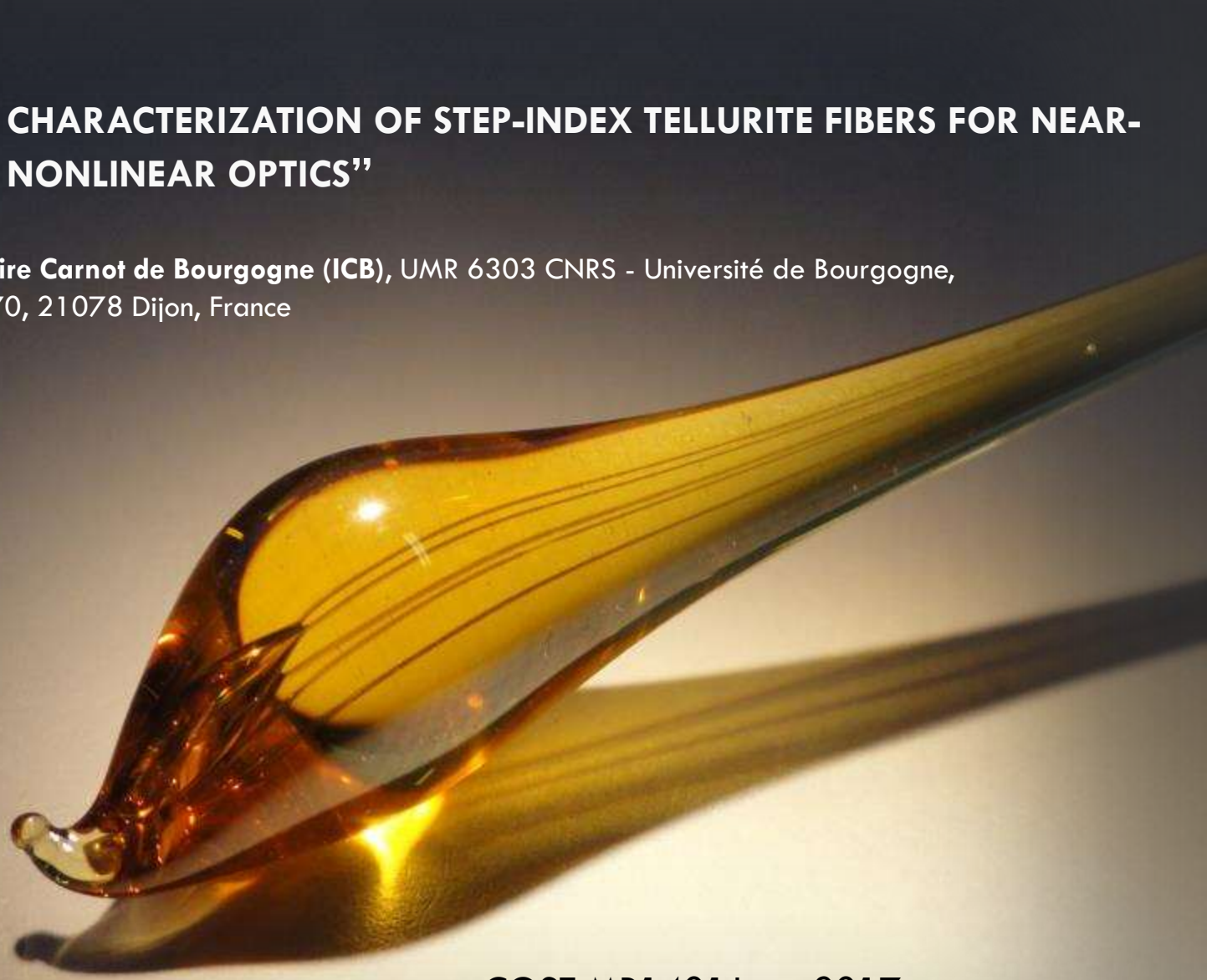
"FABRICATION AND CHARACTERIZATION OF STEP-INDEX TELLURITE FIBERS FOR NEAR- AND MID-INFRARED NONLINEAR OPTICS"

[1]**Laboratoire Interdisciplinaire Carnot de Bourgogne (ICB)**, UMR 6303 CNRS - Université de Bourgogne,
9 Av. Alain Savary, BP 47870, 21078 Dijon, France

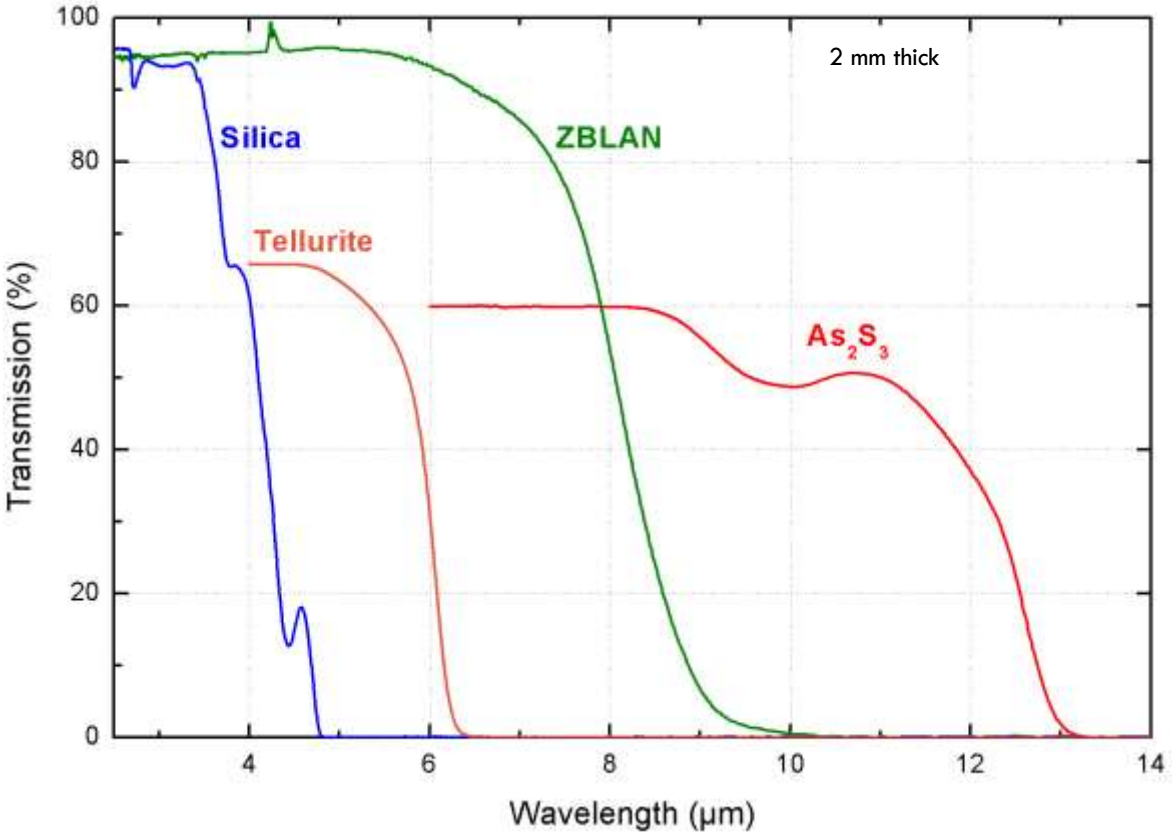
C. Strutynski
F. Désévédavy
P.Froidevaux
A.Lemière
J. Picot-Clémente
G. Gadret
J.C Jules
B. Kibler
F. Smektala



