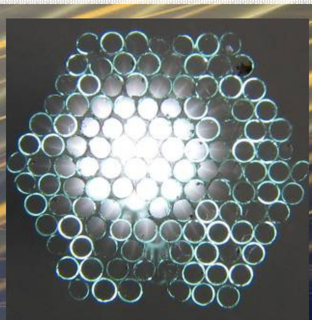
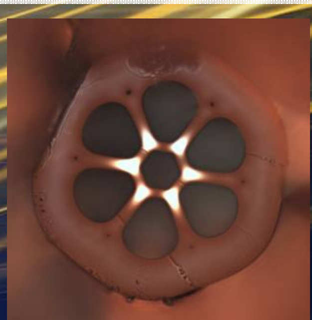
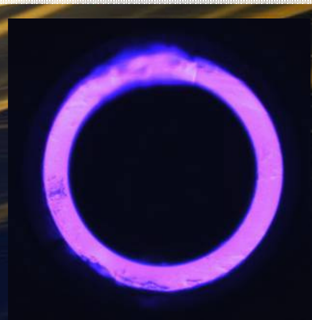
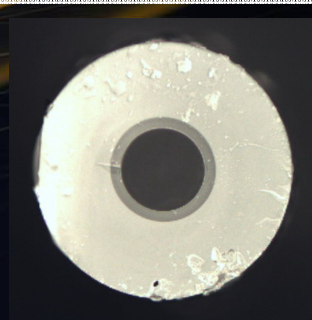
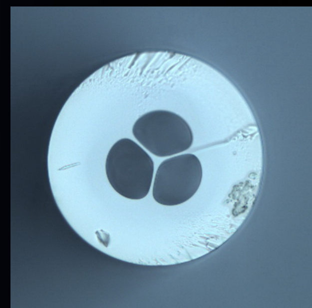
Institute of Photonics and Electronics v.v.i. (www.ufe.cz)

Technology of Optical Fibers

FILANO team

www.ufe.cz/dpt240, www.ufe.cz/~kasik

Ústav fotoniky a elektroniky AV ČR, v.v.i.

Prof. Jiří Homola
Česká hlava 2009

<u>ZÁKLADNÍ VÝZKUM:</u>

fotonika - **vláknové lasery a zesilovače, optická vlákna**
- **optické biosenzory**
- **státní etalon času, detekce pole živých buněk**

100 FTE

Outline

Intro Optical fibers

Technologies Preform preparation – MCVD & others
silica properties – MCVD vers. conventional
fiber drawing

Application Telecommunications, fiber lasers,
amplifiers, sensors

Summary

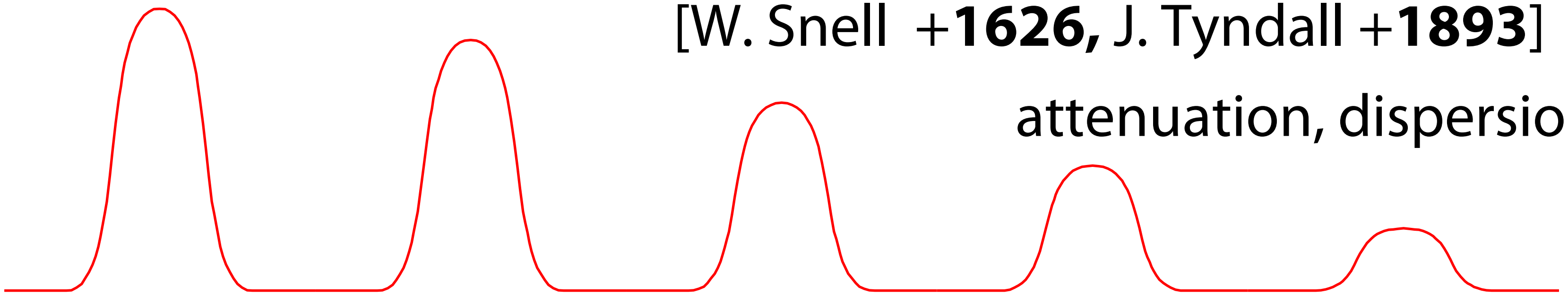
LABO MCVD, fiber drawing, sol-gel,
magnetron sputtering

Optical fiber

Optical fiber : dielectric structure, L<< r, $n_{core} > n_{clad}$

[W. Snell +**1626,** J. Tyndall +**1893**]

attenuation, dispersion



Optical losses in optical fibers

- trasparency of 3 mm of window-glass ≈ 2 km of optical fiber

[Ch.Kao, 1964]

Charles K. Kao

Nobel prize 2009

high-purity materials
max impurities acceptable in ppb (10^{-9})

ULTRA-PURE TECHNOLOGIES

Purity of material

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

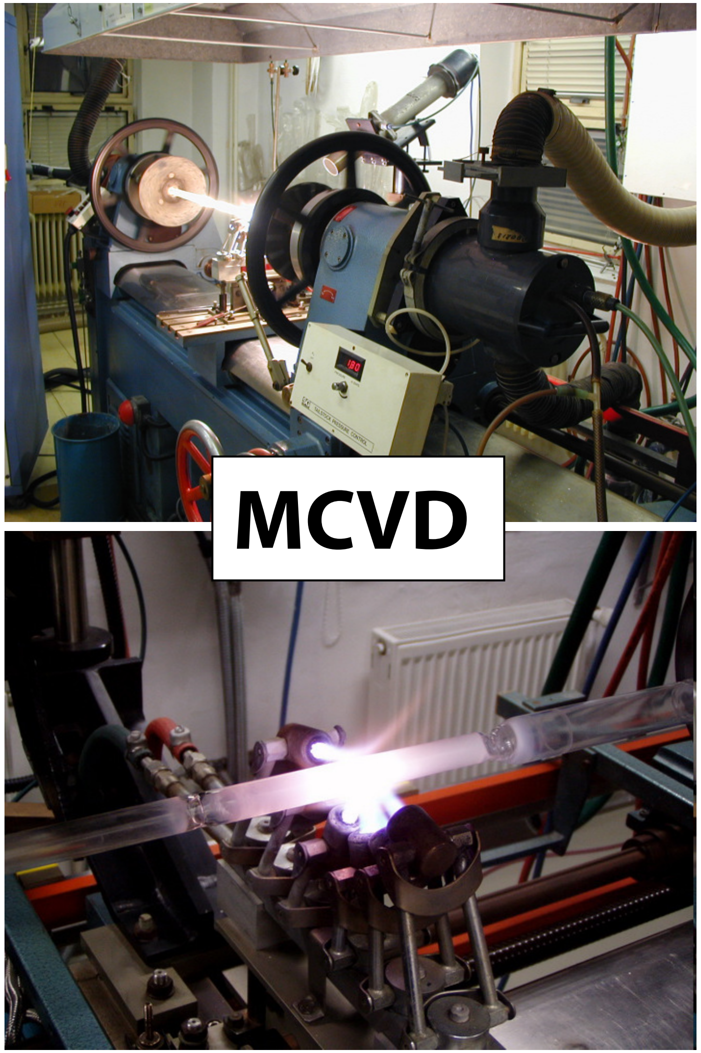
% – 10^{-2}

ppm – 10^{-6} (parts per million)

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

Ultra-pure technologies - CVD !

