WP4 Photonics Components for pre- and post- pulse conditioning

Fetah Benabid

GPPMM group, XLIM Research Institute, CNRS-Université de Limoges,
UMR 7252, Limoges, France

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687880

Work Package 4 Overview

AIM: *Pulse compression & fibre beam-delivery*

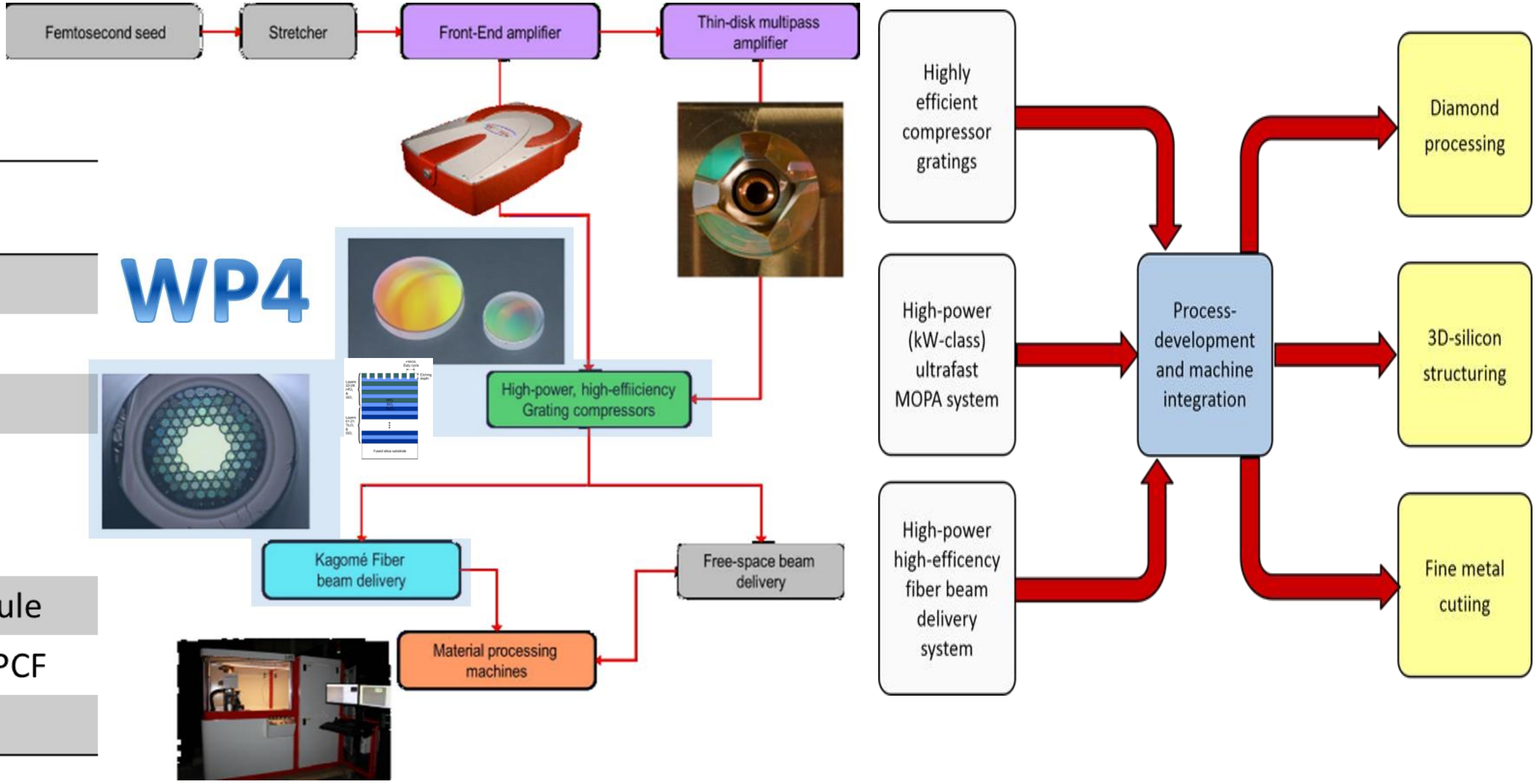
Partners & roles

PULSE COMPRESSION
(Diffraction grating with high LIDT and high efficiency)

USTUTT	Design & qualification
AMO	Process development
AMP	Spec requirement

FIBRE BEAM DELIVERY
(HC-PCF design & fabrication)

GLO	Fabrication of HC-PCF and delivery module
XLIM	Design et development of high PER HC-PCF
AMP	Spec requirement & qualification



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687880

Work Package 4 Overview

AIM: *Pulse compression & fibre beam-delivery*

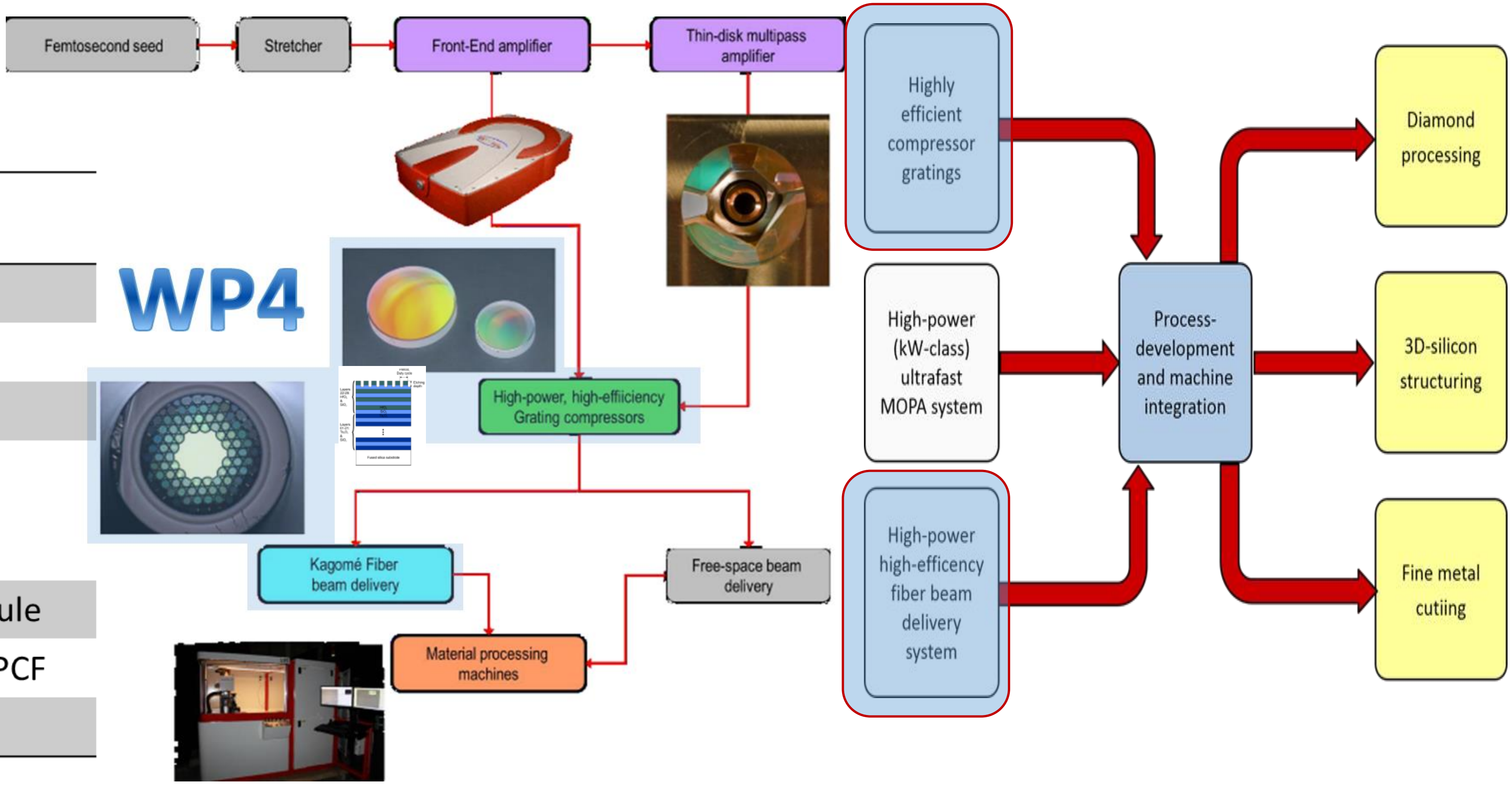
Partners & roles

PULSE COMPRESSION
(Diffraction grating with high LIDT and high efficiency)

USTUTT	Design & qualification
AMO	Process development
AMP	Spec requirement

FIBRE BEAM DELIVERY
(HC-PCF design & fabrication)

GLO	Fabrication of HC-PCF and delivery module
XLIM	Design et development of high PER HC-PCF
AMP	Spec requirement & qualification