COST MP1401Jena 2017

ICB Laboratoire Interdisciplinaire Carnot de Bourgogne
cnrs
Bourgogne Conseil régional
LabeXction Integrated smart systems
UB Université de Bourgogne
DGA

Alternative glass materials to Silica



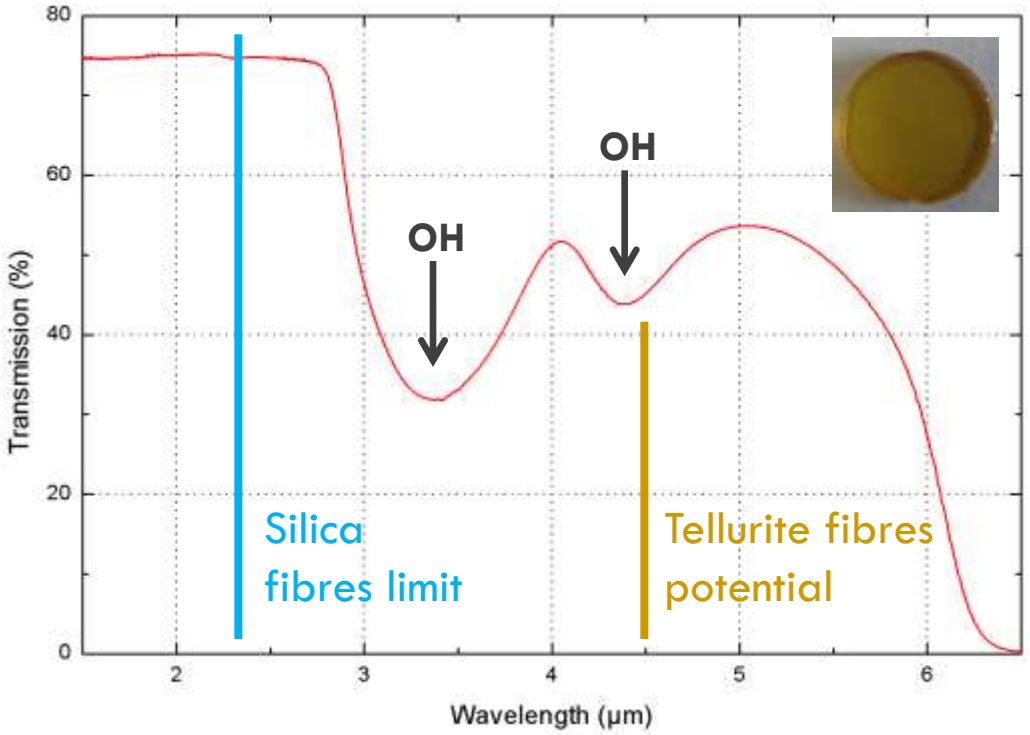
Different glass families :

- Transmission window
- Linear refractive index
  ~ 2 @ 1.06 µm
- Nonlinear Index
  ~ 51×10^{-20} $m^2.W^{-1}$ @ 1.06 µm
- Zero dispersion Wavelength
  (ZDW) ~ 2 µm
- Many compositions

→ **Tellurite** glass

Frédéric DESEVEDAVY
frederic.desevedavy@u-bourgogne.fr

Tellurite glass

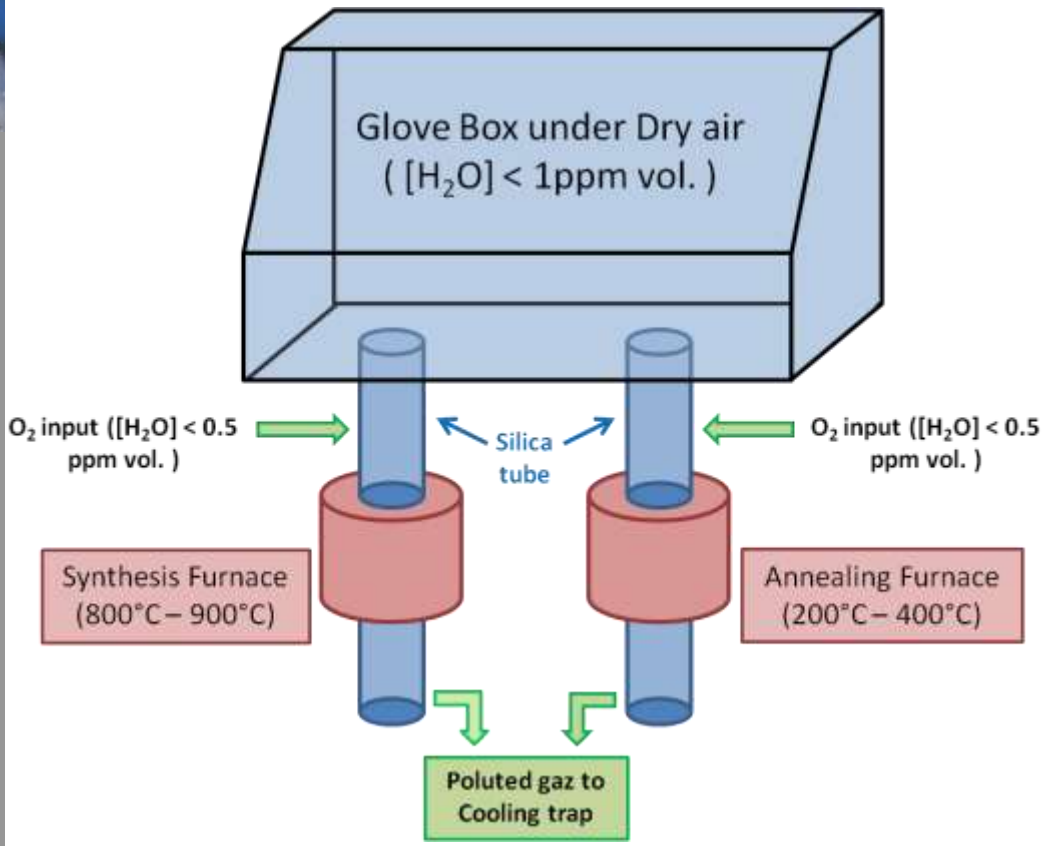


- Convenient to fabricate (melt-quenching technique) and to draw.
- Good transparency window (visible – 6µm on Bulk)
- Rare earth ions easily accepted
- High linear and nonlinear indexes
- Material ZDW around 2 µm
- T_g > 200°C

