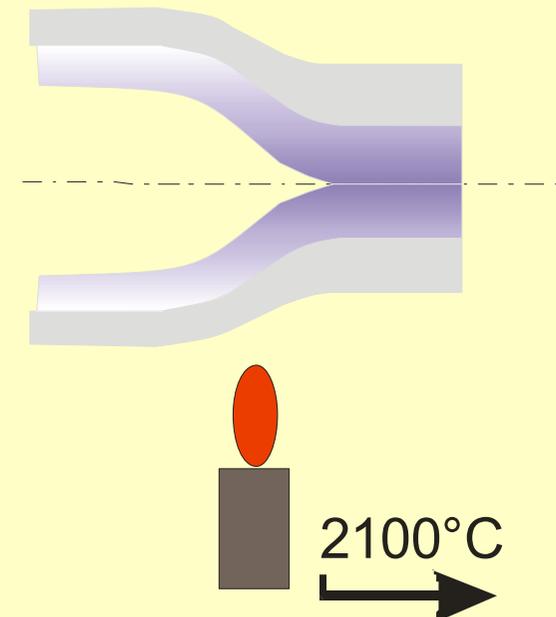
1. Deposition of layers

GAS MIXTURE



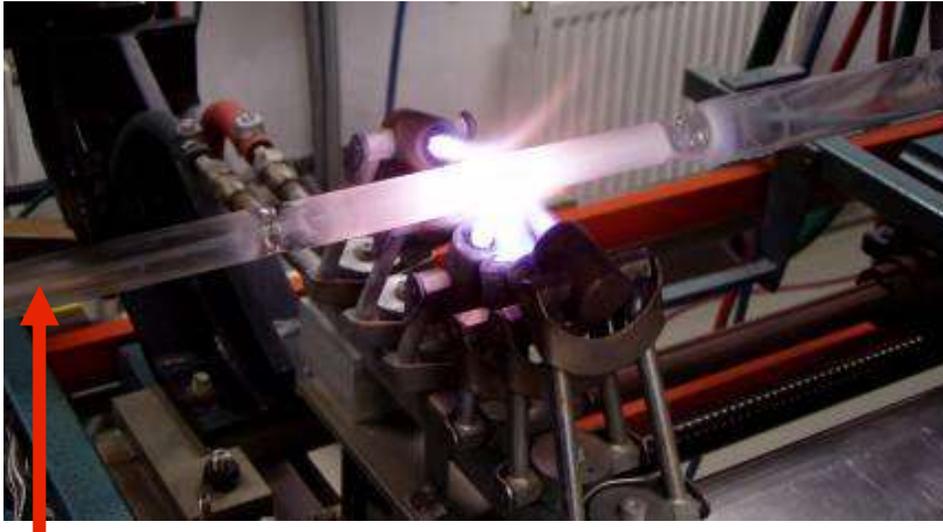
2. Collapse

GLASS - PREFORM



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

MCVD → Preform

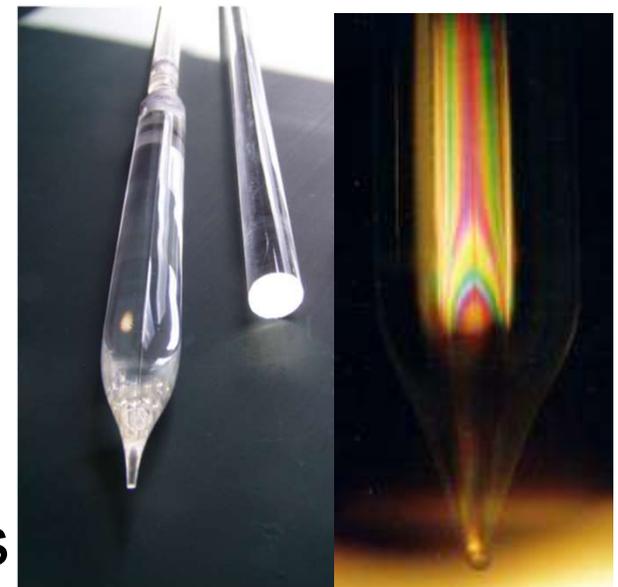


Distillation
(halogenides)