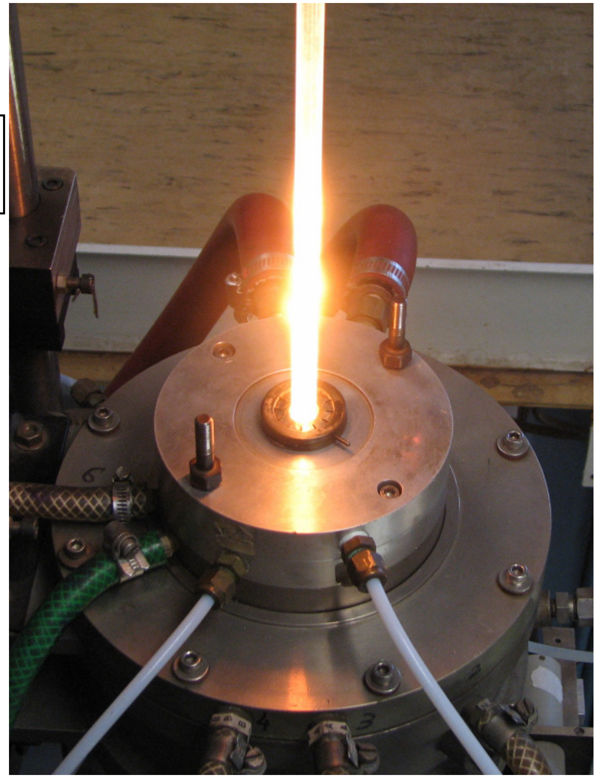
Optical fiber preparation



MCVD

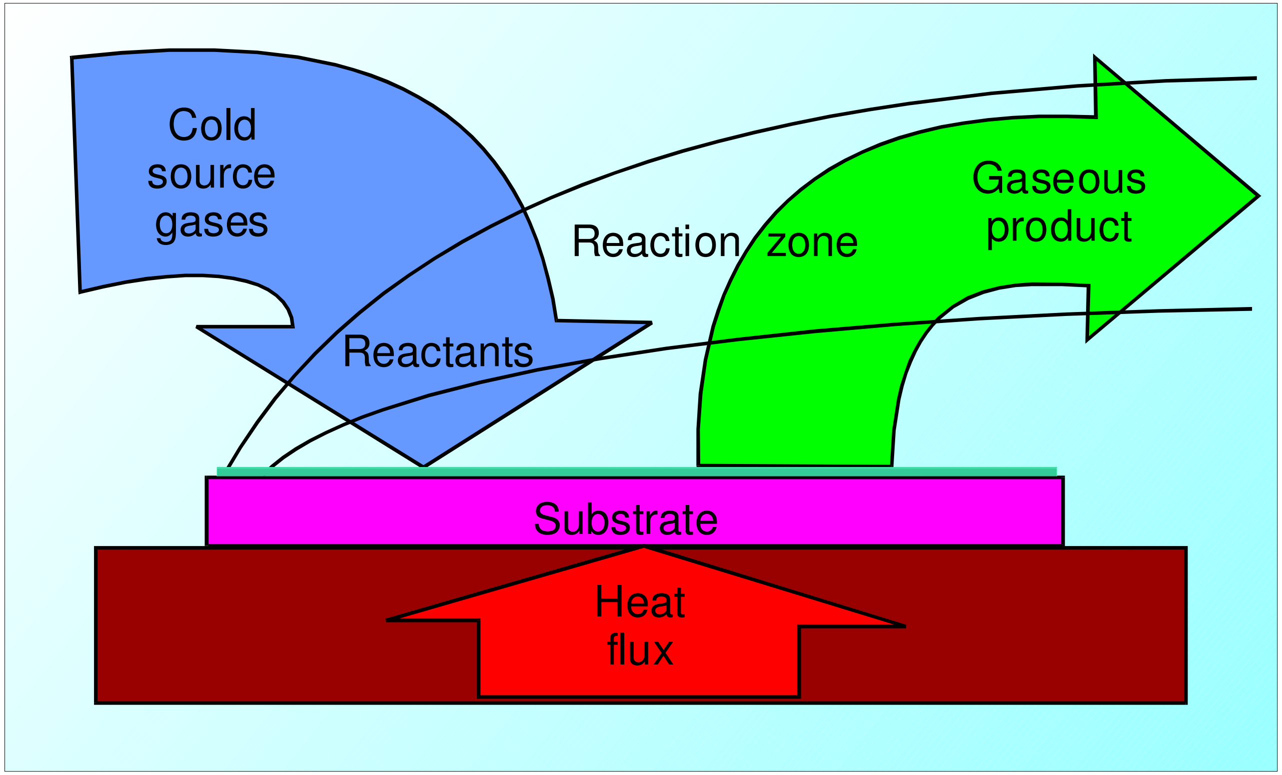
1. Preform

2. Fiber drawing



Ultra-pure technologies
CVD - Chemical Vapor Deposition

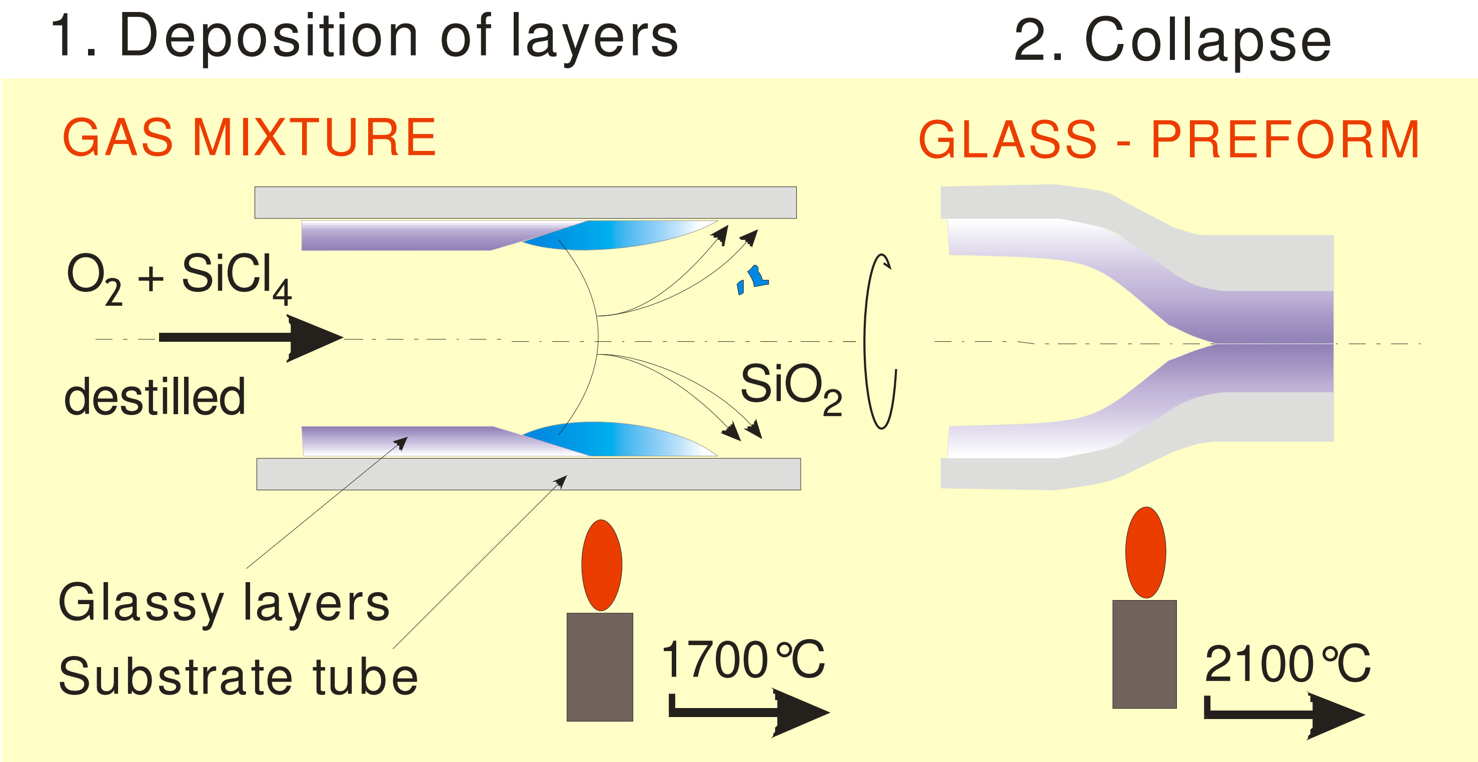
A (g) + B(g) = AB (s)



Goal : starting materials (g) or (l) can be purified (E.g. distilled)

Preform preparation

MCVD – (Modified) 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** [S. R. Nagel, 1982]
- **high purity** (~ 10^1 ppb) **high preciseness** (better than 1 %)

MCVD process model

1. Vaporization of starting materials

- $V_{XCl4} = V_{Ox} * P^{o}_{XCl4} / (P - P^{o}_{XCl4})$ … boiling point $SiCl_4$=56°C

2. Oxidation

- 1st -order kinetics, t = 0.02 s
- Chemical equilibrium :
- $SiCl_4$ (g) + O_2 → SiO_2 (s) + $2Cl_2$

  conversion ~ 0.95 – 0.99 (1500 °C)
- $GeCl_4$ (g) + O_2 → GeO_2 (s) + $2Cl_2$

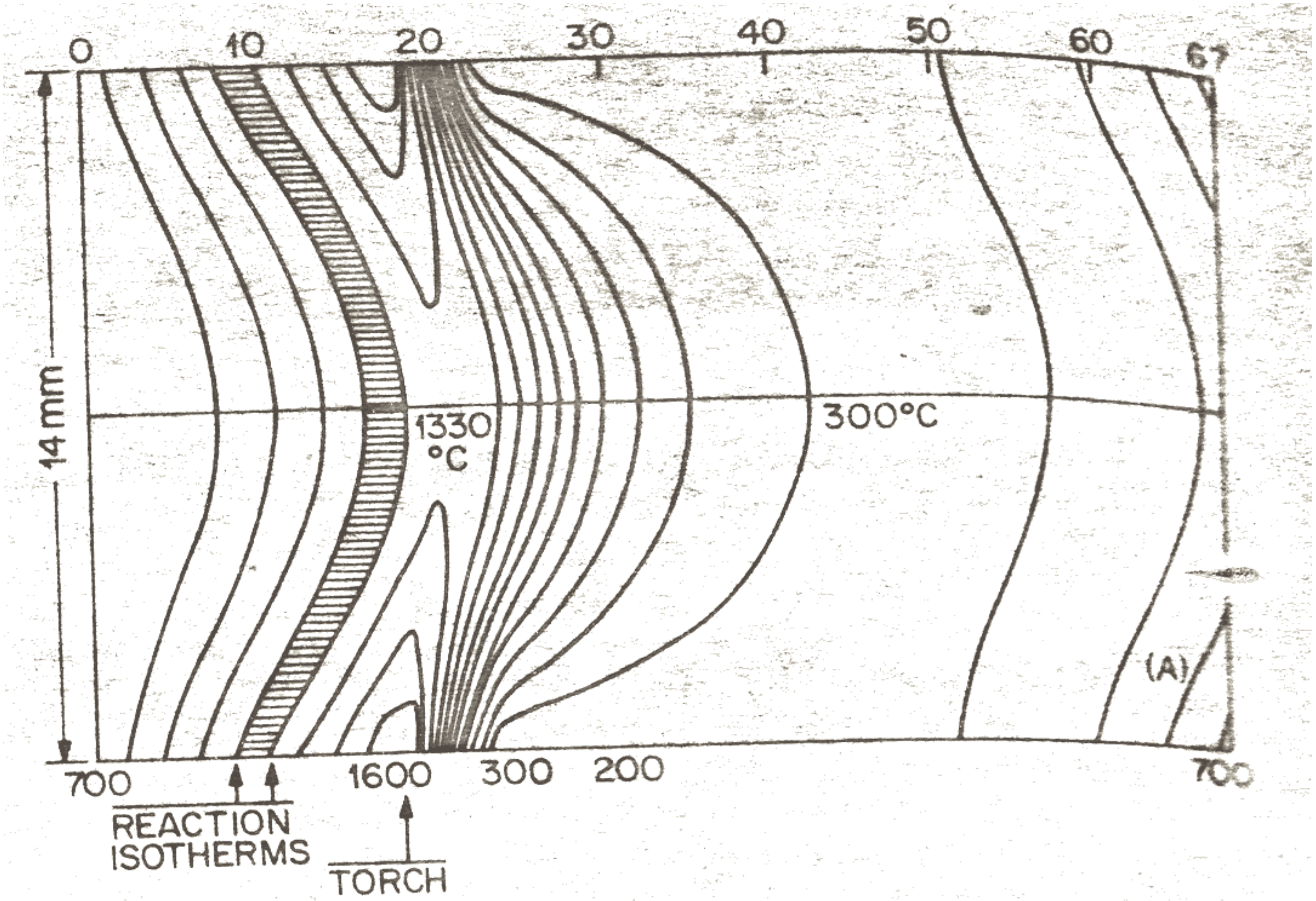
  conversion ~0.5 – 0.6 (1600 °C), $f(t, x_{SiCl4}/x_{GeCl4})$