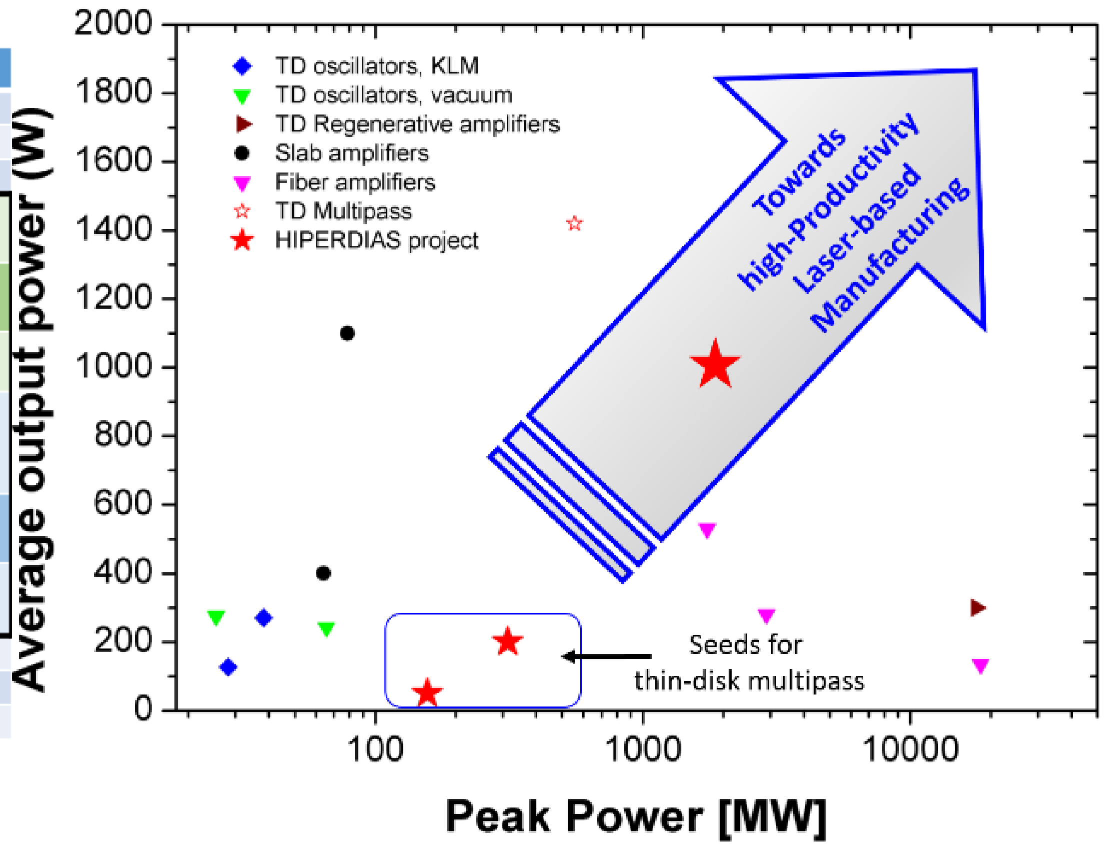


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687880

Work Package 4 Overview

AIM: *Pulse compression & fibre beam-delivery*

	Parameter	Current State-of-the-Art	HIPERDIAS Target
Laser system	Average power/peak power	1.4 kW (lab)/ 588 MW	1 kW / >1 GW
	Energy	4.7 mJ	1 mJ @ 1 MHz
	Pulse duration	8 ps	<1 ps
Grating compressors	**Overall Efficiency (%)**	**80-85**	**> 96%**
	Spectral bandwidth (nm)	**~ 10**	**Several tens of nm** (>99% efficiency)
	LIDT (@ 500 fs)	**0.3 J/cm²**	**>0.3 J/cm² (up to 1J/cm²)**
Beam delivery	**Average power / Peak power**	**150W/2GW** Note: peak power is not limiting factor in kagome fiber. Challenge is to handle larger avg power	**>500W and up to 1kW />1 GW**
	Propagation loss	**20-50 dB/km (typical)**	**10-20 dB/km typical (down to 1 dB/km is aimed for**
	PER	**17 dB** (typical in stationary configuration)	**>20dB**
Material processing	Fine metal cutting	mechanical	USP Laser
	3D silicon processing	mechanical	USP Laser
	Diamond ablation	mechanical	USP Laser



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687880

Work Package 4 Overview

TASK BREAKDOWN

6 tasks, 14 Milestones & 7 delivrables

PULSE COMPRESSION

(Diffraction grating with high LIDT and high efficiency)

TASK /Leader	Description	Milestones	Deliverables
4.1 /USTUTT	Design of grating compressor • **Design** of the gratings • Parameter space review	M4.1 (M03)	D4.1(M04) D 4.2(M12)
4.2 /AMO	Development of optimized **lithography process** for the fabrication of pulse compression gratings		
4.3 /AMO	Development of optimized **etching process** for the fabrication of pulse compression gratings	M4.3(M08) M4.4(M12) M4.8(M18)	M05-M30 D 4.2

FIBRE BEAM DELIVERY

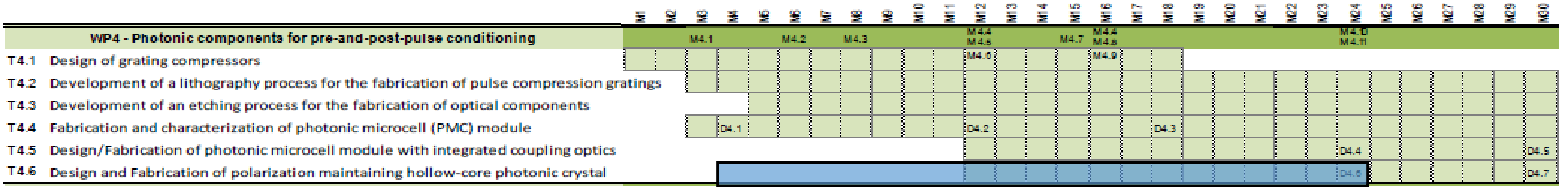
(HC-PCF design & fabrication)

TASK /Leader	Description	Milestones	Deliverables
4.4/ GLO	Fabrication & characterization of PMC module for USP fibre-delivery	M 4.1 (M06) M 4.5 (M12,18,28)	D4.4 (M24, M36) D4.7 (M30)
4.5/ GLO	Design and Fabrication of photonic microcell module with integrated coupling optics for fibre-delivery and interface with system integrator.	M4.7(M15) M4.9 (M18) M4.10(M24)	D4.6(M30)
4.6/ XLIM	Design and Fabrication of high PER HC-PCF for ultra-high energy pulse delivery	M 4.6 (M12) M4.11(M24)	D4.5 (M24)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687880

WP4 – Task 4.6: Design and fabrication of polarization maintaining hollow-core photonic crystal for ultra-high energy pulse delivery

- Overview, XLIM, GLO



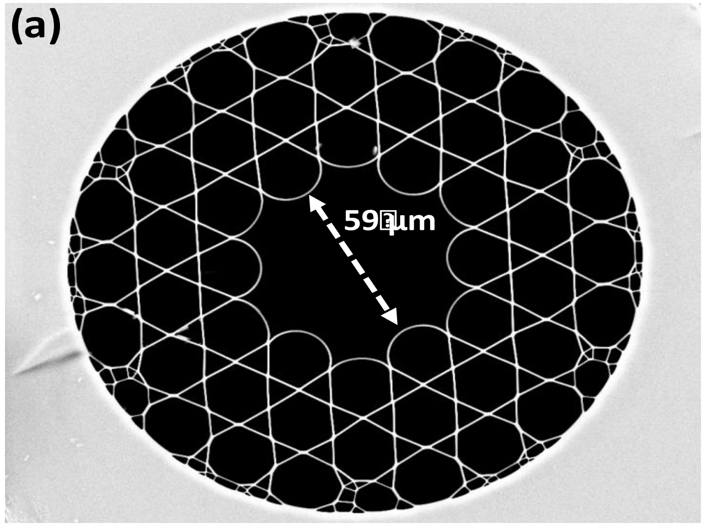
  - Two fiber designs explored (transmission loss: new records)
  - Kagome fiber parameters with PER=21 dB
  - **Start of the reproducibility and technology transfer to GLOphotonics**

- Deviations and proposed corrective actions…
  - NA

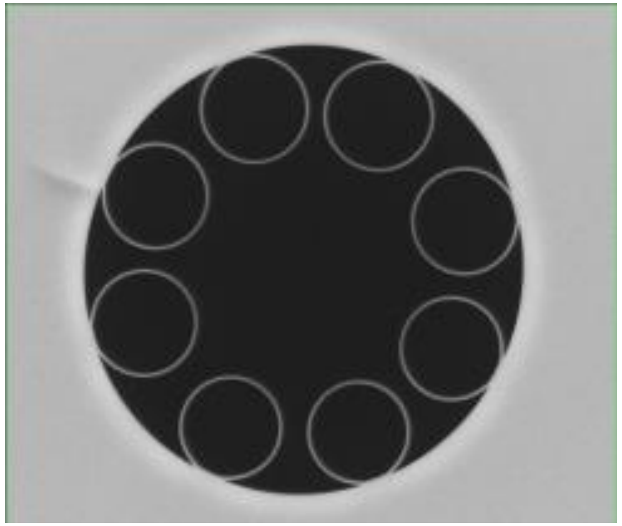
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687880