Purification needs to prevent OH absorptions

Frédéric DESEVEDAVY
frederic.desevedavy@u-bourgogne.fr

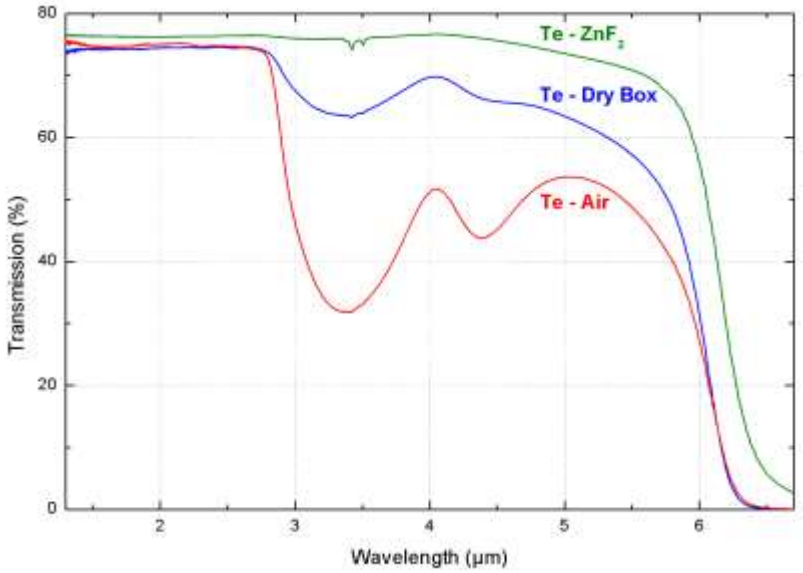
Glass synthesis setup



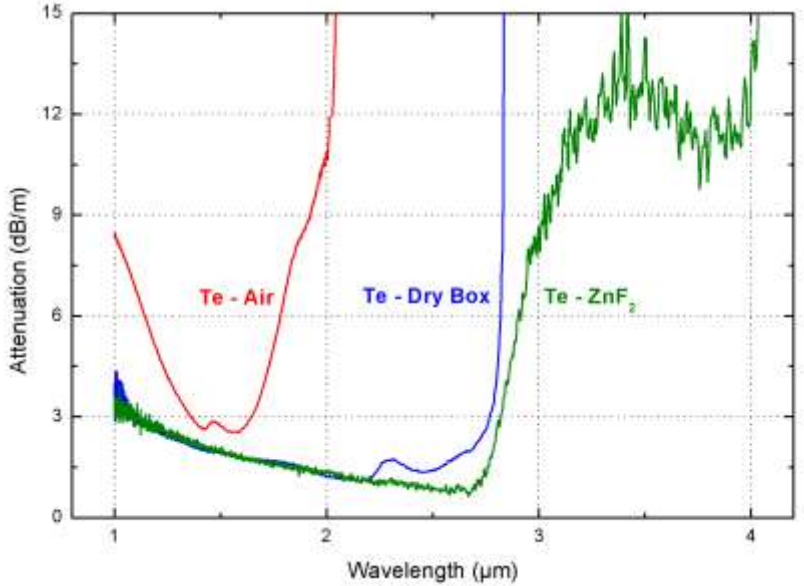
Frédéric DESEVEDAVY
frederic.desevedavy@u-bourgogne.fr

Previous results - Material

80 TeO_2 - 10 ZnO – 10 Na_2O



Bulk transmission of glass samples using different synthesis techniques



Attenuation spectrum of single index glass fibres using different synthesis techniques (Savelii and al, Optical Materials, 2013, 35, 1595).

OH absorption reduced down to 13dB/m @ 3.3µm i.e. **[OH] ≈ 1.3ppm**

Frédéric DESEVEDAVY
frederic.desevedavy@u-bourgogne.fr

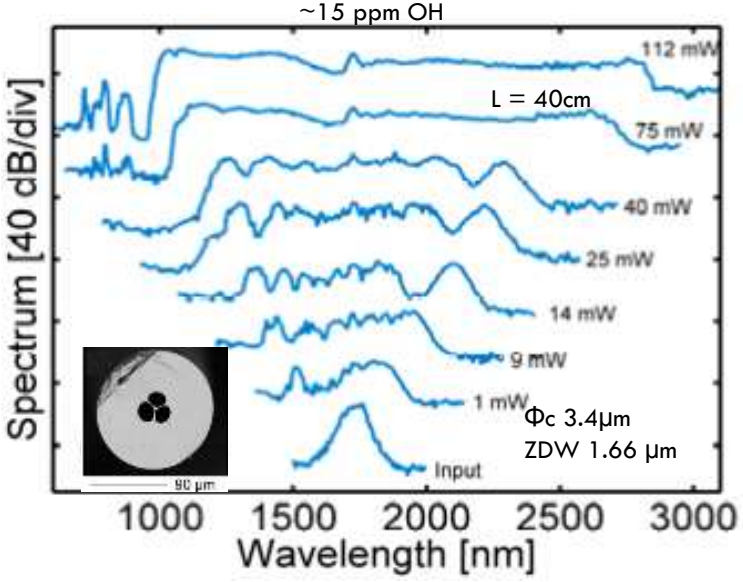
Previous results - Supercontinuum

With the collaboration of the Toyota Technological Institut, Nagoya: Y. Ohishi team.

Te – Dry Box

~15 ppm OH

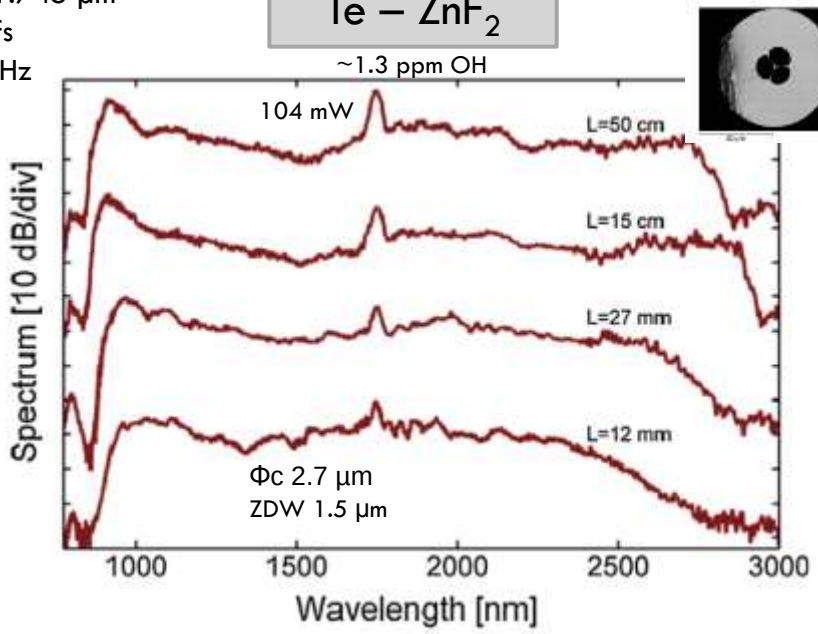
λ_p = 1.745 µm
200 fs
80 MHz



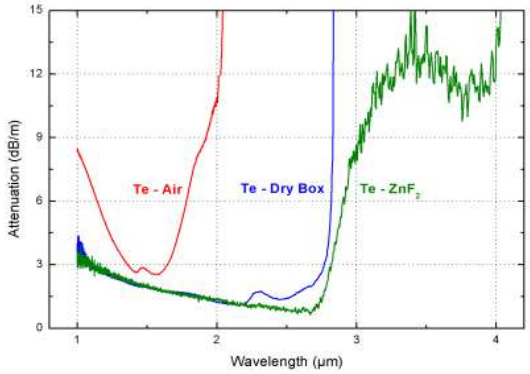
SC generated in Te – Dry Box MOF (Savelii and al. 2012)

