Vláknové lasery a optická vlákna

Pavel Peterka a Ivan Kašík
Ústav fotoniky a elektroniky AV ČR, v.v.i. (ÚFE)

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

Prof. Jiří Homola
Česká hlava 2009

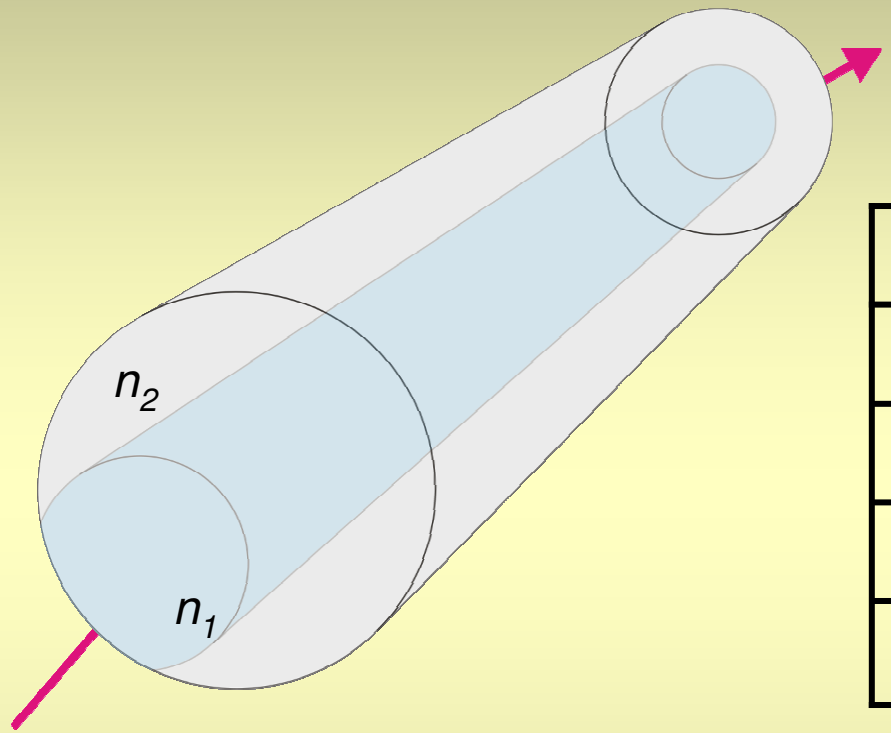
ZÁKLADNÍ VÝZKUM:

fotonika **- optická vlákna**
- vláknové lasery a zesilovače
- optické biosenzory
- fotonické a radiofrekvenční biosignály

+ etalon přesného času ČR

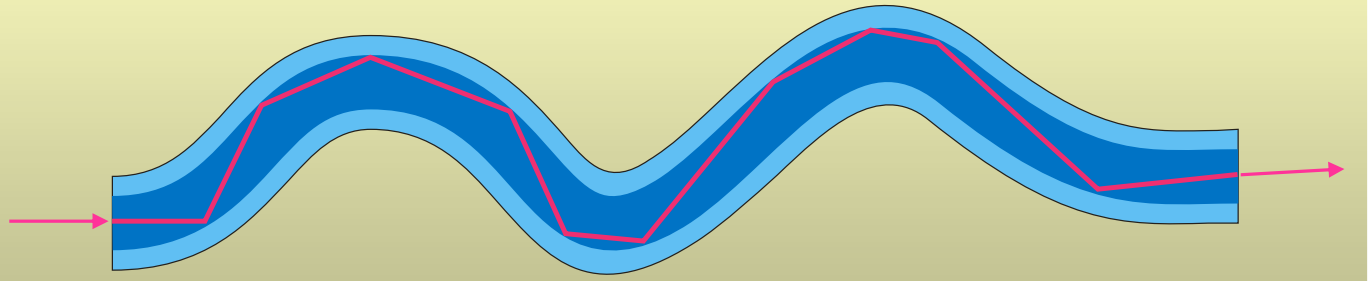
100 FTE (150 celkem), ~ 80 MKč obrat (35% z projektů)

Optical fiber

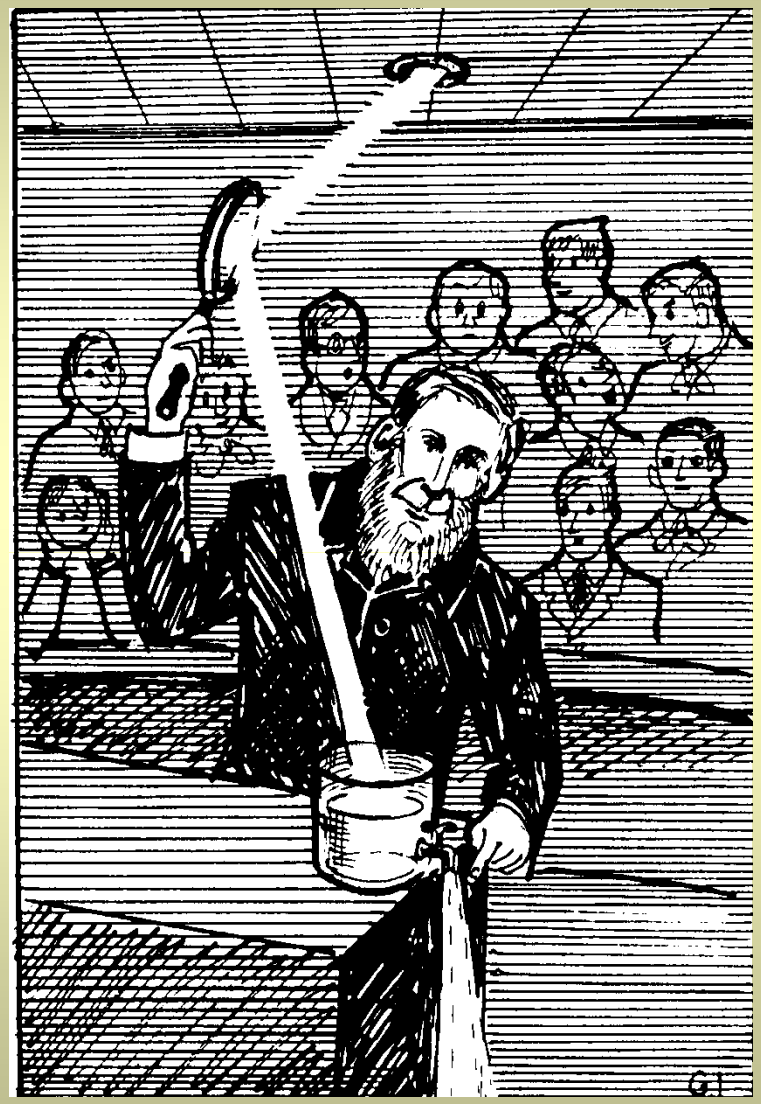


$n_1 > n_2$

Refractive index (n=c/v)	
Vacuum	1
Air	1,0003
Water	1,330
Silica	1,457



Optical waveguide

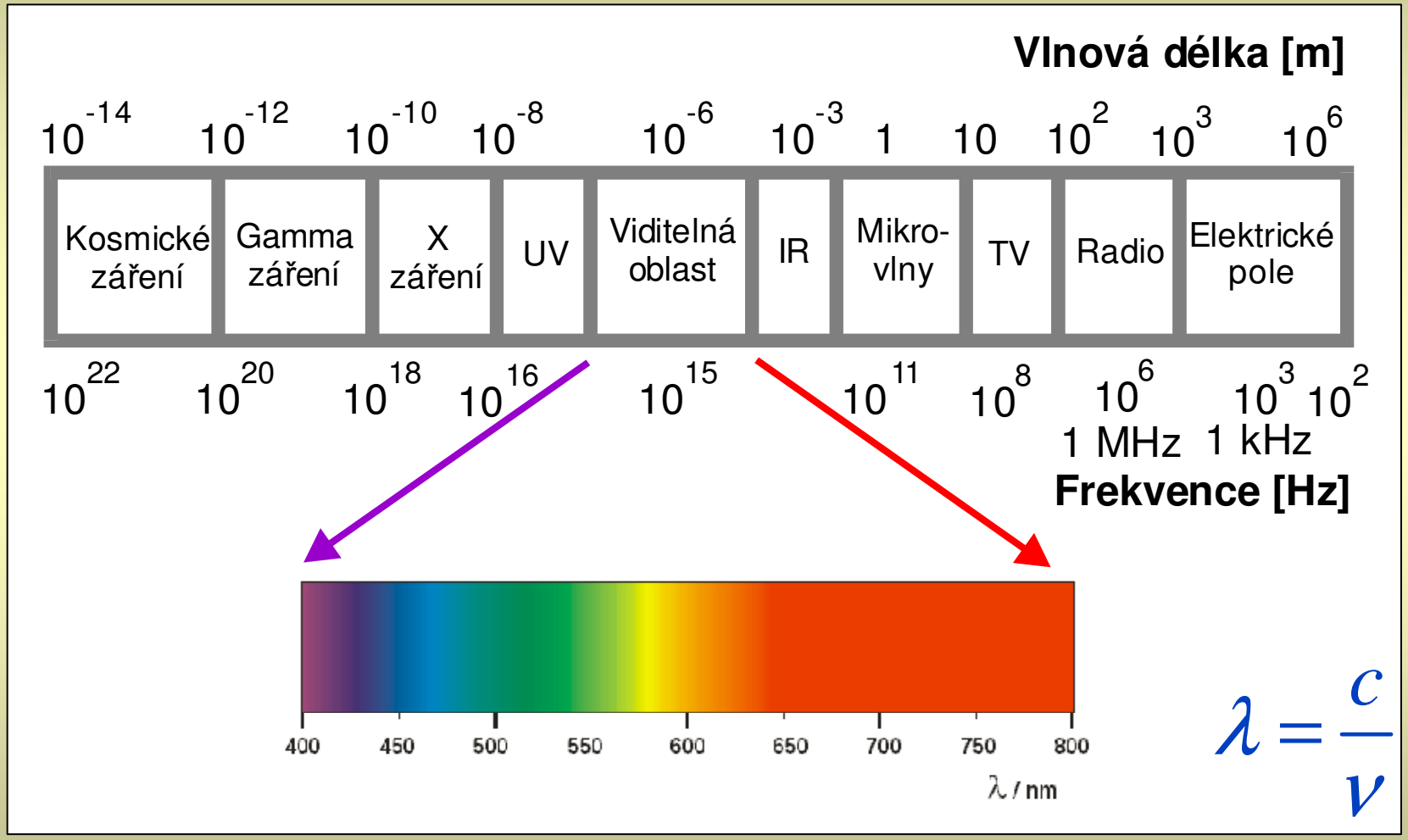


1853

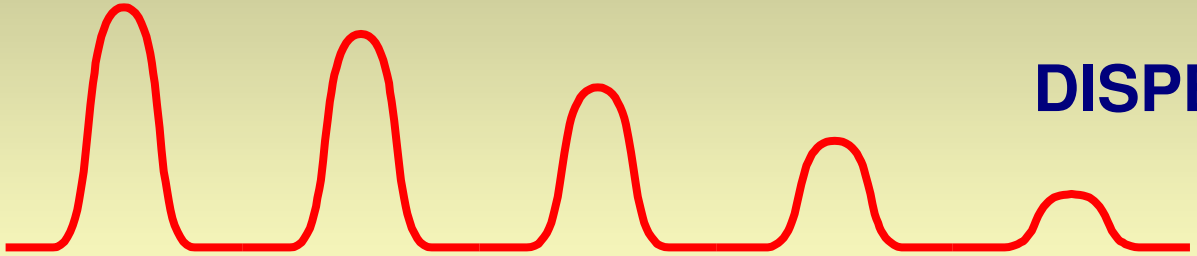
Snell Willebrord 1580-**1626**
Tyndall John 1820-**1893**