- Strategy taken

IC Kagome lattice



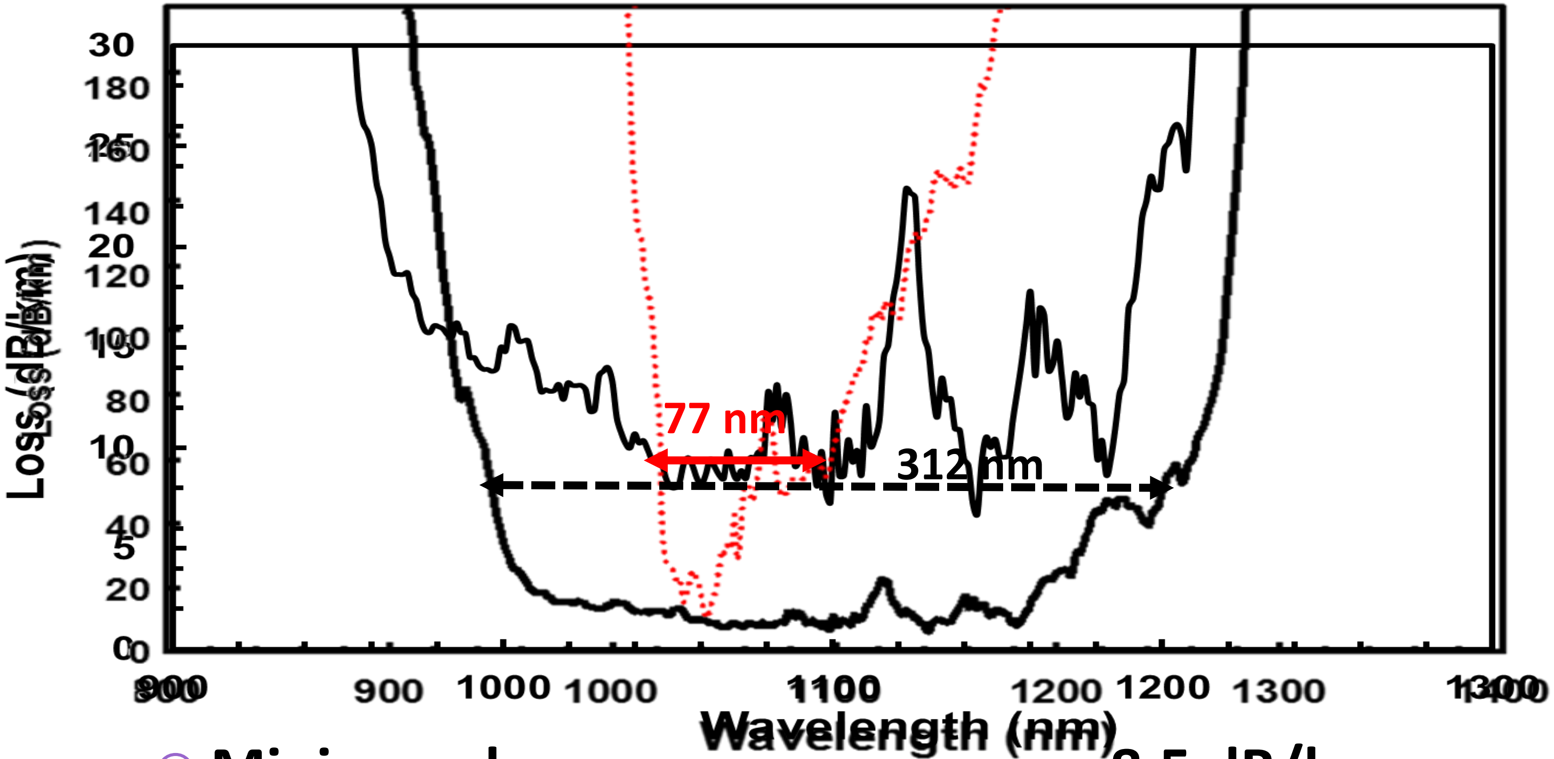
IC Tubular lattice

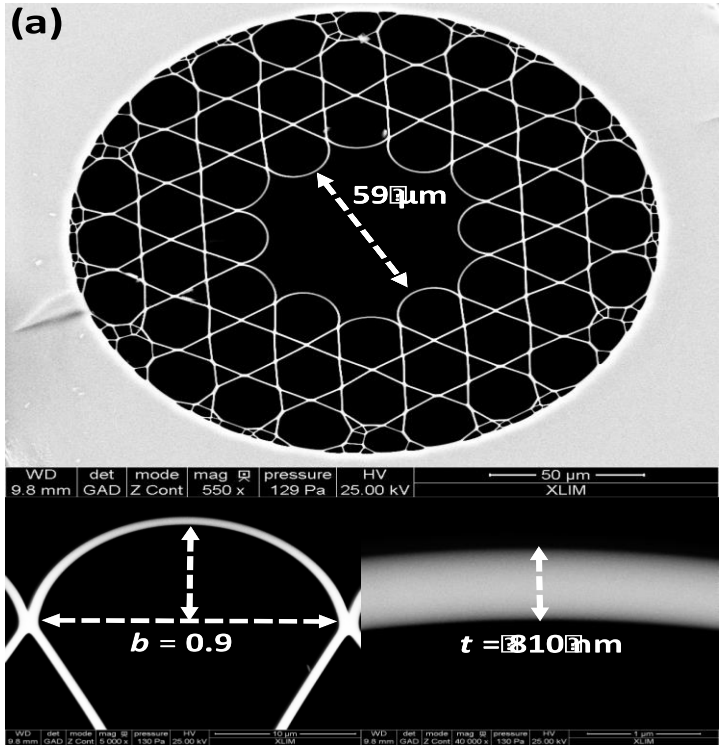


Fine tune the strcutural parameters of the fibre (strut thickness, contour curvature) to target high PER whilst keeping: ultra-low loss, ultra-low overlap with silica and close to single mode modal content

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 687880

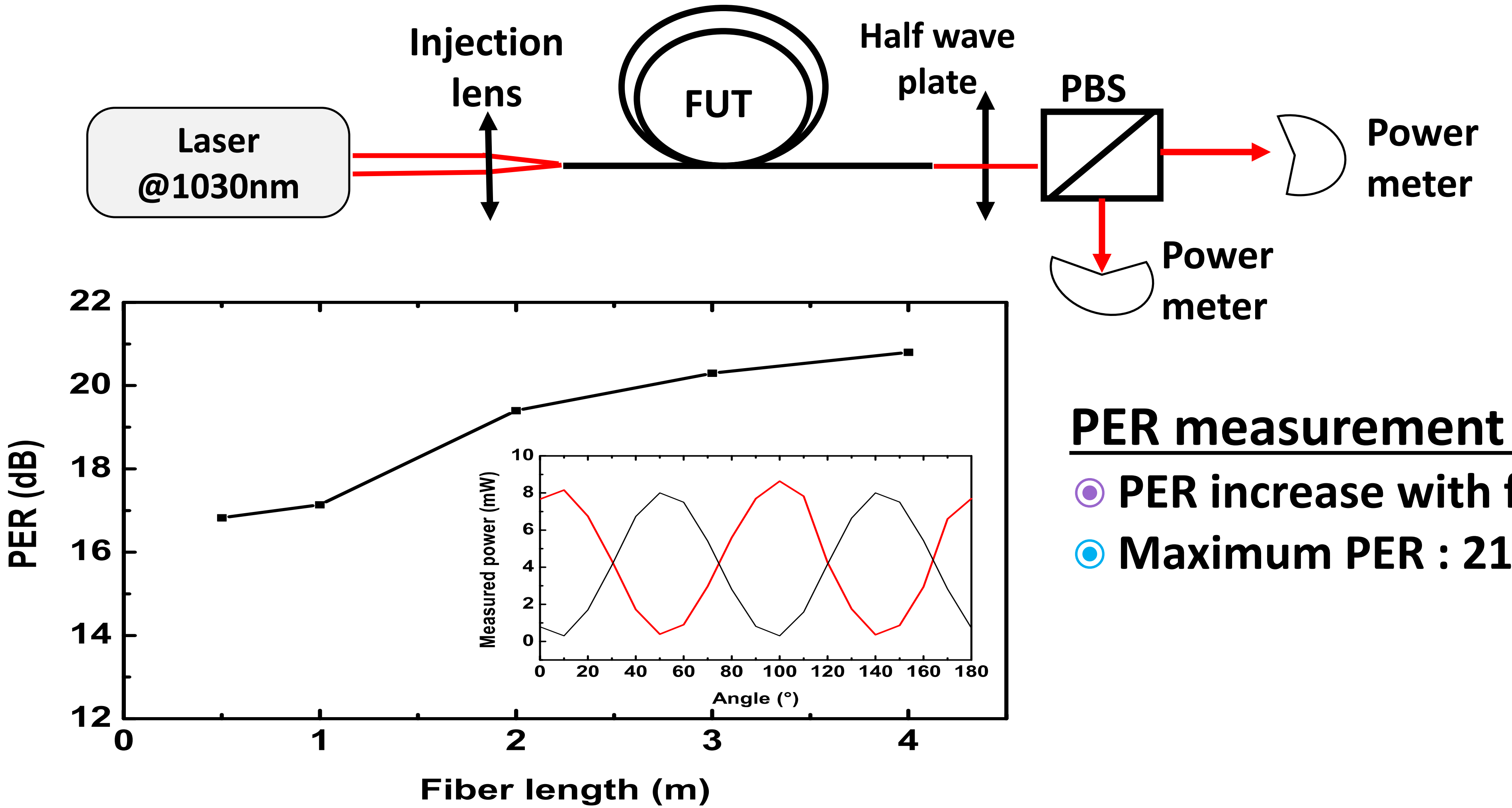
STRUCTURE AND RECORD LOSS





- Minimum loss: 8.5 dB/km
- Transmission bandwidth: 225 nm
- Core diameter: 59 µm
- Struts thickness: 810 nm

