

úfe



Optická vlákna – technologie a využití jako chemických sensorů

www.ufe.cz/~kasik

- ÚFE AV ČR, v.v.i.

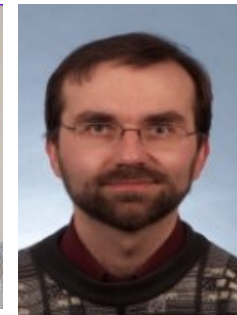
- non-profit non-university research, ASCR

Institute of Photonics and Electronics



RESEARCH:

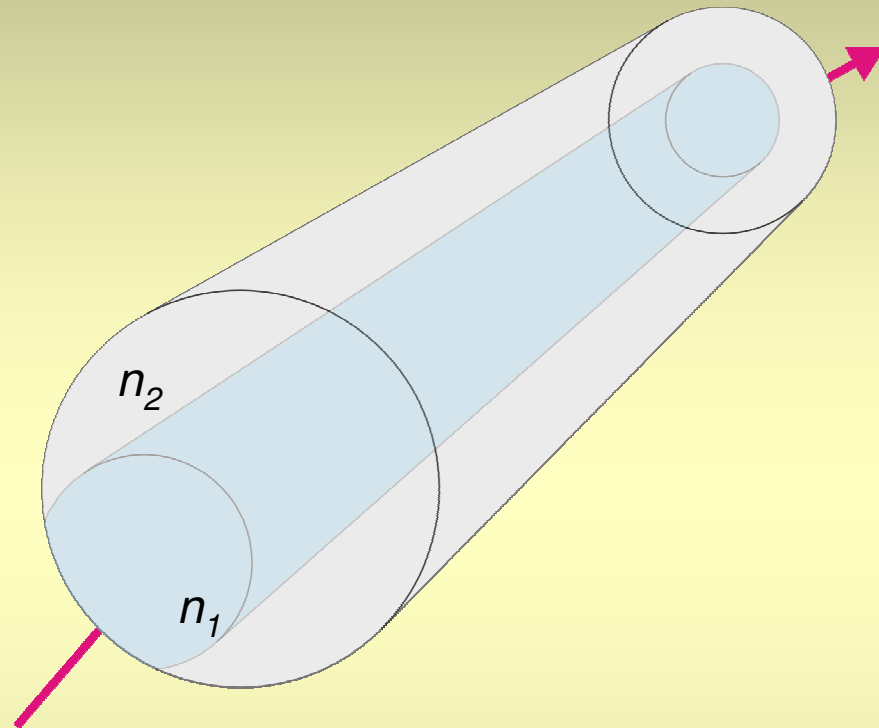
- precise time & frequency, signal processing & speech synthesis
- optoelectronics
- **photonics** (guided-wave photonics, sensors, **optical fibers**)



Outline

- **Introduction - optical fibers**
- **Technology of preparation**
- **Application**
 - **Optical telecommunications**
 - **Fiber amplifiers, lasers (non-linear applications)**
 - **Fiber-optic sensors**
 - **Medicine**
- **Summary**