František Křižík

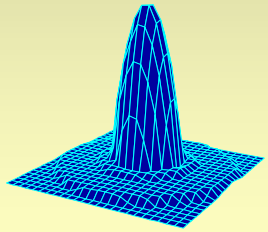
Optical communication principle

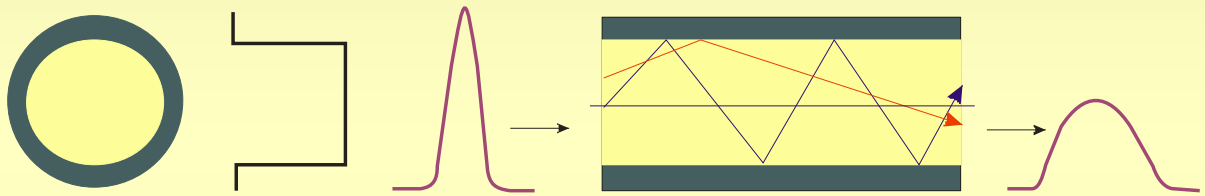


Transmission, attenuation, dispersion
Purity & structure of material

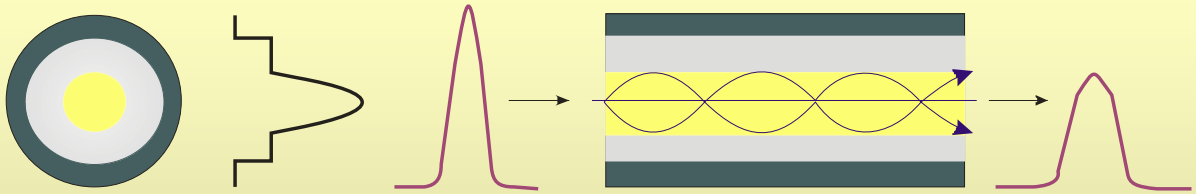


DISPERSION - structure

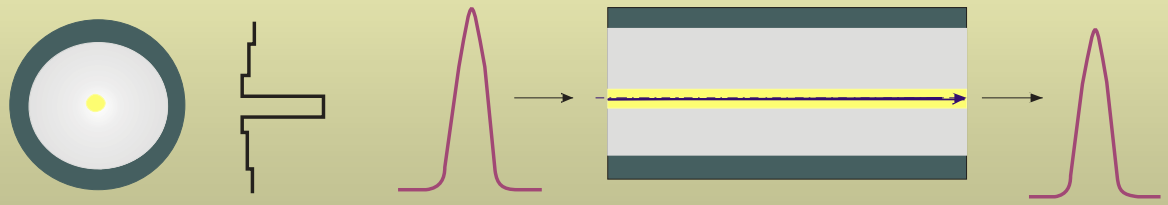




Polymer-Clad-Silica
PCS (multimode MM)

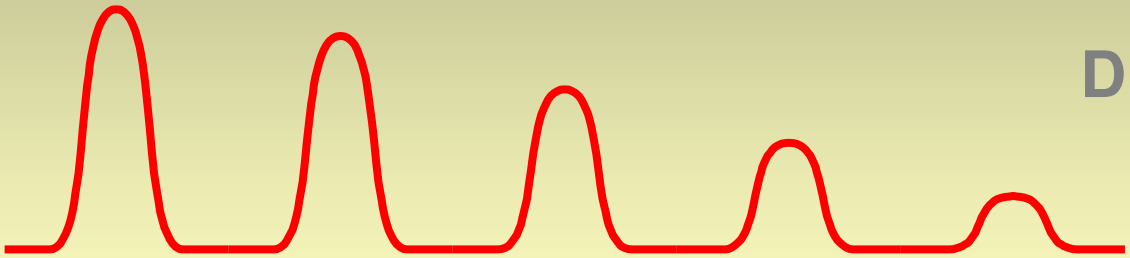


Graded-index
GI (multimode MM)



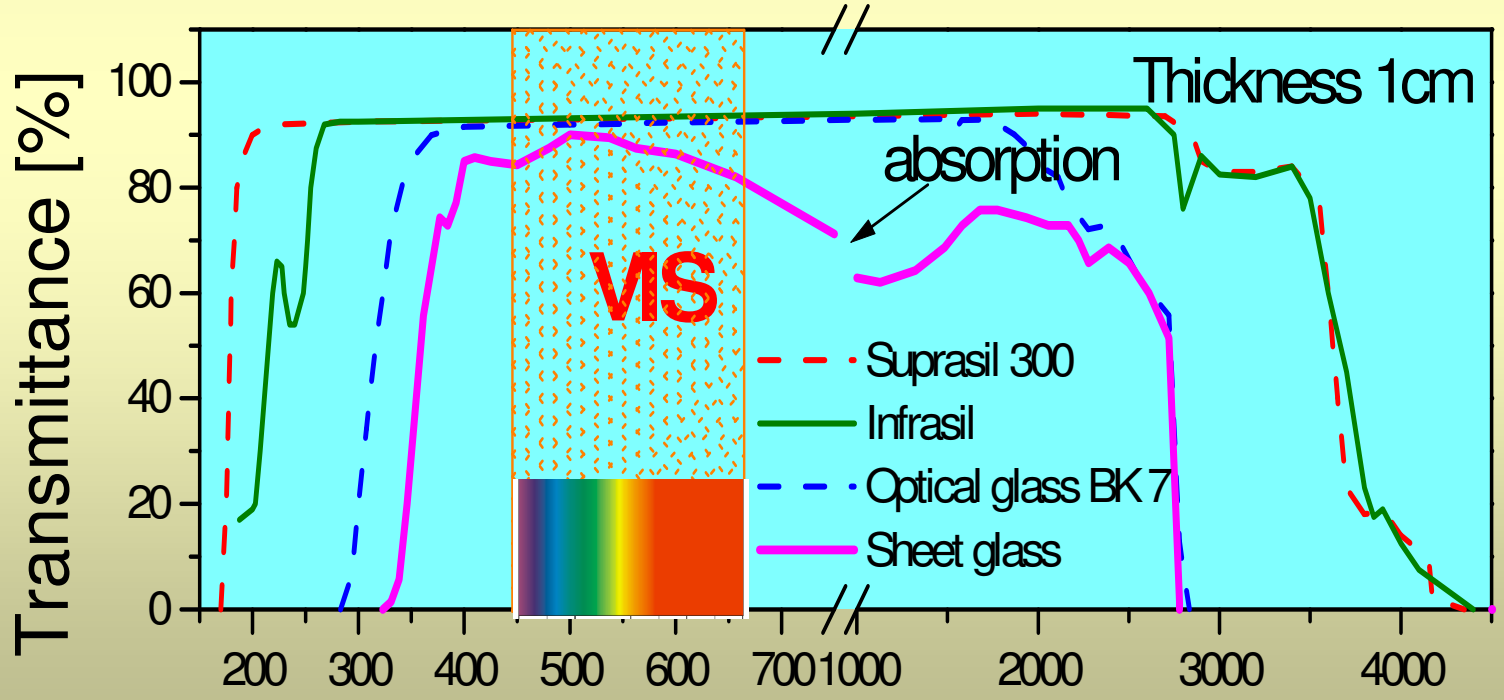
Singlemode (SM)

Transmission, attenuation, dispersion
Purity & structure of material



DISPERSION - structure

ATTENUATION (**intrinsic, extrinsic**) – **MATERIAL & PURITY**



The Nobel Prize in Physics 2009

Charles K. KAO
1/2

W.S.Boyle
1/4

G.E.Smith
1/4

For groundbreaking achievements concerning the **transmission of light in fibers for optical communication**

for the invention of an imaging semiconductor circuit – the CCD

K.C. Kao, G.A. Hockham, Dielectric-fibre surface waveguides for optical frequencies, Proc. IEE, 113, No.7, July 1966, 1151-1158

Material purity

1. Per Analysis – PA (99 - 99,5 %)
2. Semiconductor – PP (99,9995 %)
3. Ultra-pure - FO Optipur / for trace analysis [ppb]

% – 10^{-2}

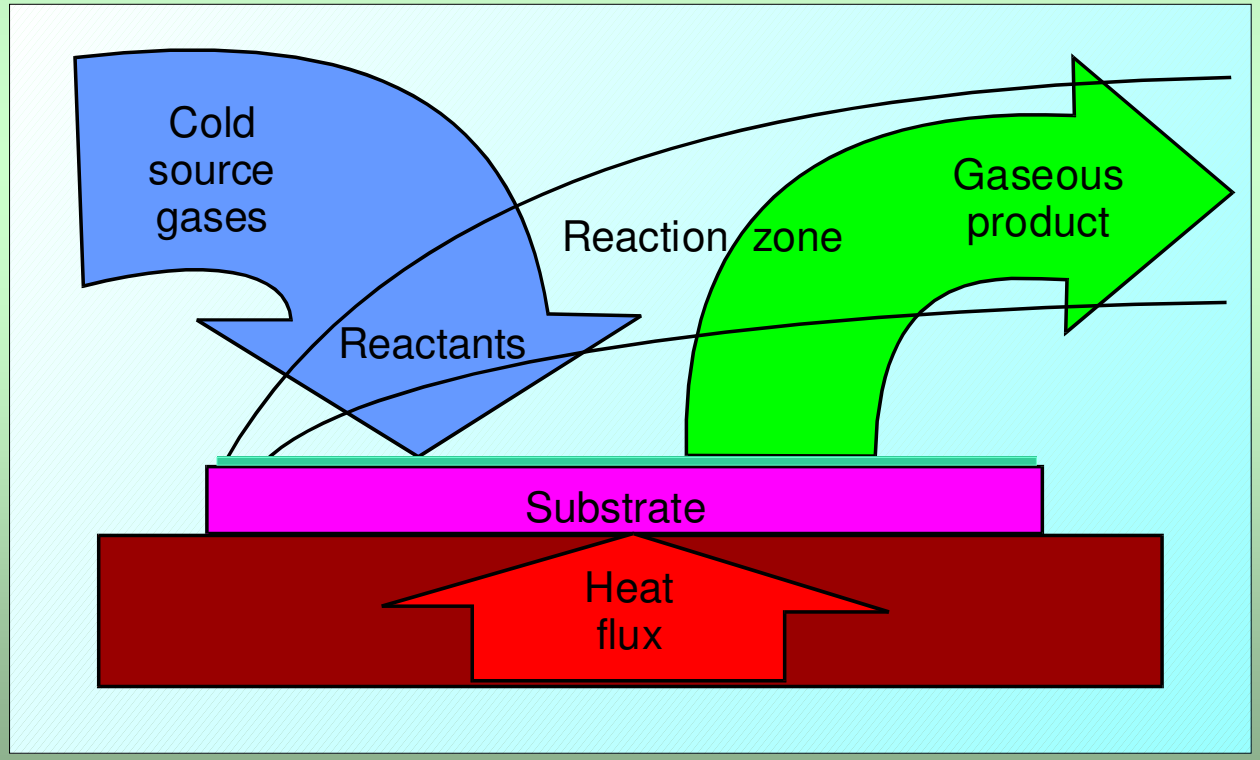
ppm – 10^{-6} (parts per million)

