Institute of Photonics & Electronics CAS

Beauties of specialty silica optical fibers

FILANO team & Ivan Kašík

2023

Outline

1. UFE & FILANO – Intro
2. Current research: fiber lasers and amplifiers
3. Preform fabrication MCVD and fiber drawing
4. Results and application
5. Summary

UFE & FILANO

Institute of Photonics and Electronics

Assoc. Prof. Pavel Peterka, PhD.

Dr. Ing. Pavel Honzátko

Academy of Sciences

~100 FTE
~ 4 M€ turnover = 100 mil Kč
~ 40/60 project / inst. finances

Optical Biosensors
Nanomaterials
Bioelectrodynamics
Nanophotonics
National Time and Frequency Standard

Fiber Lasers and Non-linear Optics = FILANO – 15-22 FTE

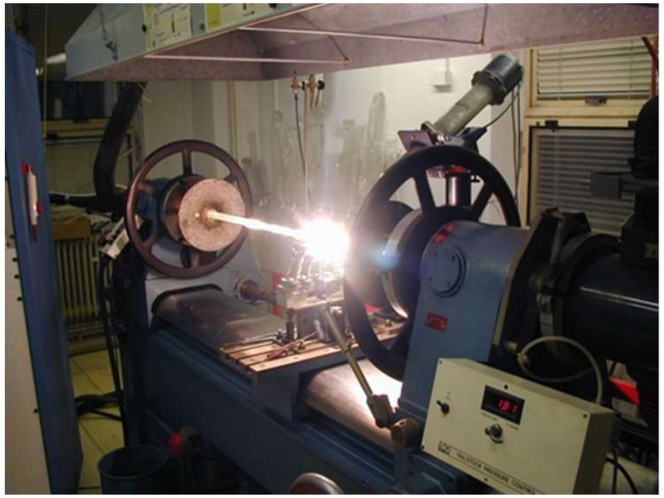
Special optical fibers and components for fiber lasers from novel materials

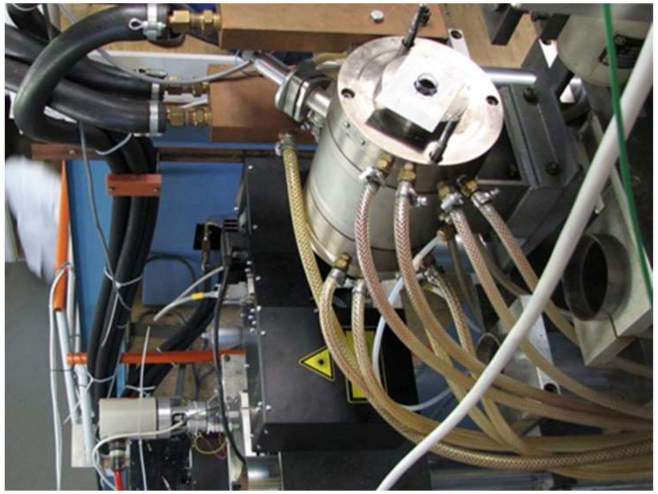
Preform preparation (MCVD)

Fiber drawing

SINCE 1979

Sol-gel





Staff (technology) : ~7 FTE, AVG age ~39-40

Collaboration

International

Projects :

IMIF-ITME Warsaw – R. Buczynski
TU Bialystok/Krakow – D. Dorosz, M. Kochanowicz, J. Zmojda
Plasil (Optacore) Ljubljana - B. Lenardic
ORC Southampton – J.K.Sahu
IPHT Jena - T. Cizmar, K. Schuster, R. Willsch, M. Becker
Uni Rennes – L. Spanhel, M. Poulain, V. Nazabal, J. Trolles
Uni Nice – B. Dussardier, W. Blanc
Inst. Material Research, Košice – V. Puchý
Inst. Physical Chemistry, Bucharest – M. Zaharescu

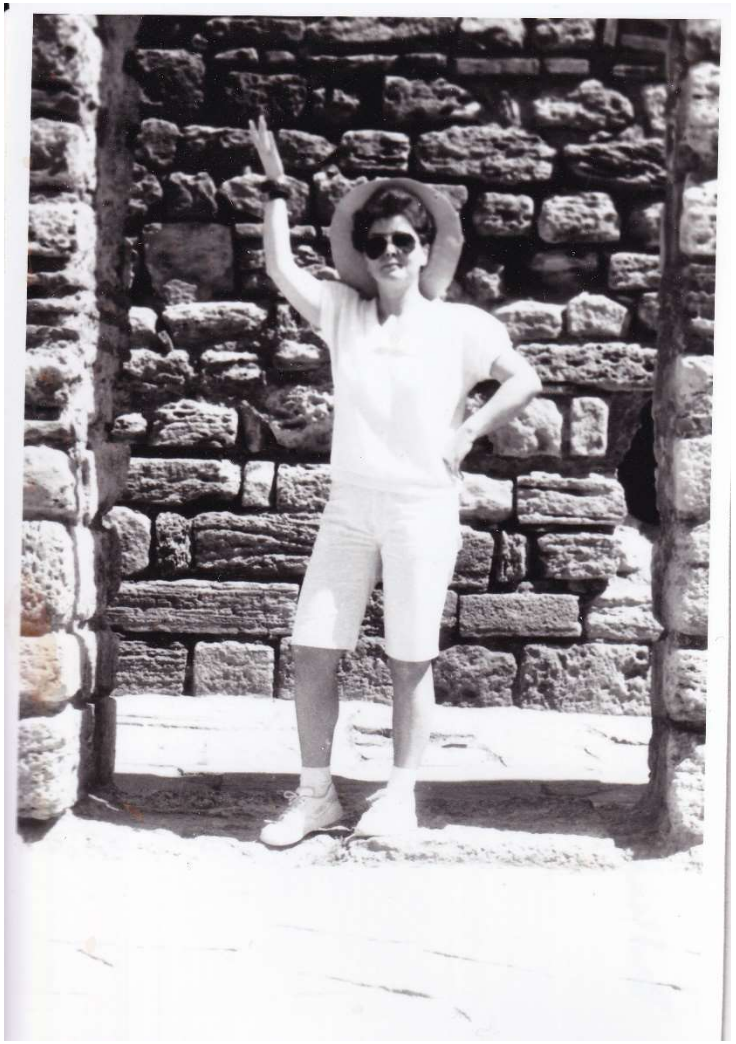
Contacts :

Uni Kiel - M. Marciniak
Uni Turku - L. Petit
Uni Maribor – D. Donlagič

National

CAS – Inst. Experimental Botany (E. Zazimalova), Inst. Physics (M. Nikl)
Czech Technical University (V.Kubecek,H.Jelinkova, V.Čuba, S. Zvanovec)
University of Chemistry and Technology (A. Helebrant, L. Nemec),
UPCE

Collaboration



Selected projects 2022

International

European Action COST MP1401 Advanced fiber lasers

NCN-GAČR - Novel nanostructured optical fibers for fiber lasers operating at dual wavelengths

DAAD - Novel glass materials and spectroscopy for high-power fiber lasers beyond 2 µm

EU Defense Agency

National

Light at the service of society (Programme of Strategy AV21)

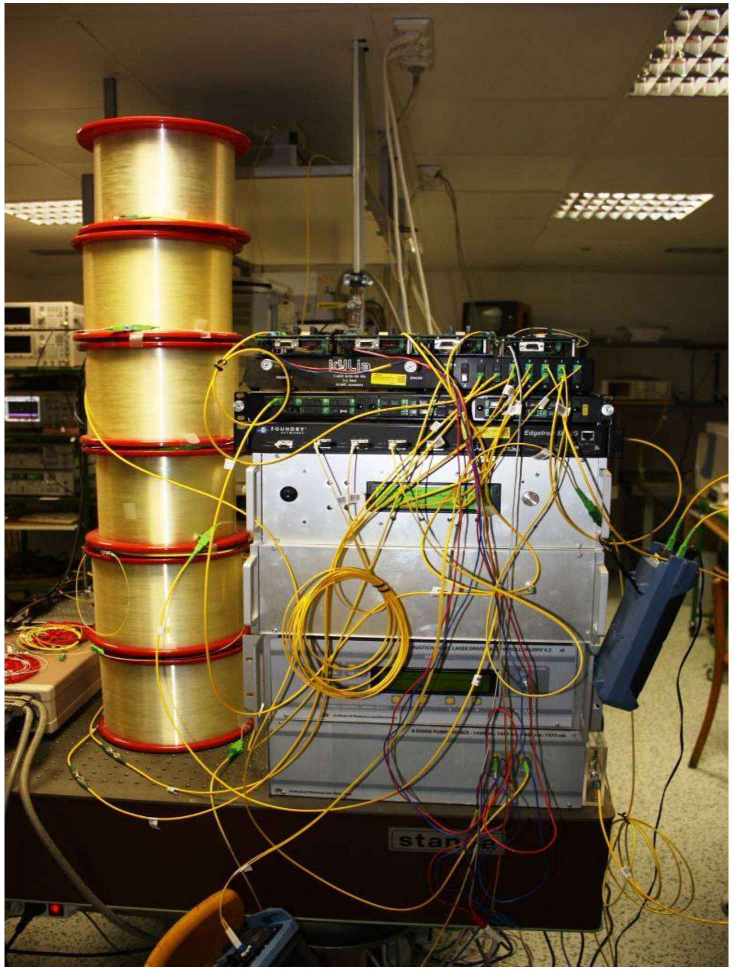
Low-phonon energy transparent ceramic luminophores emitting in the short- and mid-IR