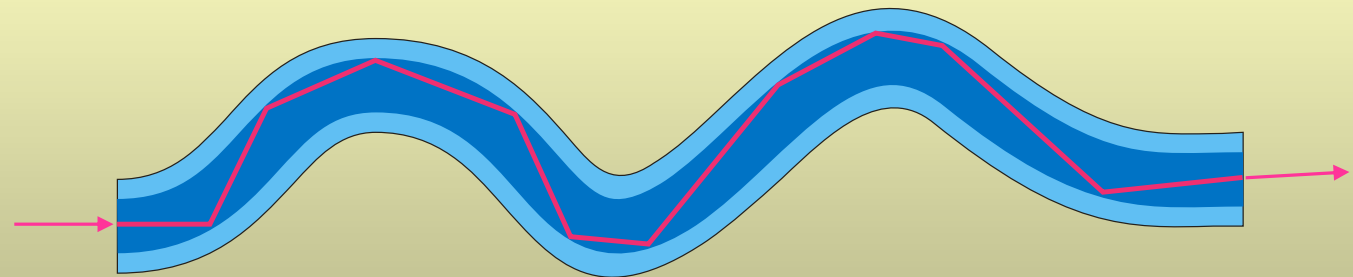
I. INTRODUCTION : Optical fibers



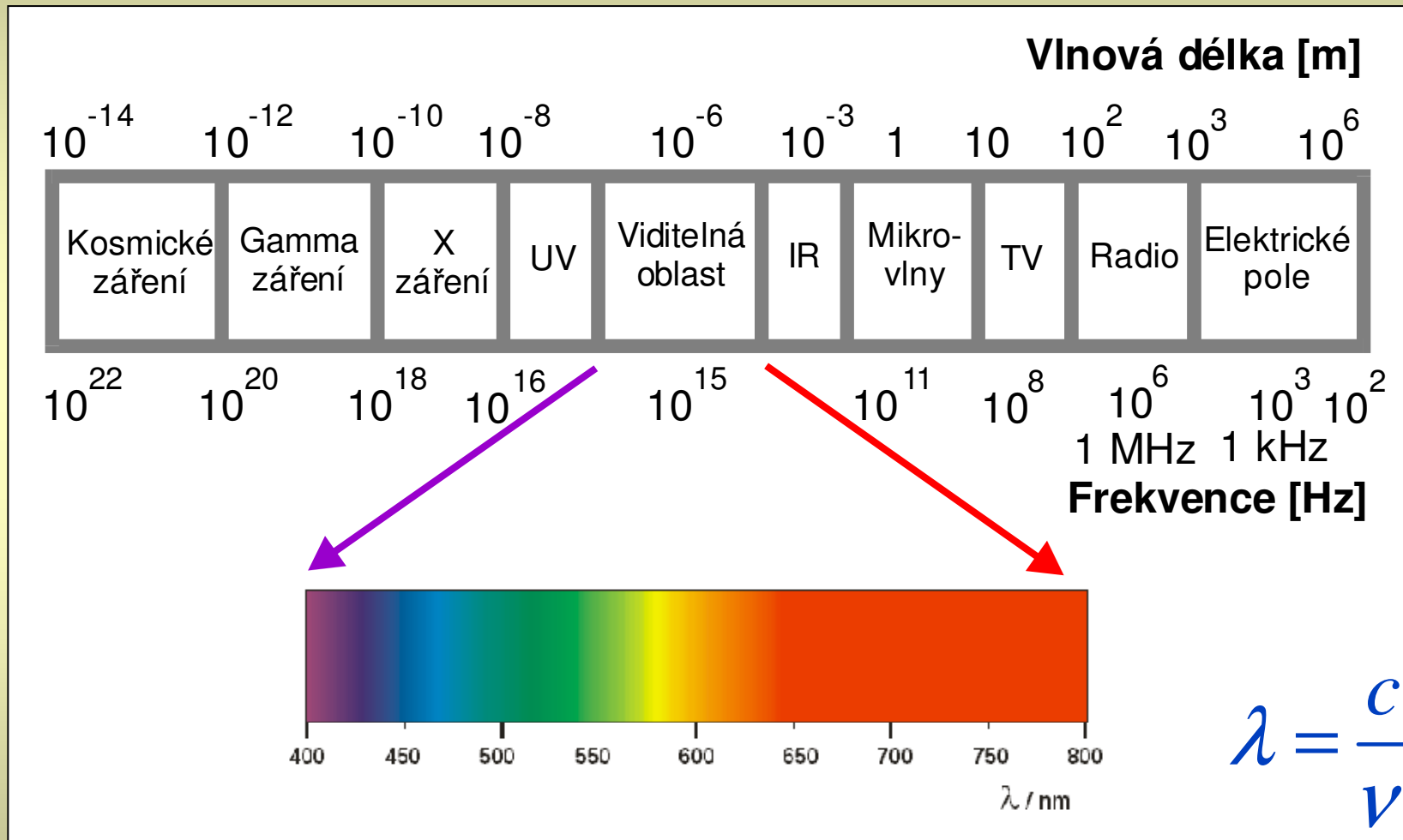
$$n_1 > n_2$$

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

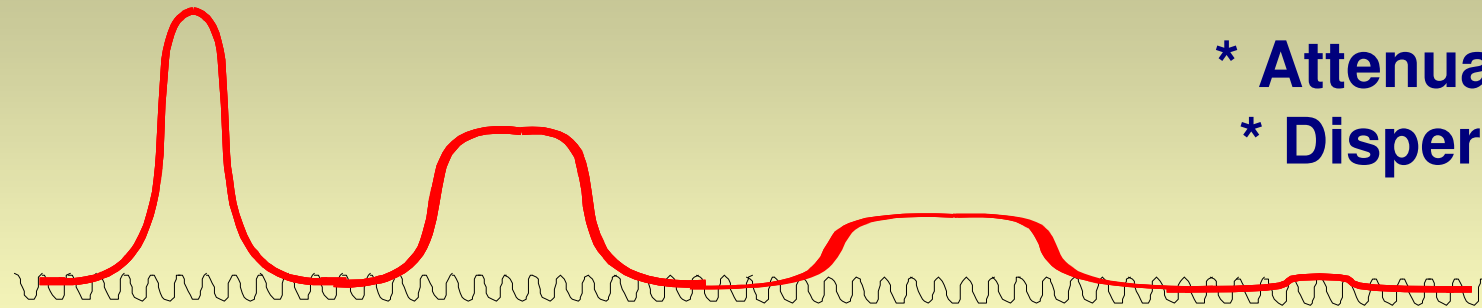
W. Snell 1580-1626
J. Tyndall 1820-1893



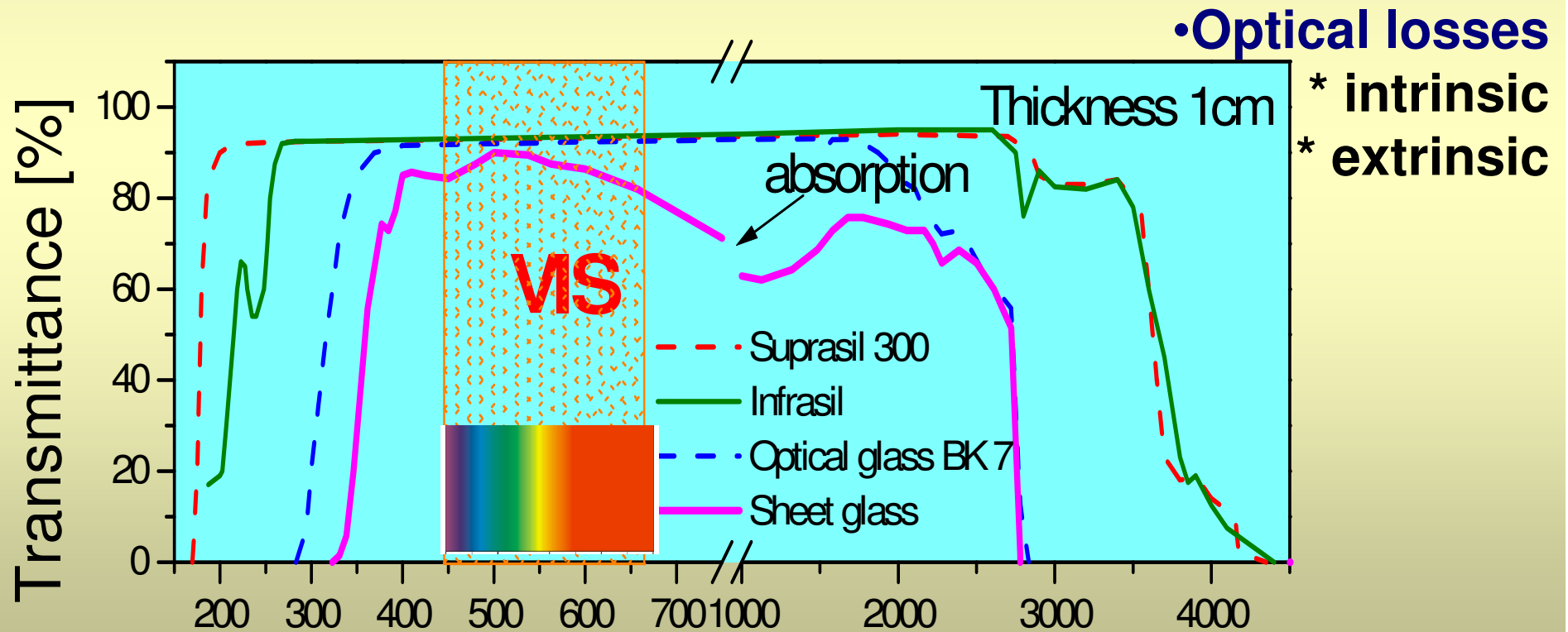
Optical communication principle



Optical properties and material purity



* Attenuation
* Dispersion

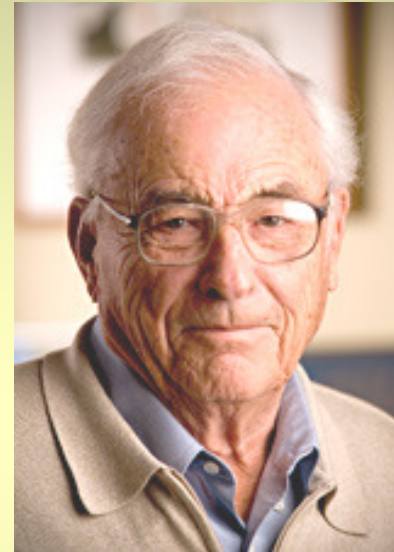


The Nobel Prize in Physics 2009



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 sensor

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)

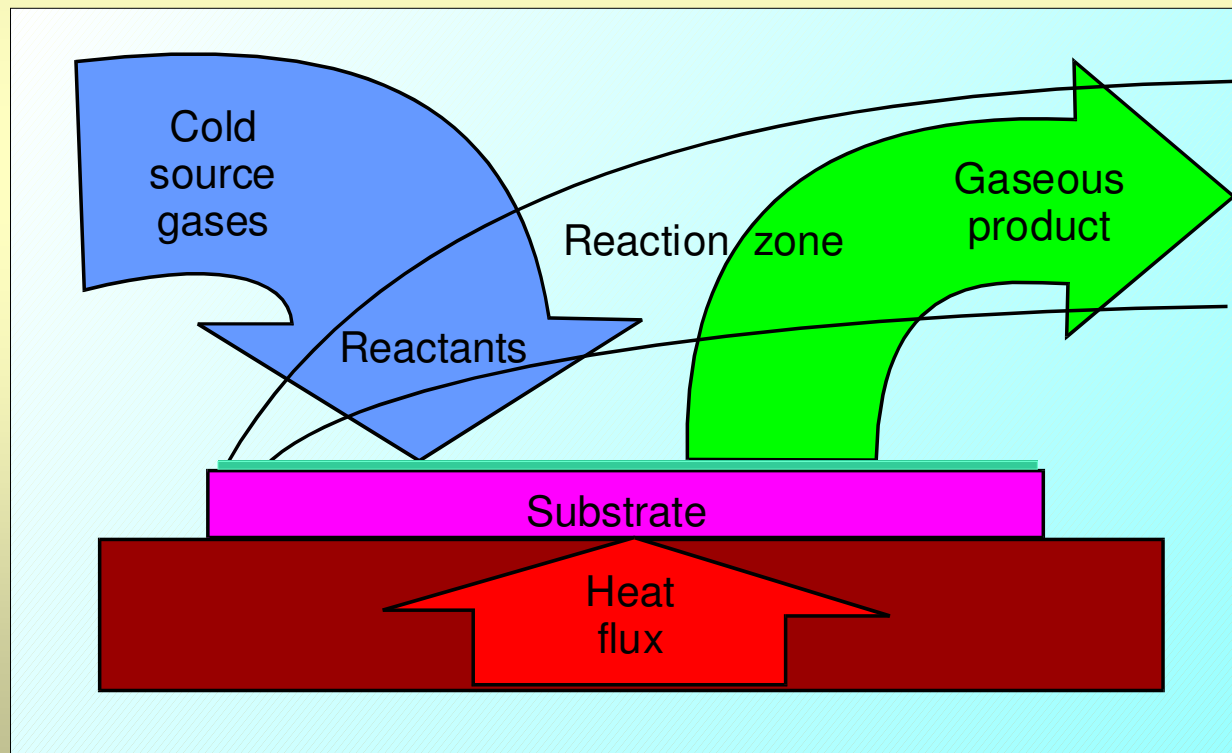
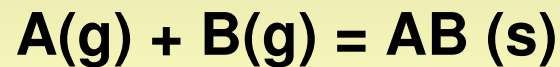
ppb – 10^{-9} (parts per billion) : content of impurities acceptable in FO Optipur materials

Ultra-pure technologies - CVD !

II. TECHNOLOGIES

CVD - Chemical Vapor Deposition

production and deposition of material in solid state from starting materials in gaseous state through a chemical reaction :

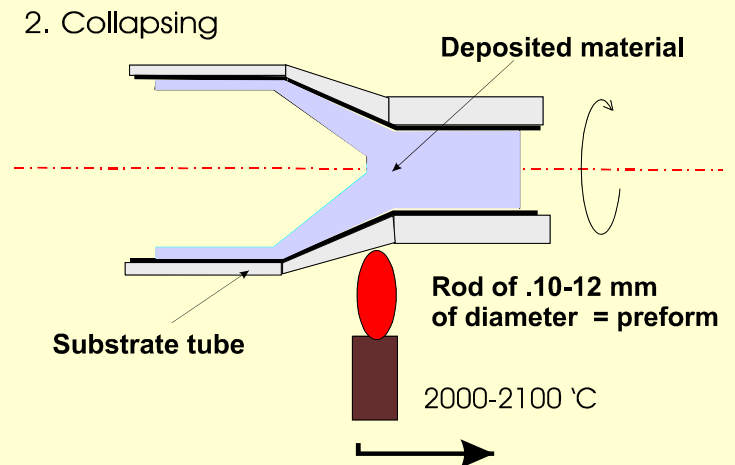
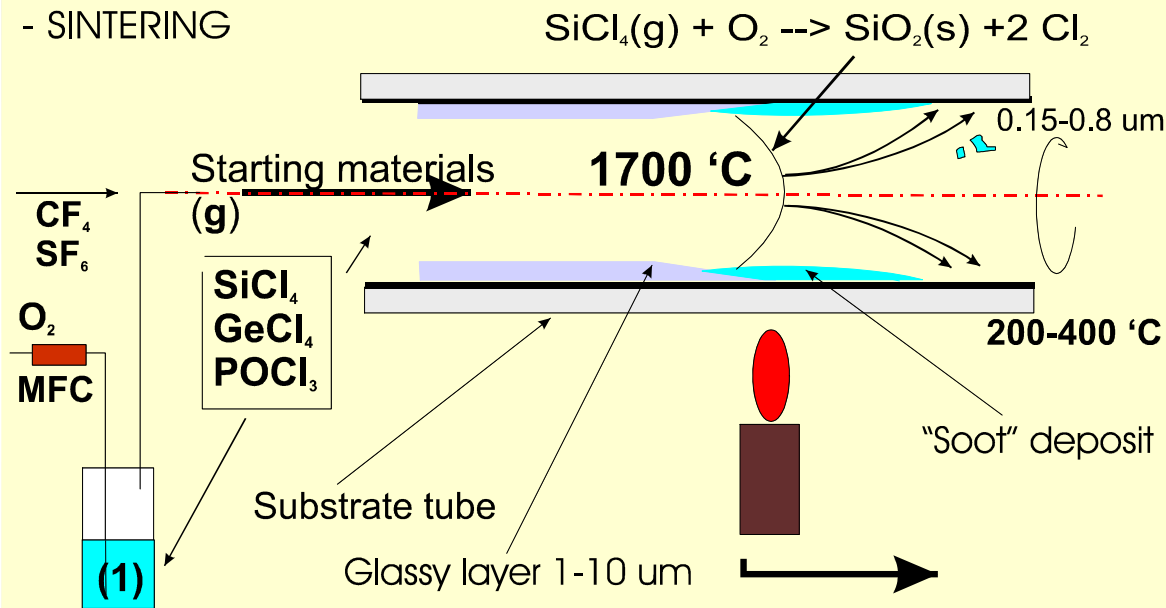


ICPF: LCVD

- Fajgar
- Dřínek
- Pola

MCVD – Chemical Vapor Deposition

- 1. - DECOMPOSITION-oxidation
- DEPOSITION
- SINTERING



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

MCVD process

- Sequential **sintering** of thin glassy layers
- **High quenching rate** $10^2 - 10^3$ °C/s.