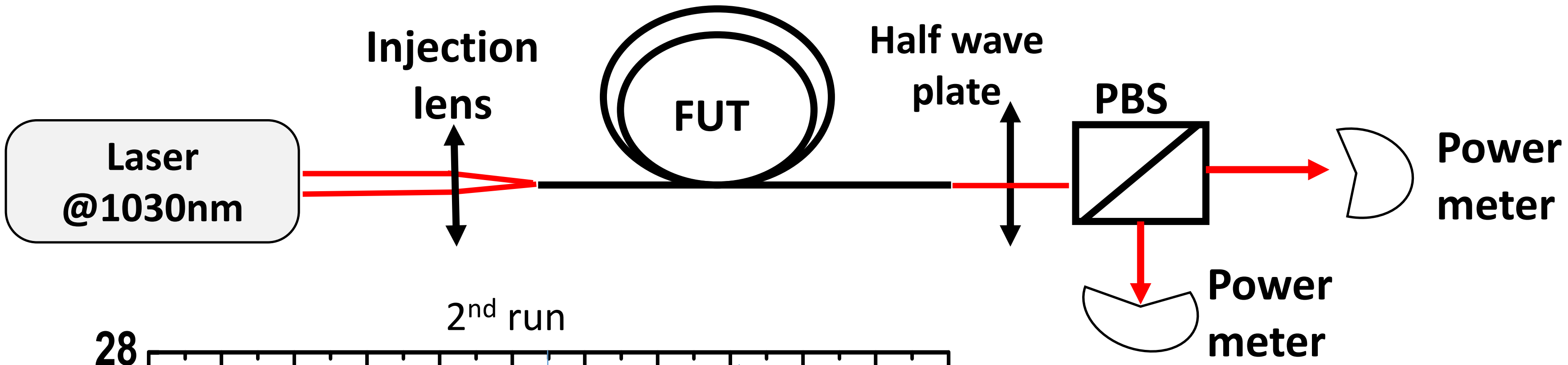
PER MEASUREMENTS

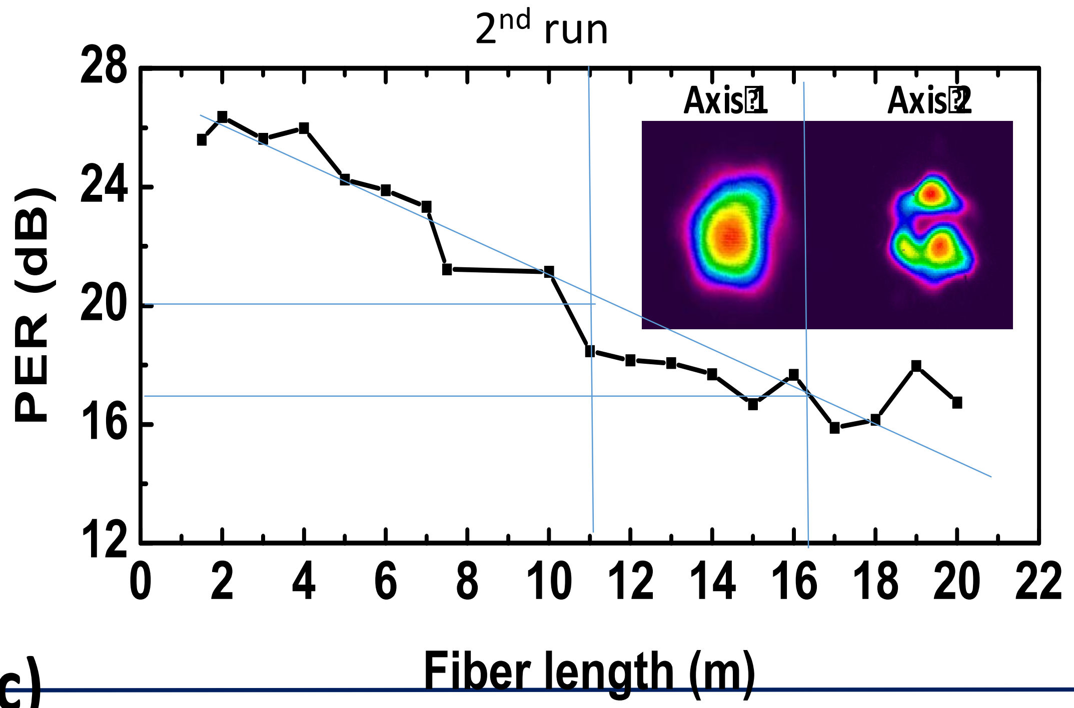


PER measurement (@ 1030nm) :