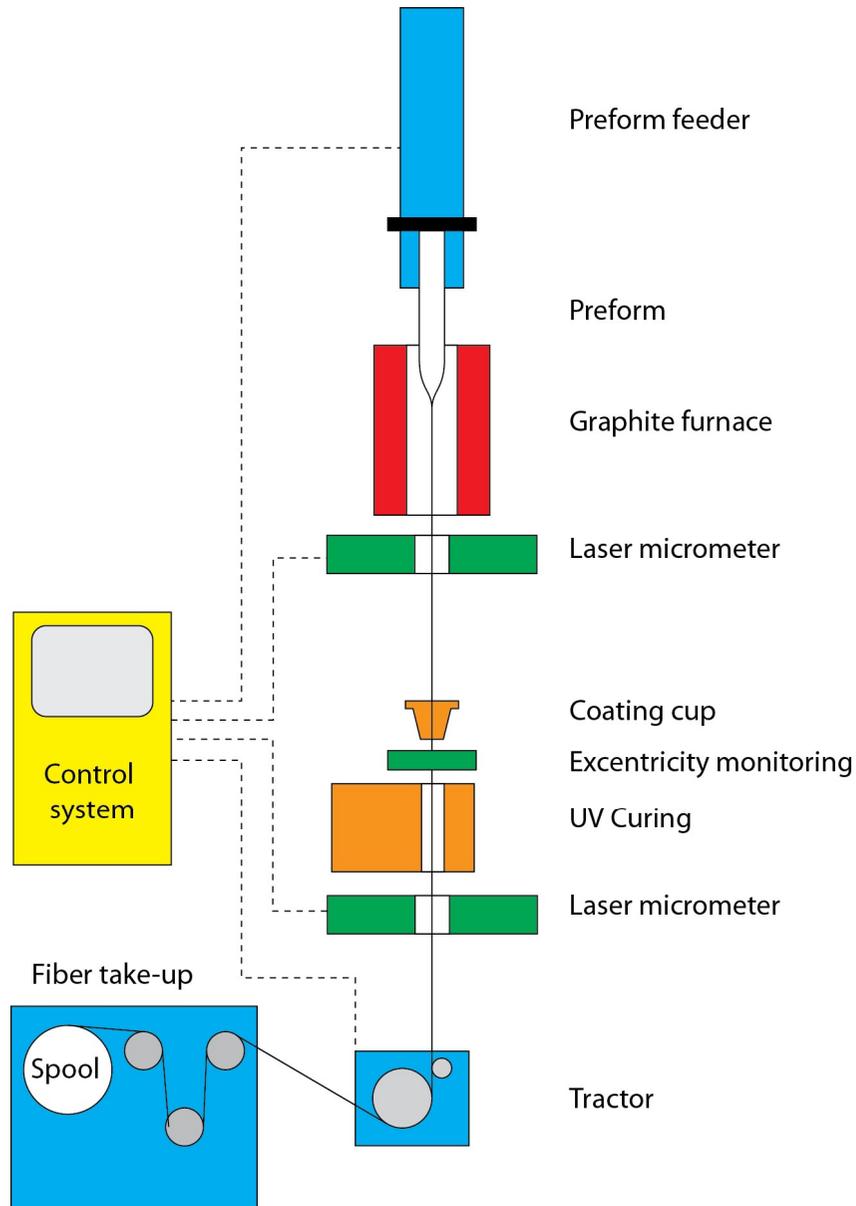
Deposition
of layers

Preform
collapse

Preforms

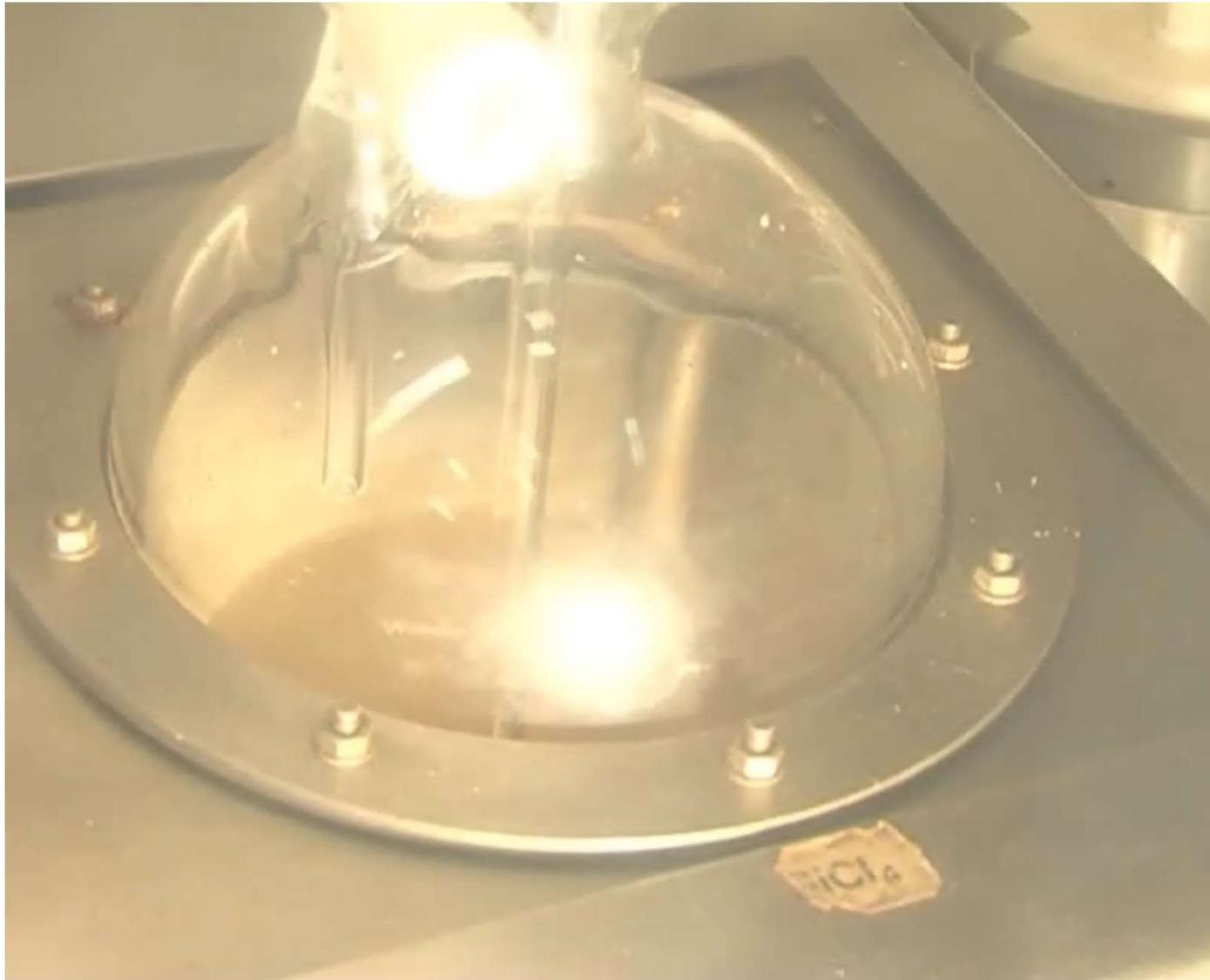


Drawing of Optical Fibers



- Fiber diameter 80-1000 μm
- Temperature 1800-2000 $^{\circ}\text{C}$
- 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

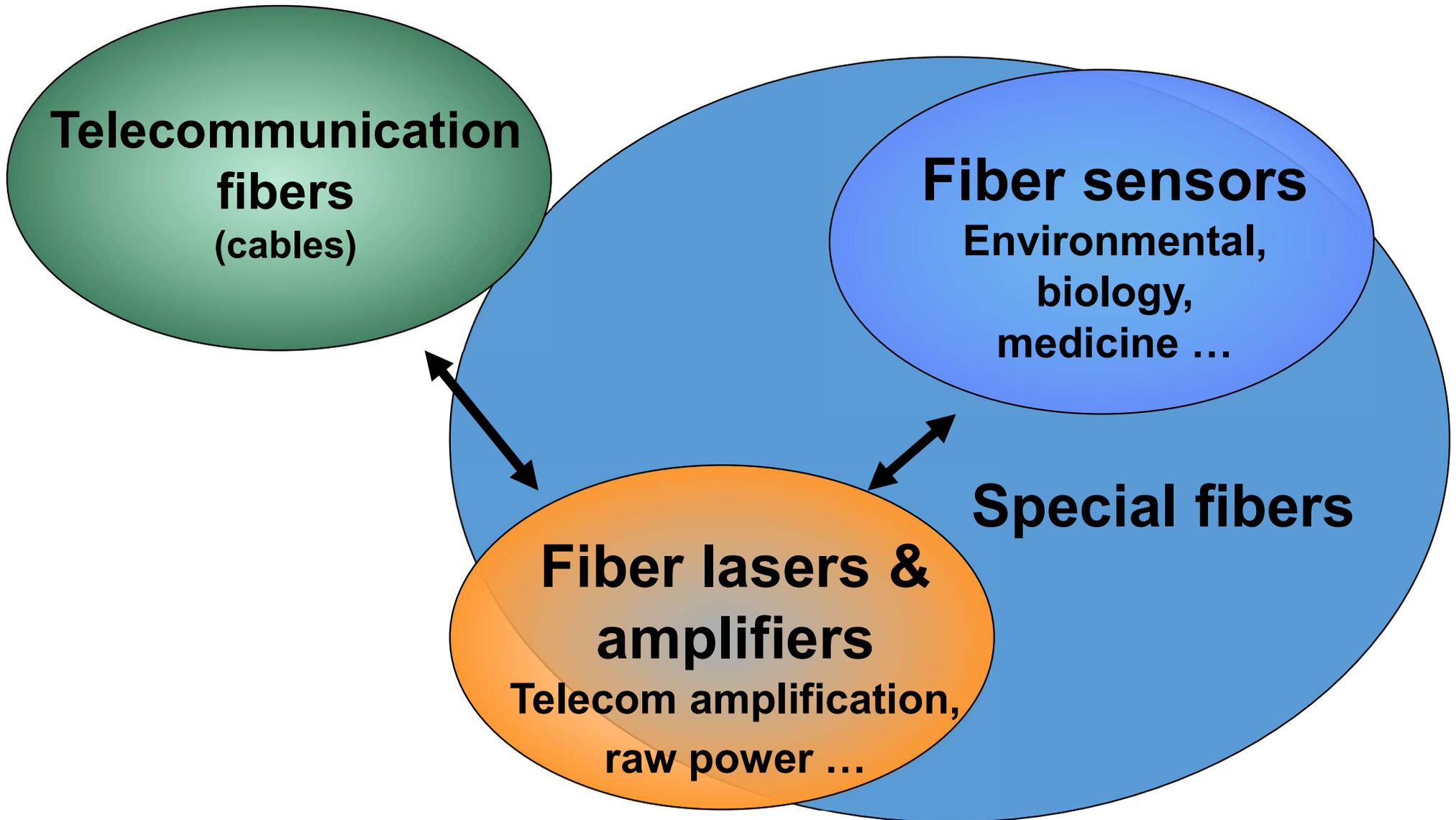


- Preform diameter
~ 230 mm
- Drawing speed
~ 1-2,5 km/min !
- Fiber length
~ 10 000 km !
- Price
<0,05 USD/m

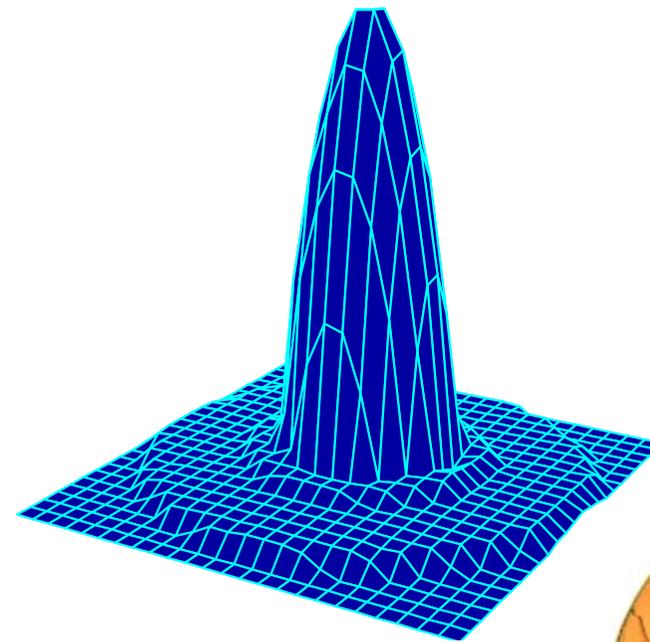
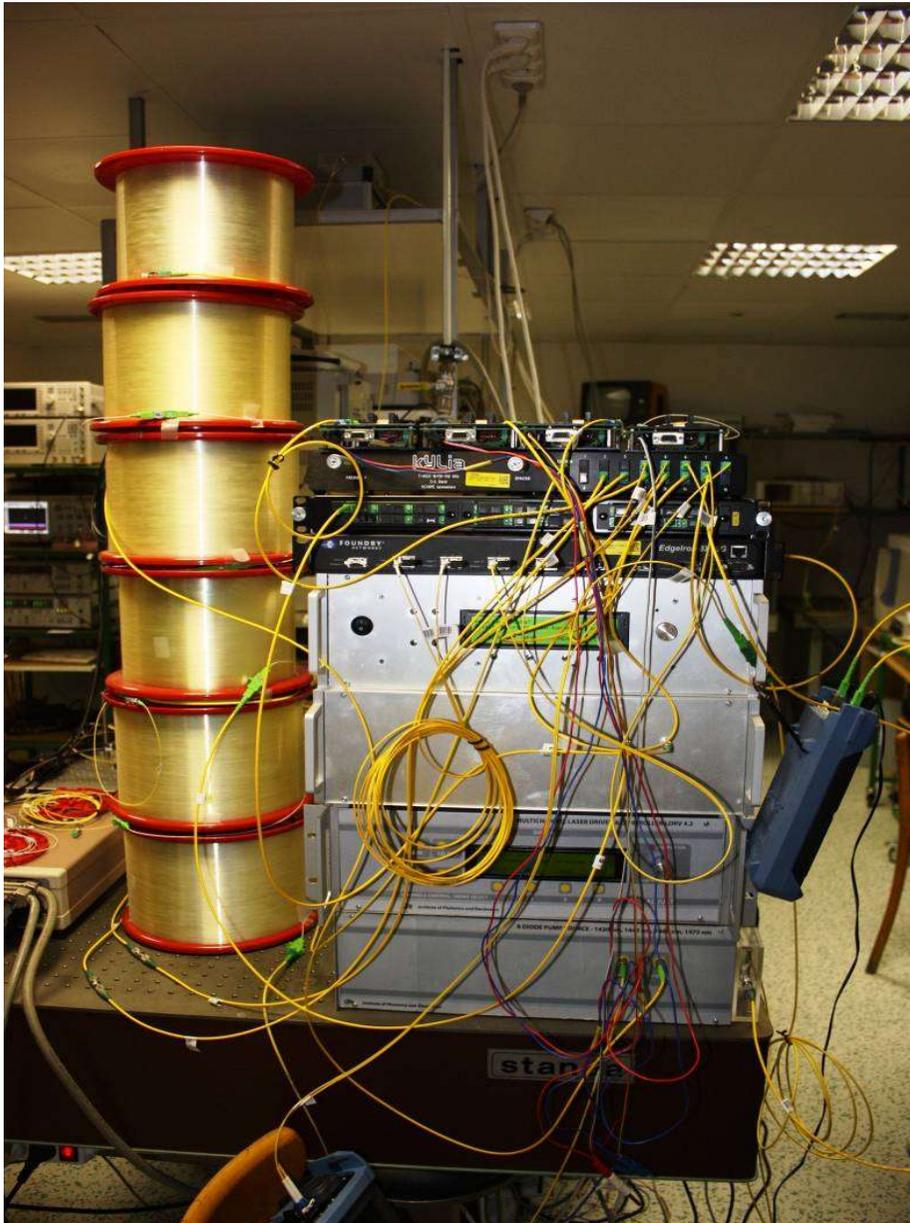
<https://rosendahlnextrom.com/fiber/products/telecom-preform-fiber/>