- **High purity** material due to FO-Optipur purity starting materials

- **MCVD process modelling** :
- 1. **Vaporization** of starting materials
$$V_{\text{XCl}_4} = V_{\text{Ox}} \cdot P^{\circ}_{\text{XCl}_4} / (P - P^{\circ}_{\text{XCl}_4}) \dots$$
- 2. **Oxidation**
- 1st -order kinetics ($t = 0.02$ s)
- Chemical equilibrium (conversion 0.95-0.99)

ICPF:
Unconventional
glass melting
Hájek
Círka
ICPF: Analytics
Horáček
Soukupová
et.al.

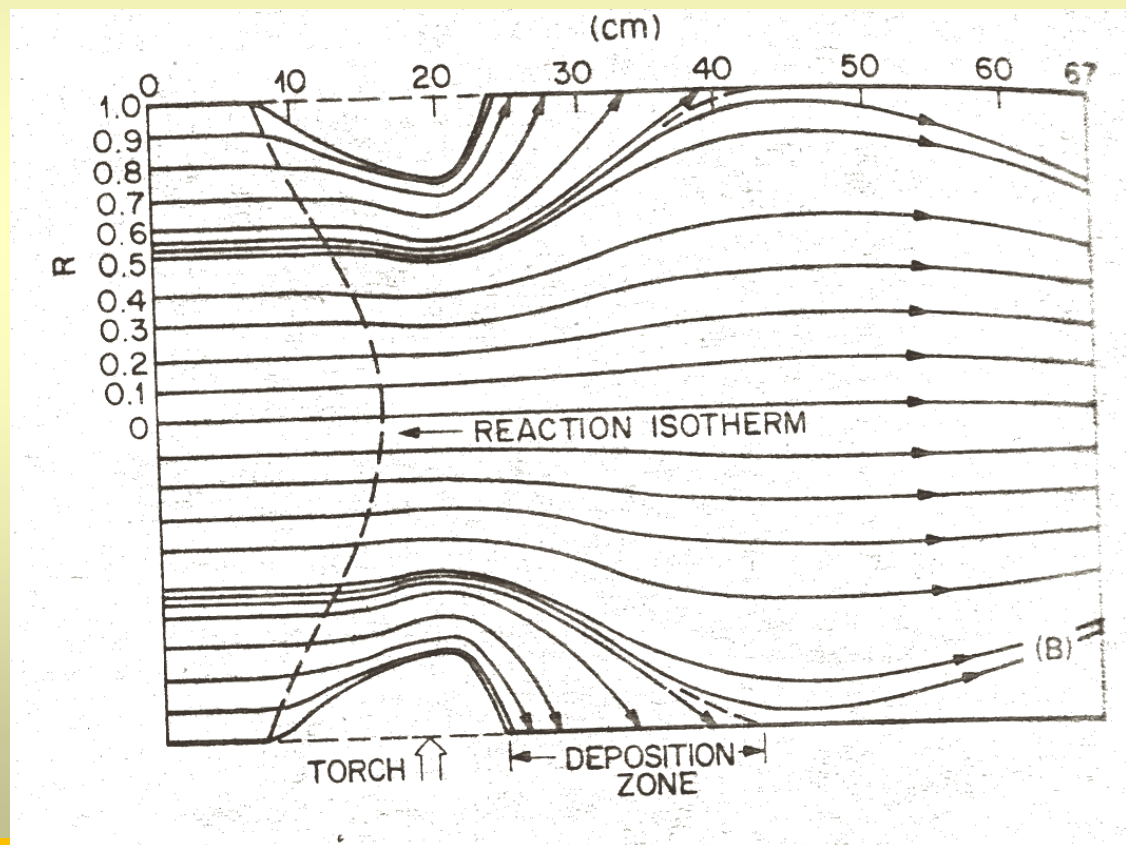
ICPF:
Phys-chem
Bendová

MCVD process

3. Deposition

Thermophoretic efficiency $f(t, x_{\text{SiCl}_4}/x_{\text{GeCl}_4})$

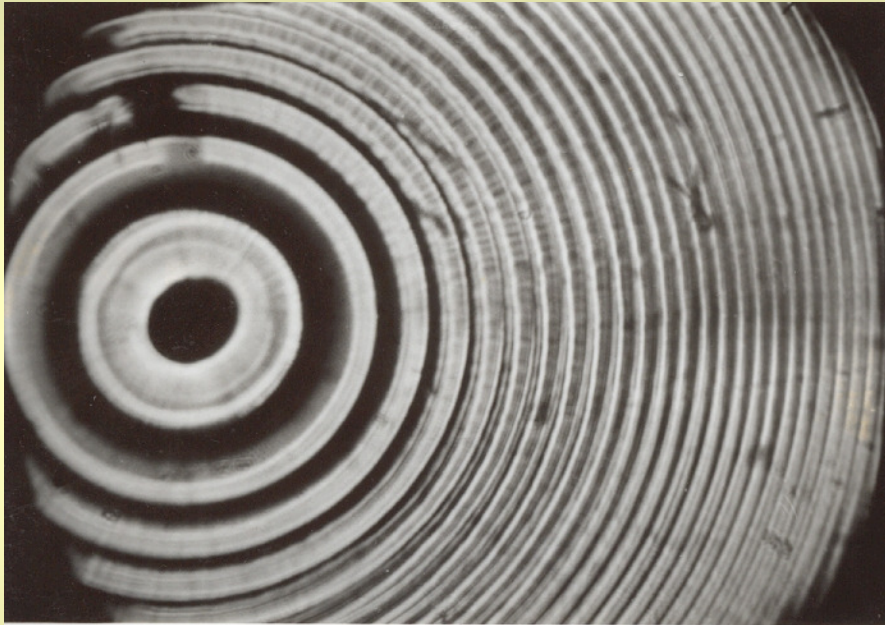
$$E = K \cdot (1 - T_{\text{cool surface}} / T_{\text{reaction}}) \sim 0.6$$



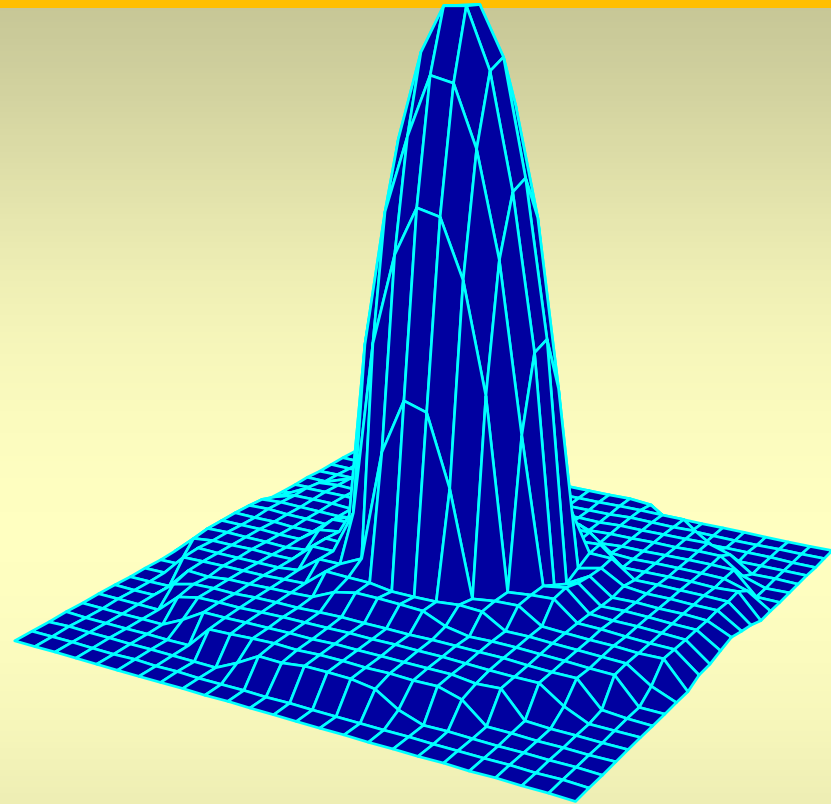
ICPF:Aerosols

- Smolík
- Ždímal
- Schwarz
- Ondráčkovi
- Kugler
- et.al.