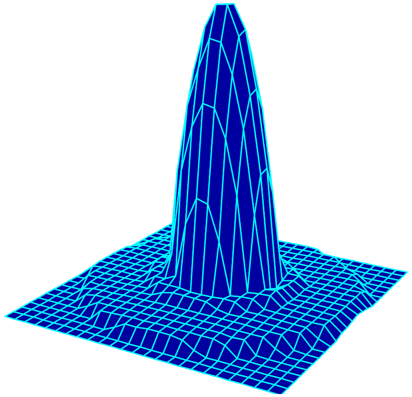
Transparent ceramics optical fibers for lasers operating around 2.9 µm

Breaking temperature limitations of kW-class thulium fiber lasers

Fiber optic amplifier for wavelengths beyond L-band (CESNET)

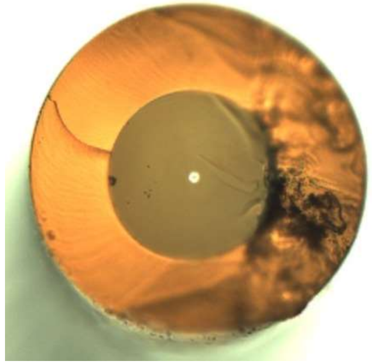
Early stage – telecom optical fibers

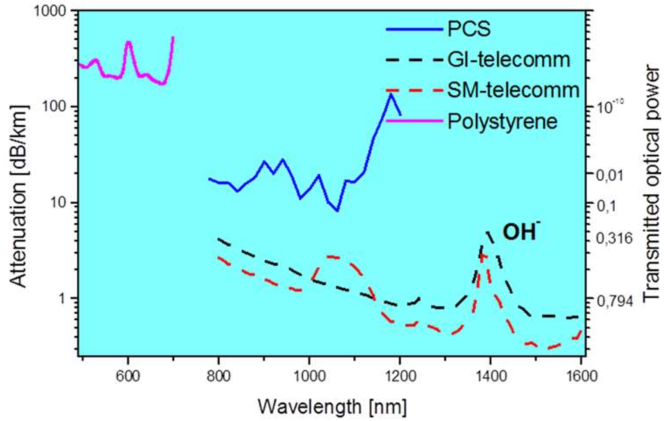




Technology transfer
UFE Prague =>
Teplice, CR =>
Hesfibel, TR
[hesfibel.com.tr]

Graded-index
1300 nm





Single-mode
1550 nm

200 km telecom line - test

Current research

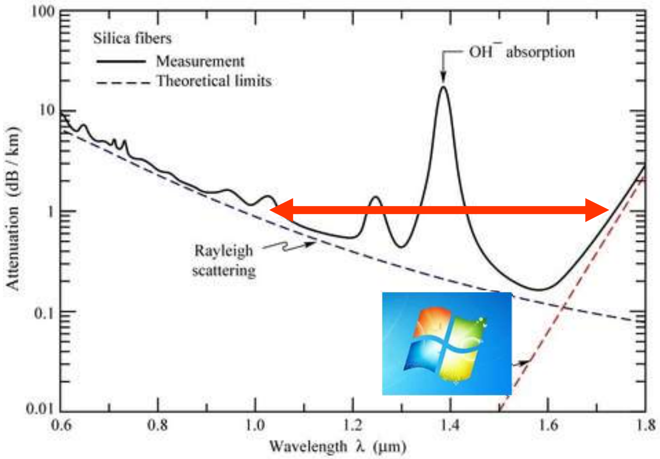
Fiber lasers and amplifiers

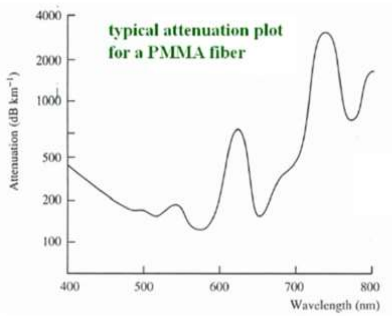
$\Rightarrow$ RE -doped specialty optical fibers

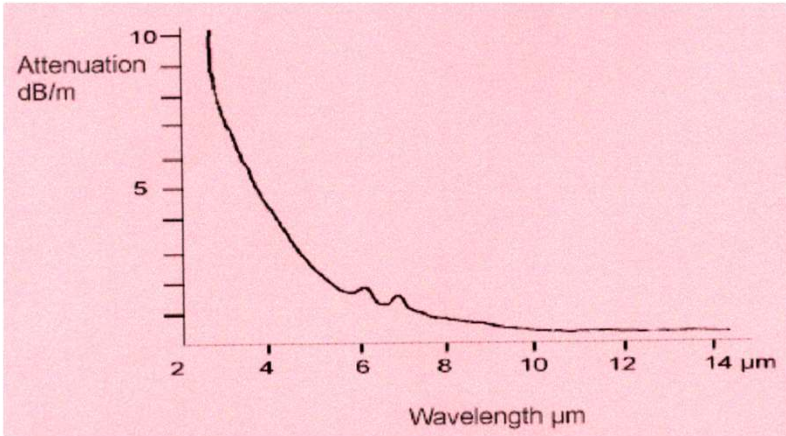
SILICA

Optical fibers

Optical materials UV – VIS – NIR – IR for optical fibers







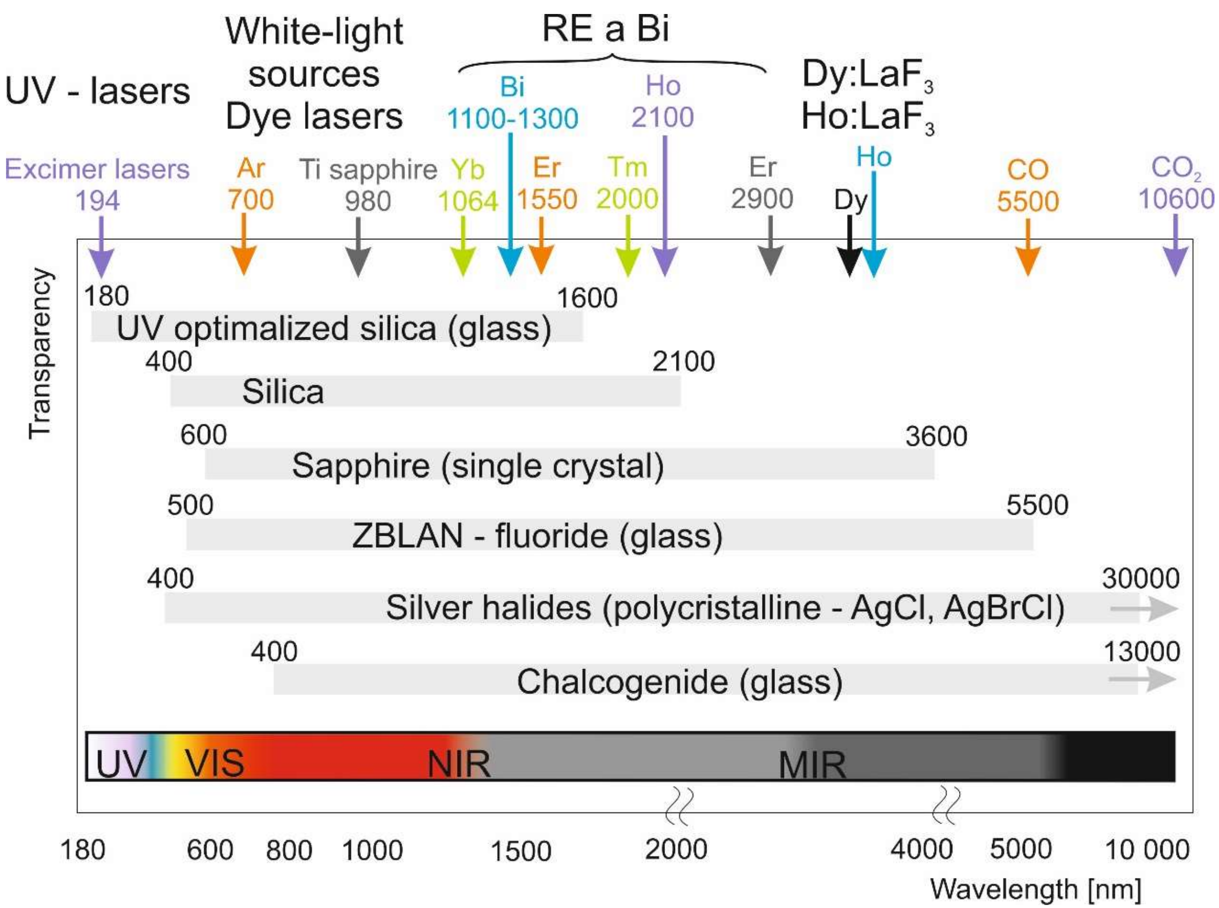
[Wiki]