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

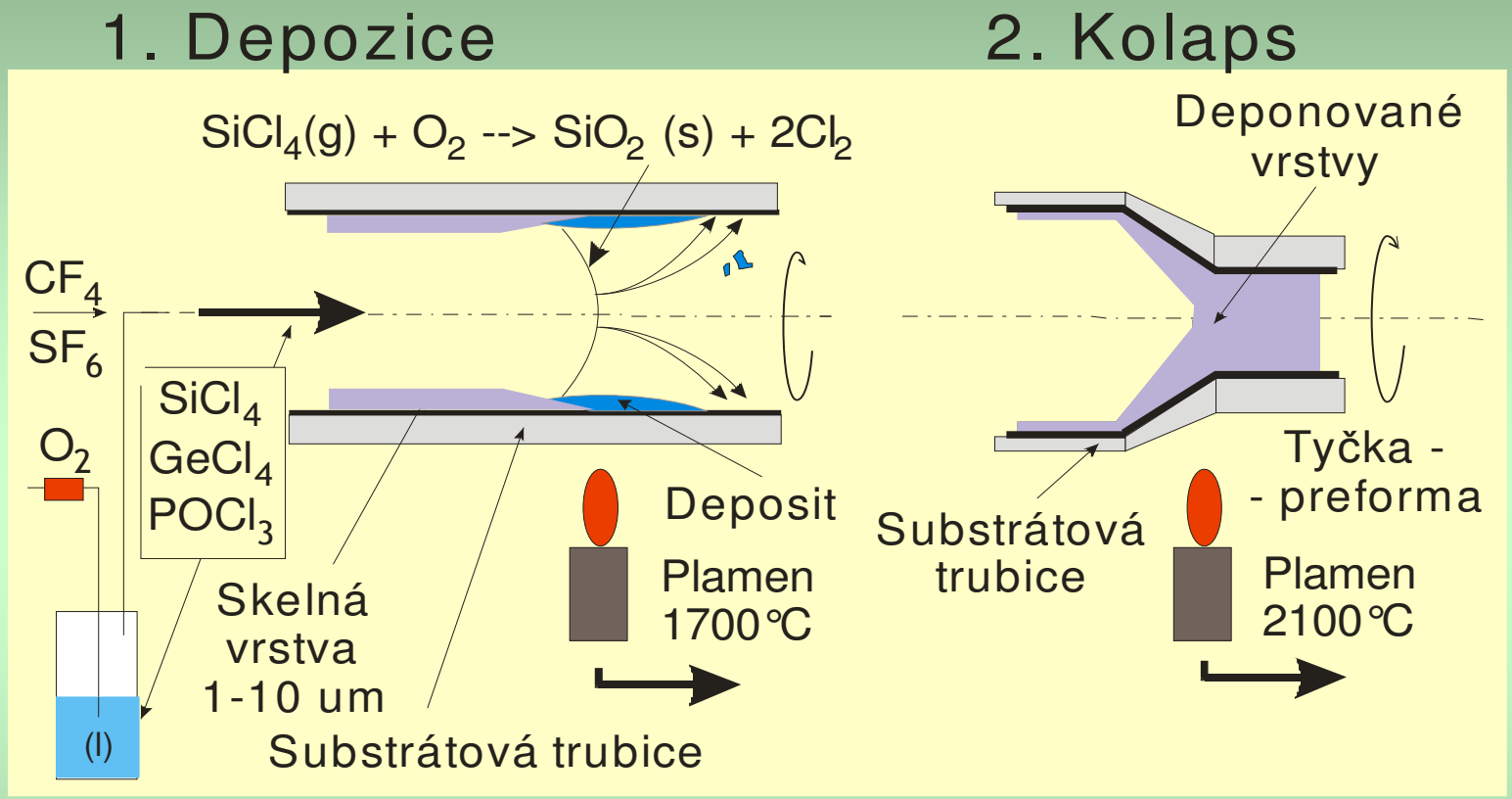
Ultra-pure technologies - CVD !

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]



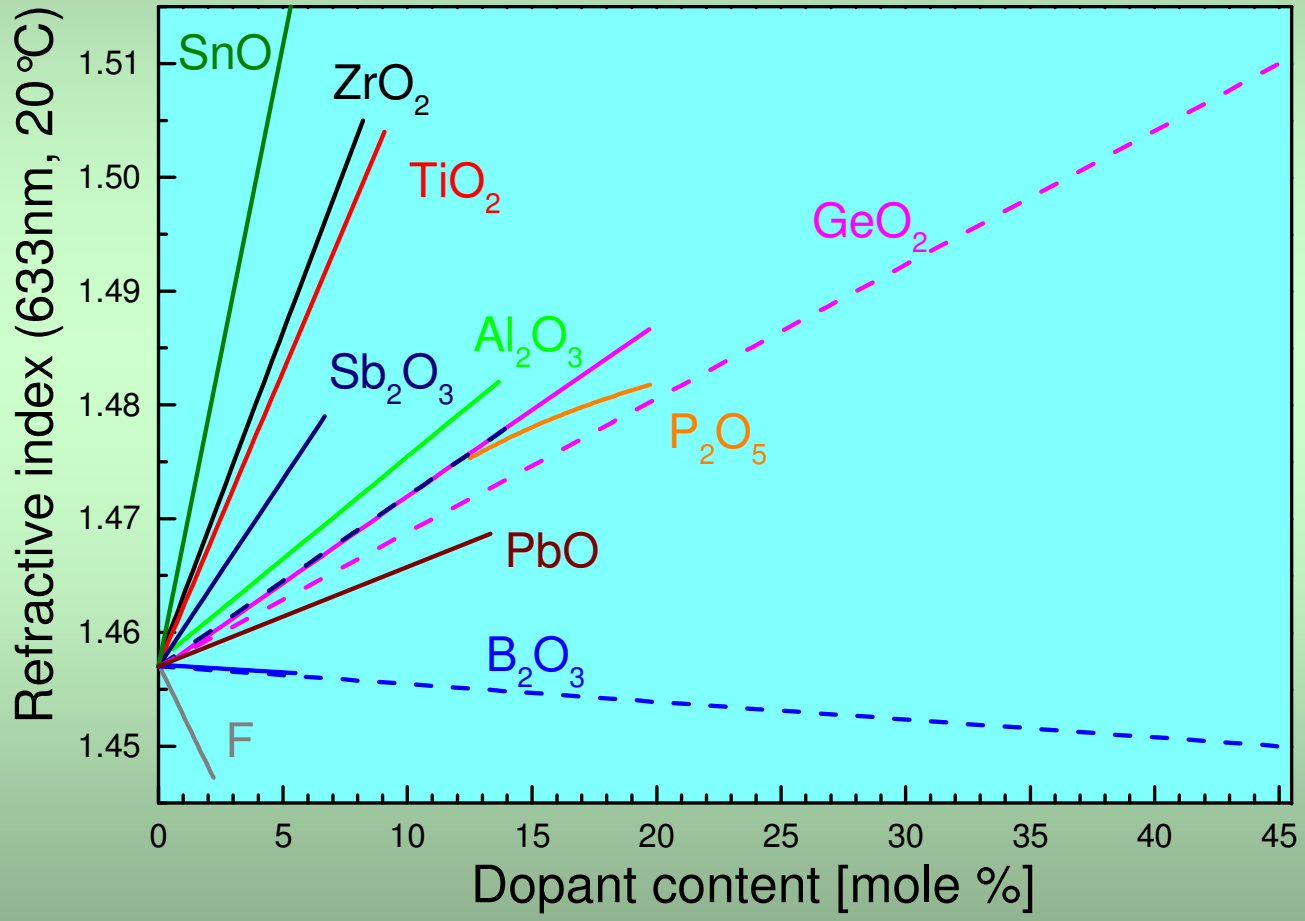
MCVD – Chemical Vapor Deposition



- Sequential sintering of **thin glassy layers** (of thickness 1-20 μm) onto inner wall of silica substrate **resulting in bulk material – preform**
- **high purity** (~ 10^1 ppb) **high preciseness** (better than 1 %)