MCVD preform preparation

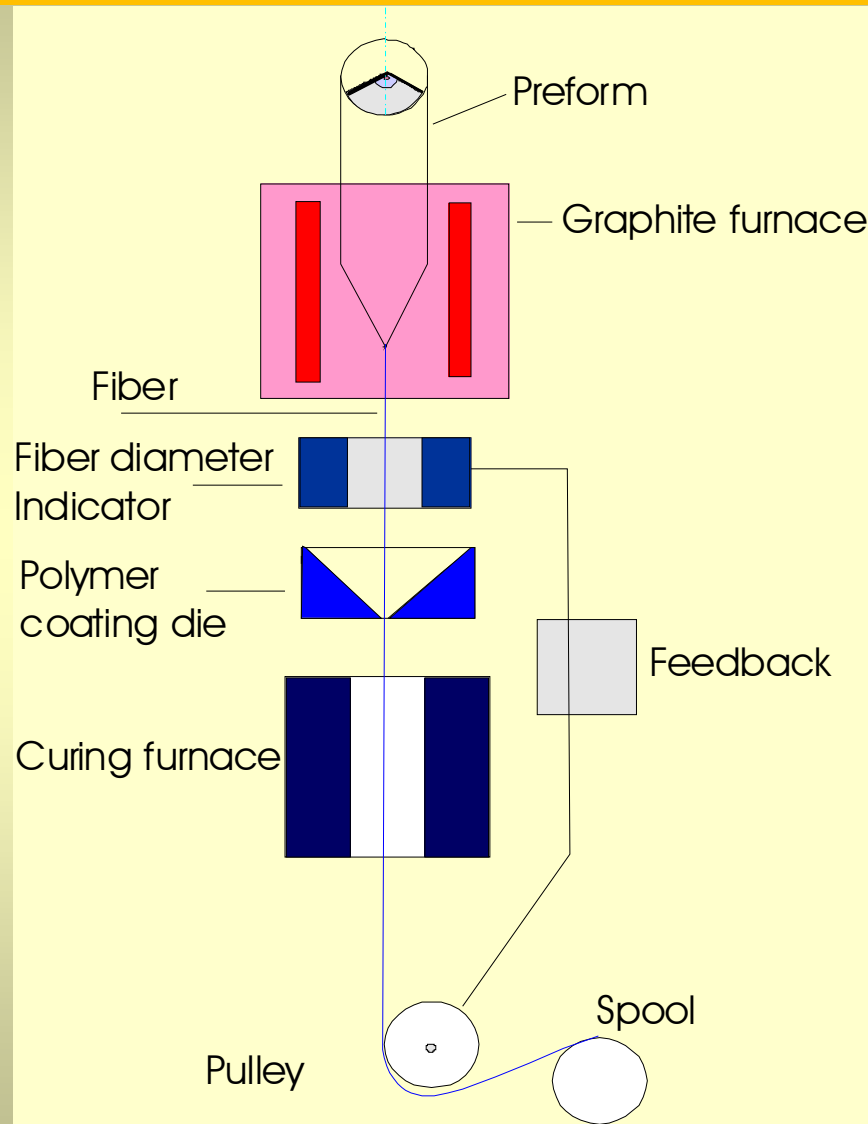


Microphoto of cross section
of produced preform



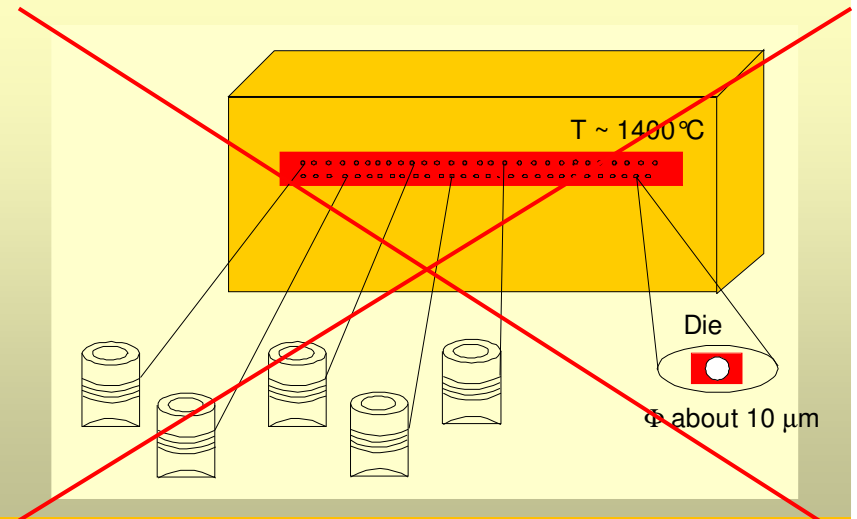
Tomography of the refractive-
index profile of preform

Drawing of Optical Fibers from preforms

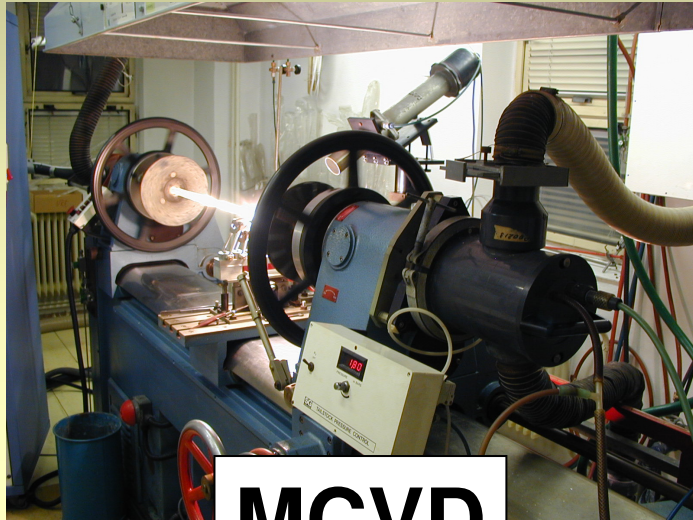


- diameter
80-1000 μm

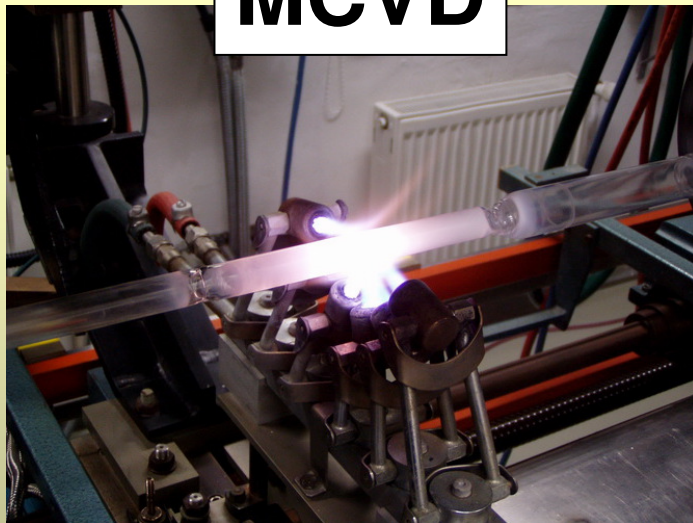
- temperature
1800-2000 $^{\circ}\text{C}$



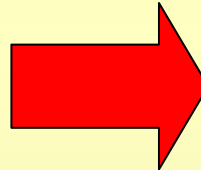
Preparation of optical fibers



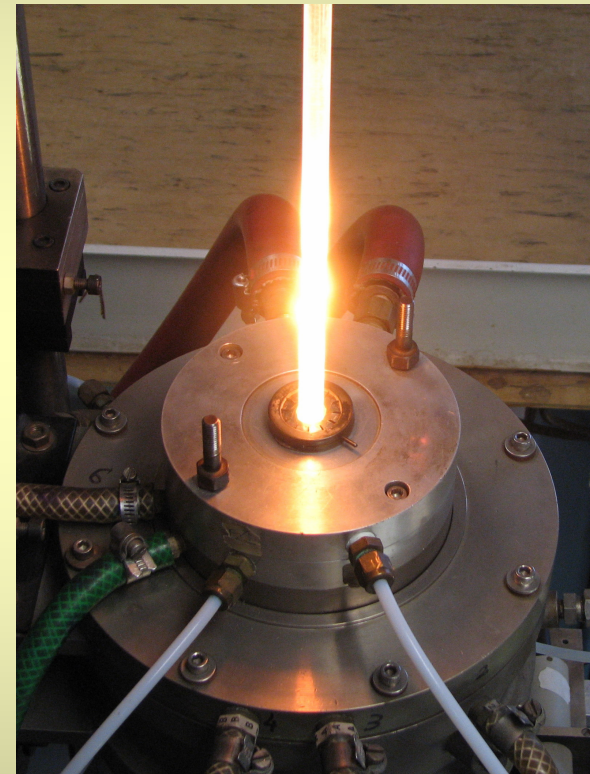
MCVD



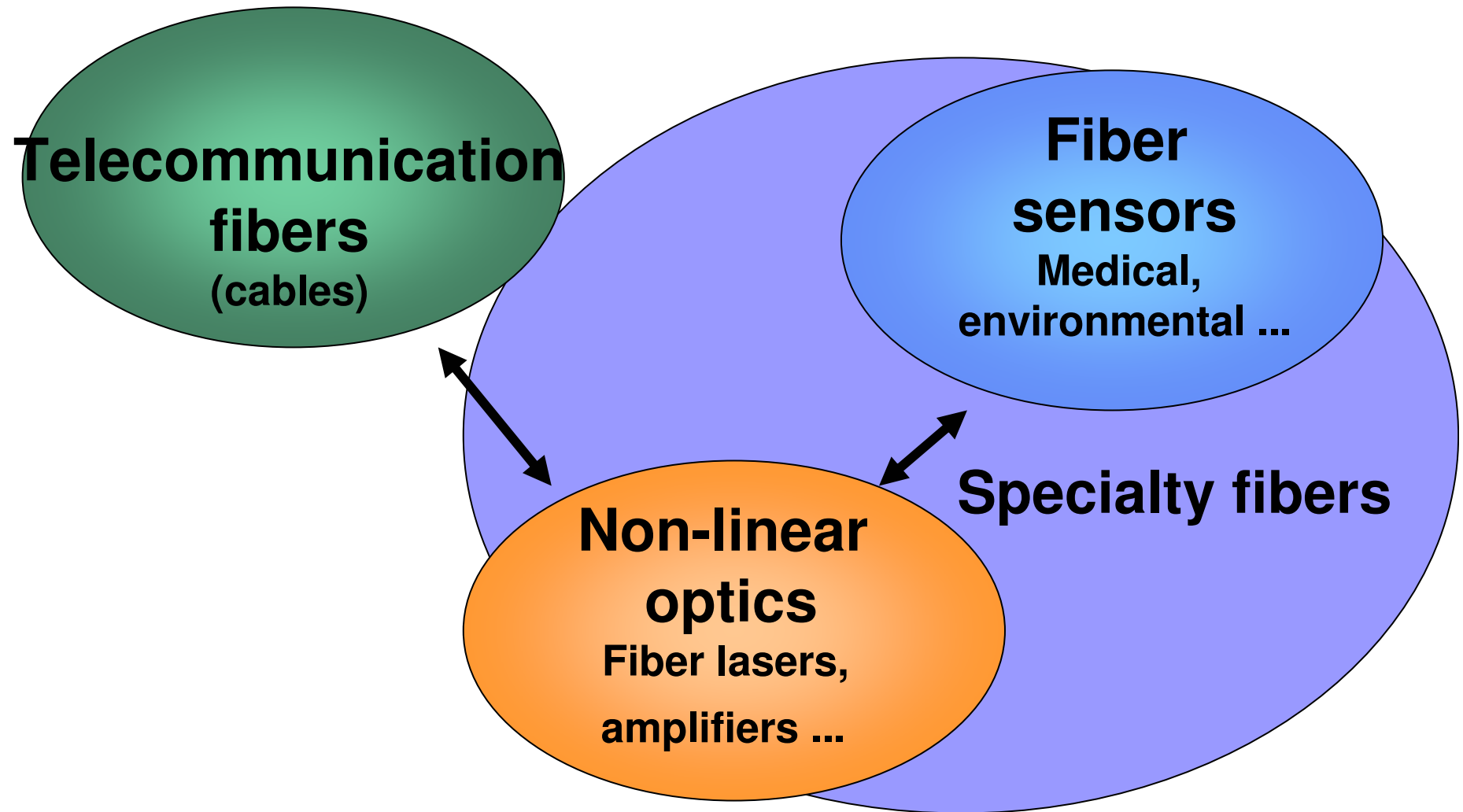
preform



Drawing

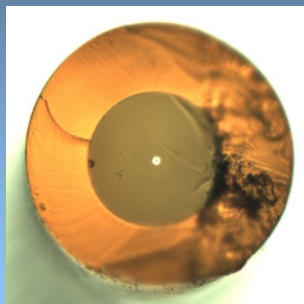
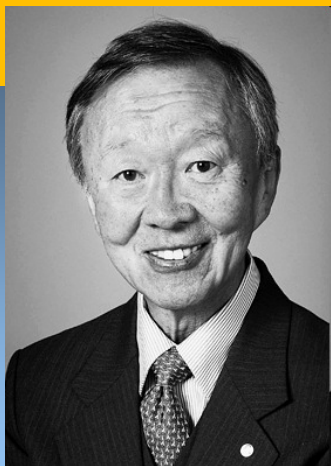