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

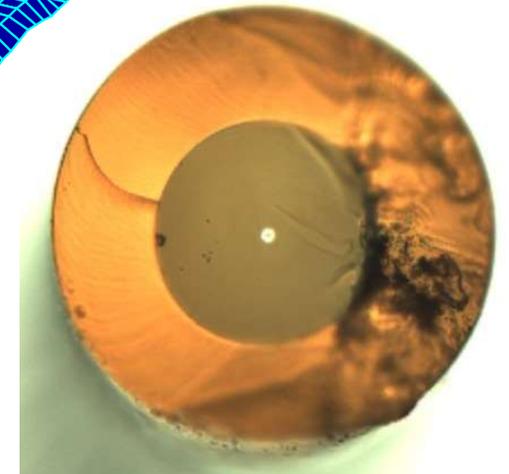
Application



Optical fibers for telecommunications (passive)



GI - multimode



SM - singlemode

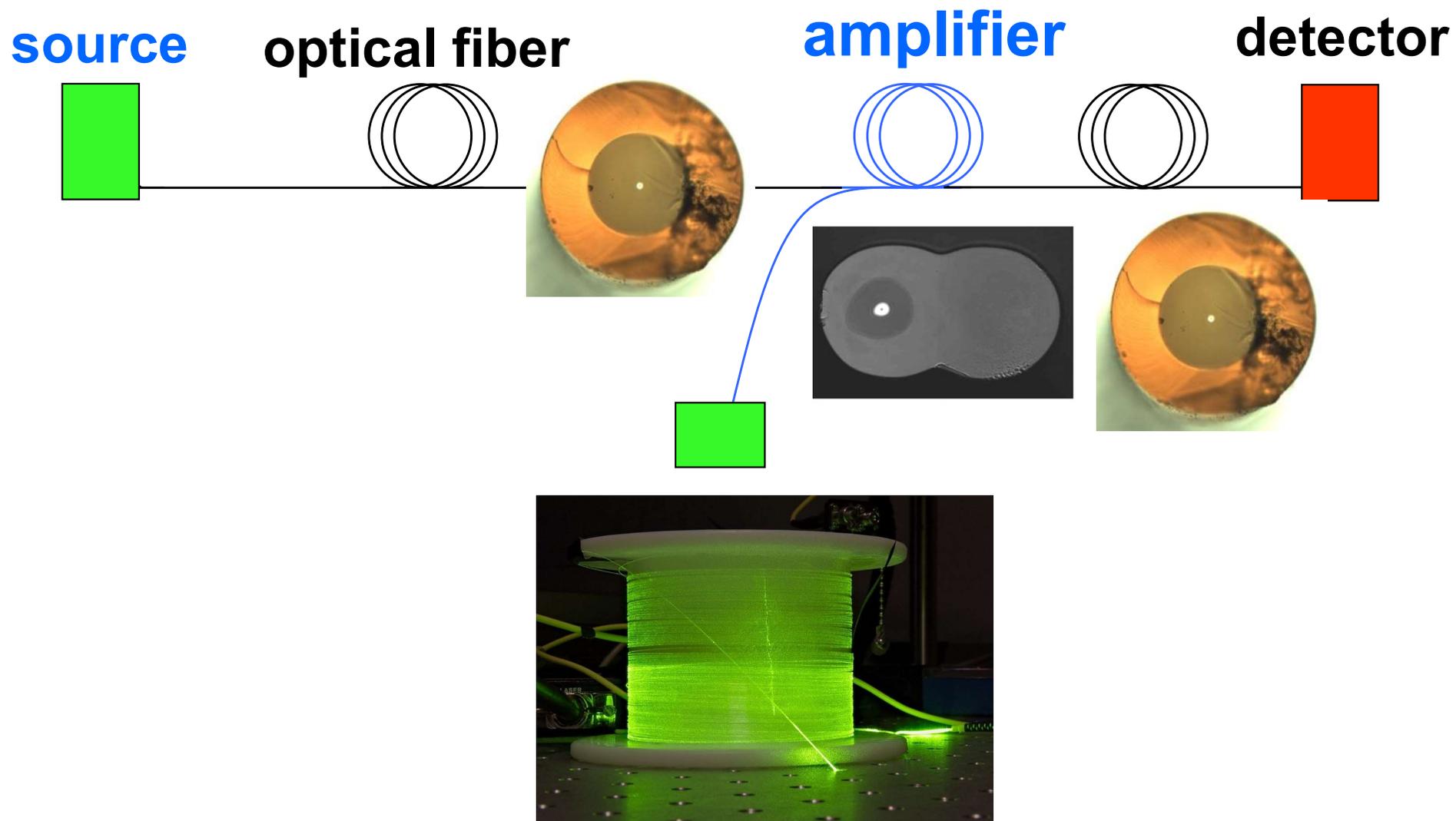
Optical fibers for telecommunications

Requirements:

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

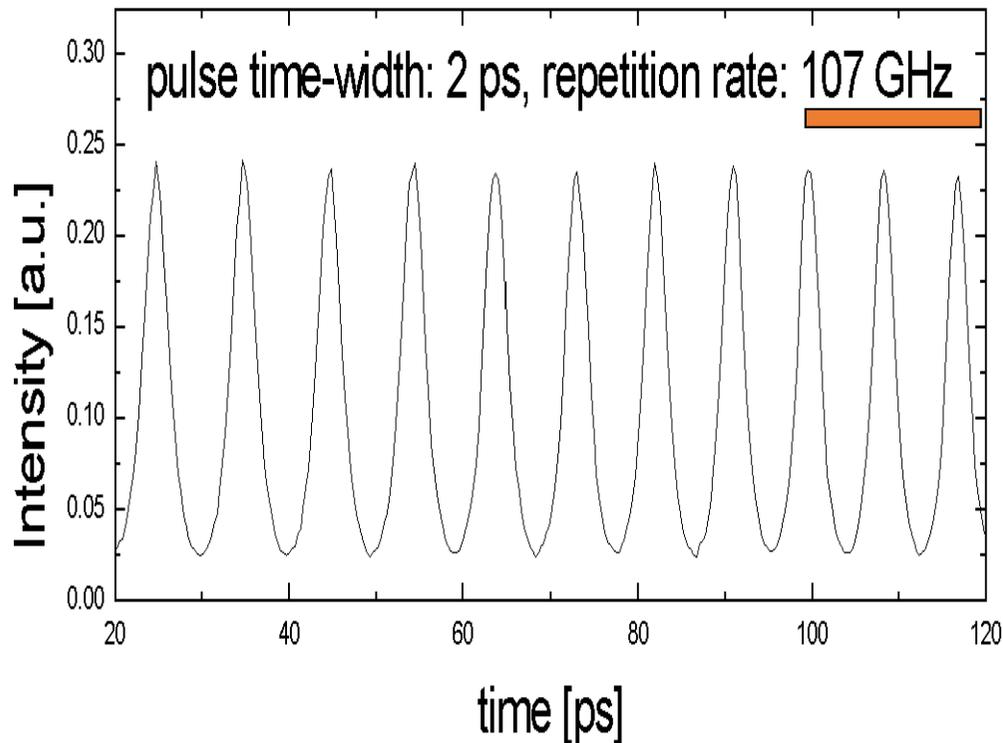


Specialty optical fibers for communications (active)

