Optická vlákna

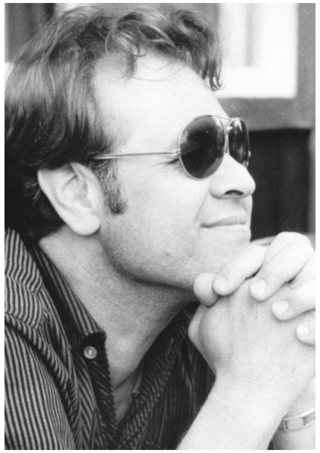
metody přípravy a použití pro vláknové senzory, zesilovače a lasery

Ivan Kašík

Ústav fotoniky a elektroniky AV ČR, v.v.i. (ÚFE)

ÚFE AVČR, Kasik® & FJFI ČVUT



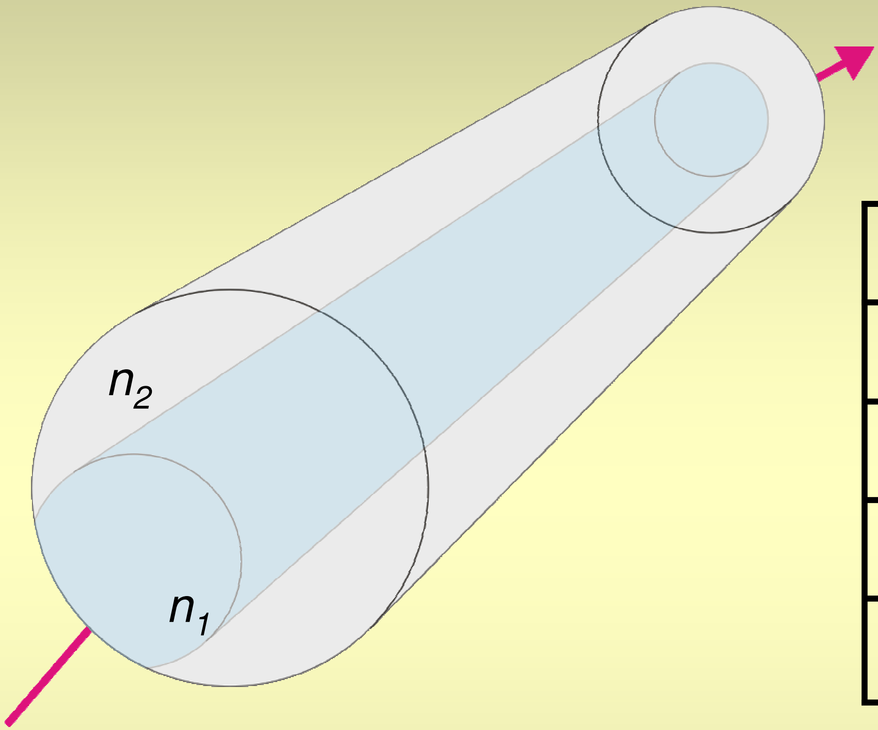
Prof.Čtyroký, doc.Homola, Dr.Matějec, **Dr. Ivan Kašík**
táta

I.Kašík, Š.Antalovský, P.Kopřiva: *Životnost ocelových válců pro válcování za studena*, ČSVTS 1977
I.Kasik, S.Antalovsky, Strojírenství (26), 1976
I.Nedbal, J. Siegl et.al., Acta polytechnica, 1974

Martin Kašík
syn
FJFI 2009-11

Personal appointment : Basketball in Trojanka & U Pomníku

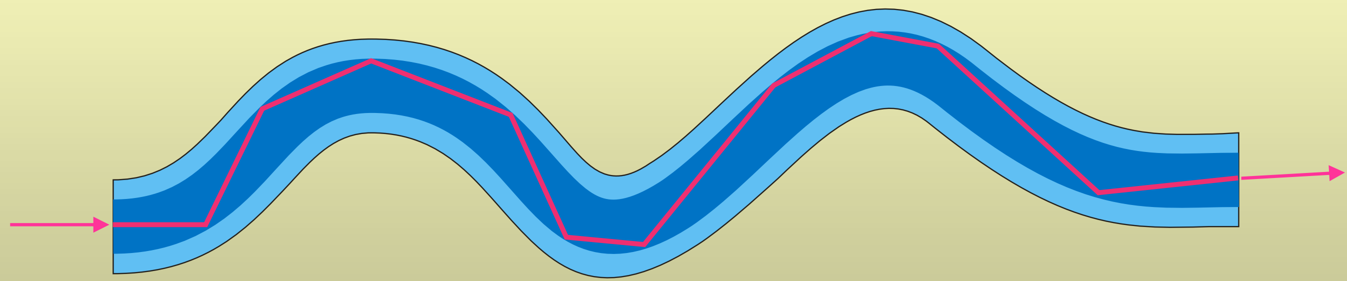
Optical waveguide - fiber



$n_1 > n_2$

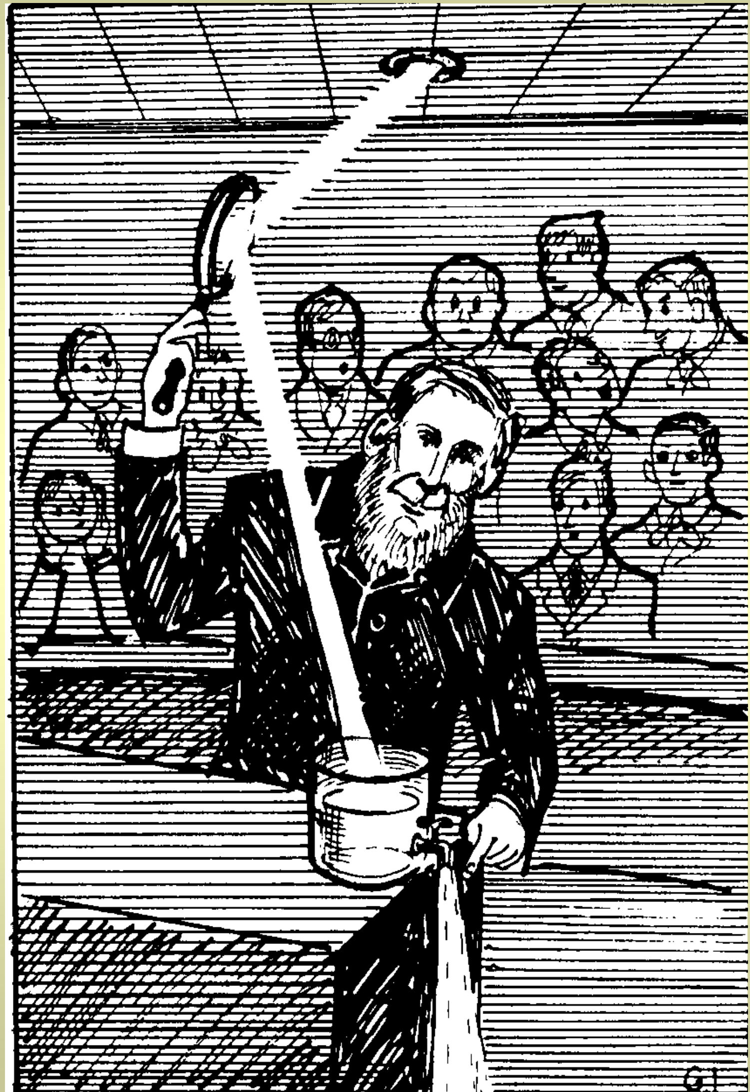
Tyndall J.

