OPTICKÁ VLÁKNA a jejich použití pro komunikace a vláknové sensory

Ústav fotoniky a elektroniky AVČR, v.v.i.

www.ufe.cz/~kasik

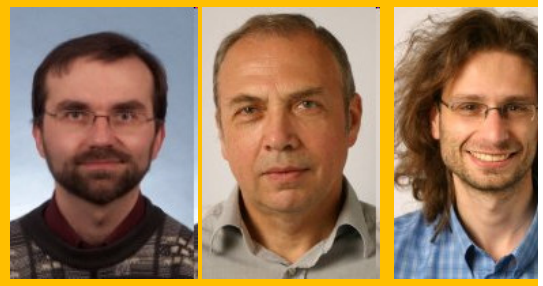
ūfe

Technologie optických vláken

Optické sensory s povrchovými plasmony

Nelineární a integrovaná optika

Český normál času a kmitočtu, syntéza řeči

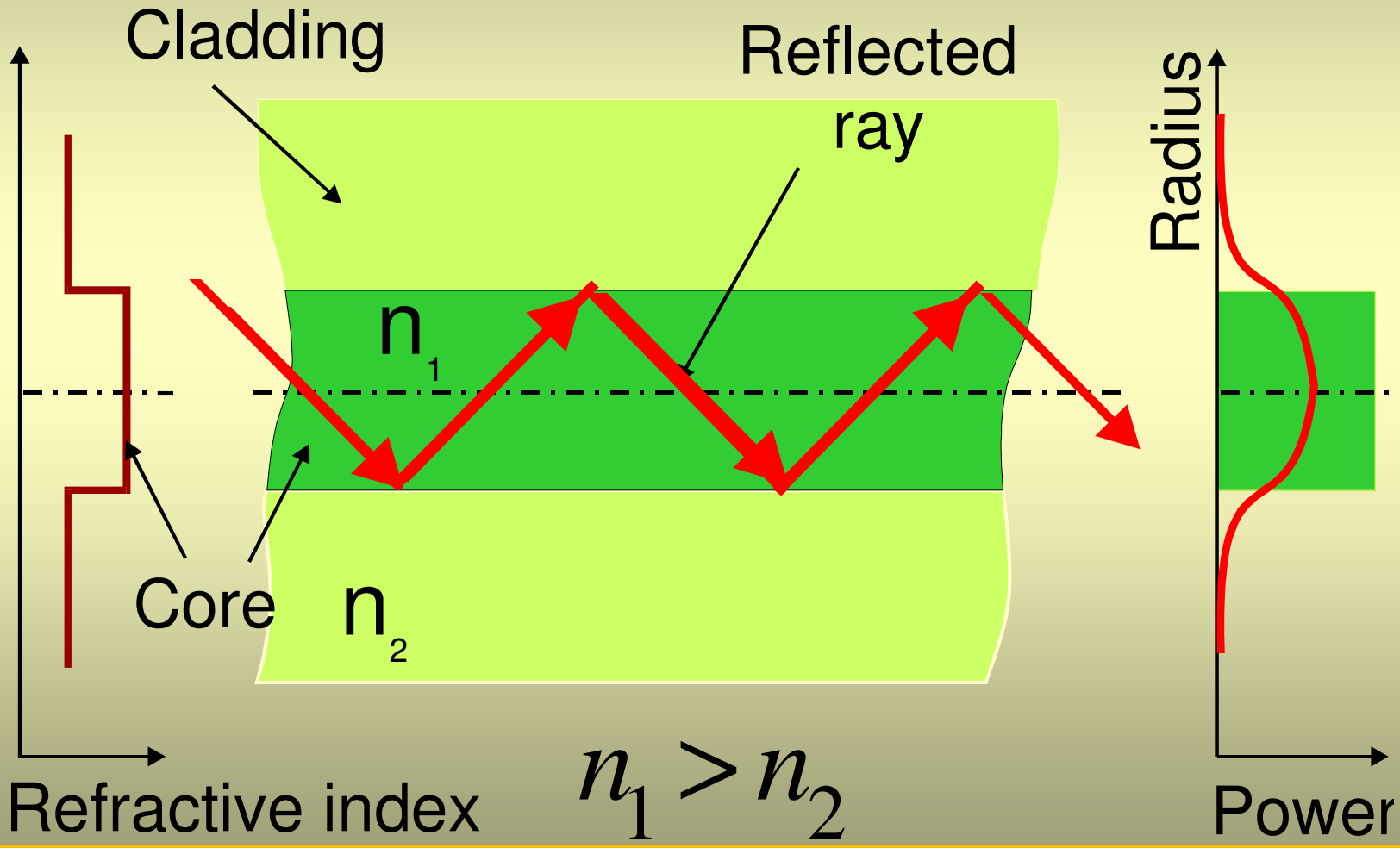


OPTICAL FIBERS & application in communications and sensors

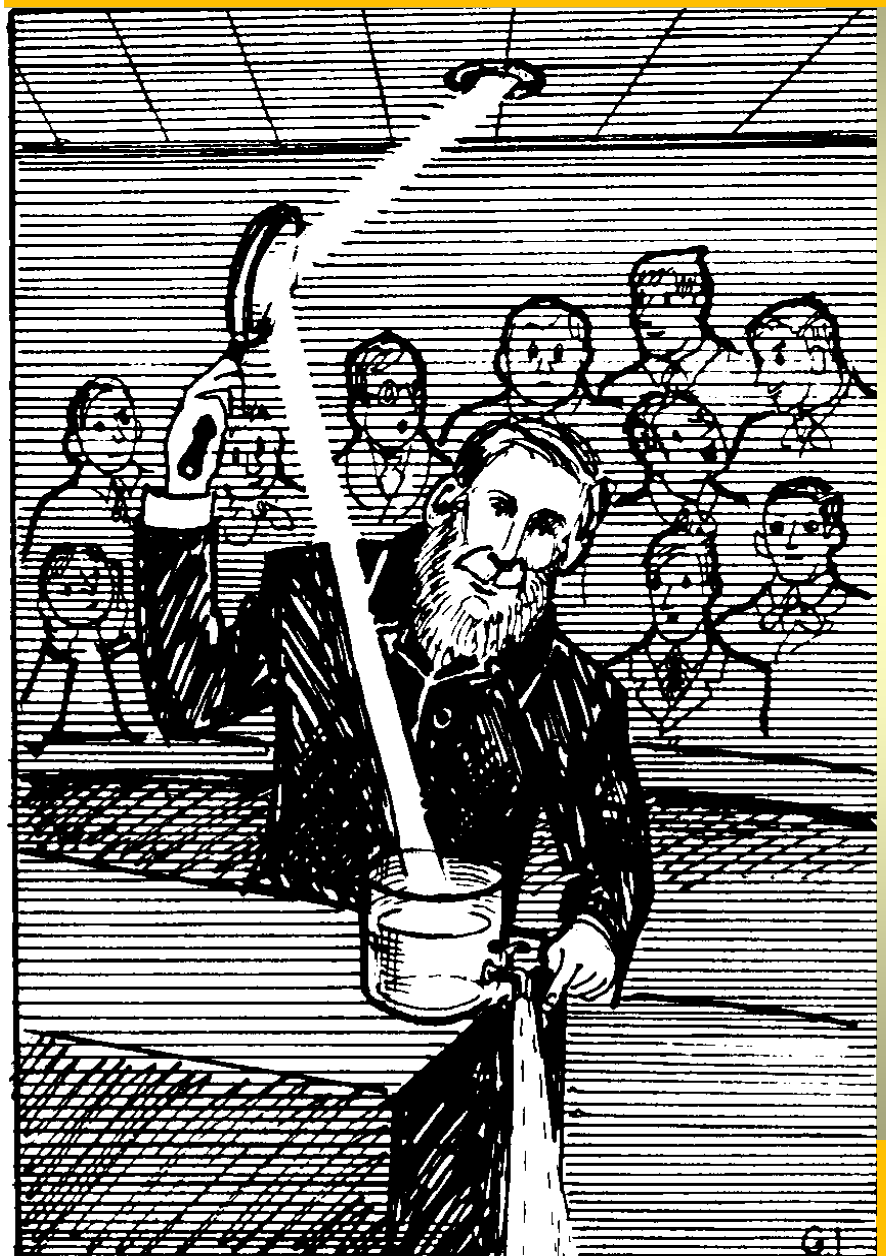
- Introduction - optical fibers
- Technologies
  - Preform preparation and fiber drawing
- Application
  - Optical communications
  - Non-linear fiber optics
    - Fibers & nanoparticles
  - Fiber-optic sensors
- Summary

I. INTRODUCTION : Optical fibers

Dielectric **structures**, mostly of cylindrical symmetry, diameter << length



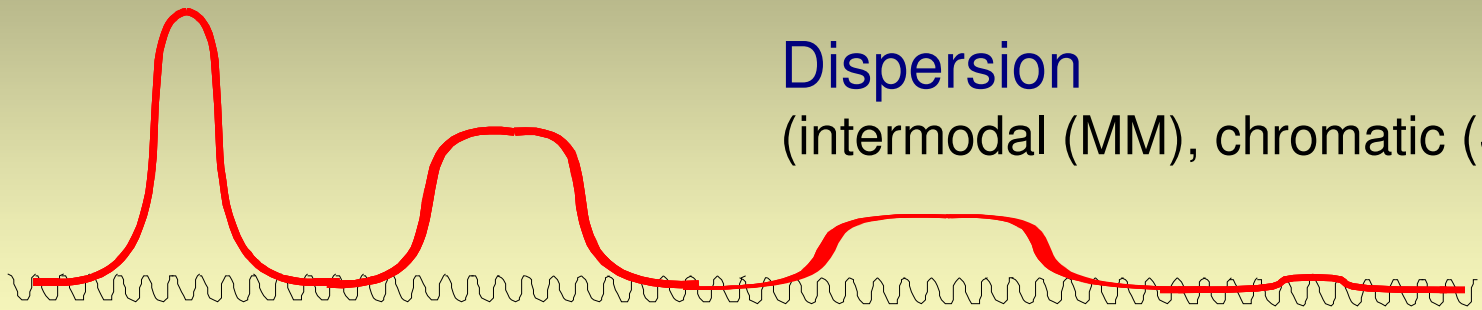
Optical fiber - principle



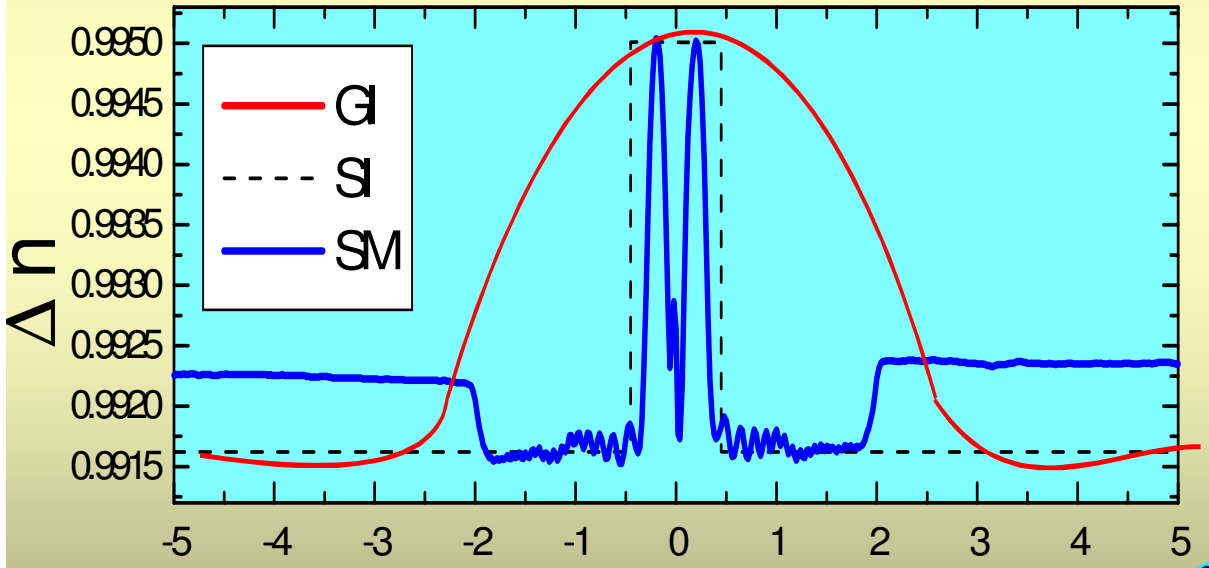
Material	Refractive index
Vacuum	1
Air	1.0003
Water	1.330
Silica glass	**1.457**
Sheet glass	1.520-1.540
Silicon	3.400

Snell Willebrord 1580-**1626**
Tyndall John 1820-**1893**

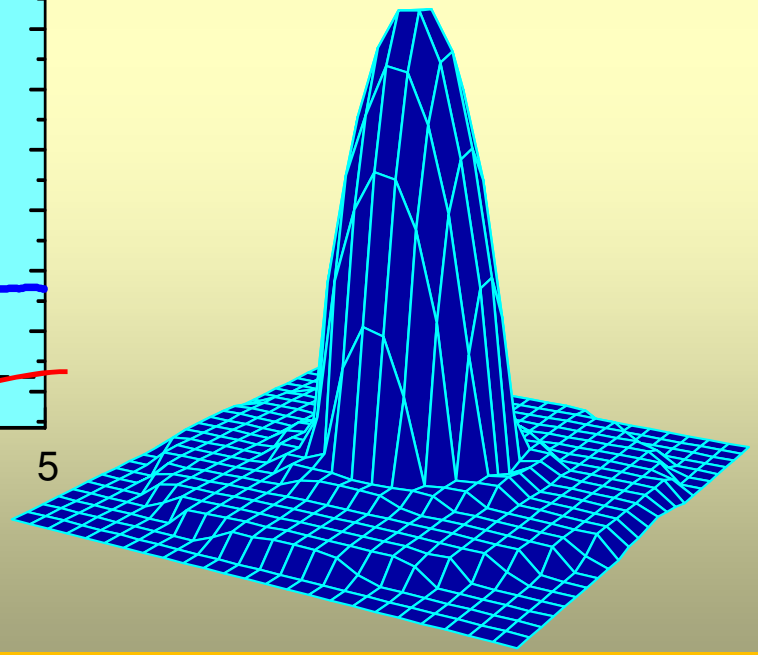
Optical fiber properties - dispersion and structure



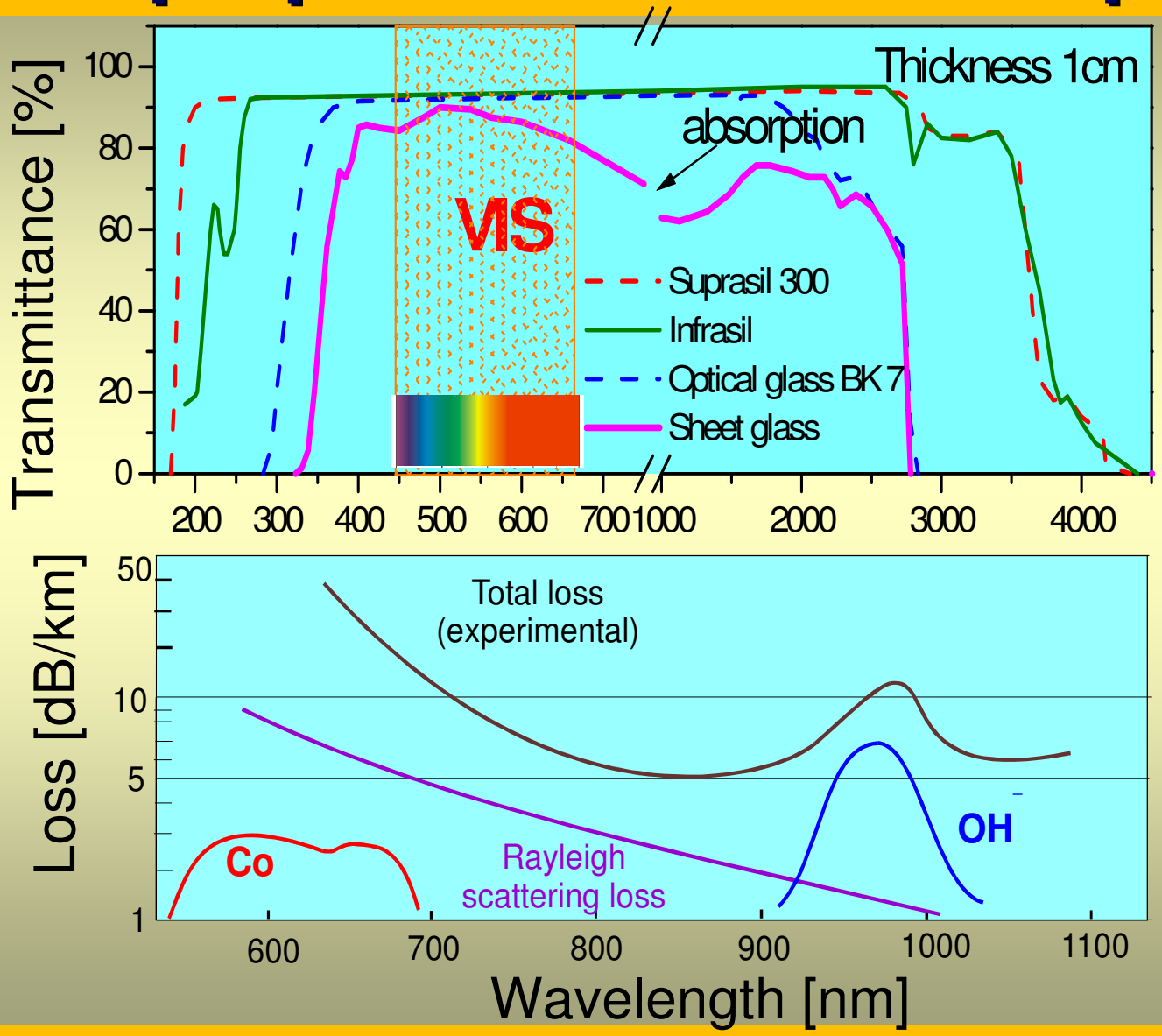
Dispersion
(intermodal (MM), chromatic (SM)