3. Deposition

- Thermophoretic efficiency

  $E = K . (1 – T_{cool\ surface} / T_{reaction}) \sim 0.6$

MCVD process model



Temperature field during deposition

MCVD process model

Process parameters :

Variable :

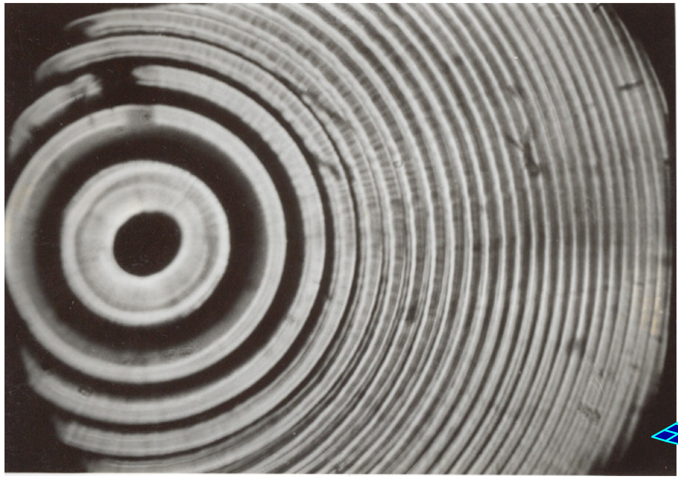
- flow rates (Si, Ge, P, B, F, Ox …)
- deposition temperature

Adjustable :

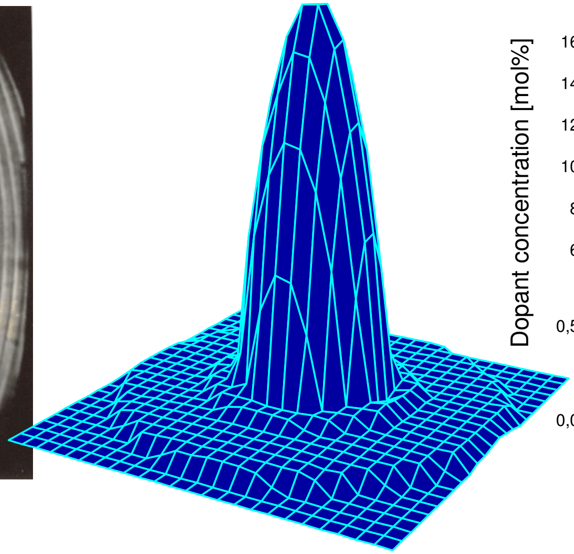
- temperature of starting materials (liquids)
- burner speed
- pressure
- rotation speed of the substrate tube
- substrate tube dimensions

[McChesney and Nagel, 1982, Wood, 1987, Kirchhof, 1986]

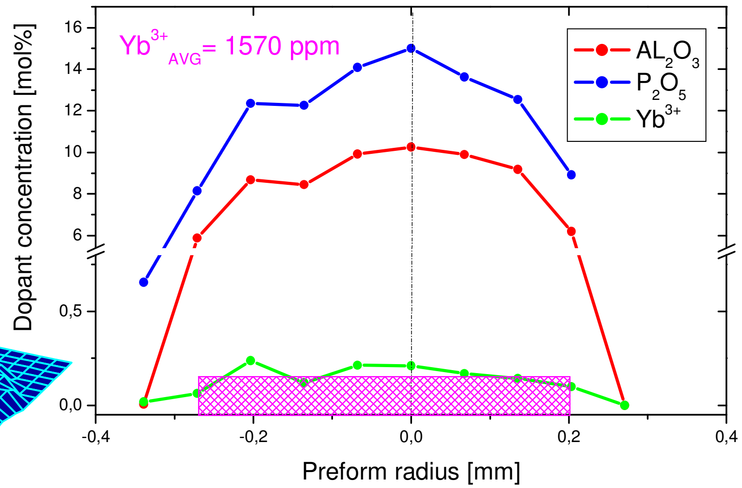
MCVD output parameters



Microphoto of cross section of preform



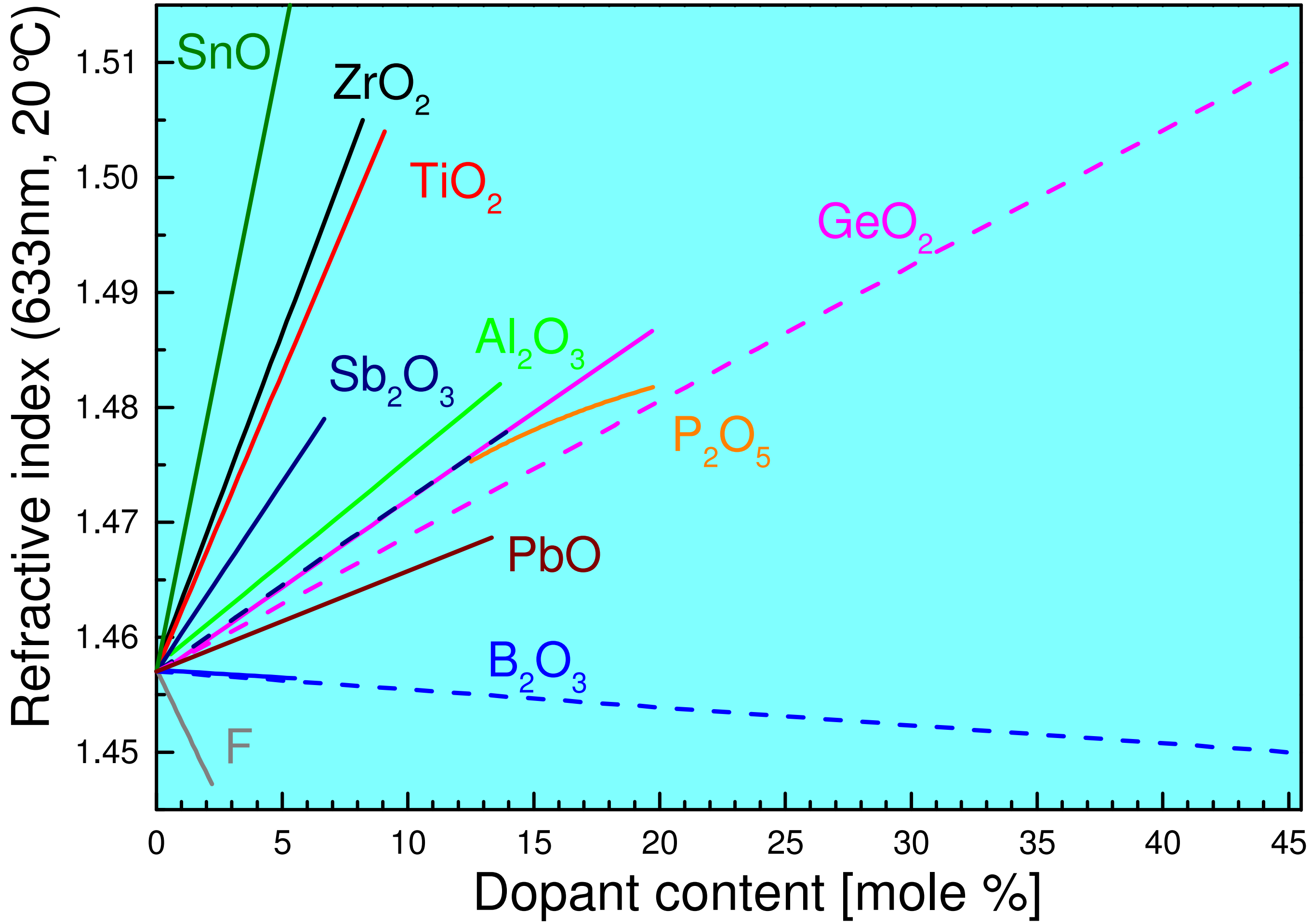
Tomography of the refractive-index profile of preform



Concentration profile

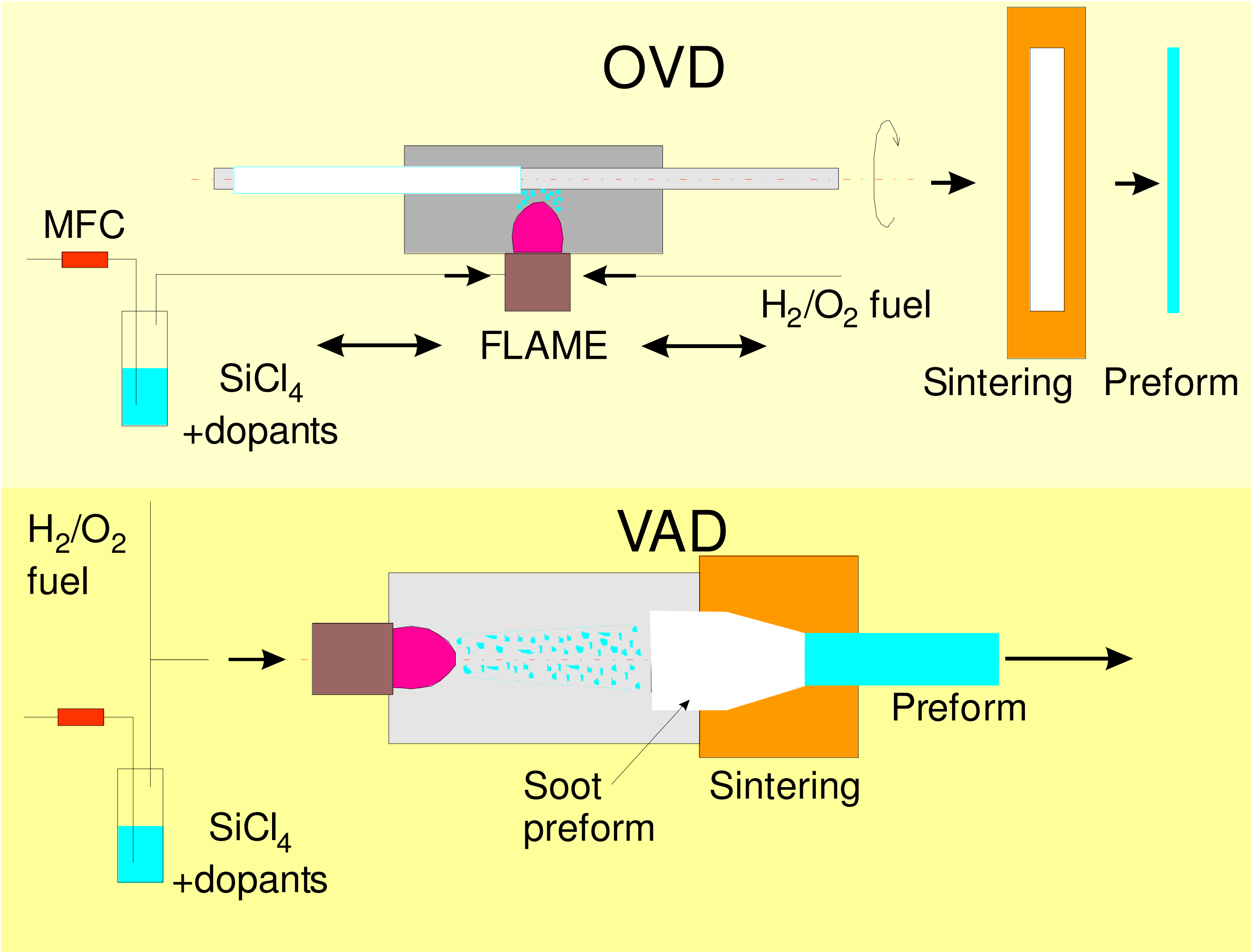
- High purity material due to FO-Optipur purity starting materials.
- High quenching rate ranging from 10^2 to 10^3 °C/s !