Te – ZnF_2

~1.3 ppm OH

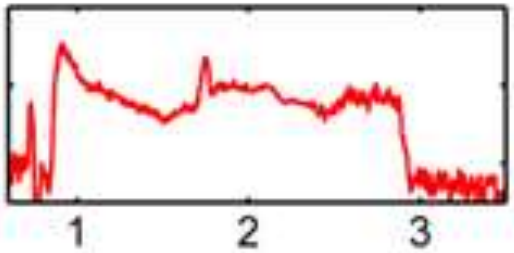


SC generated in Te – ZnF_2 MOF (Savelii and al, Optical Materials, 2013, 35, 1595)



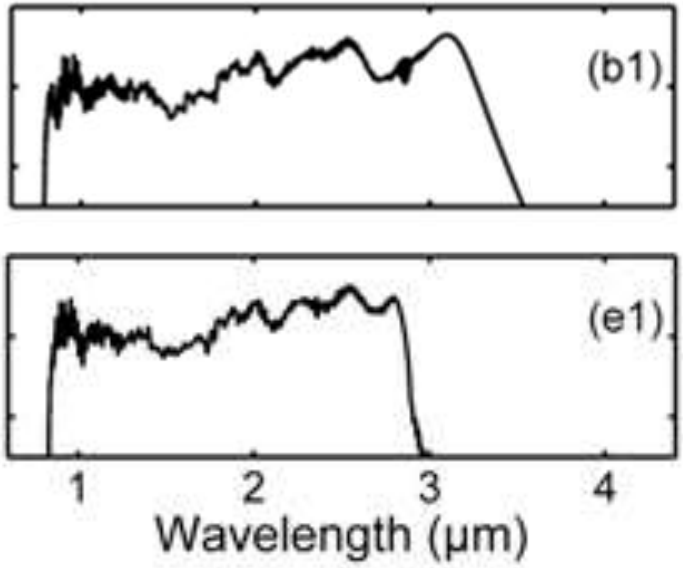
Reduction of OH absorption is not enough or/and aging phenomenon

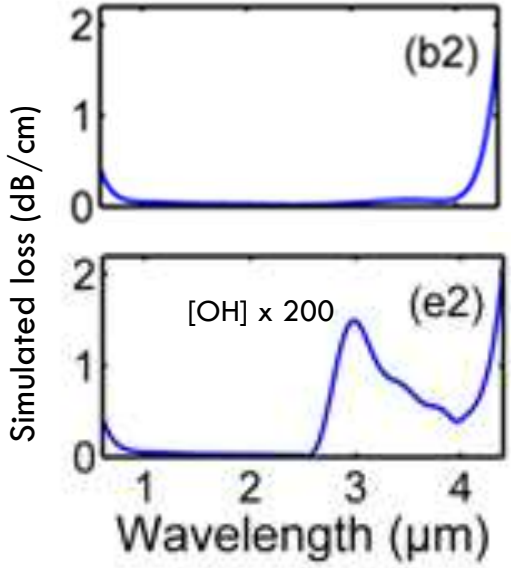
Results - Aging



Experimental SC generated in Te – ZnF_2 MOF (Savelii and al. 2013)

Numerical simulation, 15-cm-long, ϕ_{core} = 2.8-µm, λ_p = 1.745 µm, 7.5 kW, 200-fs