Refractive-index profile



Optical properties and material purity



The Nobel Prize in Physics 2009

Charles K. KAO
1/2
for groundbreaking achievements concerning the **transmission of light in fibers for optical communication**

Willard S.Boyle
1/4

George E. Smith
1/4
for the invention of an imaging semiconductor circuit – the CCD

Material purity

1) Čistá – č. (min. 98 %)
2) Per Analysis – p.a. (99 - 99,5 %)
3) *Chemicky* čistá - ch.č. (>99.9 %)
4) Polovodičová (99,9995 %)
5) Zvláště čistá- **FO Optipur** / pro stopovou analýzu [ppb]
   Ultra-pure - FO Optipur / for trace analysis

% – 10^{-2} (procenta)

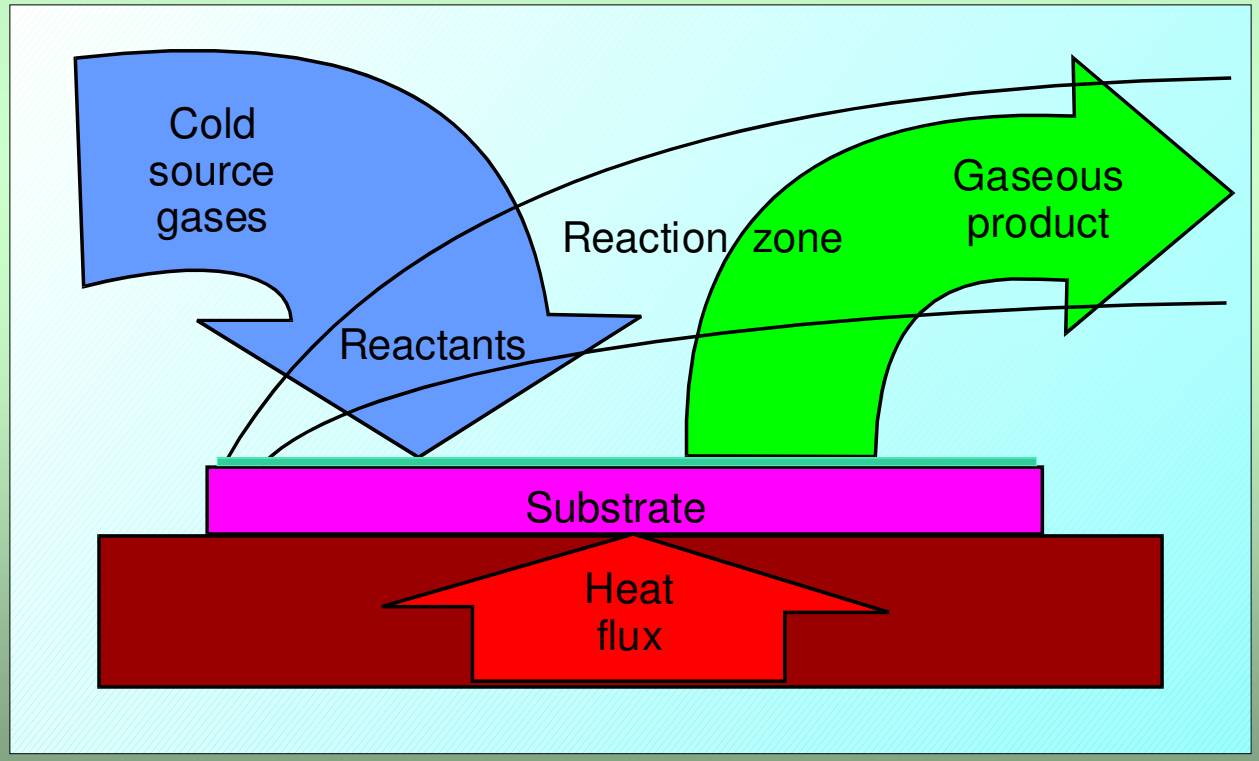
ppm – 10^{-6} (parts per million)

ppb – 10^{-9} (parts per billion) : content of impurities acceptable in FO Optipur materials

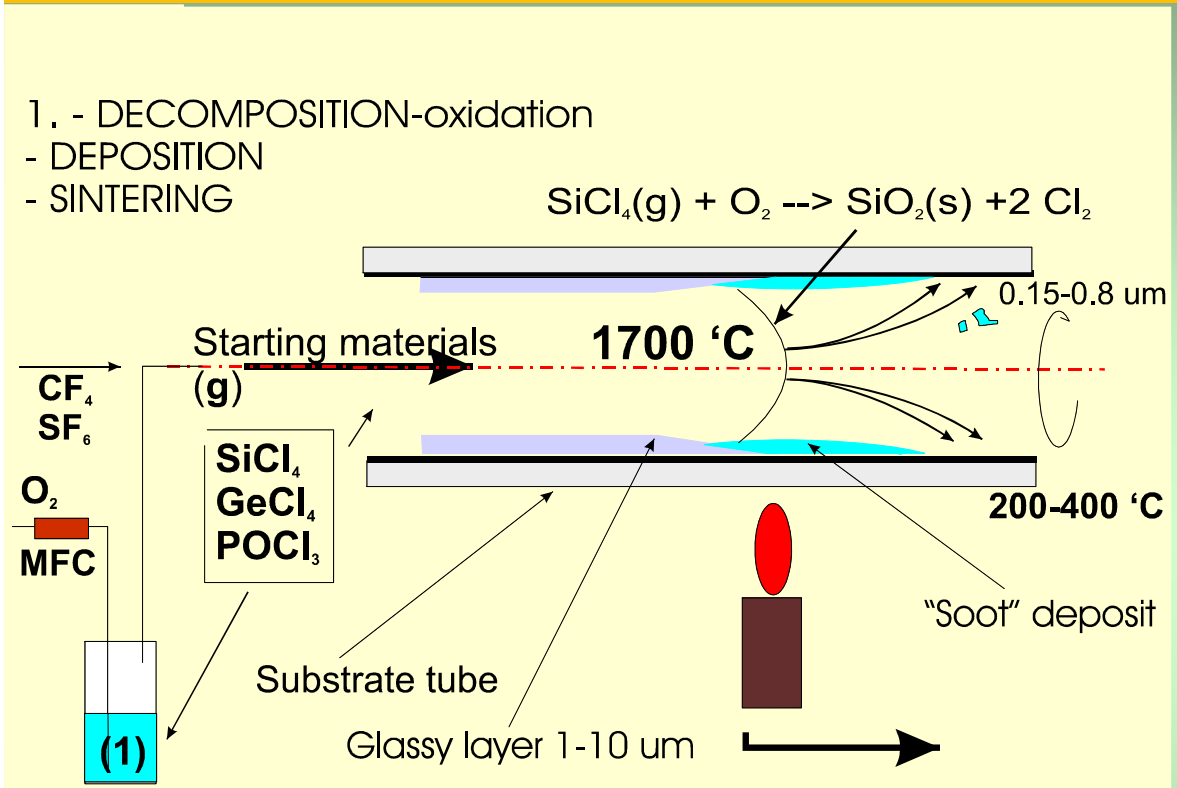
Ultra-pure technologies - CVD !

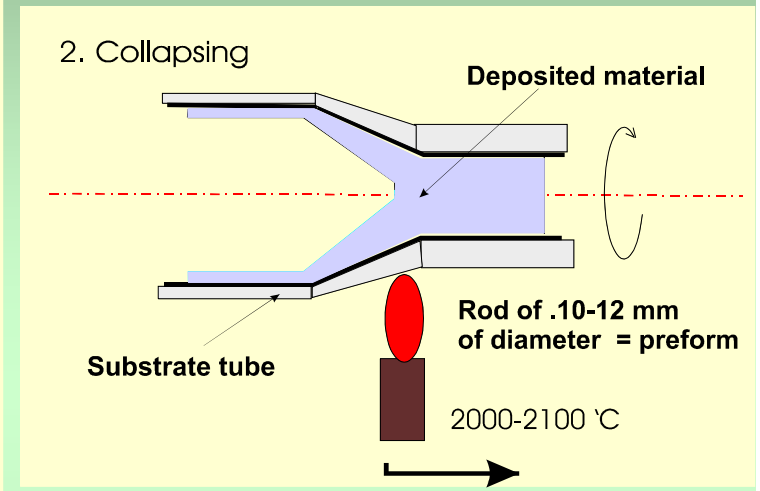
II. TECHNOLOGIES
CVD - Chemical Vapor Deposition

= production and deposition of material in solid state from starting materials in gaseous state through a chemical reaction :
A (g) + B(g) = AB (s) [after M. L. Hitchman, 1980, E. Erdos, 1983]



MCVD – Chemical Vapor Deposition

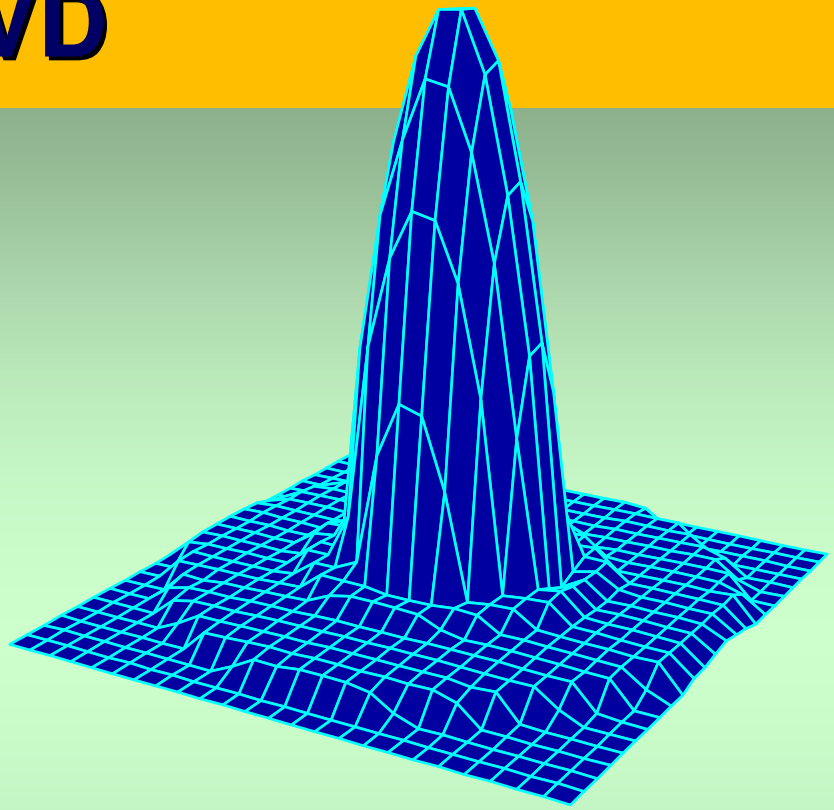




- Sequential sintering of thin glassy layers (of thickness 1-20 μm) onto inner wall of silica substrate with potential obtaining bulk material [after S. R. Nagel, 1982] = rod. No melting,
- **high purity material preparation.**

MCVD

Microphoto of cross section of produced preform

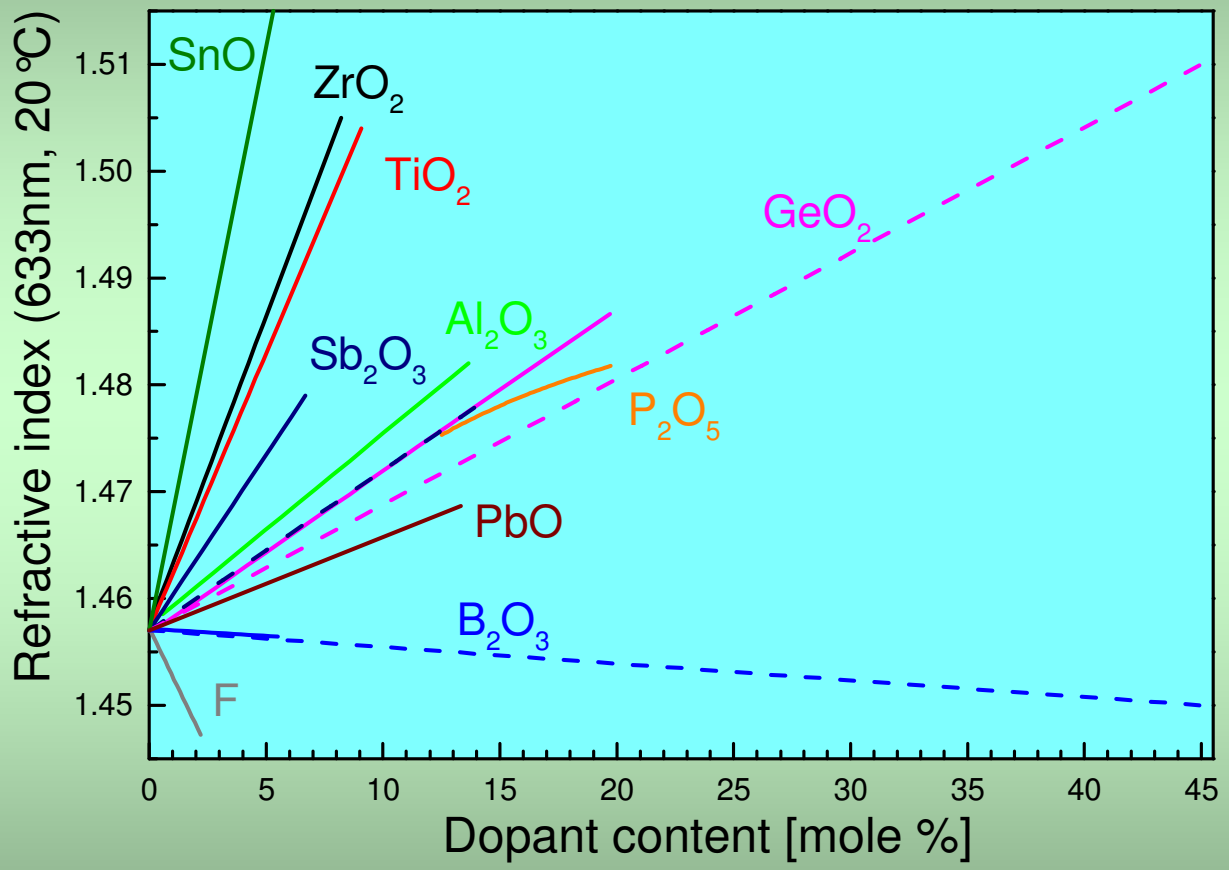


Tomography of the refractive-index profile of preform

- High purity material due to FO-Optipur purity starting materials.
- High quenching rate ranging from 10^2 to 10^3 °C/s.

