WP4 Photonics Components for pre- and post- pulse conditioning

Fetah Benabid

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

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PHOTONICS PUBLIC PRIVATE PARTNERSHIP

Work Package 4 Overview

AIM: *Pulse compression & fibre beam-delivery*

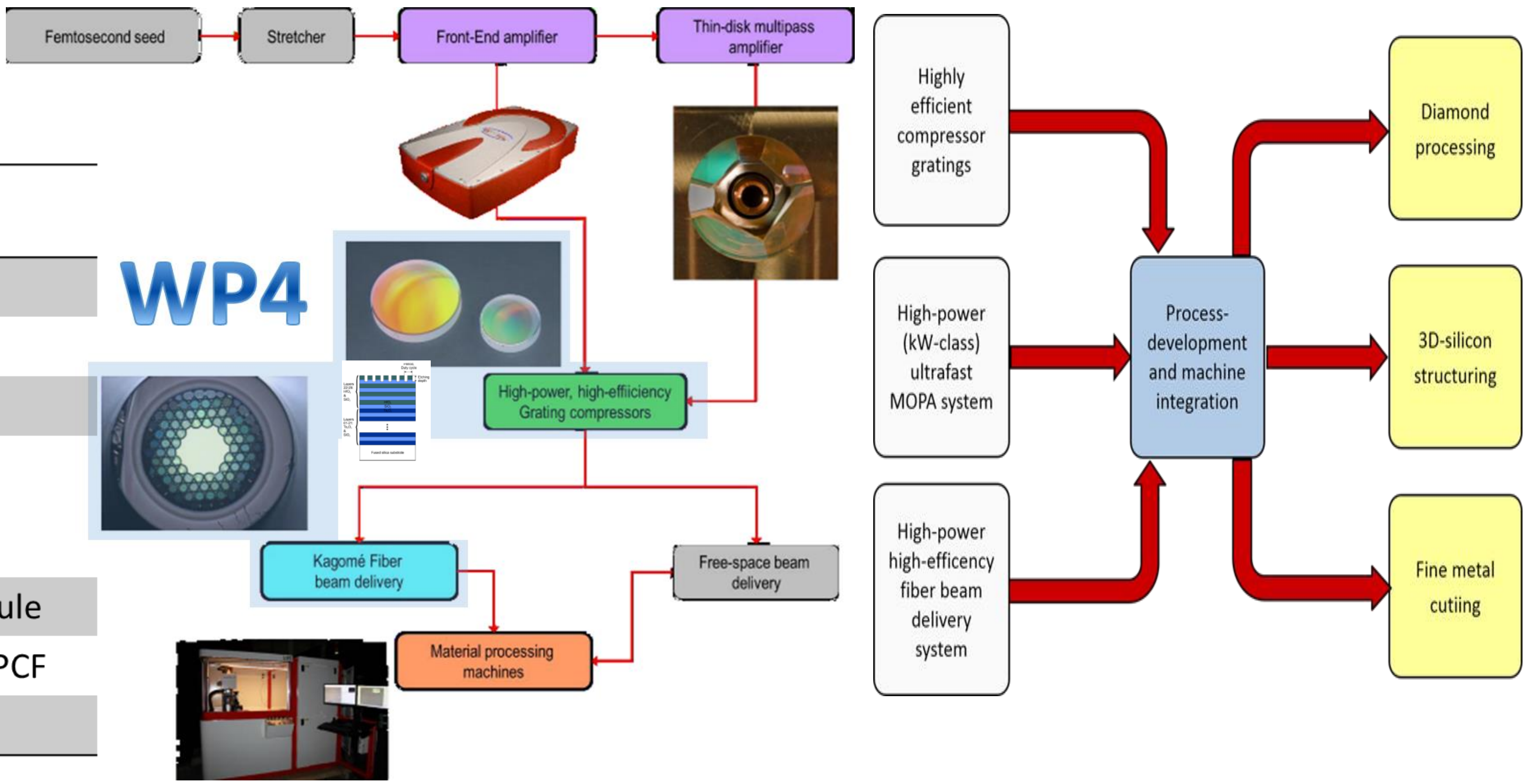
Partners & roles

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



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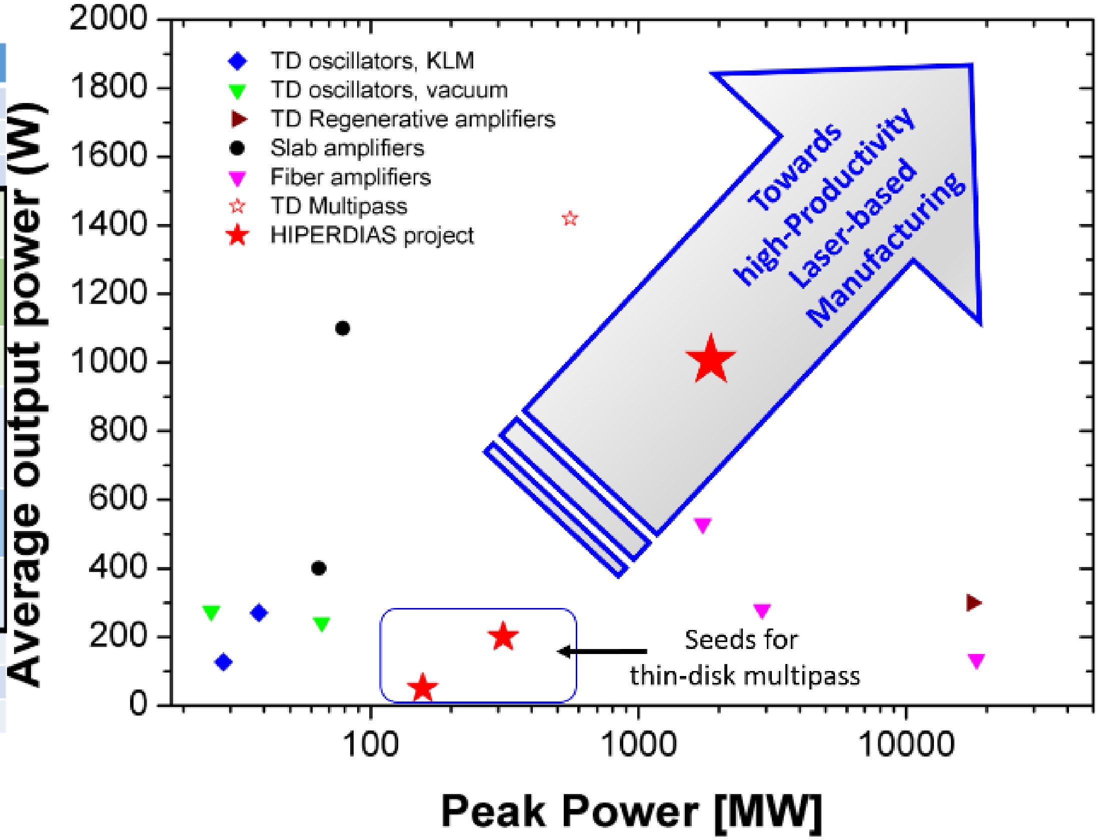
Work Package 4 Overview

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



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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)

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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
M4.10 Qualification of end-capped output PMC module for beam delivery	T4.5	M24-January 2018	
M4.11 Fabrication of HC-PCF with improved PER at 1 um (>20 dB)	T4.6	M24-January 2018	Partial fulfillment
M4.12 End-capped input PMC module for beam delivery	T4.5	M26-March 2018	

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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	
D4.4 (x2) Final version of PMC module for fiber beam delivery	M24-January 2018, M36-January 2019	
D4.5 End-capped PMC module for beam delivery	M24-January 2018	
D4.6 HC-PCF with improved PER at 1µm (>20 dB)	M30-July 2018	
D4.7 PMC module based on HC-PCF with improved PER at 1µm (>20 dB)	M30-July 2018	

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WP4 – Task 4.1: Design of grating compressors

- Overview, partners involved…

MARWAN TO COMPLETE

- Achievements…

- Deviations and proposed corrective actions…

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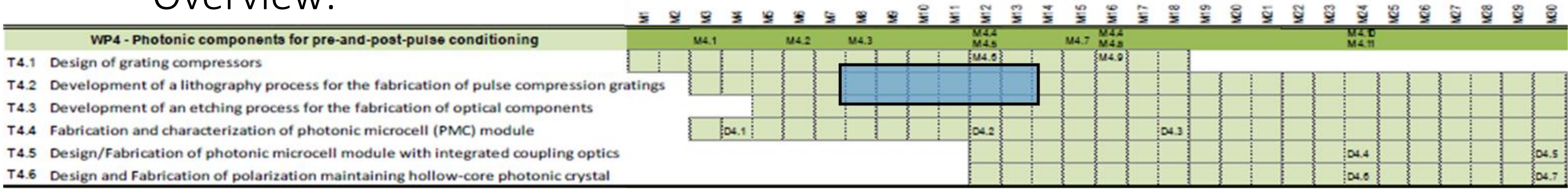
WP4 – Task 4.2: Development of an optimization of a lithography process for the fabrication of pulse compression gratings

- Partners: AMO, USTUTT
- Overview:



Photoresist coating of rectangular substrates:

- Integration of the Gyrset system in coating tool RCD8
- Basic suitability of the Gyrset technique
- Spin curves and investigation of layer homogeneity

Lithography process development for pulse compression gratings:

- Duty cycle adjustment (relevant lithography parameter)
- Process optimization
- First fabrication run + analysis DC homogeneity

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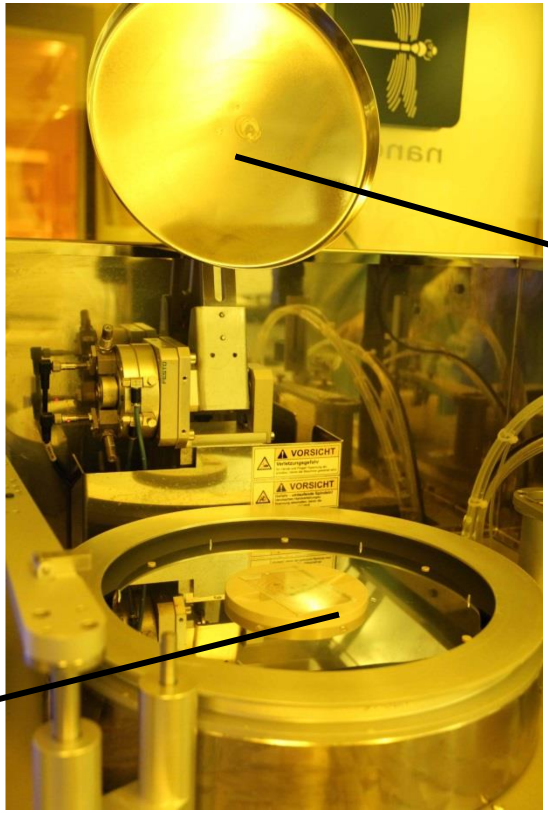
WP4 – Task 4.2: Development of an optimization of a lithography process for the fabrication of pulse compression gratings

<u>Photoresist coating of rectangular substrates:</u>

→ Integration of the Gyrset system in coating tool RCD8

• Ordered:	M05
• System delivered:	M08
• Installation + Integration:	M08
• Testing:	M08
• Mechanical problems, rework 2x service visits:	M10 + M12
• Start process development	M13