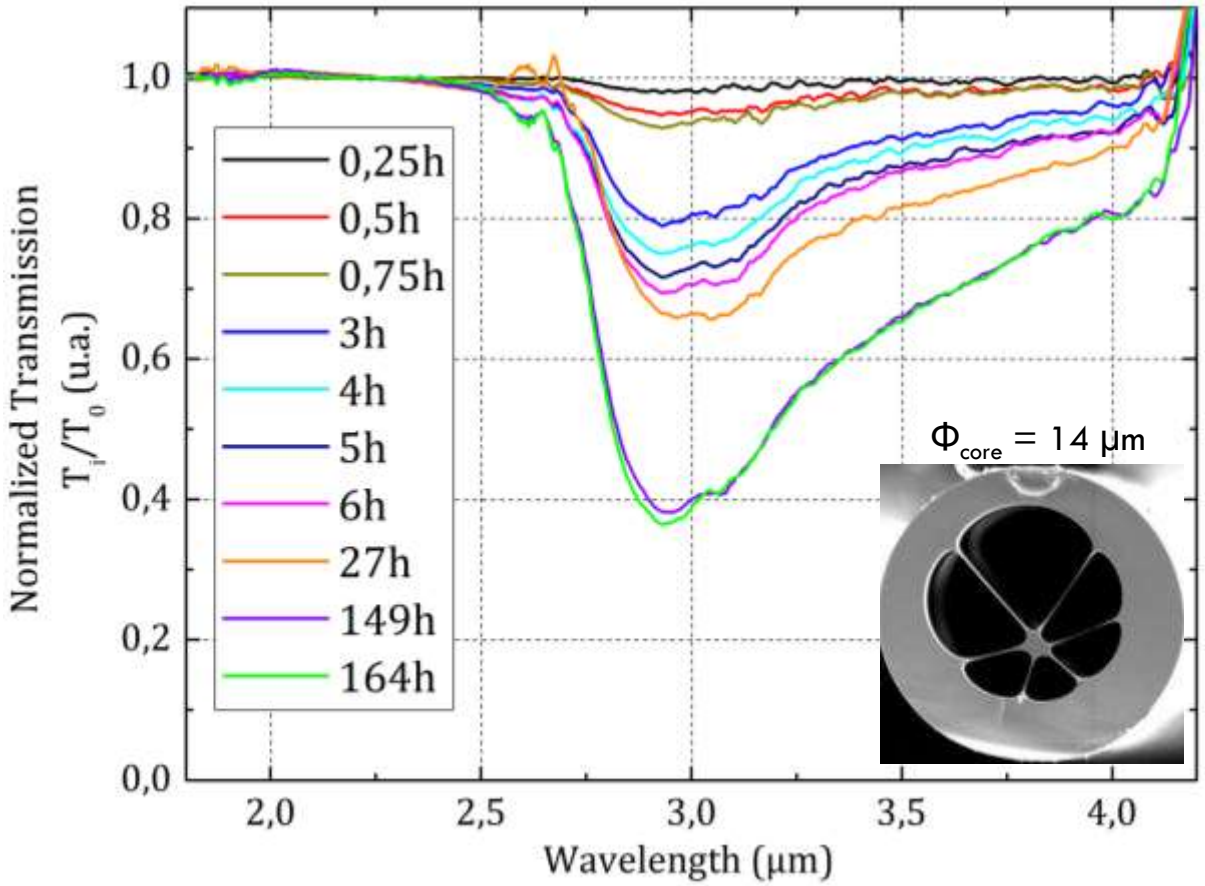
Losses measured on single index fiber

Extra losses considered for matching between experiment and simulation

→ Aging

Results - Aging

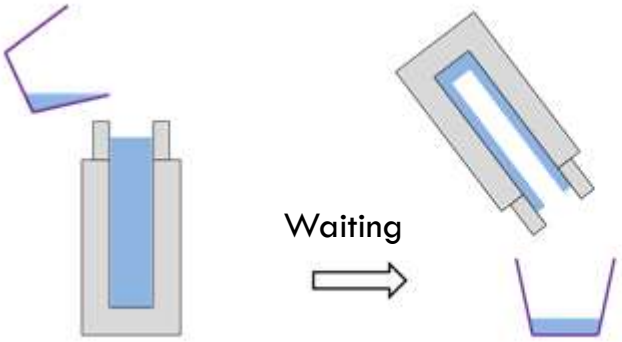
80 TeO_2 – 5 ZnO – 5 ZNF_2 – 10 Na_2O



All solid fiber to limit aging

Results – Step index fiber fabrication

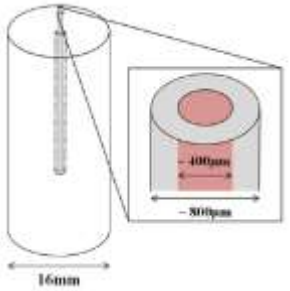
Build in casting process



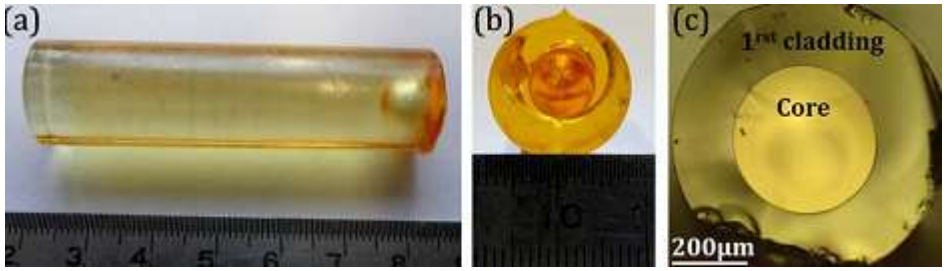
1. Cladding glass casting

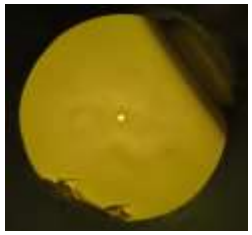
2. Removing of extra cladding glass

3. Core glass casting



4. Core/clad rod insertion in cladding tube





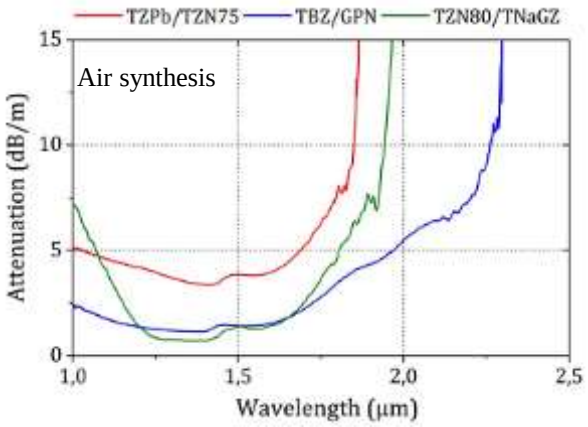
Frédéric DESEVEDAVY
frederic.desevedavy@u-bourgogne.fr

Results - Supercontinuum generation

Glass composition (% mol)		*n* (1.55 µm)	ϕ_{core} (µm)	Notation Core clad
76.5 TeO_2 - 20.5 ZnO - 3 PbO		2.053	4.0	TZPb
75 TeO_2 - 20 ZnO - 5 Na_2O	a	2.002		TZN75
60 TeO_2 - 20 Ba_2O - 20 ZnO		1.908	4.1	TBZ
55 GeO_2 - 30 PbO - 15 Na_2O	b	1.822		GPN
80 TeO_2 - 10 ZnO - 10 Na_2O		1.995	5.2	TZN80
60 TeO_2 - 20 Na_2O - 15 GeO_2 - 5 ZnO	c	1.867		TNaGZ

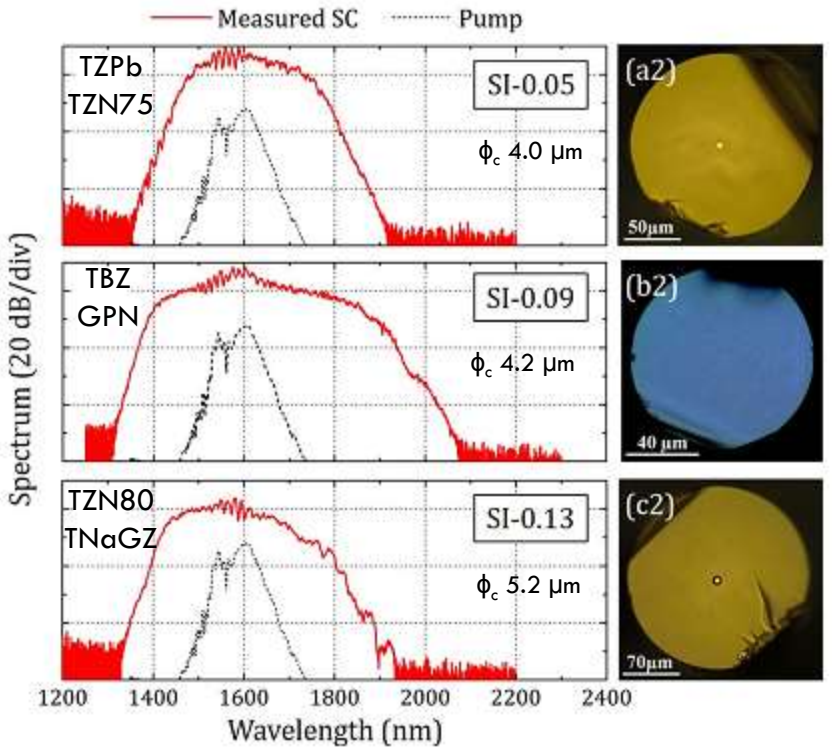
At 1.56 µm: -80 < D < -40 ps/nm/km

Fibers core/clad attenuation (air synthesis)