MCVD - doping of silica

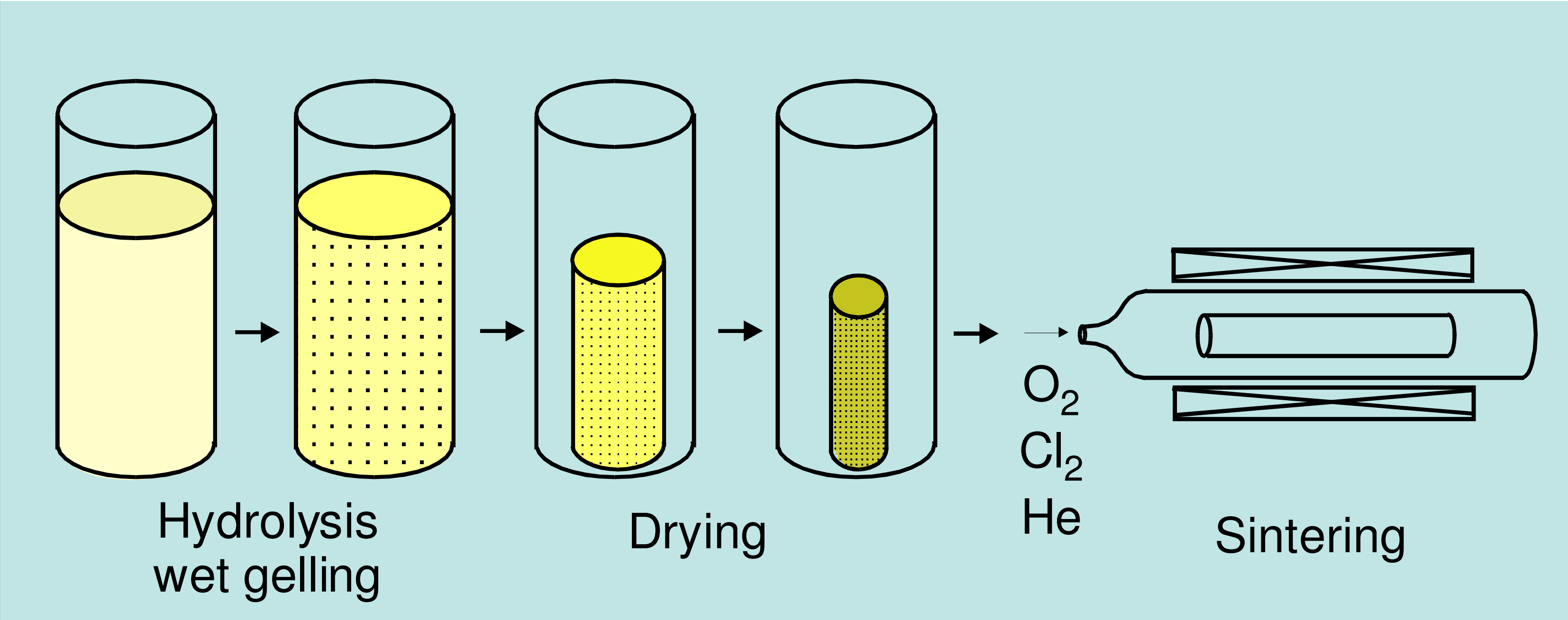


[A.B. Chynoweth, 1979, M. Shimizu, 1986, Y. Ohmori, 1983, S. H. Wemple, 1973, H. Wehr 1986, I. Kasik, 2005, K. Sanada, 1980, M. M. Karim 1994]

Other CVD technologies (ultra-pure)



Other technologies : sol-gel



No melting, disorder imprinted.

[J. McKenzie (US), J. B. McChesney, 1997, A. Pope (US), 1993, M. Guglielmi (It), J. Livage (F), R. Almeida (P), S. Ribeiro (Br), B. McCraith (Ir), J. Brinker (US), S. Sakka (J), V. Matejec & J.Mrazek (CZ)]

Comparison

CVD (Chemical) x **PVD** (Physical)

CVD (Chemical)	**PVD** (Physical)
MCVD	DC magnetron sputtering
OVD etc.	vacuum evaporation etc.

Layer thickness

CVD	PVD
1 – 10^1 **µm**	1 - 10^1 **nm**

(however, both are reported as "thin layers")

Deposition rate

CVD	PVD
HIGH	LOW

Products

CVD	PVD
Layers, bulks	Layers only

Comparison

(M)CVD x conventional

Starting materials

(M)CVD	conventional
gaseous (g) or liquid (l)	(s) solid state
melting point of oxides different	melting point comparable

Purification methods

(M)CVD	conventional
distillation	recrystallisation, remelting

Comparison

(M)CVD x conventional

Process

(M)CVD	conventional
Deposition of layers = oxidation+deposition+sintering (NO MELTING)	Melting
Collapsing of preform (MELTING)	Forming
-	Annealing

Structure of products

(M)CVD	conventional
Graded - profiles	Homogeneous

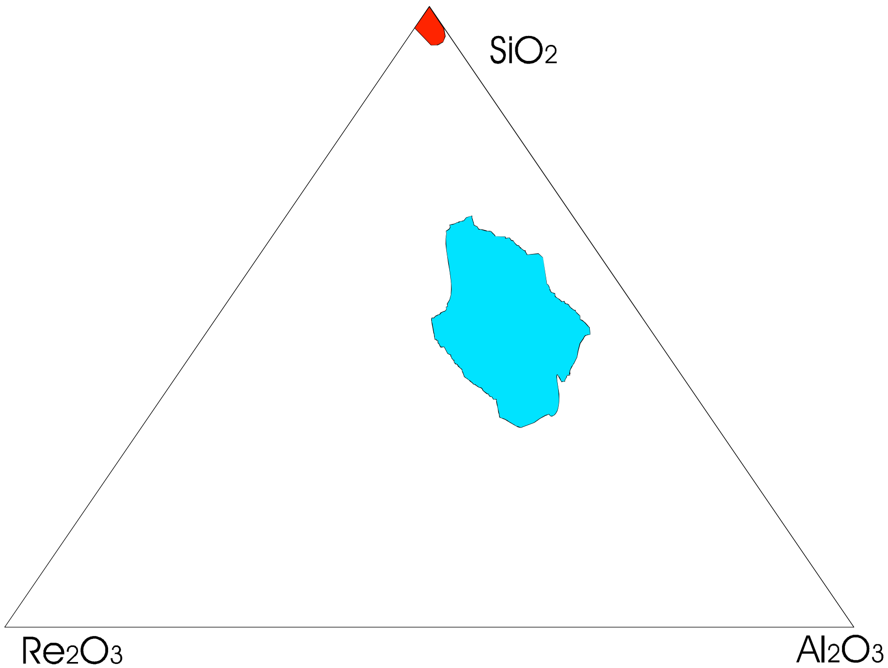
Material purity

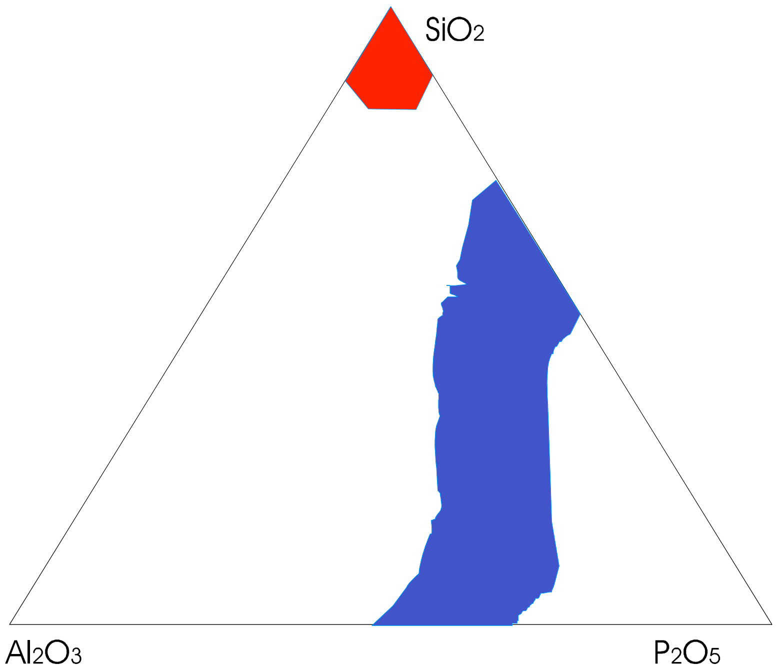
(M)CVD	conventional
ppb (10^{-9}, i.e. 10^{-7} mol%)	10^{-3} mol% (99,999%)