- PER increase with fiber length
- Maximum PER : 21 dB

PER MEASUREMENTS



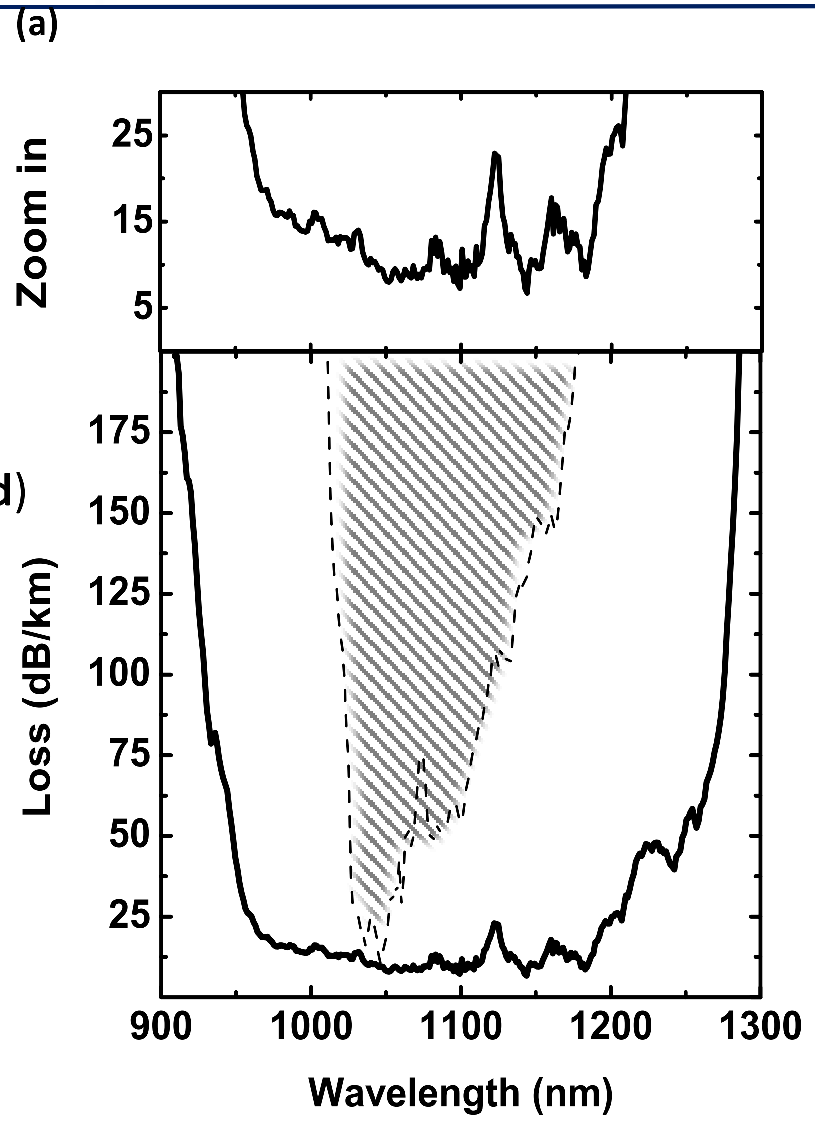


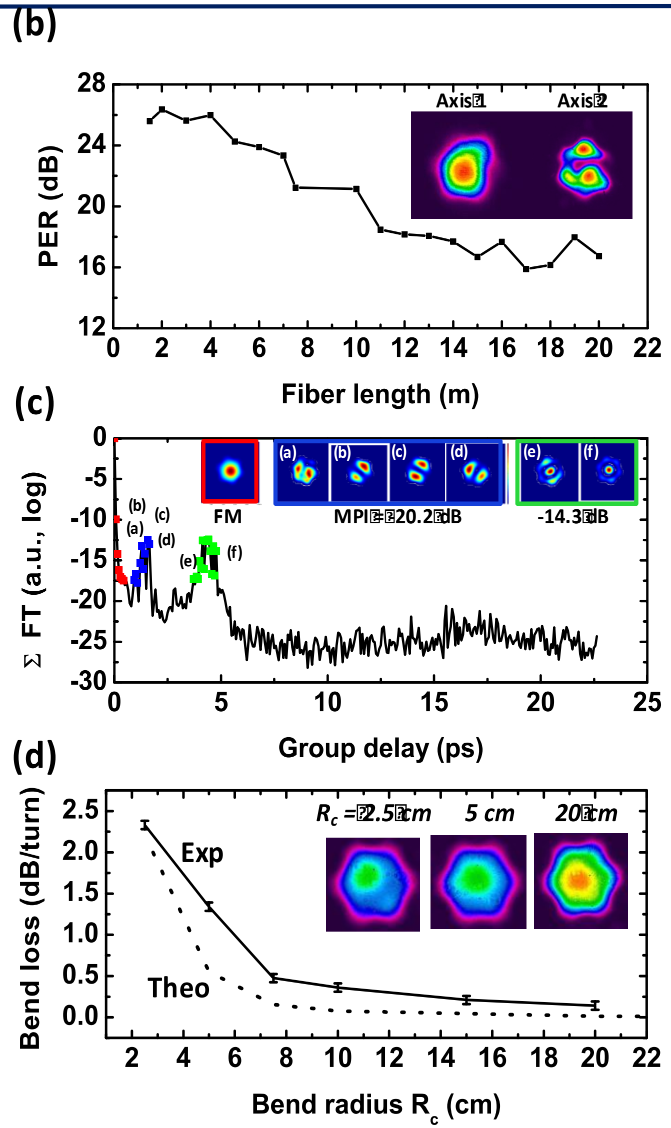
(c)

PER measurement (@ 1030nm) :

- **PER increase with fiber length**
- **Maximum PER : 27 dB for 2-3m fibre length**
- **Strong dependence on the injection cnds**
- **Degradation of the PER for L>4m at a rate of ~ 3 dB/5 m**

Loss:
~ 8 dB/km
(current world record)



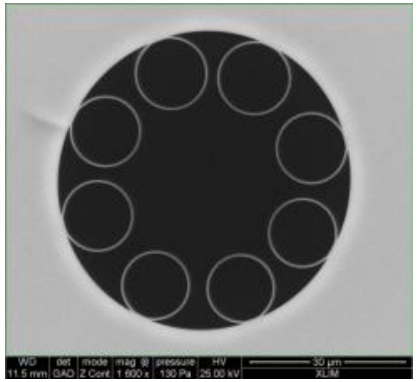


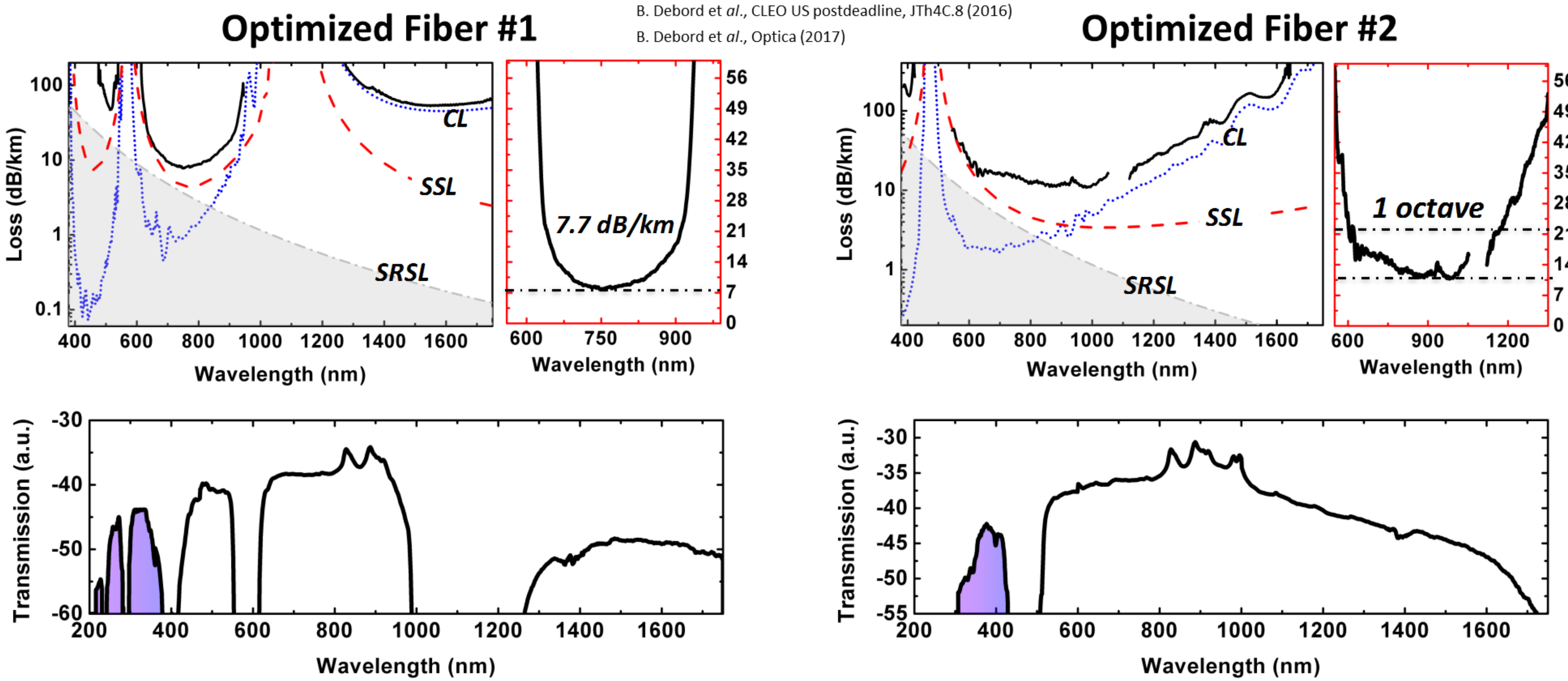
PER
up to 27dB
But
Dependence on coupling
Decrease with lengh