Silica: UV-VIS-NIR   PMMA: VIS   Chalco: IR

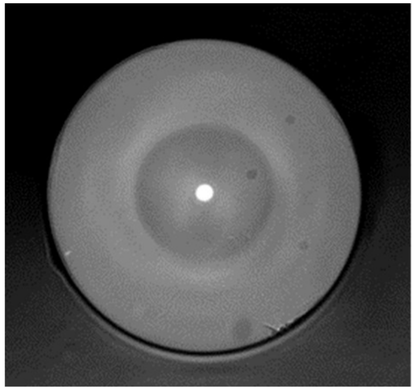
Sapphire: 600-3600 nm

20 dB/km, 1% transmitted ~limit

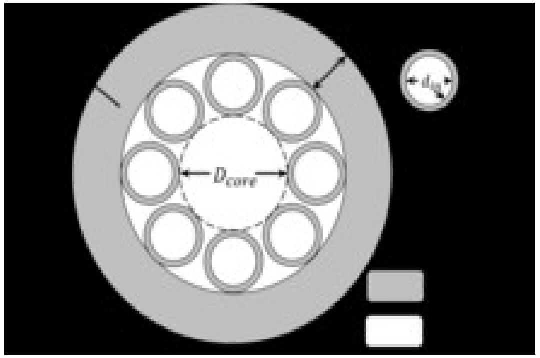
Optical fibers



Solid core



Hollow core

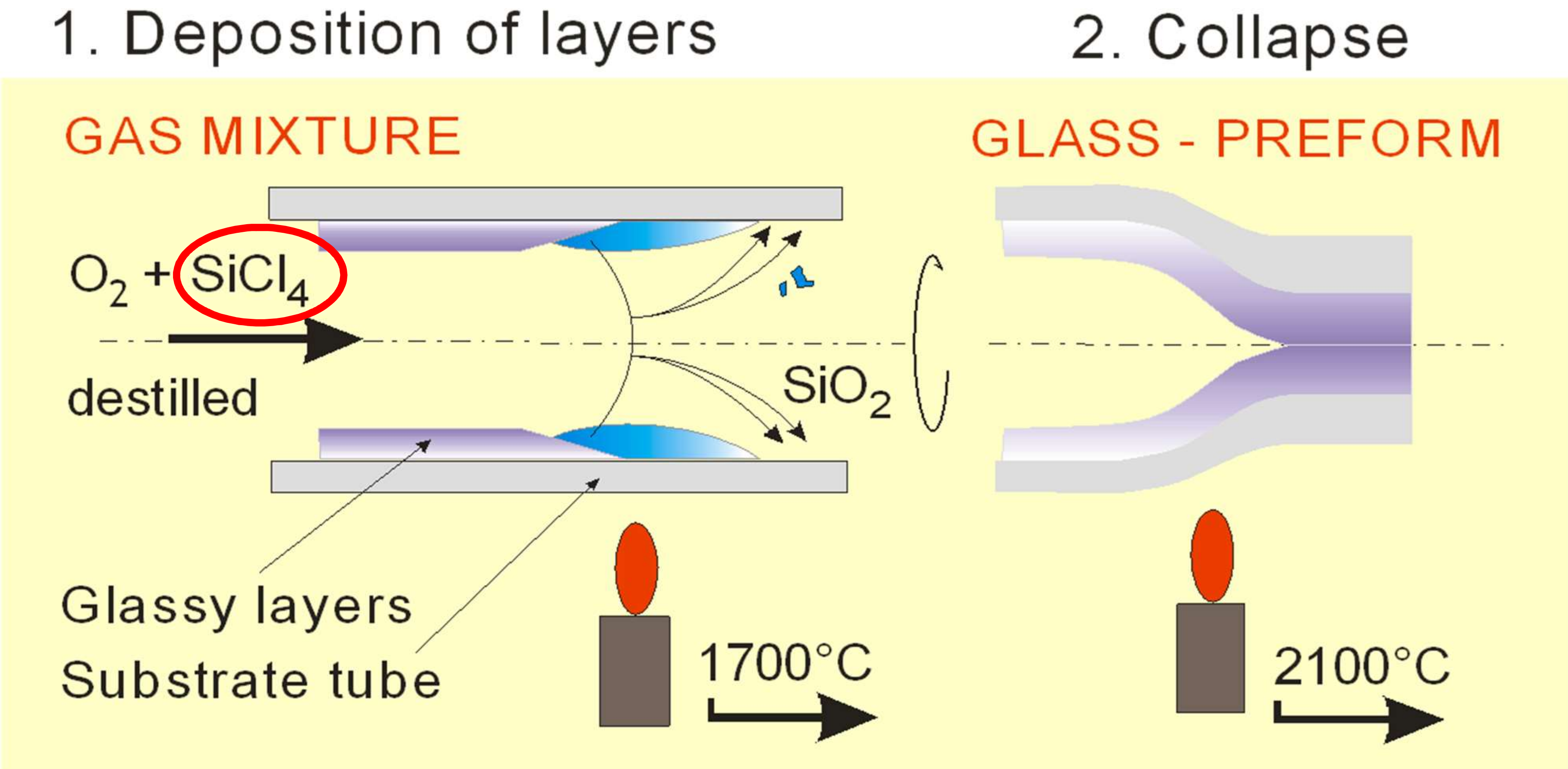


[Komsomol]

ÚFE

Preform fabrication MCVD and fiber drawing

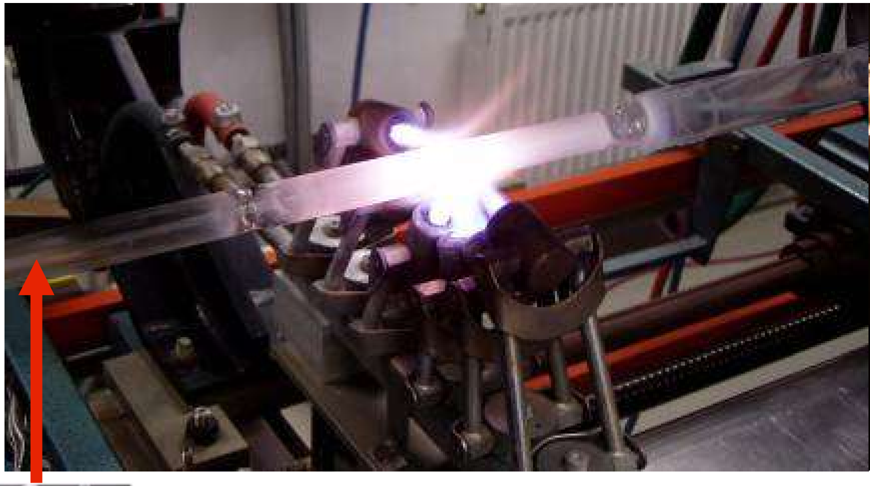
MCVD



Sequential sintering of **thin glassy layers** (of thickness 1-20 μm) onto inner wall of **silica** substrate **resulting in bulk material** = **preform** [McChesney 1982]

=> High purity (~ 10^1 ppb), **high preciseness** (better than 1%), **graded**-index (multilayered) structures.

MCVD - conventional



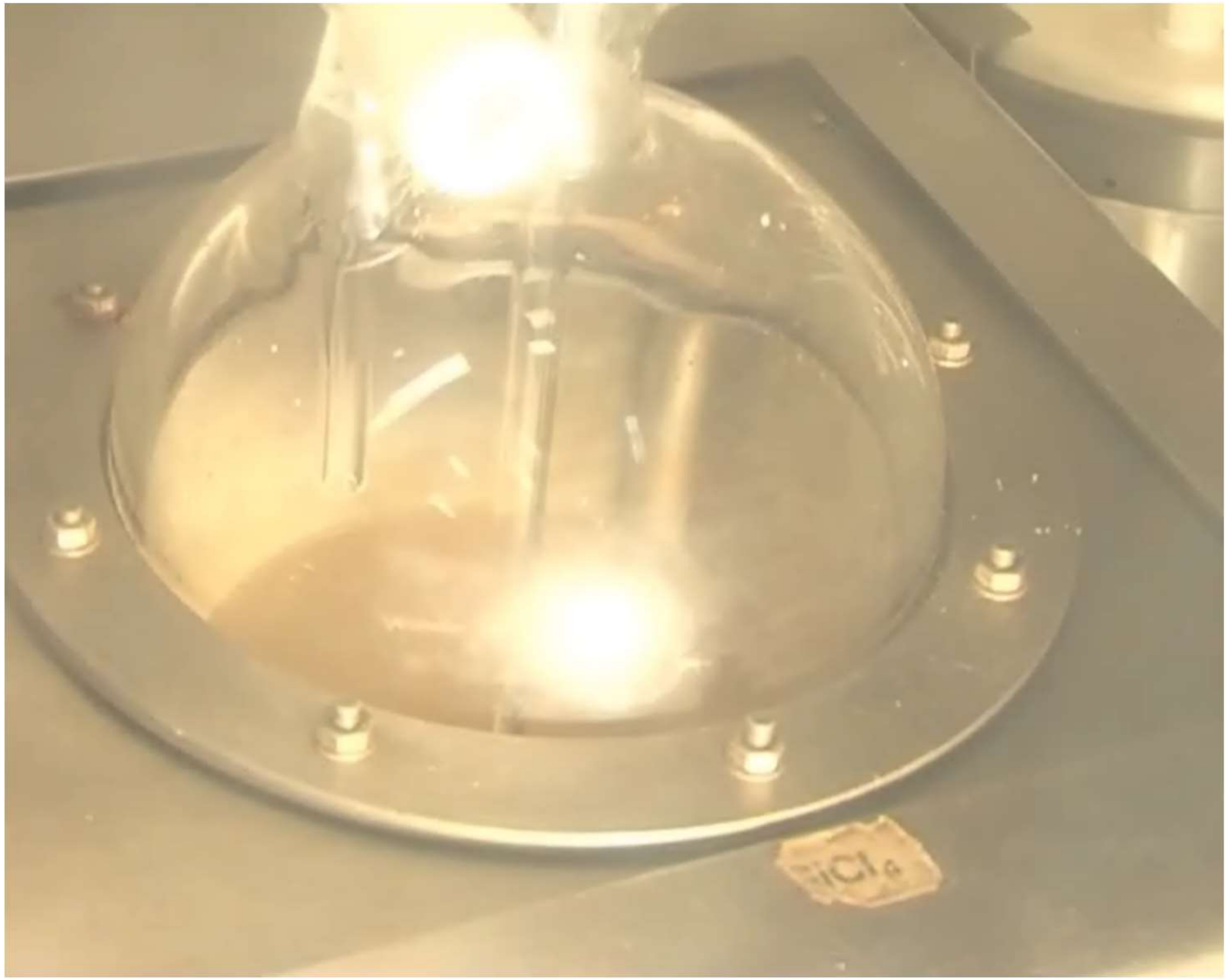
Deposition of layers

Collapse of preform

Distilled = pure halogenides

Preforms

Optical fiber technology



MCVD process model

Process parameters :