III. Application

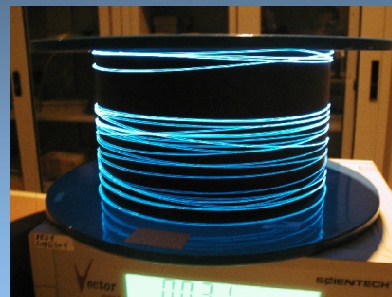


Telecommunications

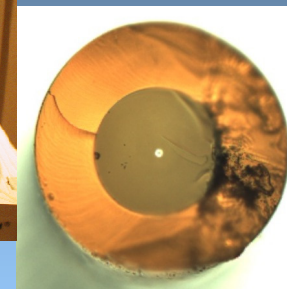
Kao
1966



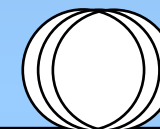
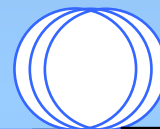
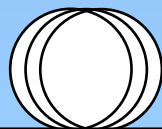
100 km vlákno



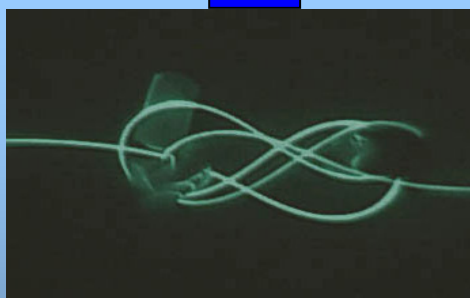
vláknový
zesilovač



zdroj signálu



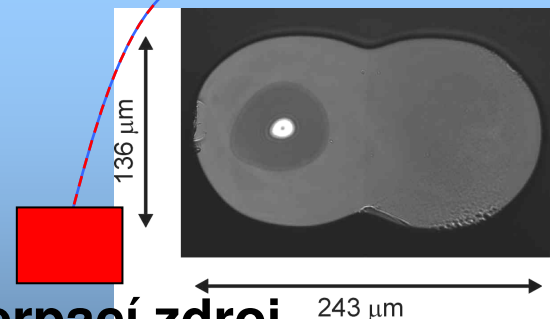
detektor



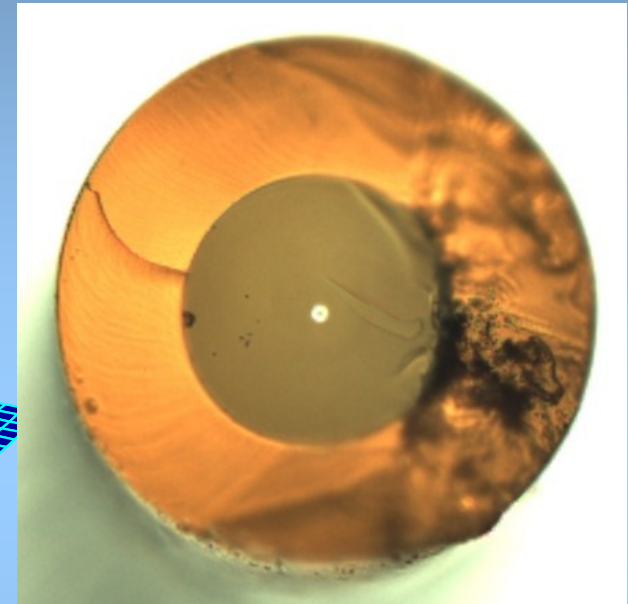
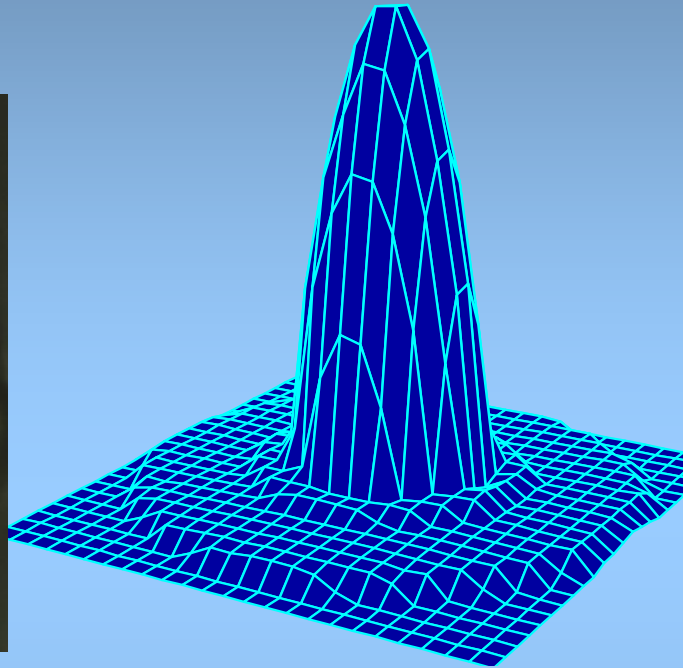
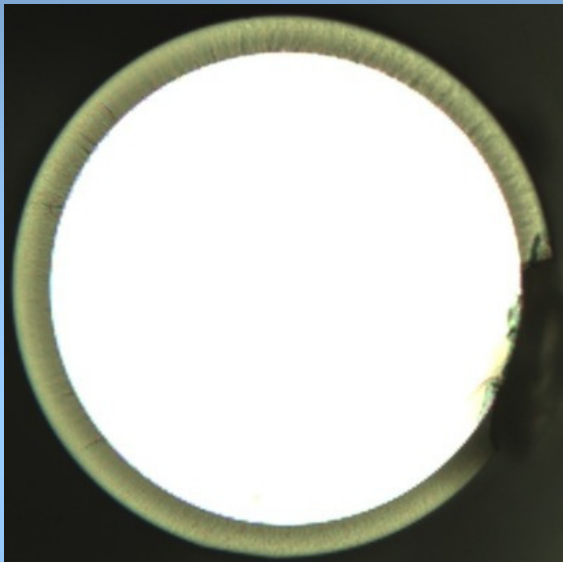
Maiman
1960



čerpací zdroj



Telecommunications



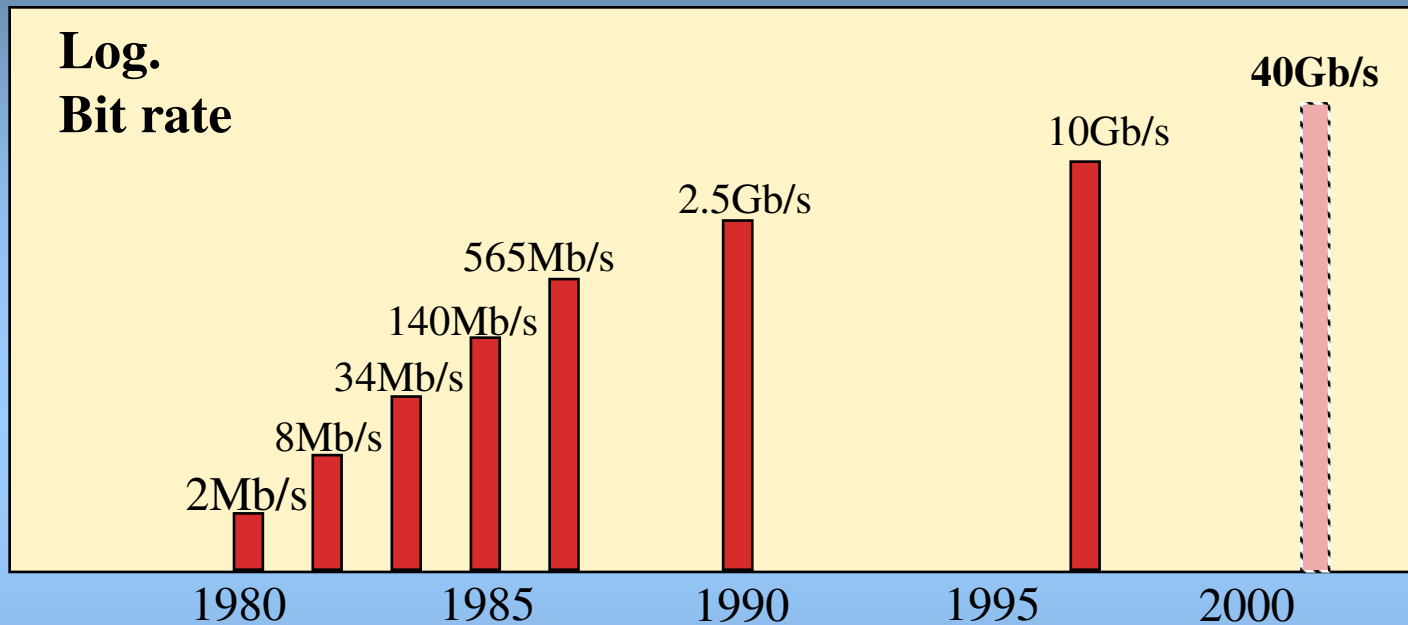
PCS Ø 200 – 600 um
technology transfer
VÚSU Teplice