Modal content
20 dB extinction ratio
But
Dependence with length

bend loss of ~0.2dB/m
@ 15 cm radius,
But
Dependence on fibre motion

DESIGN #2: TUBULAR LATTICE



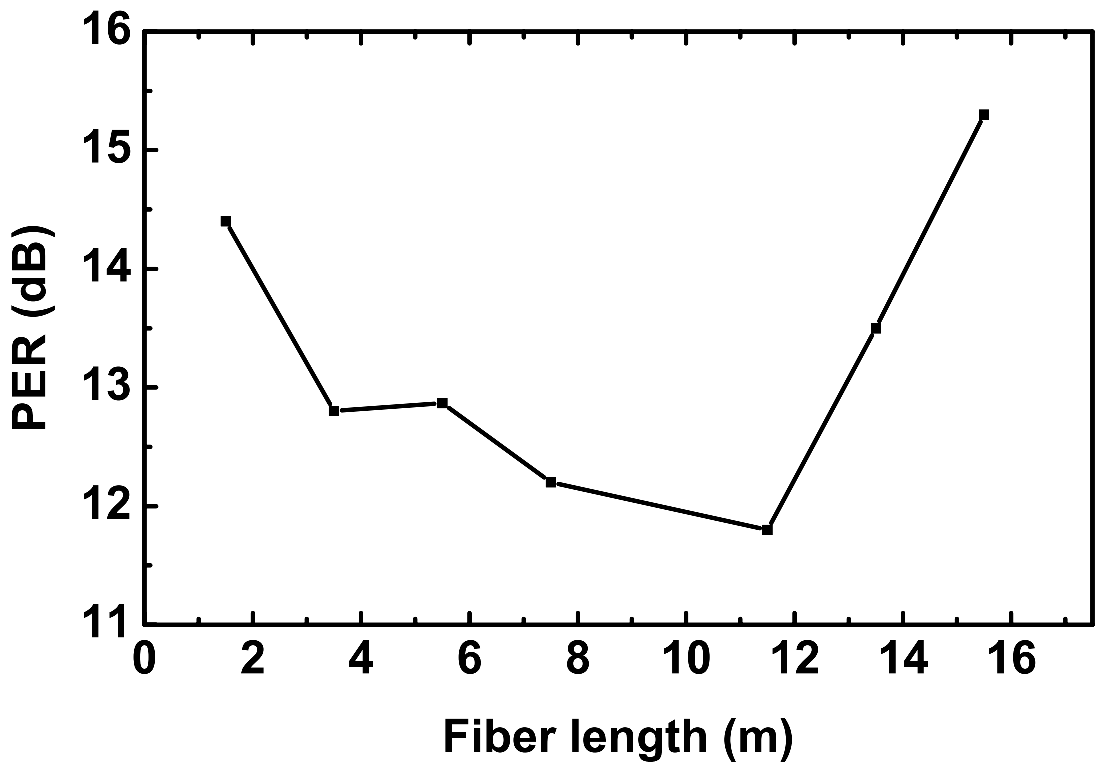


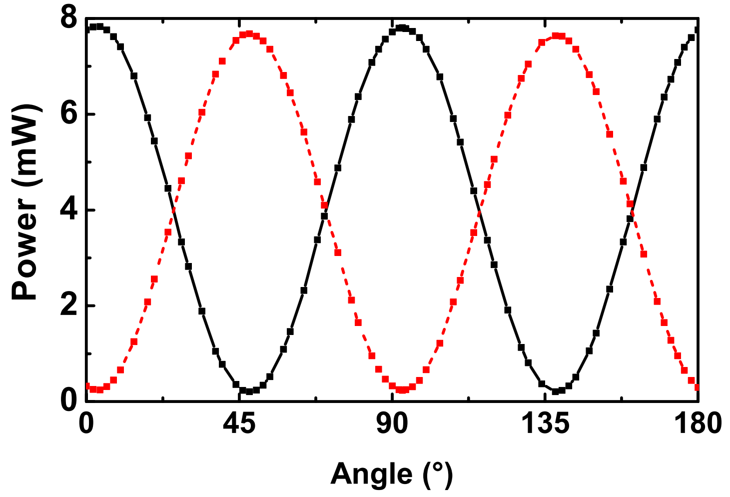
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687880

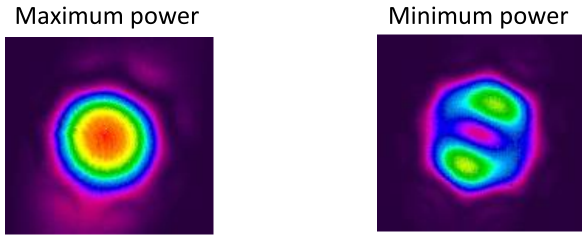
WP4	Photonic components for pre and post pulse conditioning

B. Debord et *al.*, submitted to Optica (2016)

2. IC HC-PCF with a single ring of tubular lattice cladding







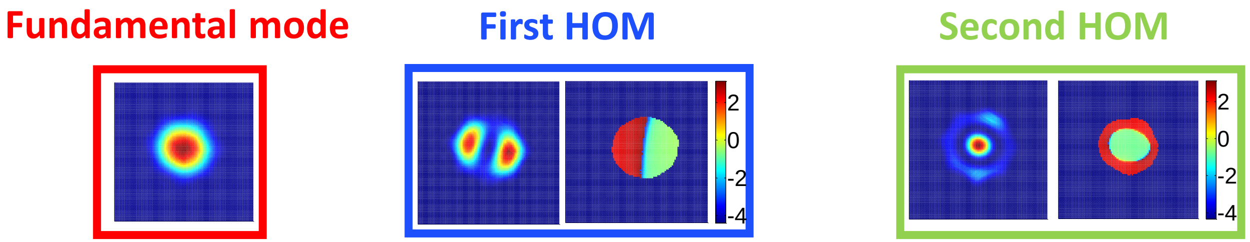
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687880

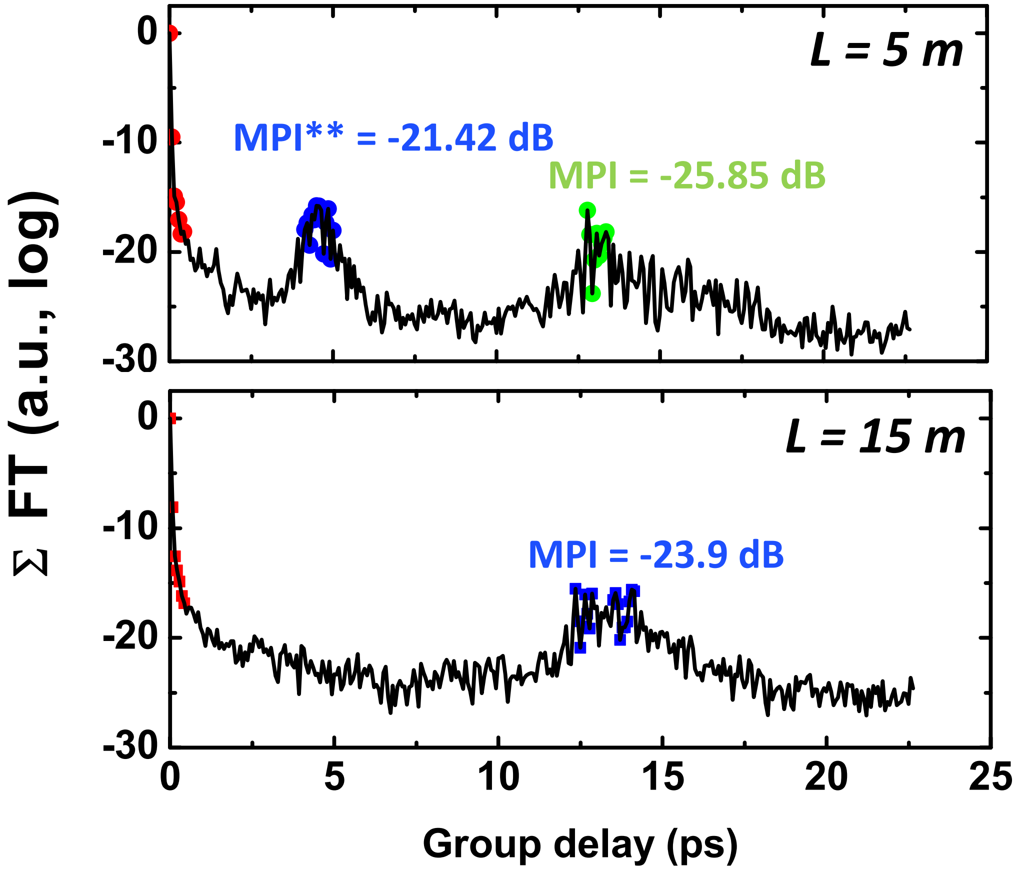
WP4	Photonic components for pre and post pulse conditioning

B. Debord et *al.*, submitted to Optica (2016)

2. IC HC-PCF with a single ring of tubular lattice cladding

2.2. S^2 measurement (collaboration)*



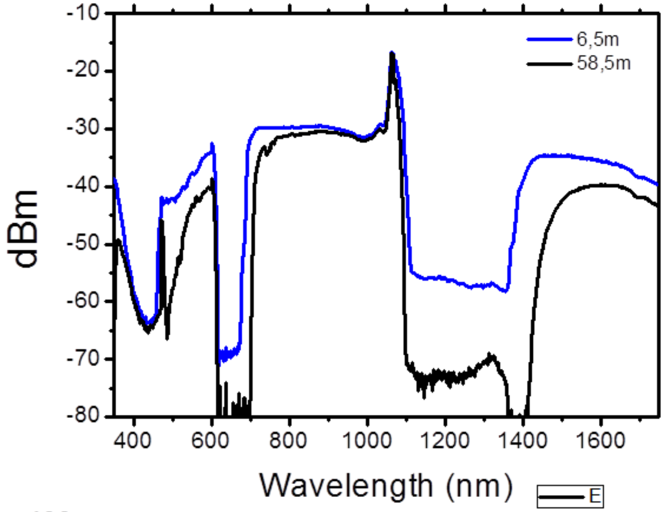


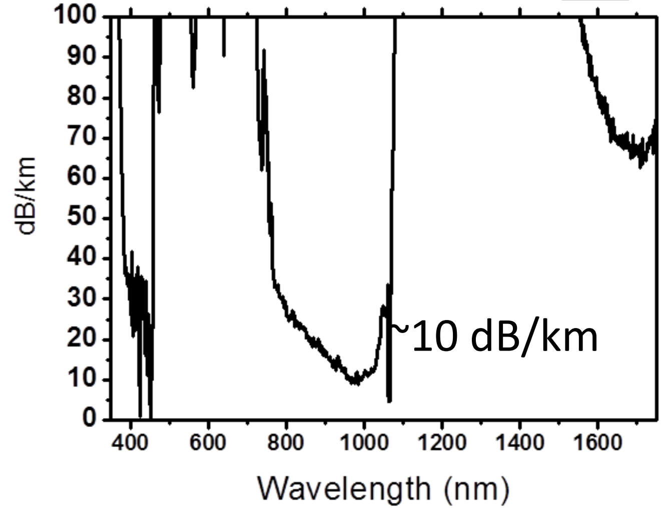
* R_b = 35 cm / λ: 1010-1070 nm (40 pm)