Variable :

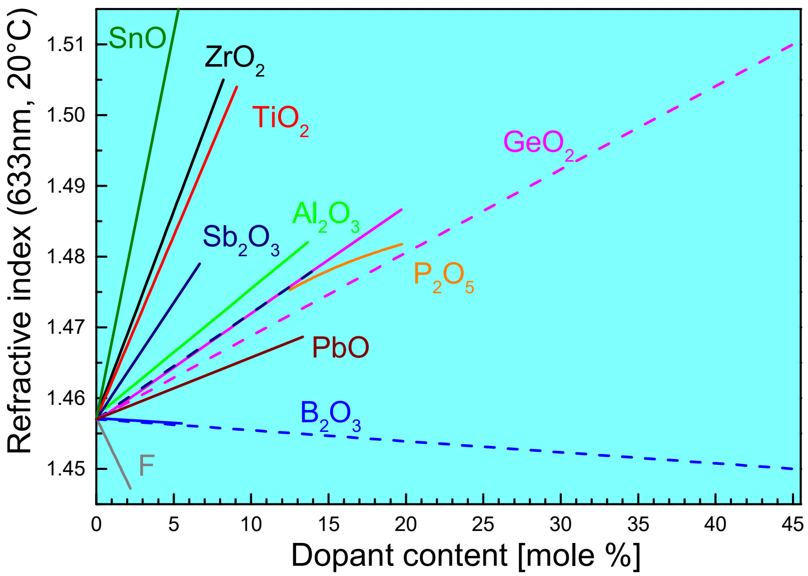
- flow rates (Si, Ge, P, B, F, Ox … He)
- deposition temperature

Adjustable :

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

Bloody :

Highly corrosive, toxic chlorides

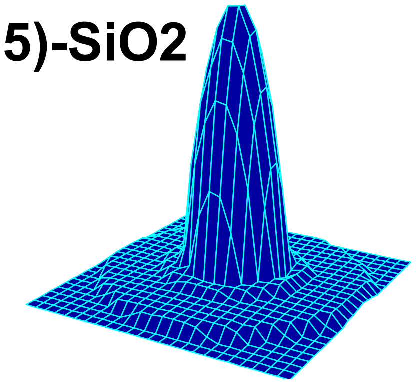


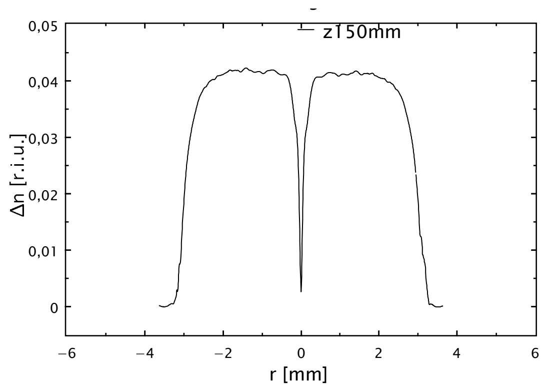
[A.B. Chynoweth, 1979, M. Shimizu, 1986, Y. Ohmori, 1983, S. H. Wemple, 1973, H. Wehr 1986, I. Kasik, 2005, K. Sanada, 1980, M. M. Karim 1994]

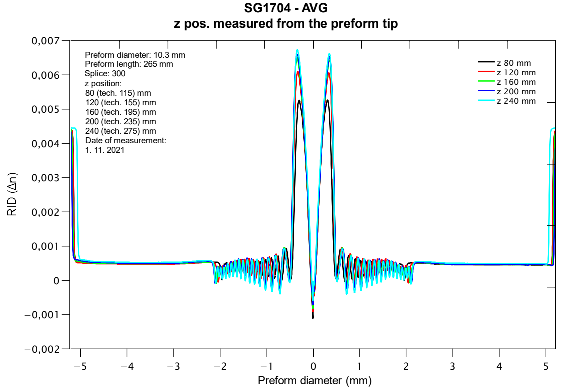
[McChesney and Nagel, 1982, Wood, 1987, Kirchhof, 1986]

MCVD – conventional

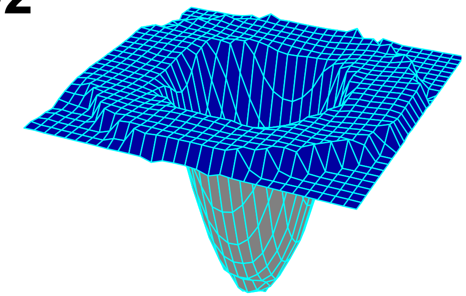
GeO2-(P2O5)-SiO2

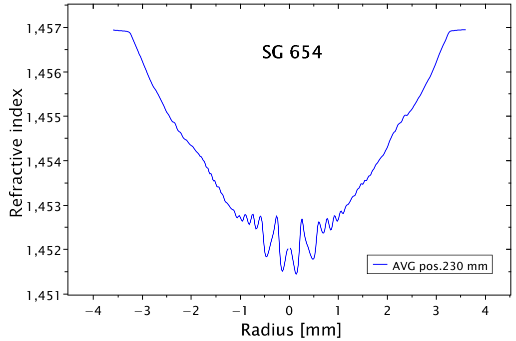


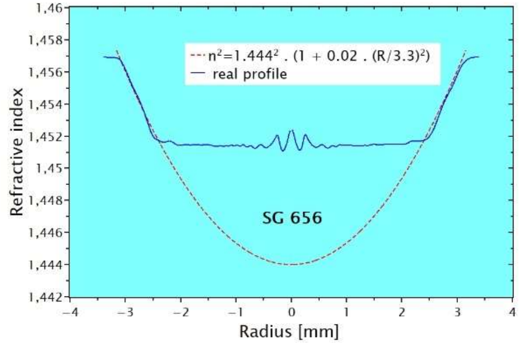




B2O3-SiO2
F-SiO2





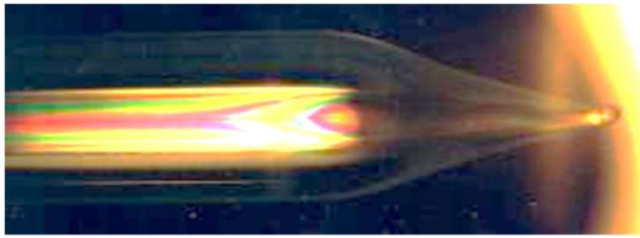


UFE

Preform core ~ 0,5 – 6 mm

Δn +0,002 to +0,040 (0,050), Δn -0,005

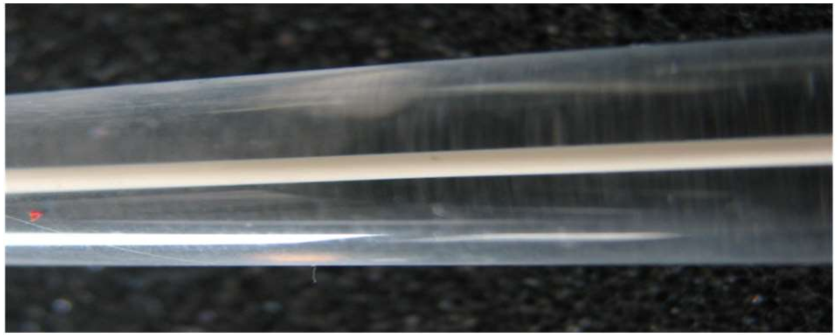
Typical preform diameter ~10 mm

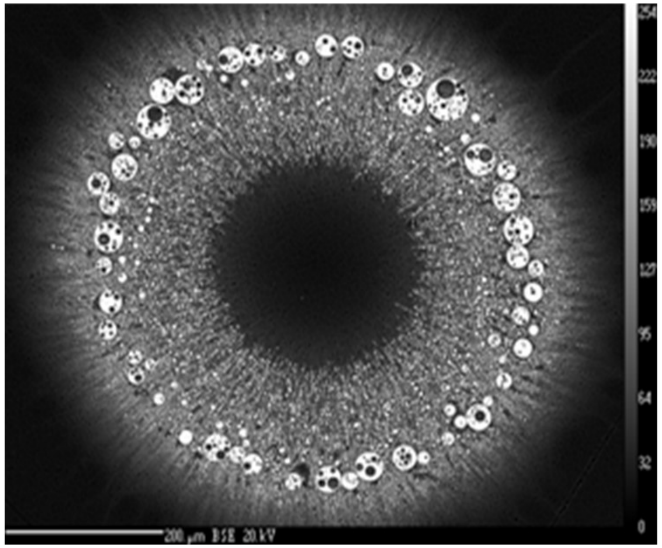


MCVD – RE doping

SILICA

+ low optical losses, good thermal durability and stability
- low miscibility of RE & high phonon energy