Complex Material Problem

Doped Silica - Optical Properties



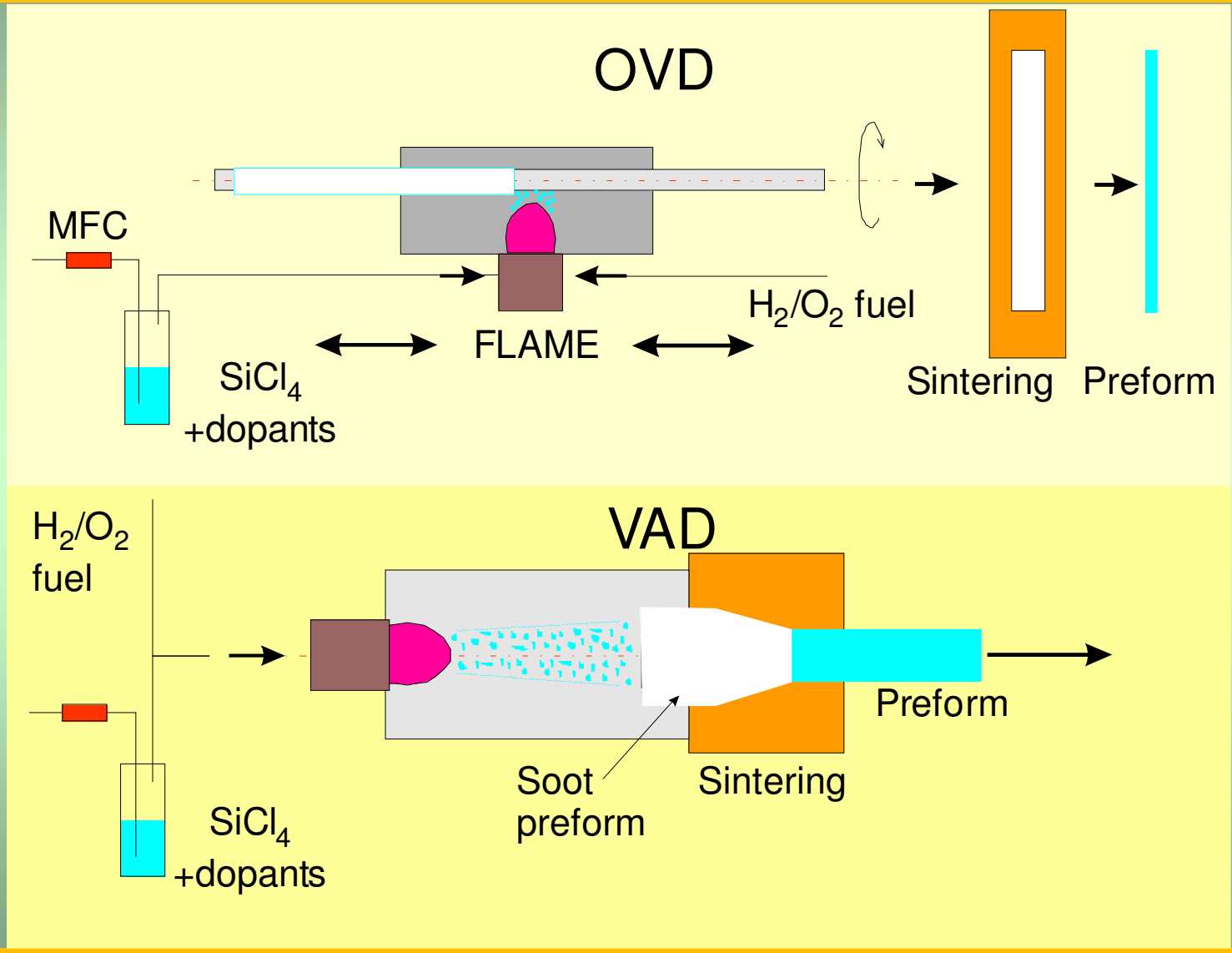
[after A.B. Chynoweth, 1979, M. Shimizu, 1986, Y. Ohmori, 1983, S. H. Wemple, 1973, H. Wehr 1986, I. Kasik, 2005, K. Sanada, 1980, M. M. Karim 1994

MCVD

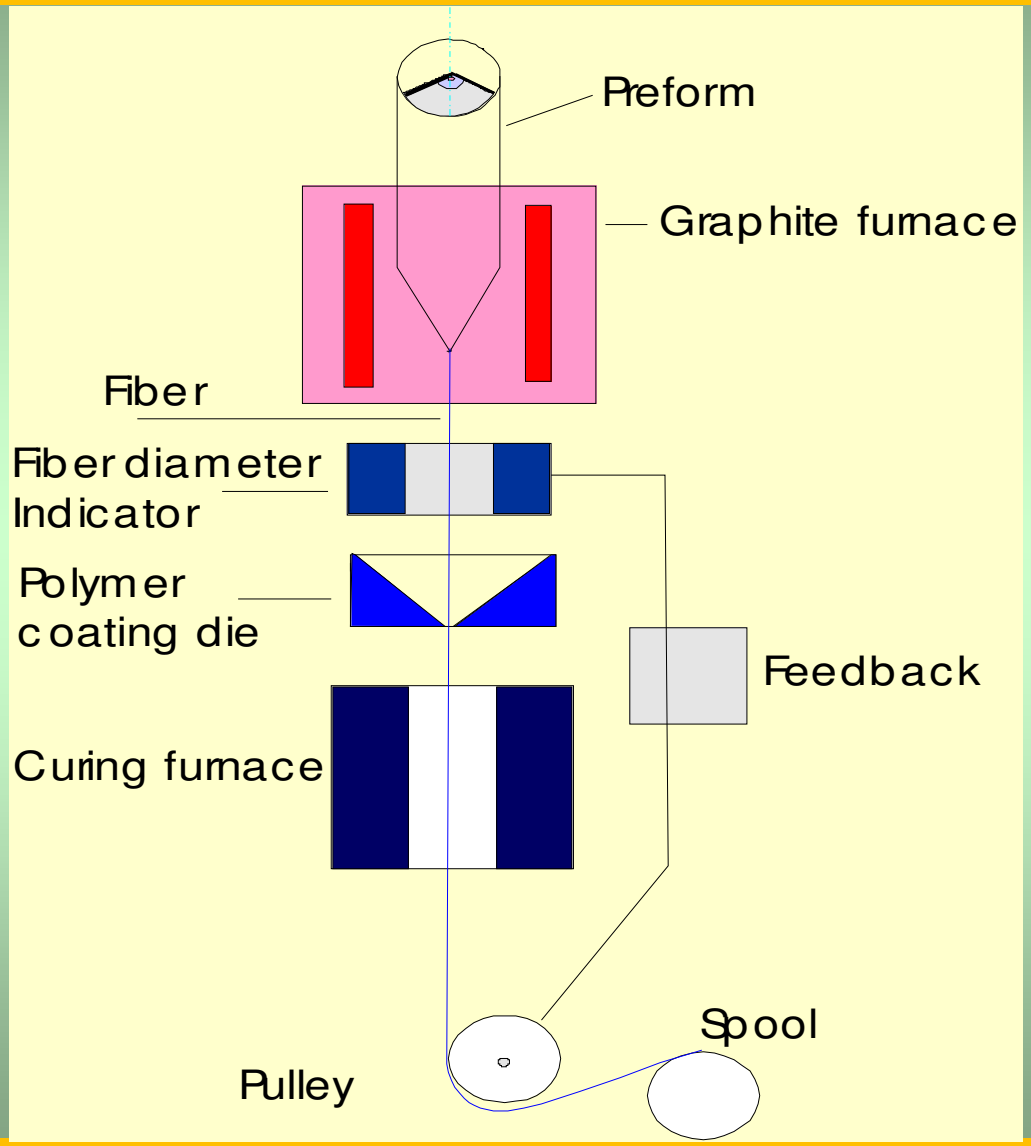
Suitable for the preparation of :

- **silica-based** materials, **doped** (up to 50 mol%)
- **few-component** (up to ~ 6 components) materials
- materials for **photonics, optics**, optoelectronics
- materials of **high-level purity** (~ 10^1 ppb)
- products requiring high preciseness of geometry (better than 1 %)

Other CVD Technologies



Drawing of Optical Fibers



- diameter
  80-1000 μm
- temperature
  1800-2000 °C

Preparation of Optical Fibers

1) **Physical design** of structure

   Material choice **SCIENCE**

2) **Preparation of** original glass material - **preform**

   Ultra-pure **TECHNOLOGIES** !!!

   CVD – MCVD [(**M**odified) **Ch**emical

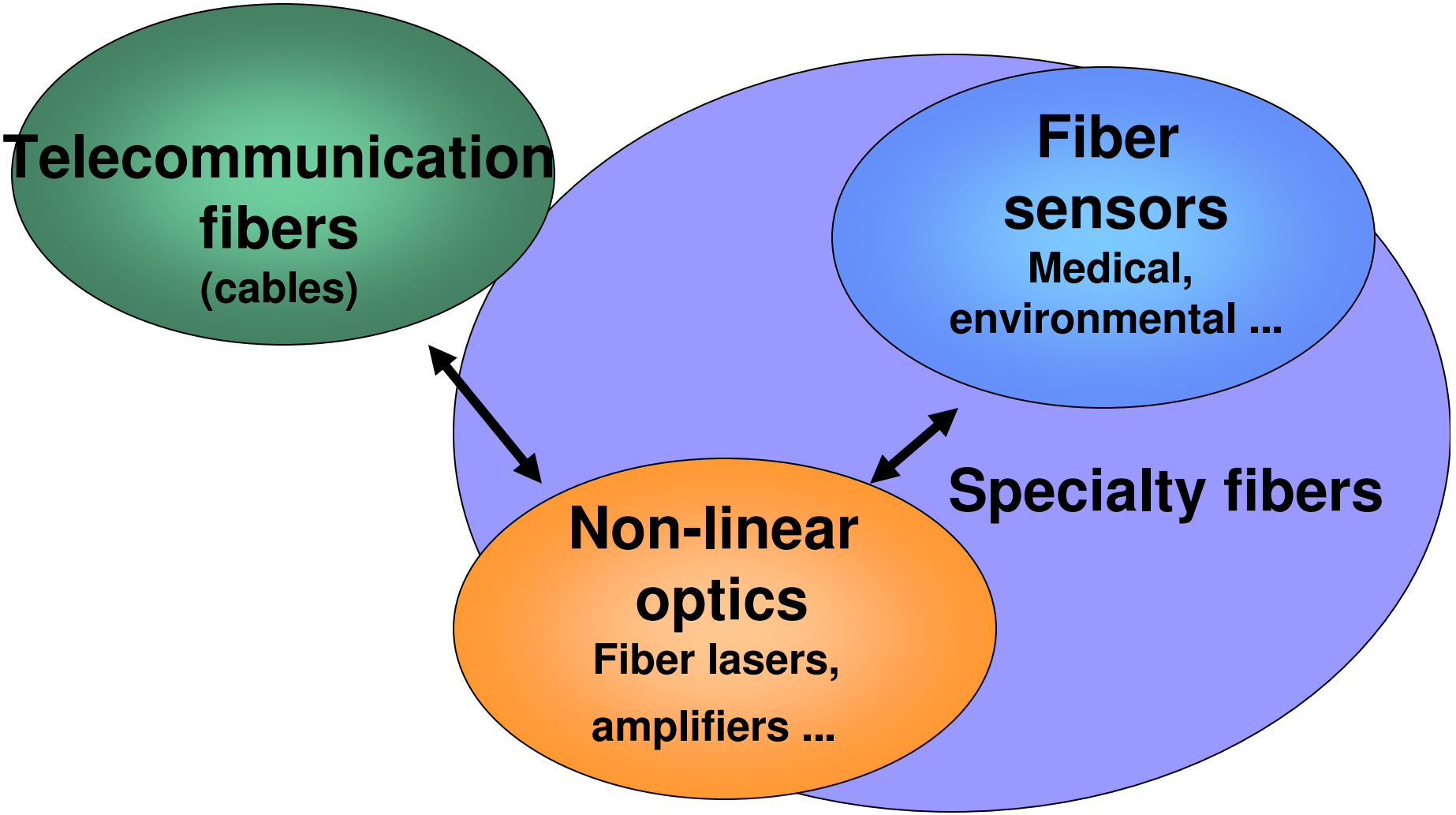
   Vapour **D**eposition]

   (melting in crucible – C.Kao/history)

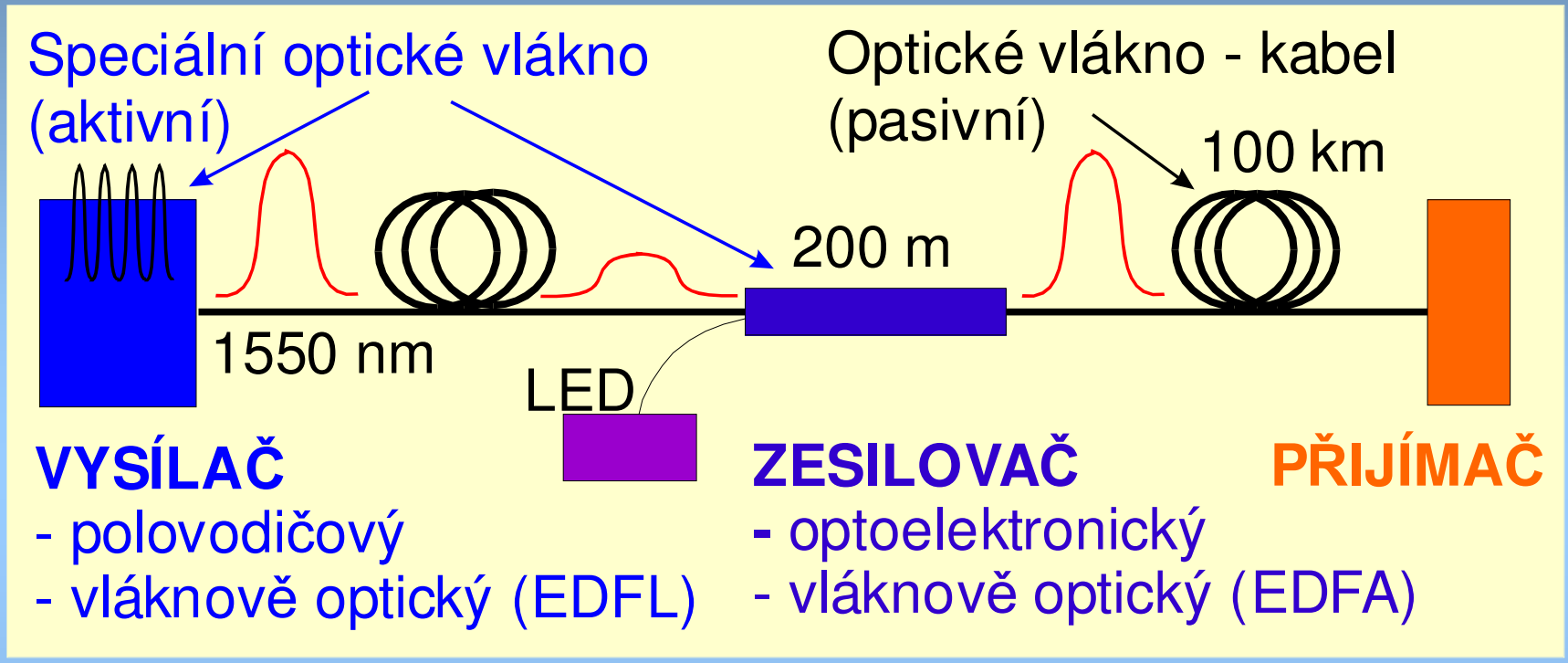
3) **Fibre drawing** from preform

   (drawing from crucible - history)

III. Application



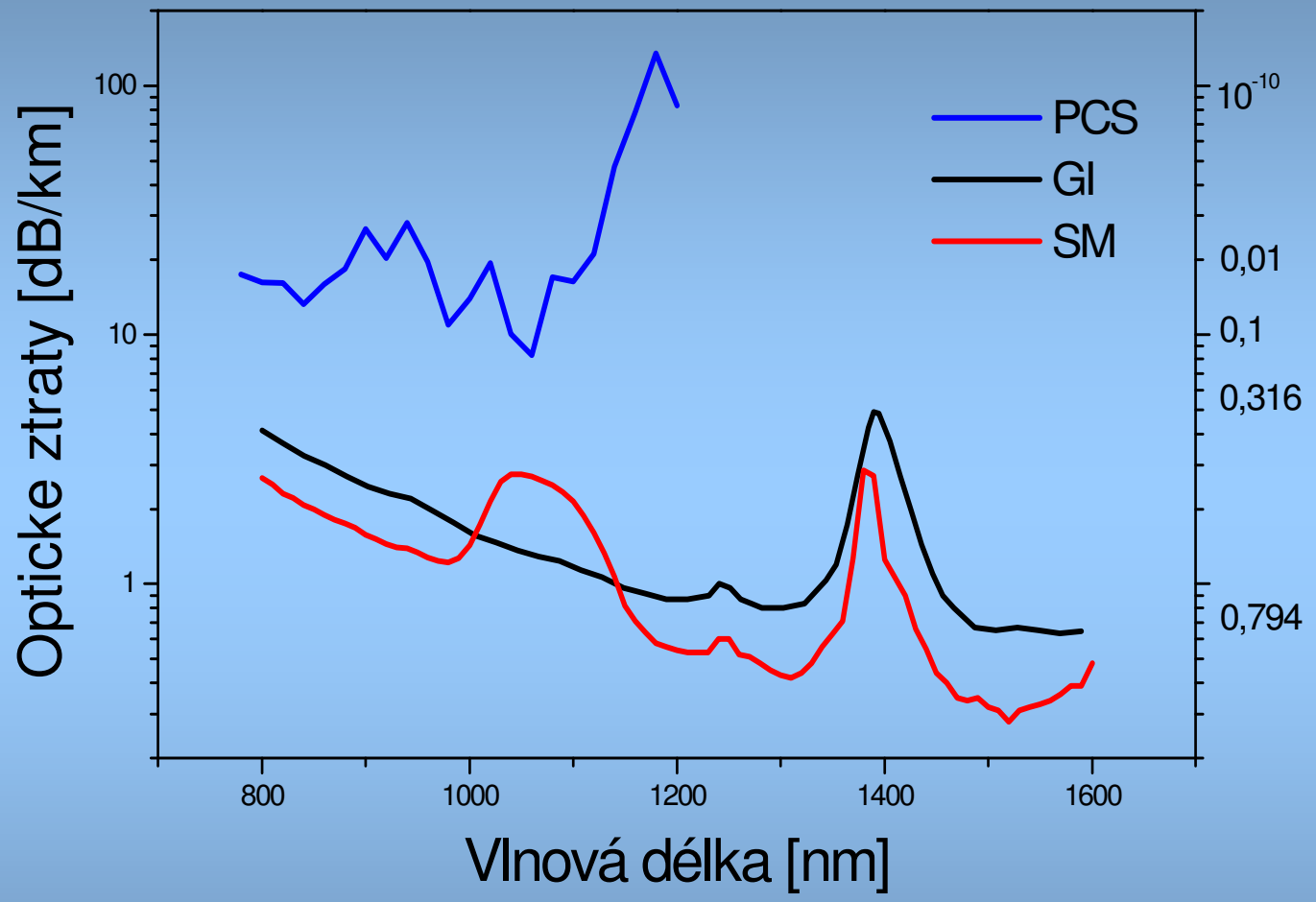
Telecommunications

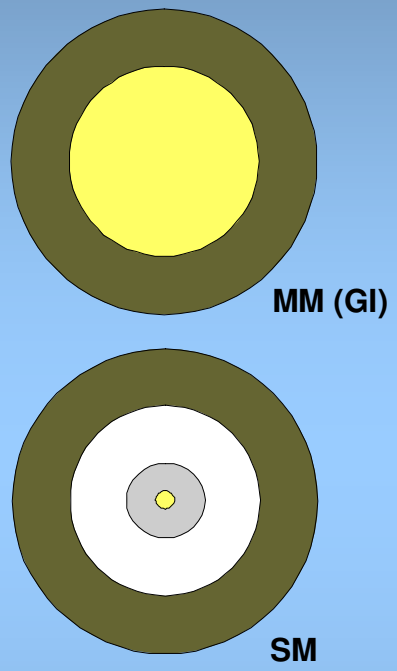


Requirements (cables) :