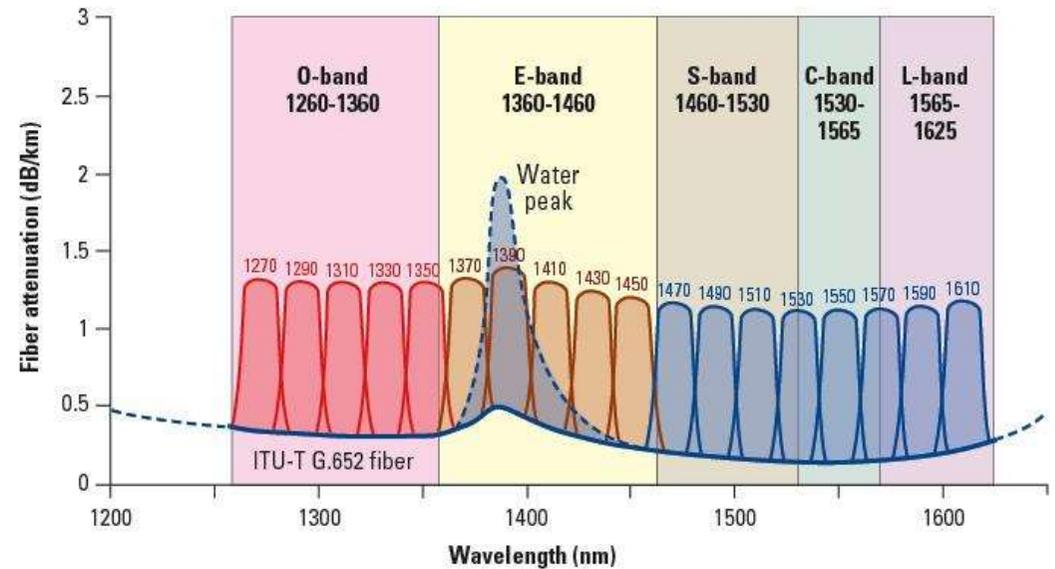


Multiplexing

Time Division Multiplexing (TDM) Q-switched FL



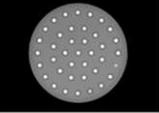
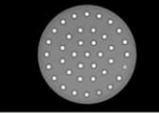
CWDM wavelength grid as specified by ITU-T G.694.2



Wavelength Division Multiplexing (WDM)

Fastest data transmission over single OF

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

	38 core, 3 mode	4 core	This study
	Mar. 2020	May 2022	Oct. 2023
Fiber type	38 core, 3 mode	4 core	38 core, 3 mode
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



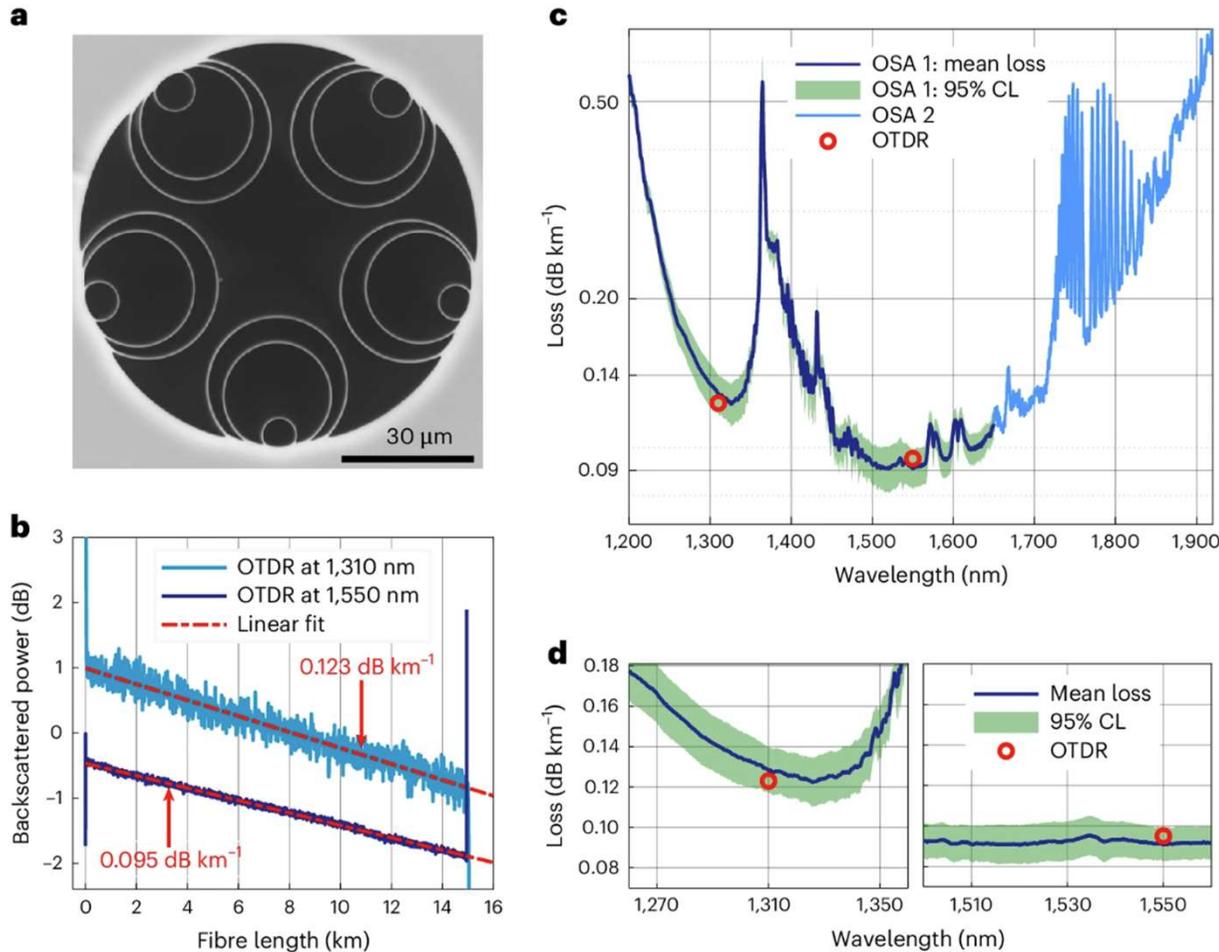
<https://www.nict.go.jp/en/press/2023/11/30-1.html>

Novel Transmission Technique Enables World Record 430 Tb/s in a Commercially Available, International-Standard-Compliant Optical Fiber

<https://www.nict.go.jp/en/press/2025/11/11-1.html>

Anti-resonant hollow-core fibers

From: [Broadband optical fibre with an attenuation lower than 0.1 decibel per kilometre](#)



a, SEM of the fabricated HCF2. **b**, Bi-directional OTDR traces at 1,310 nm and 1,550 nm. **c**, Mean loss and 95% confidence level (CL) of four separate cutbacks (1,200–1,650 nm) compared with OTDR results and a fifth cutback to show the spectral loss in the 1,650–1,950 nm range. **d**, Cutback loss details in the 1,270–1,350 nm and 1,500–1,560 nm bands.

Loss < 0.010dB/km !!

$$n_{\text{SiO}_2} \sim 1.457$$

$$n_{\text{air}} \sim 1.0003$$

=> c ~45% faster !!

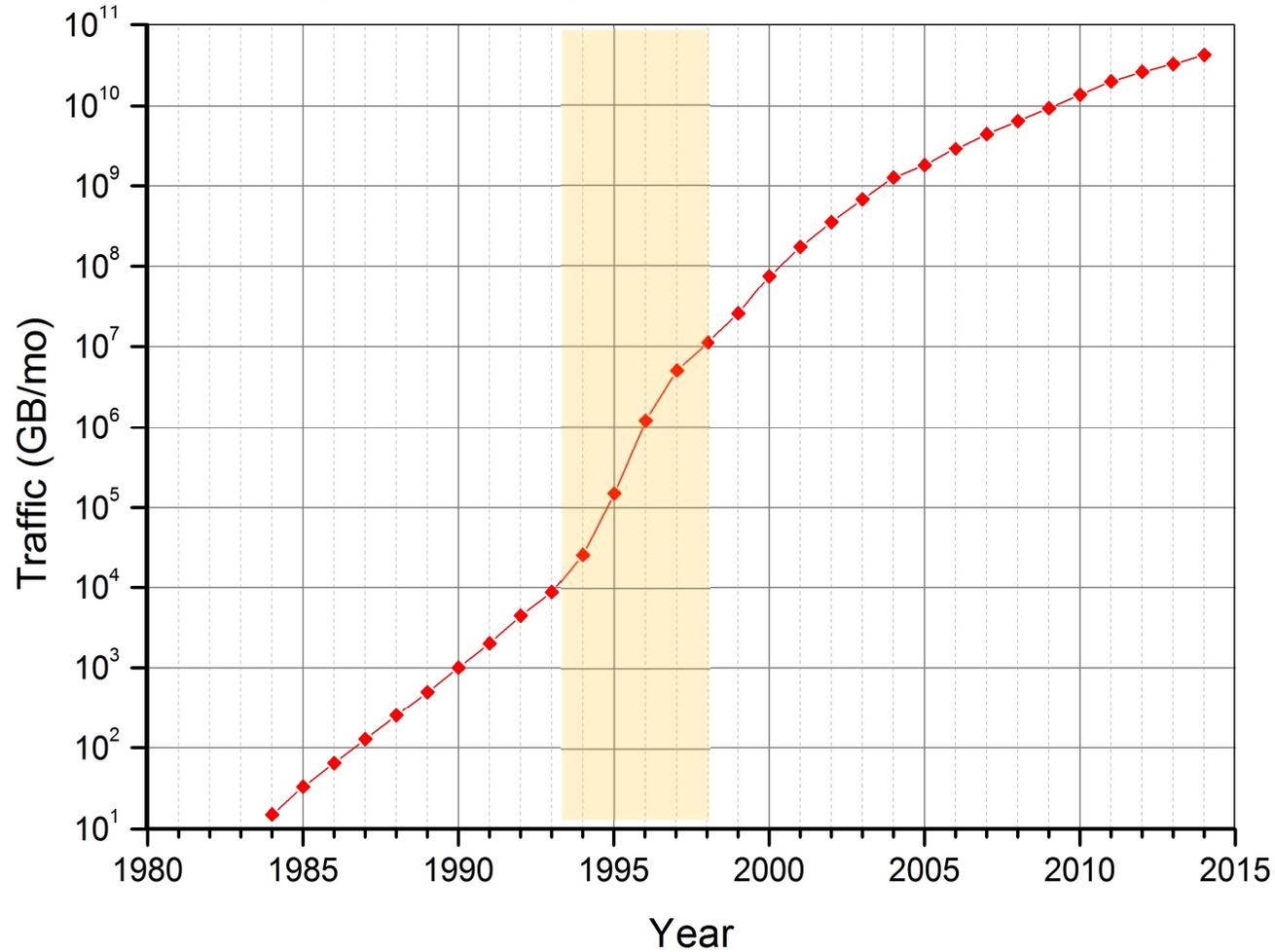


Petrovich, M., Numkam Fokoua, E., Chen, Y. *et al.* Broadband optical fibre with an attenuation lower than 0.1 decibel per kilometre. *Nat. Photon.* **19**, 1203–1208 (2025).