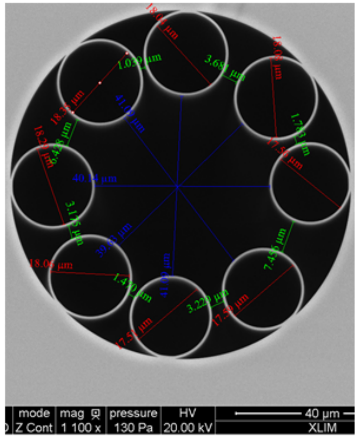
** MPI = Multi-path interference

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687880

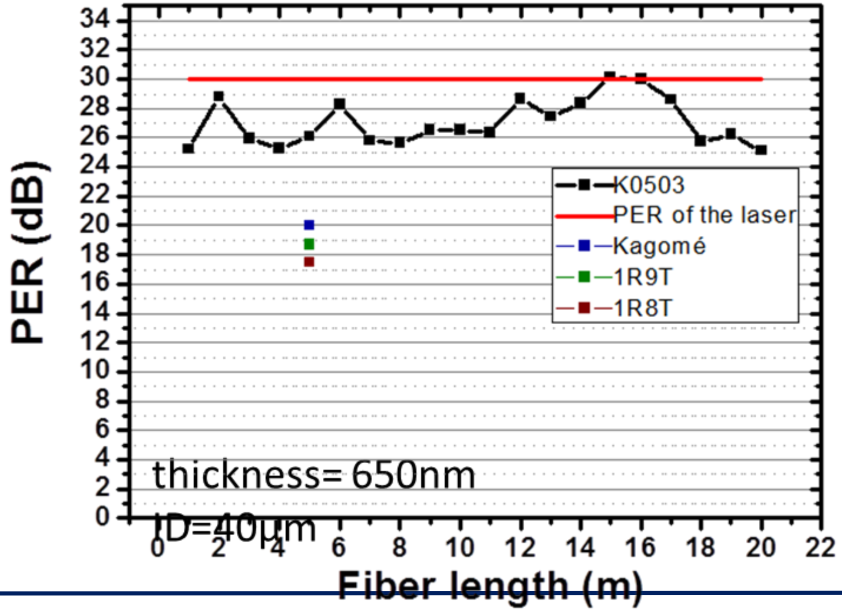
Latest Tubular HC-PCF







PER
up to 30dB
STABLE WITH LENGTH



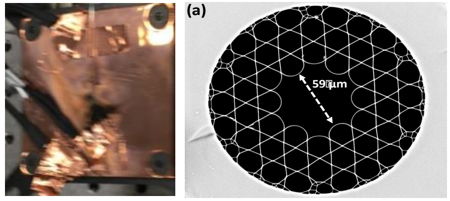
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687880

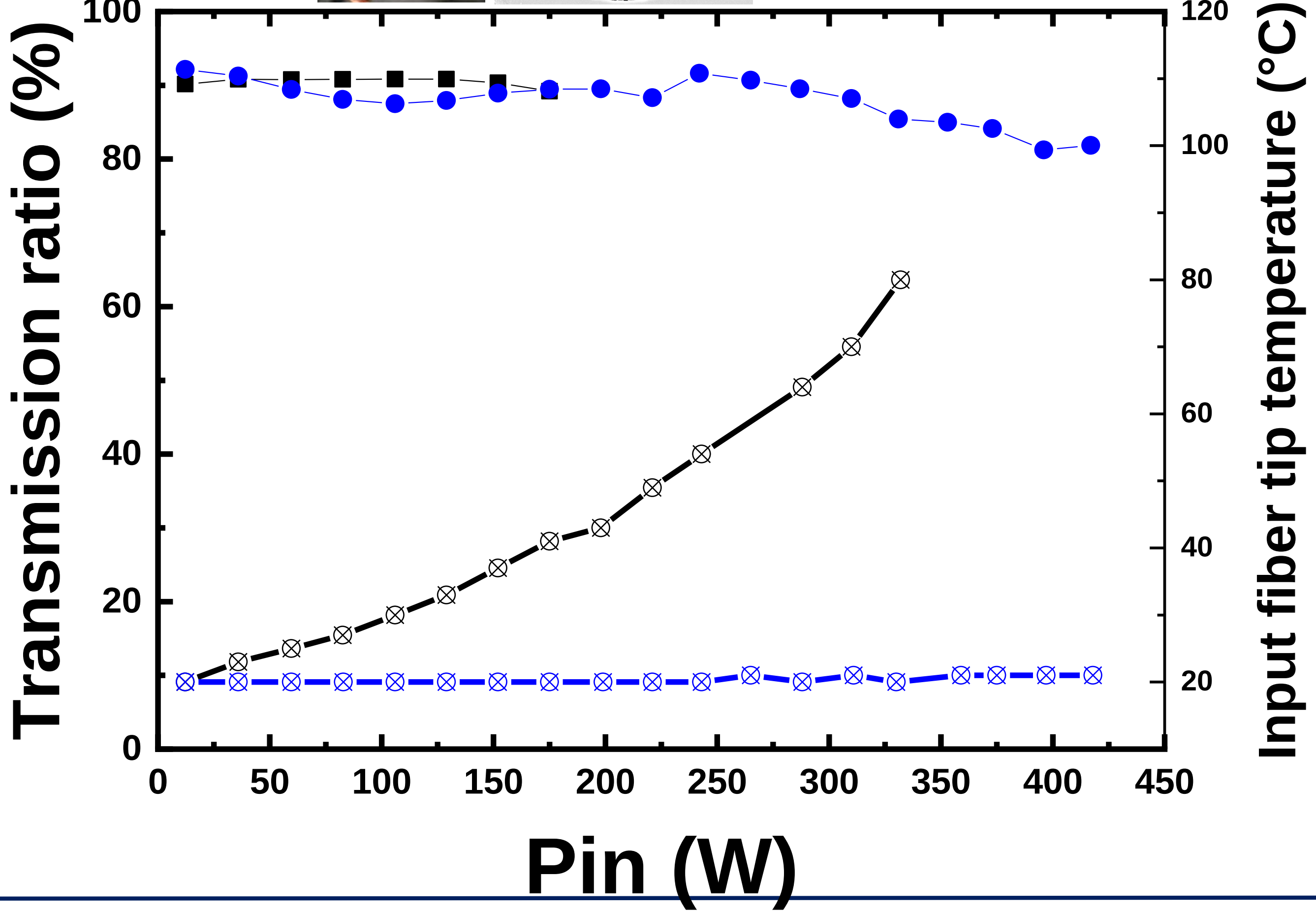
On going task

- Carry on the characterization of the different fibres:
  - S2 and PER with fibre length, motion, bend.
  - Transfer of « depolarization » upon stress/motion to power fluctuation.
- Reproducibility
  - How loss, PER, MFD, S2, bend loss change from draw to draw
- Technology transfer to GLOphotonics
  - Fibre fabrication and qualification by GLO

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 687880

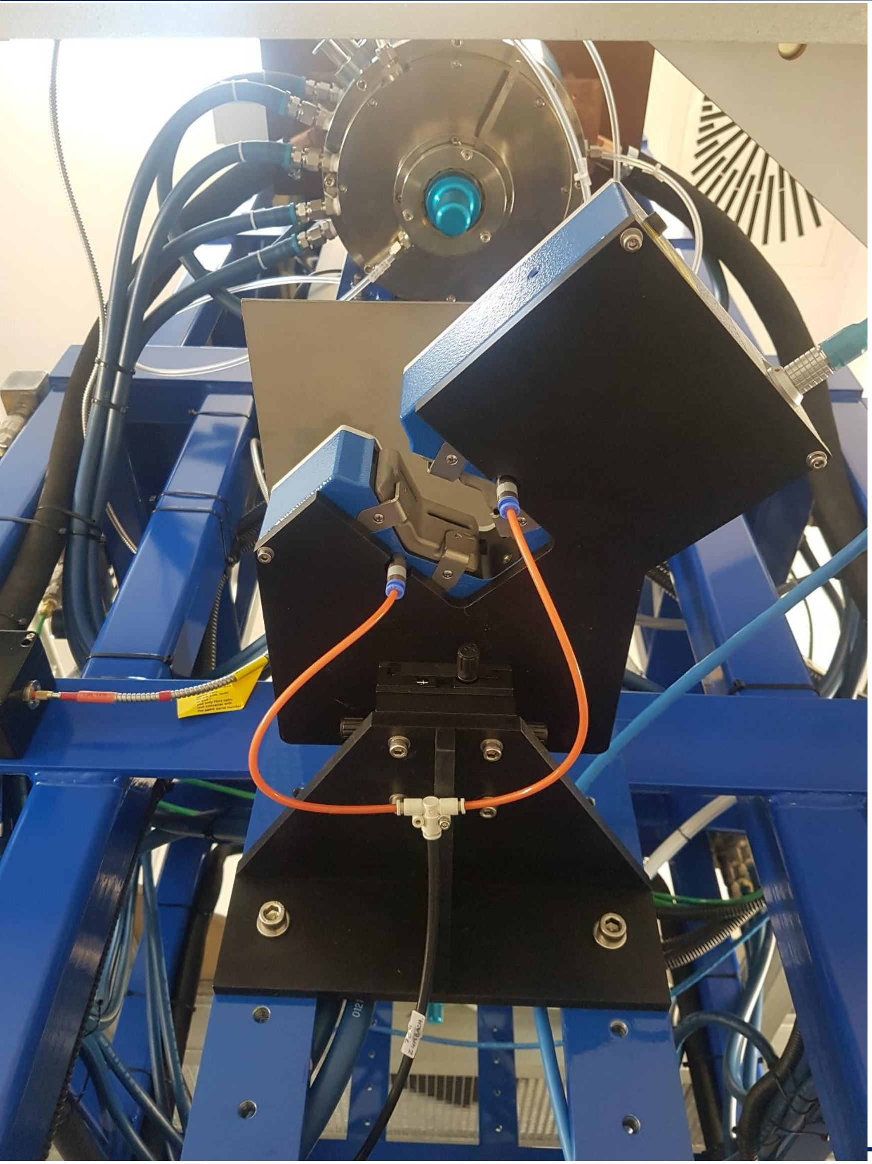
Fiber Power handling preliminary test (lab conditions)