- Low loss, low dispersion
- **Durability** to surroundings (temperarure, pressure, e.field...)
- Low price

Telecommunications

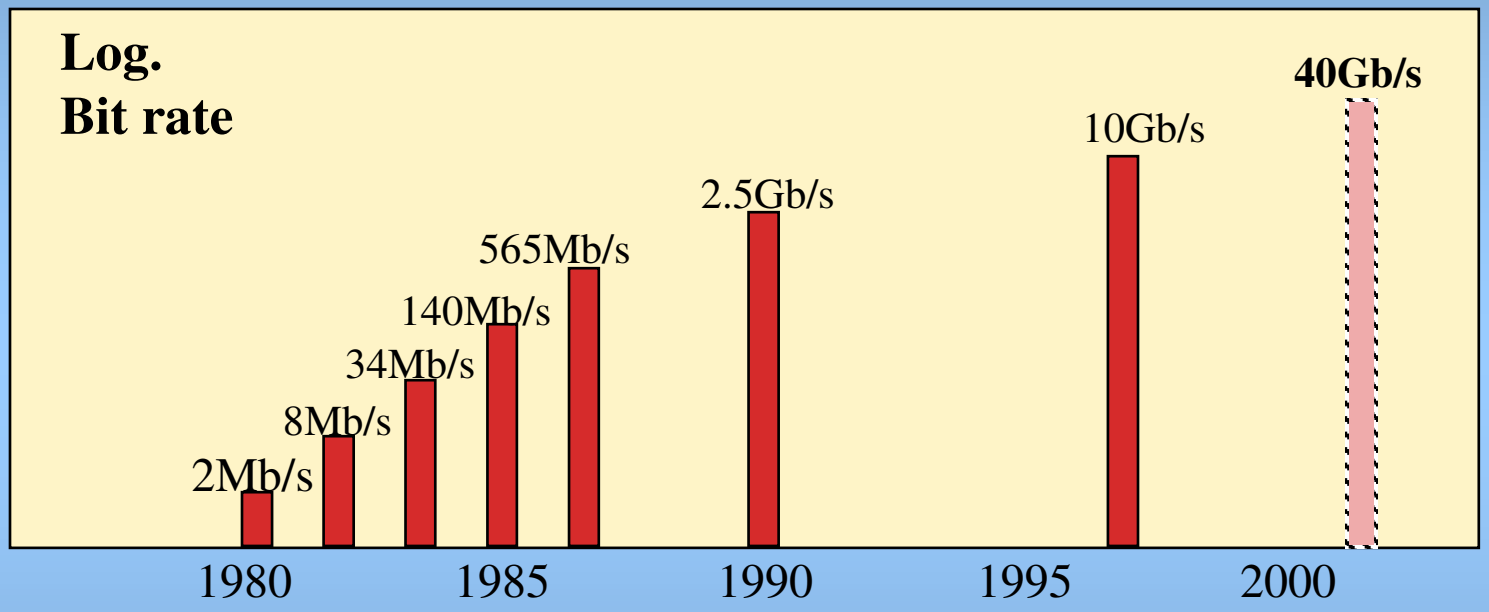




1981 : 1st demonstration of PCS optical fiber (CR)
2007 : 700 000 km telecom fibers in CR installed

Non-linear fiber optics

High bit-rate transmission

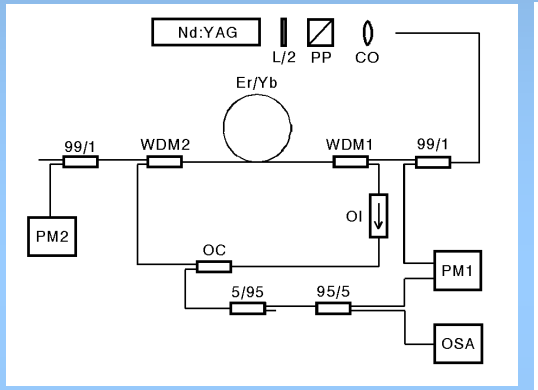


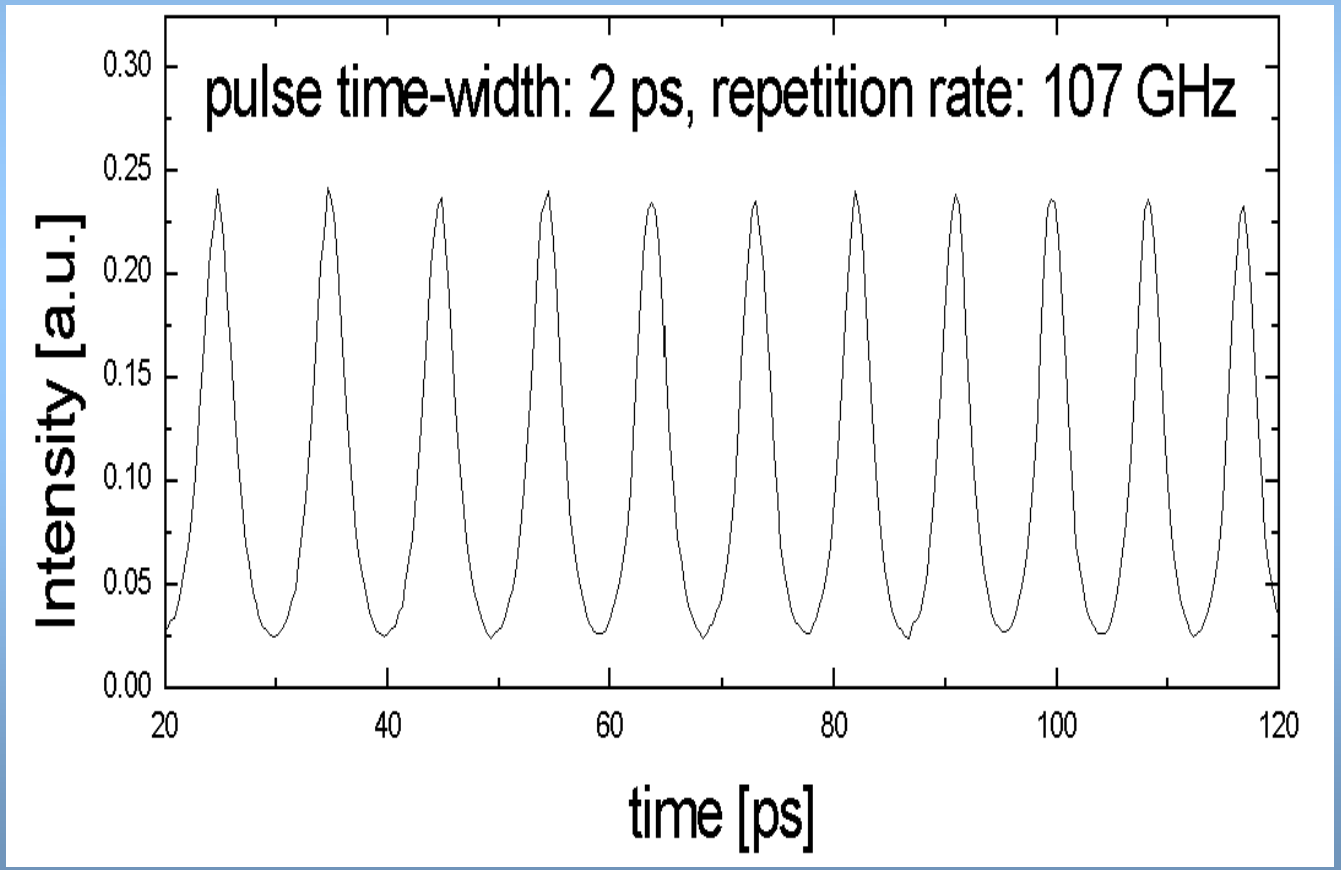
„Information society“

- Vision : all-optical processing of information
- **Solutions : multiplexing in time or spectral domain**

Time Division Multiplexing (TDM)

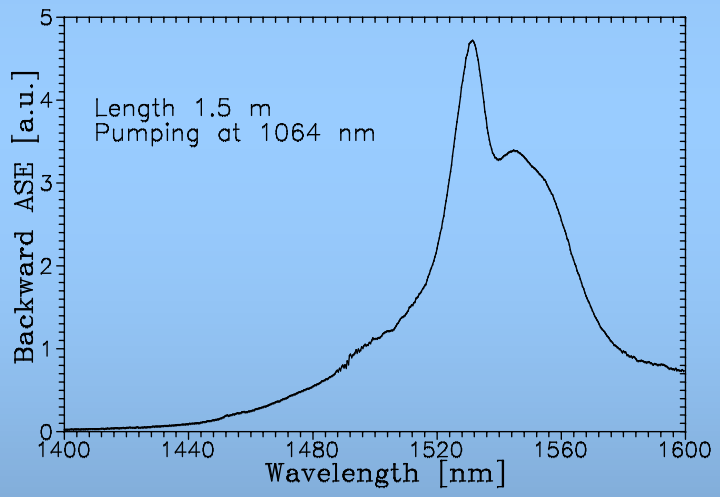
GOAL : Ultrafast sources - soliton fiber lasers (increase of transmission rate); hundreds of GHz >> conventional semiconductor sources

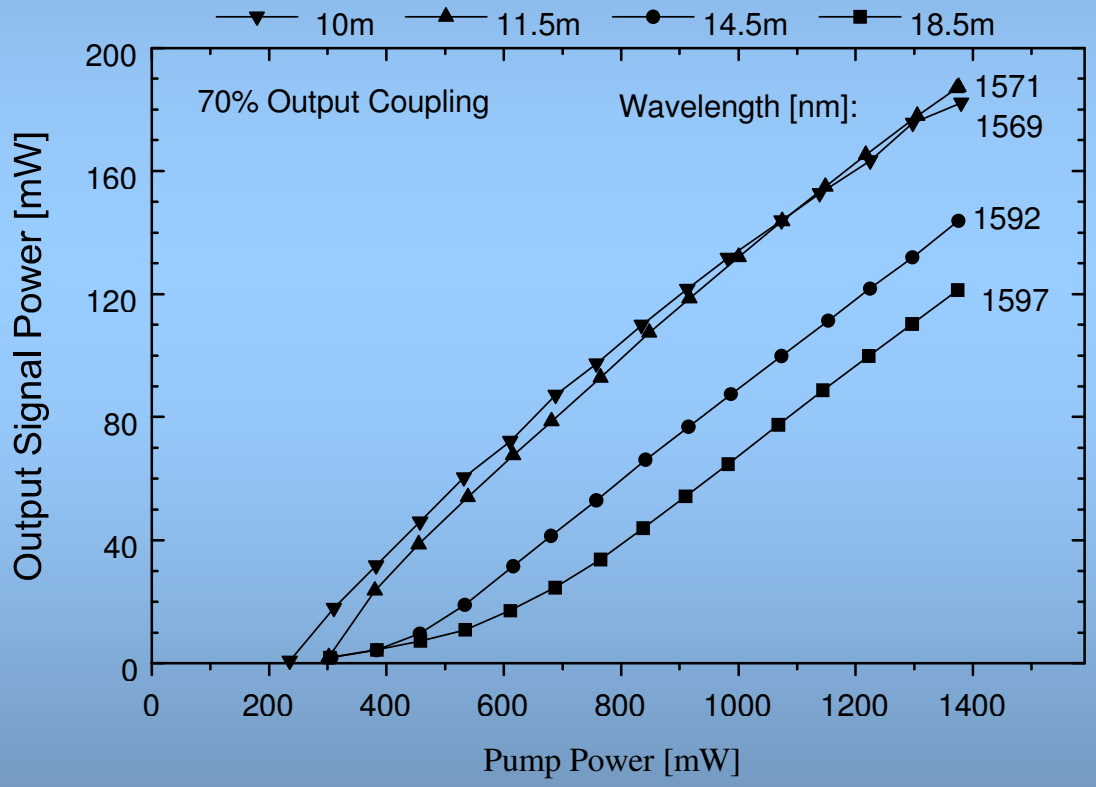




Specialty fibers – Er^{3+}/Yb^{3+}- doped

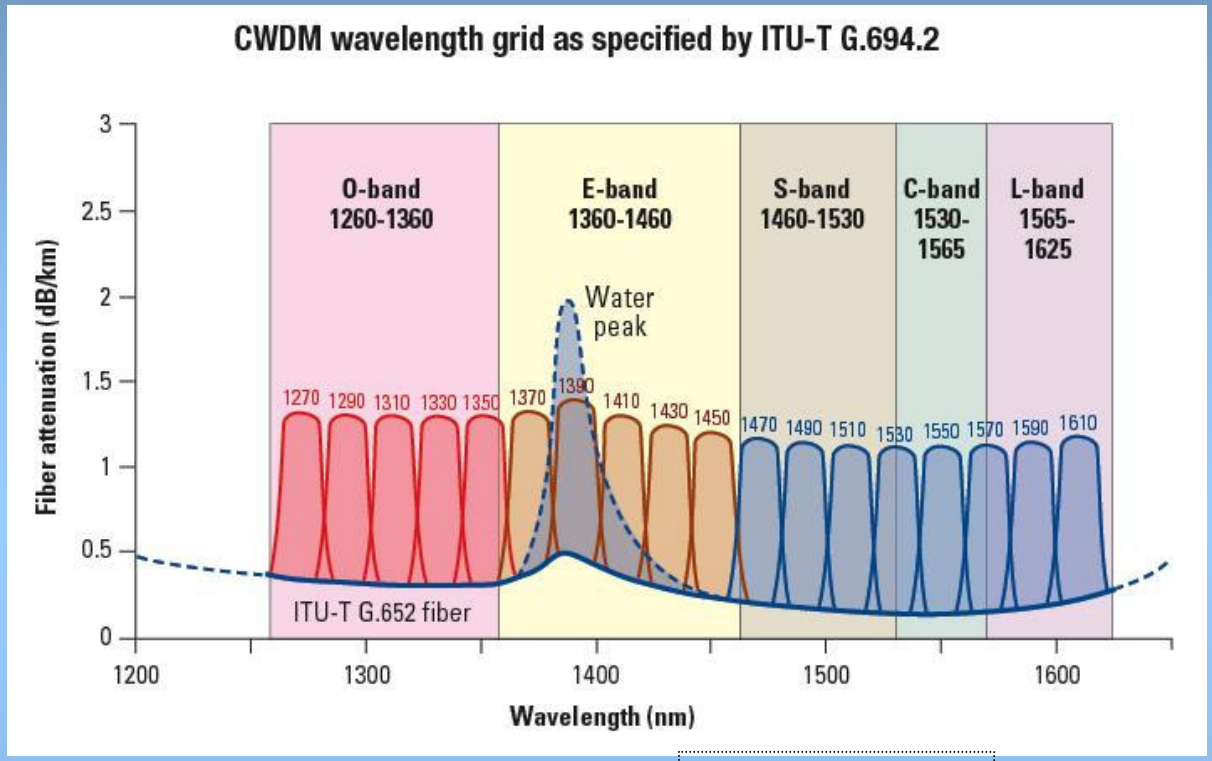
Technol. challenge : specialty optical fiber efficiently operating at ~1550 nm and suitable for pumping at 1064 nm (mini-YAG).
Er/Yb-P2O5-Al2O3-SiO2 fiber