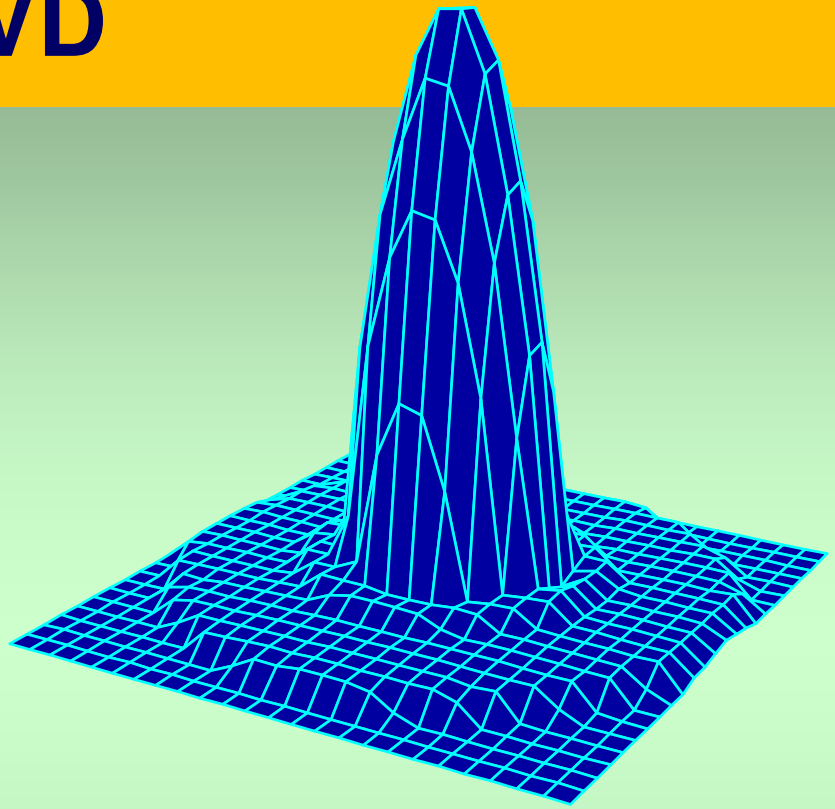
Complex material problem

Doped silica - optical properties



MCVD

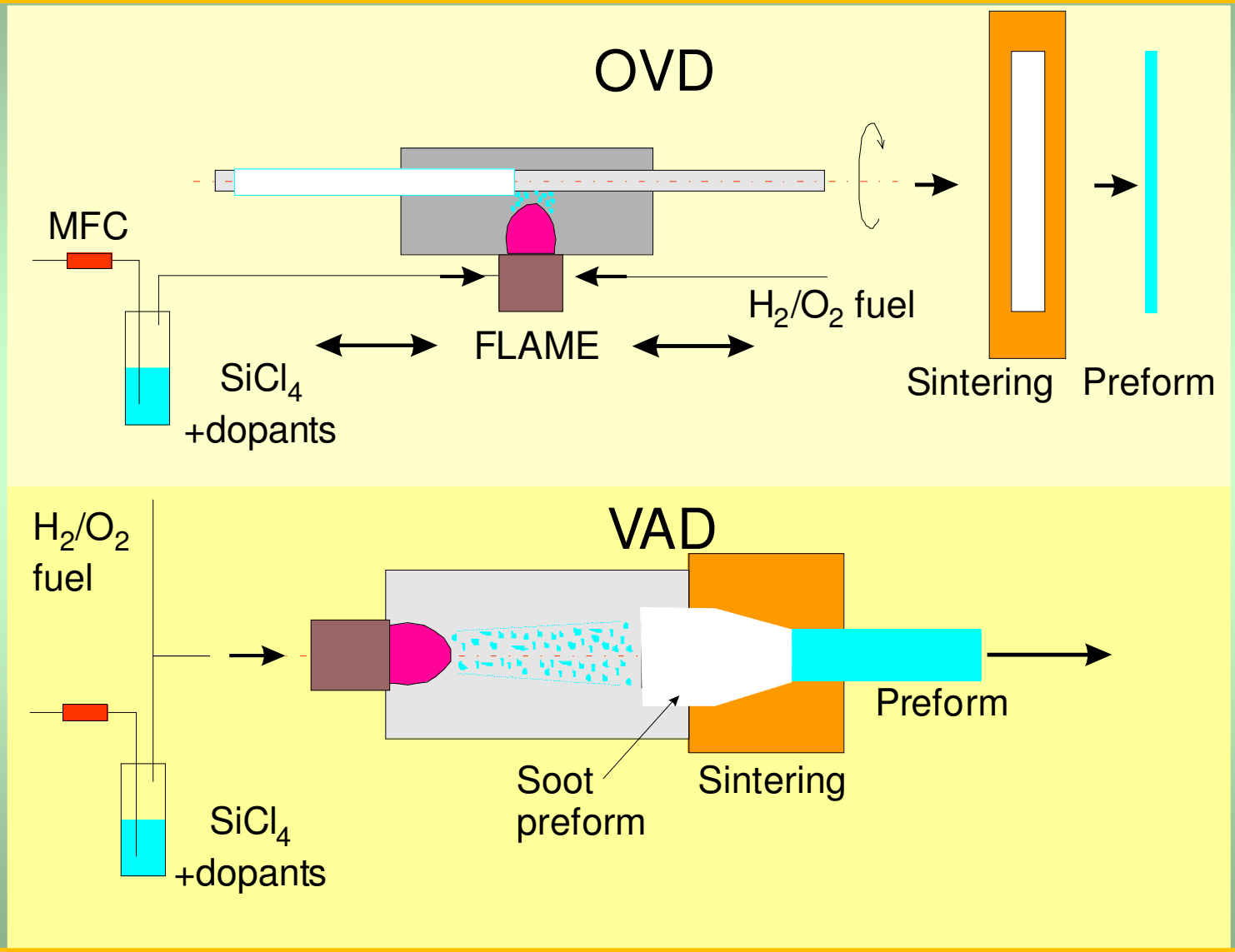
Microphoto of cross section of produced preform



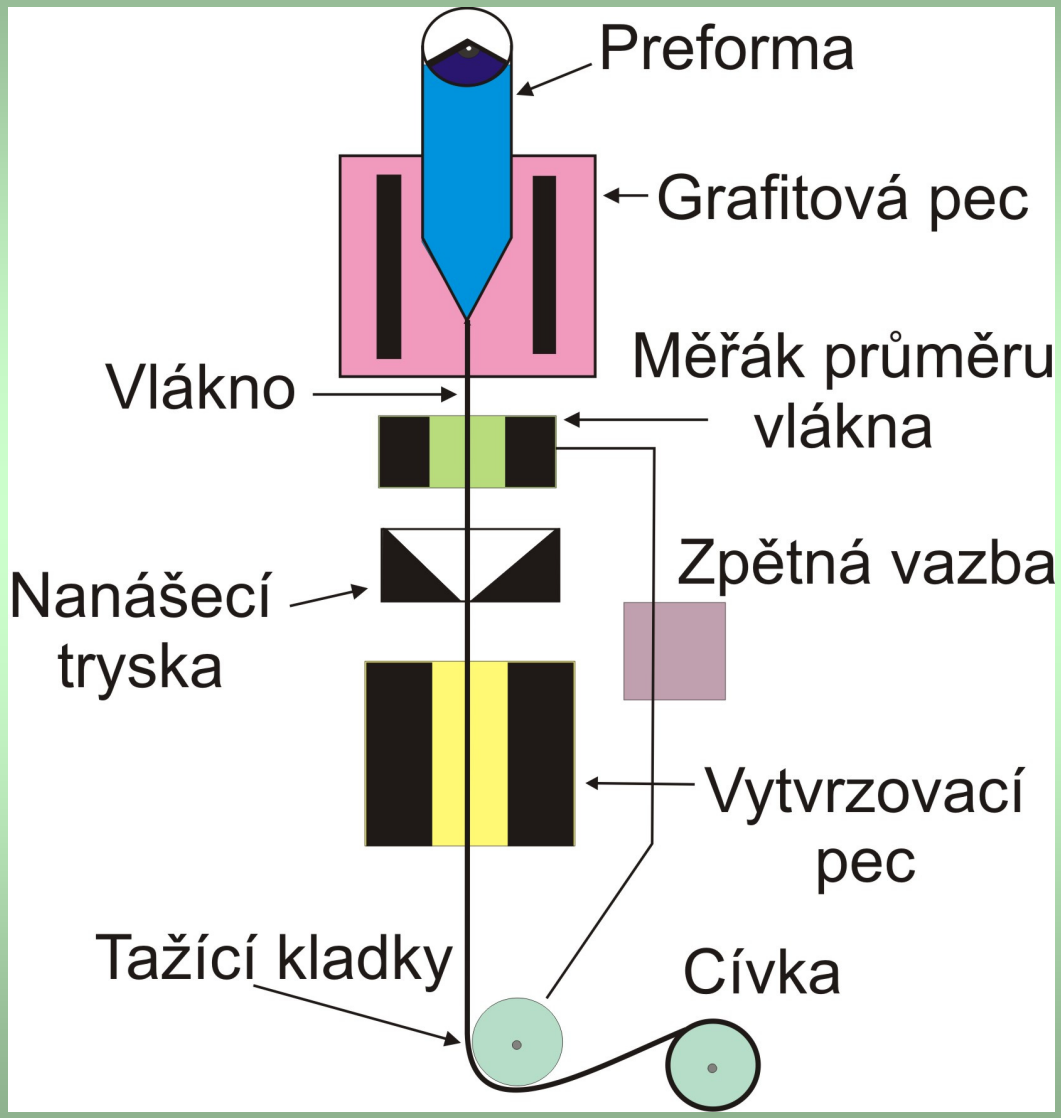
Tomography of the refractive-index profile of preform