Importance of fiber amplifiers

Historical Global Internet Traffic Data, 1984 through 2014

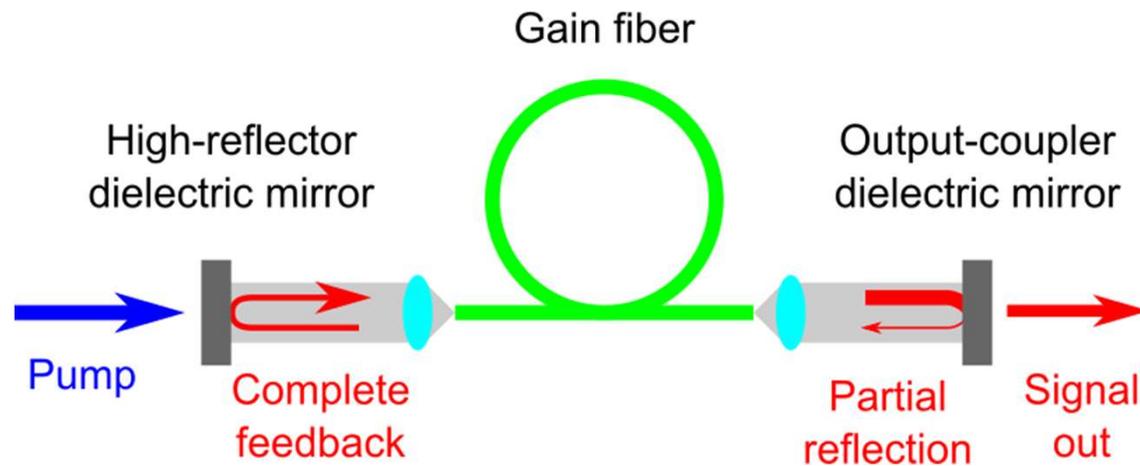
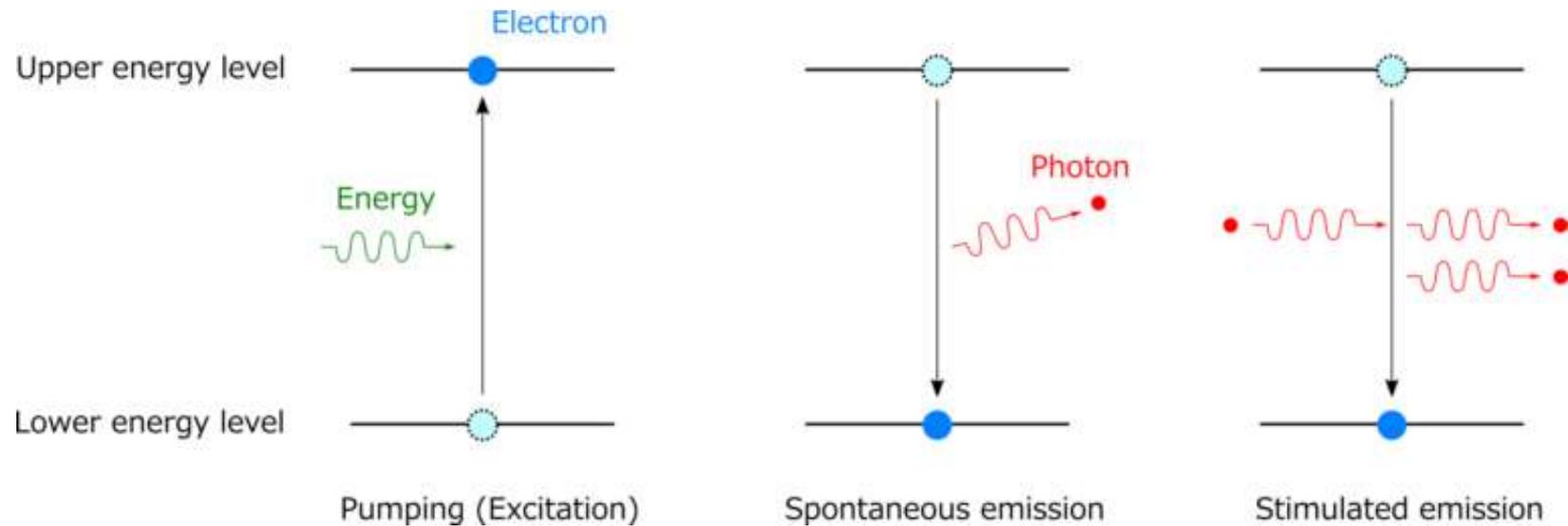
<https://blogs.cisco.com/sp/the-history-and-future-of-internet-traffic>



EDFA+Dispersion management=>WDM

Fiber lasers

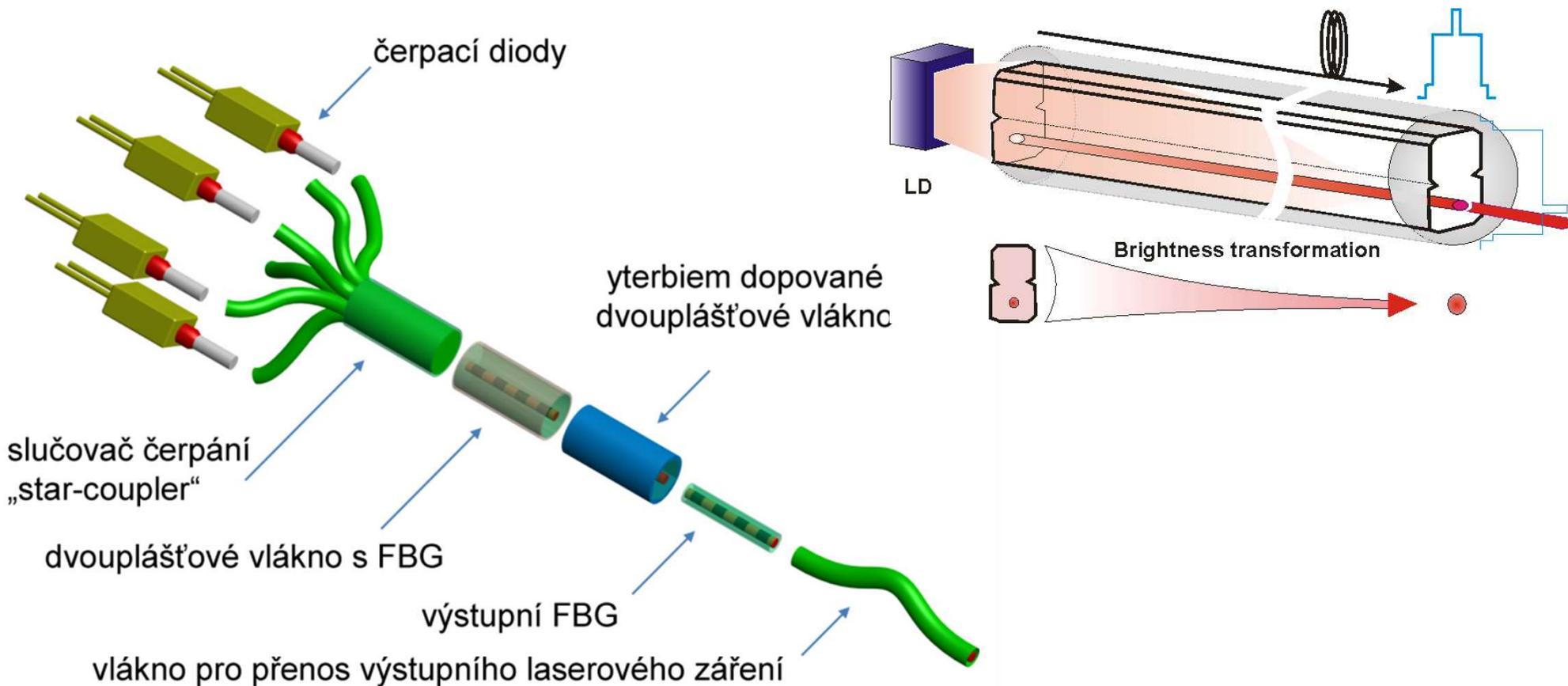
Light Amplification of Stimulated Emission of Radiation