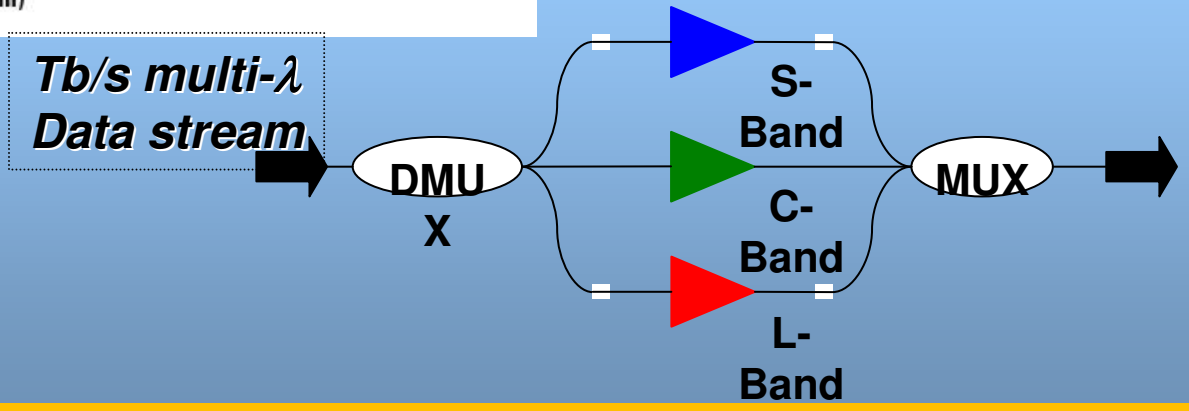
- *In collaboration with NLO group*

Wavelength Division Multiplexing (WDM)

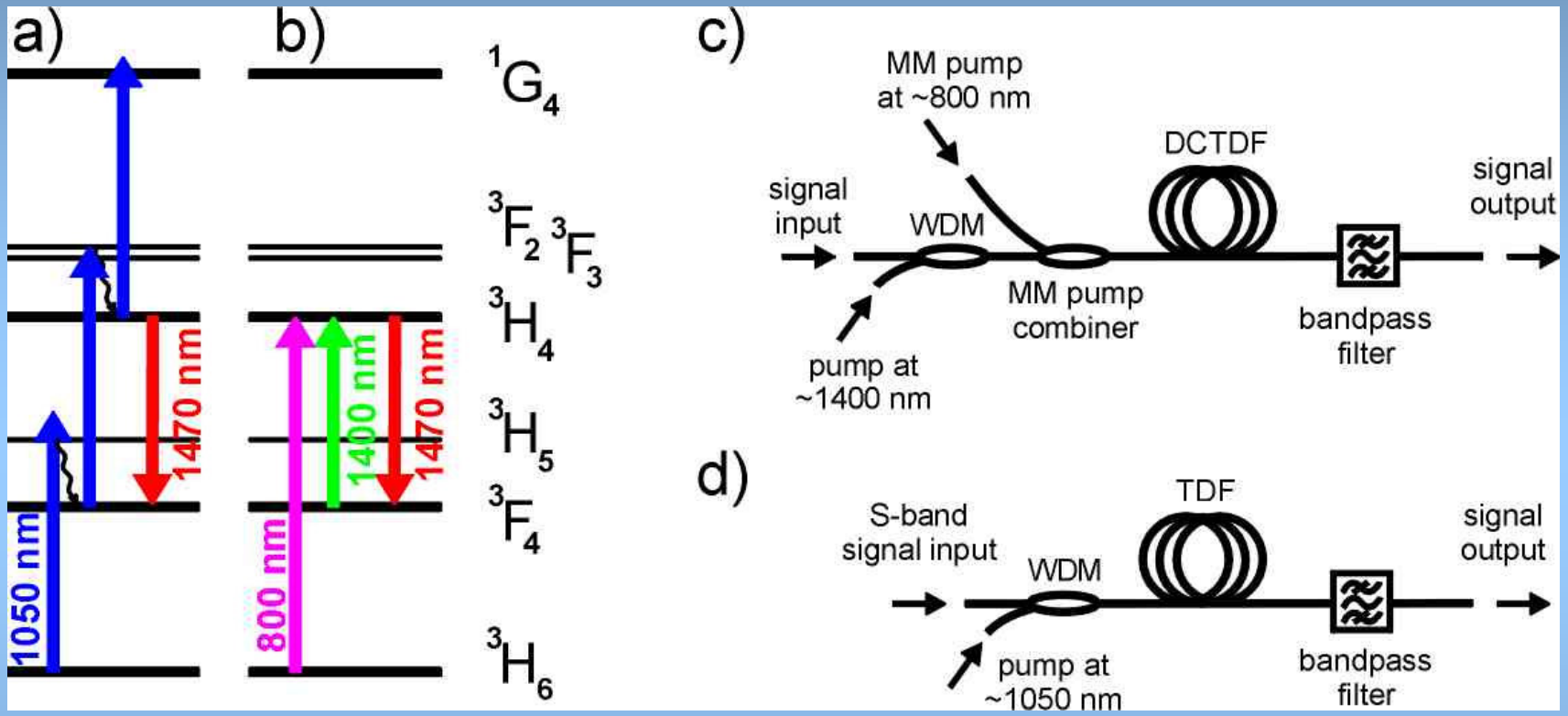


Increase of capacity by an increase of number of channels

=> Need of sources emitting at wavelength different from 1550 nm

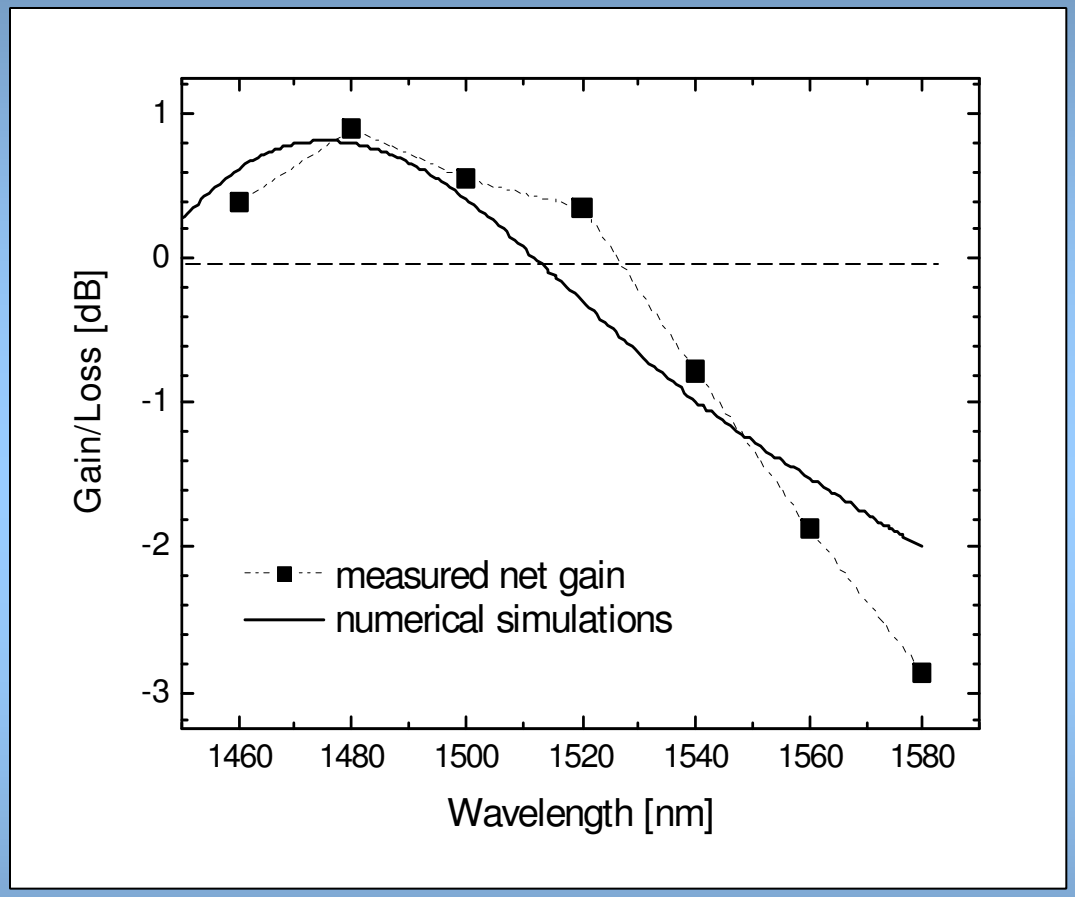


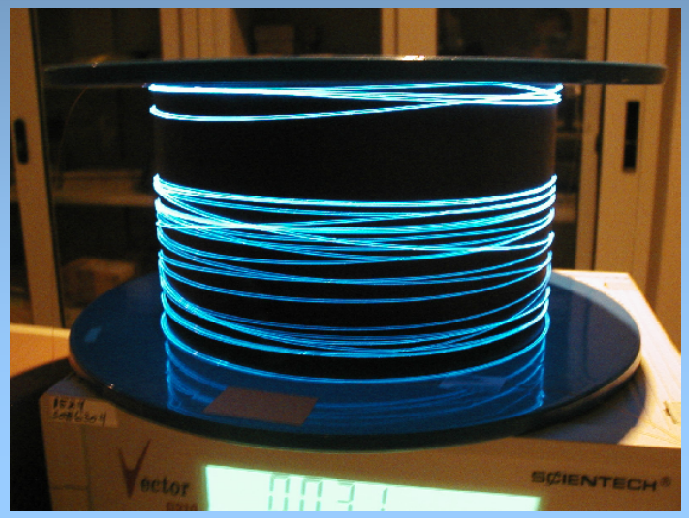
Specialty fibers – Tm^{3+} -doped



Technol. challenge : specialty optical fiber suitable for generation/ amplification at spectral region other than ~1550 nm (Er-doped). Tm^{3+}-Al_2O_3-GeO_2-SiO_2 fiber efficiently operating in S-band (~1470 nm) and compatible with network; high NA, narrow core.

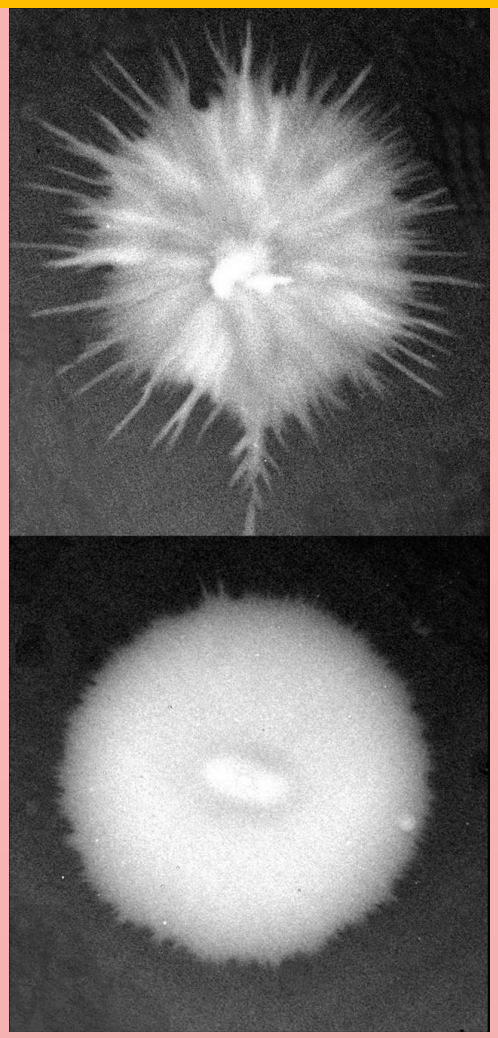
Specialty fibers – Tm^{3+} -doped



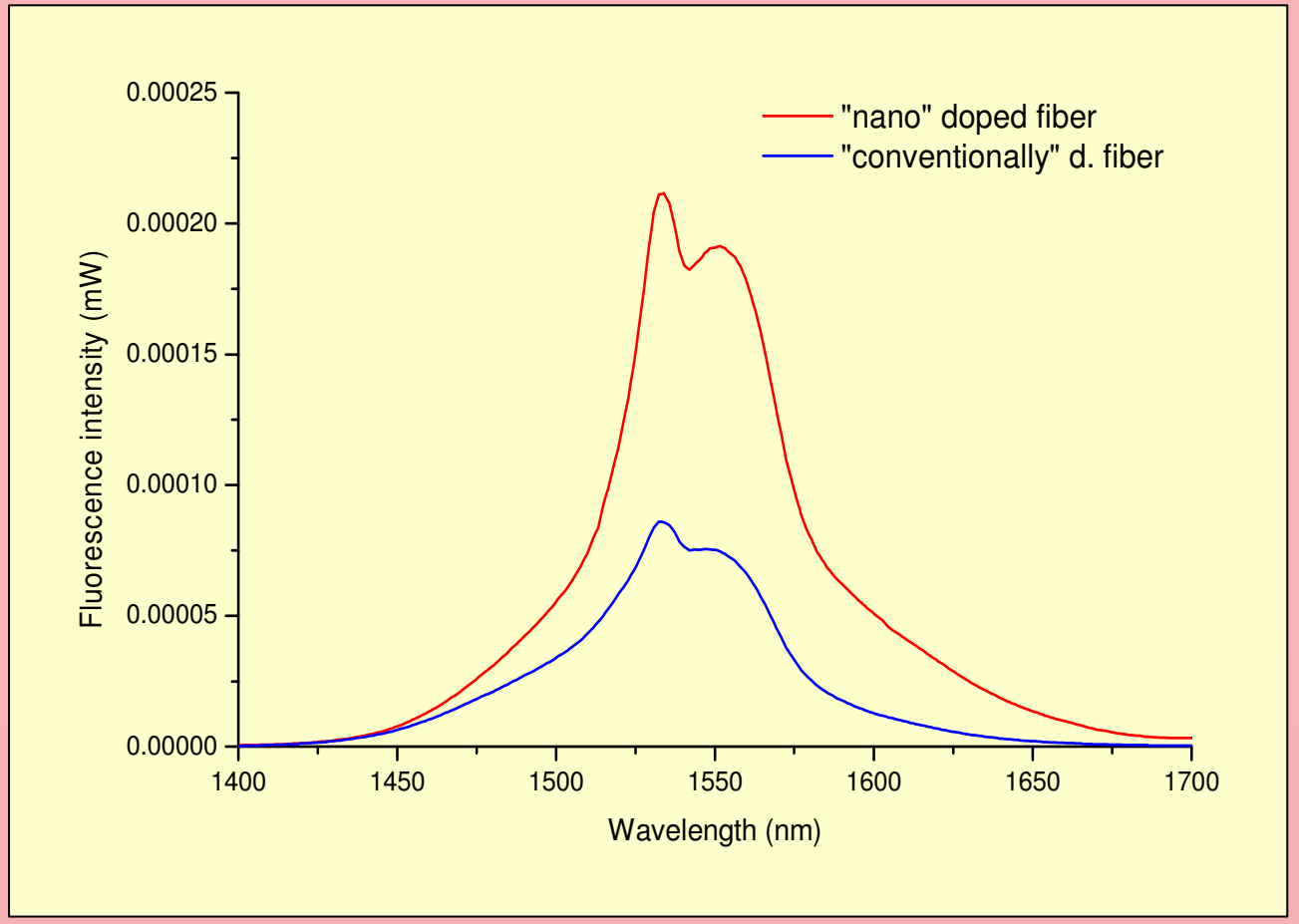


- *In collaboration with NLO group (P.Peterka) and LPMC Nice*

Specialty fibers – doped with nanoparticles



Er^{3+} + Al_2O_3 (ceramic); $\lambda_{excitation}$=980 nm



Specialty fibers – doped with nanoparticles

Er^{3+} (Tm^{3+}) + Si (semiconductor) [Watekar et.al.]

enhancement of fluorescence

Si (semiconductor) **[J.Valenta et.al.]**

~100 nm=>5 nm: fluorescence

Challenges : nanoparticle formation, application, saving & characterization methods