→ Not available for the first fabrication run



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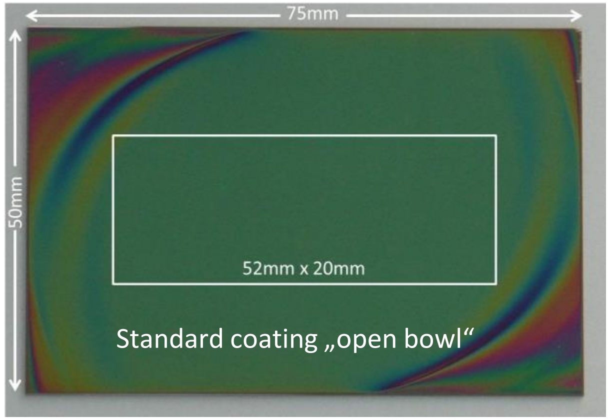
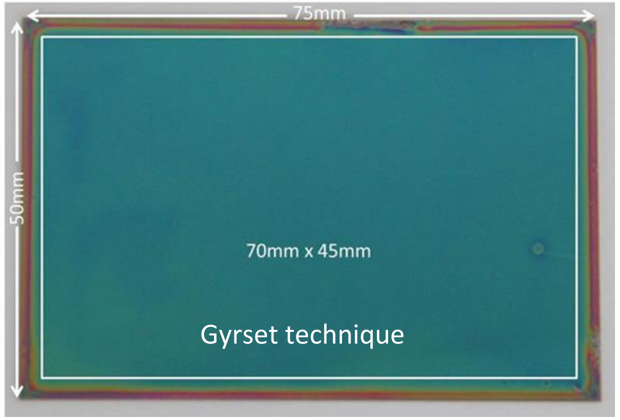
WP4 – Task 4.2: Development of an optimization of a lithography process for the fabrication of pulse compression gratings

Photoresist coating of rectangular substrates:

→ Basic suitability of the Gyrset technique





Substrate size	Aspect ratio	Open bowl field size	Gyrset field size	Area gain factor
70mm x 70mm	1:1	51mm x 51mm	62mm x 62mm	1,48
75mm x 50mm	1,5:1	52mm x 20mm	70mm x 45mm	3,03
70mm x 40mm	1,75:1	42mm x 16mm	65mm x 32mm	3,10

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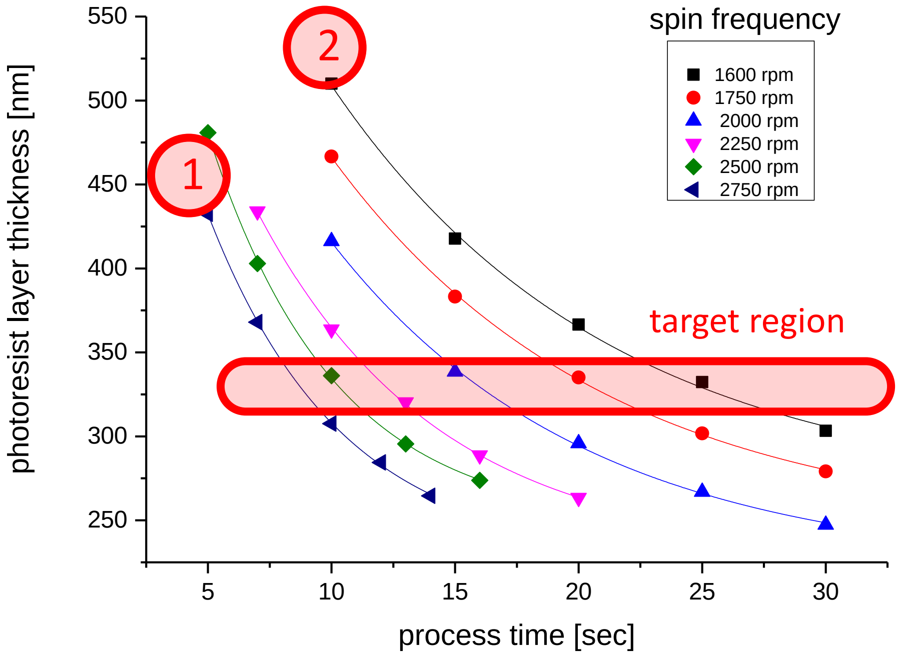
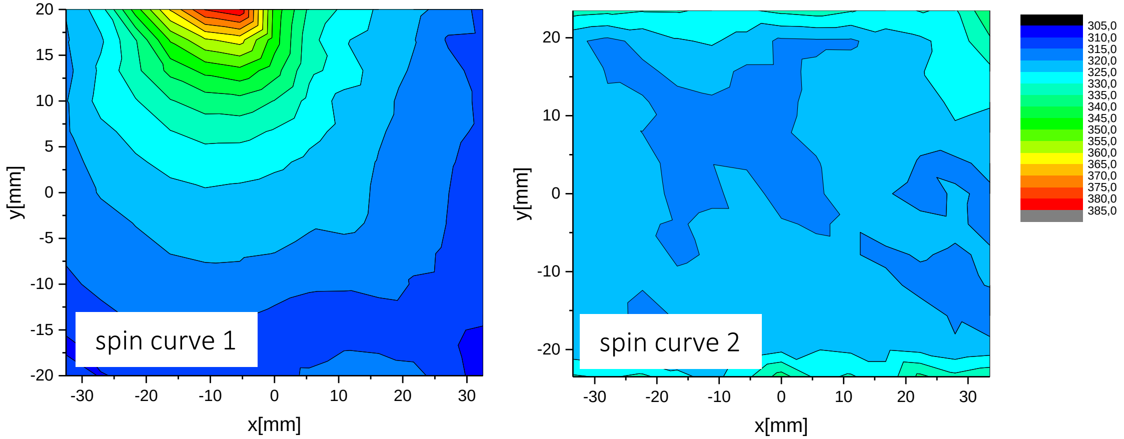
WP4 – Task 4.2: Development of an optimization of a lithography process for the fabrication of pulse compression gratings

<u>Photoresist coating of rectangular substrates:</u>

→ Spin curves



→ Investigation of layer homogeneity 13 x 13 points



Photoresist layer [nm]	Spin curve 1	Spin curve 2
Max	306,5	317,4
Min	384,5	339,4
Sigma	12,1	4,2

(measured with Philips PQ Ruby Ellipsometer)

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WP4 – Task 4.2: Development of an optimization of a lithography process for the fabrication of pulse compression gratings

Lithography process development

→ Duty cycle adjustment (relevant lithography parameter)

- Exposure time
  - 4 calibrated photodiodes at the substrate holder identify power drifts of the laser during the exposure
  - Software controlls the exposure time and keeps exposure dose constant

- Post exposure bake
  - Baking time and temperature effect the chemical amplification of the photoresist
  - Precision hotplate specially for semiconductor industry

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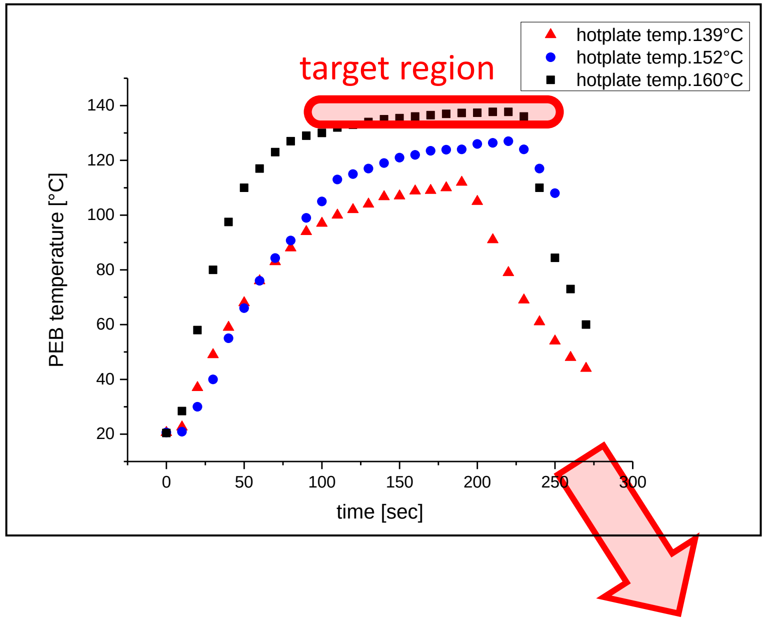
WP4 – Task 4.2: Development of an optimization of a lithography process for the fabrication of pulse compression gratings

Lithography process development

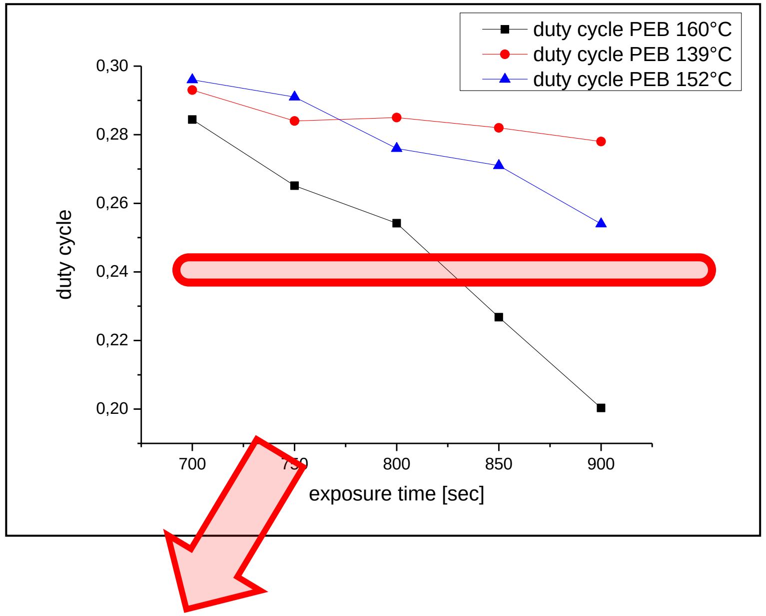
→ Process optimization

→ Post exposure bake



240sec, 160°C post exposure bake

→ Duty cycle vs. exposure time



825sec exposure time

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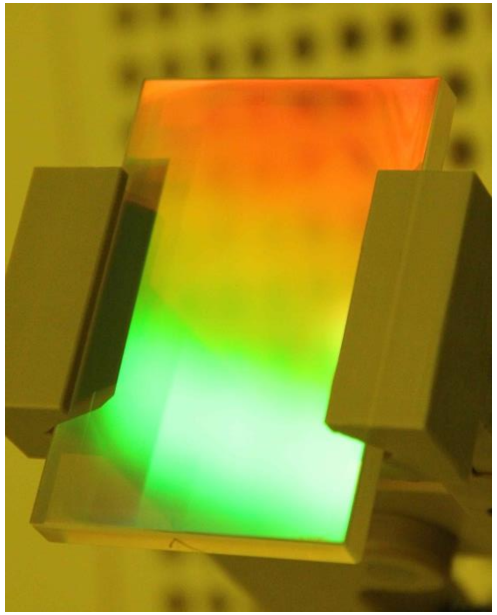
WP4 – Task 4.2: Development of an optimization of a lithography process for the fabrication of pulse compression gratings