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

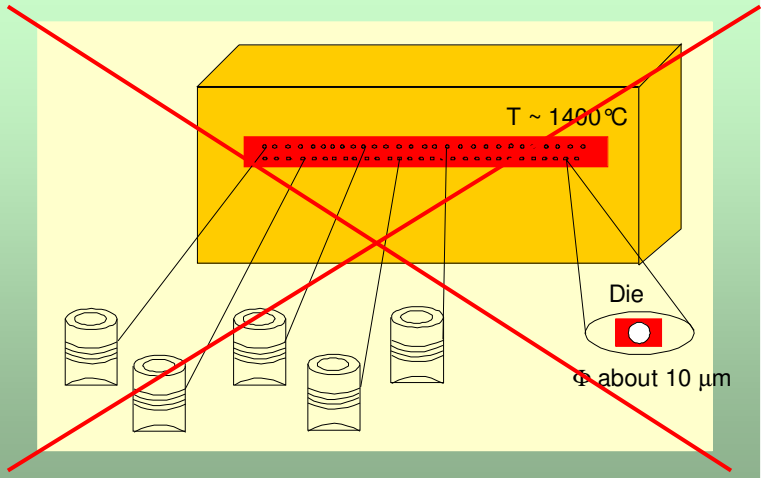
Other CVD Technologies



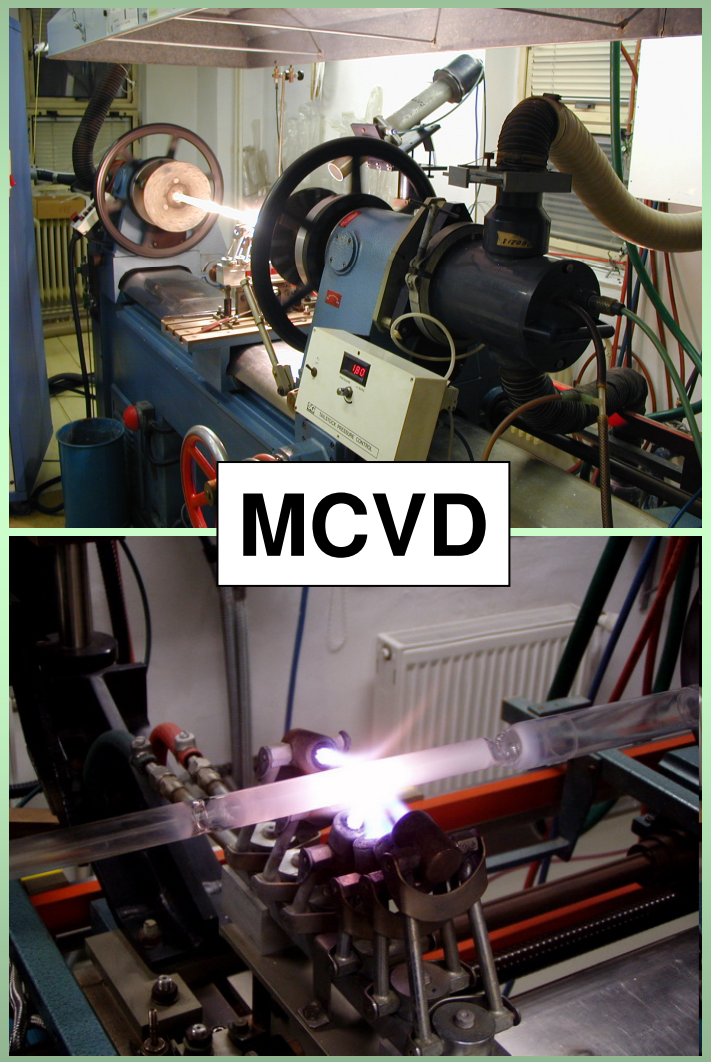
Drawing of optical fibers



- diameter
  80-1000 μm
- temperature
  1800-2000 ℃



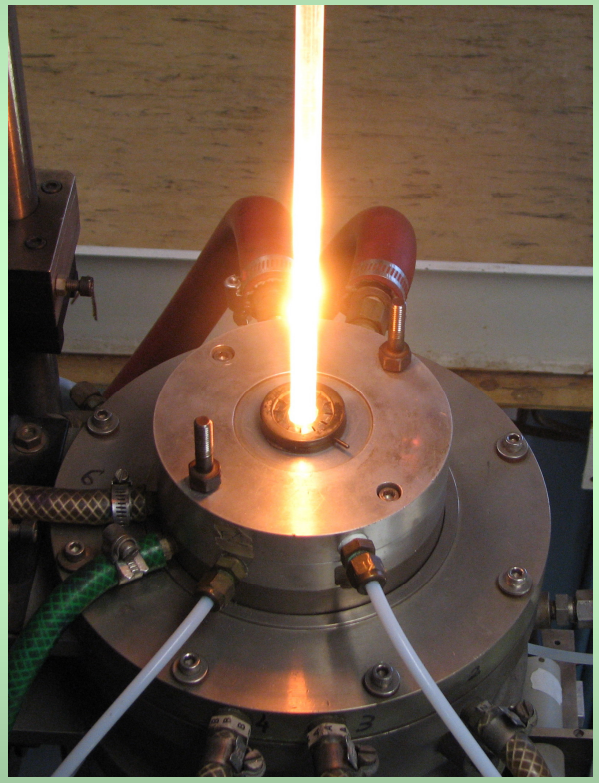
Technology of optical fibers



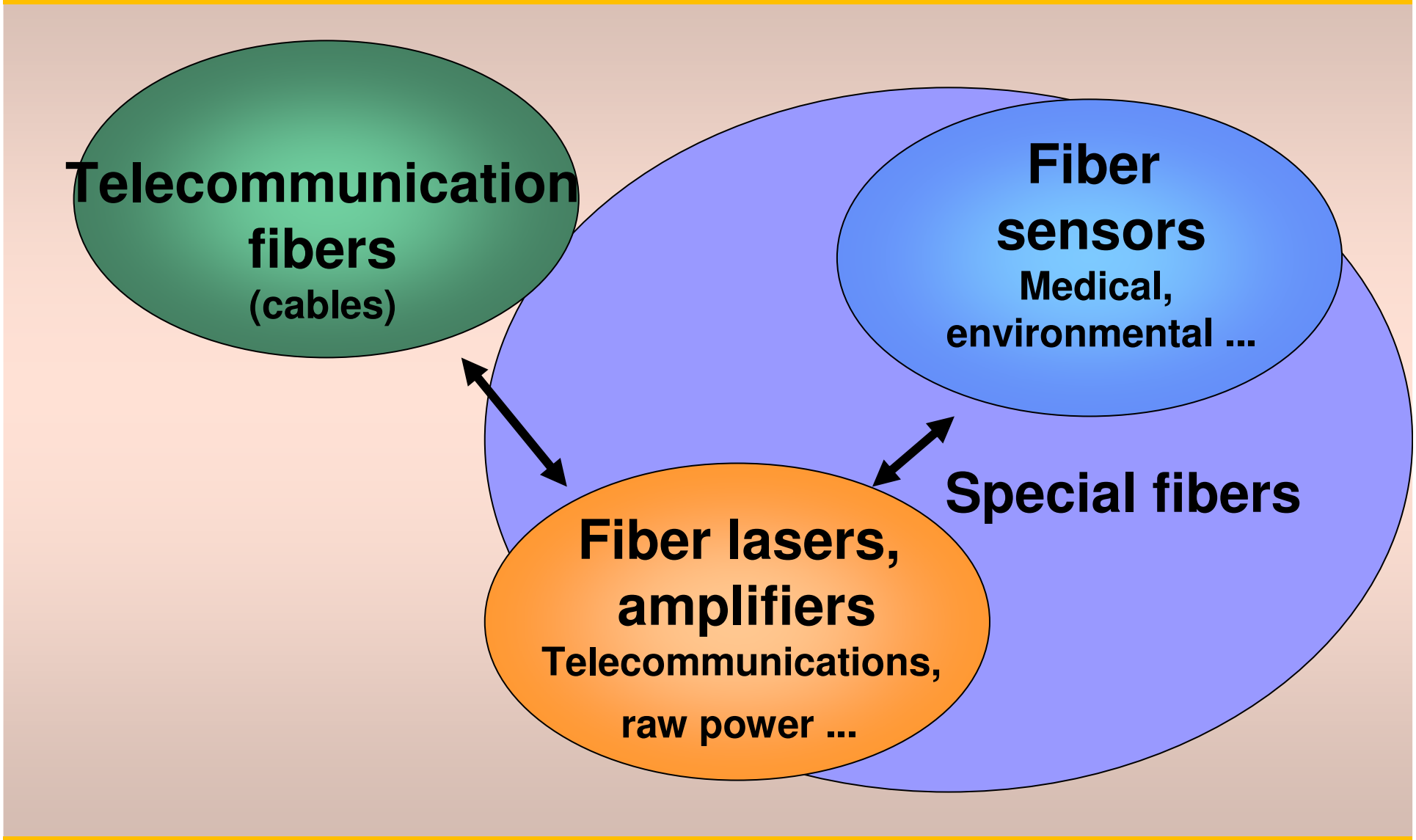
MCVD

preform

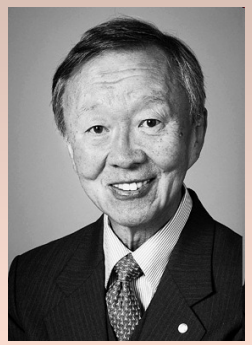
Drawing



Application



Telecommunications

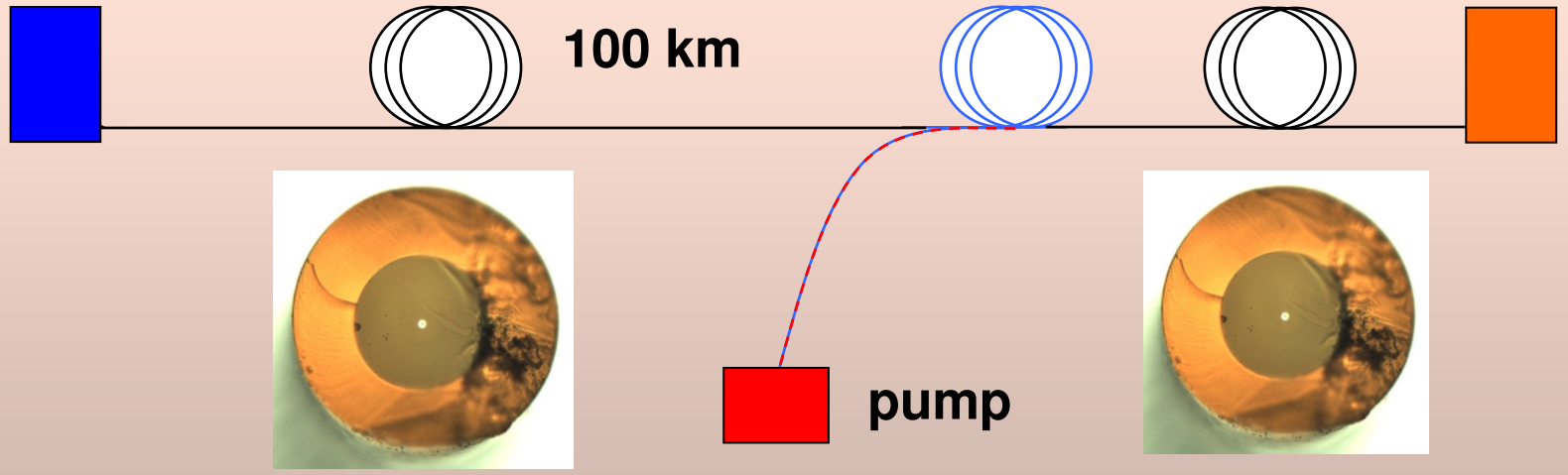


optoelectronics
fiber-optic (laser)

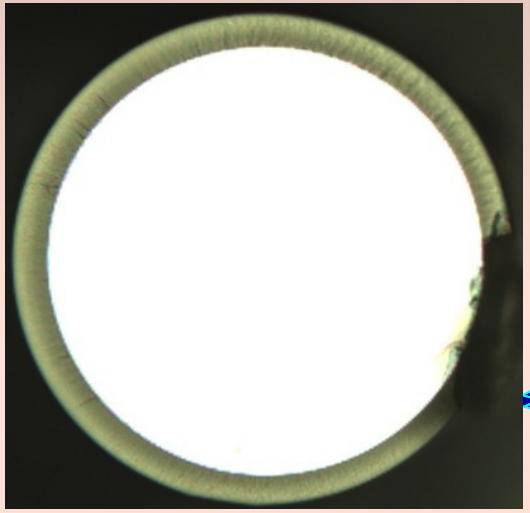
Kao **Maiman**

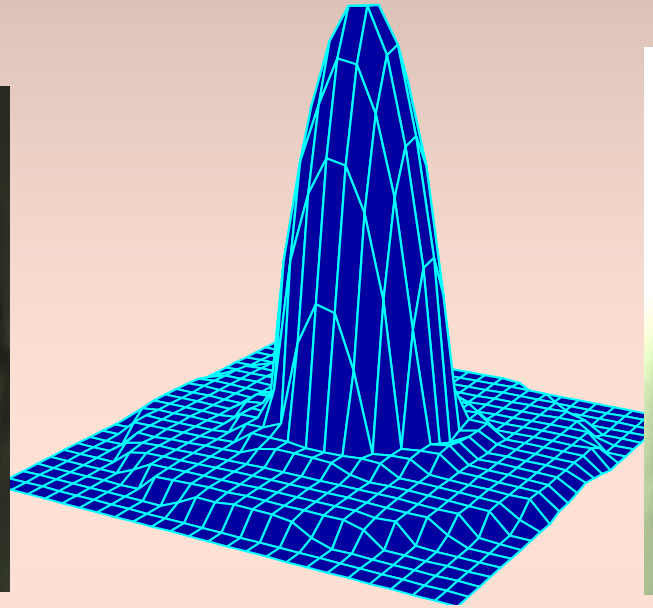
optoelectronics
fiber-optic (amplifier)

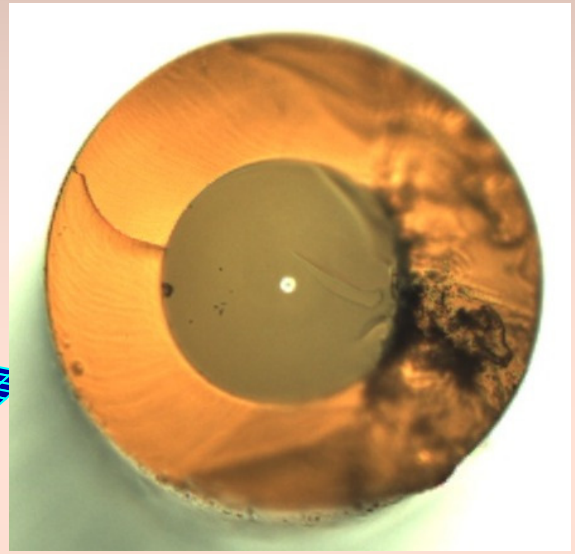
source **fiber** **amplifier** **detector**