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

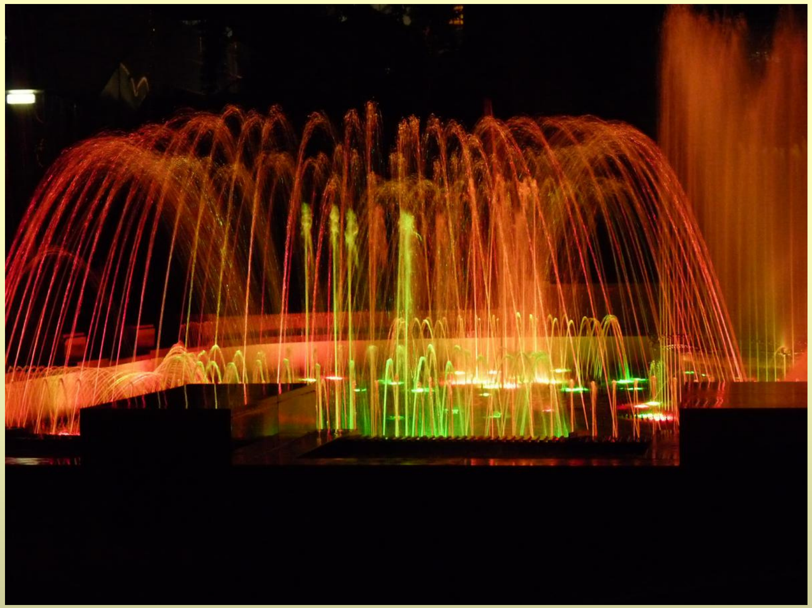


Optical waveguide

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

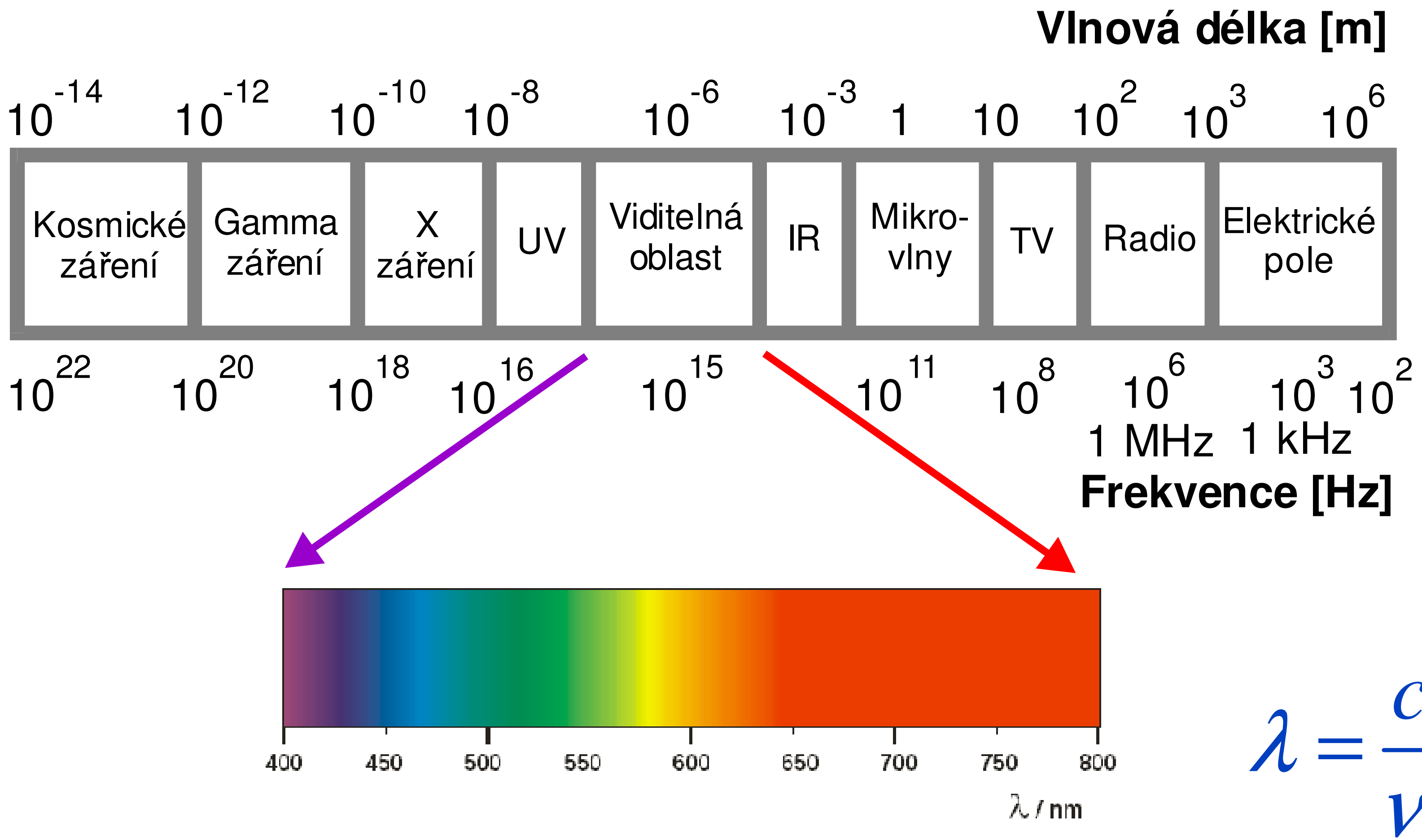


1853



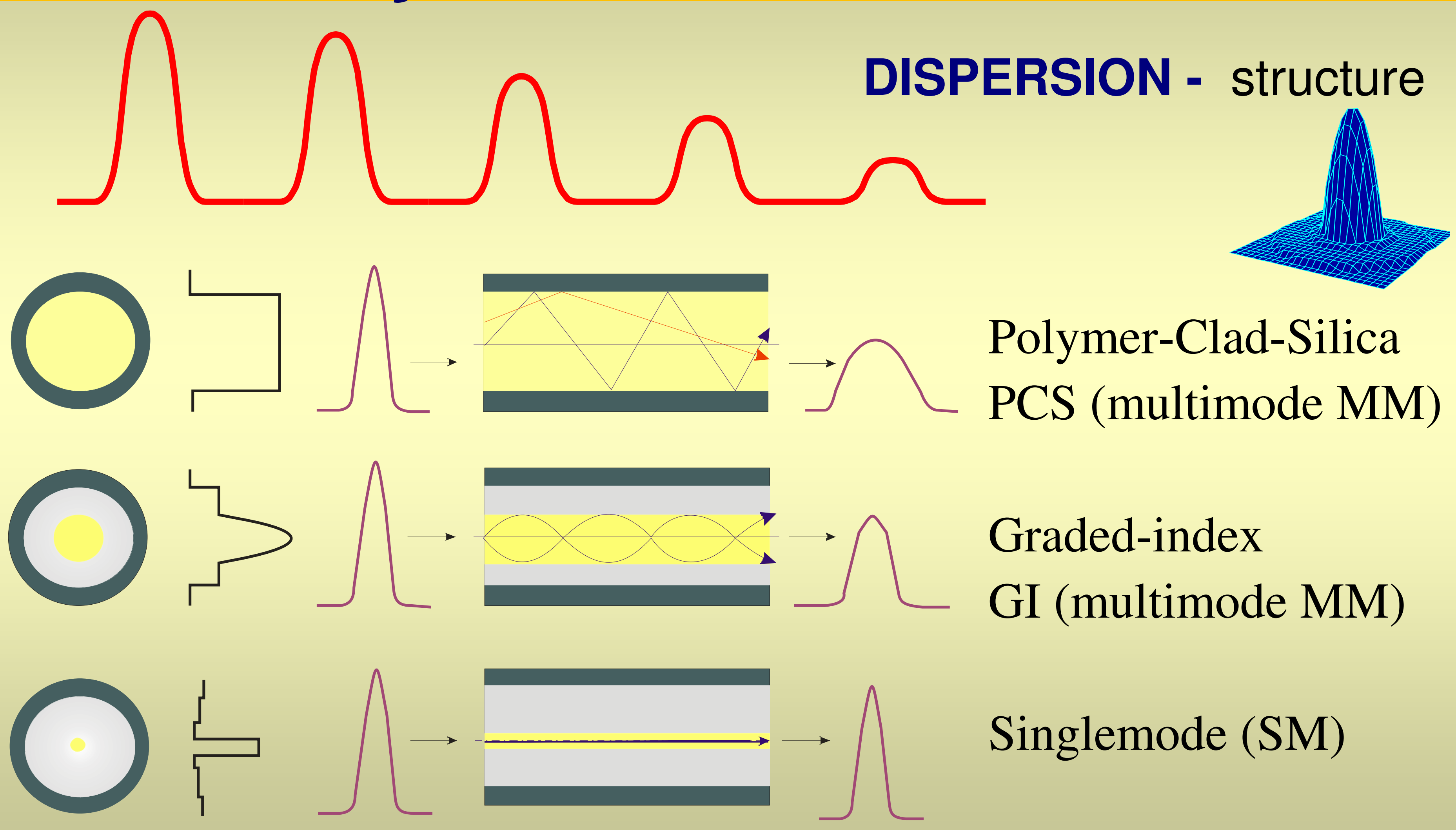
František Křižík

Optical communication principle

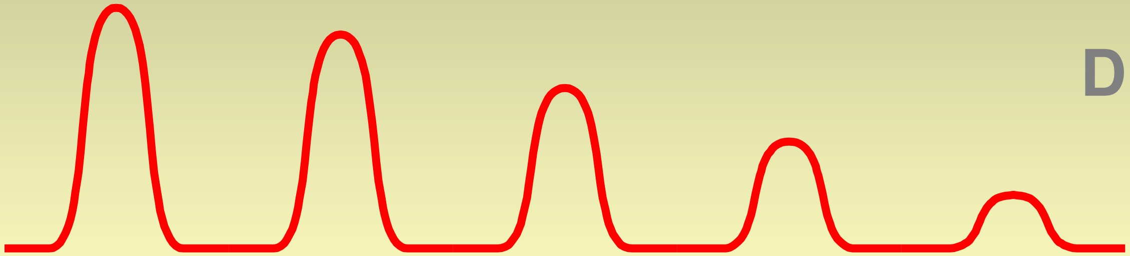


$$\lambda = \frac{c}{\nu}$$

Transmission, attenuation, dispersion
Purity & structure of material

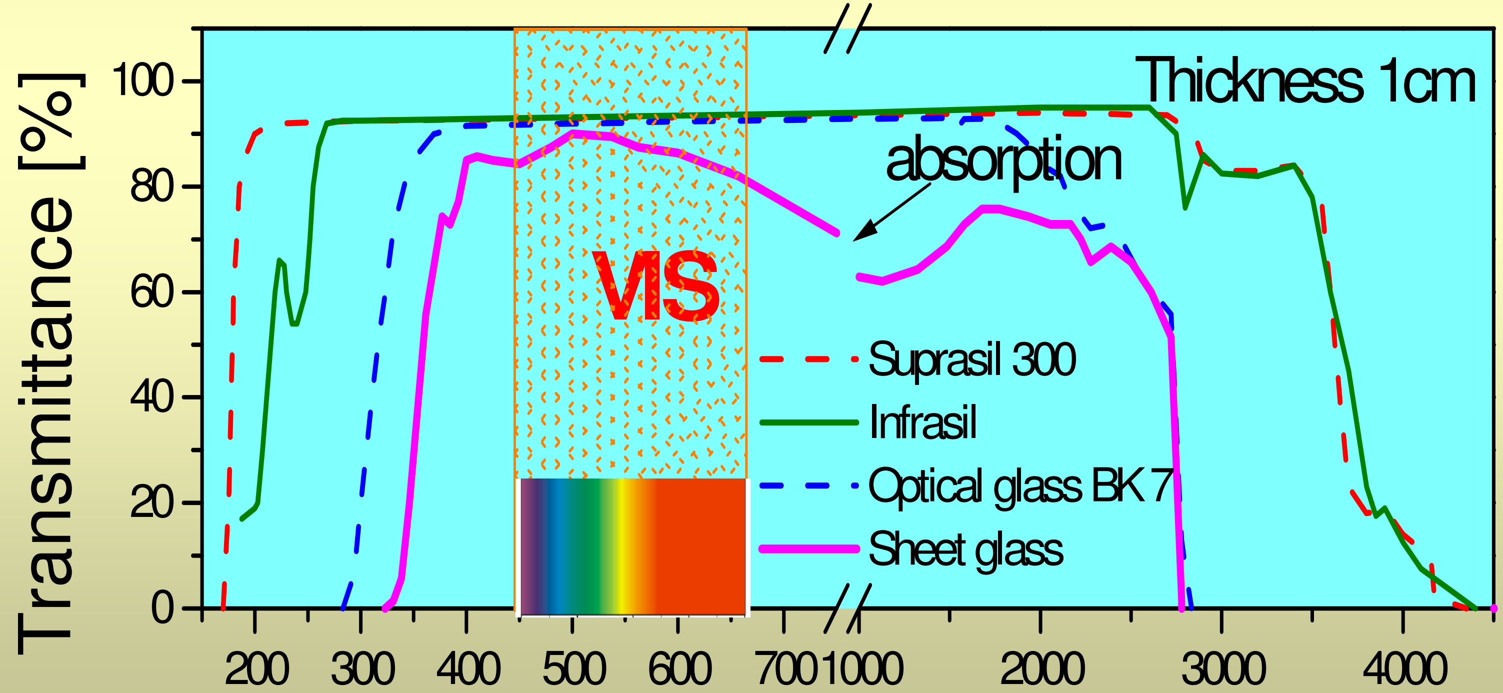


Transmission, attenuation, dispersion
Purity & structure of material



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)

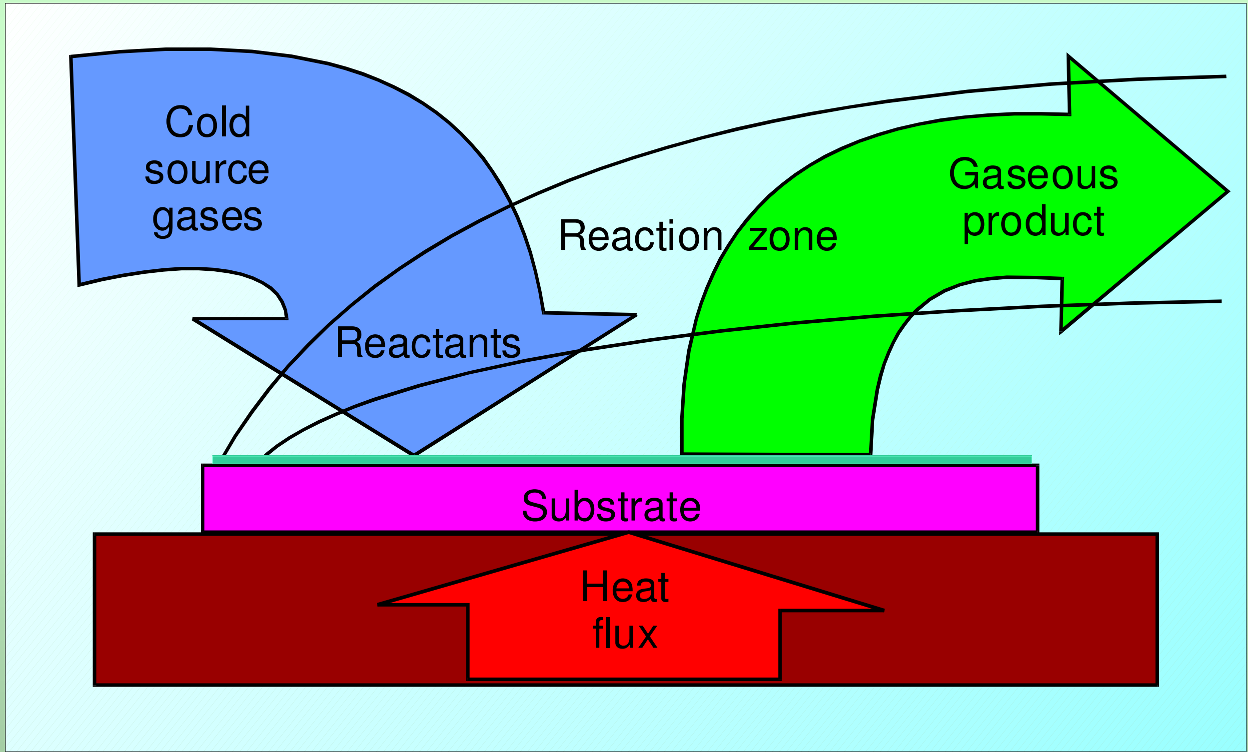
ppb – 10^{-9} (parts per billion) : content of impurities acceptable in FO Optipur materials

Ultra-pure technologies - CVD !

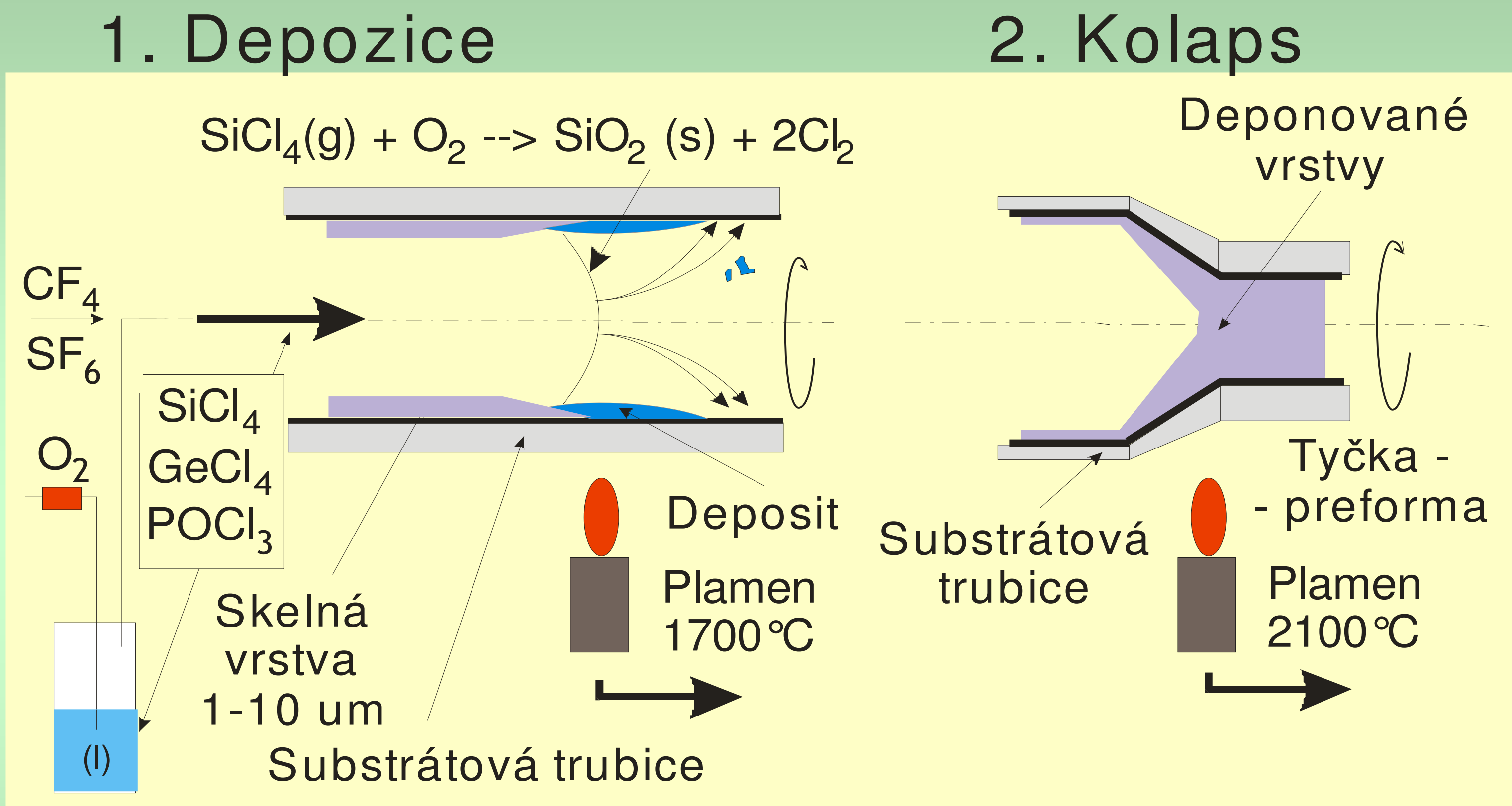
TECHNOLOGIES
CVD - Chemical Vapor Deposition

= 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]



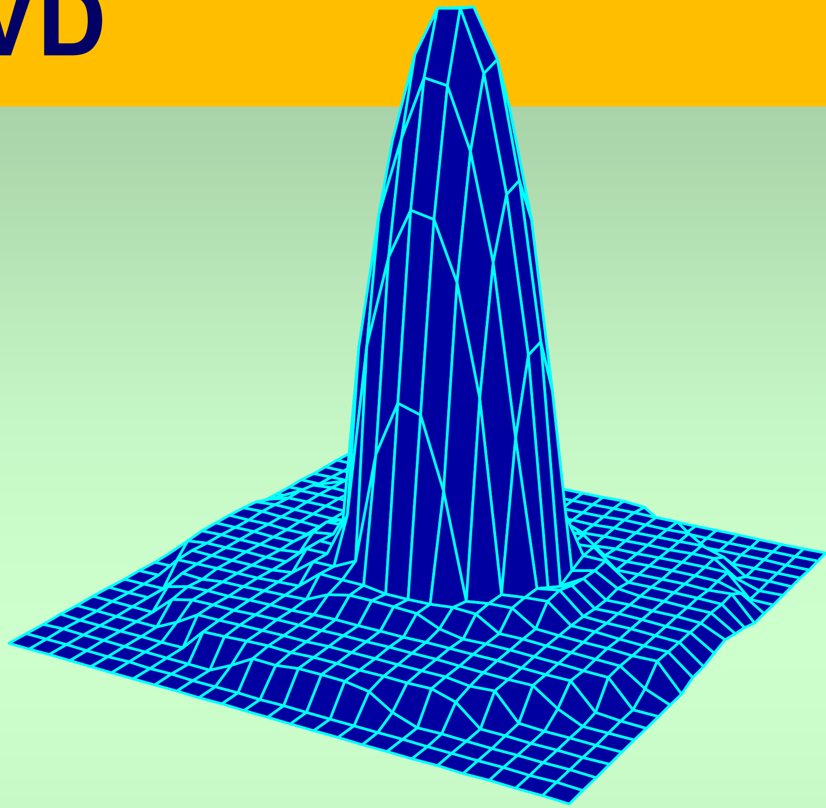
MCVD – Chemical Vapor Deposition



- 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 %)