Lithography process development

→ Fabrication Run1

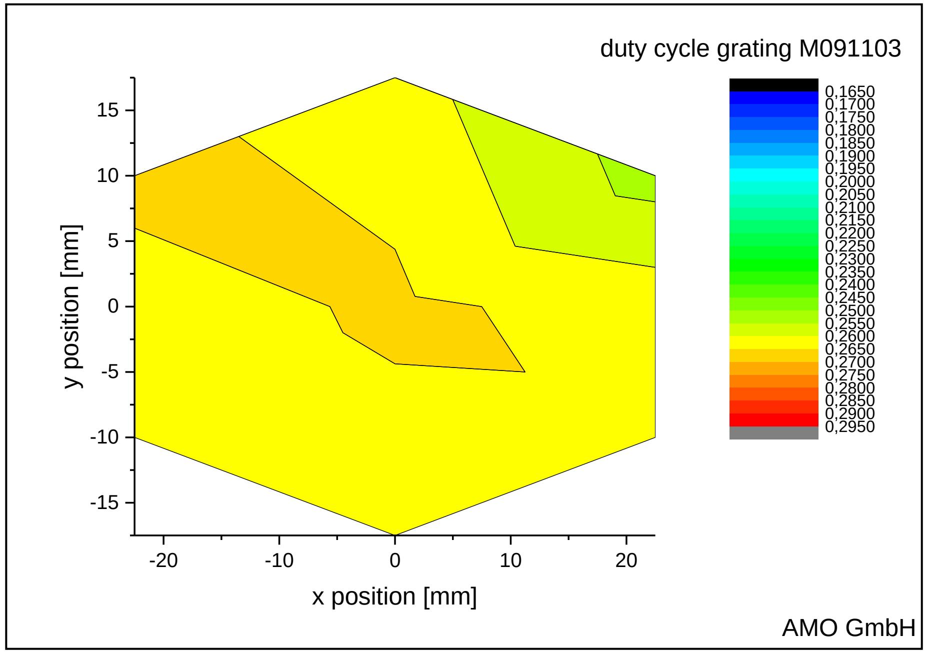
→ Analysis of the duty cycle from grating to grating

→ 2d scan of dc over the active area on 3x3 positions



Grating	Minimal	Maximal	Range
M081103	0,168	0,237	0,069
M081104	0,25	0,279	0,029
M081105	0,242	0,265	0,023
M081106	0,238	0,262	0,024
M091101	0,175	0,242	0,067
M091102	0,212	0,268	0,056
M091103	0,253	0,267	0,022
M091104	0,250	0,270	0,020
M091105	0,229	0,268	0,039
M091106	0,241	0,261	0,020

=13,4nm



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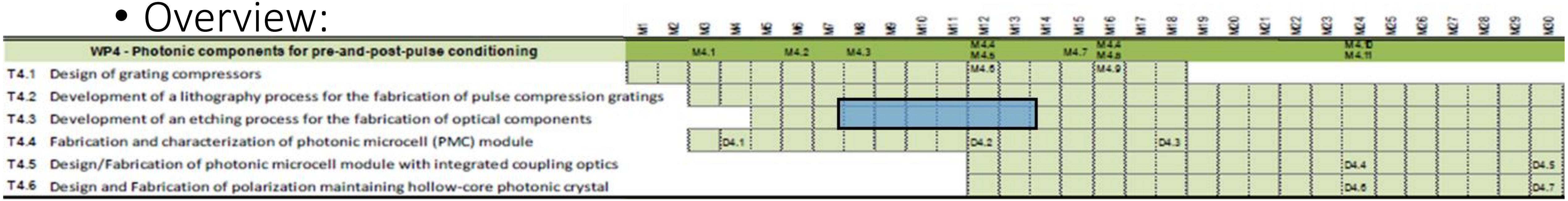
WP4 – Task 4.3: Development and optimization of an etching process for the fabrication of optical components

- Partners: AMO, USTUTT
- Overview:



- Etch process optimization for tantalum pentoxide top layer
- SEM investigation of the line profile
- Fabrication Run1 + analysis of etch depth homogeneity

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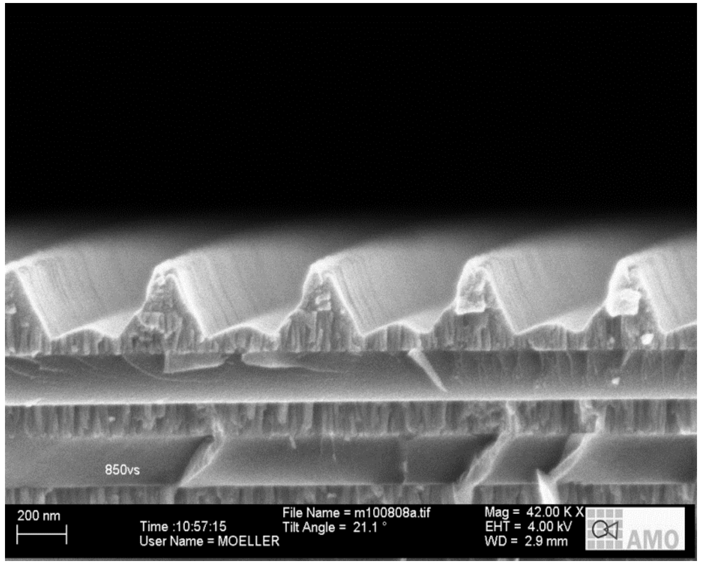
WP4 – Task 4.3: Development and optimization of an etching process for the fabrication of optical components

Etch process optimization for tantalum pentoxide top layer

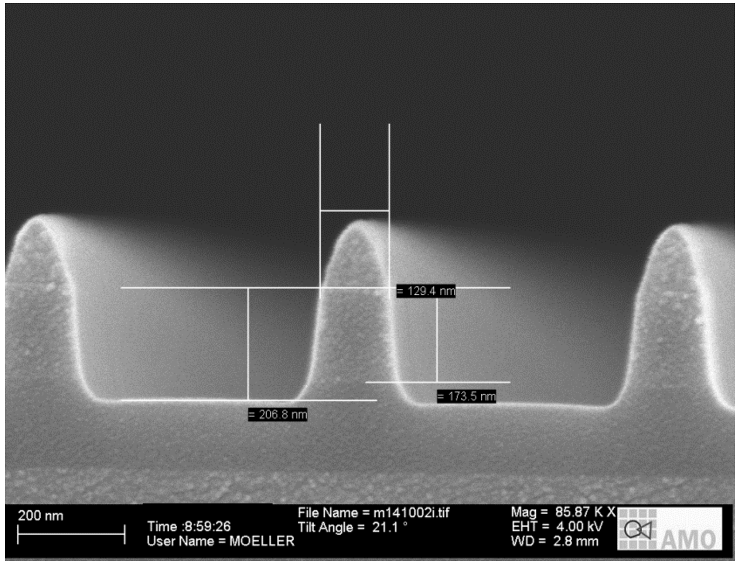
→ Variation of etch parameter

- ICP power
- Gas flow / gas mixture
- Chamber pressure
- Backside cooling

→ Influence of the backside cooling



15°C cooling



2°C cooling

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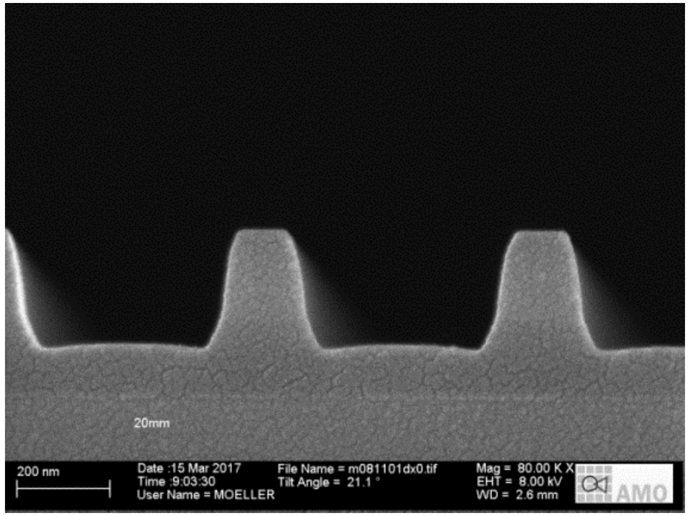
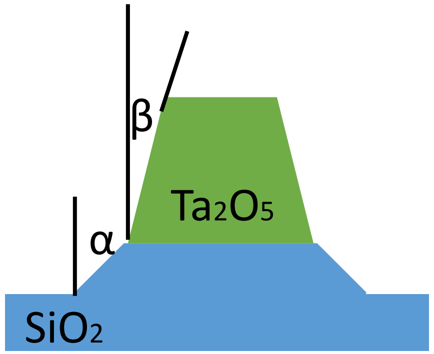
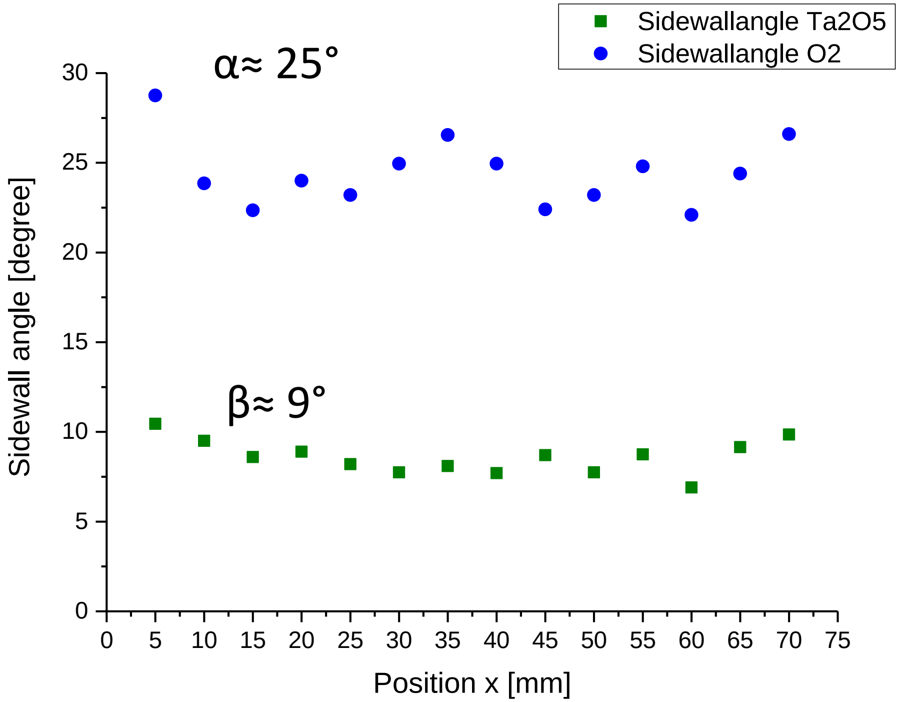
WP4 – Task 4.3: Development and optimization of an etching process for the fabrication of optical components

SEM investigation of the line profile



SEM PC grating





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WP4 – Task 4.3: Development and optimization of an etching process for the fabrication of optical components

Etch process development

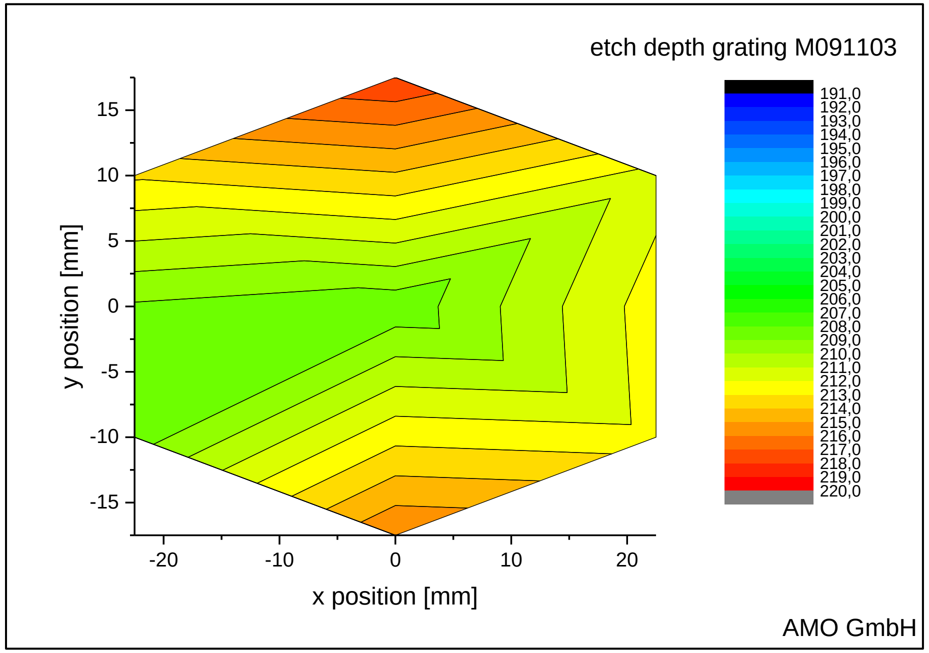
→ Fabrication Run1

→ Analysis of the etch depth homogeneity

→ 2d scan etch depth over the active area on 3x3 positions

Grating	Minimal [nm]	Maximal [nm]	Range [nm]
M081103	208,6	217,6	9,0
M081104	197,8	209,1	11,3
M081105	204,5	215,7	11,2
M081106	202,1	212,6	10,5
M091101	200,8	212,6	11,8
M091102	200,7	208,8	8,1
M091103	208,3	218,0	9,7
M091104	207,1	216,0	8,9
M091105	192,0	199,0	7,0
M091106	208,4	219,6	11,2