Telecommunications







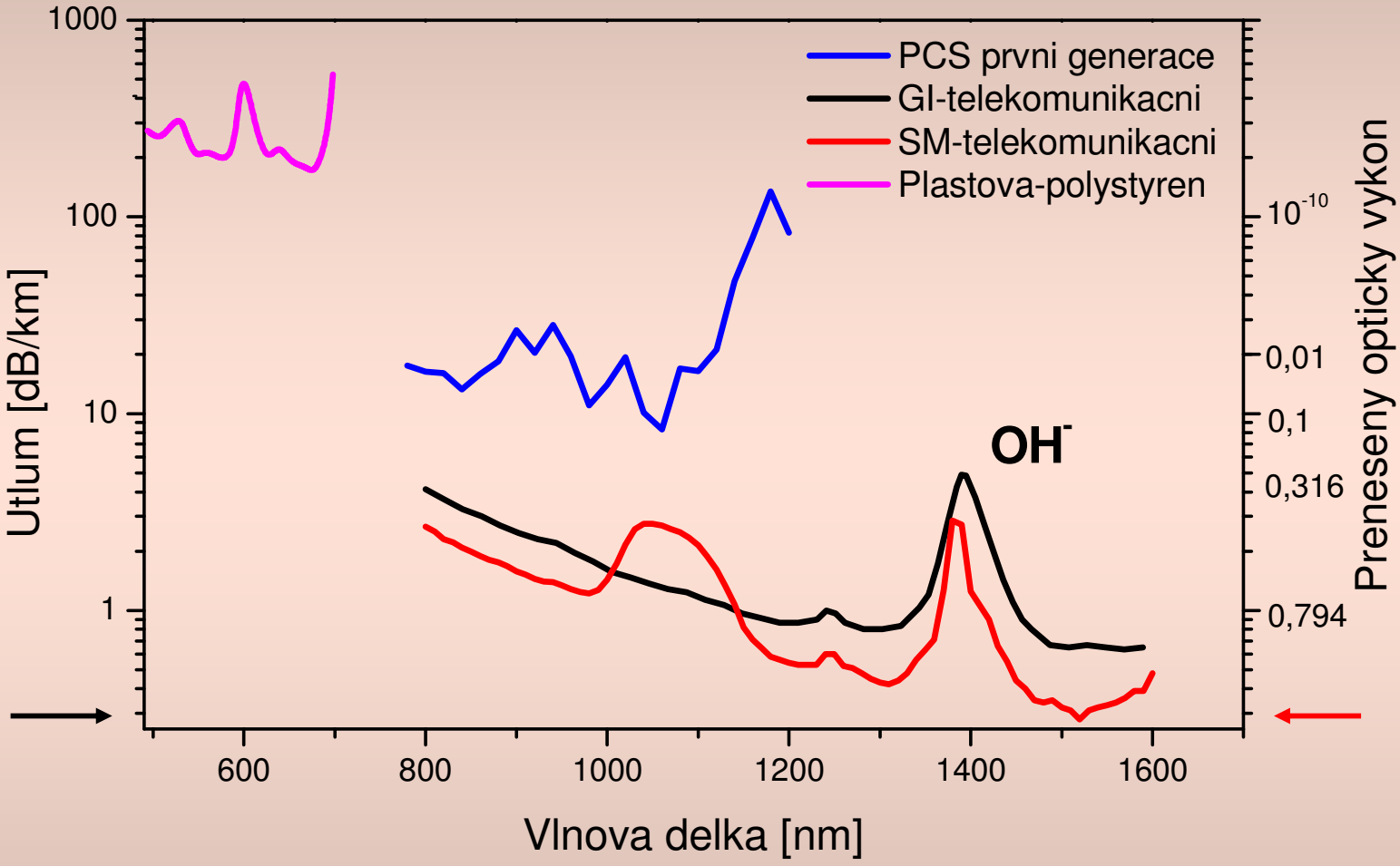
PCS Ø 200 – 600 um
technology transfer
VÚSU Teplice, MM

GI - technology transfer
VÚSU Teplice, Hesfibel

SM 1300, 1550 nm

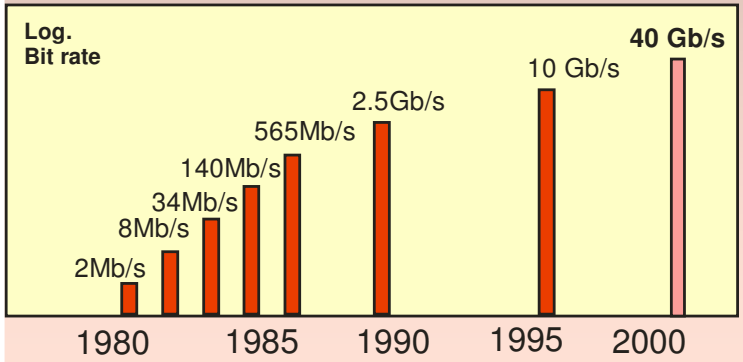
1981 – 1st demonstration of PCS optical fiber – CZ
2007 : 700 000 km telecom fibers in CR installed

Telecommunications



$$\alpha(\lambda) = -(10/L) \cdot \log(P_{output}/P_{input}) \quad [dB/km]$$

Communications : increasing requirements on speed and ammount of information

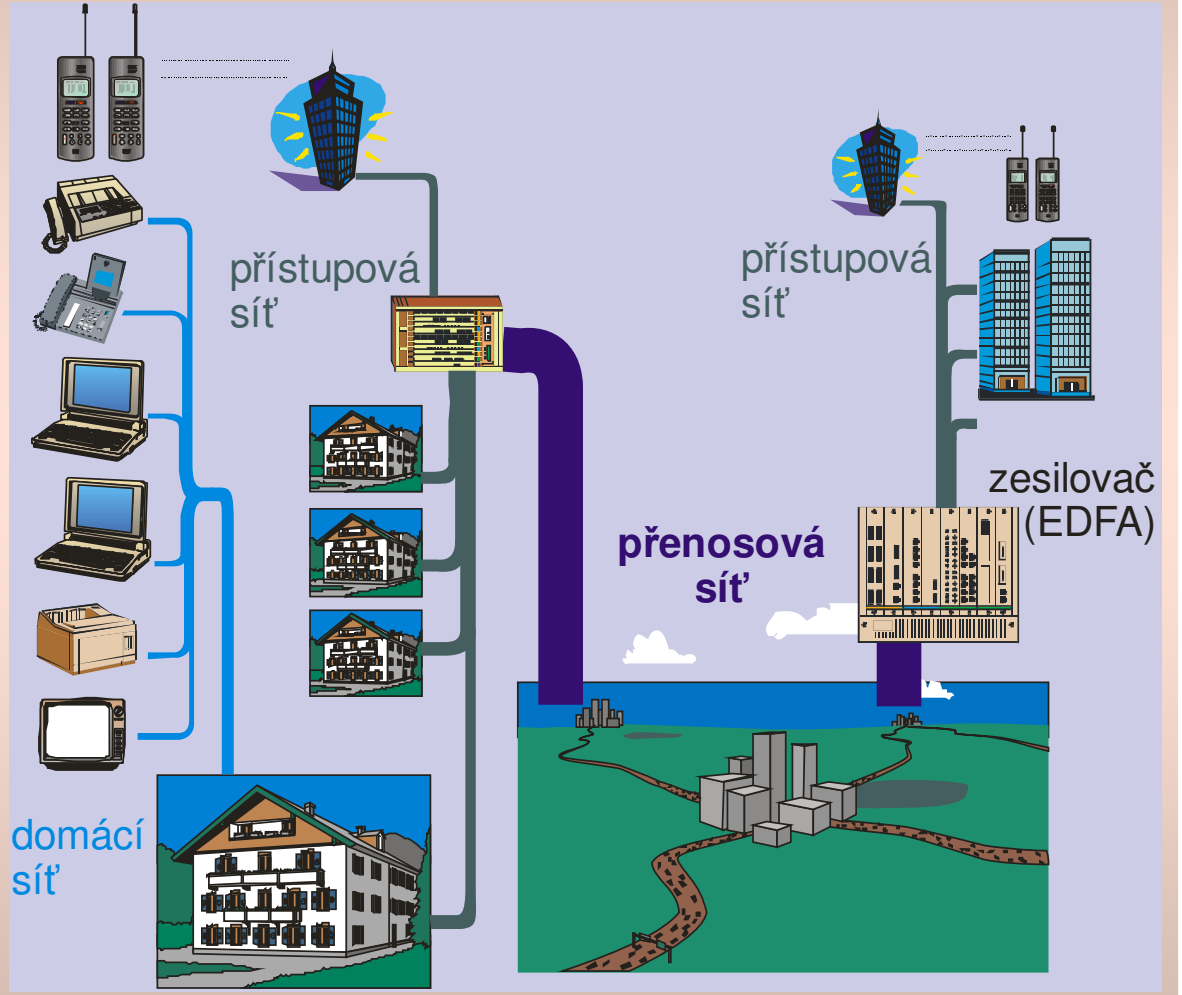


Solution : multiplexing

Time-division (TDM)

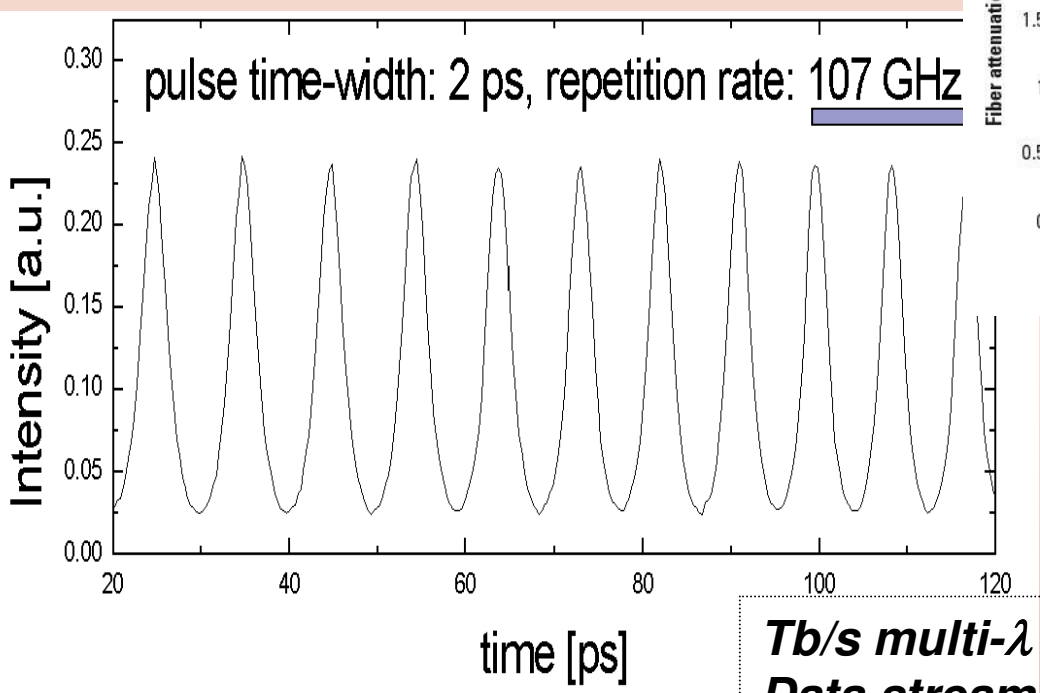
Wavelength (WDM)