MCVD

Microphoto of cross section of produced preform

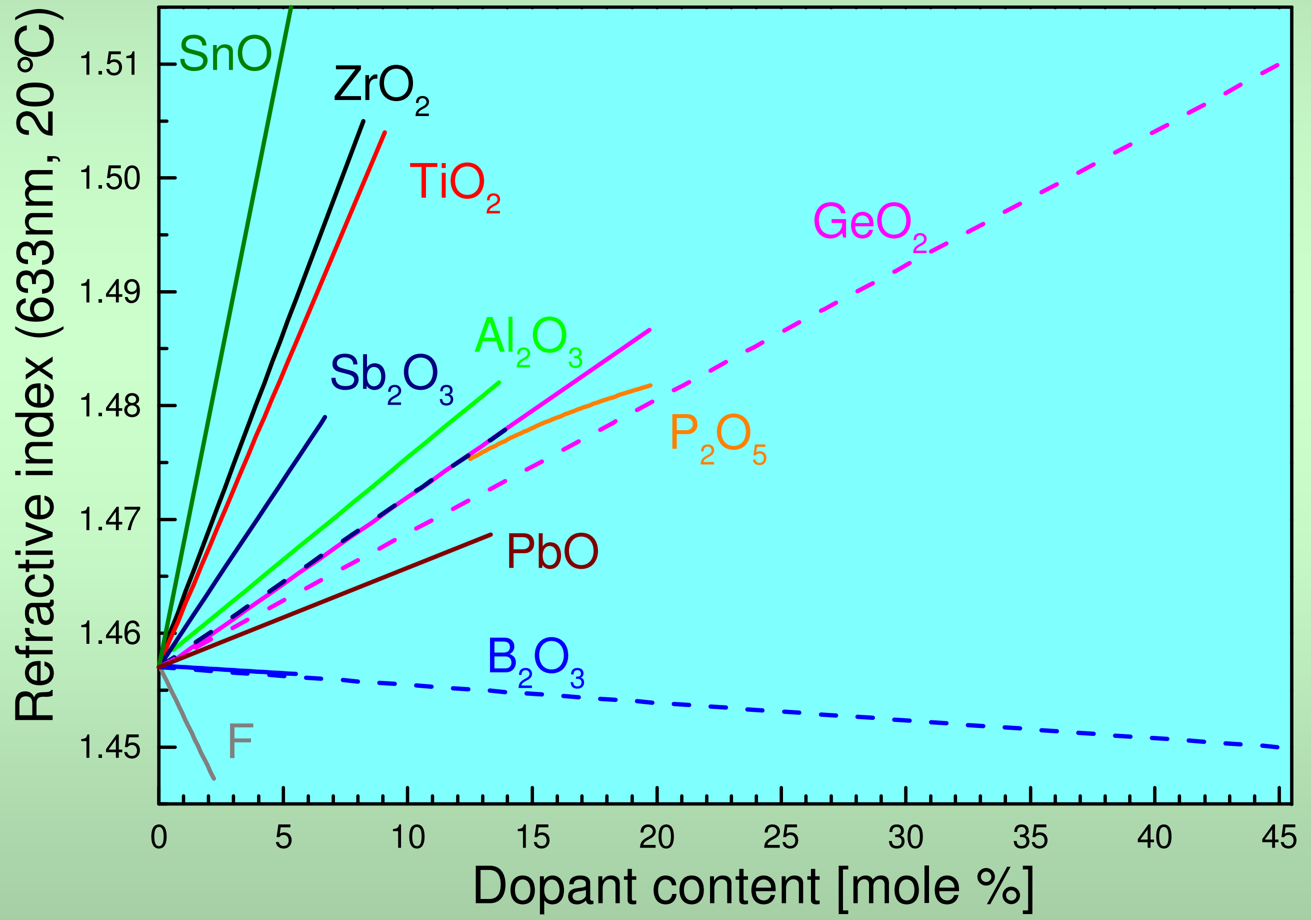


Tomography of the refractive-index profile of preform

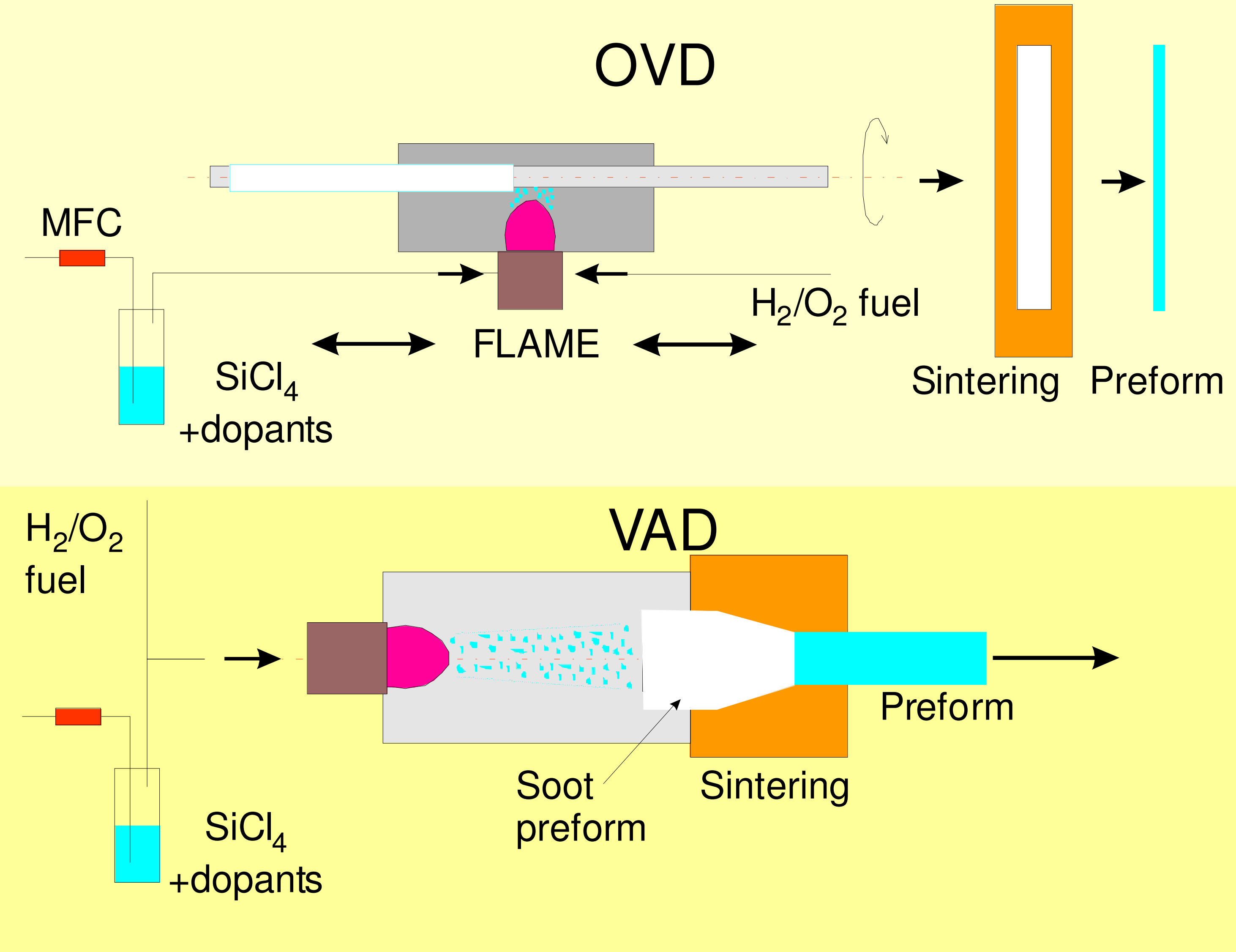
- High purity material due to FO-Optipur purity starting materials.
- High quenching rate ranging from 10^2 to 10^3 °C/s.