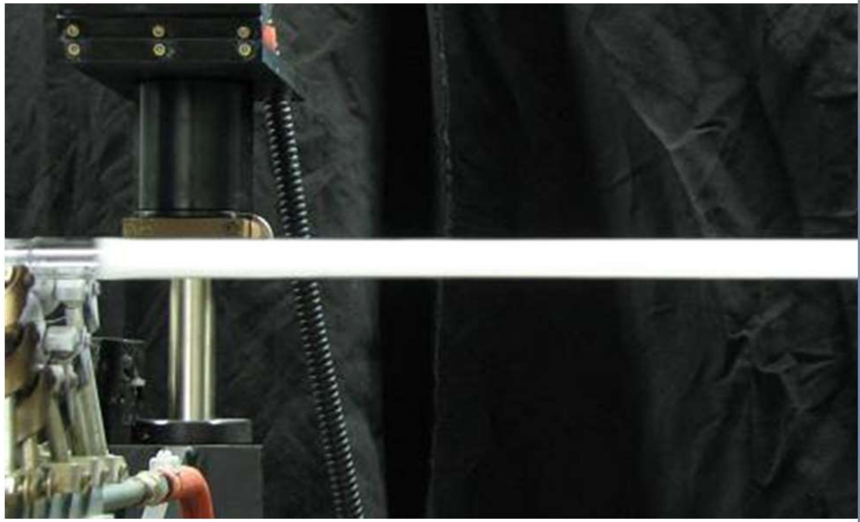
=> **modification of matrix with** (GeO_2), **Al_2O_3, P_2O_5 … Sb_2O_3**

= **dissolving of RE in glass matrix** + modification of phonon enrgy + ↑ RI

=> modification of technology <=> starting materials in solid state

MCVD – „solution-doping“

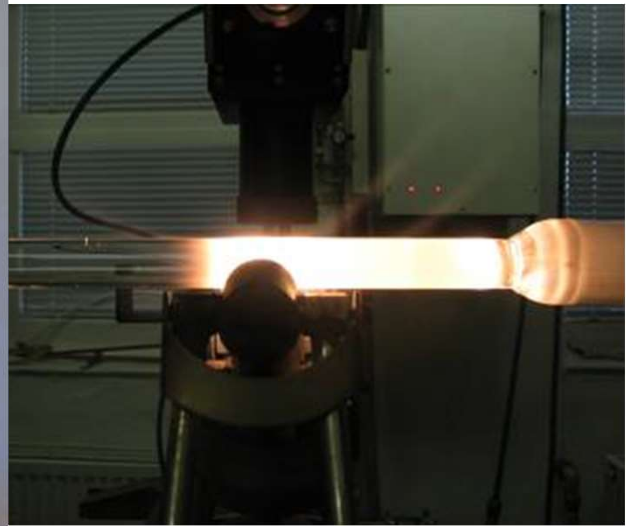
Solution doping, Sol-gel (UFE), REPUSIL (IPHT Jena)



Porous layer

(SiO_2, GeO_2-SiO_2 …)

Soaking – solution, sol, nanoparticles



Oxidation, drying, sintering

Towndsend, El. Lett. **23**, 329, 1987], [Sysala, Ceramics, **35**, 361, 1991], [Podrazky, IEEE LEOS, 1-2, 246, 2007]

Comparison

(M)CVD **x** **conventional**

Starting materials

gaseous (g) or liquid (l) | (s) solid state

melting point of oxides different | melting point comparable

Purification methods

distillation | recrystallisation, remelting

Structure of products

Graded - profiles | Homogeneous

Material purity

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

Comparison

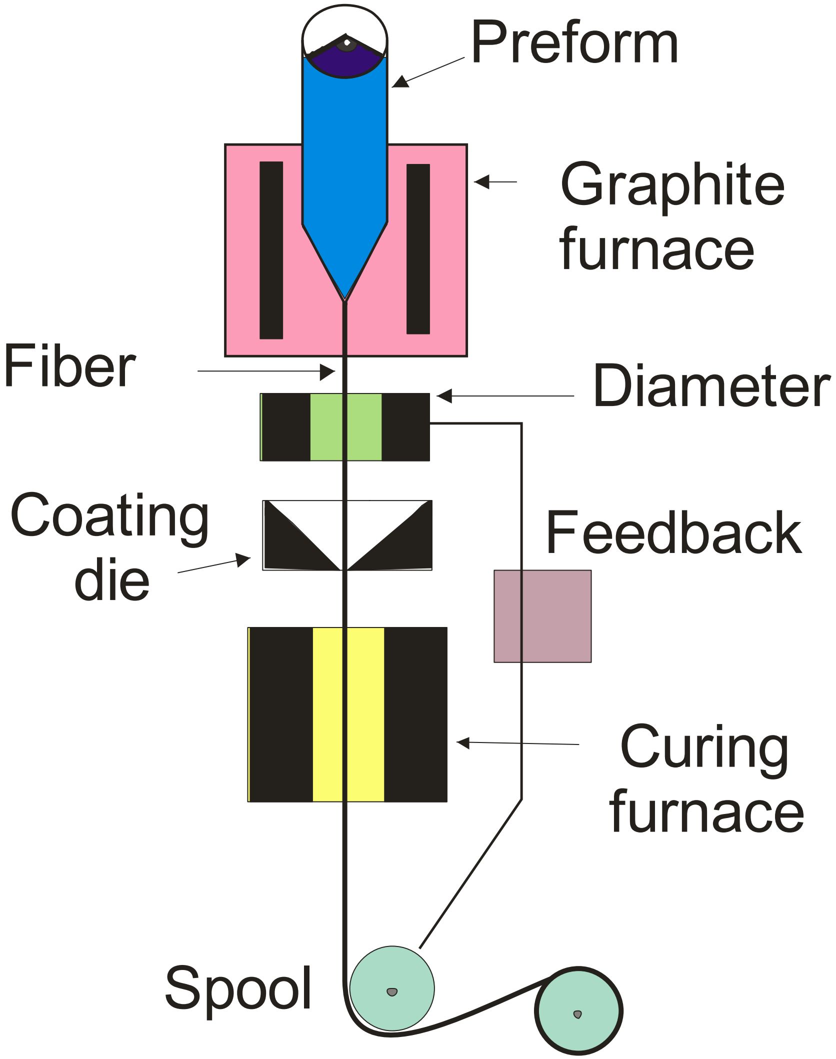
CVD (Chemical) x PVD (Physical)

CVD (Chemical)		PVD (Physical)
MCVD **OVD etc.**		**DC magnetron sputtering** **vacuum evaporation etc.**
	Layer thickness	
1 – 10^1 μm		1 - 10^1 nm
	(however, both are reported as "thin layers")	
	Deposition rate	
HIGH		LOW
	Products	
Layers, bulks		Layers only