X/2009

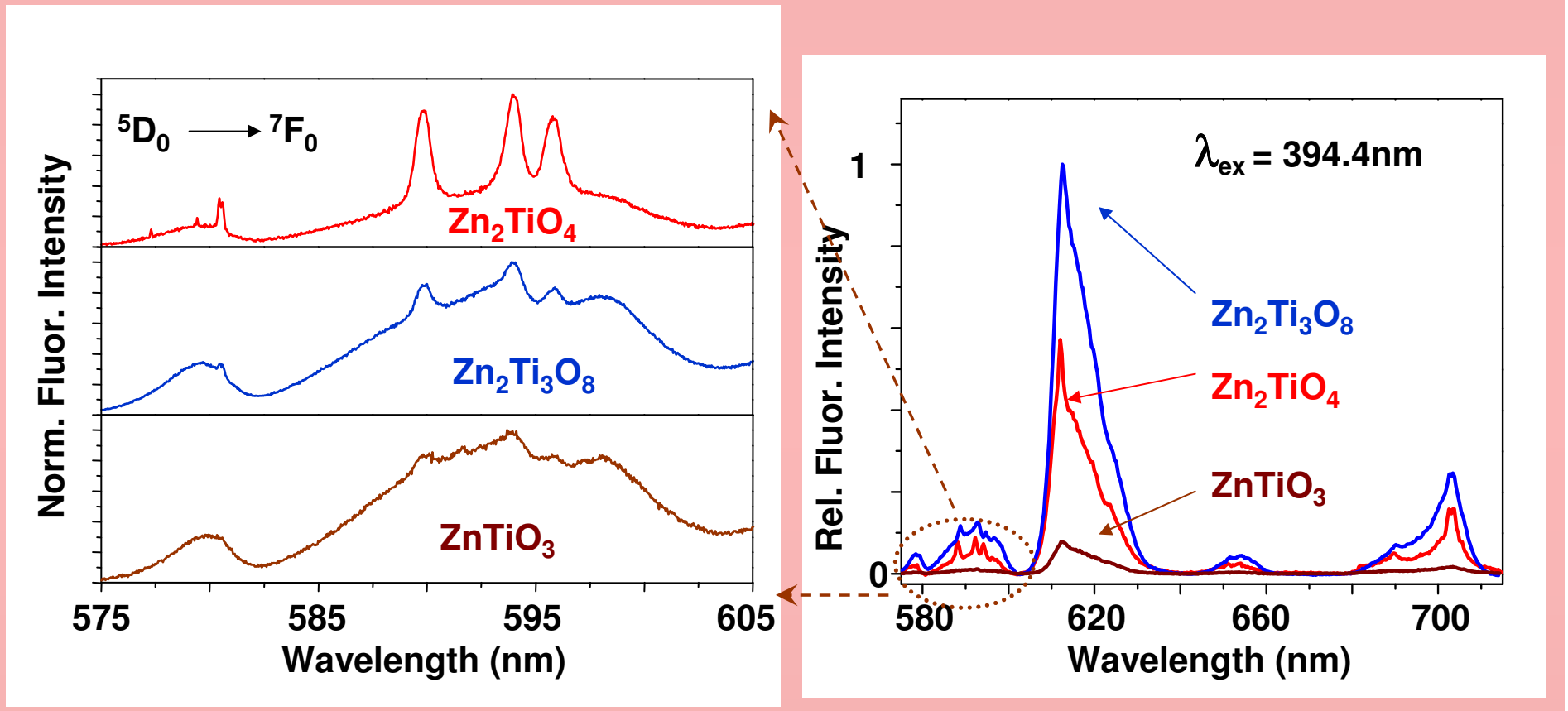
Er^{3+} +Si *(~100 nm) :*

** Transparent preform, intensive green coloration*

Si

** Transparent preform*

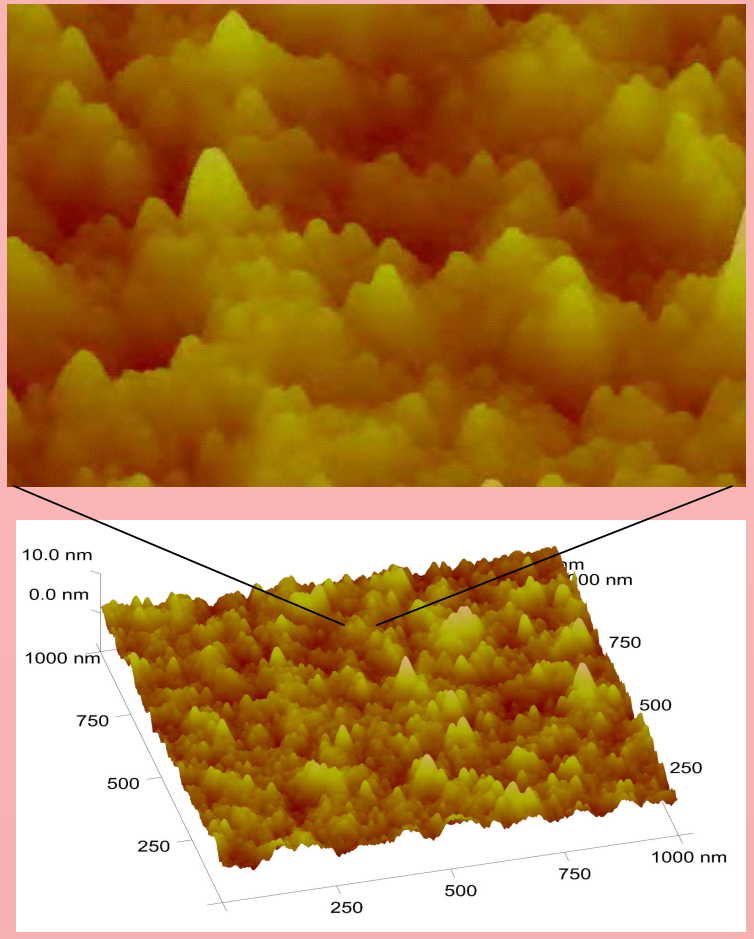
Specialty fibers – coated/doped with nanoparticles

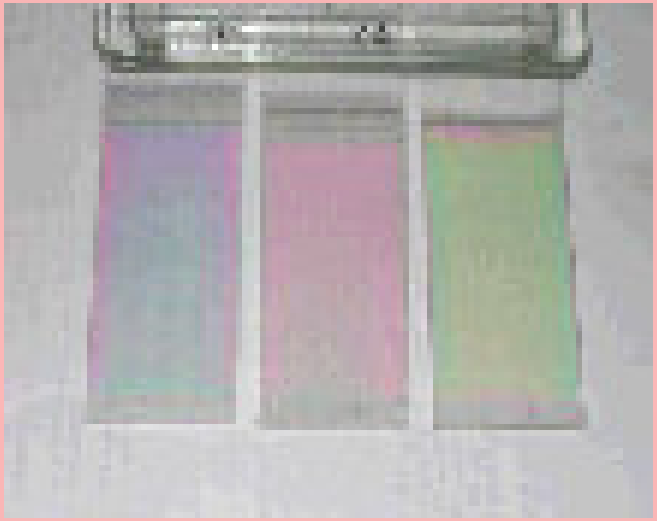


$Eu^{3+}@Zn_xTi_yO_z$ hetero-nanostructure *layers (planar)*

Specialty fibers – coated/doped with nanoparticles

$Eu^{3+}@Zn_xTi_yO_z$ hetero-nanostructure *layers (planar)*

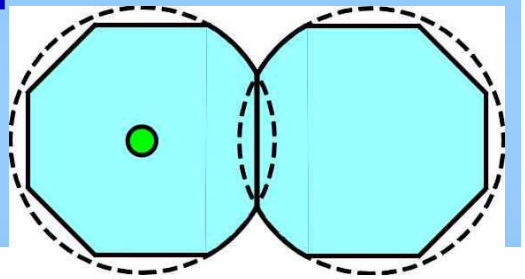


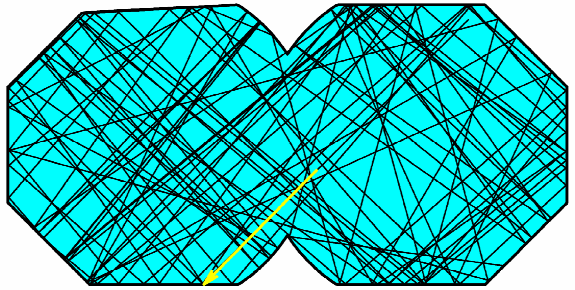


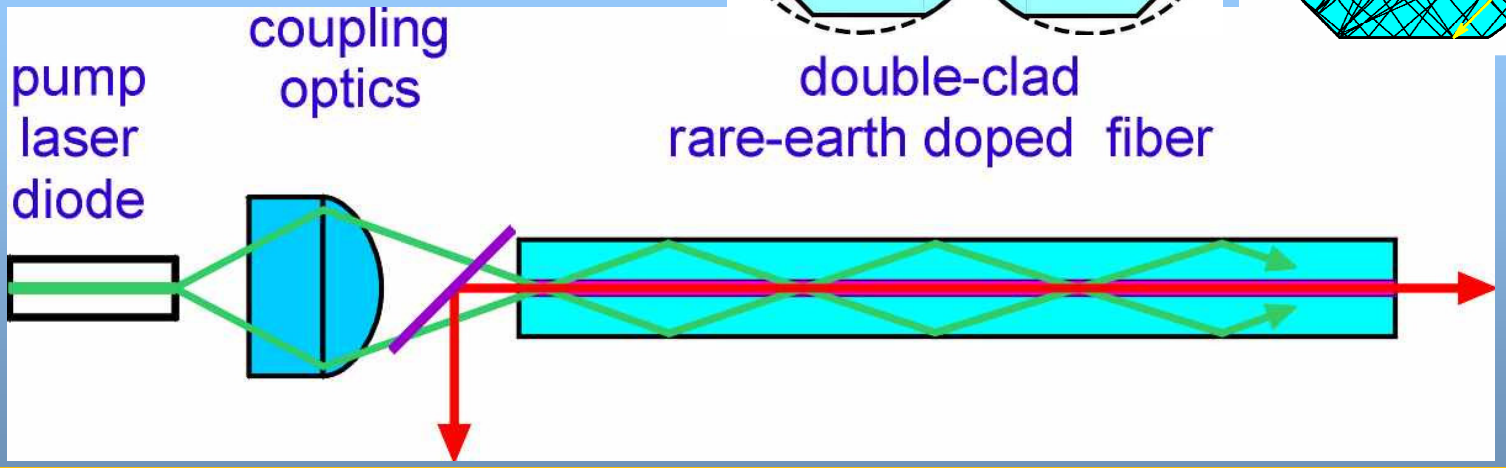
TiO_2 nanostructure *layers (fiber) - photocatalysis*

Fiber-optic components
Double-clad (DC) doped optical fibers

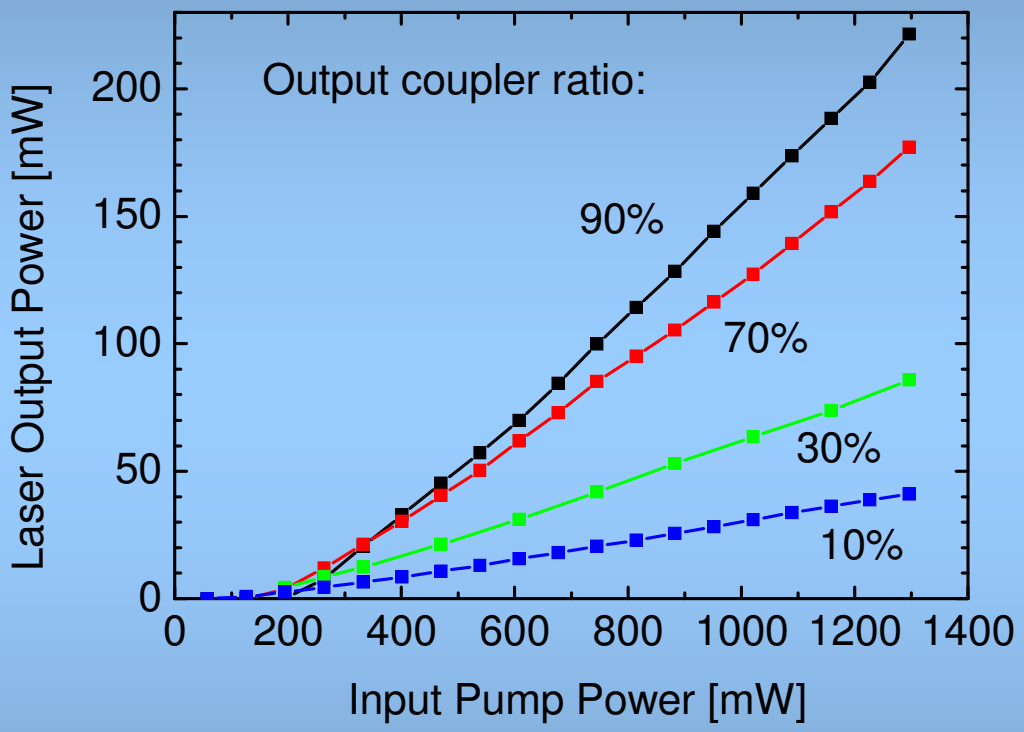
- **GOAL:** efficient pumping of fiber lasers (using LD, LED) - employing whole fiber end-face of suitable shape for coupling
- Technol. challenge : specialty optical fiber of Double-clad (DC) structure and doped core

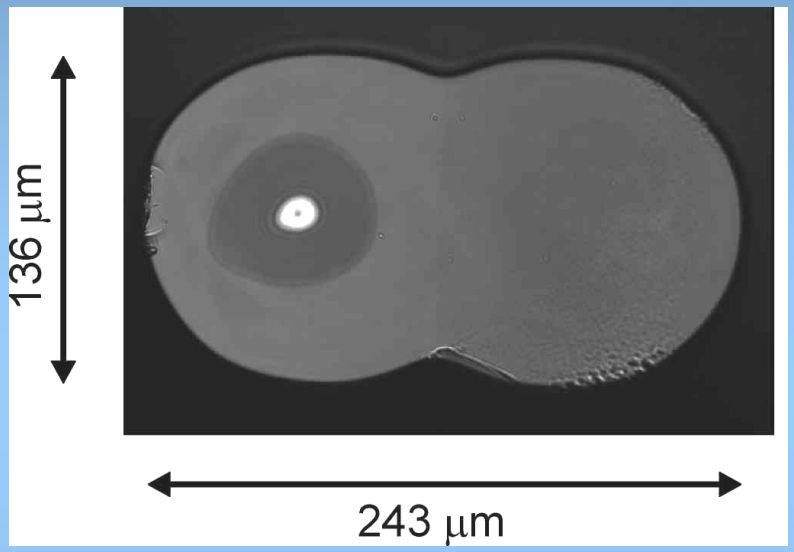






Fiber-optic components
Double-clad (DC) doped optical fibers





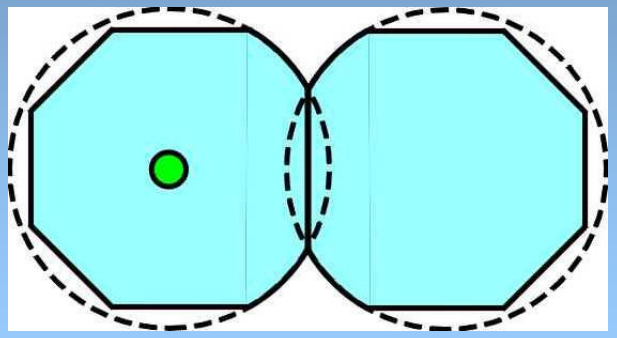
In collaboration with NLO group & Nuclear Sci. Eng. Faculty CTU

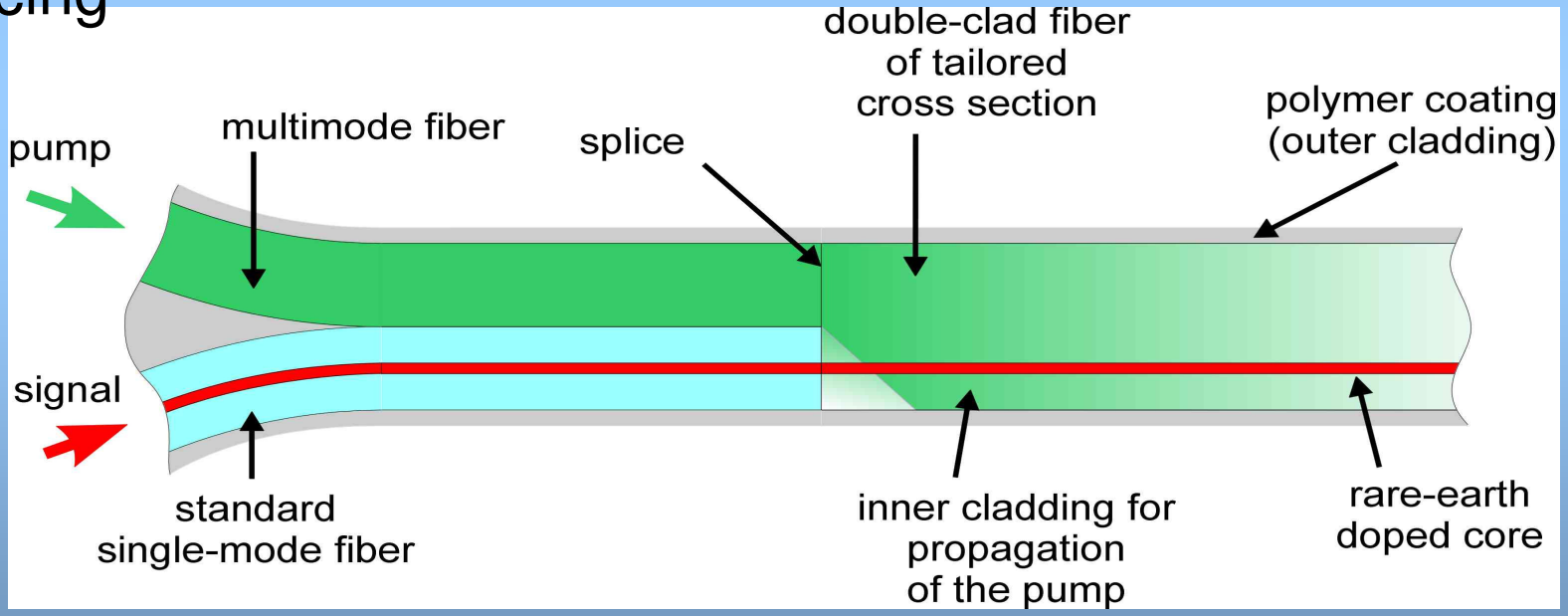
Maximum slope efficiency 22.6%; Yb/Er-doped DC fiber.