9,7nm



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Summary:

Task 4.2

Photoresist coating of rectangular substrates

- Gyrset system is installed and ready for use
- Photoresist layer thickness variation smaller 10%

Lithography process development

- Lithography parameter optimized
- Frist fabrication run carried out
- DC homogeneity better 0,022 (13,4nm)

Work in progress and planned work

- Further process optimization for the Gyrset system
- Integration in fabrication processs
- Second fabrication run

Task 4.3

Etch process development and optimization

- Pattern transfer for the first fabrication run carried out
- Sidewall angle 9° for Ta_2O_5 and 25° for SiO_2
- Etch depth homogeneity better 10nm

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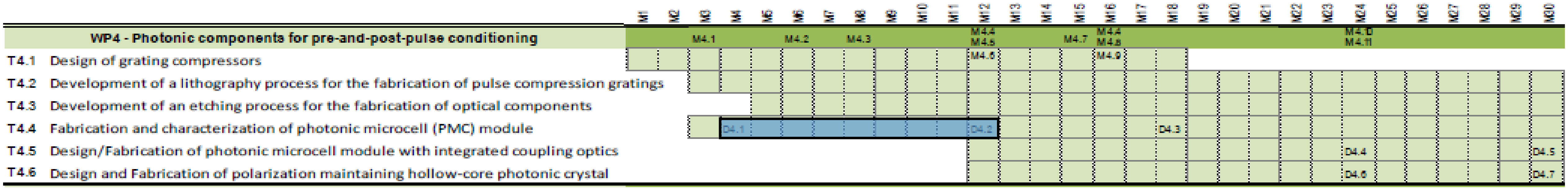
WP4 – Task 4.4: Fabrication and characterization of photonic microcell (PMC) module for fiber-delivery of ultra-short high power pulse

- Partners: GLO, XLIM, AMP



- Design review undertaken
- Prototype of α-prototype made
- Initial Characterization (USP Energy/duration handling, modal content)
- Prototype #2 been achieved and sent to partner AMP (Fab. 2017)

- Deviations and proposed corrective actions…
  - NA

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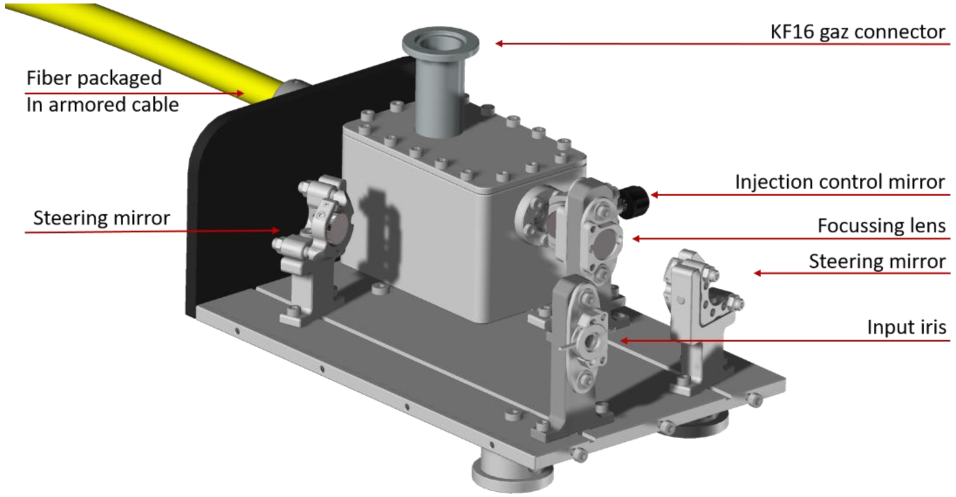
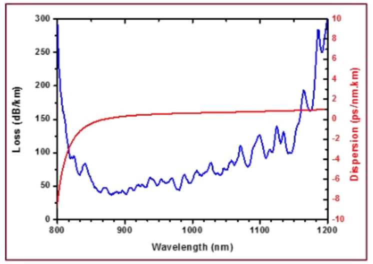
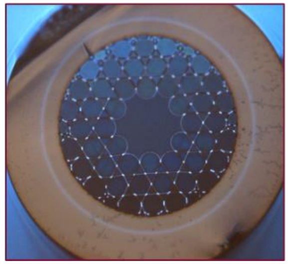
WP4 – Task 4.4: Fabrication and characterization of photonic microcell (PMC) module for fiber-delivery of ultra-short high power pulse

- Design and fabrication







Optical Properties	
Center Wavelength	1030 nm
Attenuation @ 1030 nm	50 dB/km ± 5
Dispersion @1030 nm	1 ps/nm/km ± 0.5
Transmission band** **Attenuation lower than 100 dB/km for the 900-1100nm	>300nm
Mode Field Diameter (1/e²)	39 µm ± 1
3 dB bend loss radius @1030 nm	5 cm ± 2

Physical Properties	
Core contour	Hypocycloid with negative curvature parameter *b=1***
Inner Core Diameter	57 µm ± 1
Outer Fiber Diameter	320 µm ± 1
Fiber Coating Layer	Primary polymer coating

3D design of the 2nd PMC beam delivery system incoupling module (left) and specification of the integrated fiber (center) and optical micrograph of the first assembled prototype (right).

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WP4 – Task 4.4: Fabrication and characterization of photonic microcell (PMC) module for fiber-delivery of ultra-short high power pulse

- Design and fabrication

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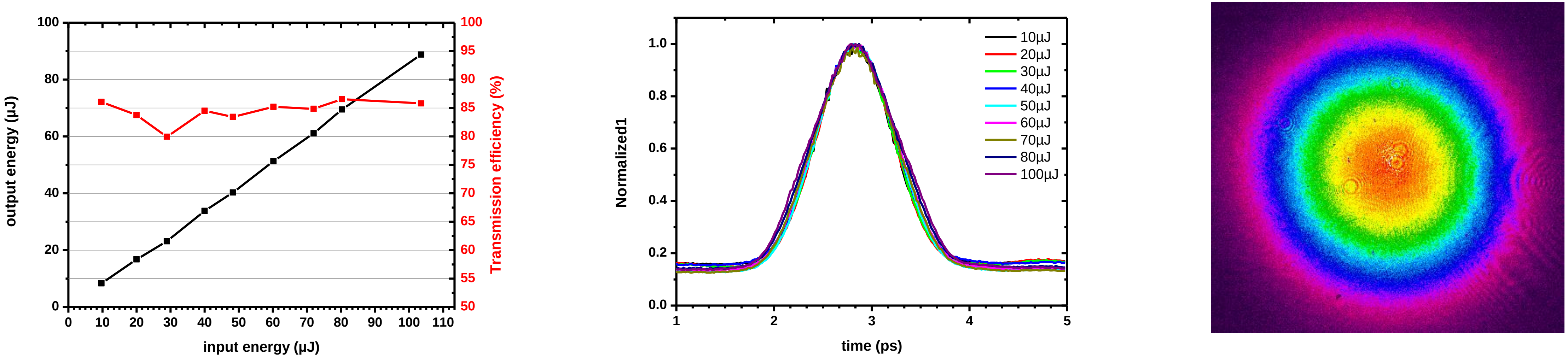
WP4 – Task 4.4: Fabrication and characterization of photonic microcell (PMC) module for fiber-delivery of ultra-short high power pulse

- Energy handling, pulse fidelity and beam quality



BDS transmission efficiency (Left), BDS output AC trace (middle), BDS output beam profil (right)

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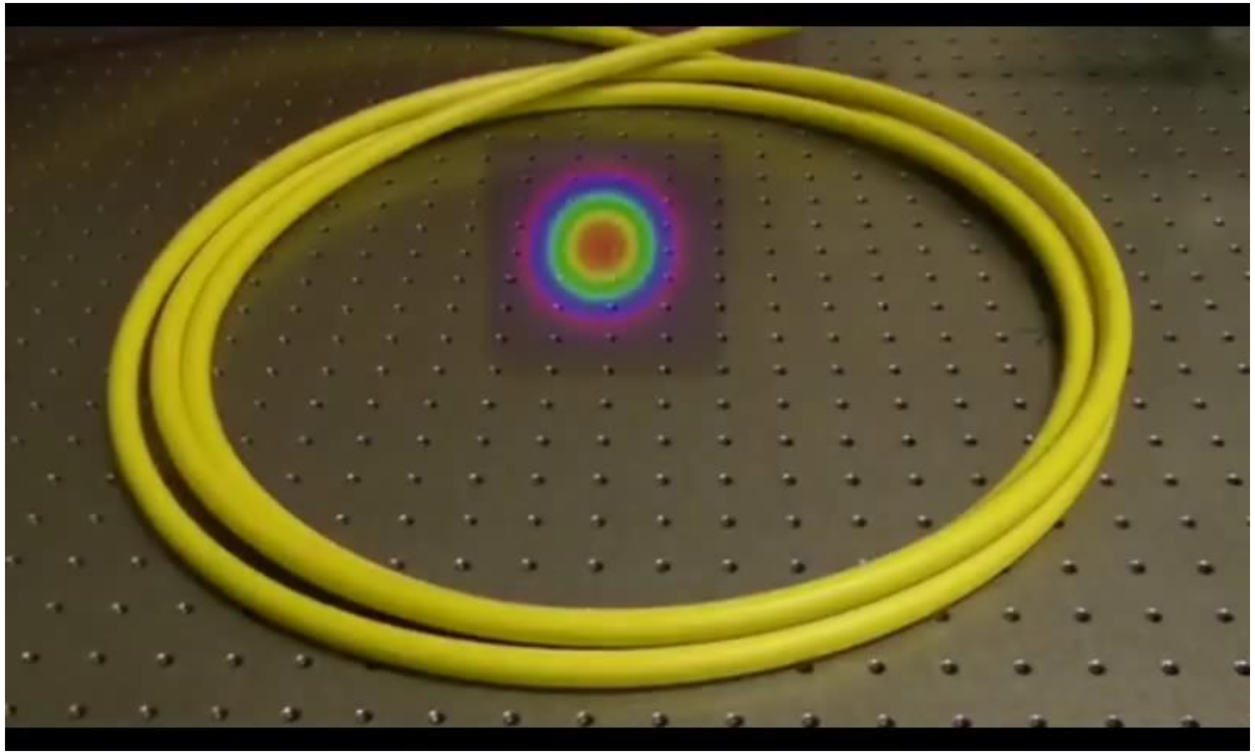
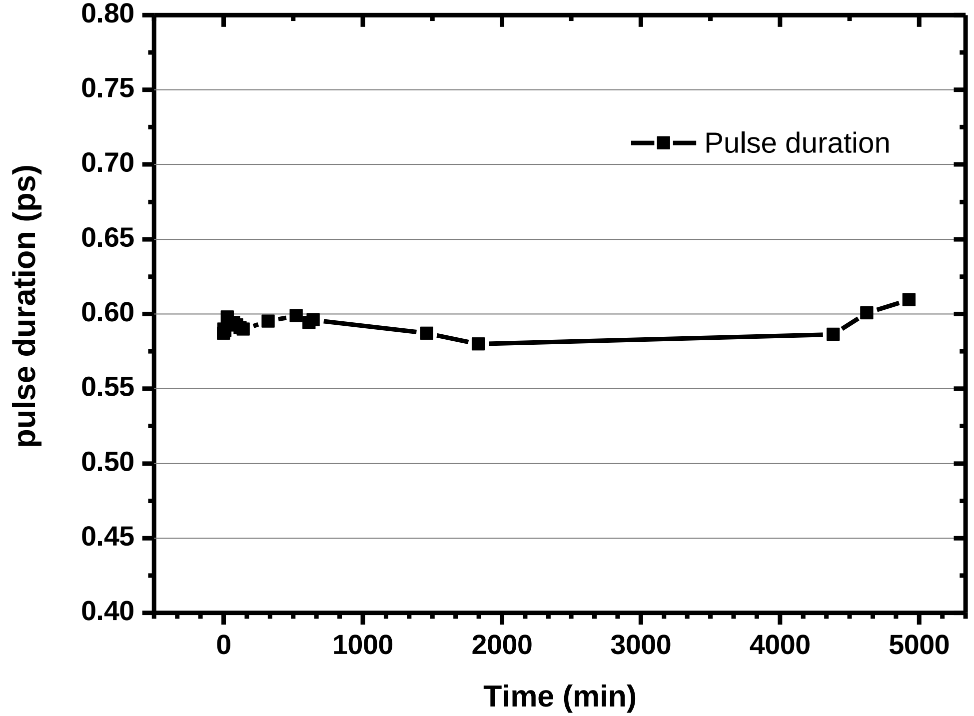
WP4 – Task 4.4: Fabrication and characterization of photonic microcell (PMC) module for fiber-delivery of ultra-short high power pulse