GI - technology transfer
VÚSU Teplice, Hesfibel

SM 1300, 1550 nm

1981 – 1st demonstration of PCS optical fiber - CZ

Communications : increasing requirements on speed and ammount of information



Information Society - IST - Priority of 7 FP

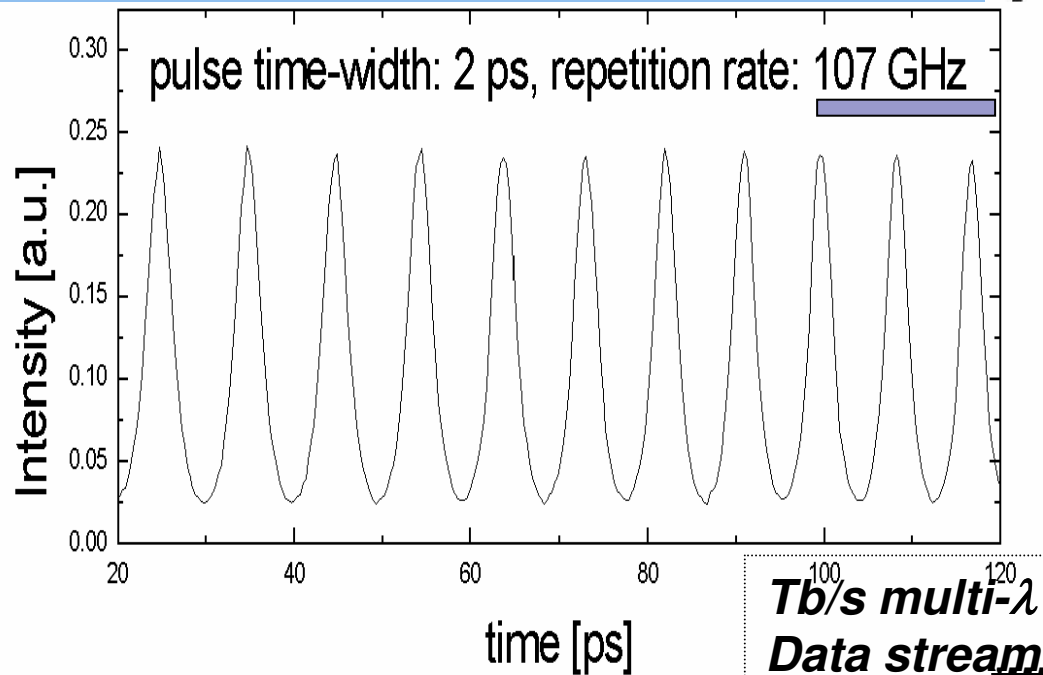
Solution : multiplexing

Time domain (TDM)

Spectral domain (WDM)

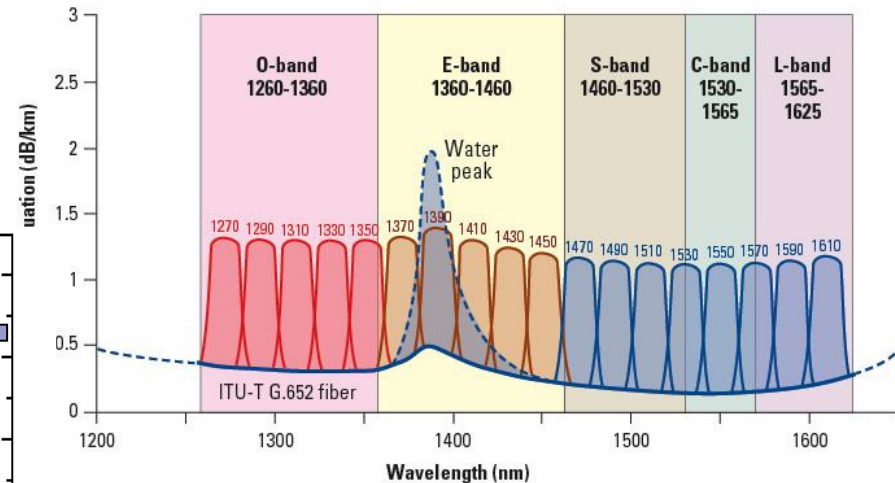
TDM

Time Division Multiplexing (TDM)

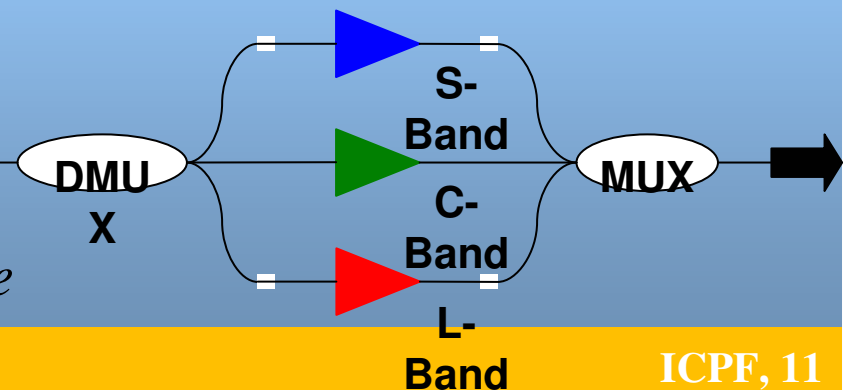


WDM

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

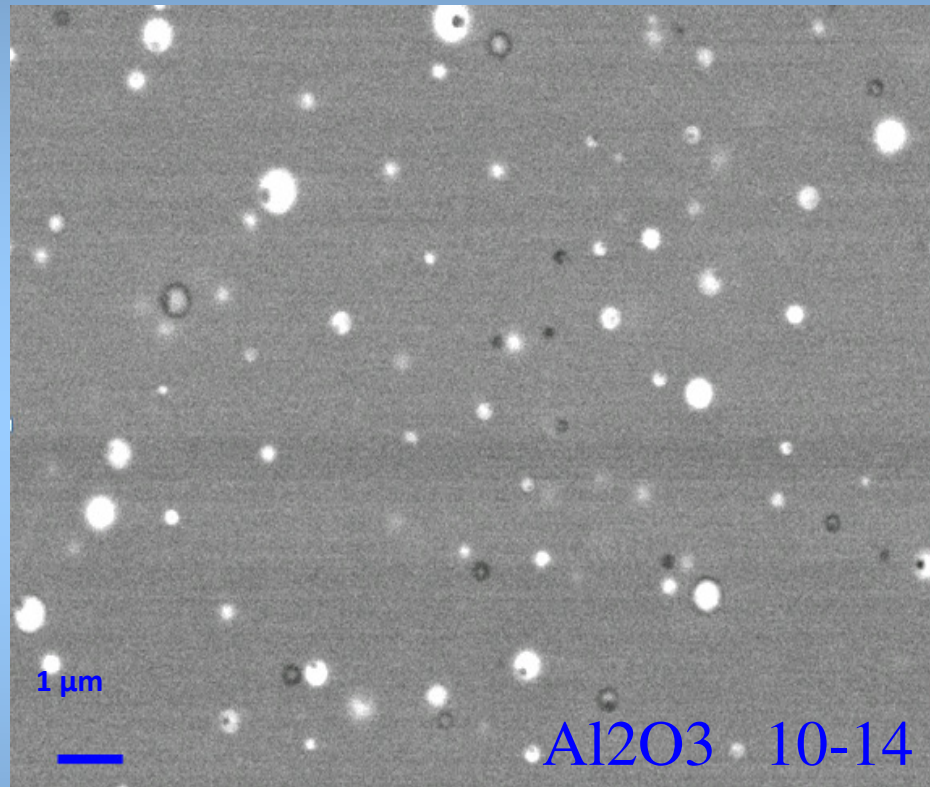


Wavelength Division Multiplexing (WDM)



In collaboration with CTU-FJFI, LPMC Nice

Er-doped nanocrystalline phase-separated optical fibers



Al₂O₃ 10-14 mol%
BaO 0.2 mol%
ZrO₂ 0.9 mol%
Er₂O₃ 3500 ppm

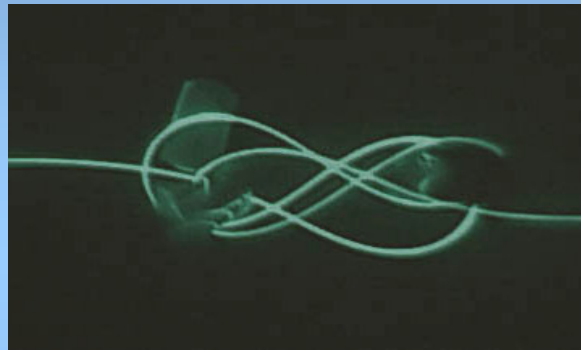
*In collaboration with
CGCRI Kolkata,
LPMC Nice*

ICPF :
Rare-earth chem.
Gruber
Nanoparticles
Fajgar
Dřínek
Pola
Rheology/dispersion
Wein
Pěnkavová
Tovčigrečko
PGS- defense
Čermák

SPECIAL OPTICAL FIBERS

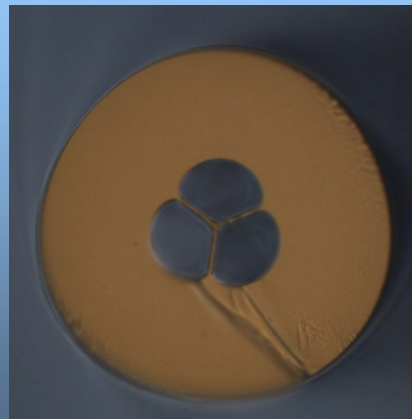
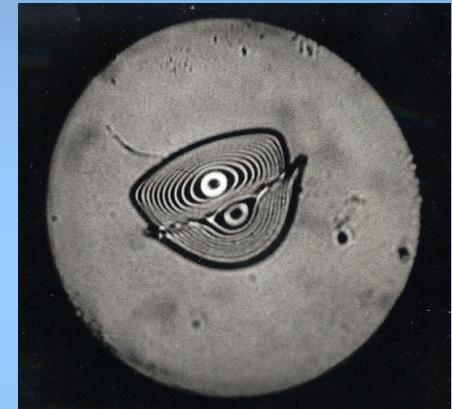
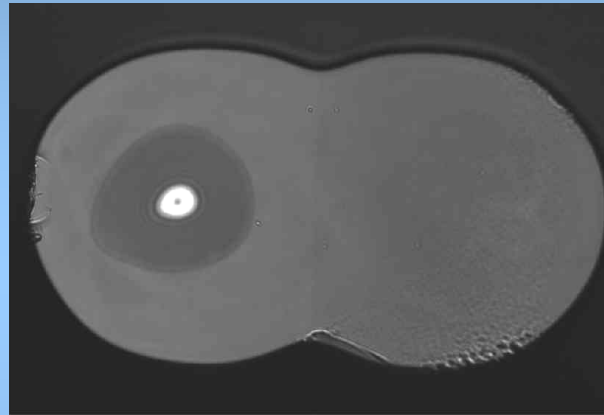
for fiber lasers, amplifiers (non-linear)