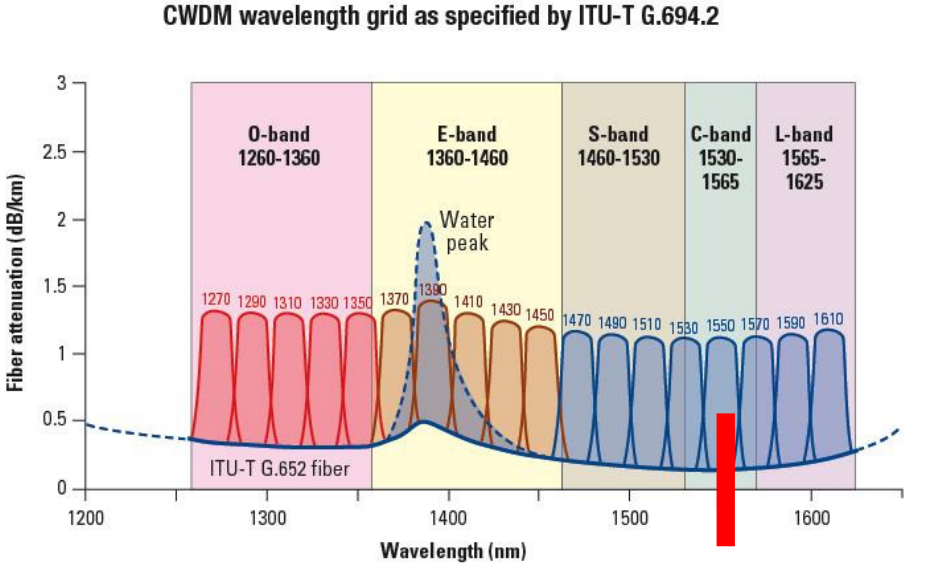
=> Full optical data processing



TDM

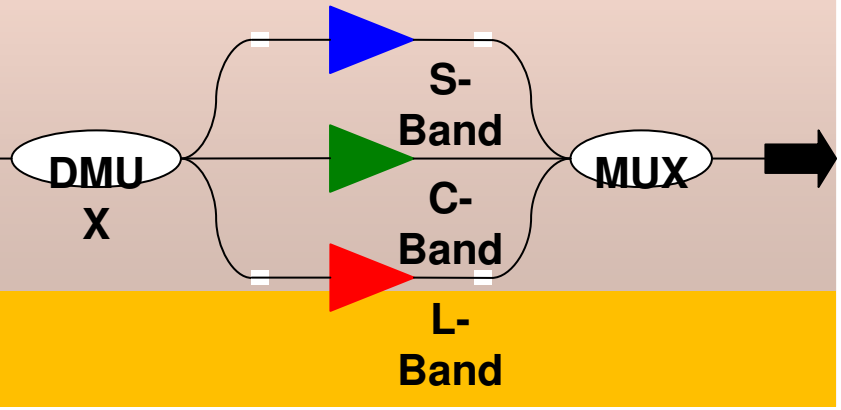
WDM





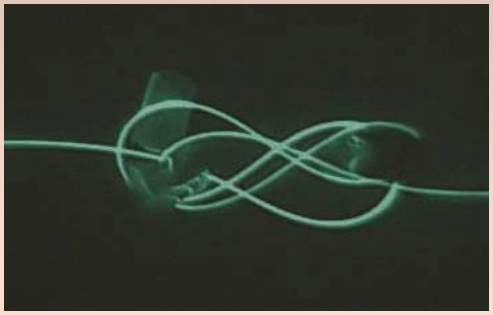
In collaboration with
CTU-FJFI, LPMC Nice

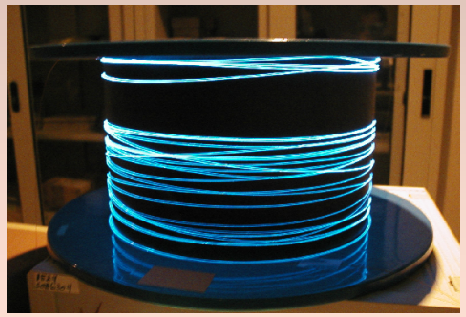
Tb/s multi-λ Data stream



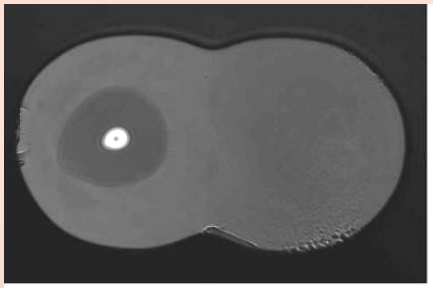
Optical fibers for fiber lasers, amplifiers

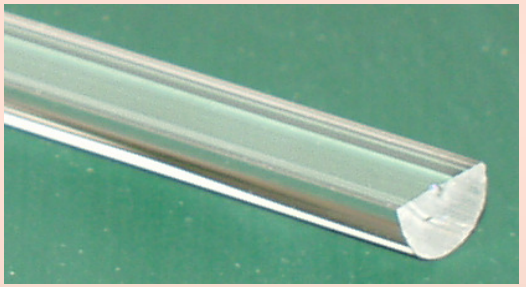
- Modification of :
- Composition
  - Doping with Er^{3+}, Tm^{3+}...



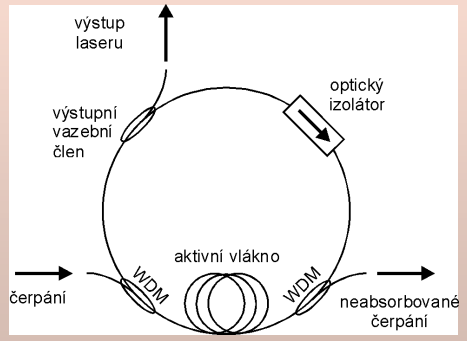


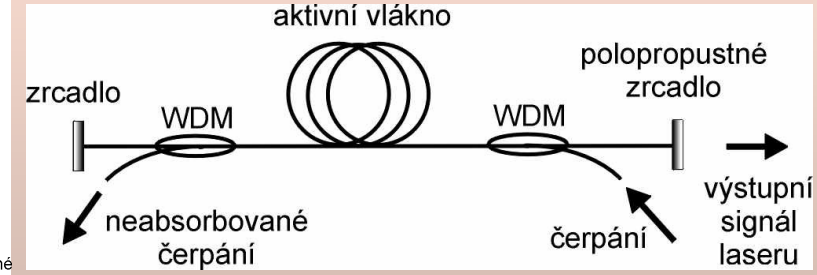
- Shape
  - stadium, D, flower ...



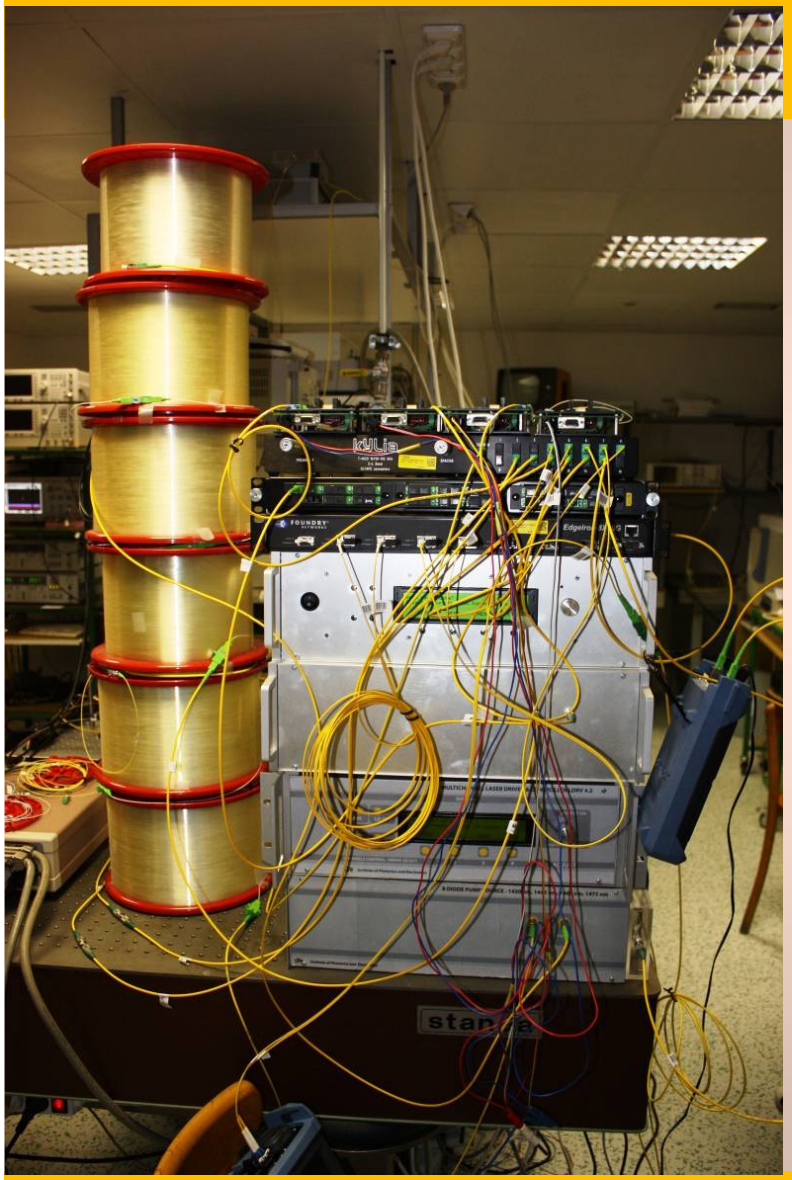


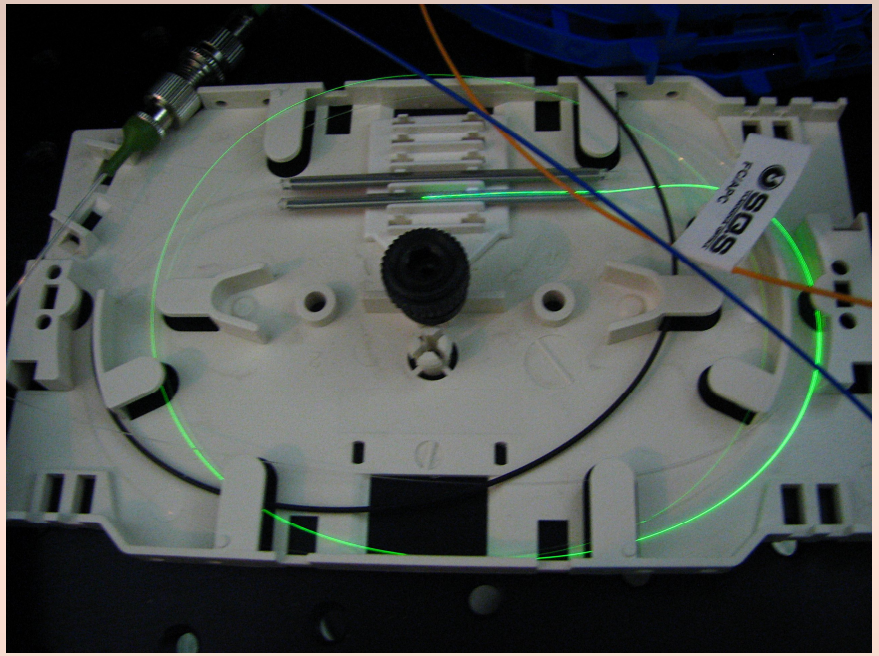
- Setup
  - ring
  - Fabry-Perot...