Complex material problem

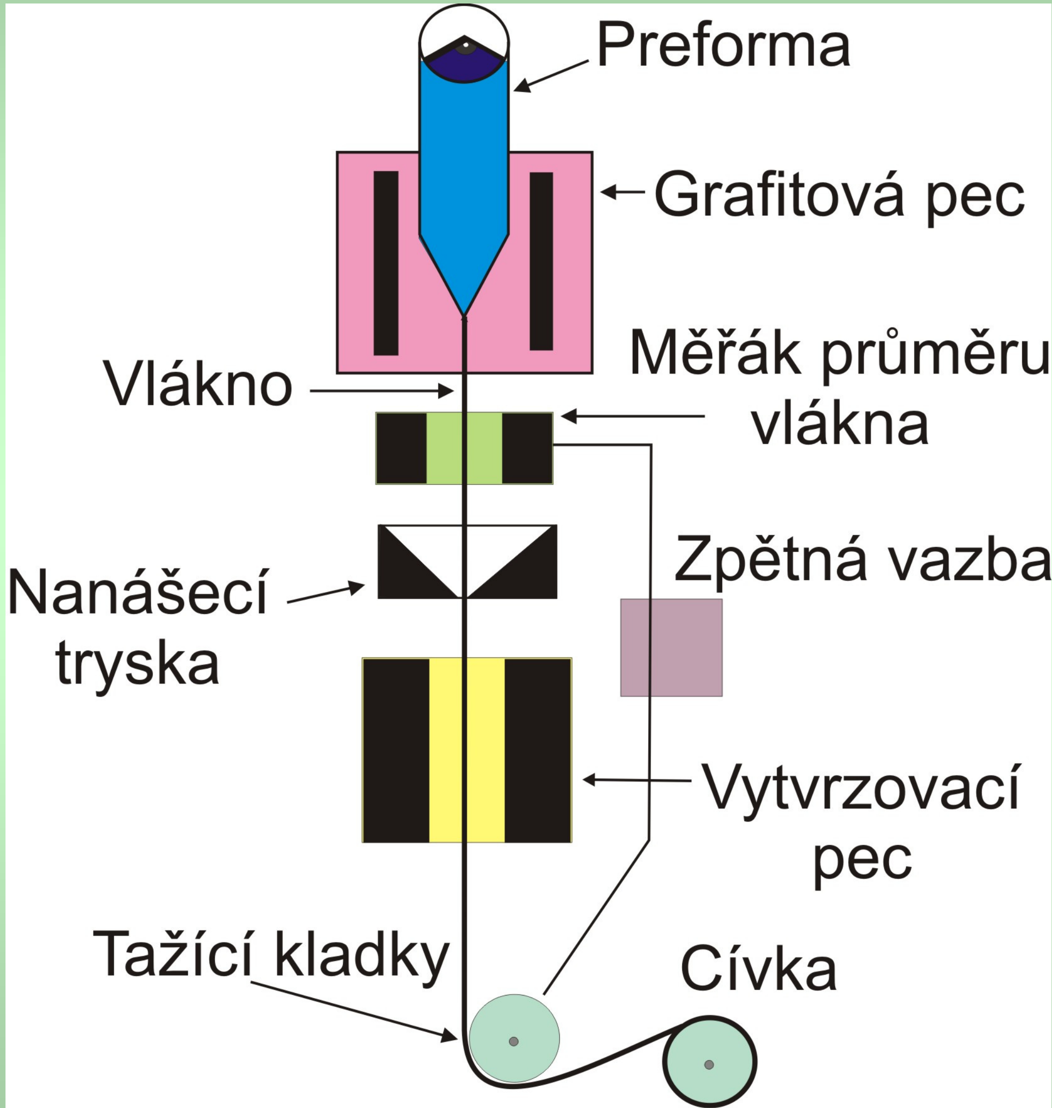
Doped silica - optical properties



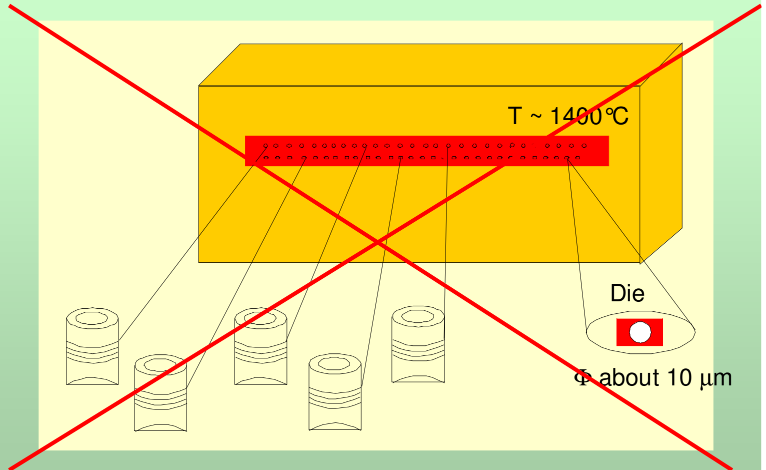
Other CVD Technologies



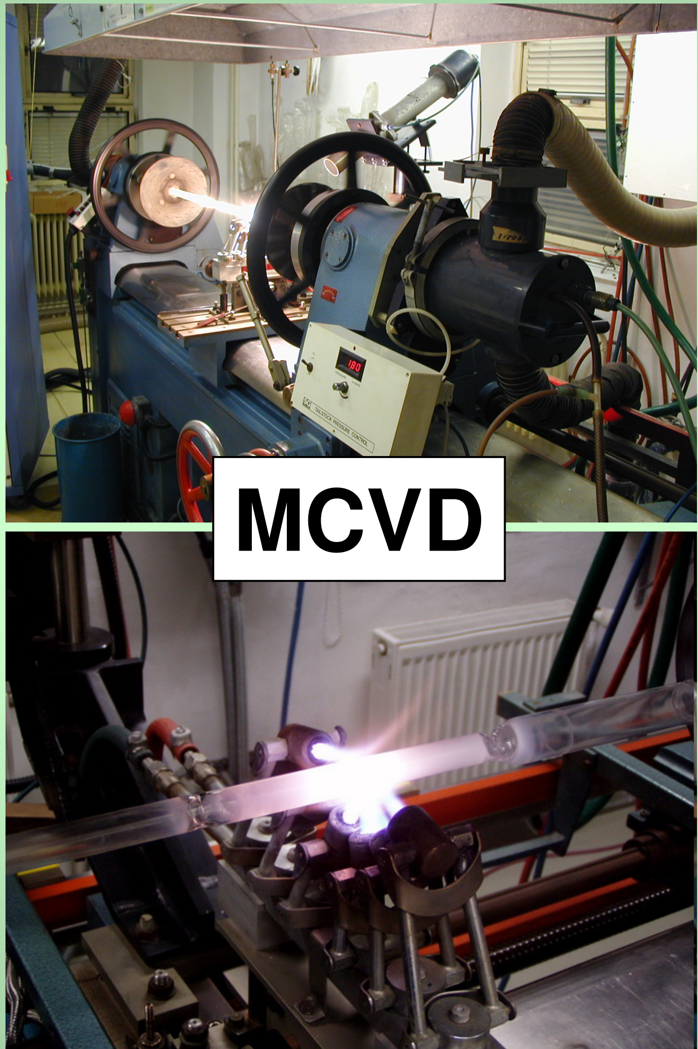
Drawing of optical fibers



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



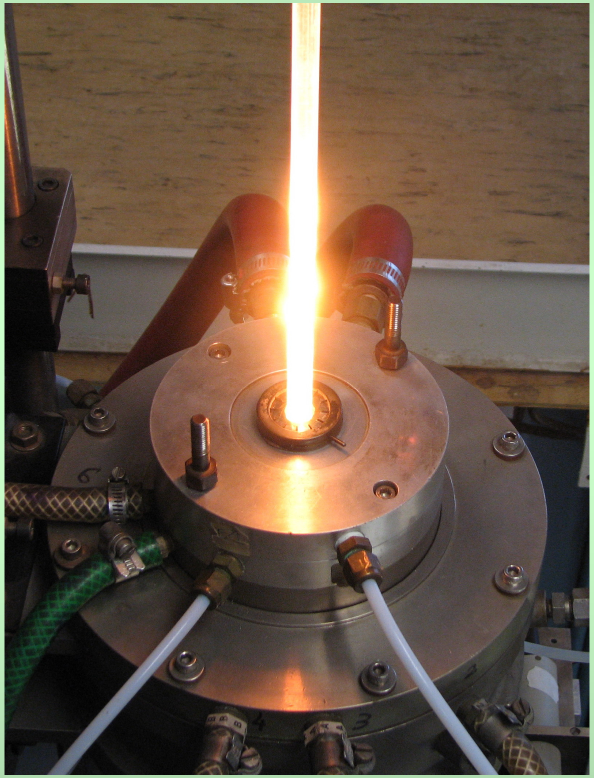
Technology of optical fibers



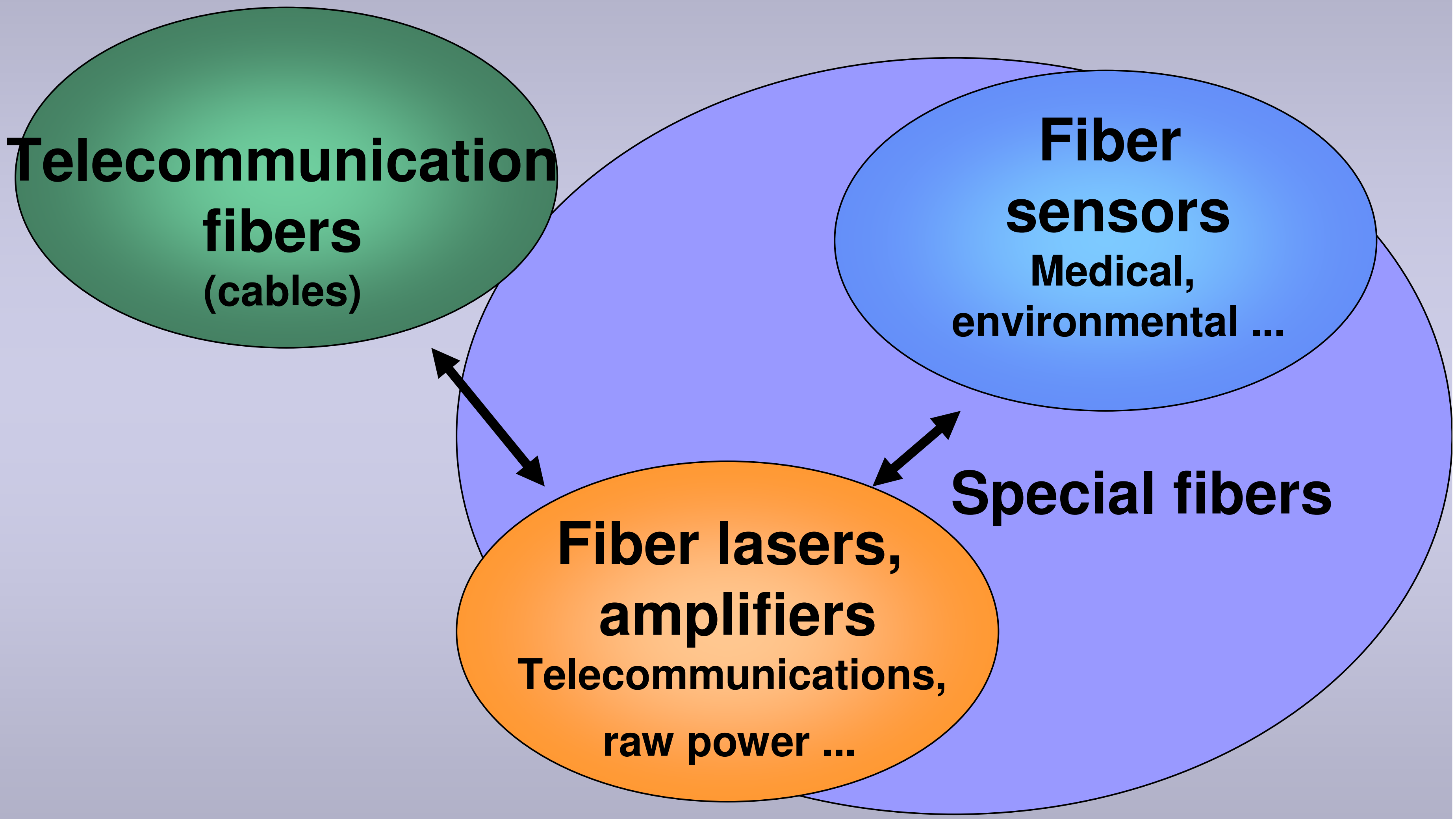
MCVD

preform

Drawing

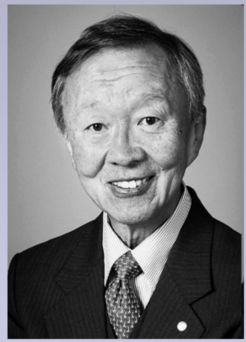


Application



Telecommunications

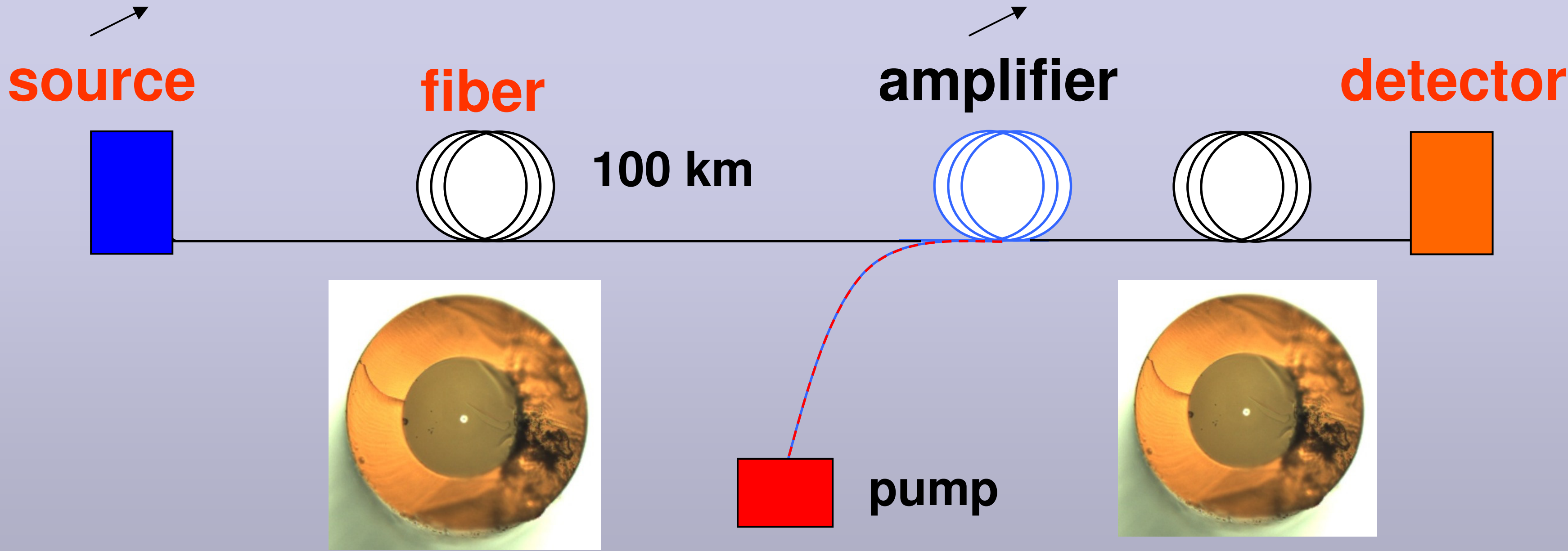
Kao



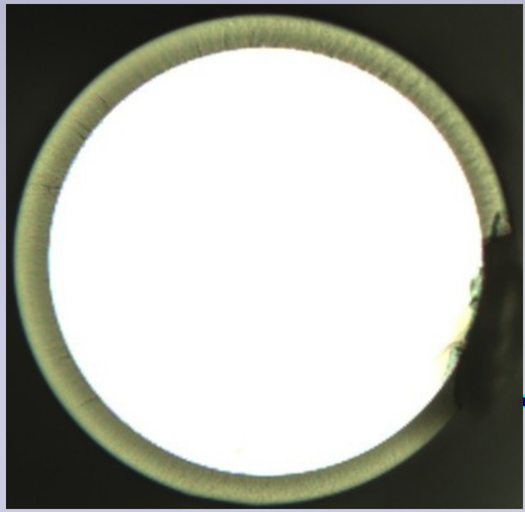
Maiman
Townes, Basov, Prochorov

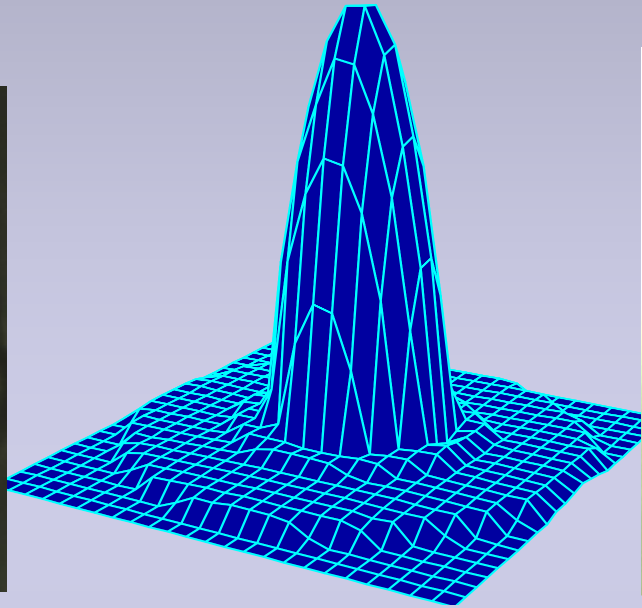
optoelectronics
fiber-optic (laser)

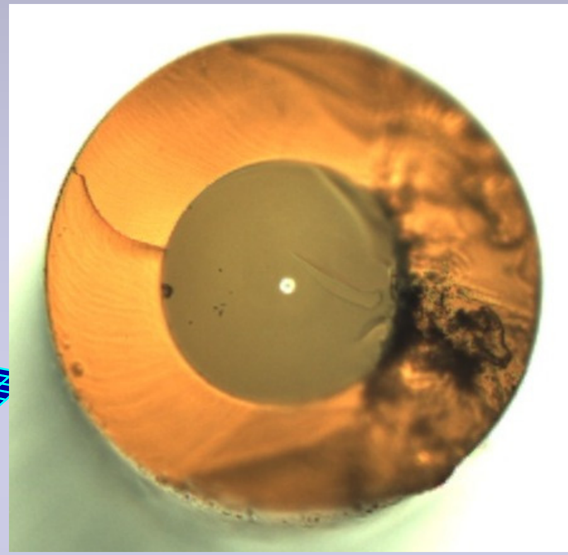
optoelectronics
fiber-optic (amplifier)



Telecommunications







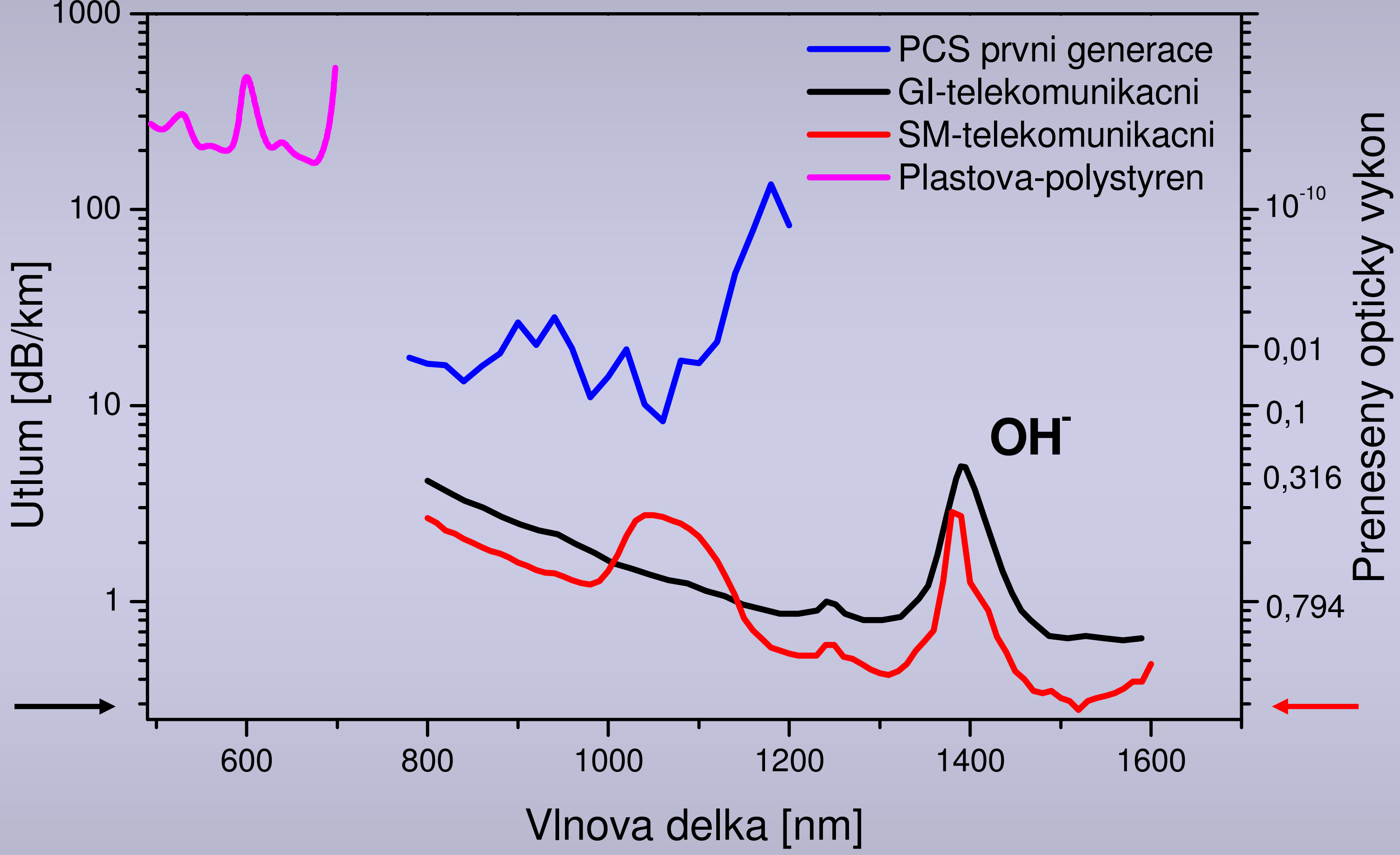
PCS Ø 200 – 600 um
technology transfer
VÚSU Teplice, MM

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



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

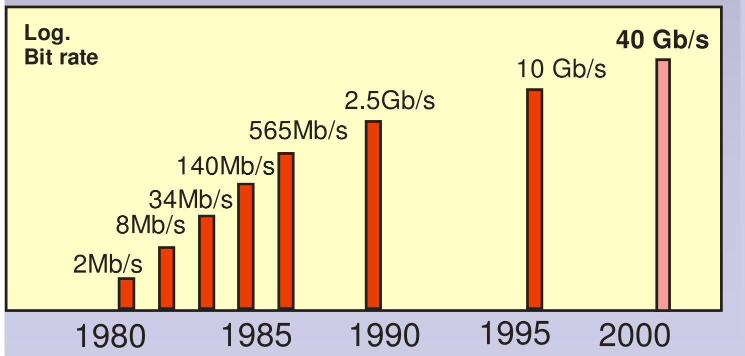
Telecommunications

Fiber attenuation measurement;

Cut-back method

1981, in collaboration with FJFI

Communications : increasing requirements on speed and ammount of information

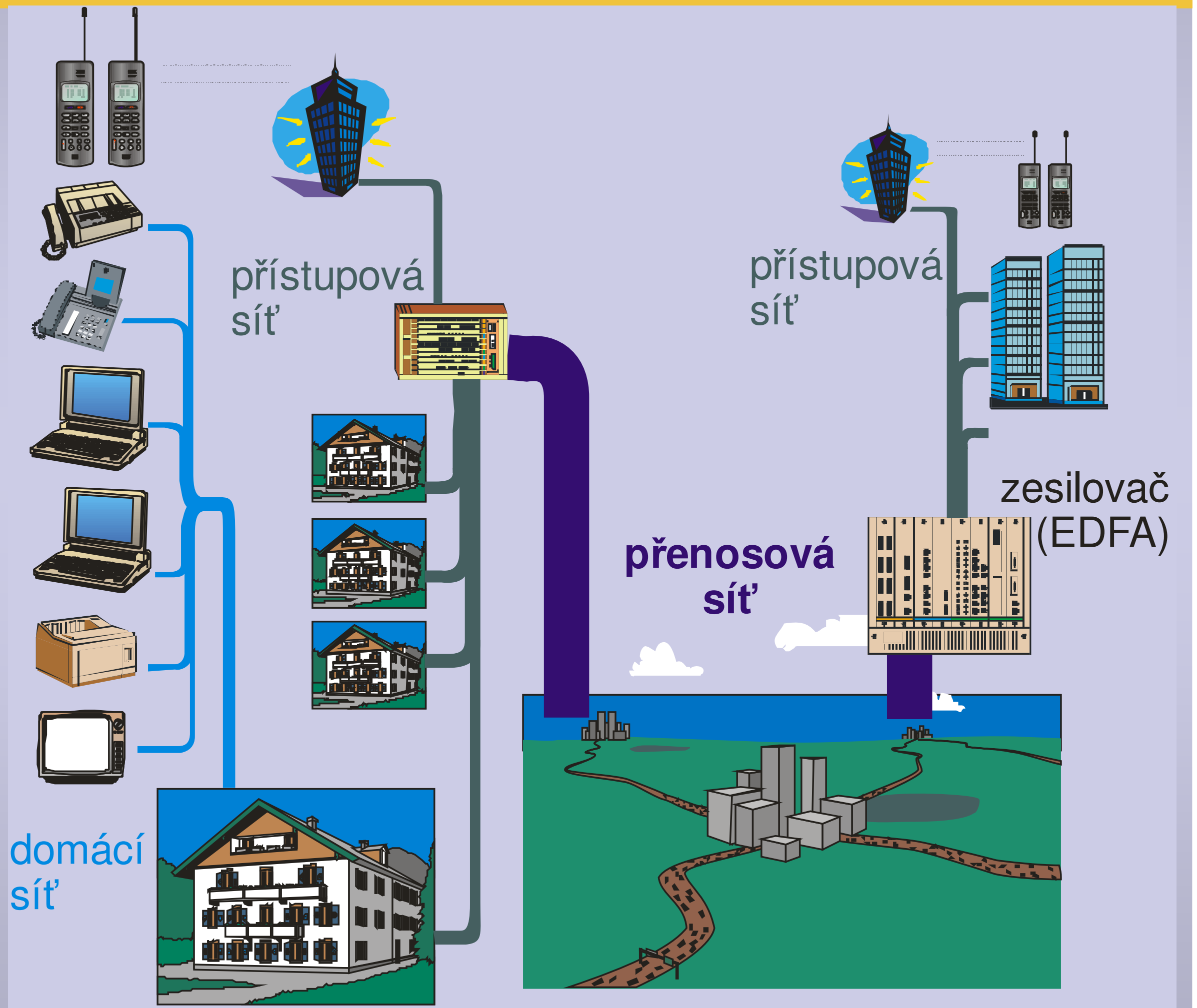


Solution : multiplexing

Time-division (TDM)

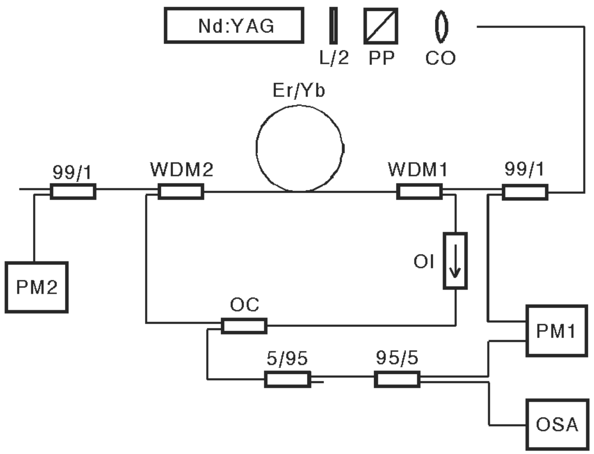
Wavelength (WDM)