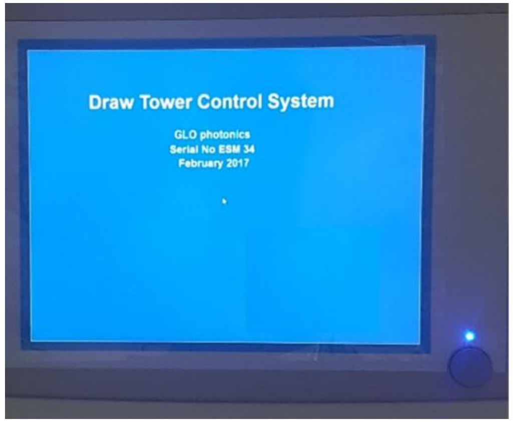
- Laser beam quality (M2 and jitter) dependent Performance
- Fiber Mounting dependent
- Guidance of 250-300 W range with no fiber cooling
- up to 400W (laser limit) demonstrated with water cooled fiber tip mount

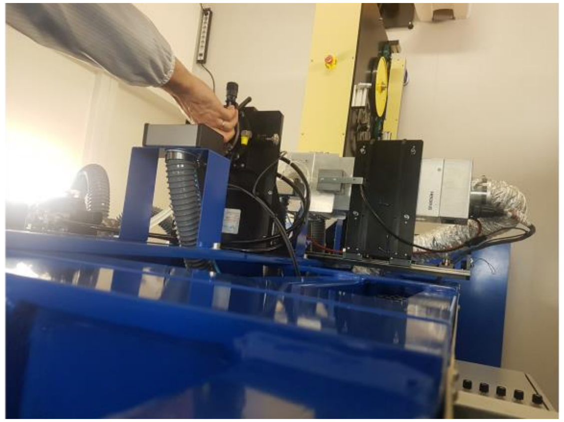
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687880

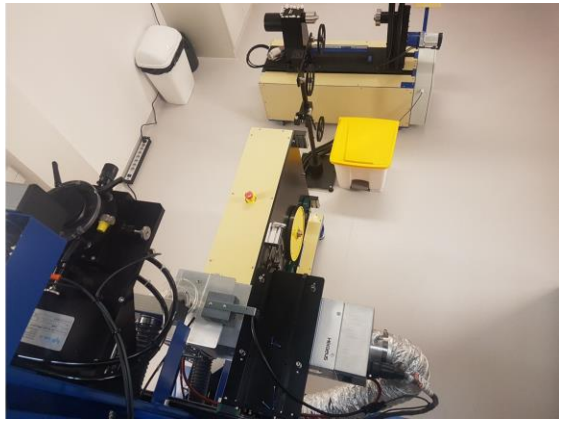


Installation of GLO new drawing facilities

- Prefrom drawing tower
- Fibre drawing tower
- Double layer coating capabilities
- Clean room and monitered ambient conditions







This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687880

Stacking and fibre & preforms pre-processing

- Clean room (ISO7)
- Stacking rigs
- Stocking
- Annealing systems

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687880

Stacking and fibre & preforms pre-processing

- Clean room (ISO7)
- Stacking rigs
- Stocking
- Annealing systems

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687880

First test runs & Tech transfer

- Cane draw tested/validated
- Std diameter fibre draw tested/validated
- Instrument calibration of IC HCPCF ongoing
- GPPMM fibres qualification to start on Sept. 2018

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687880

WP4 - Milestones

Milestone title	Task	Due date	Status
M4.1 First design, high efficient grating mirrors	T4.1	M03 – April 2016	Fulfilled
M4.2 PMC module for fiber beam delivery prototype #1	T4.4	M06 – July 2016	fulfilled
M4.3 1st generation grating mirror on large area, rectangular substrates fabricated	T 4.3	M08 – September 2016	fulfilled
M4.4 Fully optical characterization of grating mirror regarding diffraction efficiency and LIDT	T4.3	M12 – January 2017	Ongoing Diffraction efficiency: fulfilled LIDT: carried out
M4.5 PMC module for fiber beam delivery prototype #2 PMC module for fiber beam delivery prototype #3 PMC module for fiber beam delivery prototype #4	T4.5	M12 – January 2017 M18-July2017, M28-May 2018	Fulfilled. Ongoing qualification by AMP & USTUTT
M4.6 Design of HC-PCF with improved PER at 1µm (>20 dB)	T4.6	M12 – January 2017	Fulfilled with ongoing characterization and improvement
M4.7 End-capping definition and process design	T4.5	M15 – April 2017	Partial fulfillment
M4.8 Demonstration of optimized grating mirrors, 99% DE	T4.3	M18 – July 2017	
M4.9 End-capped output PMC module for beam delivery	T4.5	M18-July 2017	Partial fulfillment Fulfilled
M4.10 Qualification of end-capped output PMC module for beam delivery	T4.5	M24-January 2018	Fulfilled
M4.11 Fabrication of HC-PCF with improved PER at 1 um (>20 dB)	T4.6	M24-January 2018	Partial fulfillment Fulfilled
M4.12 End-capped input PMC module for beam delivery	T4.5	M26-March 2018	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687880

WP4 - Deliverables

Deliverable title	Due date	Status
D4.1 Report on simulation of pulse compression gratings with diffraction efficiency >=99% over large spectral bandwidth (5 – 10 nm) around 1030 nm	M04 – May 2016	Delivered
D4.2 Report on first fabrication of pulse compression grating with 98% diffraction energy on large area, rectangular substrate material	M12 – January 2017	delivered
D4.3 Report on fabrication and optical characterization of optimized gratings with single-pass diffraction efficiency >=99% over large spectral bandwidth (5 – 10 nm) around 1030 nm	M18 – July 2017	Delivered?
D4.4 (x2) Final version of PMC module for fiber beam delivery	M24-January 2018, M36-January 2019	BDS#1#2 delivrerd
D4.5 End-capped PMC module for beam delivery	M24-January 2018	Delivered
D4.6 HC-PCF with improved PER at 1µm (>20 dB)	M30-July 2018	NA
D4.7 PMC module based on HC-PCF with improved PER at 1µm (>20 dB)	M30-July 2018	NA

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687880

Progress	**GPPMM/XLIM**: 2 fibers designs have been explored and fabricated. Both designs show ultra-low transmission loss (<10 dB/km world record). The fibers show PER >20dB for length <10 m and in static configuration, thus fullfiling the project requirements. **GLO**: Several fiber beam delivery modules has been explored. A design with prelaligned injection head has been developed (BDS). The BDS version 2 has been qualified by AS. BDS with water cooling system has been designed. It is currently under test. Preliminary results show avg power handling up to 400 W. Test are on going and one version is under development to send to C4L. **AMO**: Lithography/etching process has been defined and developed. Several gratings has been fabricated. Gratings have been fabricated using both processes. Grating depth uniformity has been improved by a factor x2 over(size 70mmx50mm). Diffraction efficiency >99% over an area of 50mmx30mm. Demonstration of damage threshold increase up to 0.3J/cm2.
Delivrable updates	D4.1: Compressor grating design delivered (USTUT/AMO) D4.2: Lithography process for compression grating delivered (AMO) D4.3: Lithography process for compression grating delivered (AMO) D4.4: Two version of BDS have been developed (GLO). The final version scheduled for M36. D4.6: Two high PER fibers have designed and fabricated (GPPMM/XLIM) D4.7: BDS with high PER fibers scheduled for M30
Next	GPPMM/XLIM: to transfer the fabrication process to GLO. GLO: to fabricate under industrial grade hi-PER HCPCF GLO: To test the power handling of the BDS with water cooling GLO: To make a BDS with hi-PER fibers AMO: Demonstration of the achieved performances with larger areas. Enhancing further the LIDT.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 687880