Spectral broadenings limited by the linear fiber losses

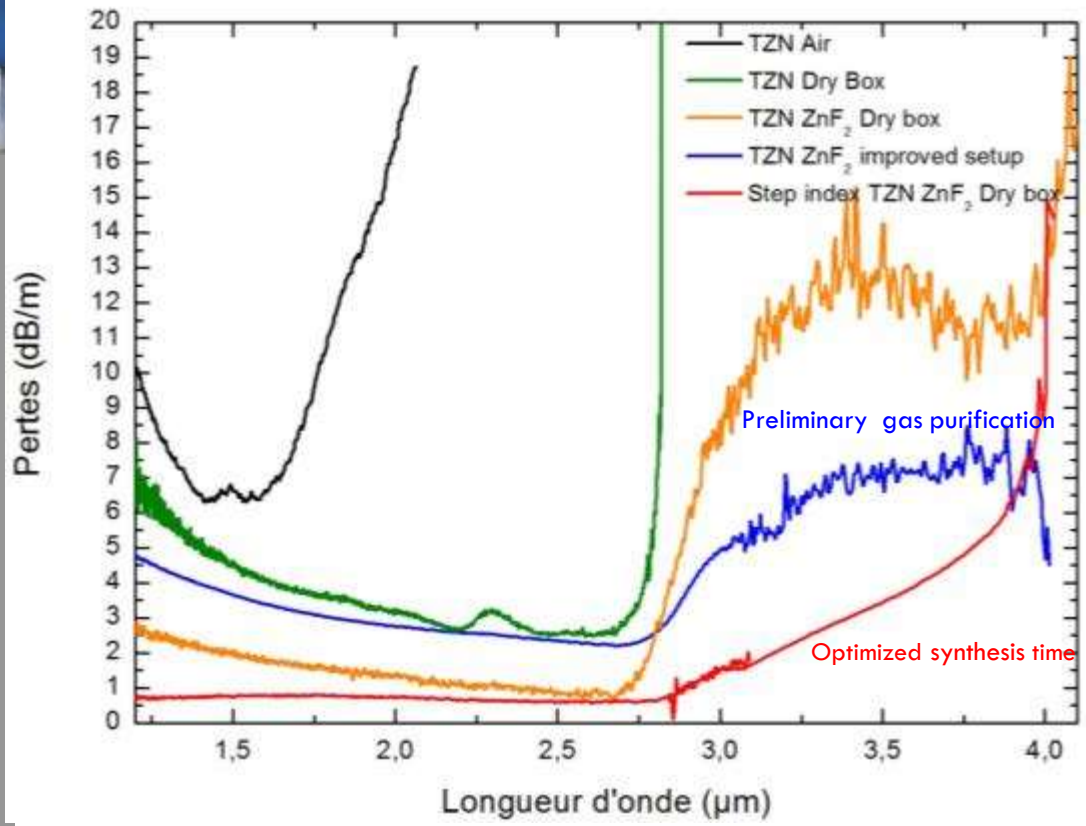
λp =1.56 µm, 70 fs, 80 MHz, 130 mW
7 kW coupled input peak power
30 cm fiber length



C. Strutynski et al, *J. Opt. Soc. Am. B*, 33(11):D12–D18, 2016.

Frédéric DESEVEDAVY
frederic.desevedavy@u-bourgogne.fr

Results - Reducing OH absorption



- Controlled atmosphere : **dry box**
- Dehydration reagents : **ZNF_2**
- **Highly pure precursor** 5N or more (especially Na_2CO_3)
- **In line gas purification** before entering the furnace.
- Improvement of the **air tightness of the glass synthesis setup**
- **Core clad interface** and optimized **time synthesis**

[OH] ≈ 0.2 ppm

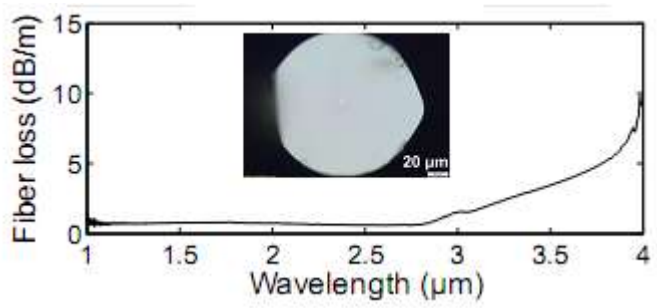
Reduction of the OH absorption at 3.3µm well bellow 10dB/m

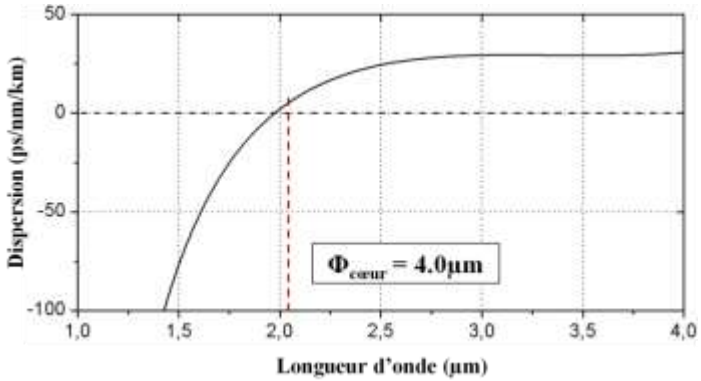
Frédéric DESEVEDAVY
frederic.desevedavy@u-bourgogne.fr

Results - Supercontinuum generation

Tellurite step index fiber

	Composition	Tg	n @ 1.55 µm
Core glass	80 TeO_2 – 10 ZnO- 10 Na_2O	285°C	2.005
Cladding glass	60 TeO_2 20 Na_2O-15GeO2 - 5 ZnO	272°C	1.908