- Mode quality with movement, pulse stability with sealed BDS





Evolution of sealed (no pumping) BDS output pulse duration at 100μJ input energy with time

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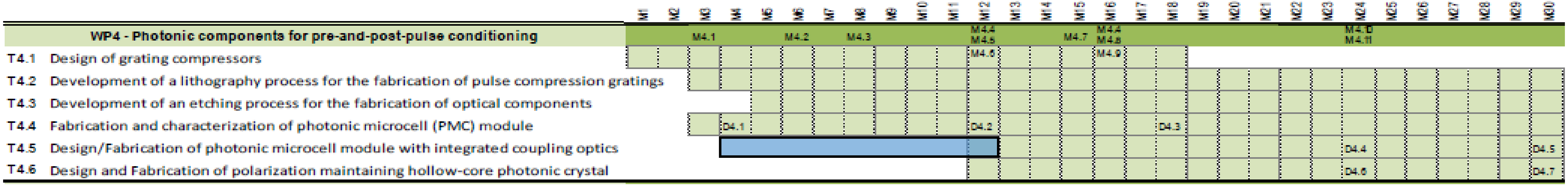
WP4 – Task 4.5: Design and fabrication of photonic microcell module with integrated coupling optics for fiber-delivery and interface with system integrator

- Partners: GLO, XLIM, AMP



- Achievements…
  - End-termination design undertaken
  - End-user requirement definition ongoing
- Deviations and proposed corrective actions…
  - NA

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

- Overview, XLIM, GLO

		M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20	M21	M22	M23	M24	M25	M26	M27	M28	M29	M30
	WP4 - Photonic components for pre-and-post-pulse conditioning			M4.1			M4.2		M4.3				M4.4 M4.5			M4.7	M4.4 M4.8								M4.10 M4.11						
T4.1	Design of grating compressors												M4.6				M4.9														
T4.2	Development of a lithography process for the fabrication of pulse compression gratings																														
T4.3	Development of an etching process for the fabrication of optical components																														
T4.4	Fabrication and characterization of photonic microcell (PMC) module				D4.1								D4.2						D4.3												
T4.5	Design/Fabrication of photonic microcell module with integrated coupling optics																								D4.4						D4.5
T4.6	Design and Fabrication of polarization maintaining hollow-core photonic crystal																								D4.6						D4.7

- Achievements…
  - Two fiber designs explored (transmission loss: new records)
  - Kagome fiber parameters with PER=21 dB

- Deviations and proposed corrective actions…
  - NA

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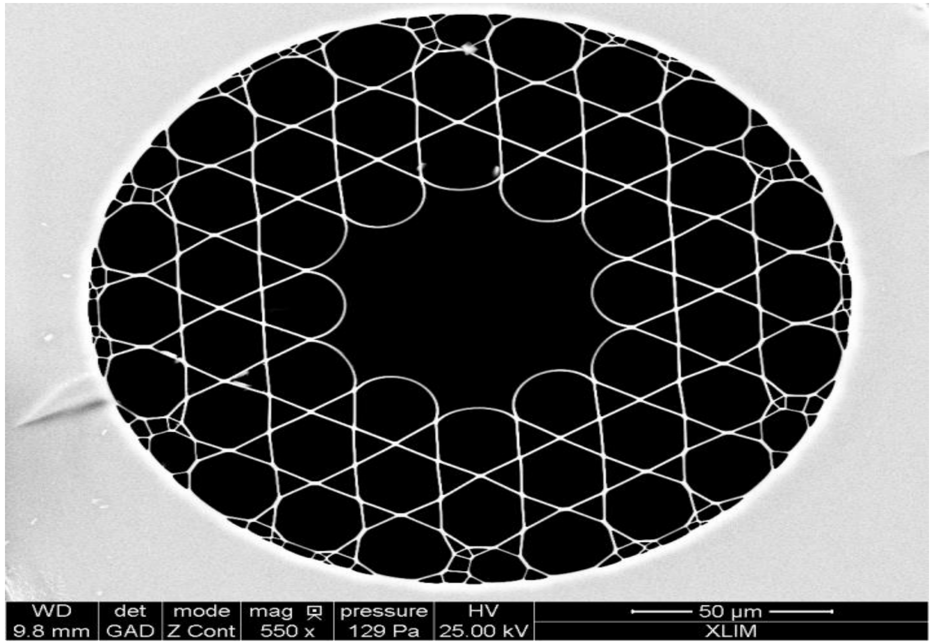
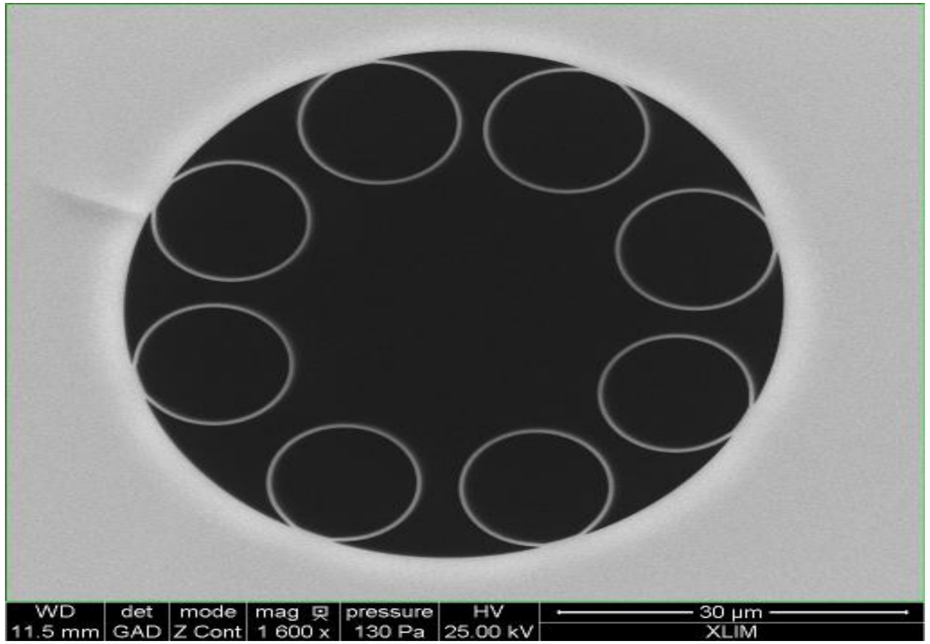
KAGOME LATTICE

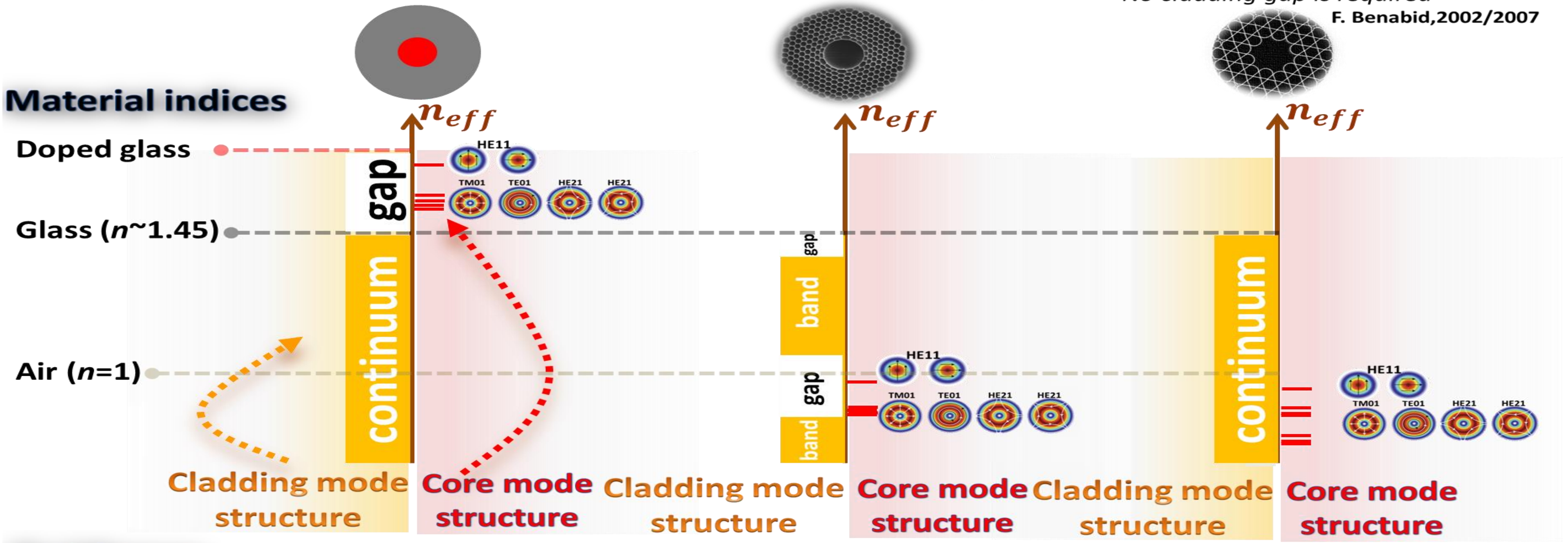


TUBULAR AMORPHOUS LATTICE



FIBER OPTICS: THREE GUIDANCE MECHANISMS

	TIR guiding fiber	PBG guiding fiber	IC guiding fiber
	Higher index core material required	*Guiding below the material lowest index cut-off* P. Russell,1995	*Guiding below the material lowest index cut-off* *No cladding gap is required* F. Benabid,2002/2007



Guidance principle

$\{|\varphi_{clad}\rangle\} = \emptyset$ $\{|\varphi_{clad}\rangle\} = \emptyset$