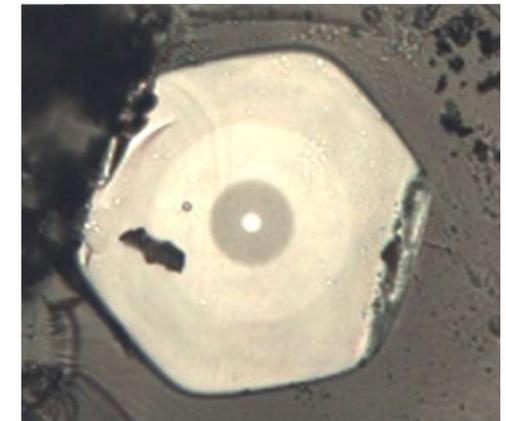
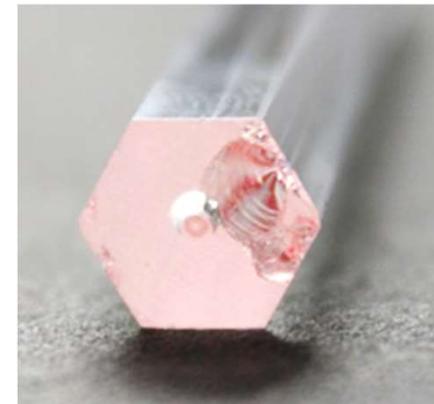
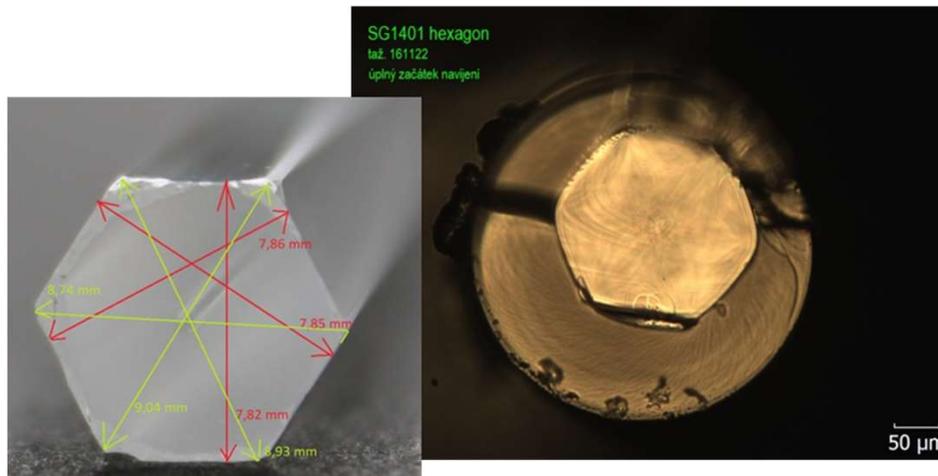
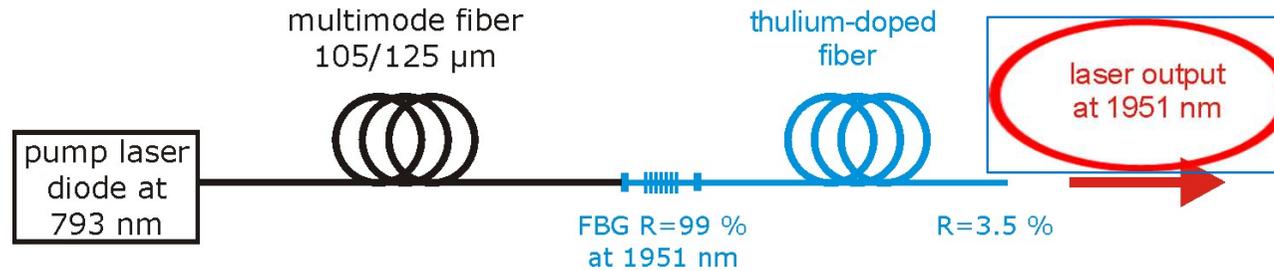
Credit: <http://fiberlabs.com>

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

DC structures, beam combining ..



Core-pumped active fibers

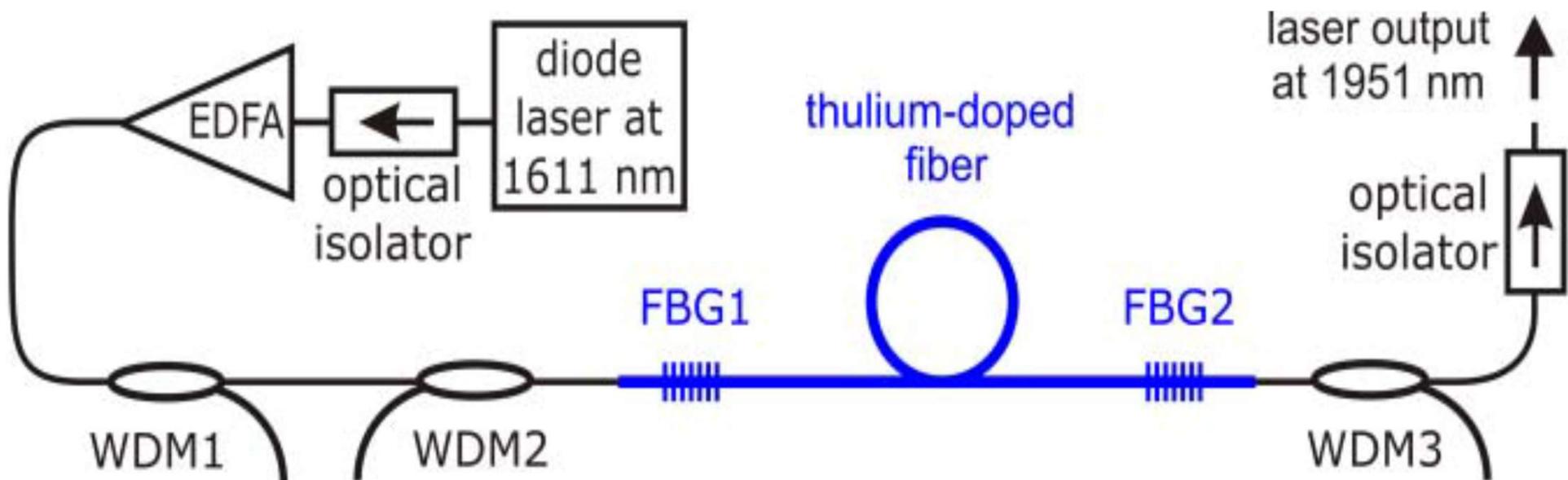


Preform /
20 μm / 250 μm fiber
 $\text{NA}_{\text{max}}=0.077$ (LMA), hot-twist

Preform /
12 μm /130 μm fiber
 $\text{NA}_{\text{max}}=0.22$, cold-twist

Monolithic Tm- doped fiber laser at 1951 nm

Eye-safe spectral region

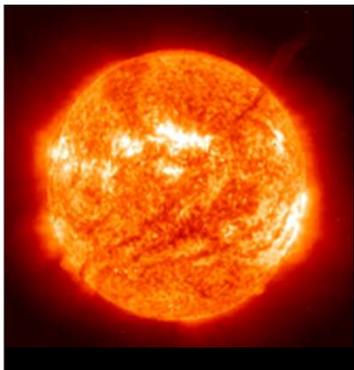


- * Tm^{3+} - Al_2O_3 - SiO_2 core (Al_2O_3 nanoparticles),
- * 1000 ppm Tm^{3+} , 11mol% Al_2O_3 , 0 mol% P_2O_5 or GeO_2 ,
- * **deep-UV inscription of FBG**

[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)