Properties

(M)CVD x conventional

Glassforming region





Quenching rate

~ 10^2 - 10^3 °C/s

~10 °C/min

[O. V. Mazurin, 1980, J. E. Shelby, 1992]

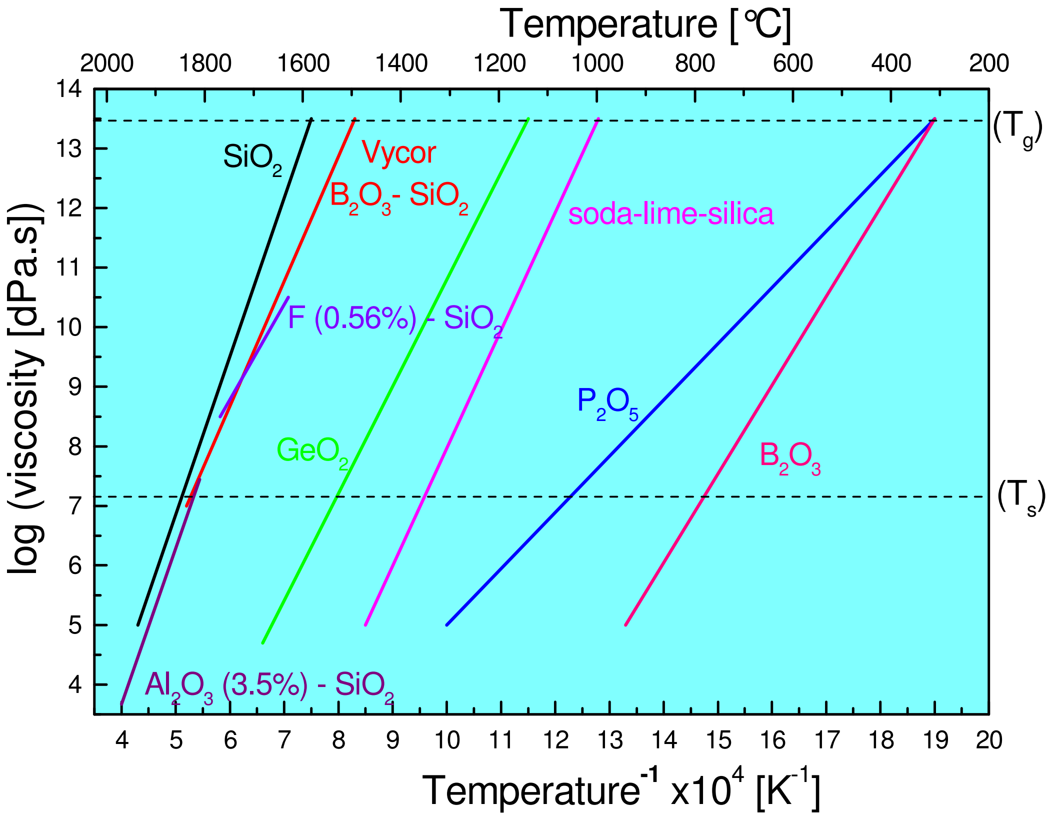
Properties

(M)CVD x conventional

Viscosity curves

Short

Long



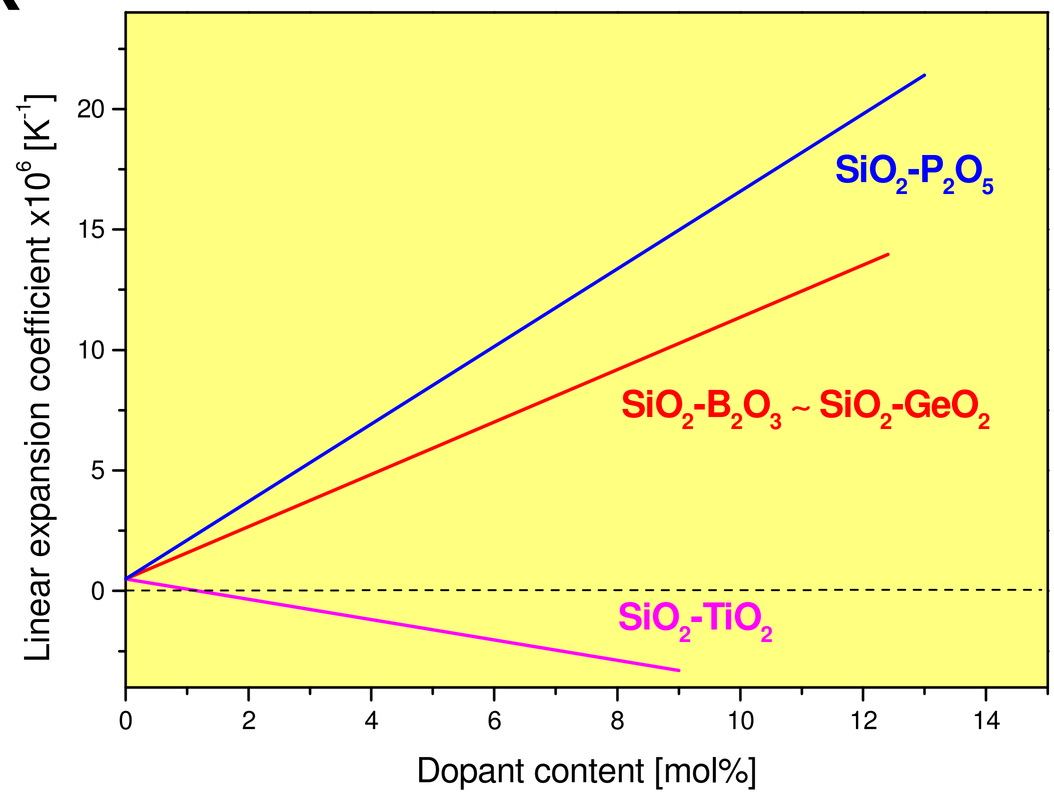
Annealing ~ 1120-1180 °C [www.Heraeus, M. B. Volf, 1987, A. B. Chynoweth, 1979, M. Ohashi, 1992, O. V. Mazurin, 1980, K. Shiraki, 1993]

Properties

(M)CVD x conventional

Expansion coefficient KLTR

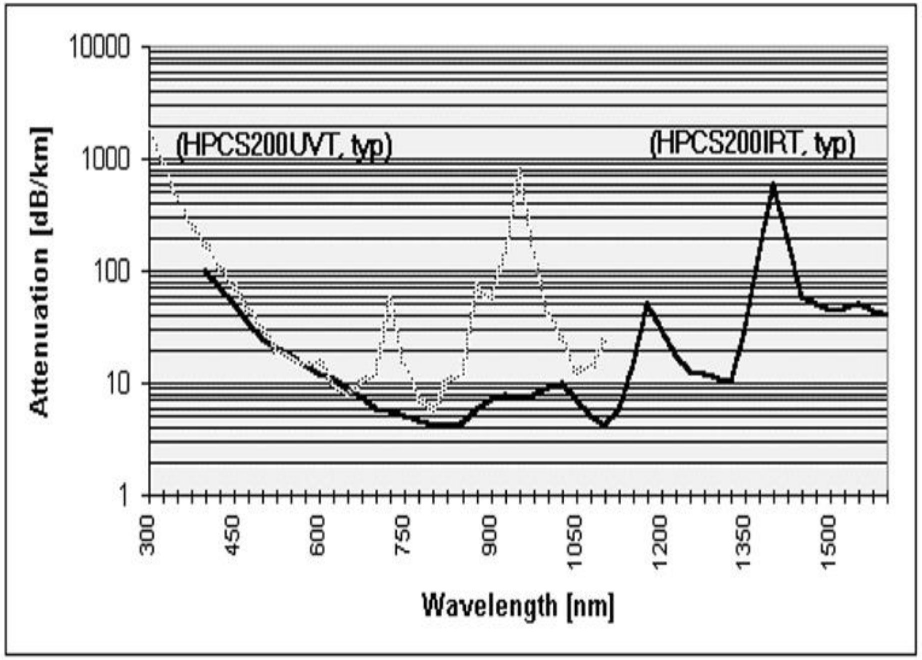
$0.5 \cdot 10^{-6}$ K^{-1} $< 3.3 \times 10^{-6}$ K^{-1}

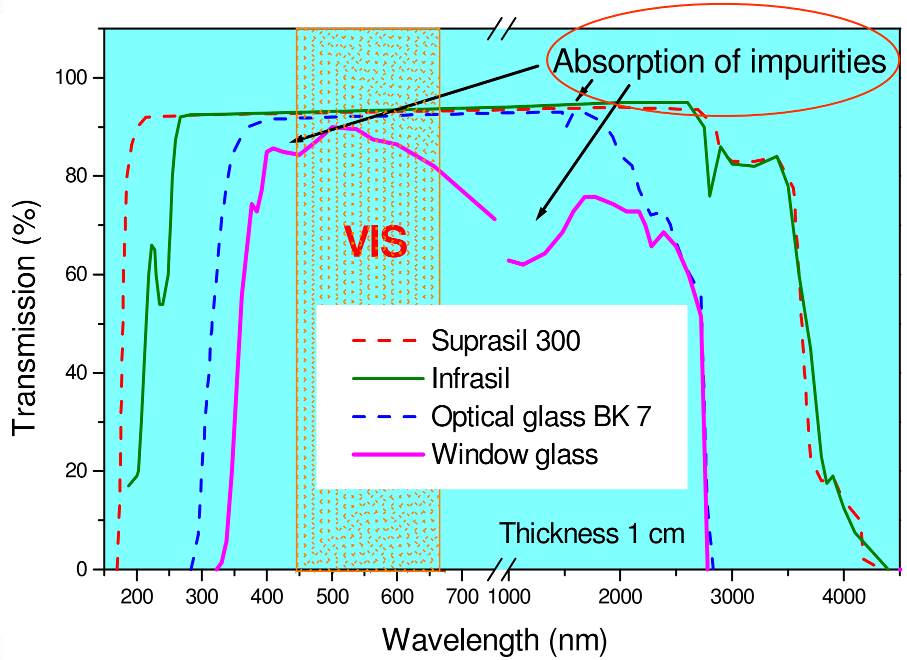


[A. B. Chynoweth, 1979, O. V. Mazurin, 1980, S. H. Wemple, 1973]