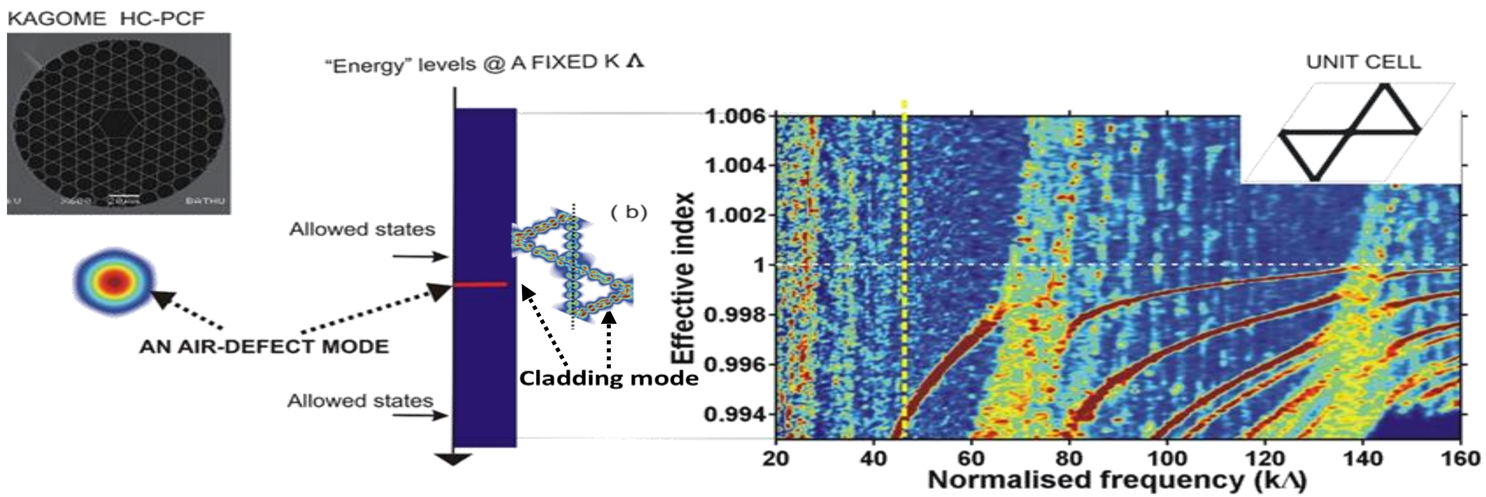
No cladding mode is required for core guidance

$\langle\varphi_{clad}|\Delta n^2|\varphi_{core}\rangle \rightarrow 0$

cladding & core modes coexiste with no strongly interacting

Ultra-short Pulse laser handling	Nano-Joule High nonlinearity High dispersion	Micro-Joule Moderate nonlineariry Moderalte dispersion	Milli-Joule Low nonlineariry Low dispersion

INHIBITED COUPLING MECHANISM



Cladding structure :
continuum of cladding modes

↓

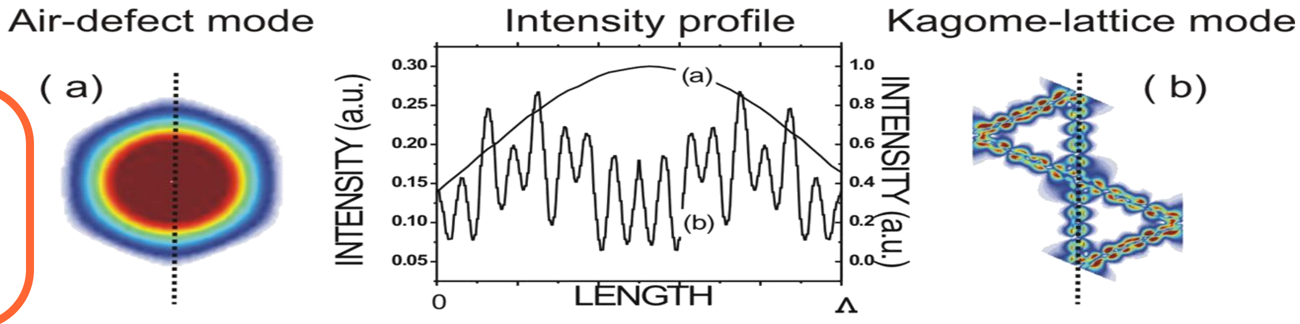
No band gap

$$\langle \varphi_{clad} | \Delta n^2 | \varphi_{core} \rangle \propto \frac{OD}{g(m)}$$

OD: core mode optical overlap with the silica
g(m): a positive & increasing function with m

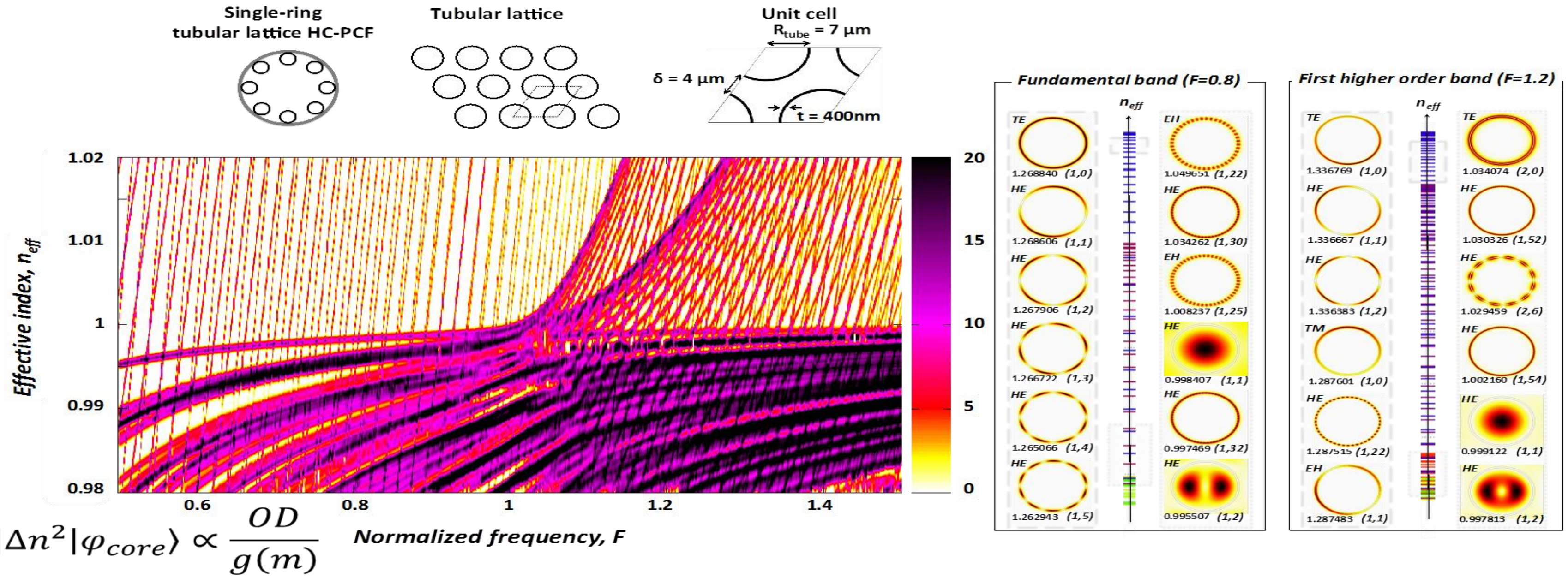
Large azimuthal number mismatch m:

- **Fast oscillation in struts**
- **Slow oscillation in core**



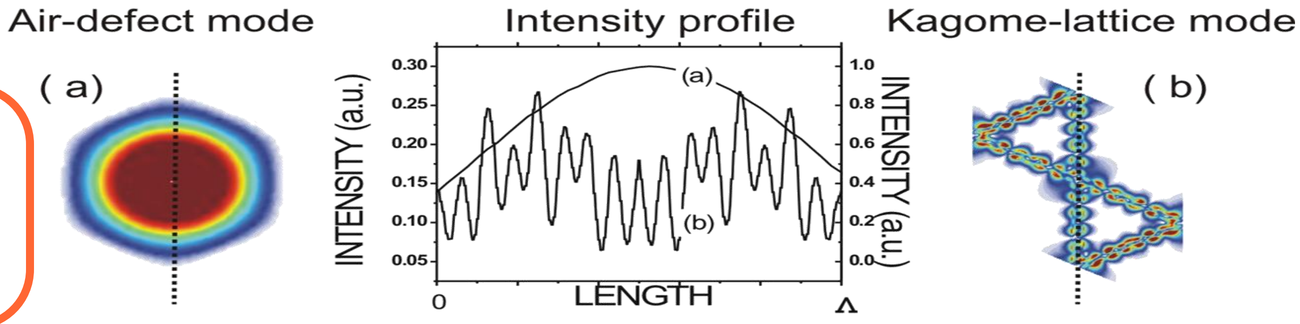
<u>Guiding rules for IC:</u>
A cladding structure that favourably support high "azimuthal-number"-modes. E.G. a cladding with elongated <u>thin</u> strings with <u>no bends or corners</u> and made of a dielectric material.

INHIBITED COUPLING MECHANISM



$$\langle \varphi_{clad} | \Delta n^2 | \varphi_{core} \rangle \propto \frac{OD}{g(m)}$$

OD: core mode optical overlap with the silica
g(m): a positive & increasing function with *m*

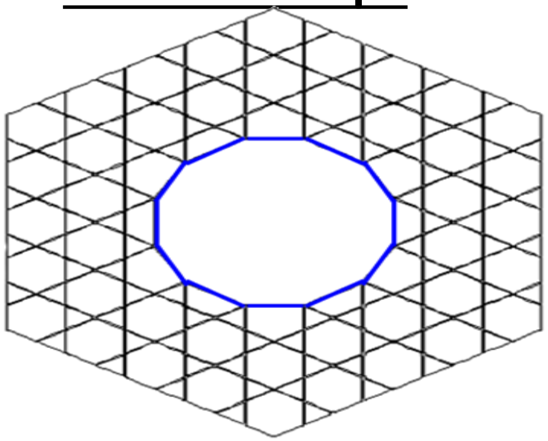


Large azimuthal number mismatch m:
- **Fast oscillation in struts**
- **Slow oscillation in core**

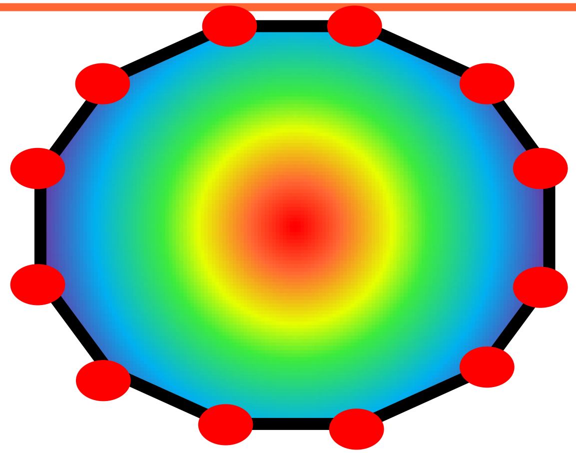
Guiding rules for IC:

A cladding structure that favourably support high “azimuthal-number”-modes. E.G. a cladding with elongated thin strings with no bends or corners and made of a dielectric material.