Preform processing - shaping

Mechanical grinding - diamond tolls

Drawing of optical fiber from preforms



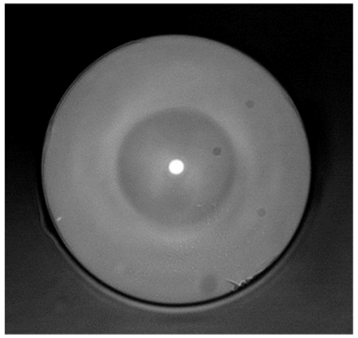
Diameter
80-1000 μm

Temperature
1800-2100°C

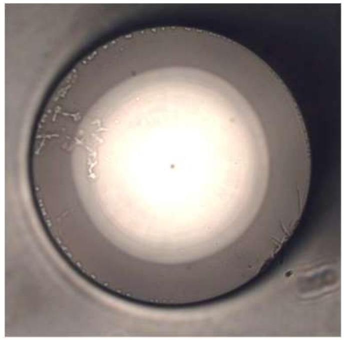
- No textile
- No thermo-insulation

Optical fibers for lasers

SM & LMA

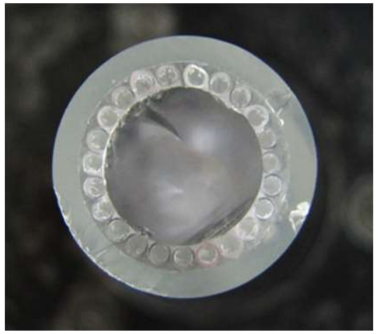


SM 125/10



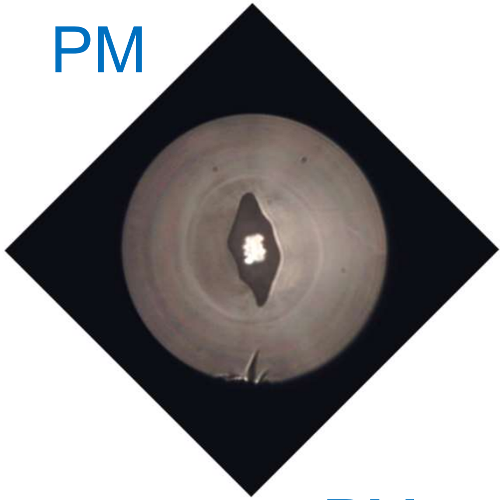
TDF 125/65

MSF

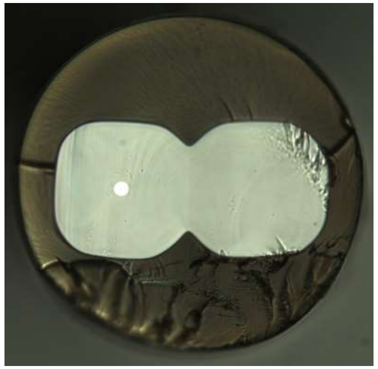


Airclad 400

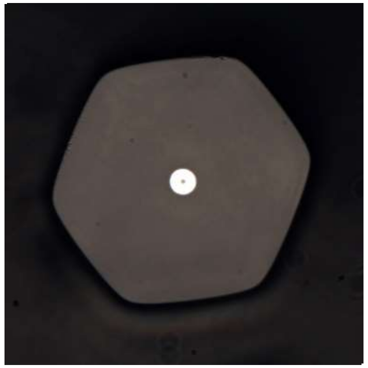
PM



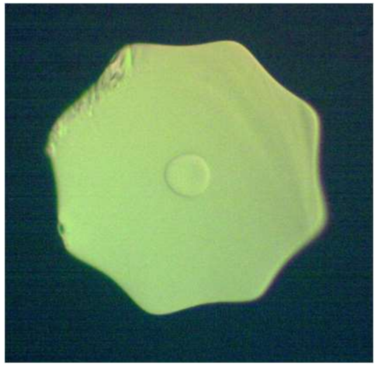
DC*



EDF 250x125/7



TDF 130/12



TDF 130/15

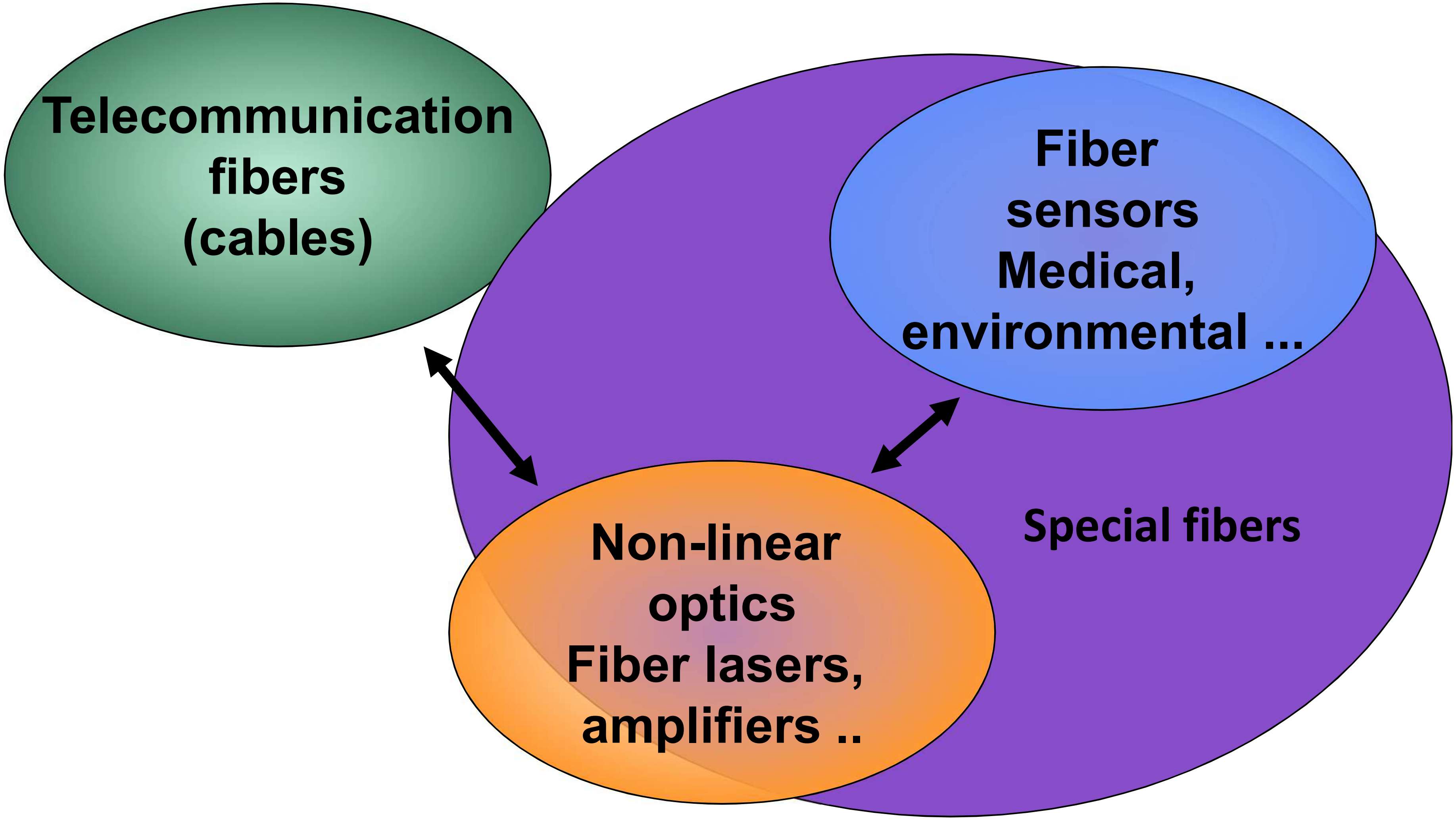
PM

TDF PANDA 125/8

[Peterka et.al., Opt. Lett., **31**, 3240, 2006], [Koska et.al., Op.Ex. **24**, 102, 2016], [Jasim et.al., Op.Ex. **28**, 13601, 2020]

Results & Application

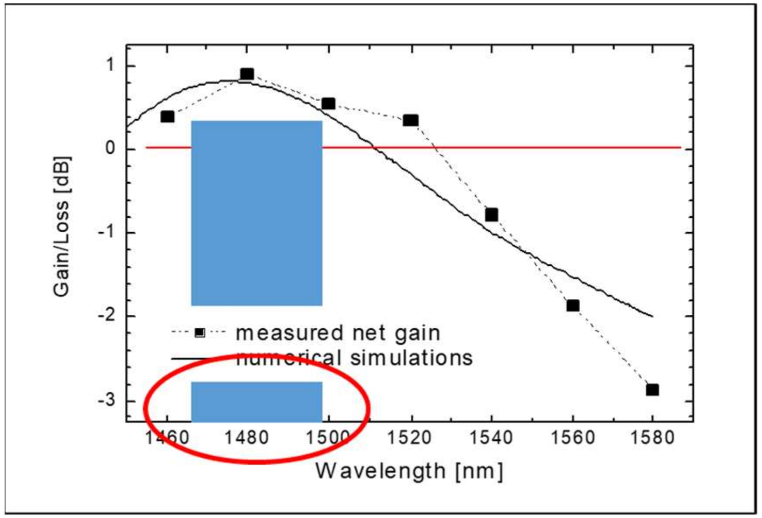
Application

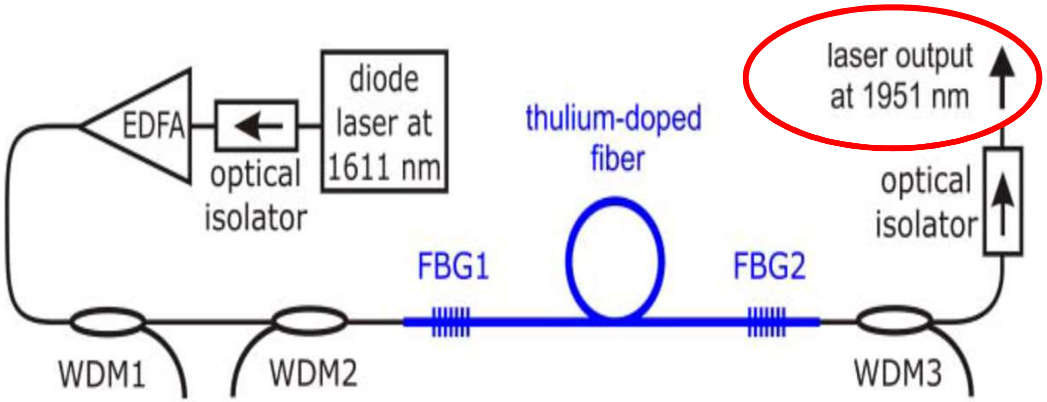


TmFL sources

S-band source or monolitic Tm FL **at 1951 nm** “eye-safe“ region

(≠ 1550 nm)