Doped fibers



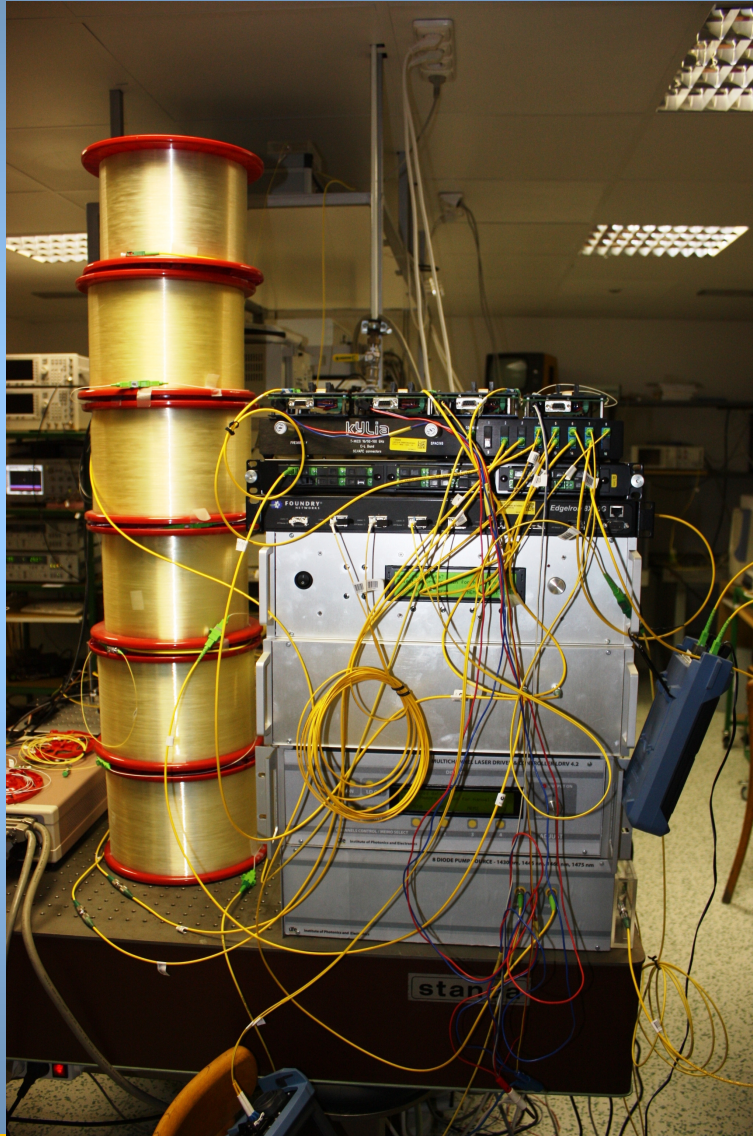
Yb/Er, Tm

Components



Twin-core (TCF)
Photonic crystal (PCF)
Double-clad (DC)

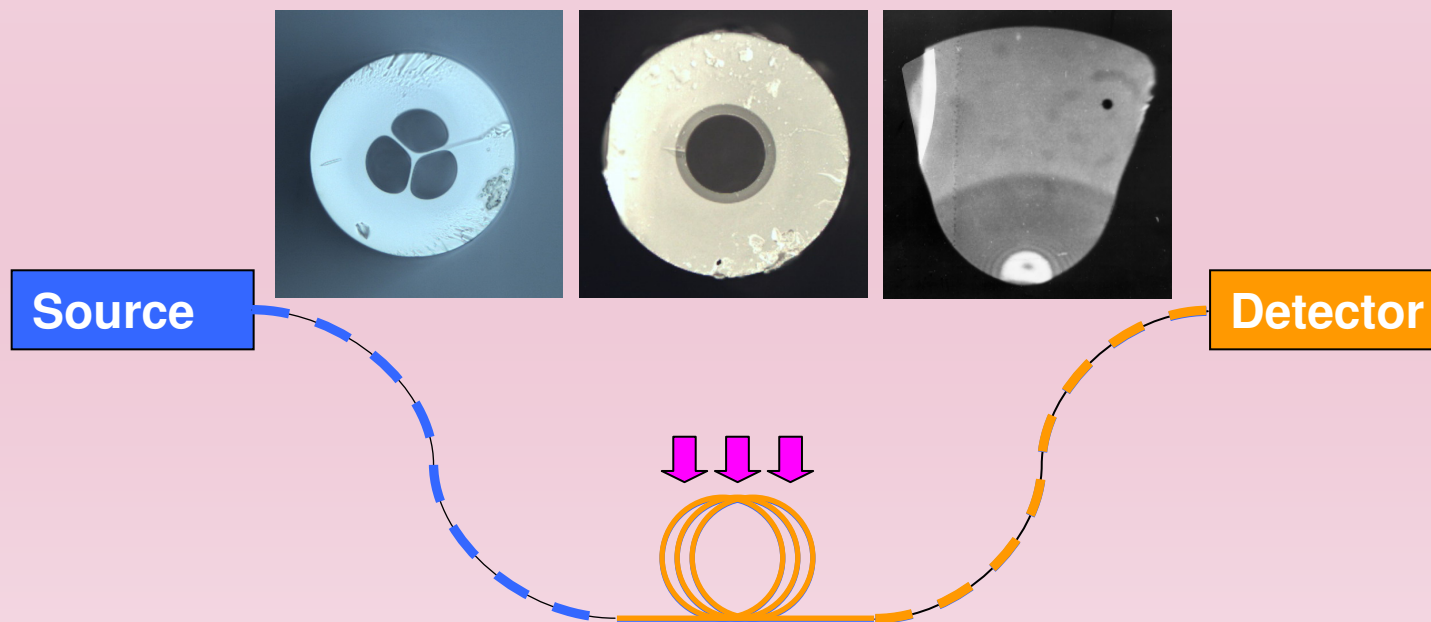
Telecommunication and fiber amplifiers



ÚFE : M.Karásek
in collaboration
with Cesnet :
testing 200 km
line

Fiber-optic sensors

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



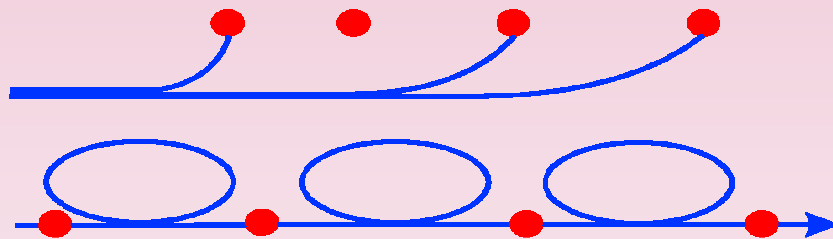
Change of output optical signal due to (bio)chemical changes in fiber vicinity.

Environmental monitoring, medicine, biology, homeland security

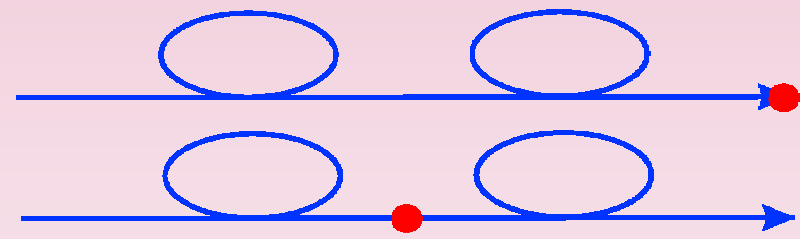
- + Remote sensing
- + Distributed
- + Explosive, high-voltage areas, human body

Solution : fiber-optic sensors

Multipoint (distributed) detection



Point detection



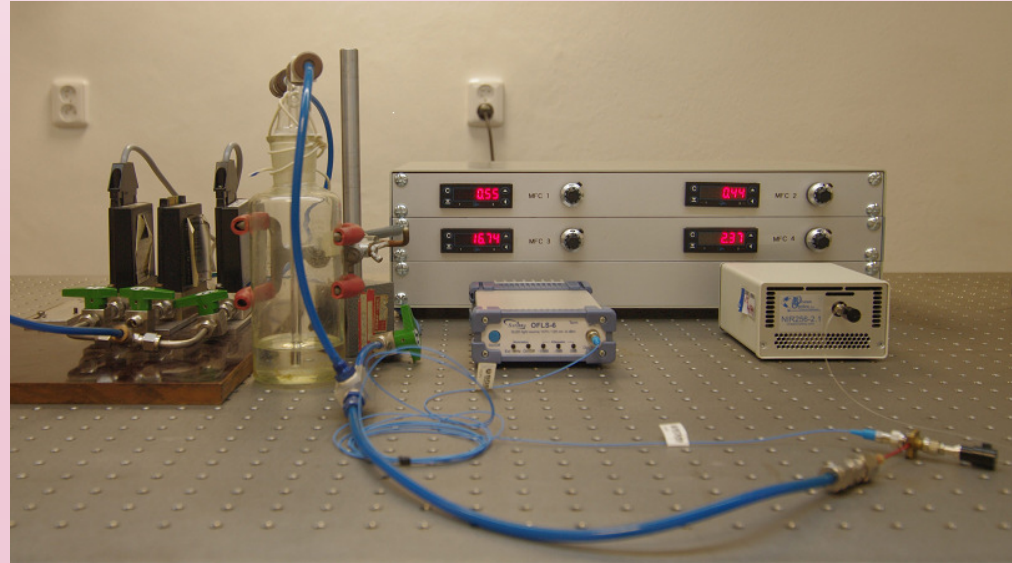
Refractometric sensor of hydrocarbons



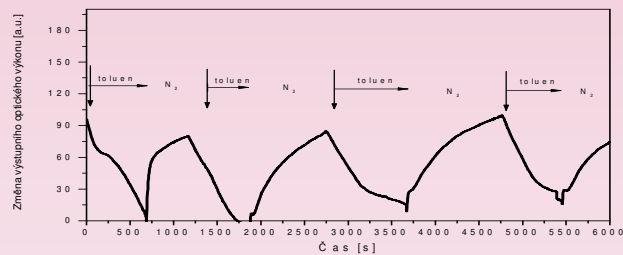
- + **sensitivity** : LOD ~ 3-5 mg/l ~ comparable to EU ecological limit
- + **time response** : seconds