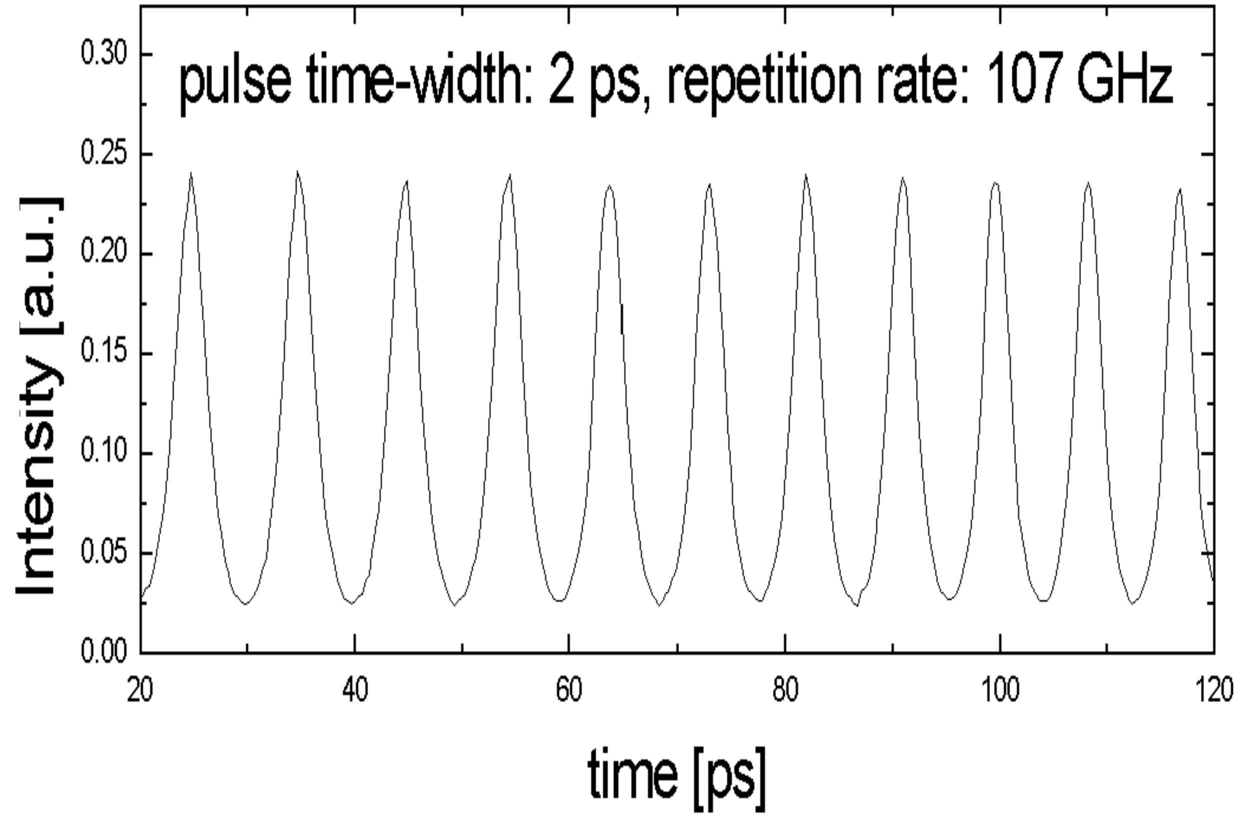
=> Full optical data processing



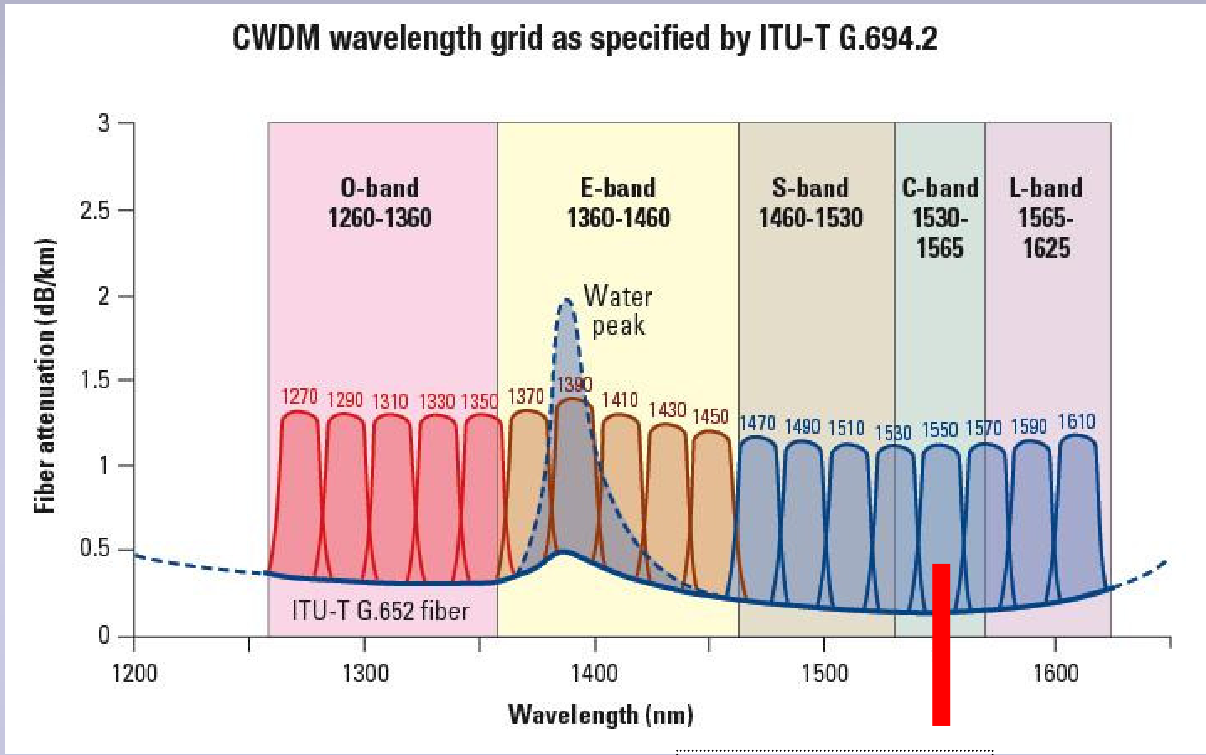
Time Division Multiplexing (TDM)

GOAL : Ultrafast sources - soliton fiber lasers ;
hundreds of GHz >> conventional semiconductor sources

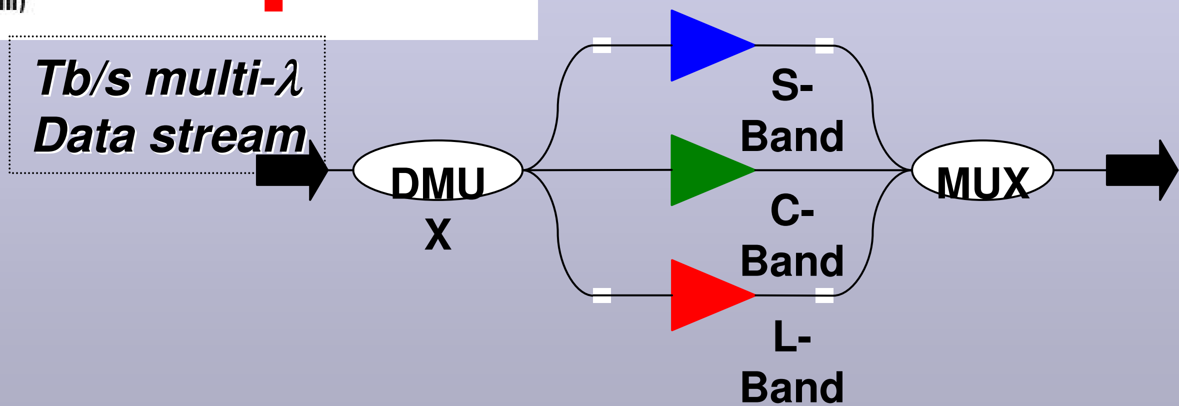




Wavelength Division Multiplexing (WDM)



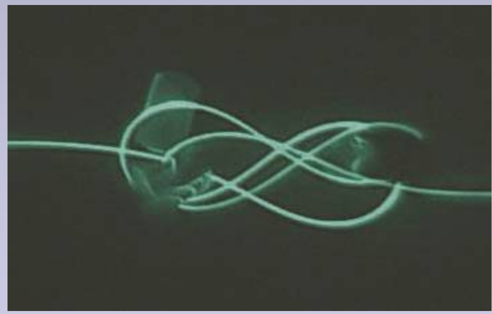
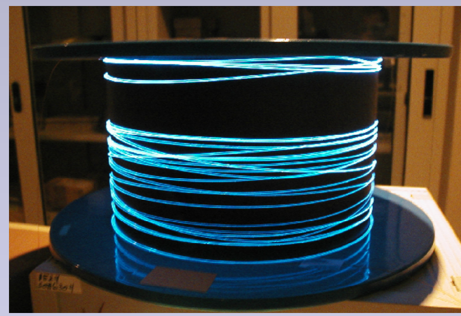
Increase of capacity by an increase of number of channels



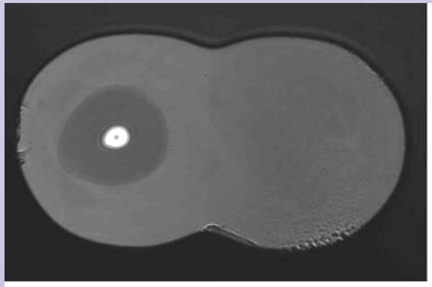
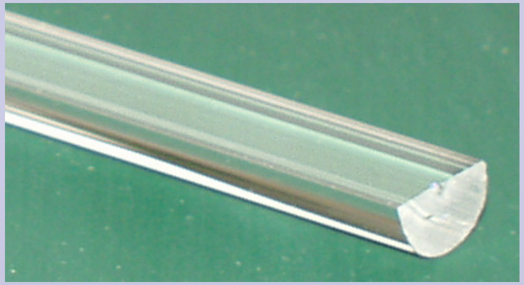
=> Need of sources emitting at wavelength different from 1550 nm

Optical fibers for fiber lasers

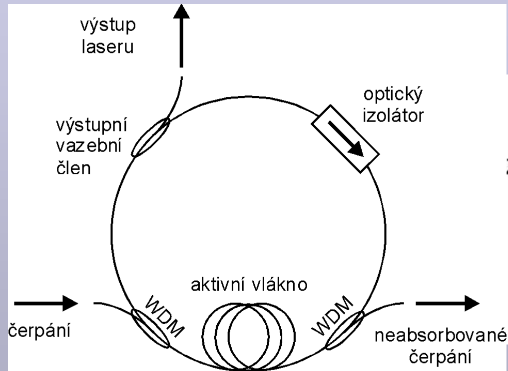
- Modification of :
- Composition
  - Doping with Er^{3+}, Tm^{3+}...

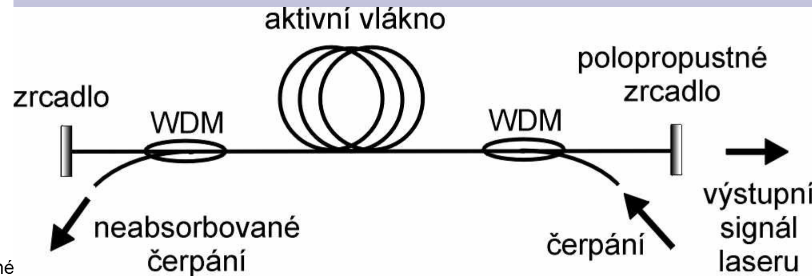



- Shape
  - stadium, D, flower ...

- Setup
  - ring
  - Fabry-Perot...

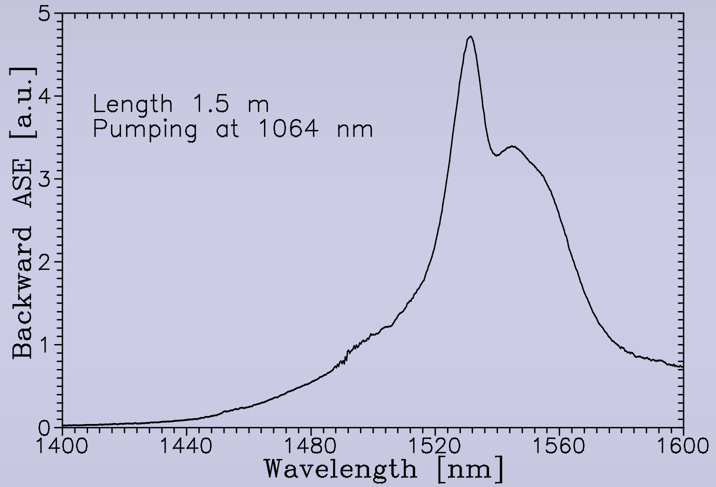


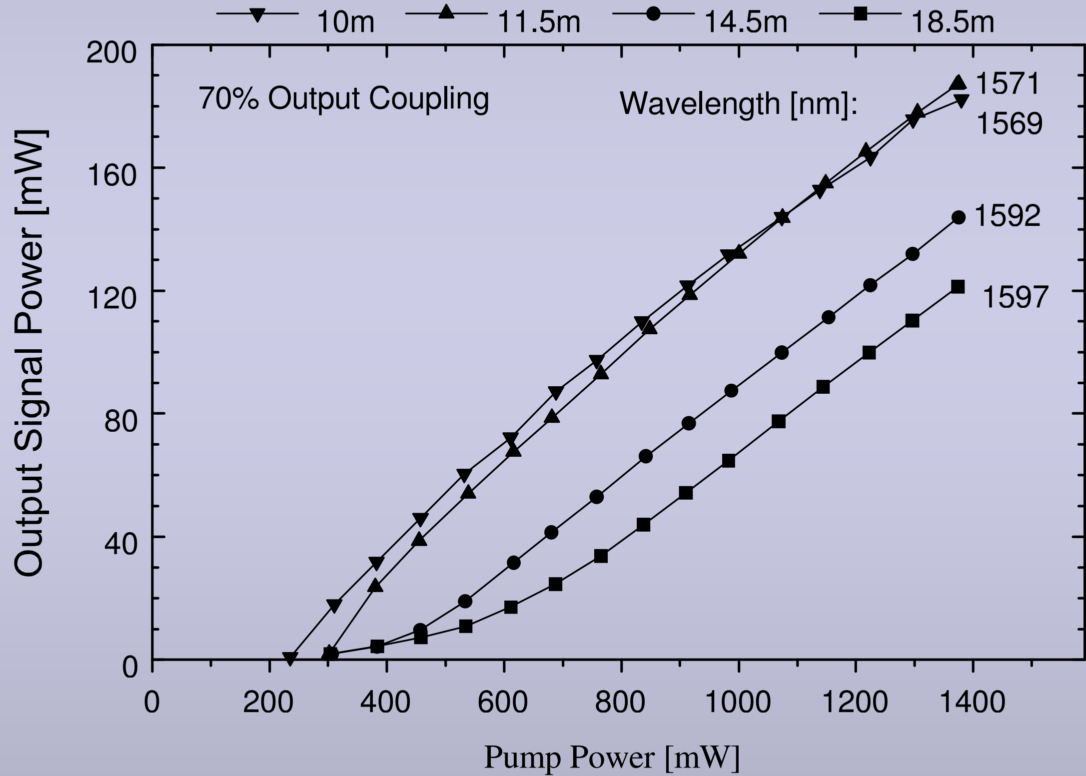


Special fibers doped with Er^{3+}/Yb^{3+} for TDM

Technol. challenge : special optical fiber efficiently operating at ~1550 nm and suitable for pumping at 1064 nm (mini-YAG).

Er/Yb-P2O5-Al2O3-SiO2 fiber – highly doped



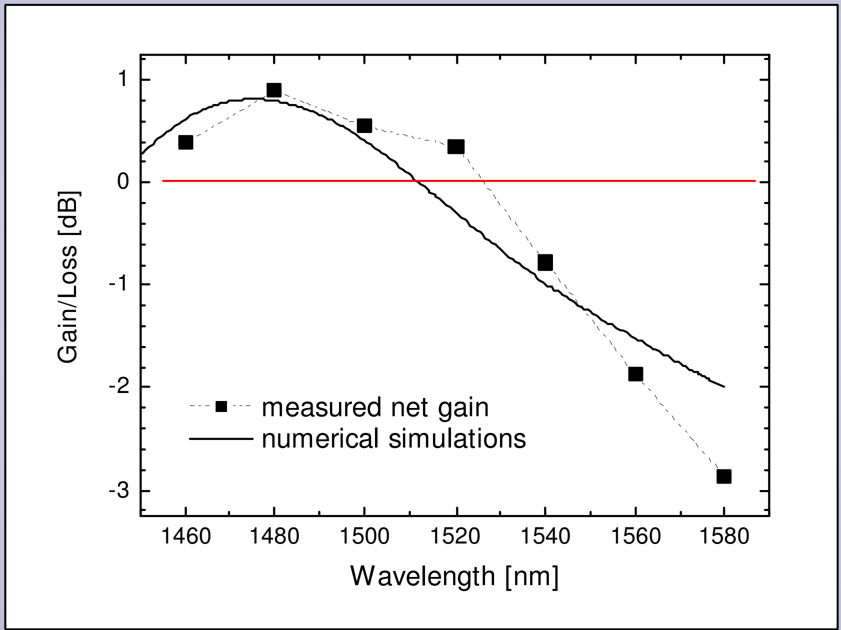


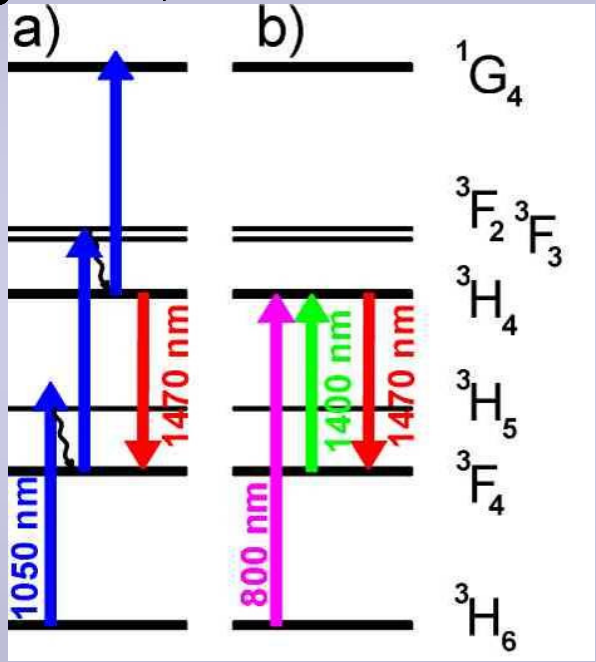
Kasik, V. Matejec, J. Kanka, P. Honzatko : Pure and Appl. Opt. **7** (1998) 457-465

I. Kasik, V. Matejec, M. Pospisilova, J. Kanka, J. Hora : Proc. **SPIE 2777** (1995) 71-79

Tm $^{3+}$ -doped fibers for WDM

- Goal : amplification at S-band - WDM
- Technol. challenge : special optical fiber fiber efficiently operating at S-band (~1470 nm) and compatible with network. Tm^{3+}-Al_2O_3-GeO_2-SiO_2 , high NA, narrow core fiber.