Telecommunications &
High-power fiber lasers





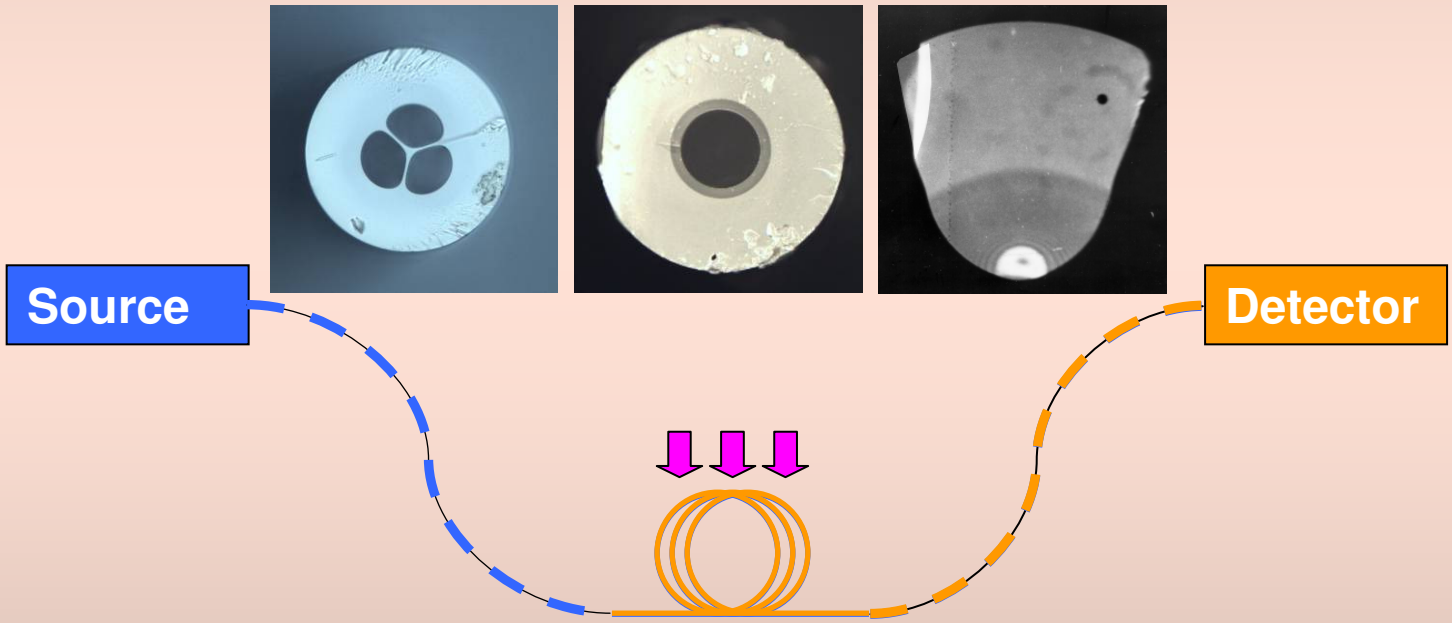
Er- fiber laser, length 5m, Liekki

Pavel Peterka

in collaboration with Cesnet :
testing 200 km line

Fiber-optic sensors

Continual reversible monitoring of (bio)chemical species and their concentration



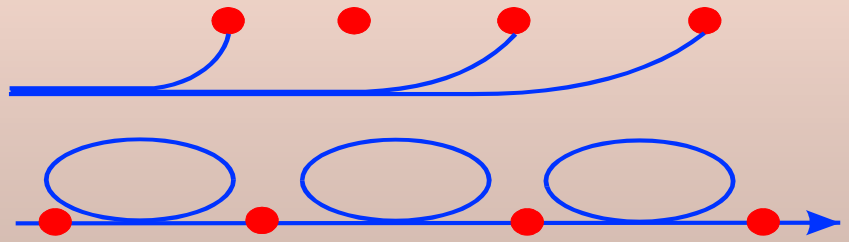
Change of output optical signal due to (bio)chemical changes in fiber vicinity.

Environmental monitoring, medicine, biology, homeland security ....

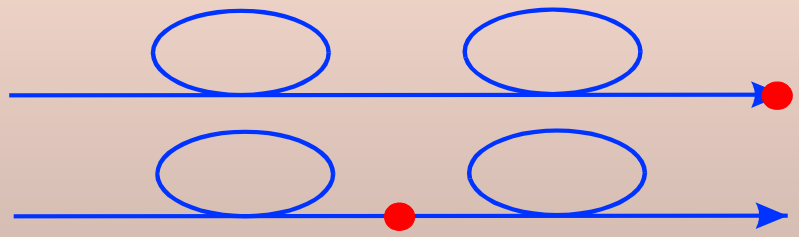
+ Remote sensing
+ Distributed
+ Explosive, high-voltage areas, human body

Solution : fiber-optic sensors

Multipoint (distributed) detection



Point detection



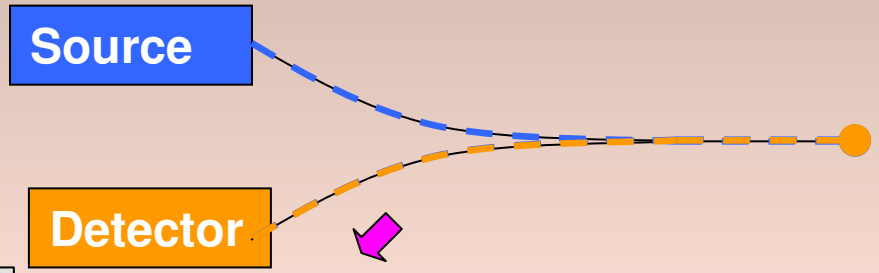
Refractometric sensor of hydrocarbons

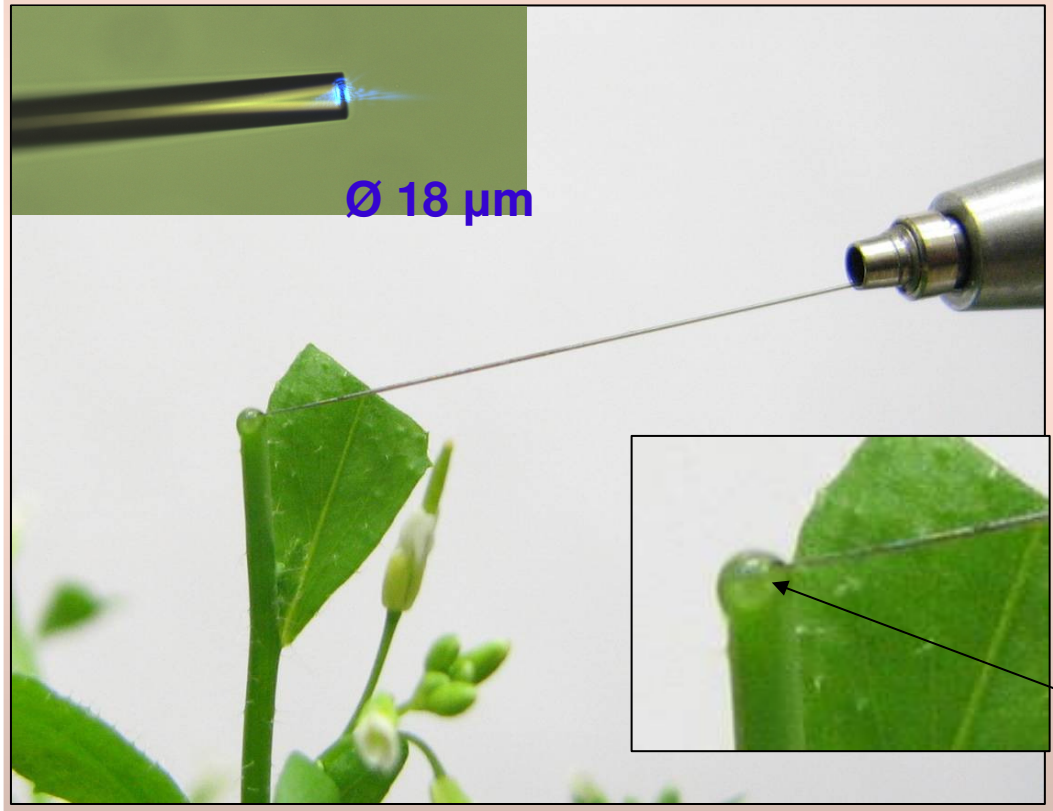
+ **sensitivity** : LOD ~ 3-5 mg/l ~ comparable to EU ecological limit
+ **time response** : seconds

In collaboration with Jean Monnet Saint-Etienne, Ecole Centrale de Lyon

In vivo detection of pH in biosamples

(droplets, cells)

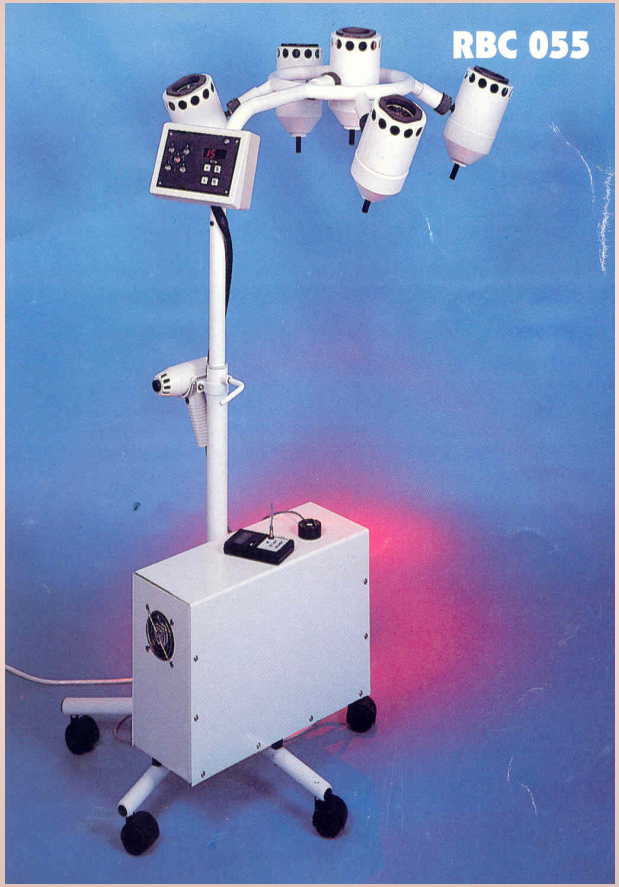




Fiber-optics for medical application

In collaboration

- Angioplastics - cleaning of arteries using an intensive laser pulse
- Fotodynamic diagnosis and therapy
- Optical biopsy - cancer diagnosis



SUMMARY

1. Fiber technology : preparation of structures of high preciseness from materials of ultra-high purity (impurities in ppbs only).
2. Fiber technology in two steps : preform preparation and fiber drawing.
3. Fibers conventional (passive) and special (active).
4. Optical fiber – one of the most important invention of 20th century – everyday use
5. Research of optical fibers (CR) :

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
- **V. Matejec, I. Kasik**, M. Chomat : Fundamentals and performance of the MCVD aerosol process, in Aerosol chemical processes in the environment, Levis (2000)
- **J. Schrofel, K. Novotný** : Optické vlnovody, SNTL, 1986
- **Saaleh,** Fotonika (1 - 4), Matfyzpres

- Československý časopis pro fyziku 1/2010, 4-5/2010, 1/2011
- Jemná mechanika a optika 55 (2010)
- Sdělovací technika 3/2011
- Panorama 21. století 3/2012
- ČT2 – PORT : Co dokážou lasery - 29/9/2010
- ČT2 – Věda a vědci : Zkrocené světlo - 6/10/2010
- ČT1 – České hlavy – 10/2/2006