Properties
(M)CVD x conventional

Optical properties - transparency





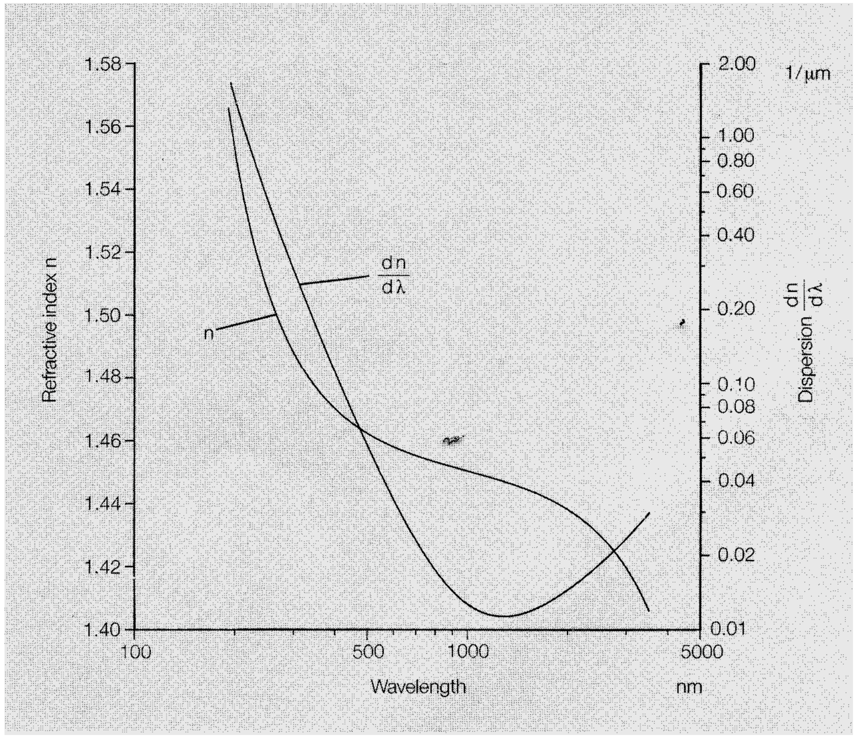
Dependence of absorption at UV on technology of silica production

[Safibra, 2010 & M. B. Volf, 1987]

Properties

(M)CVD x conventional

Optical properties – refractive index



$n_{633\ nm,\ 20\ °C}$ = **1.457**

$n_{10.6\ \mu m,\ 20°C} < 1$ [www.heraeus.de]

1.48 < n < 1.95

[www.schott.com]

Comparison : GLASS
(M)CVD x conventional

GLASS : *solid state material, amorphous, usually produced by quenching of melt, in glassy state (stable below T_g) [Hlaváč, 1981]*

Structure

amorphous | amorphous

short-distance order (< 1 nm)
longer-distance disorder (>1 nm)
no X-ray crystallographic signal
nano-structure imprint feasible (glass/glassceramics)

Production - kinetics

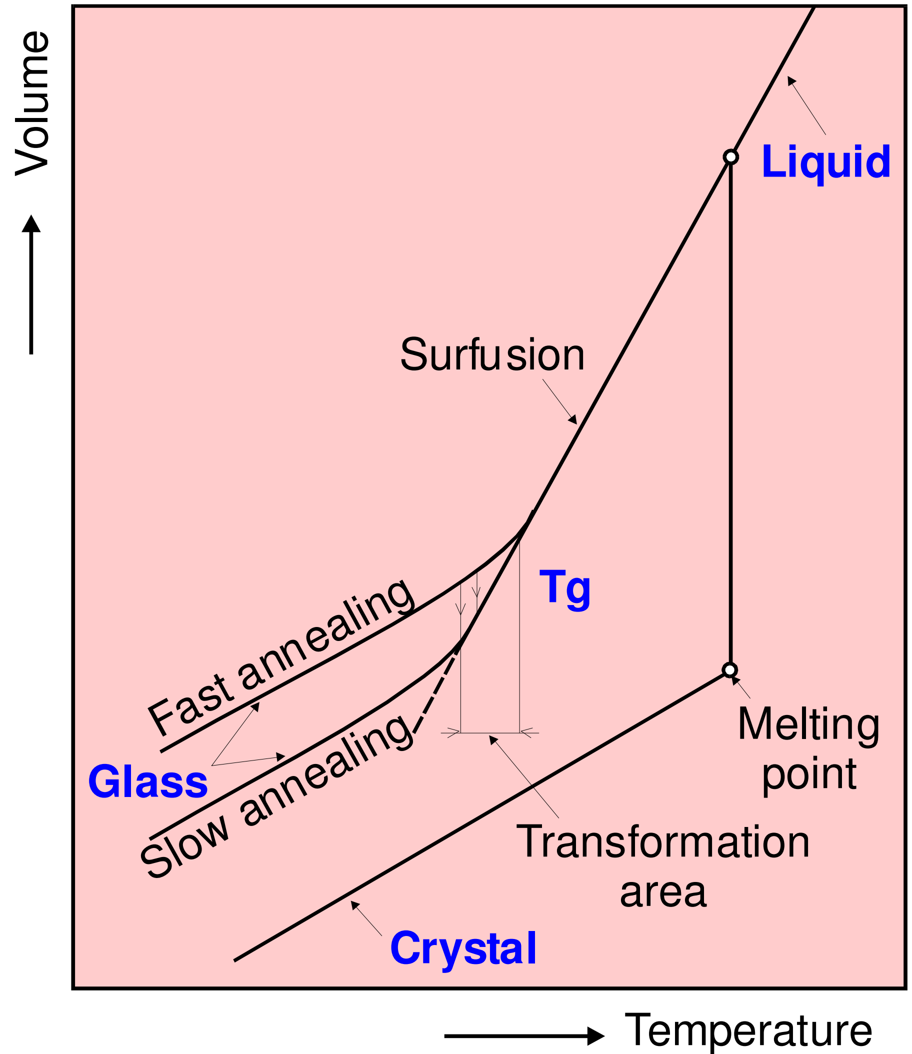
(M)CVD	conventional
sintering +	melting +
melting & quenching ~10^2 -10^3 °C/s	quenching ~10°C/min
	[G. Tammann, 1933]

Comparison : GLASS
(M)CVD x conventional

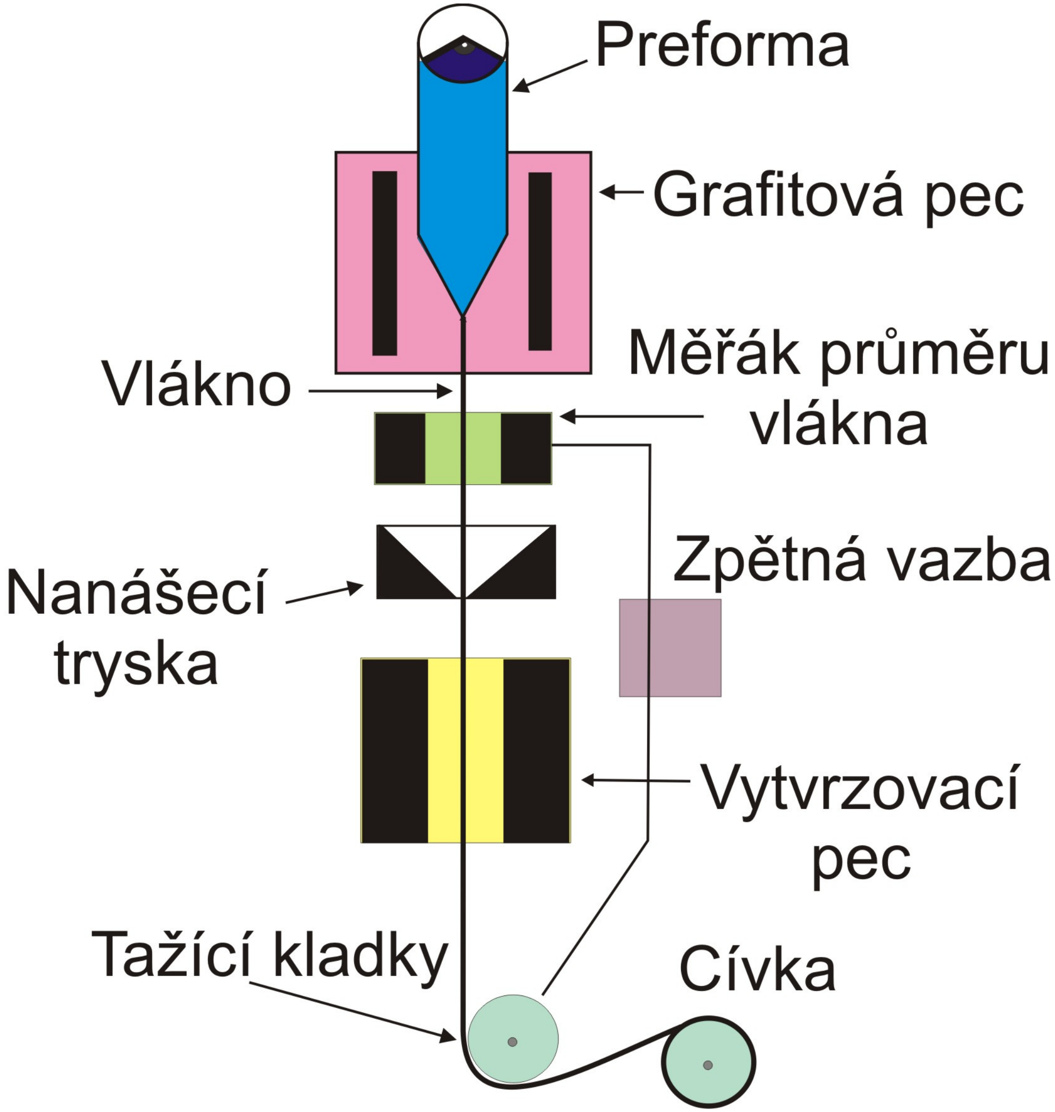
Thermodynamics

Glassy state : *stable bellow Tg (depending on quenching rate)*

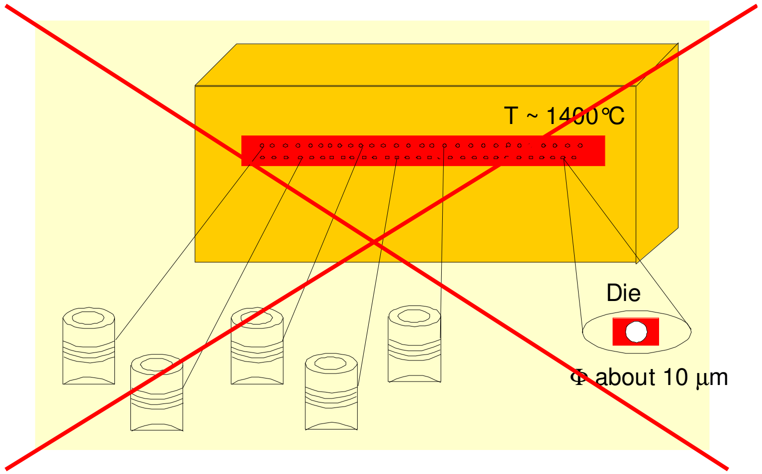
- extremely high quenching
- stable
- ? Reproducibility
- higher porosity
- lower density