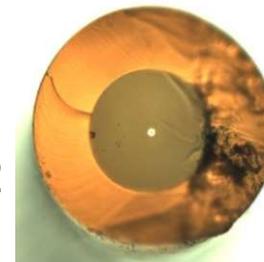


sun

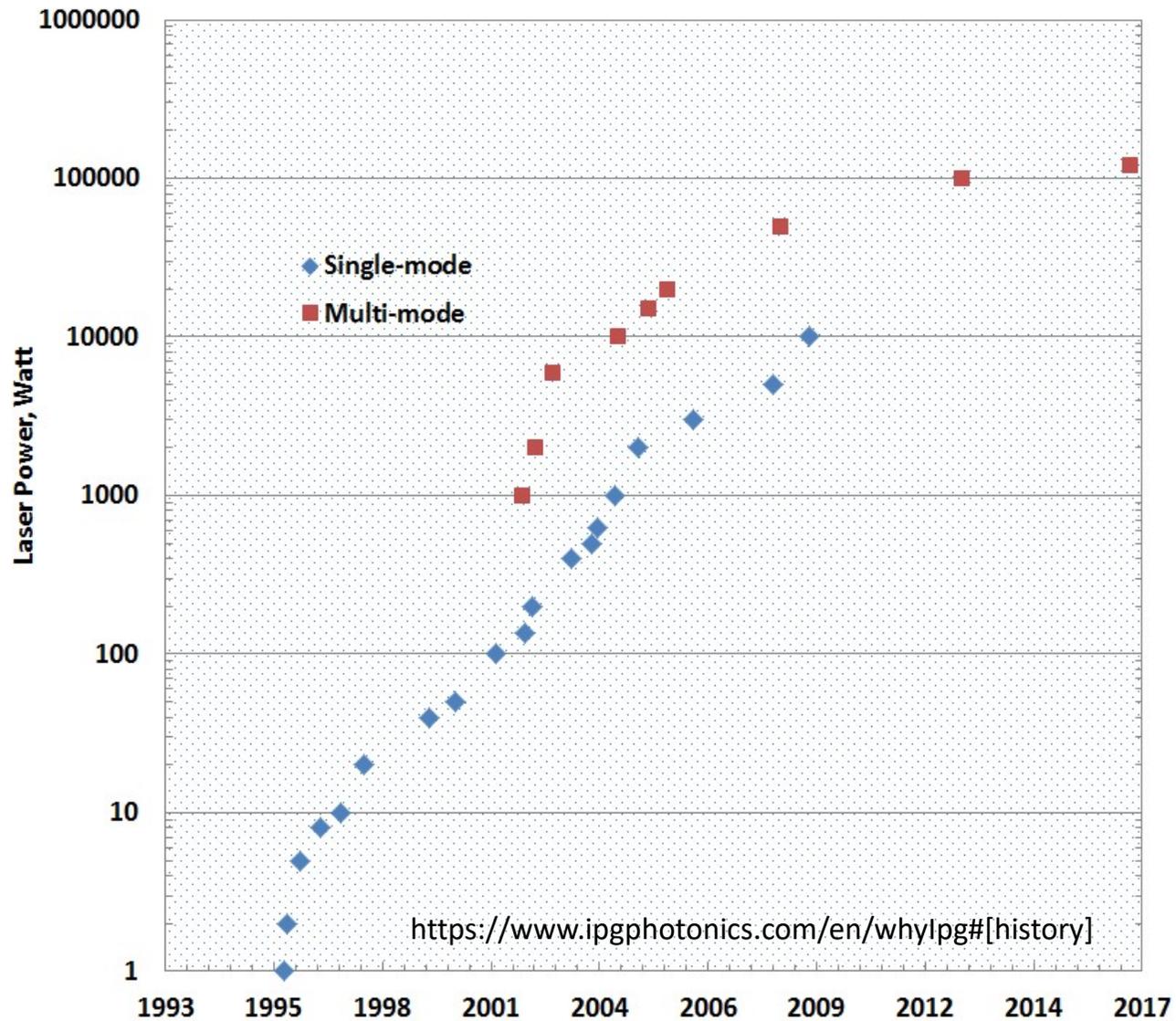
63 MW/m²

fiber laser

12.7 GW/m²



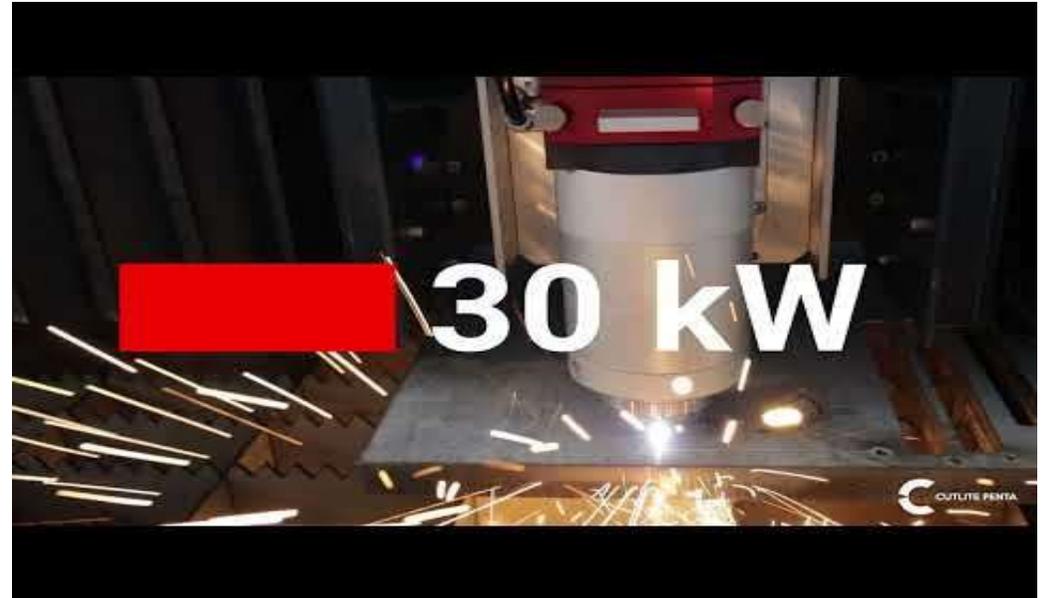
Fiber lasers – from mW to kW



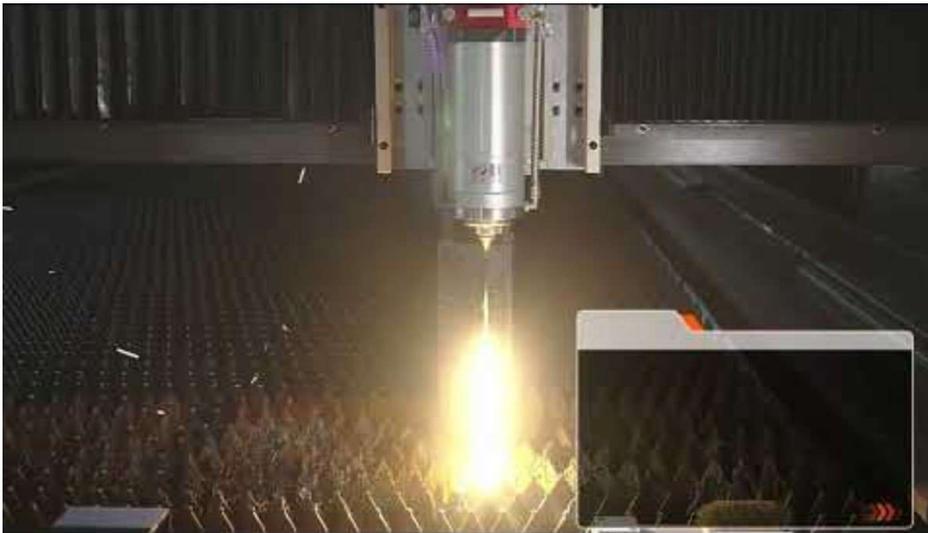
Fiber lasers - videos



<https://www.youtube.com/@NarranCzLaser>

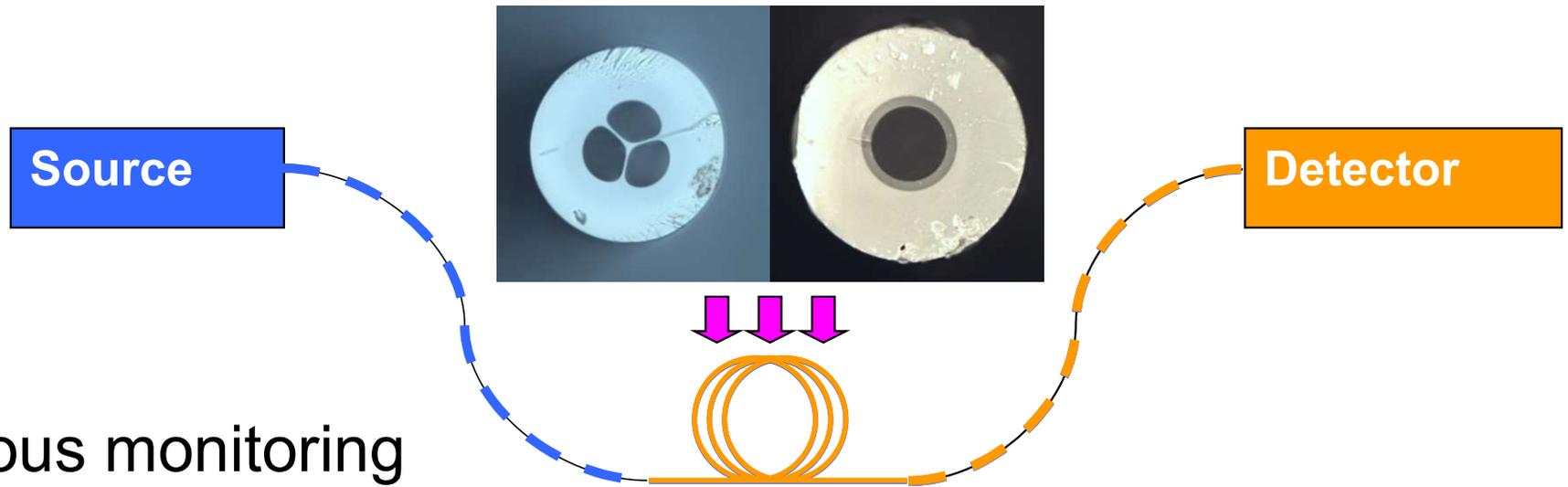


<https://www.youtube.com/watch?v=7J-nhEnHWbM>

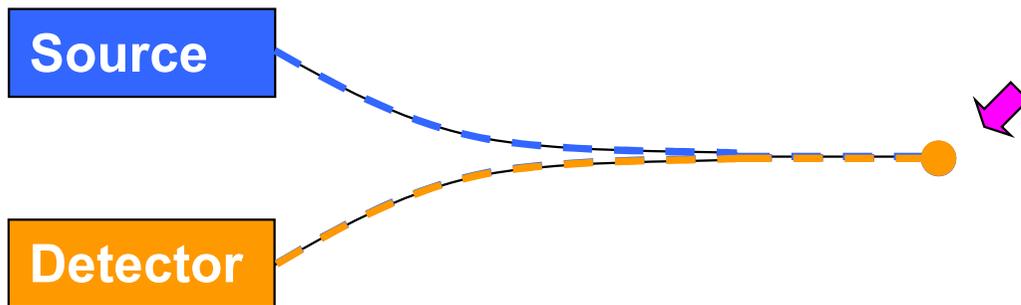


<https://www.youtube.com/watch?v=4oGWWi63Tok>

Optical fiber sensors



Continuous monitoring of (bio)chemicals and their concentration.