Fiber-optic components
Double-clad (DC) doped optical fibers

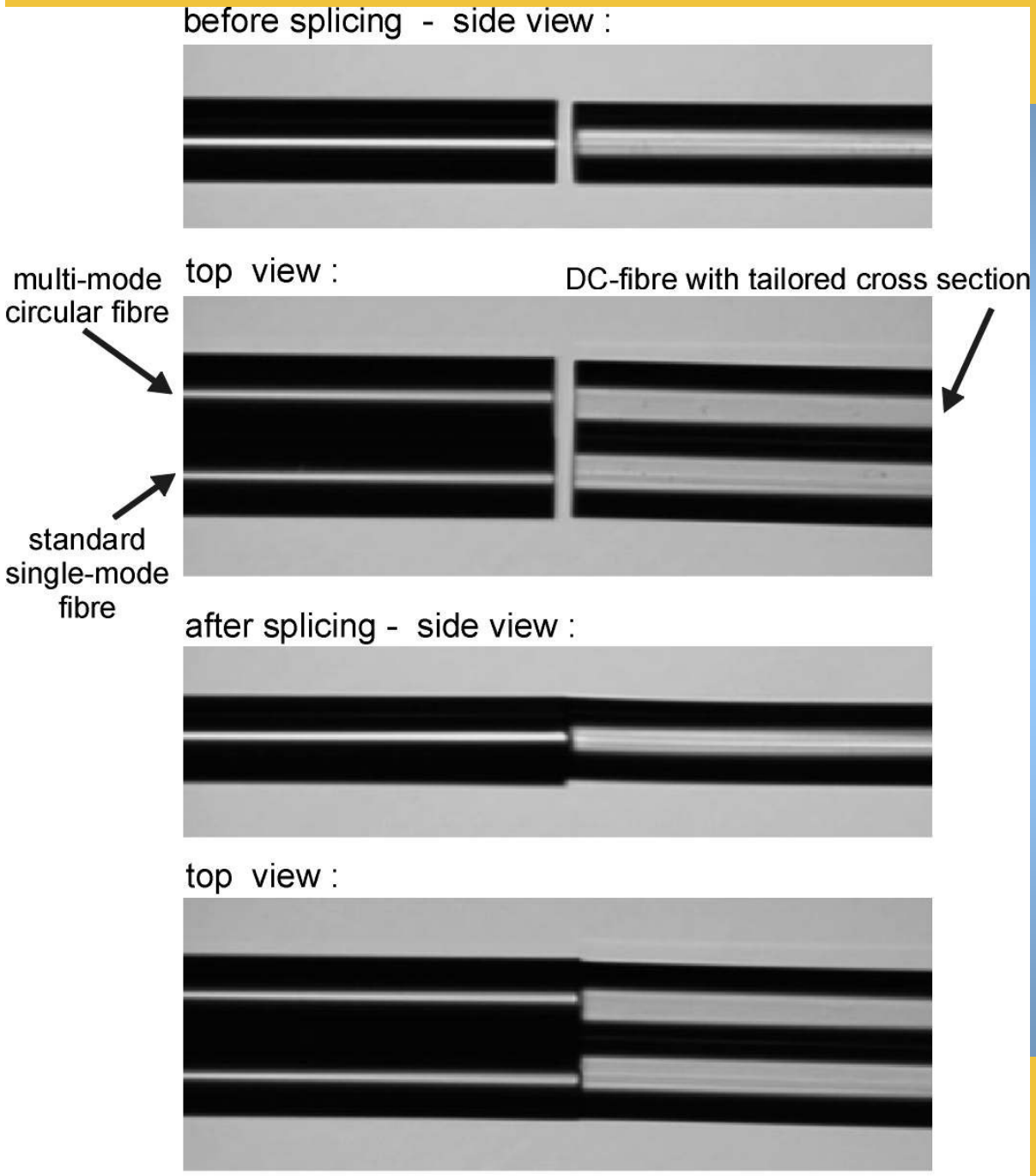
GOAL: coupling element easy to produce reproducively

Technol. challenge: specialty fiber of tailored structure suitable for conventional splicing



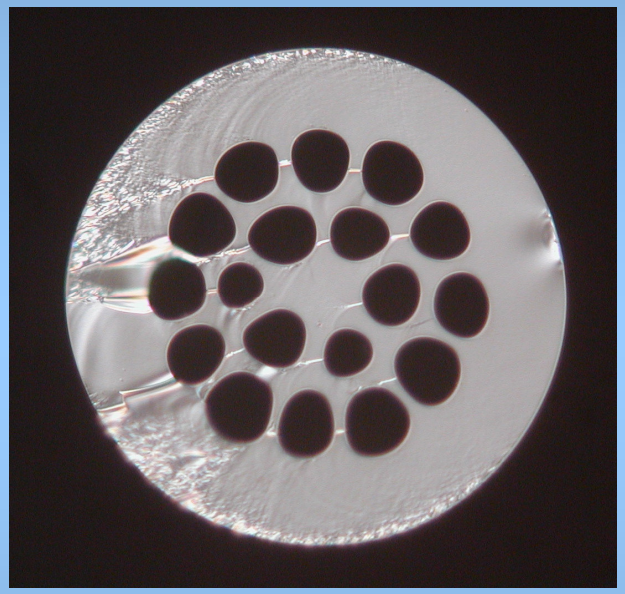


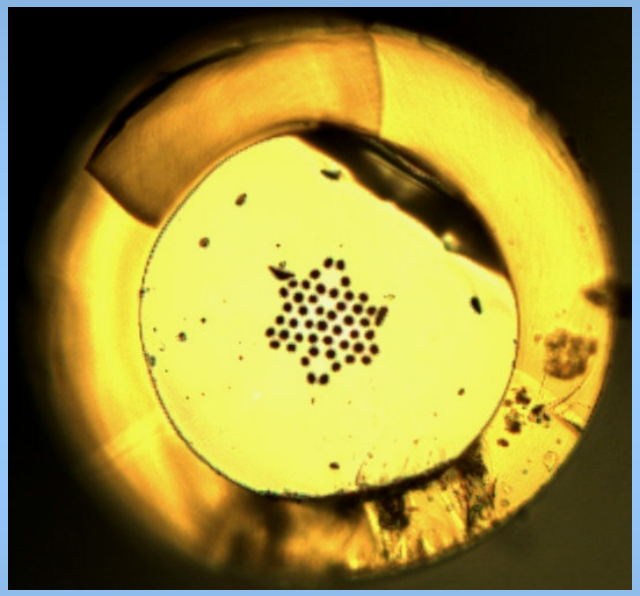
Double-clad (DC) fiber structures

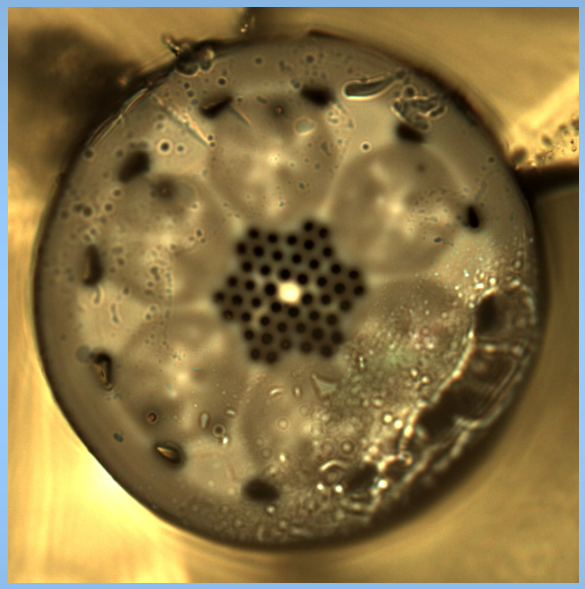


- *In collaboration with NLFO group & Nuclear Sci. Eng. Faculty CTU*

Microstructure (specialty) fibers

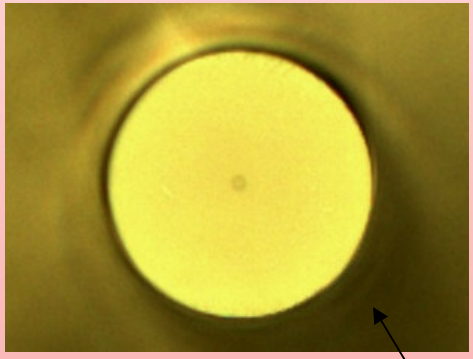






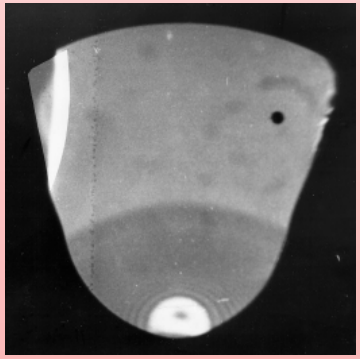
Structure close to PCF
for communications

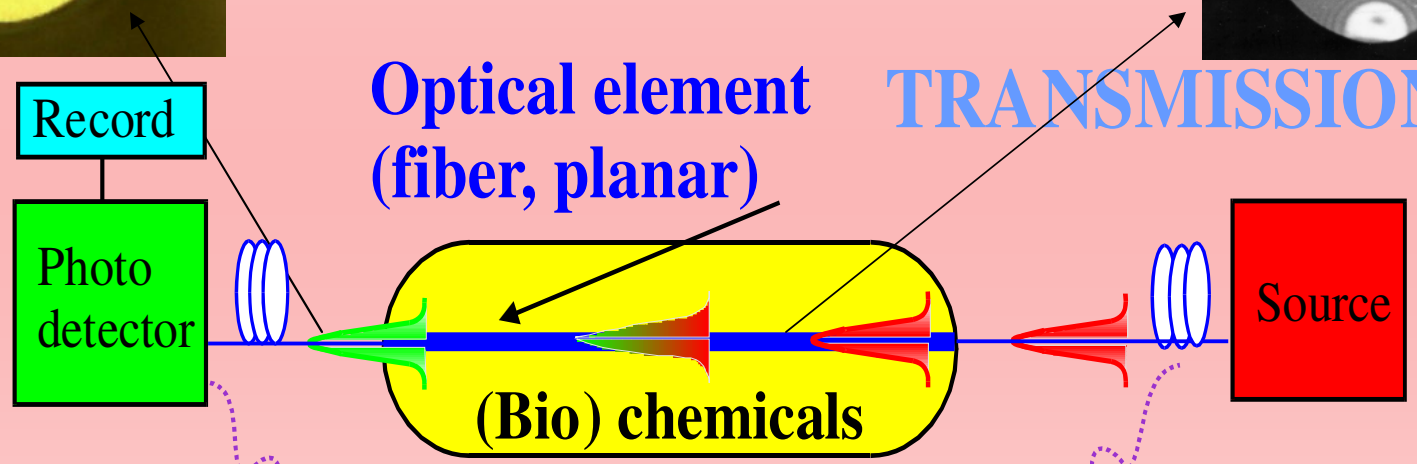
Fiber-optic sensors

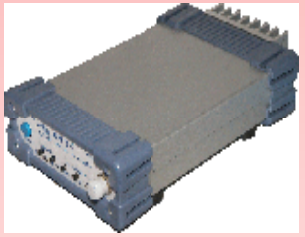


Sensitivity x immunity

* Change of refractive index
* Change of absorption coeff.

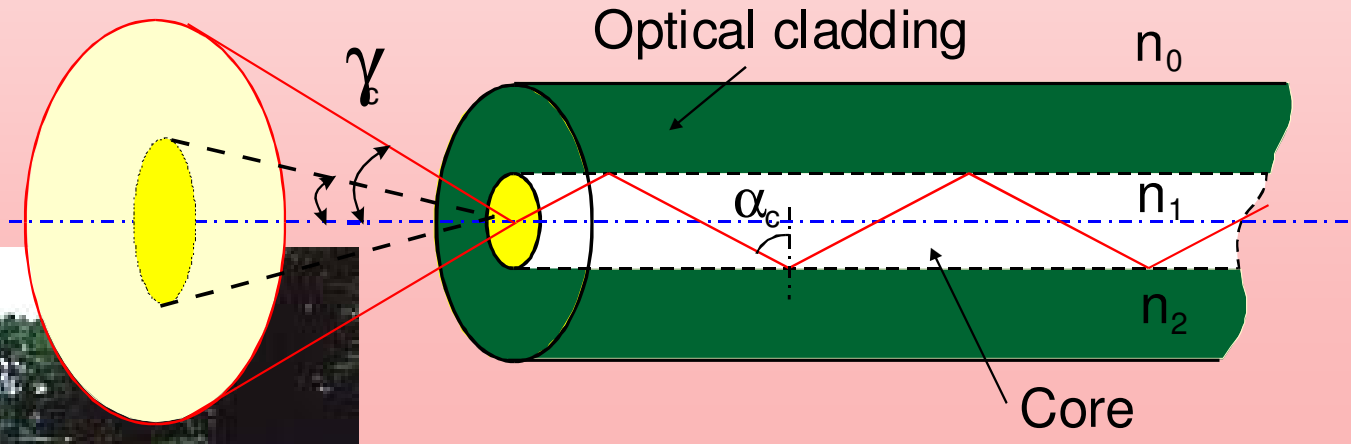






SENSITIVITY!!

Refractometric sensor of hydrocarbons

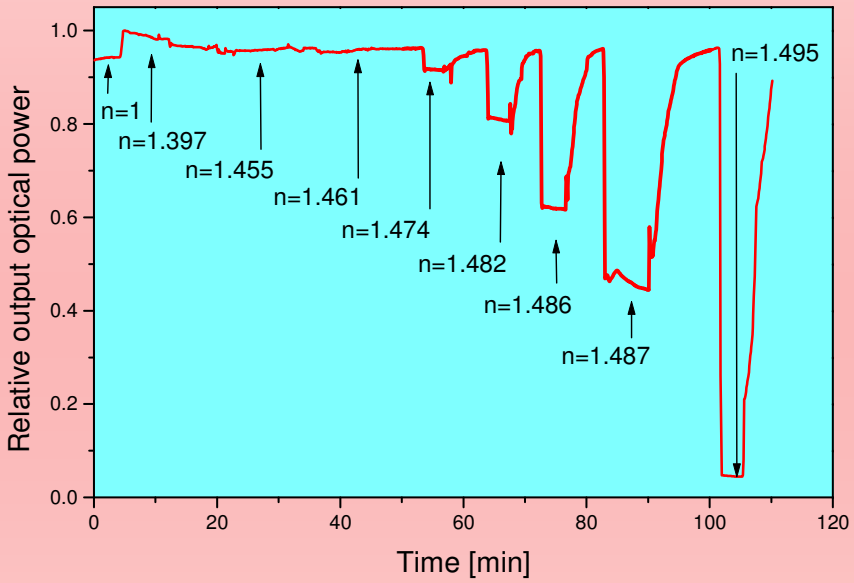


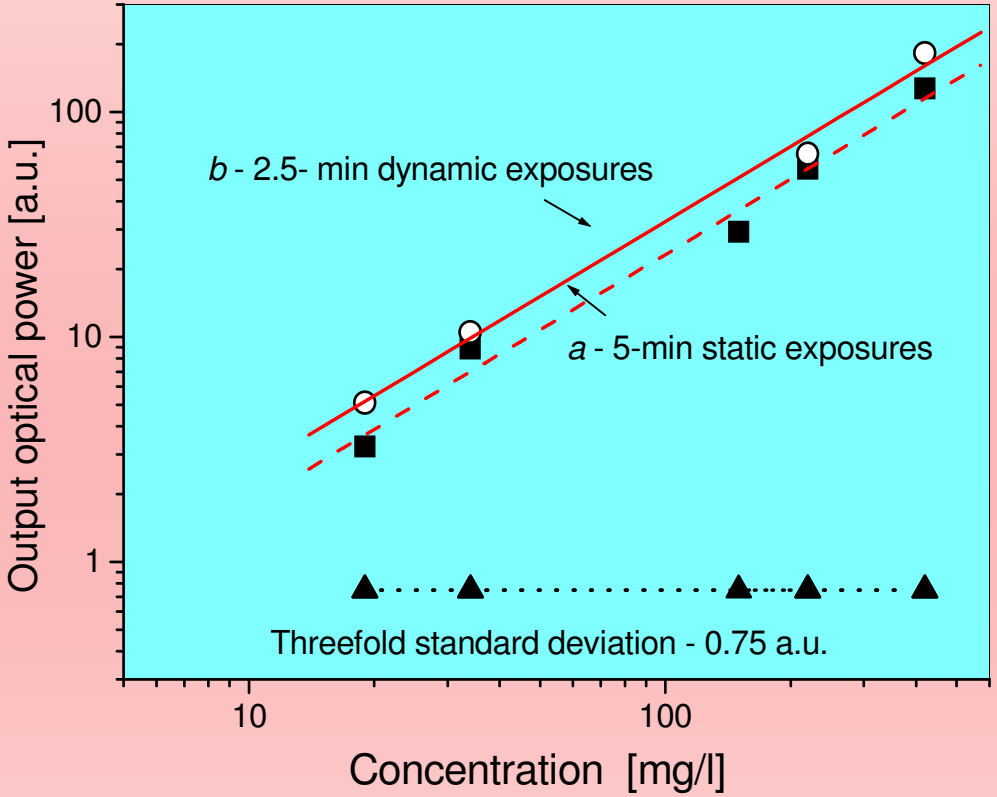
toluene : $n_{20°C,\ \lambda=633\ nm)} = 1.496$