Drawing of optical fibers



- diameter 80-1000 μm
- temperature 1800-2000 °C
- No thermo-insulation
- No textile
- No nanofibers !



Comparison of fibers

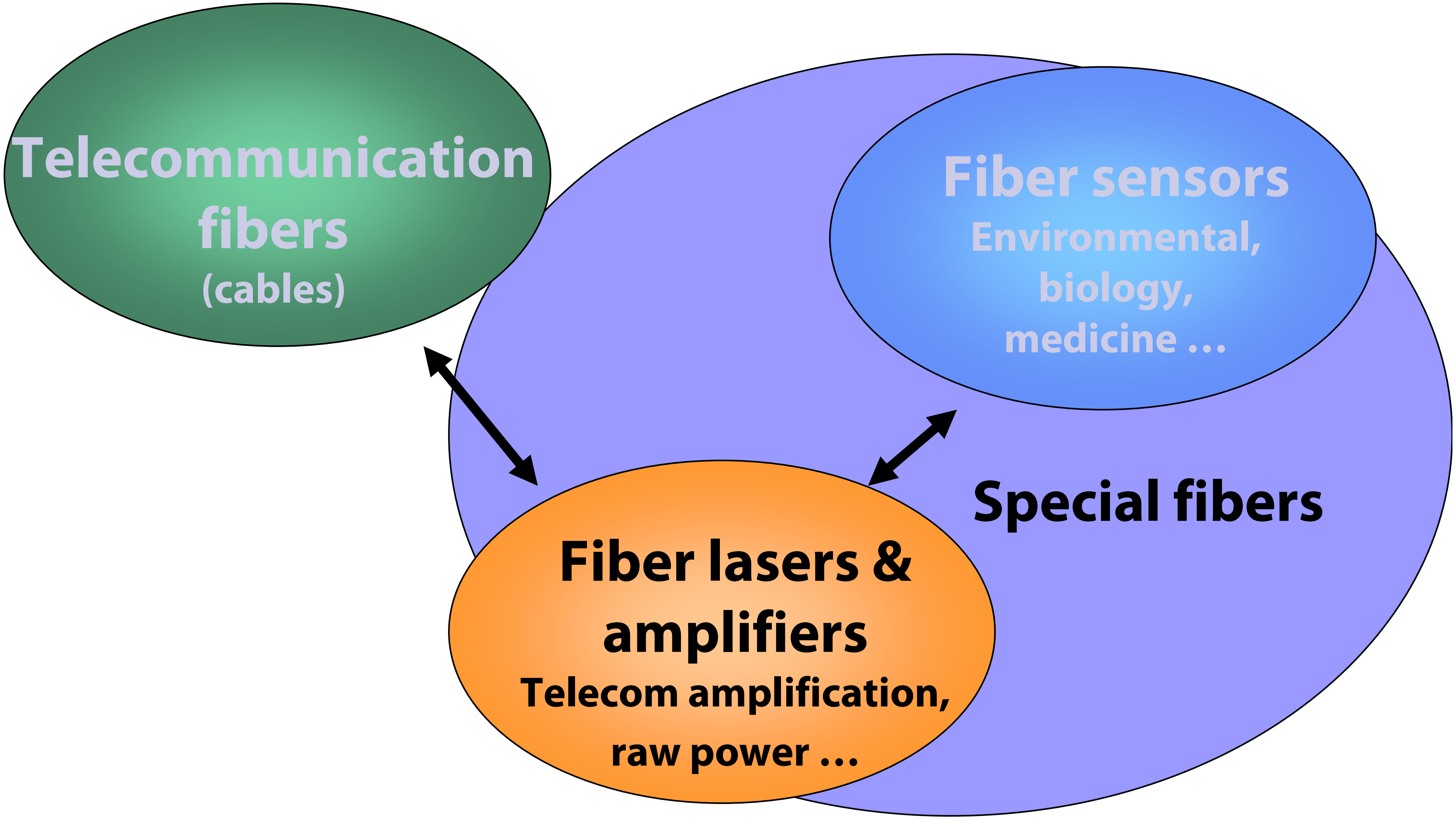
optical x soft-glass

SILICA (doped with GeO_2, P_2O_5, B_2O_3 …)
High productivity (relative)

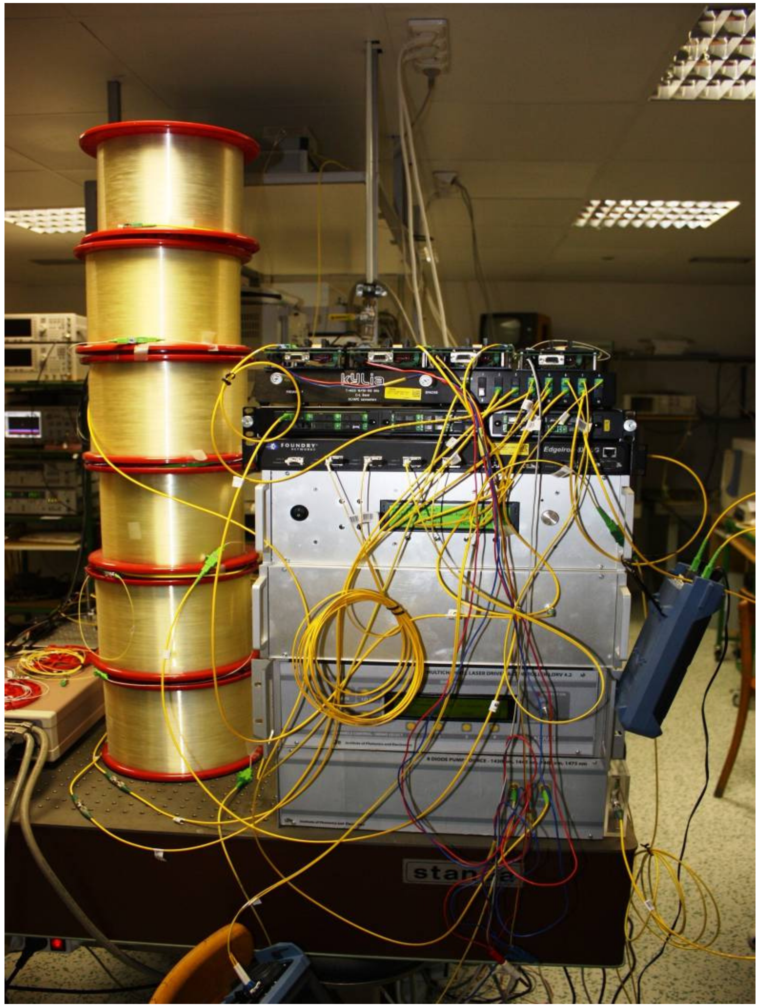
- $(CaO, MgO)-Al_2O_3-B_2O_3- SiO_2$
- Na_2O - CaO - (Al_2O_3) - SiO_2
- High productivity – *low processing temperature, cheap starting materials*

optical	soft-glass
Purity FO Optipur grade	Thermo-insulating properties
Chemical durability	Chemical durability
Precise geometry (<0.5 μm)	A geometry allowing weaving
Low optical loss ~ 0.2 dB/km	
Strength ~ 5 GPa due to coating	Strength ~ 2.5 GPa (without coating, temporary)
Use in **OPTICS**	Use as insulators and textiles