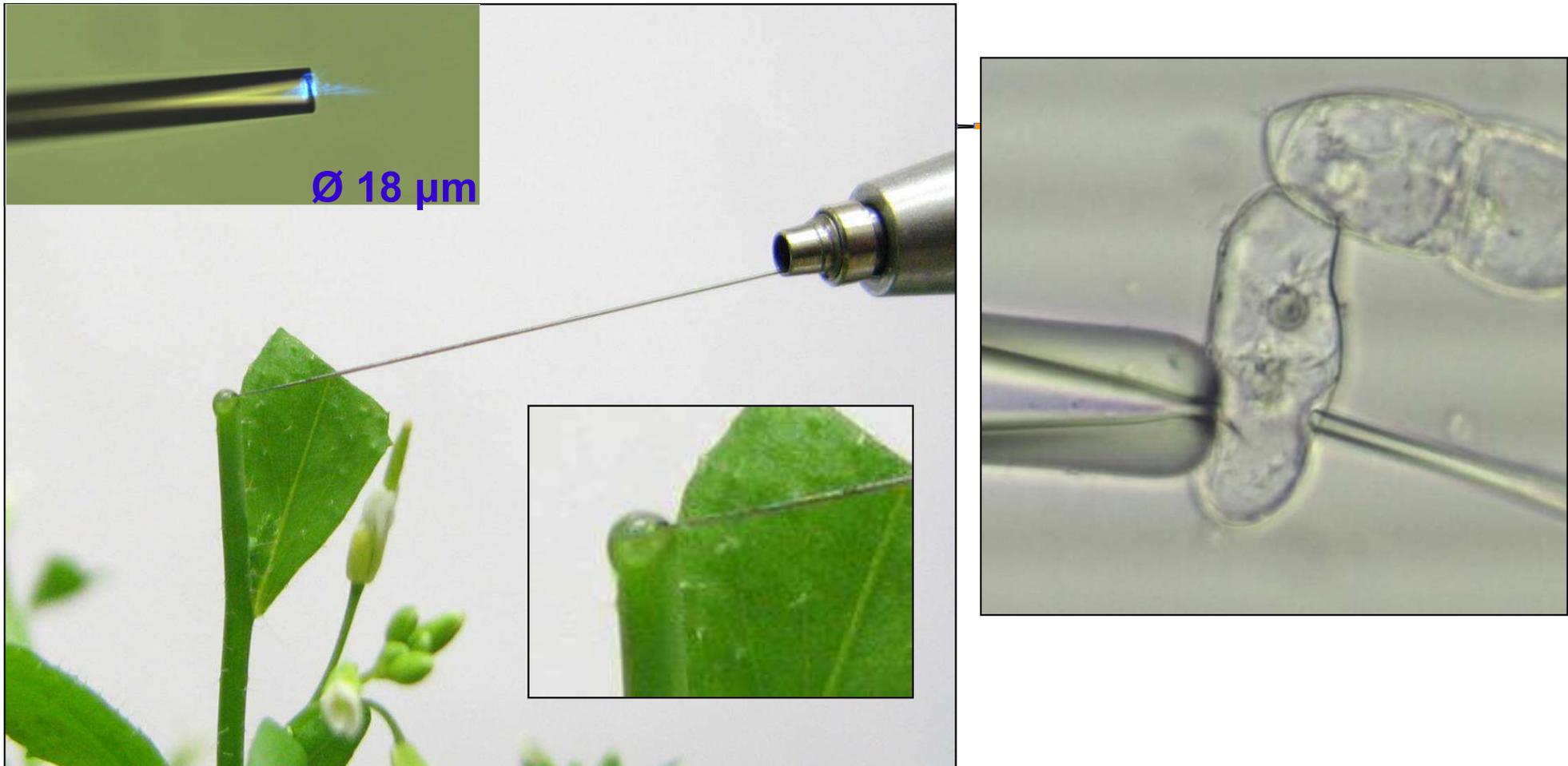


Suitable for :

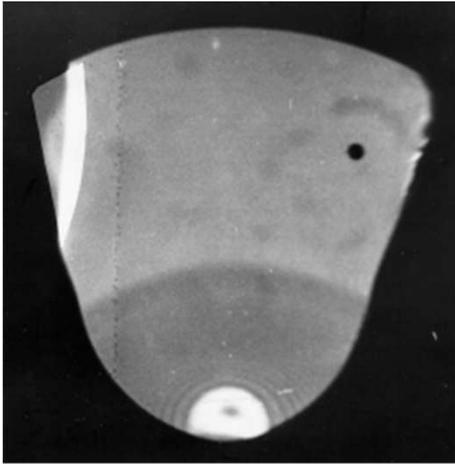
- remote sensing
- flammable or explosives
- in high-voltage areas
- human body
- distributed sensing

Optical fiber sensors

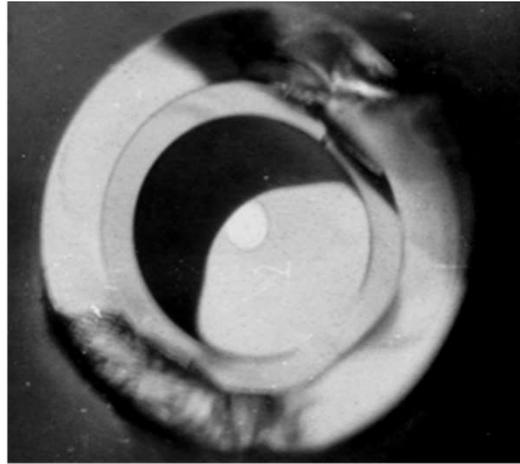
Detection of pH in small samples (droplets, cells)



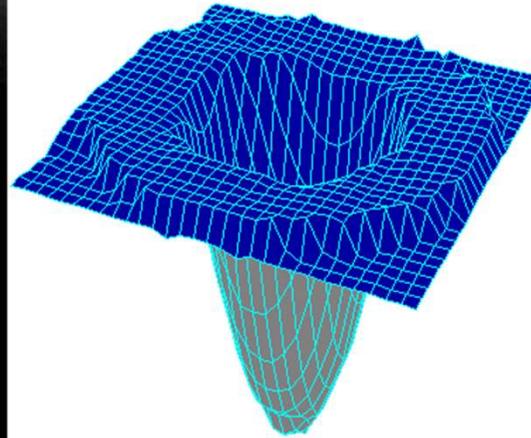
Optical fibers for sensors



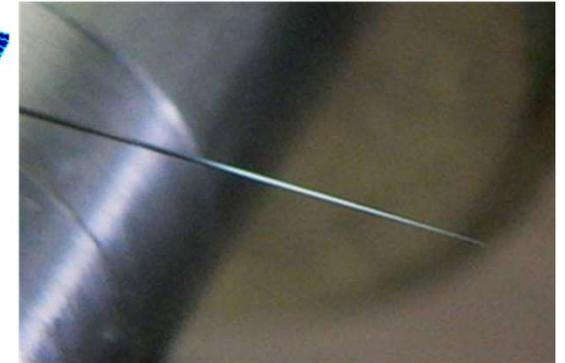
segment f.



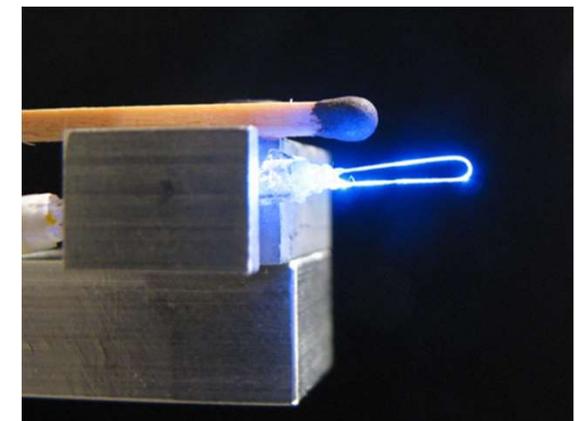
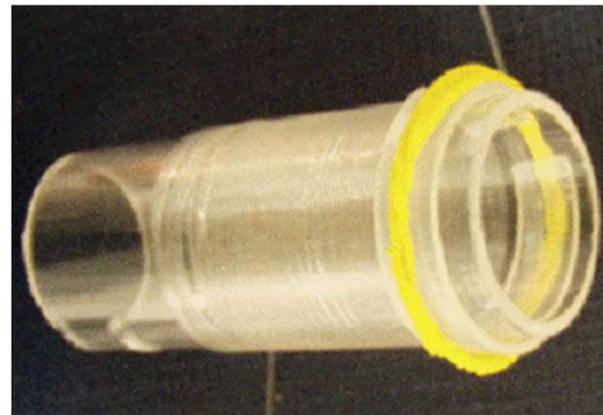
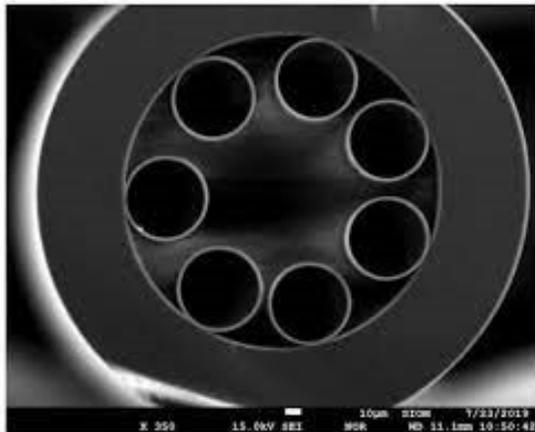
capillary seg. f.



IGI fiber



fiber taper



+ special coatings

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

- **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.
- **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

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Be carefull !