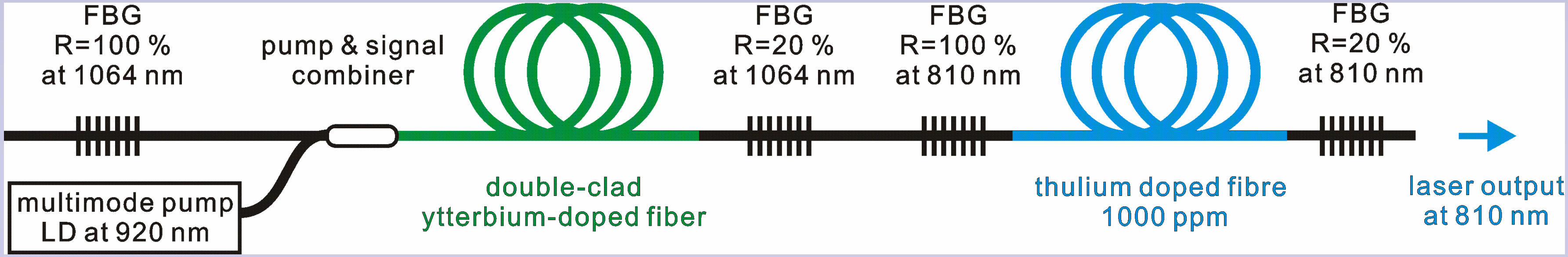
* P. Peterka, B. Faure, W. Blanc, M. Karasek and B. Dussardier, Opt. & Quantum El., **36**, 201-212, 2004

* W. Blanc, P. Peterka, B. Faure, B. Dussardier, G. Monnom, I. Kasik, J. Kanka, D. Simpson, G. Baxter, Proc. **SPIE 6180,** 2006, 61800V.1-6

* P. Peterka, I. Kašík, V. Matějec, W. Blanc, B. Faure, B. Dussardier, G. Monnom, V. Kubeček, *Optical Materials* **30** (2007) 174-176

Tm^{3+} -doped fibers for fiber lasers

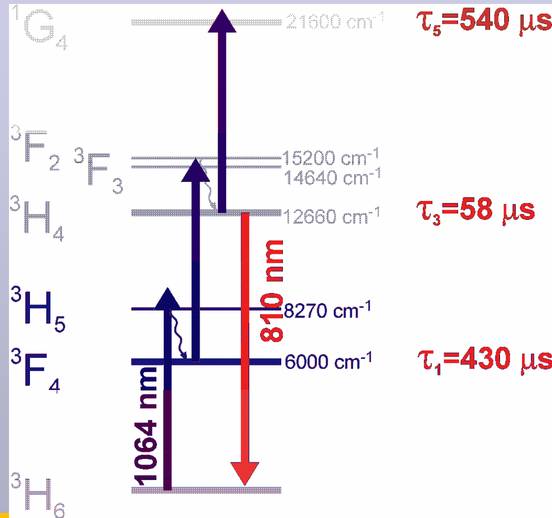
- Goal : a compact upconversion fiber laser operating ~810 nm
- Technol. challenge : special optical fiber efficiently operating (~810 nm) - Tm^{3+}-Al_2O_3-SiO_2 with enhanced 3H4 lifetime.



P. Peterka

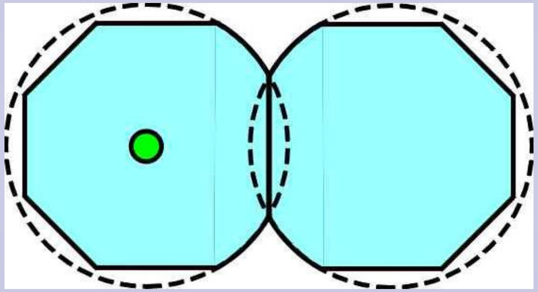
* Peterka, I. Kašík, A. Dhar, B. Dussardier, W. Blanc, *High-power Lasers and Applications V (SPIE)* **7843**, 2010, 78430A

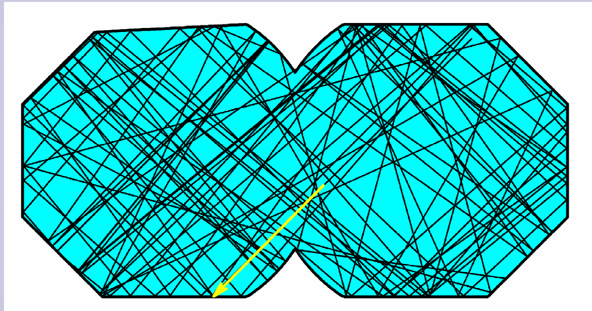
* P. Peterka, I. Kašík, A. Dhar, B. Dussardier, W. Blanc, *Optics Express* **19** (2011) 2773-2781

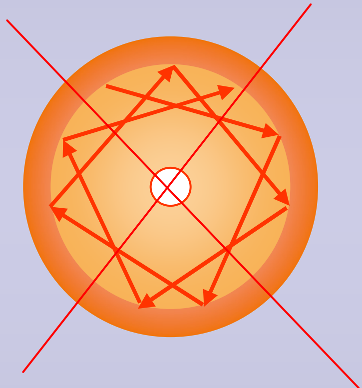


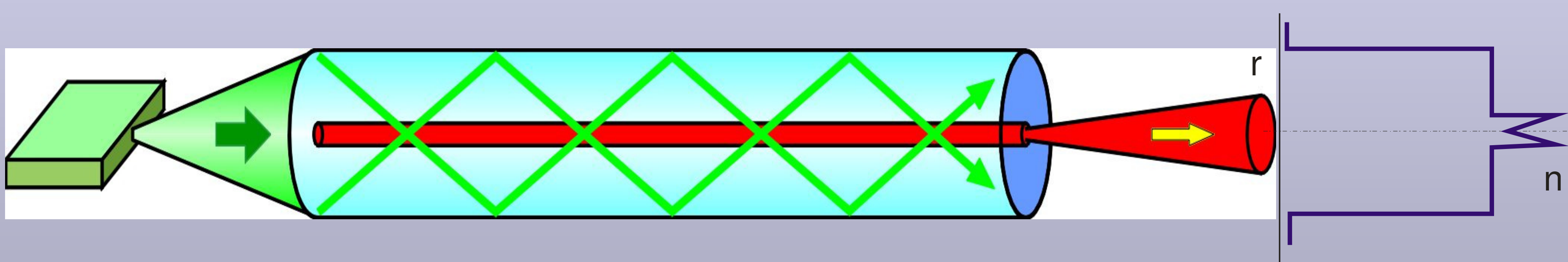
Double-clad (DC) doped optical fiber

- Goal: efficient pumping of fiber lasers (using LD, LED)
- Technol. challenge : special optical fiber of Double-clad (DC) structure and doped core of suitable shape for coupling

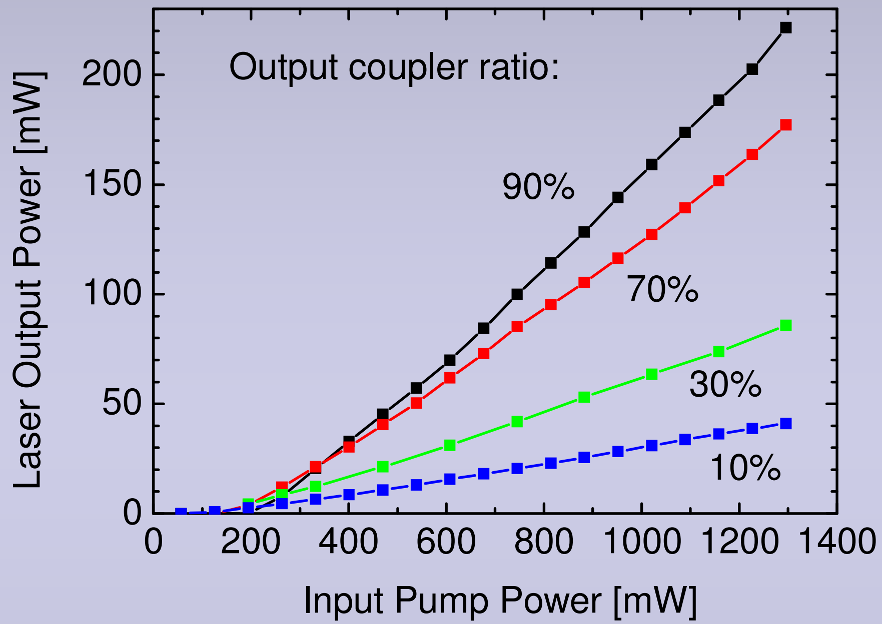


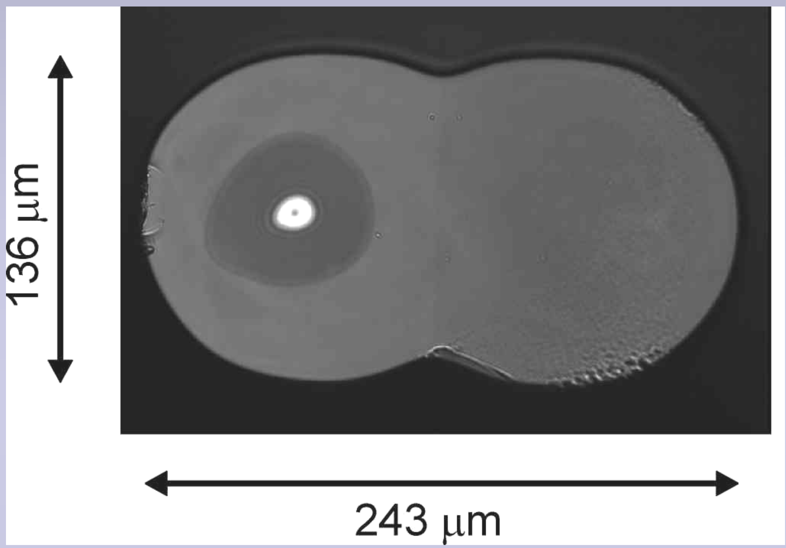






Double-clad (DC) doped optical fiber



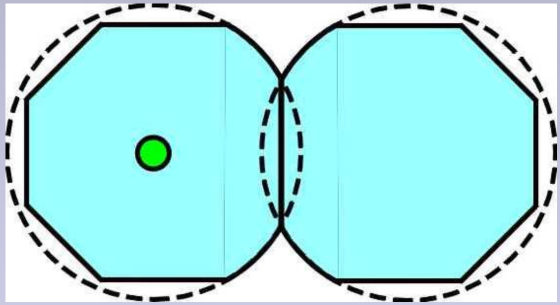


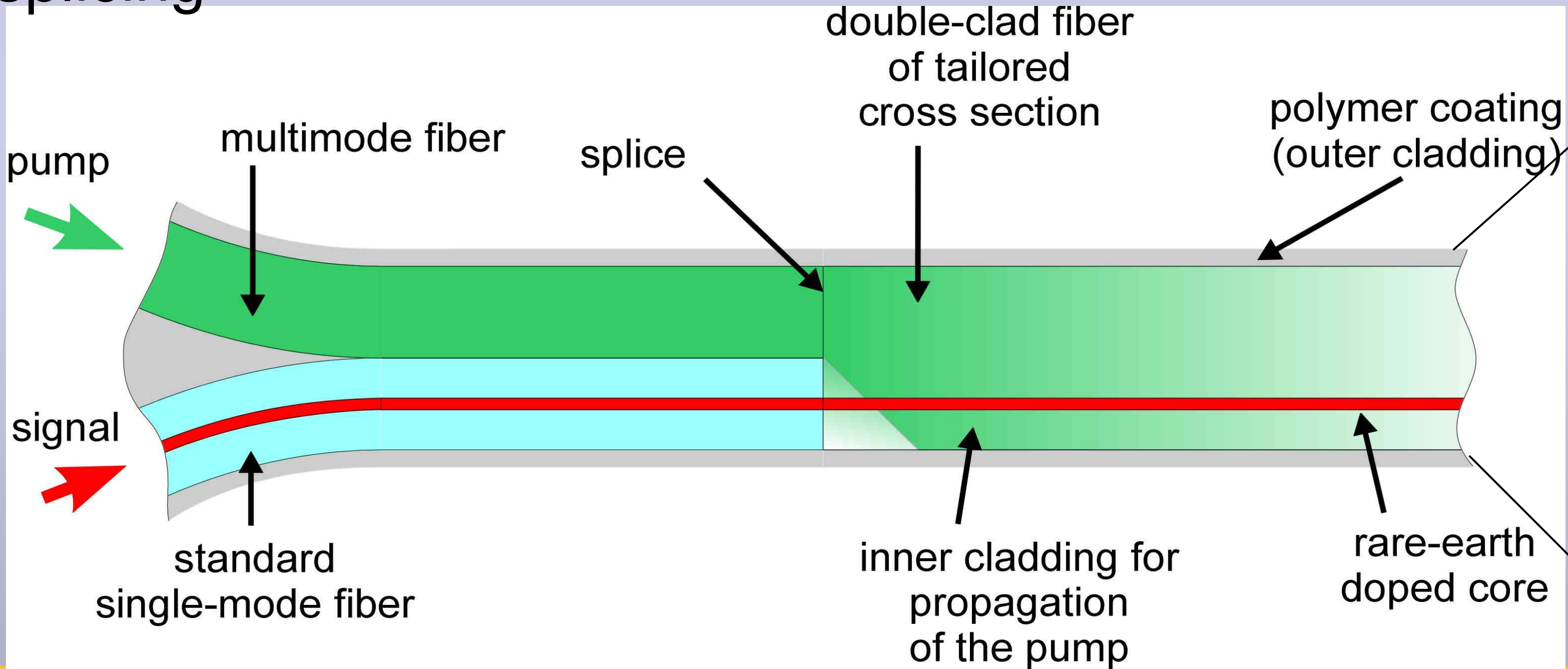
Max. PCE=19%; Yb/Er-doped DC fiber

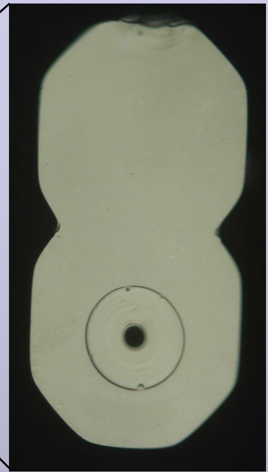
- P. Peterka, I. Kasik, V. Matejec, V. Kubecek, P. Dvoracek, Optics Letters. **31** 22 (2006), 3240-3242
- P. Peterka, I. Kasik, V. Kubecek, V. Matejec, M. Hayer, P. Honzatko, A. Zavadilova, P. Dvoracek, Proc. **SPIE 6180,** 2006, 618010.1-618010.6