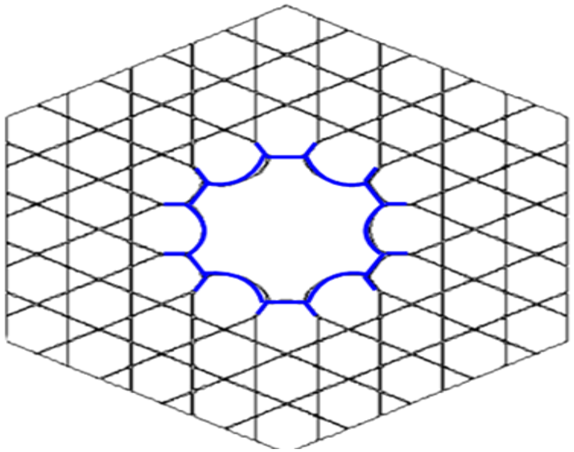
Standard shape

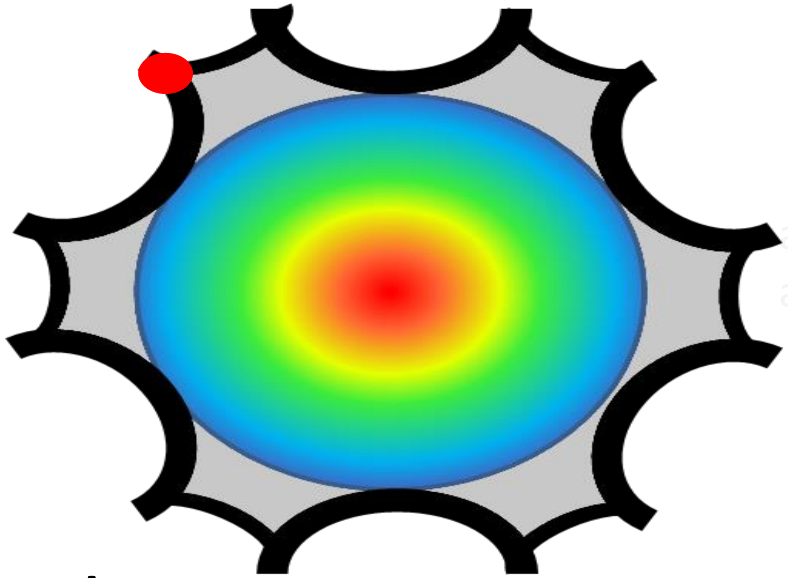


Nodes: leakage source



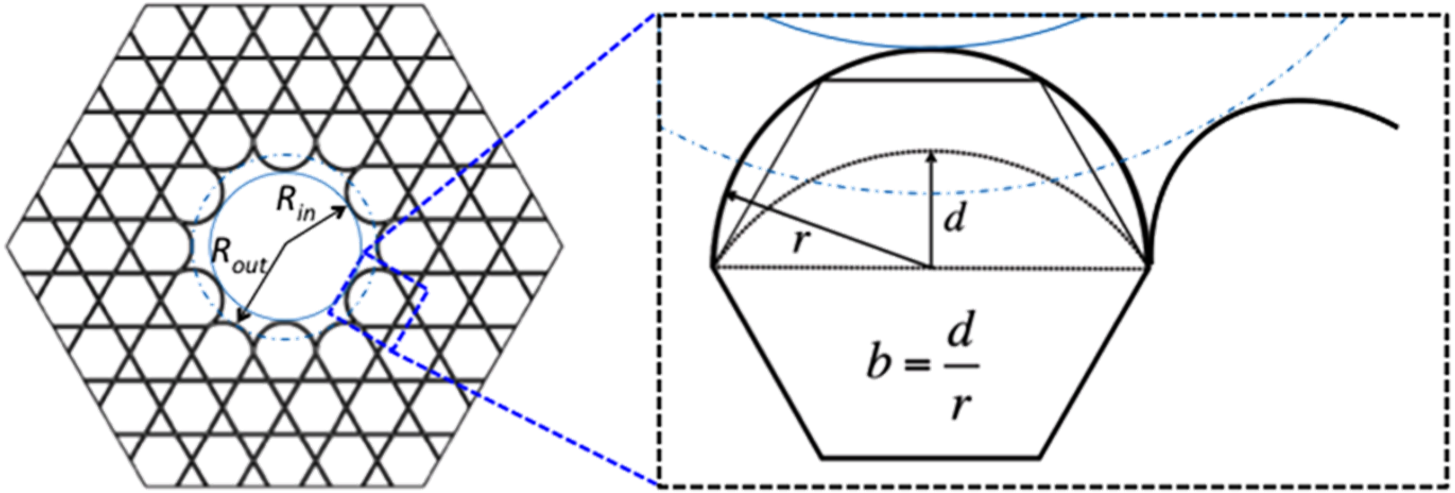
Hypocycloid shape



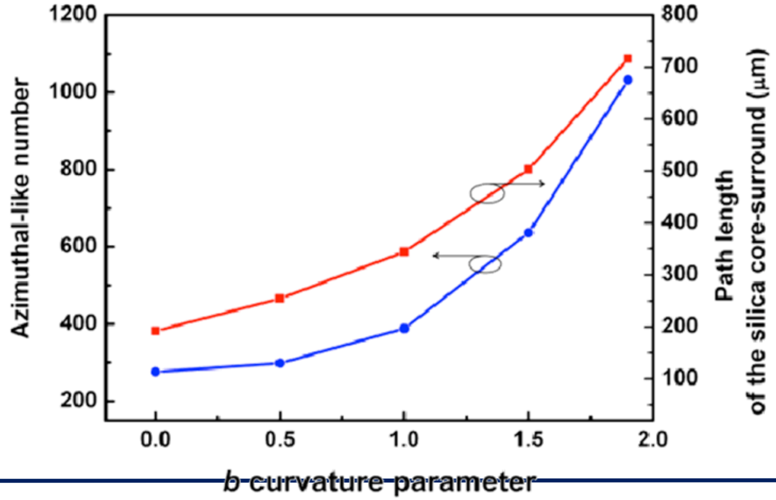


Nodes are "pushed away" from the core guided mode
Lower coupling

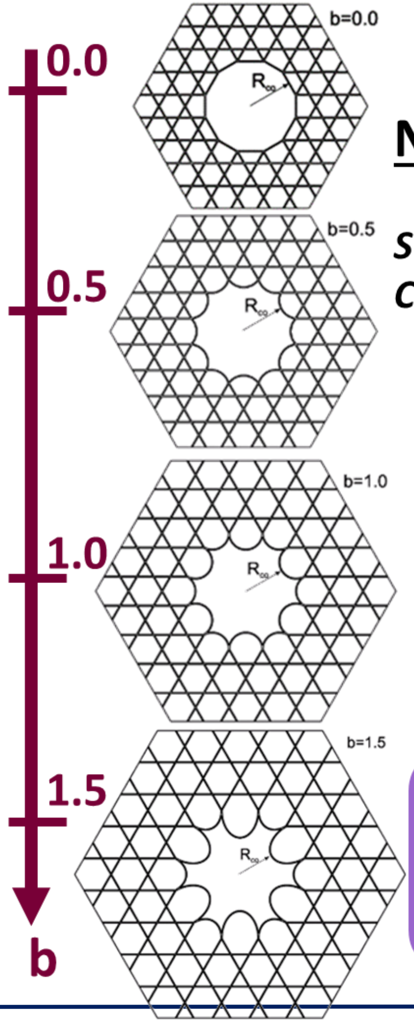
b PARAMETER : MISMATCH ENHANCEMENT



- Increase the strut path
- Increase of the struts azimuthal number
- Decrease of the spatial overlap between core and silica nodes
- Better light confinement