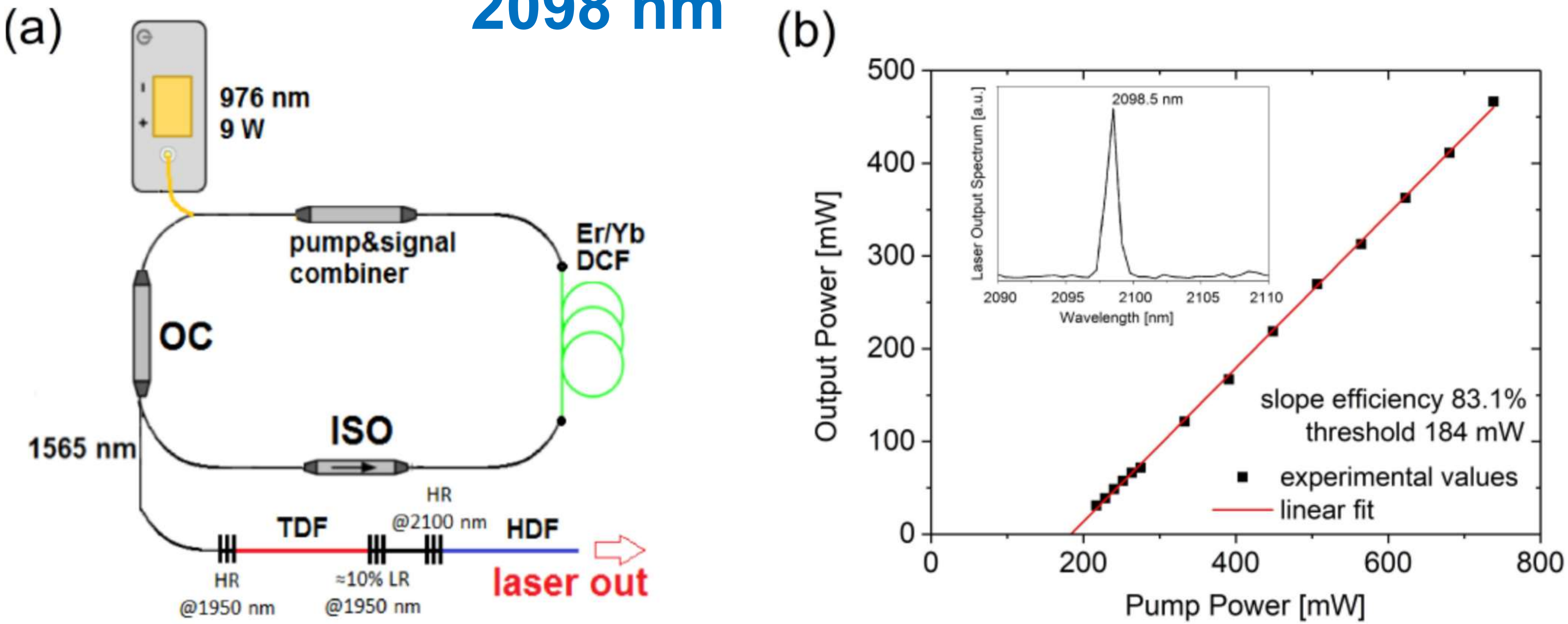


Optical fiber : 1000 ppm Tm^{3+}, 11mol% Al_2O_3, 0 mol% P_2O_5 or GeO_2
FBG inscription by deep-UV

* *P.Peterka, P. Honzátko, M. Becker, F. Todorov, M. Písařík, O. Podrazký, I. Kašík: “Monolithic Tm-doped fiber laser at 1951nm with deep-UV femtosecond-laser-induced FBG pair“, IEEE Photonics Technology Letters 25 (2013) 1623-1625*

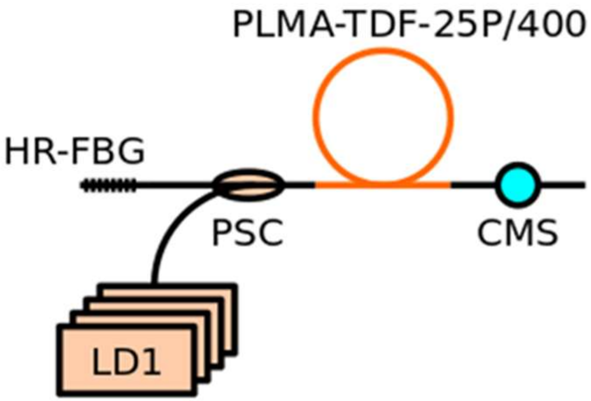
Ho FL

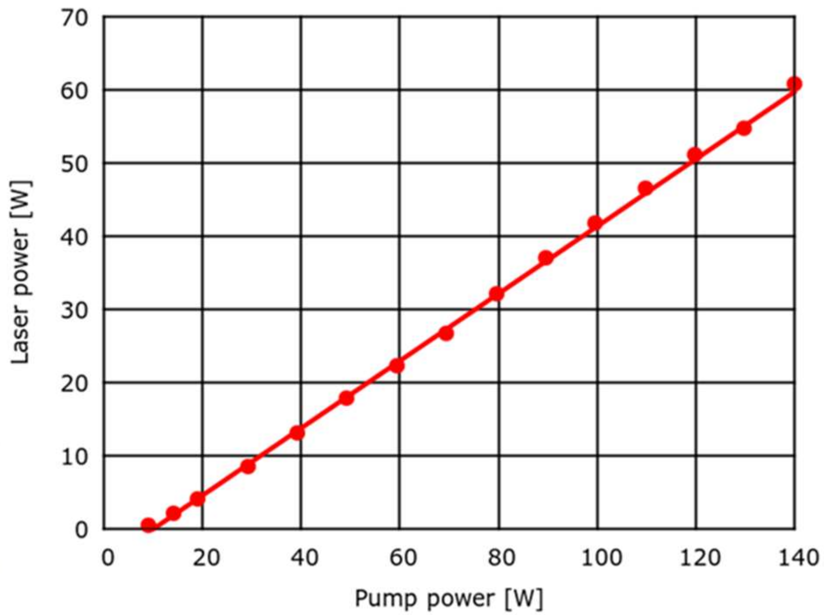
2098 nm

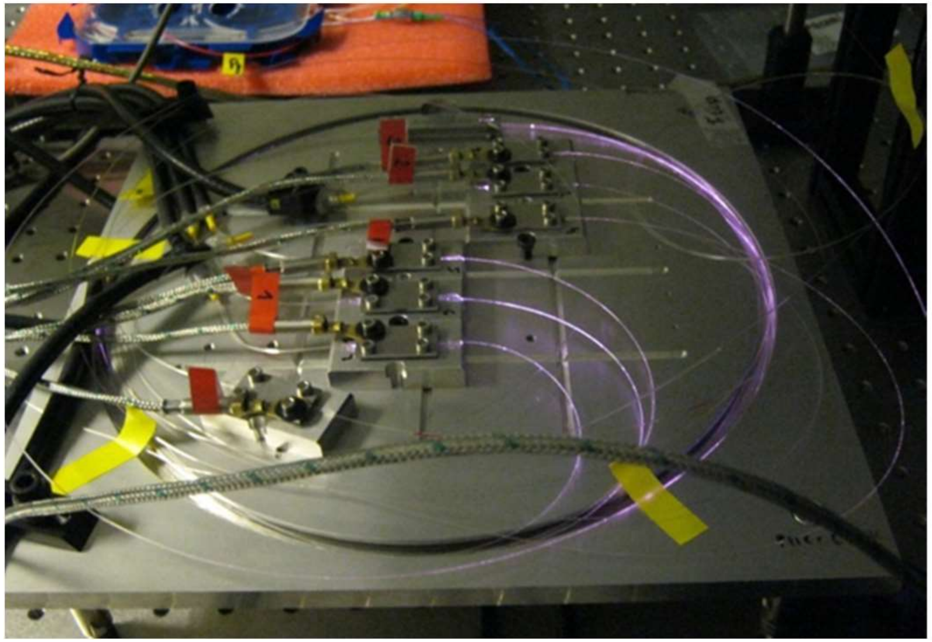


M. Kamrádek, I. Kašík, J. Aubrecht, J. Mrázek, O. Podrazký, J. Cajzl, P. Vařák, V. Kubeček, „Ceramic nanoparticle-doping implementation into MCVD method for fabrication of holmium-doped fibers for fiber lasers, IEEE Photonics J. 11 (2019)