toluene – water : $n_{min} = 1{,}33$ $n_{critical} = 1.457$ $NA = < 0.59 ; 0>$

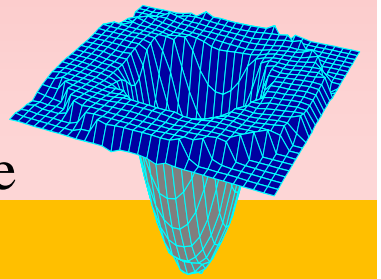
Detection of hydrocarbons – fast and sensitive (multipoint, distributed)

specialty coatings, structures

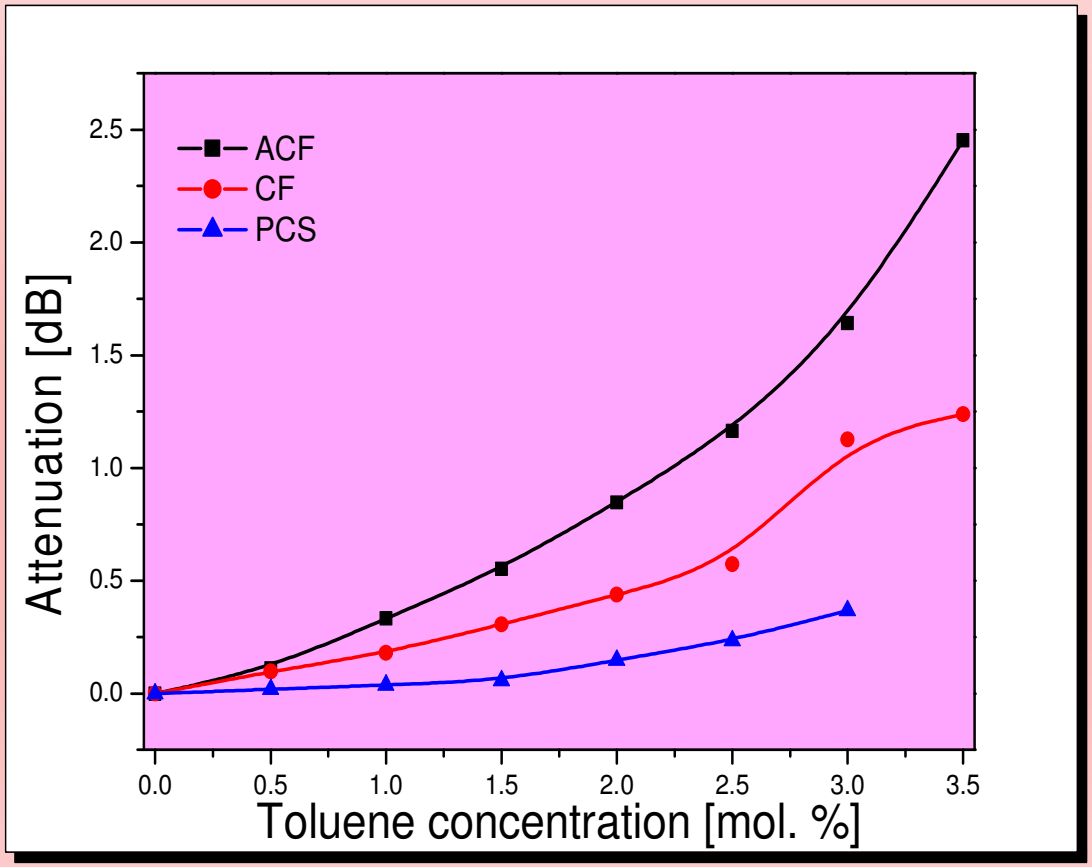


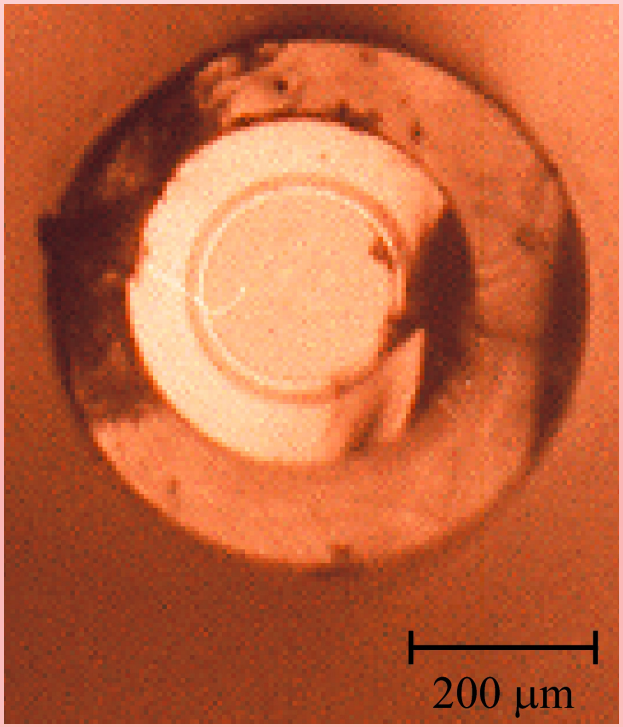


+ **sensitivity** : LOD ~ 3-5 mg/l ~ comparable to EU ecological limit
+ **time response** : seconds
+ **stability - reproducibility** : < months
- **selectivity** : temperature – referencing, protective membrane



Annual core fiber capillaries



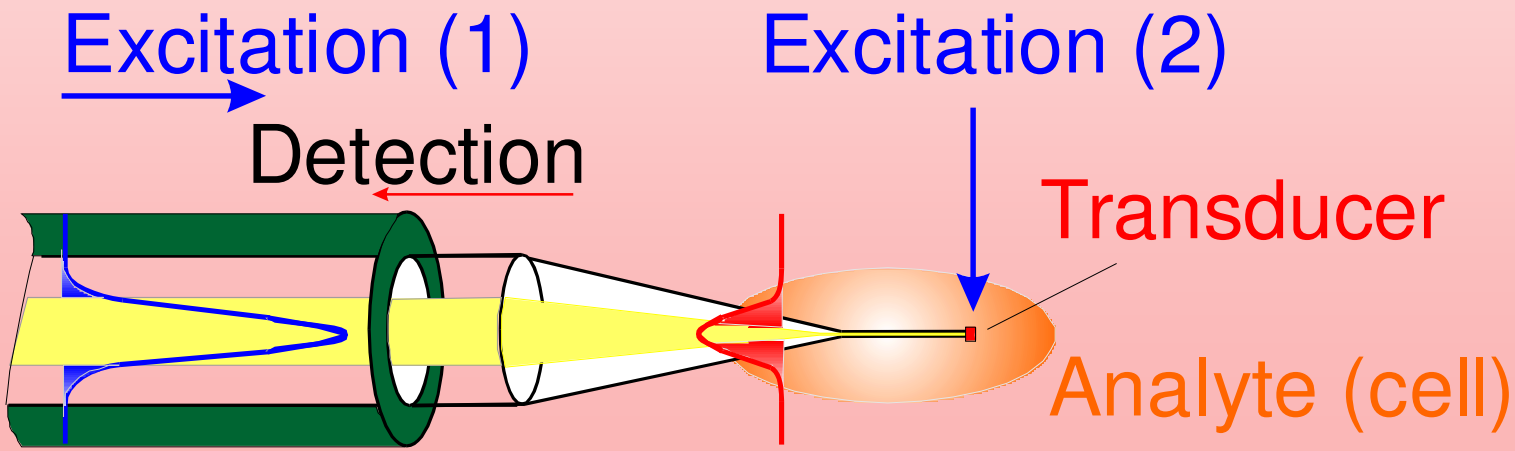


ACF-fiber capillary

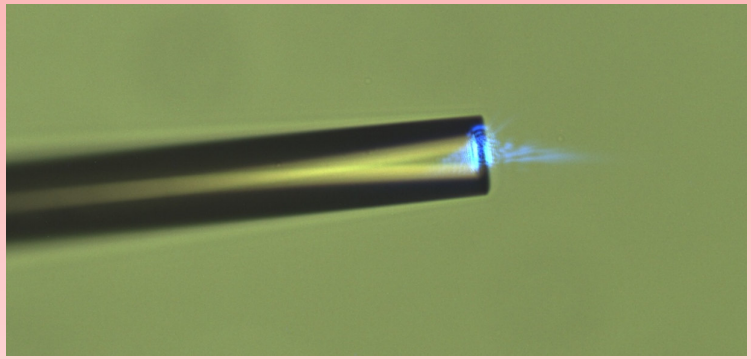
380/210 μm

- *In collaboration with CTU*

pH fluorescence sensor & fibre tapers

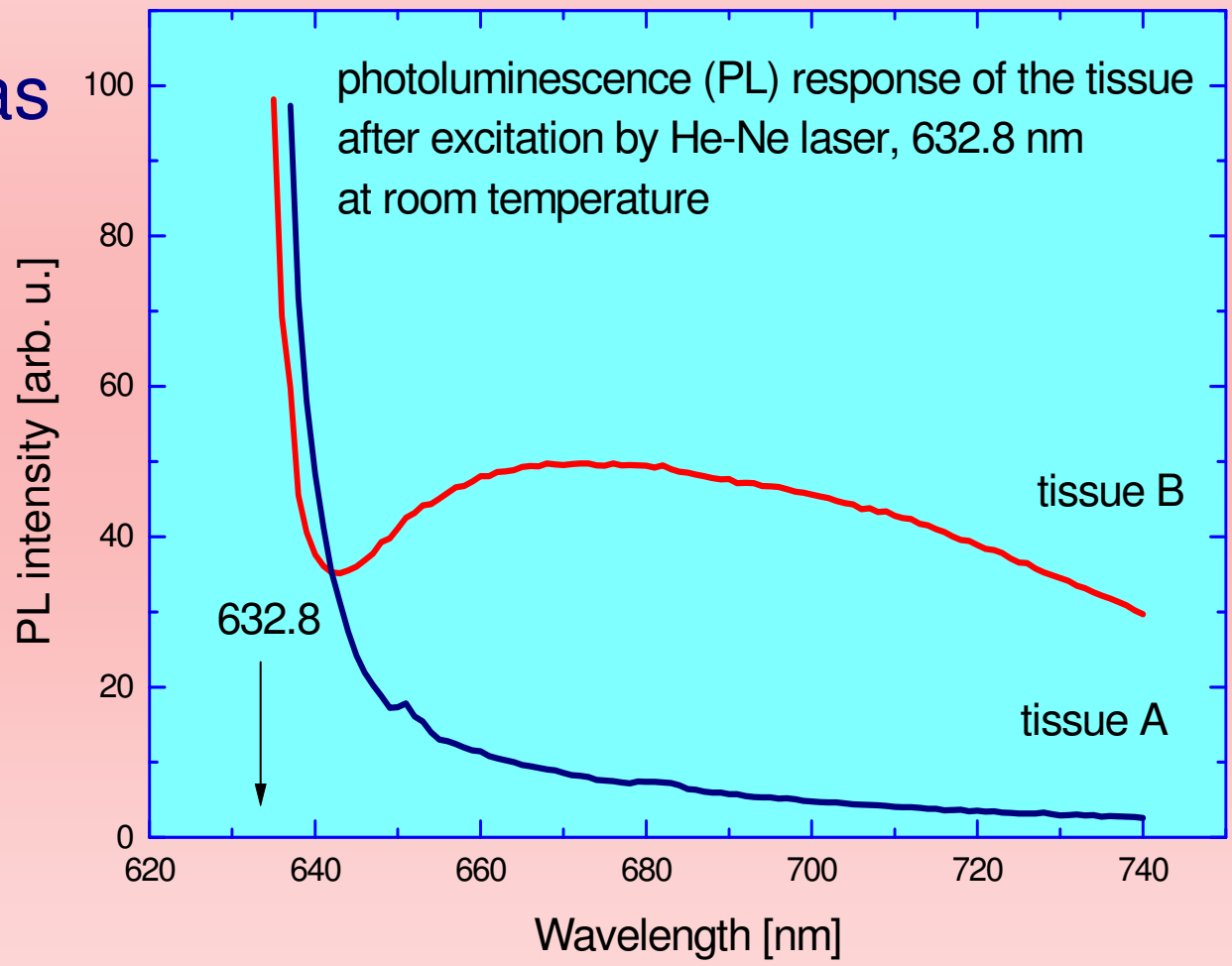


- Excitation 473 nm, emission 525 nm
- **Small area monitoring** : Ø 18 μm:
- Preparation
  - *Flame processing [Martan]
  - *Slow withdrawing from HF-containing solution [Ligler, Lieberman]



Fiber-optic detection

Indispensable:
High/voltage areas
Explosives
Medicine :



IV. SUMMARY

1. Fiber technology : preparation of structures of high preciseness from materials of ultra-high purity (impurities in ppbs only)

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. Research of conventional/specialty optical fibers (CR) : ufe

References

- **A. B. Chynoweth, S. E. Miller** : Optical fiber telecommunications, Academic Press, 1979
- **J. Schrofel, K. Novotný** : Optické vlnovody, SNTL, 1986
- J. Šavel : Přenos informací na optických kmitočtech, SNTL, 1982
- **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
- V. Matejec, I. Kasik, M. Chomat : Chapter 13 - Fundamentals and performance of the MCVD aerosol process, in Aerosol chemical processes in the environment, Levis (2000)

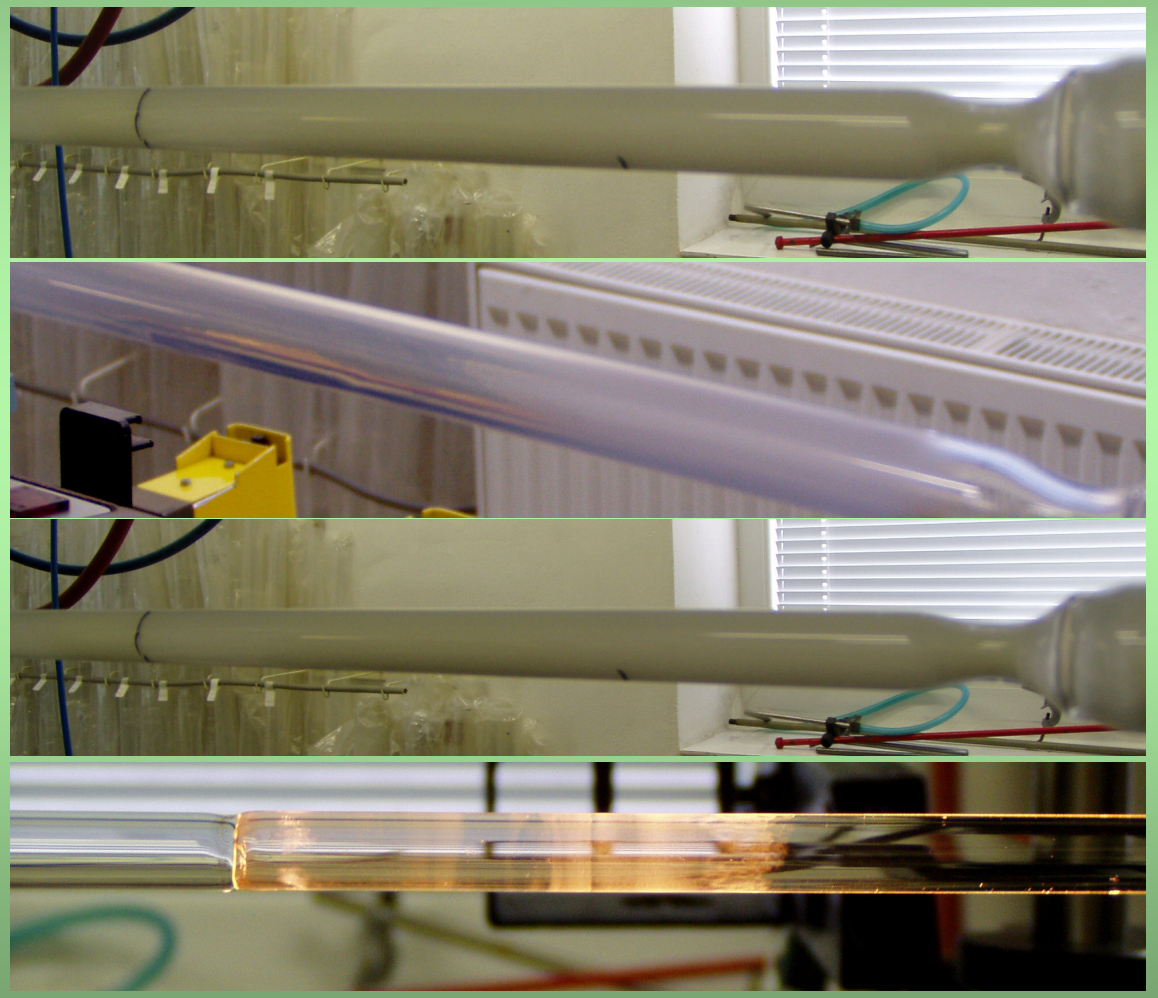
Thank you for attention

Technology - modifications

Starting materials - **solids**

Methods :

- Solution doping
- Sol-gel
- Additional burner
- Aerosol



Solution doping :

1. Porous layer depositon
2. Soaking
3. Drying
4. Sintering