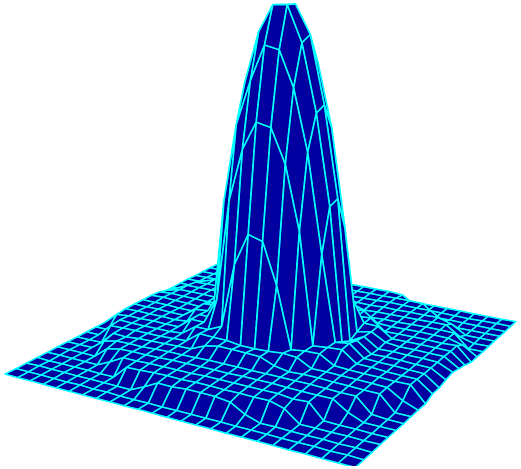
Application

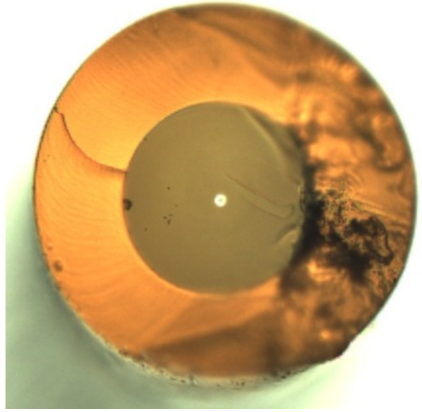


Telecommunications



Testing of 200 km telecom line



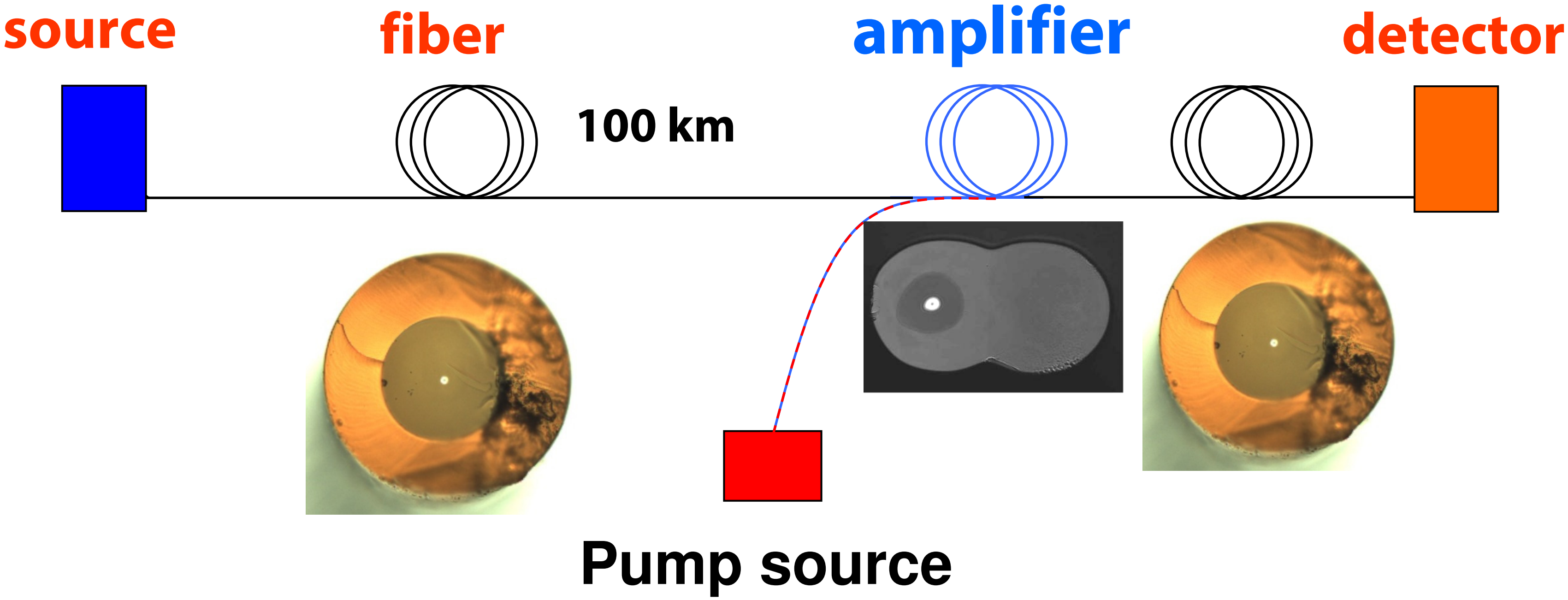


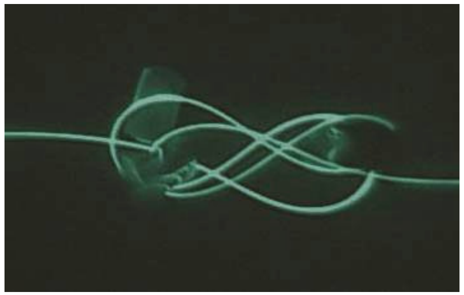
SM 1300, 1550 nm

GI - technology transfer
VÚSU Teplice, Hesfibel TR

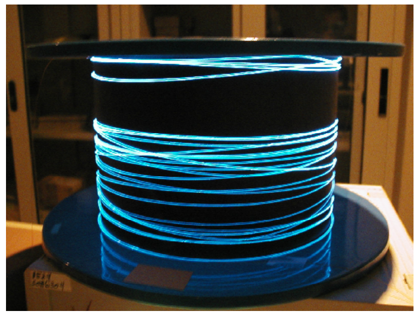
1981 – 1st demonstration of CZ optical fiber – UFE/URE/JLS

Telecommunications : fiber lasers and amplifiers

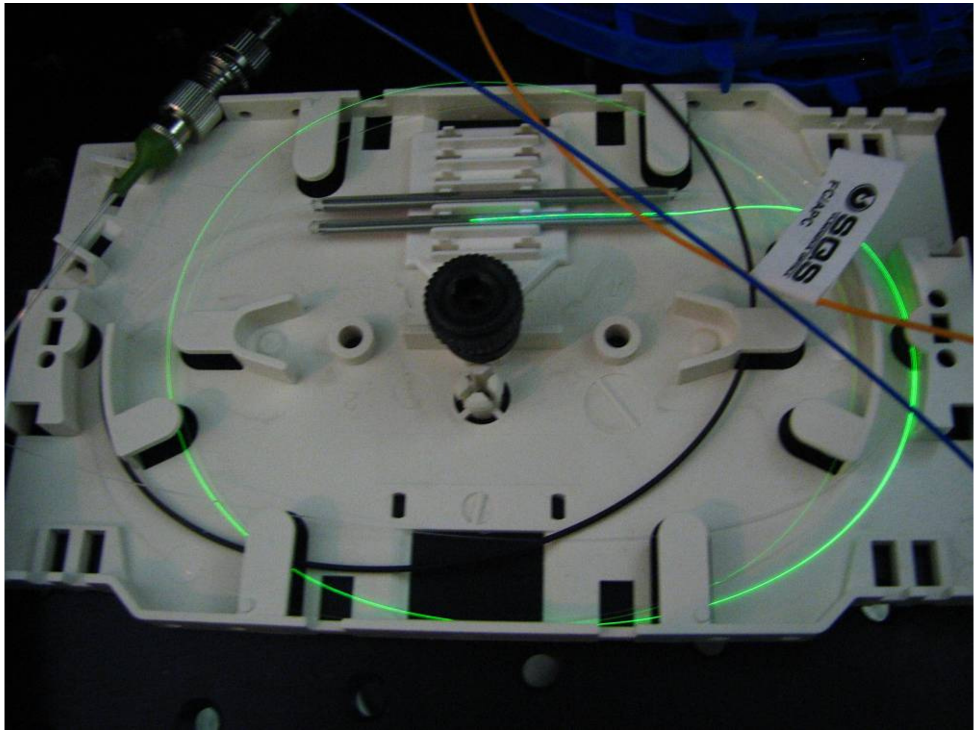




Fiber laser



High power fiber lasers



Intensity of light

Sun	63 MW/m2
1W-fiber laser	12.7 GW/m2

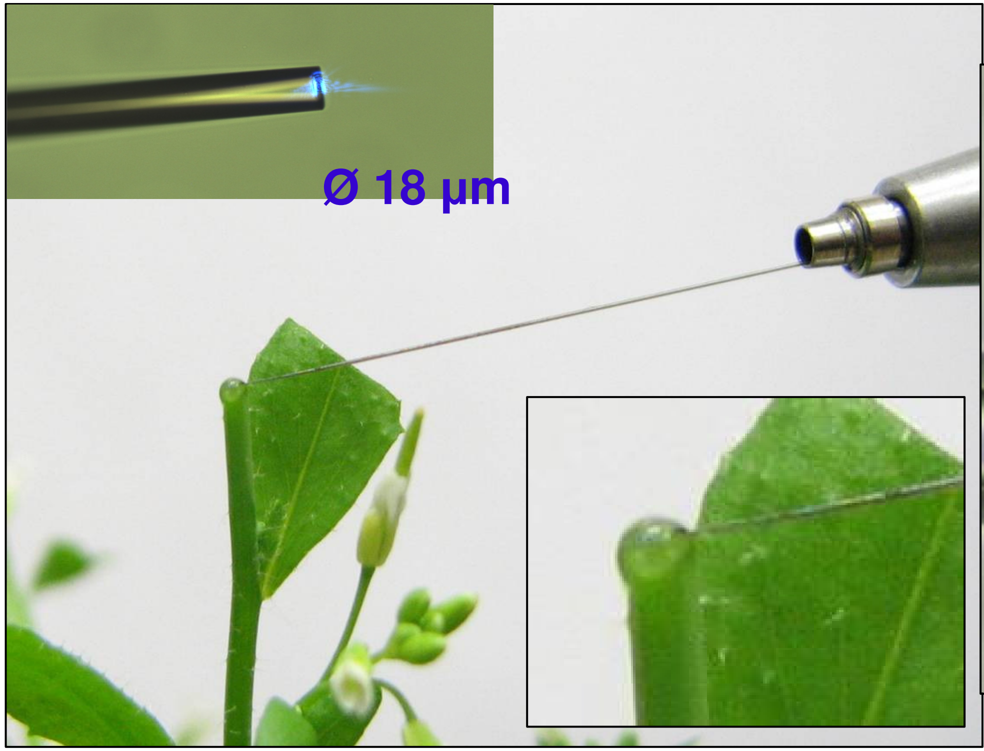
Er- fiber laser,
pulsed 197 fs,
5m resonator
Liekki

PALS

Welding, cutting < 2kW
savings, fast process

Fiber-optic sensors

Small devices capable of continuous and reversible monitoring of (bio)chemical species and their concentration



Principle : change of properties of the light due to chemical (physical) changes of medium.

SUMMARY

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 1 %)

SUMMARY

1. **OF technology : preparation of structures of high preciseness from materials of ultra-high purity (impurities in ppbs only).**
2. **OF 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).
4. Research of optical fibers (CR) :

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- **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)
- Sdělovací technika 3/2011

Uplatnění v oboru

UCHP - Oddělení aerosolových a laserových studií : Laserová ablační příprava nanostrukturovaných prášků, RNDr. Vladislav Dřínek, CSc., PROJEKT MAGISTERSKÉHO/BAKALÁŘKÉHO STUDIA

UCHP - Oddělení aerosolových a laserových studií : Laserová ablační příprava nanostrukturovaných prášků v kryogenních atmosférách RNDr. Vladislav Dřínek, CSc., PROJEKT DOKTORSKÉHO STUDIA

ALMA - Akademická laboratoř materiálového průzkumu malířských děl , RNDr. Janka Hradilová