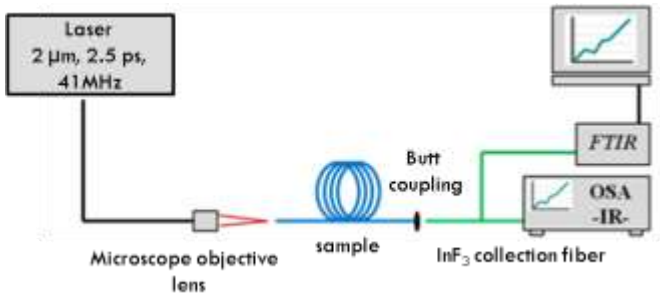


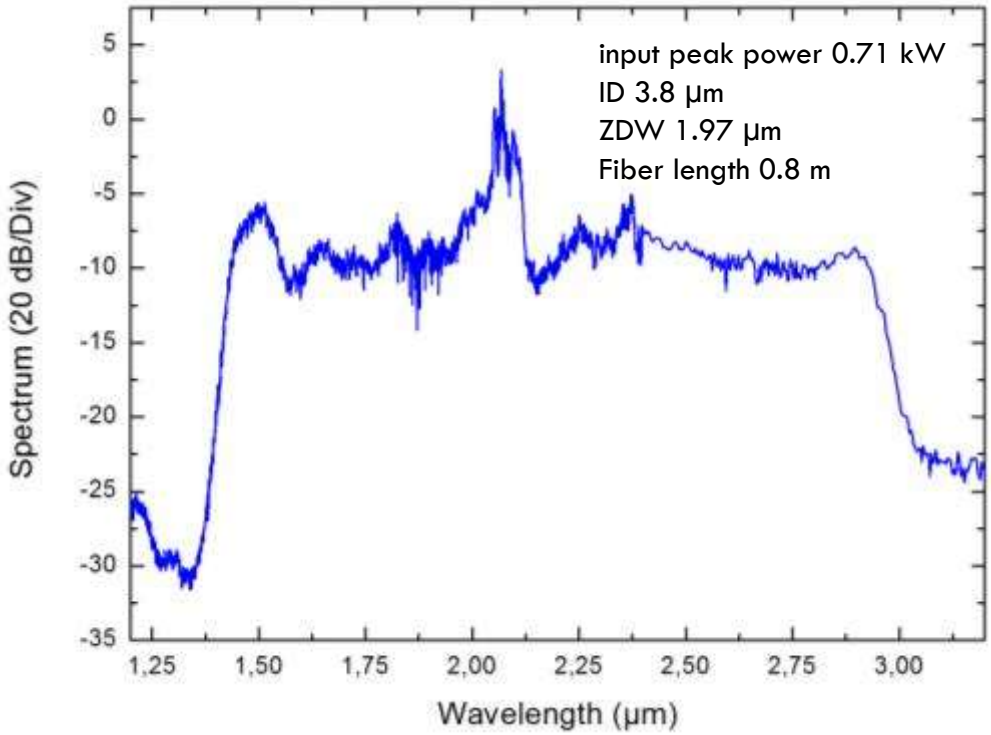
Lowest losses reported on tellurite fiber

Results - Supercontinuum generation

Pumping at 2.06 µm

Tm doped fibered source

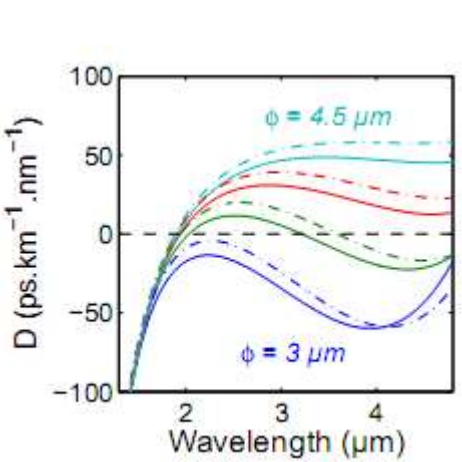


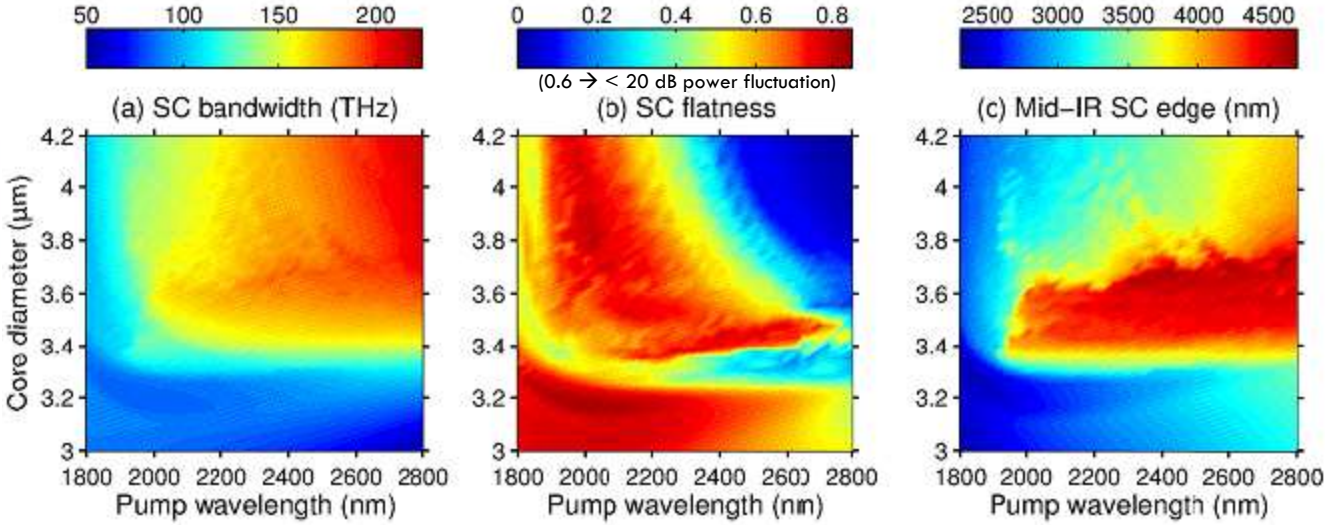


Equivalent to our best result with core suspended fiber pump at 1.7 µm with an OPO

Results - Supercontinuum generation

SC generation parameter optimization





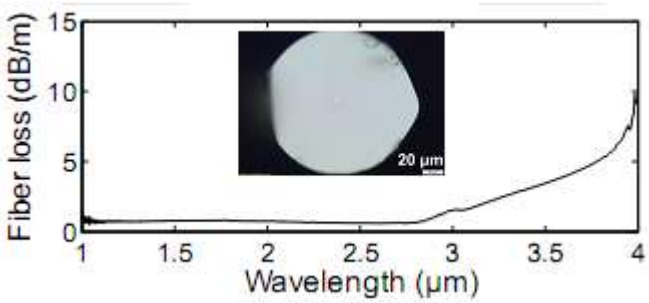
250 fs, 6 kW input peak power, 10 cm fiber length

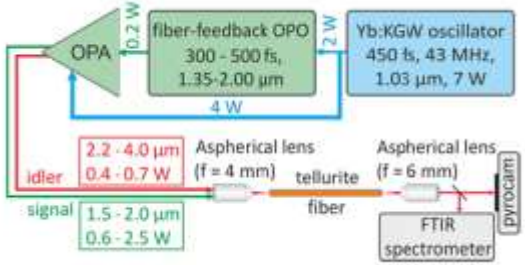
Pump wavelength between 2.2 and 2.6μm
3.4 μm < Φ_c < 3.7 μm

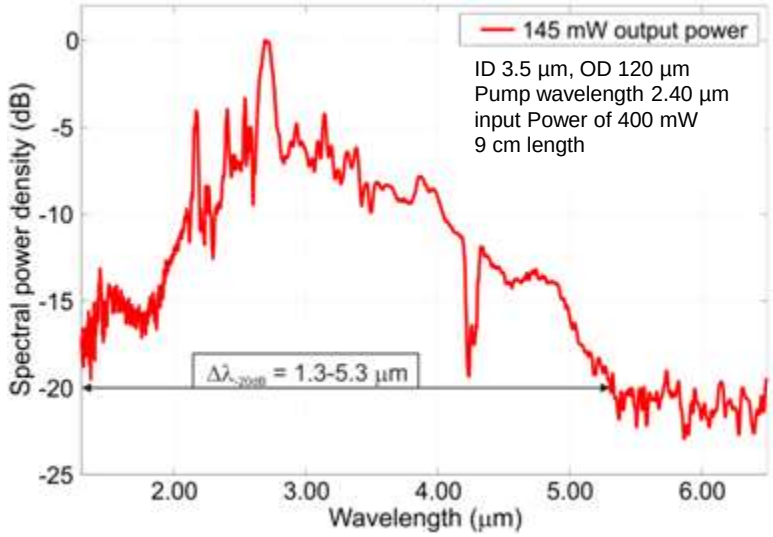
Frédéric DESEVEDAVY
frederic.desevedavy@u-bourgogne.fr