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

Detection of vapors

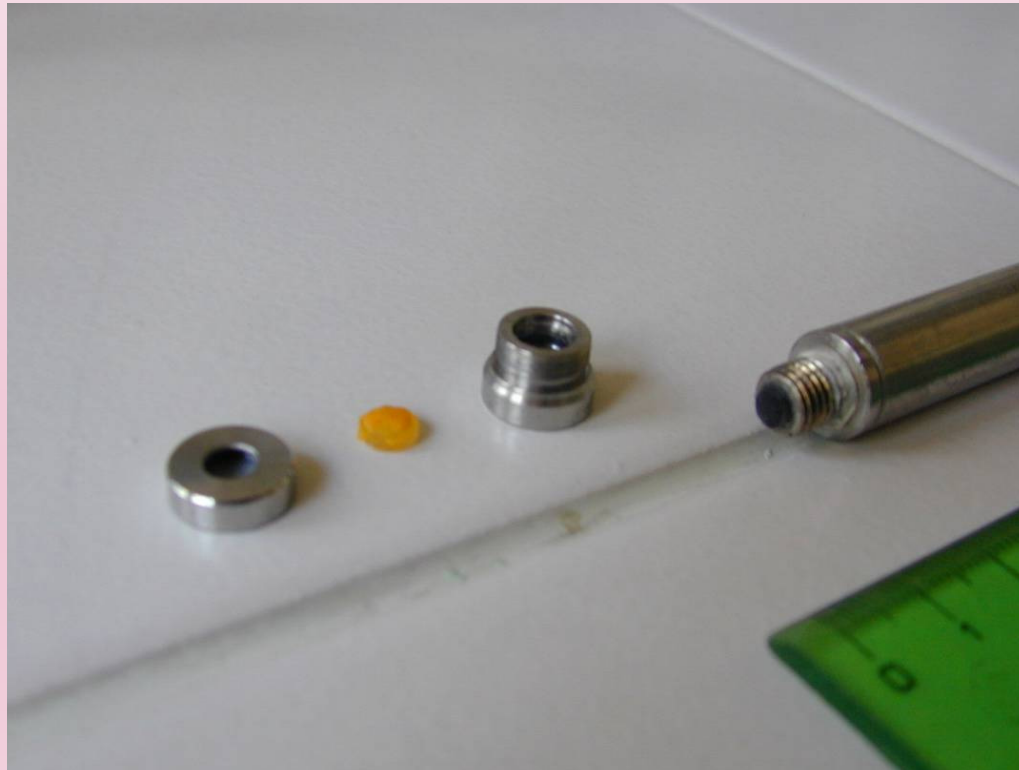


*In collaboration with ICPF
in progress*



ICPF: (analytics)
Sýkora

Fluorescence detection of oxygen



Detection of oxygen in fermentors :
6FP GRD project MATINOES

*In collaboration with ICPF, ISC
Wurzburg, UMIST Manchester ...*

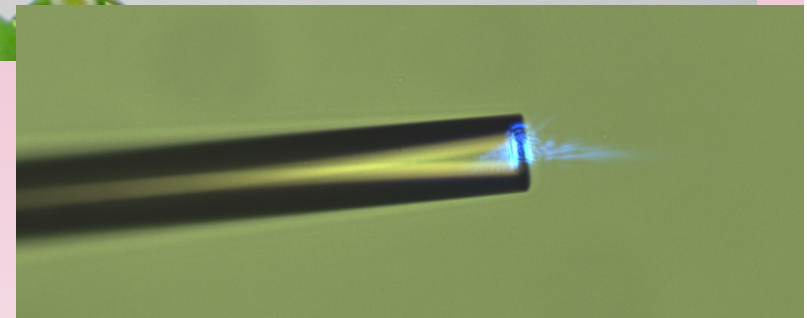
ICPF: (analytics)

Kuncová & Maléterová,
Bolyo, Trogel, Vrbová

Local pH detection in microsamples



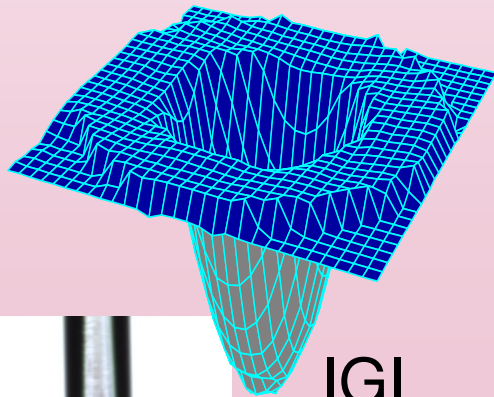
Fiber tapers :



Detection of pH $<5; 7>$ in xylem exudates, intracellular detection

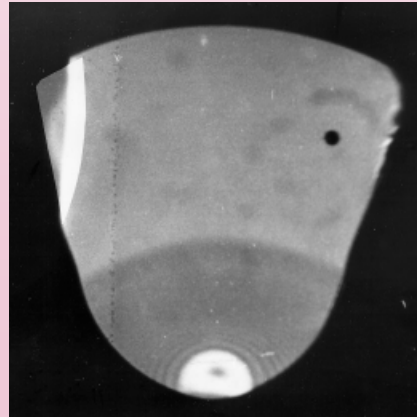
In collaboration with IEB ASCR, UK, MU, VSCHT, MZLU

SPECIAL OPTICAL FIBERS for fiber sensors

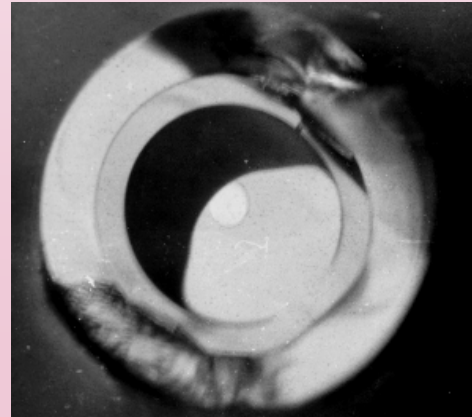


IGI

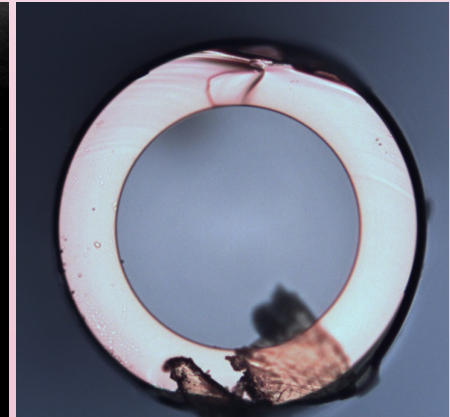
LPG



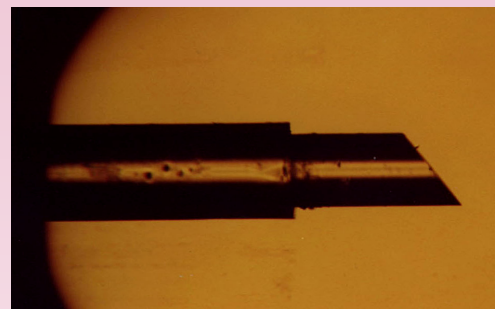
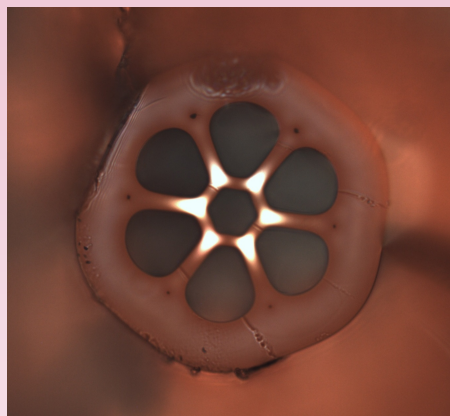
S-fibers



COF-fibers



capillaries



[PCF], tapers

ICPF: HPLC

Sýkora

ICPF: bubbling

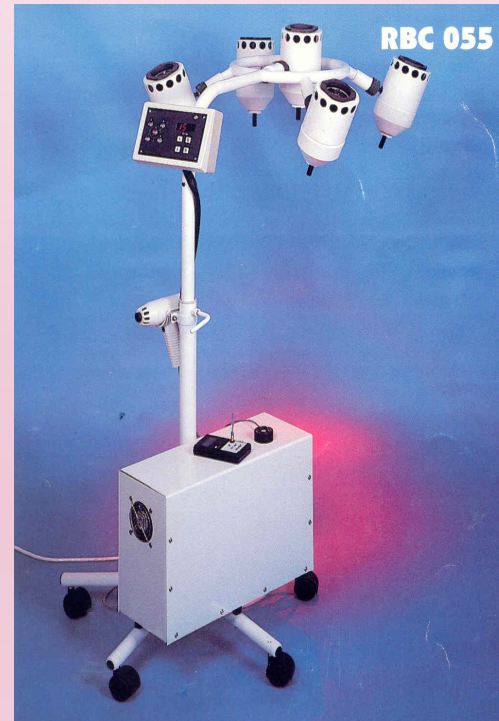
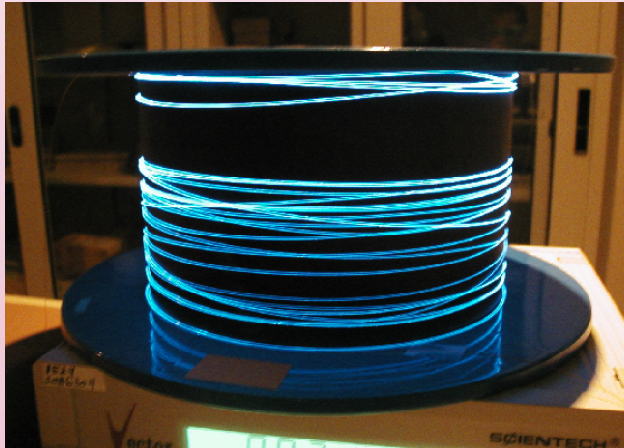
Růžička et.al.

ICPF: membranes

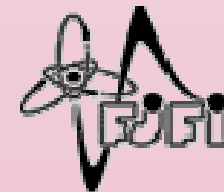
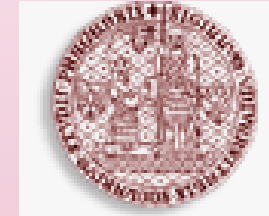
Uchytíl et.al.

ICPF: Punčochář

Fiber-optics for medical application



Ve spolupráci



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

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. **Fibers conventional and special.**
4. **Research of optical fibers (CR) :**





ČT2 – PORT : Co dokážou lasery - 29/9/2010

ČT2 – Věda a vědci : Zkrocené světlo - 6/10/2010

ČT1 – České hlavy – 10/2/2006

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.
- **J. Schrofel, K. Novotný** : **Optické vlnovody**, SNTL, 1986
- **Saaleh**, **Fotonika** (1 - 4), Matfyzpres
- **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
- Československý časopis pro fyziku 1/2010, 4-5/2010, 1/2011
- Jemná mechanika a optika 55 (2010)