Terapeutic Tm FL







Output power **60 W**

Wavelength **2039 nm**

$M^2 \leq 1{,}76$

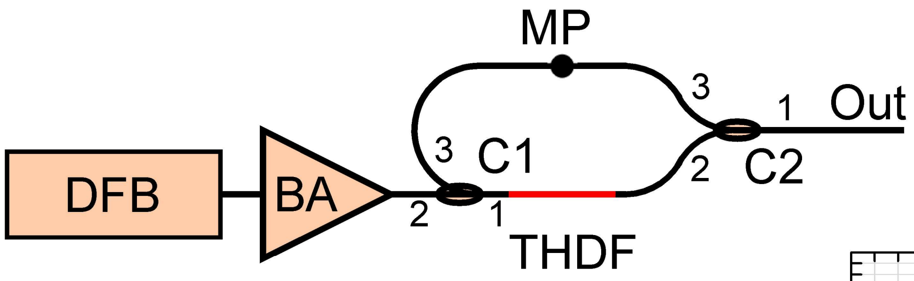
Threshold 0.2 W

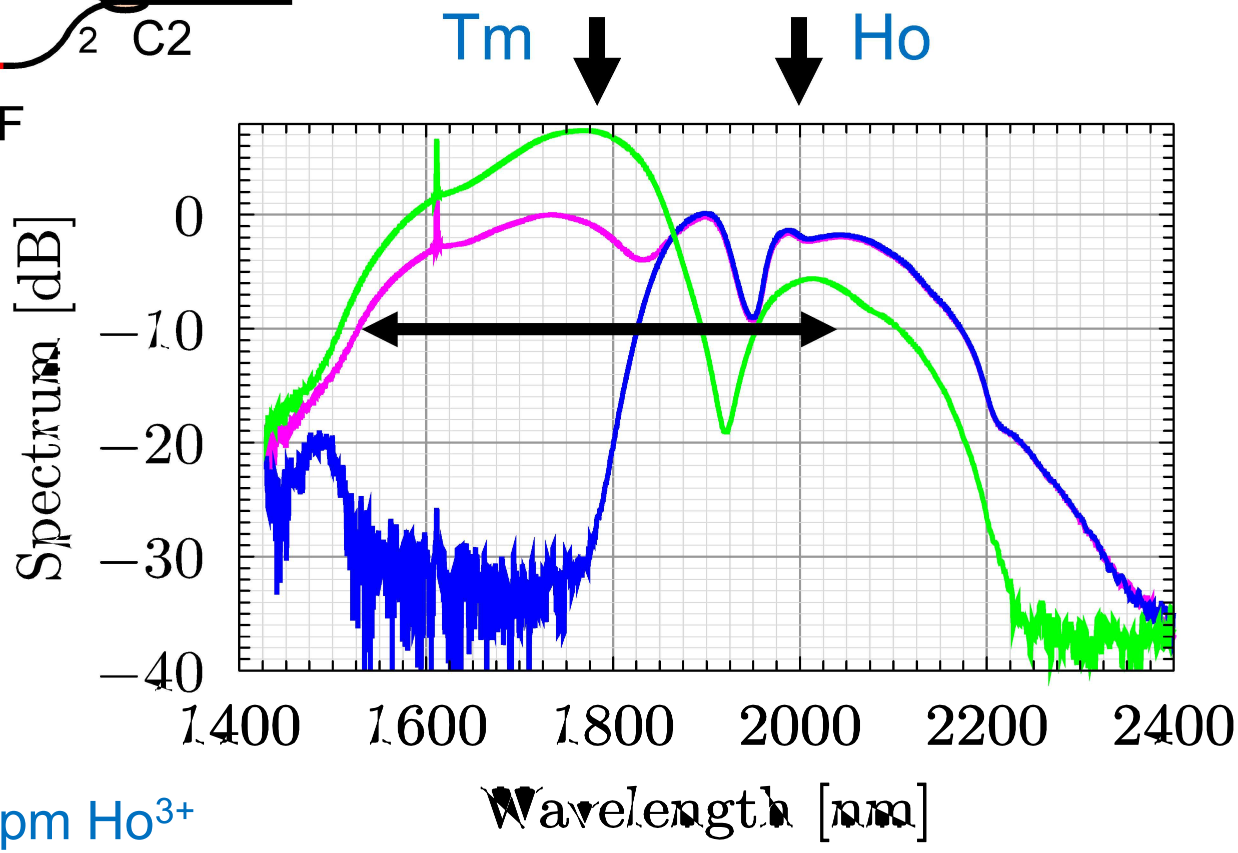
SLE 46 %

ÚFE

Tm/Ho ASE source (1550-2050 nm)

(≠ 1550 nm)



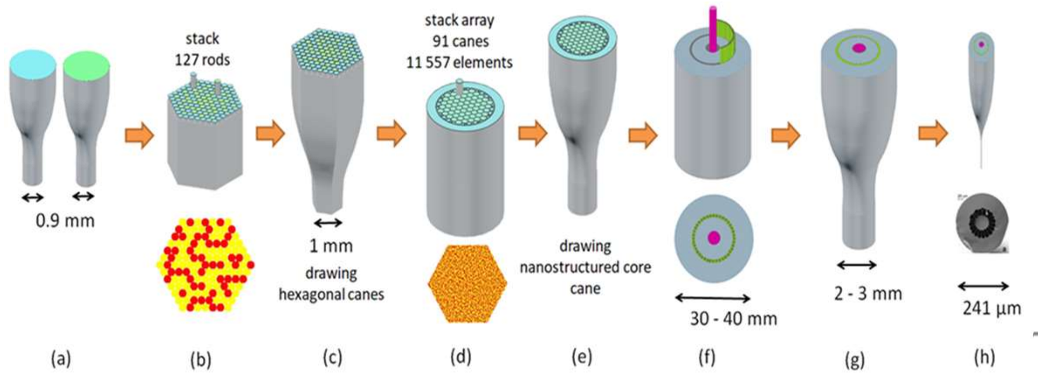


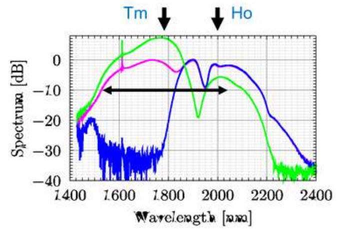
Optical fiber
1800 ppm Tm^{3+} / 360 ppm Ho^{3+}

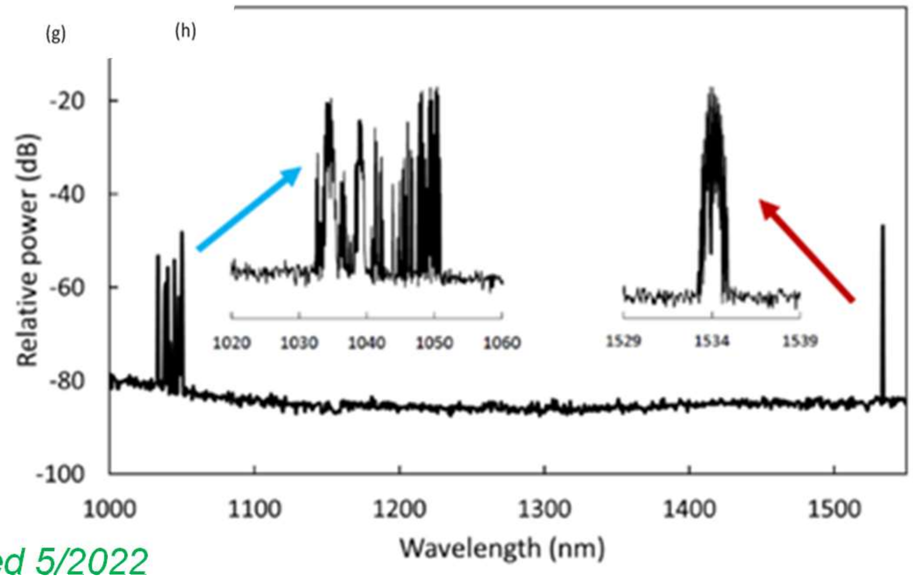
*P. Honzátko, Y. Baravets, I. Kašík, O. Podrazký: „Wideband thulium-holmium-doped fiber source with combined forward and backward ASE at 1600-2300 nm spectral band“, Optics Letters 39 (2014) 3650-3653

Nanostructurized Er–Yb fibers for dual-wavelengths fiber lasers

Stack and draw – well defined nanostructurization







+ Alternative to

* nano-engineering phase separation (M.Paul, W. Blanc)

* NP condensation (B. Coole)

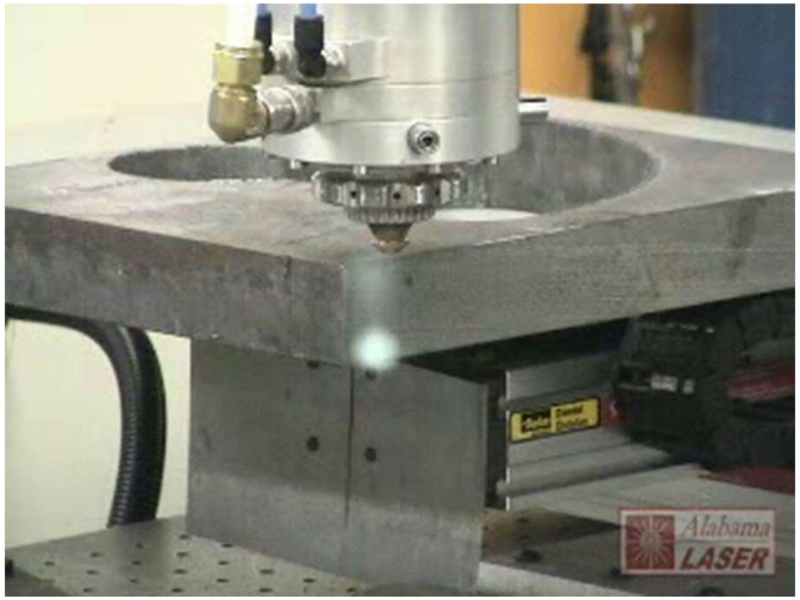
* Direct NP doping (Tammela)

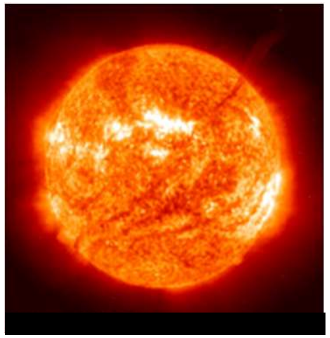
M. Franczyk, R. Buczynski et. al., JLT, submitted 5/2022

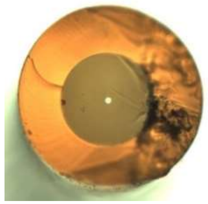
ÚFE

Fiber lasers mW → kW

* high conversion efficiency (fiber lasers ~70-90%) - savings
* high quality beam (nearly Gaussian, low divergency)
* **high brightness** (high concentration of power)
* good thermal management (cooling)
* effective pumping
* tunability
* compactness
* size (long resonator in small space)







sun	63 MW/m^2
fiber laser	12.7 GW/m^2

[IPG]

SUMMARY

1. Fiber technology : preparation of structures of high precision from materials of ultra-high purity (impurities in ppbs only). Difference between CVD and PVD.
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 (passive) and special (active).
4. Research of optical fibers (CR) : ÚFE

References

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