Results - Suppercontinuum generation

With the collaboration of the University of Stuttgard: Harald Giessen team, Stefen Kedenburg and co-workers







S. Kedenburg, C. Strutynski, B. Kibler et al., JOSA B, vol. 34, no. 3, pp. 601–607, 2017.

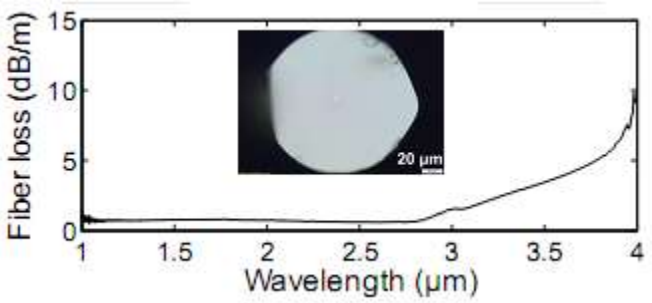
<u>Broadest supercontinuum reported on tellurite fiber</u>

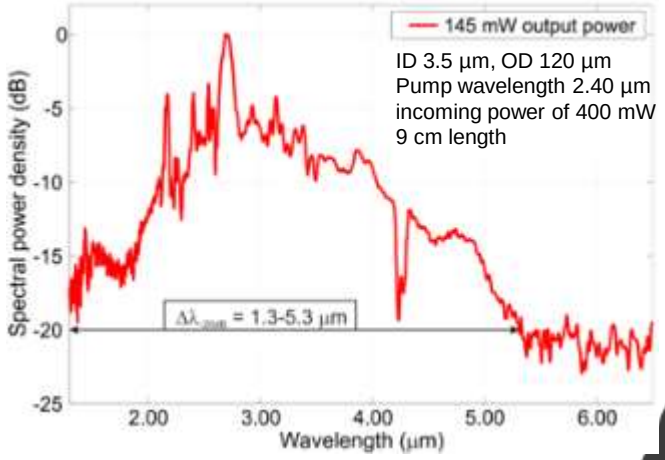
145 mW out put power, 45% in 3 - 5 µm atmospheric window

9cm fiber length

Conclusion and prospects

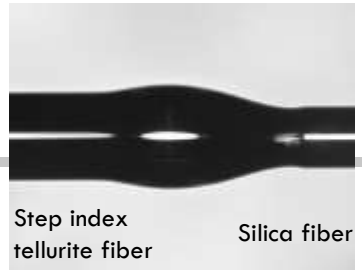
-Aging demonstration
-All solid fiber
-OH decreasing, **fiber transmission up to 4 µm**
Lowest losses reported on tellurite fiber
-Tellurite fiber with engineered dispersion profile
-**Broadest SC reported on tellurite fiber**
from 1.3 to 5.3 µm



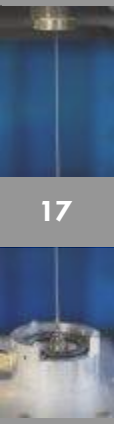


-Application in gas detection
Supercontinuum absorption spectroscopy
Clément Strutynski et al, Laser Physics Letters, 13(7):075402, 2016
-Compact source by pumping around 2µm: fs regime
(Tm doped fiber lasers)
-Improve the input coupling (silica - tellurite welding)

Coupling losses: 3 dB



Frédéric DESEVEDAVY
frederic.desevedavy@u-bourgogne.fr



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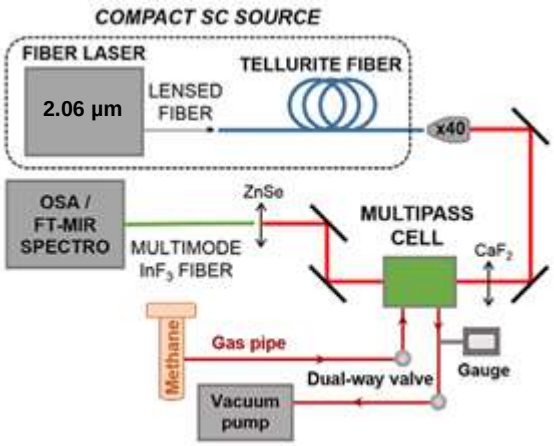
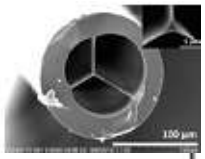
frederic.desevedavy@u-bourgogne.fr

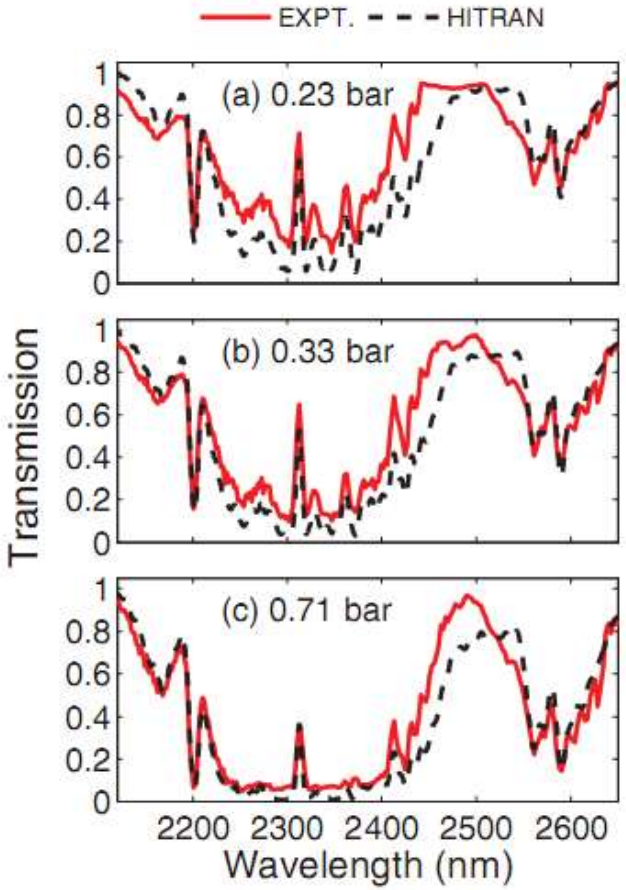
CH_4 spectroscopy : proof of principle

Supercontinuum absorption spectroscopy in the mid IR



Fiber length 0.6 m





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