Double-clad (DC) optical fiber

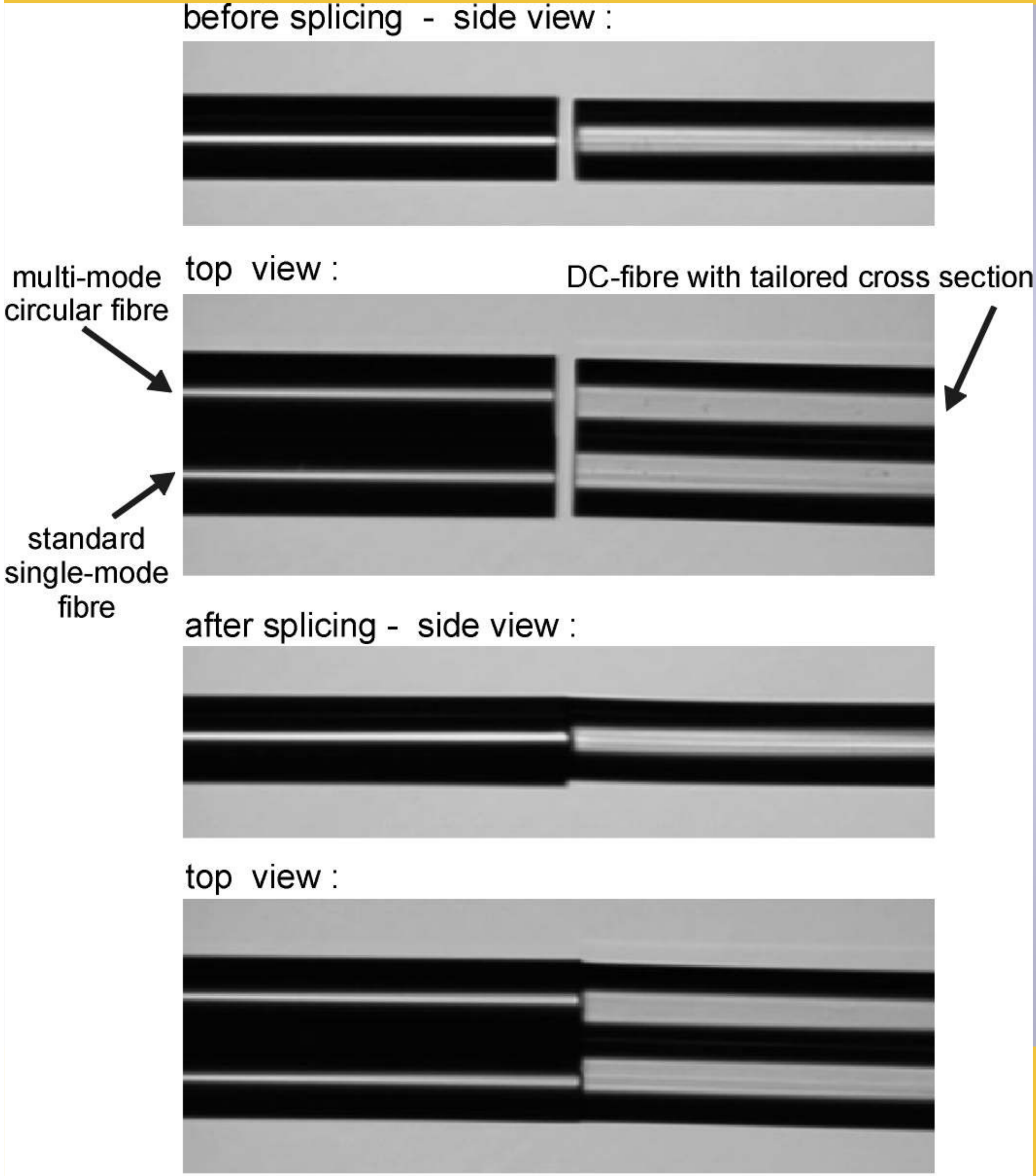
Goal: efficient coupling – efficient pumping (easy to produce reproducively)
Technol. challenge: special DC fiber of tailored structure suitable for conventional splicing





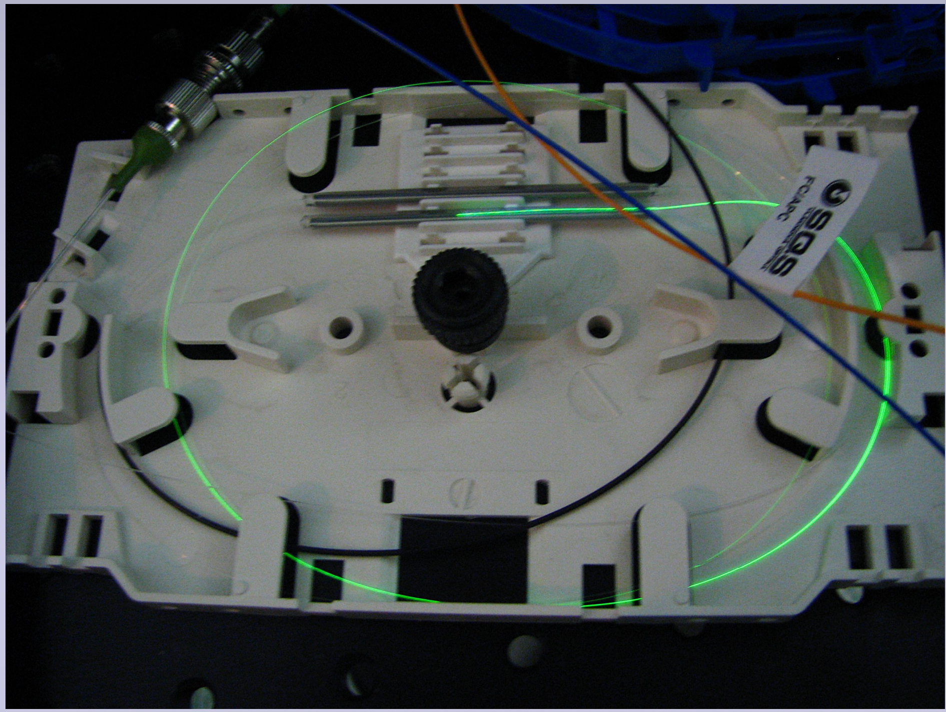


Double-clad (DC) optical fiber



* P. Peterka, I. Kašík, V. Kubeček, V. Matějec, M. Hayer, P. Honzátko, A. Zavadilová, P. Dvořáček, Proc. SPIE 6180, 2006, 618010
•* P. Peterka, V. Kubecek, P. Dvoracek, I. Kasik, V. Matejec, Proc. CLEO/QELS'06 and PhAST - 2006, CTuQ7.pdf
* P. Peterka, I. Kasik, V. Matejec, J. Kanka, M. Karasek, M. Hayer, J. Slanicka, ECOC 2005,755 – 756
* A. Zavadilová, V. Kubeček, I. Kašík, V. Matějec, *Proc. OAA- Vienna, OSA Trends in Optics and Photonics Series 98*, 2005, 526-530
* P. Peterka et.al. : CZ Pat. 301215, 2009

High-power fiber lasers



Er- fiber laser,
pulse 197 fs,
5m rezonator
Liekki

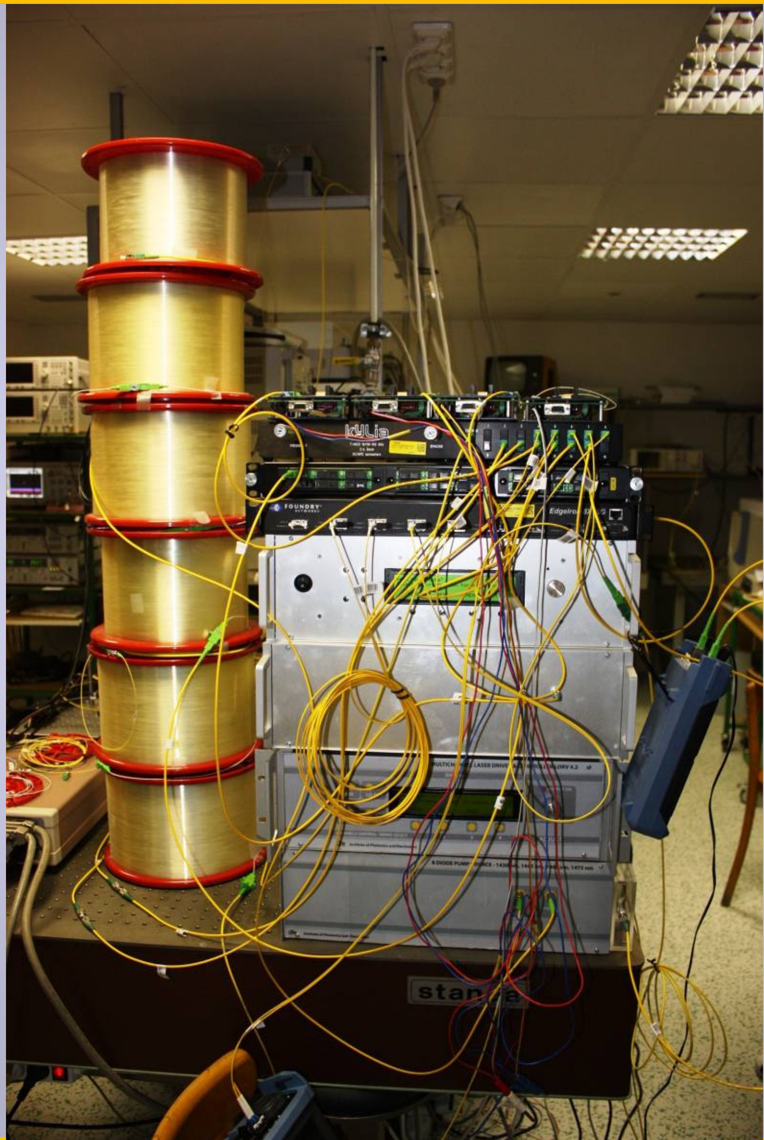
Cutting, welding < 2kW

PALS

Intensity of light

Sun	63 MW/m^2
1W-fiber laser	12.7 GW/m^2

Telecommunication and fiber amplifiers

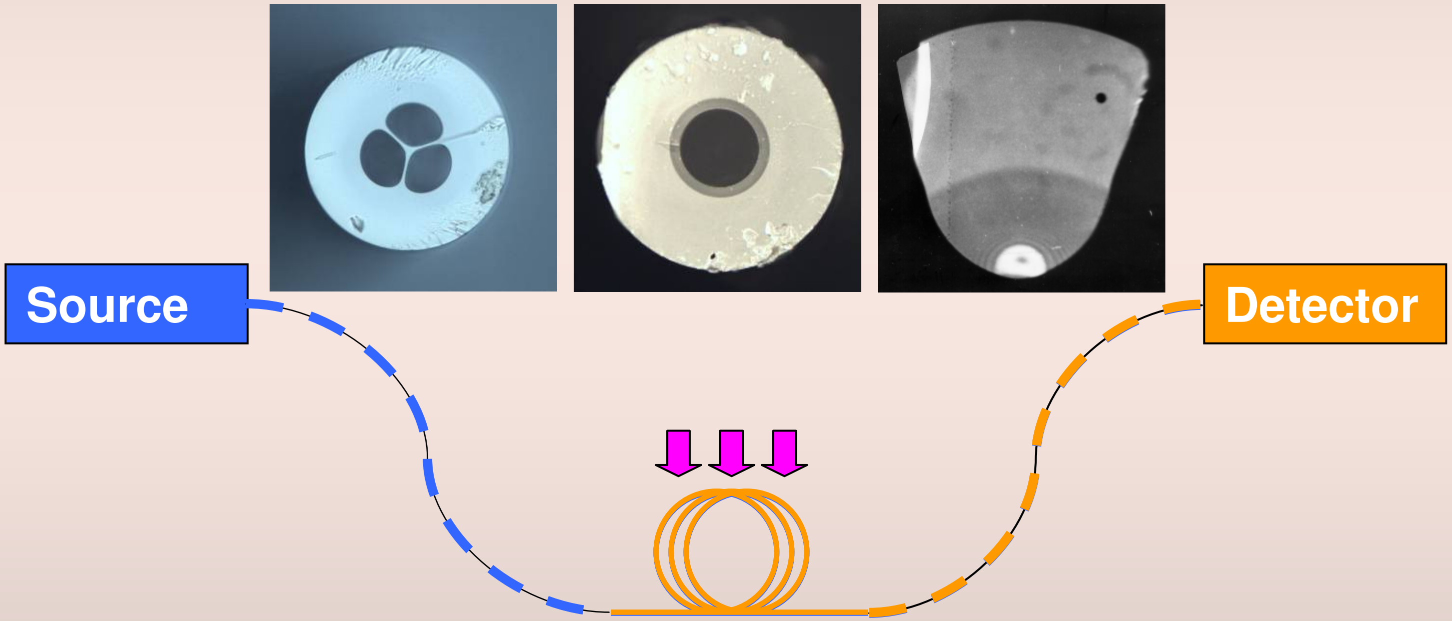


M.Karasek
in collaboration
with Cesnet :

testing 200 km line

Fiber-optic sensors

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



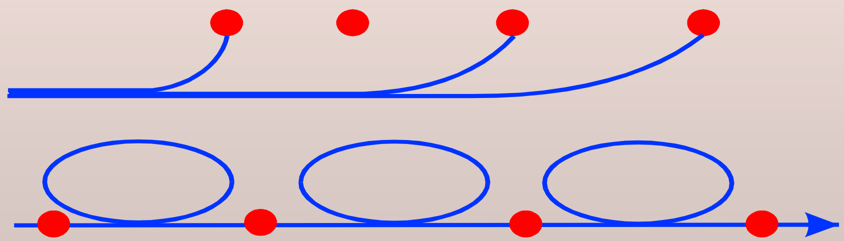
Change of output optical signal due to (bio)chemical changes in fiber vicinity.

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

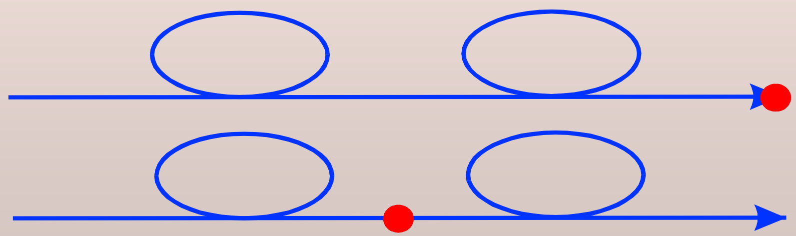
+ Remote sensing
+ Distributed
+ Explosive, high-voltage areas, human body

Solution : fiber-optic sensors

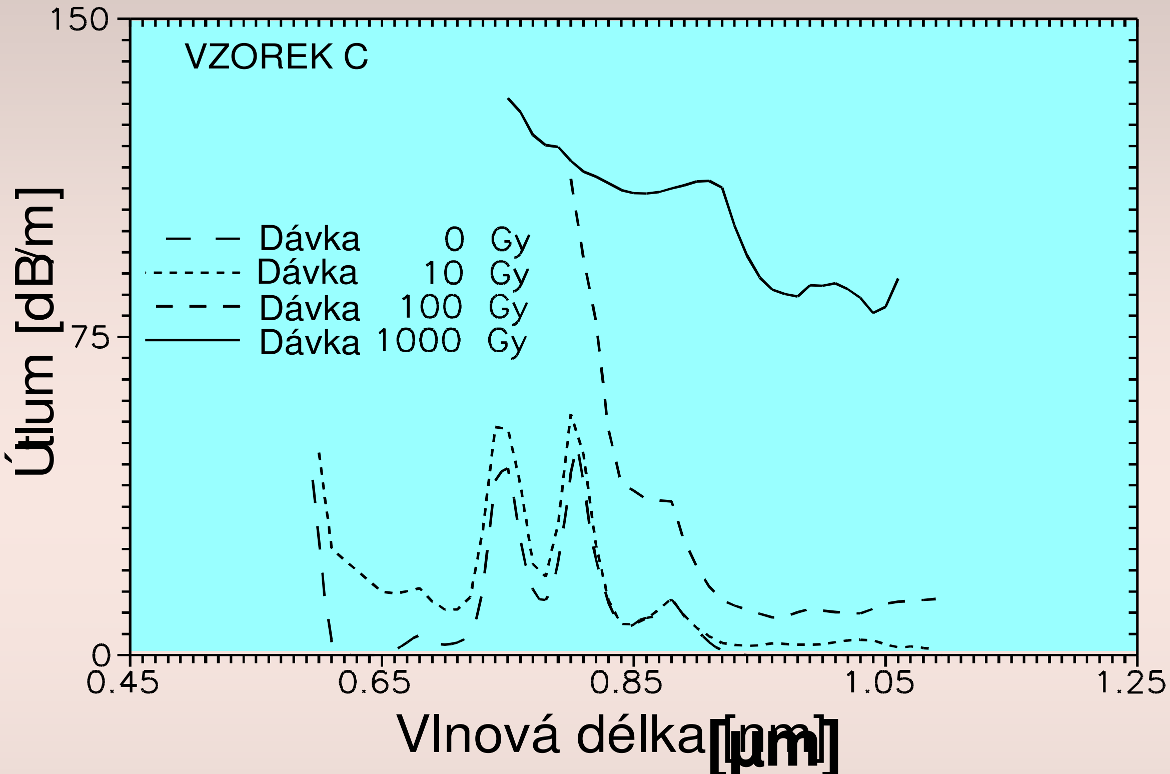
Multipoint (distributed) detection



Point detection



Remote detection : dosimetry



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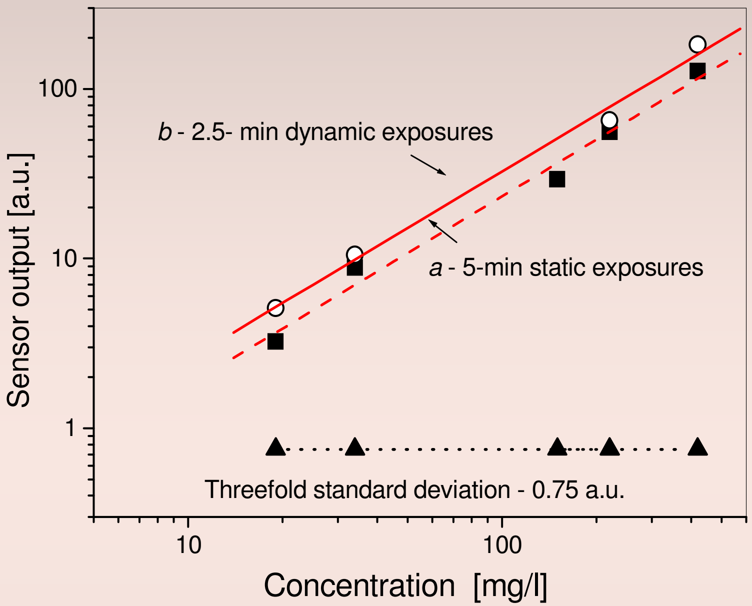
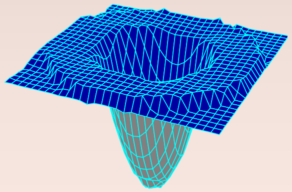
* A. Daříčková, V. Matějec, M. Pospíšilová, M. Chomát, I. Kašík: „Silica optical fibers doped in the core with special dopants and their sensitivity to ionizing radiation“, *Proc. Photonics '95*, **2A**, Prague, 1995, 257-260

Distributed refractometric detection of hydrocarbons





<u>Goal :</u> enhancement of evanescent field (sensitivity)

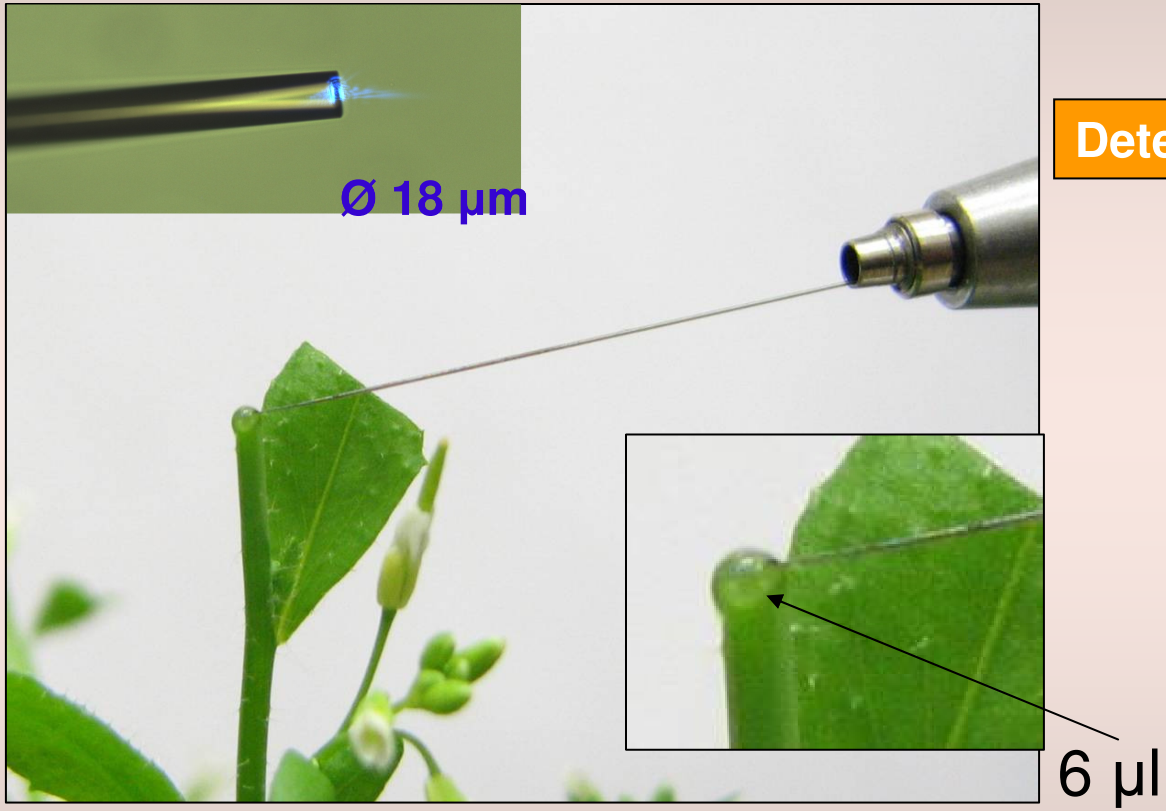
<u>Technol. challenge :</u> special fiber of tailored structure (Inverted Graded-Index - IGI) or with functionalized coating (e.g. PDMS)

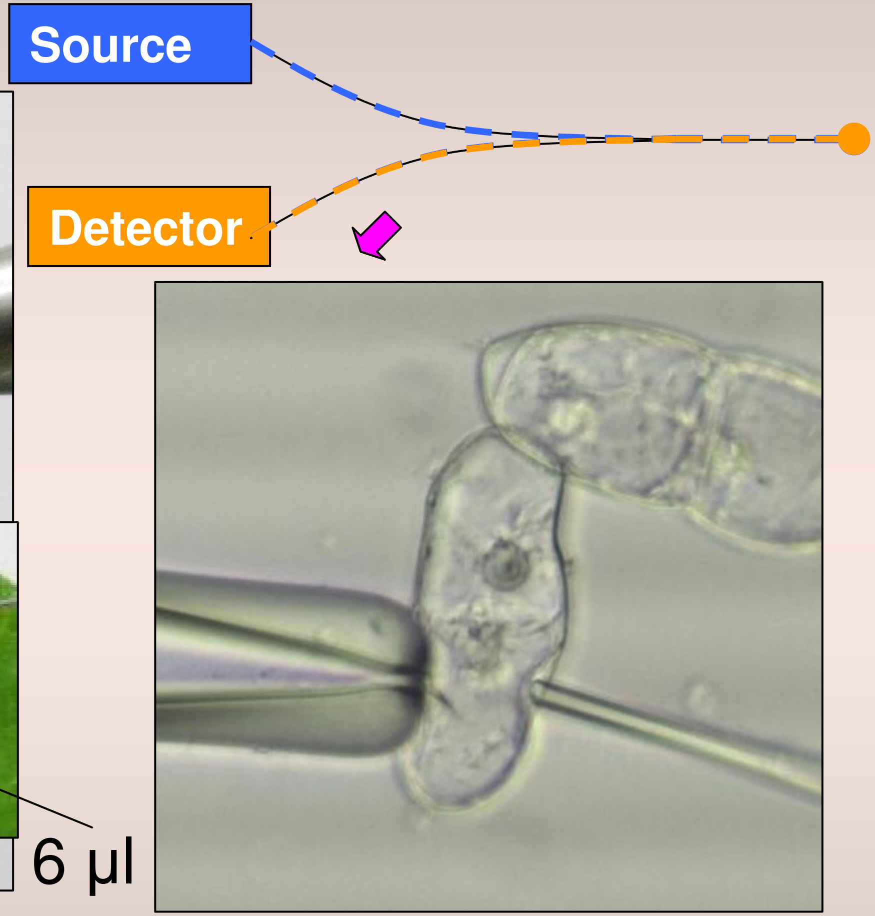
LOD ~ 3-5 mg/l ~ comparable to EU ecological limit

* K. Cherif, S. Hleli, A. Abdelghani, N. Jaffrezic-Renault, V. Matejec: Sensors, **2** (2002), 195-204
* V. Matejec, D. Berkova, M. Chomat, M. Zabrodsky : Materials Science and Engineering C- **21** (2002), 217-221
* M. Chomat, D. Berkova, V. Matejec, I. Kasik, G. Kuncova: Sensors and Actuators **B90** (2003), 151-156

In vivo detection of pH in biosamples

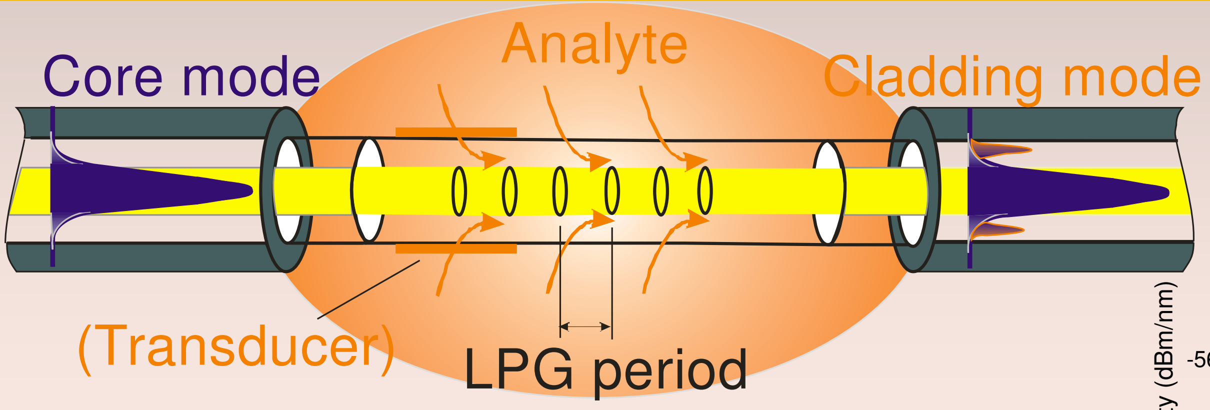
(droplets, cells)





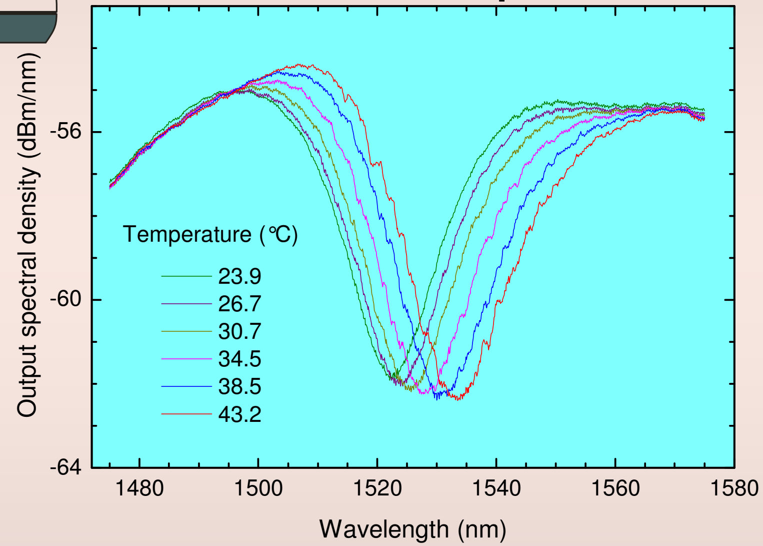
* I. Kašík, J. Mrázek, T. Martan, M. Pospíšilová, O. Podrazký, V. Matějec, K. Hoyerova, M. Kamínek, *Analytical and Bioanalytical Chemistry* **398** (2010) 1883-1889
* O. Podrazký, J. Mrázek, M. Seidl, I. Kašík, P. Tobiška, V. Matějec, T. Martan, J. Aubrecht, *Optical Sensing Technology and Applications (SPIE)* **6585**, 2007, 65850Y

Fiber sensors based on Long Period gratings (LPG)



In collaboration with FJFI GACR 102/06/1851

transmission spectrum



* M. Chomát, D. Berková, V. Matějec, I. Kašík, J. Kaňka, R. Slavík, A. Jančárek, P. Bitner, *Materials Science & Engineering C-biomimetic and Supramolecular Systems* **26** (2006) 457-461

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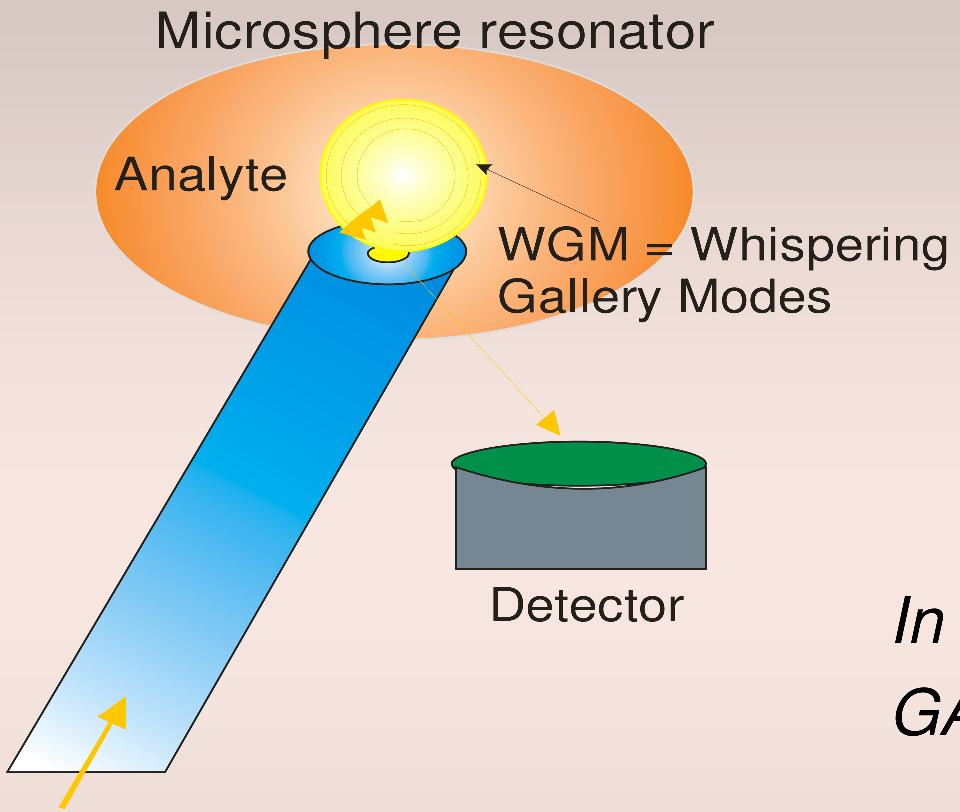
Microresonators



In collaboration with FJFI

GACR 102/09/1763

* F. Todorov, M. Jelínek, V. Matějec, M. Chomát, V. Kubeček, D. Berková, R. Sedlář, *Micro-optics 2010 (Proc. SPIE)* **7716**, 2010, 77161X

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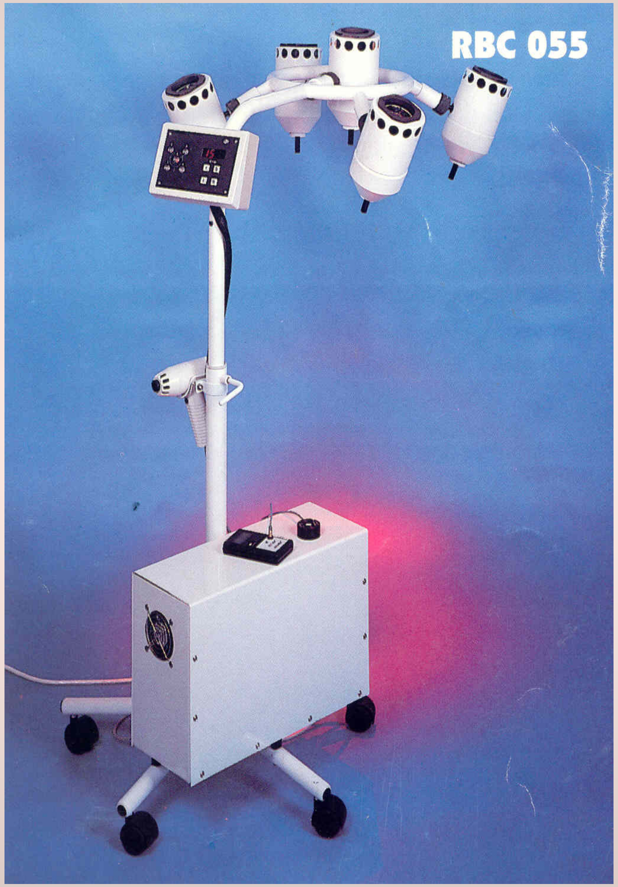
Fiber-optics for medical application

In collaboration

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

* **Laser scalpel**



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) : ÚFE

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- 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