b PARAMETER

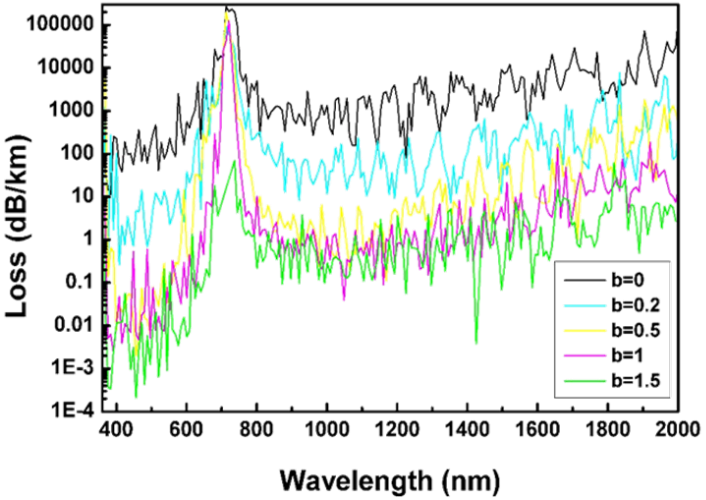


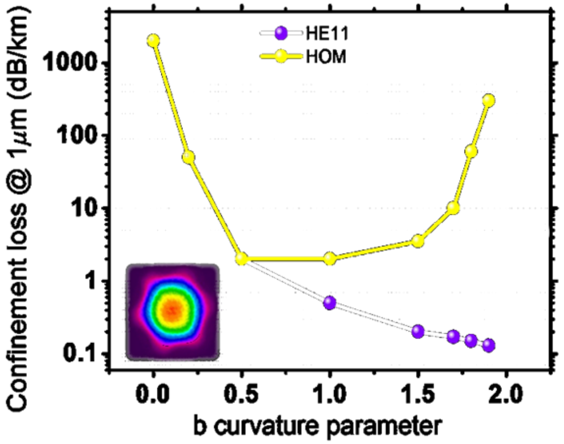
Numerical study

Struts thickness **: 1400 nm**
Core size**: 60 µm**

Loss decrease

Better modal content: high order mode filtered



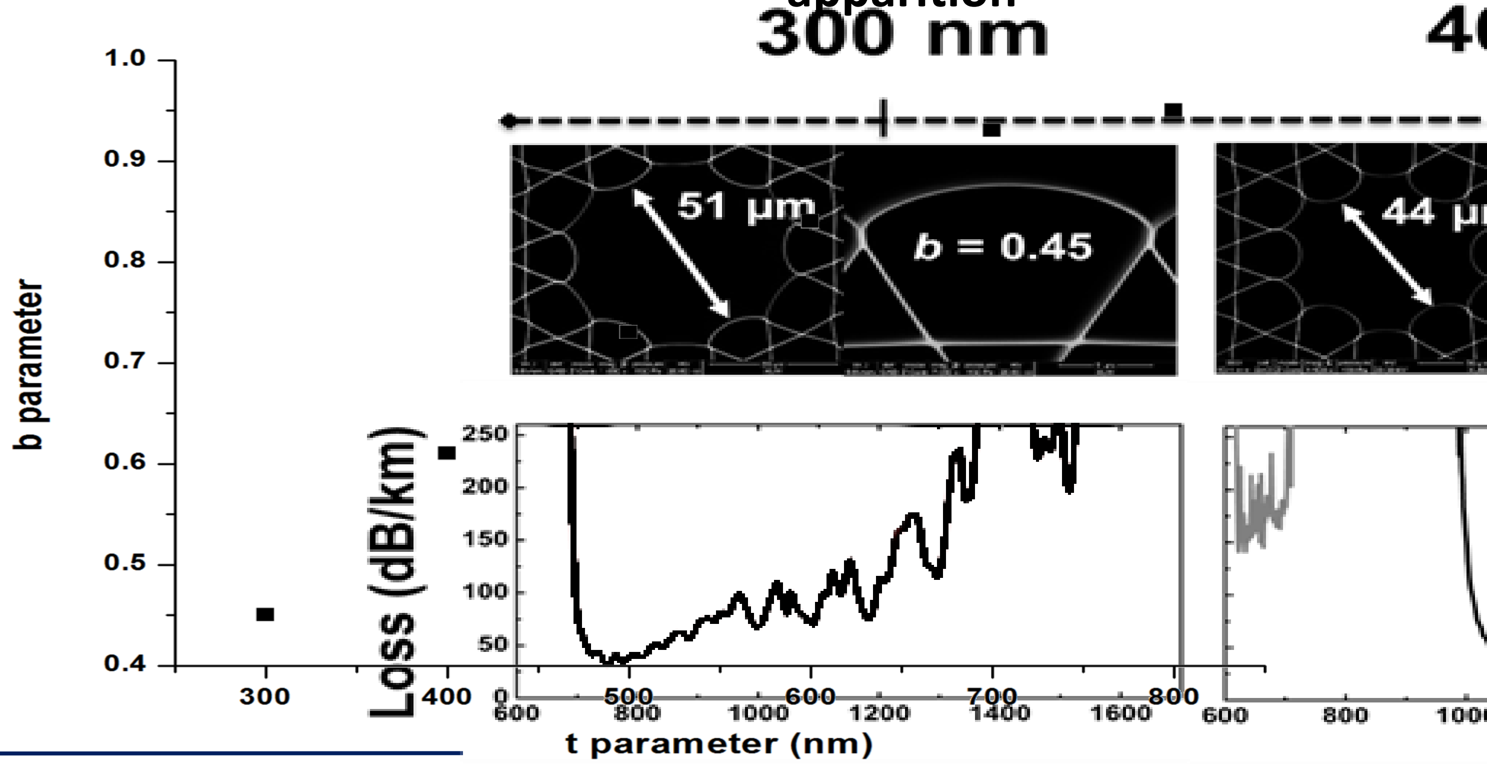


SYSTEM EXPERIMENTAL STUDY

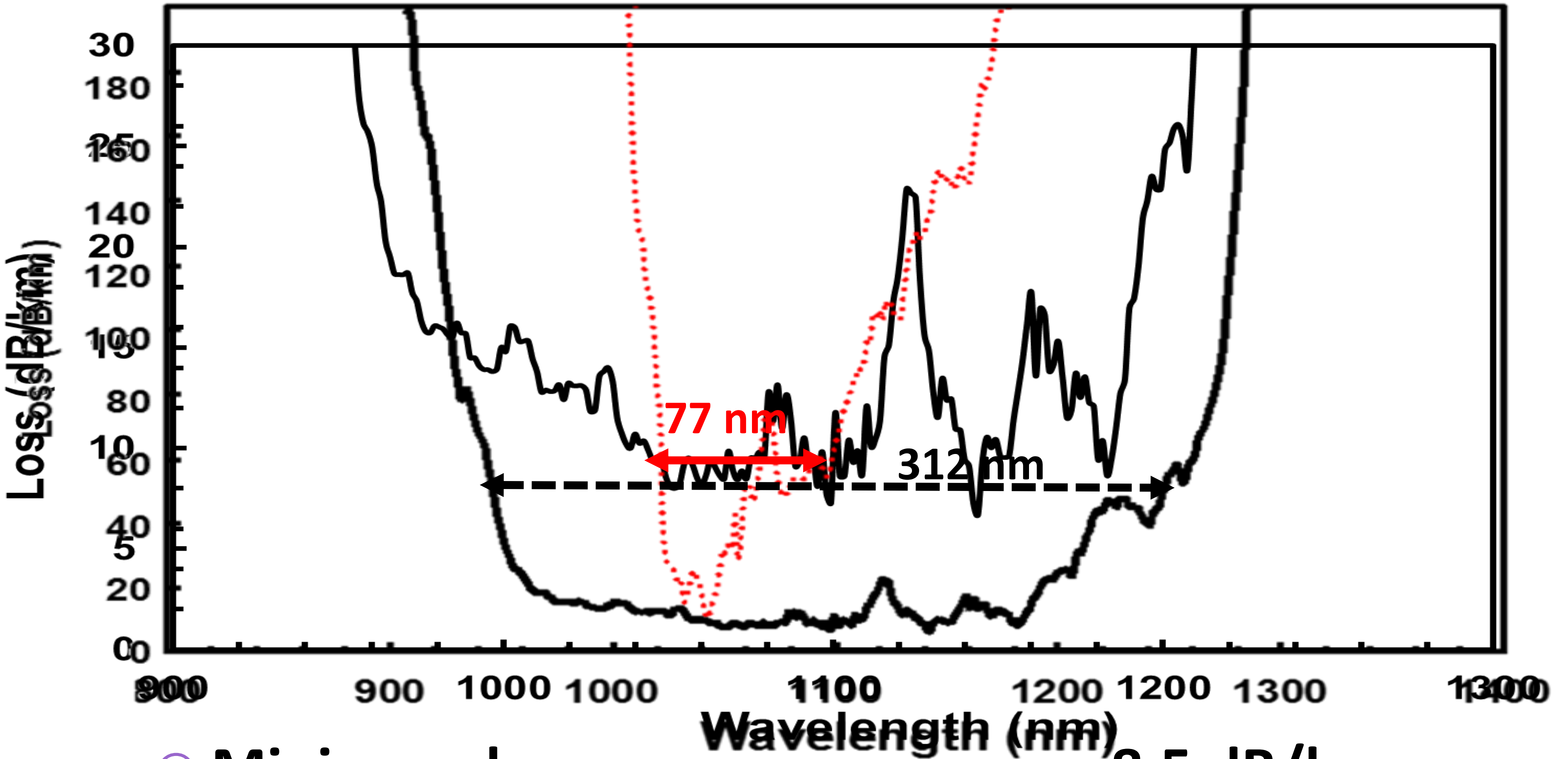
Loss measurement for different:

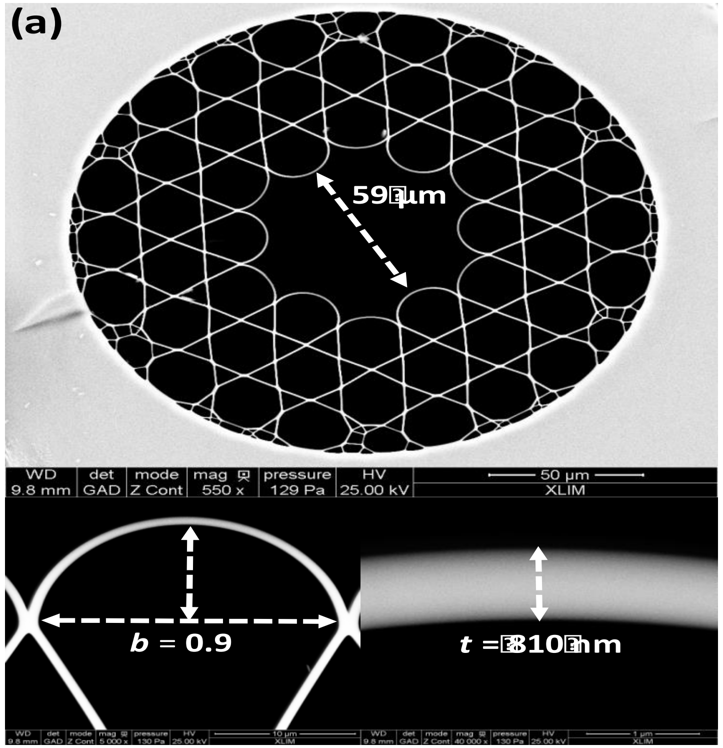
- Struts thickness (t parameter)
- Negative curvature (b parameter)

The fundamental band shifts to higher wavelength
and
First high order transmission band apparition



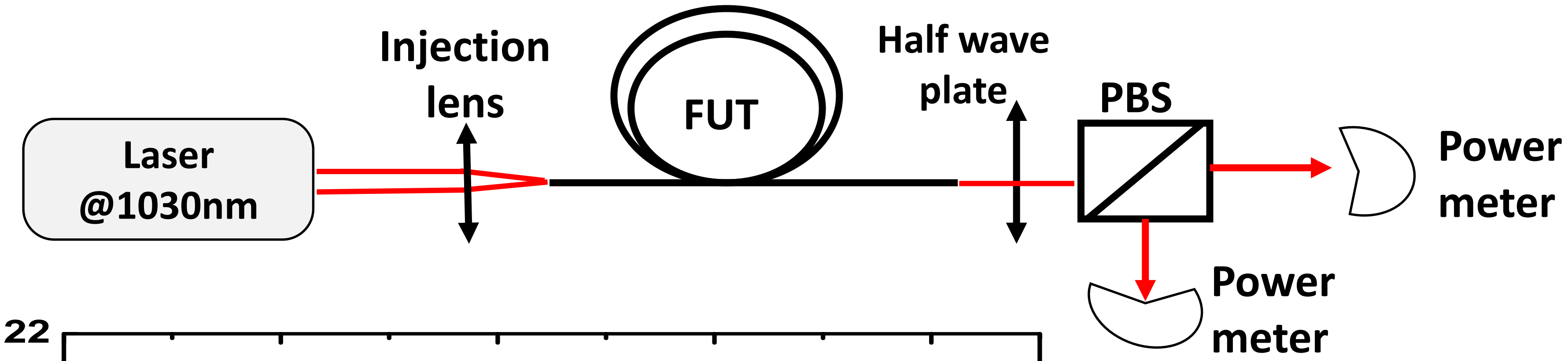
STRUCTURE AND RECORD LOSS

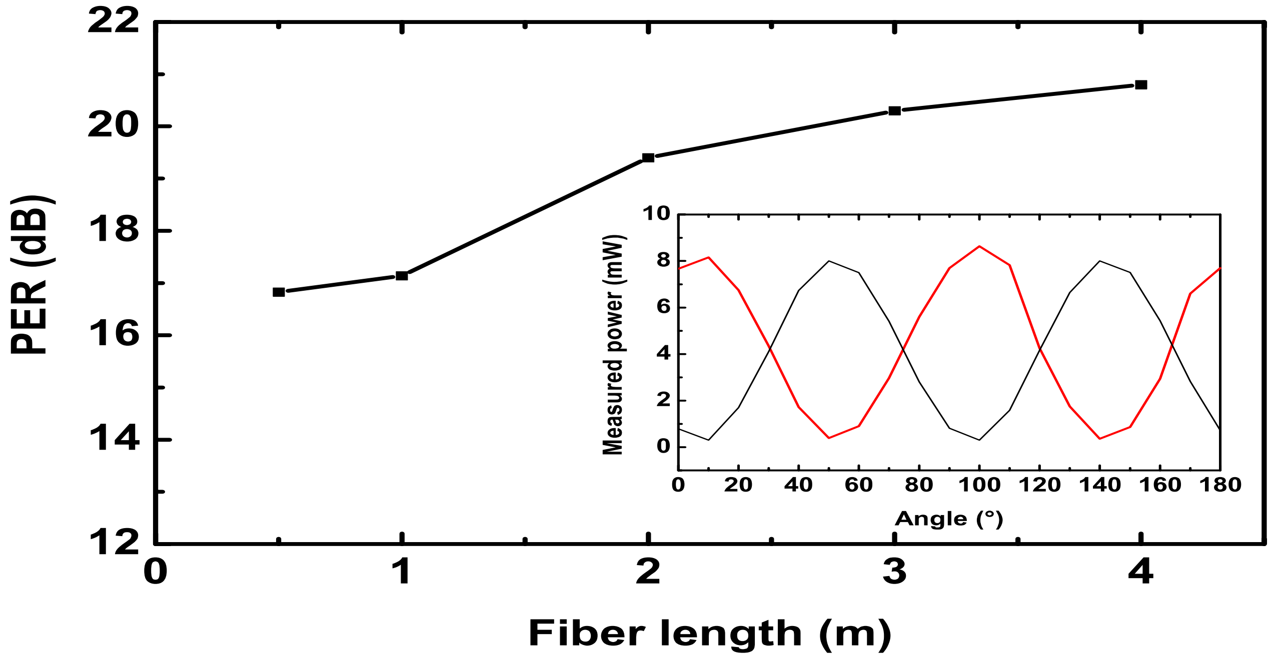




- Minimum loss: 8.5 dB/km
- Transmission bandwidth: 225 nm
- Core diameter: 59 µm
- Struts thickness: 810 nm

PER MEASUREMENTS



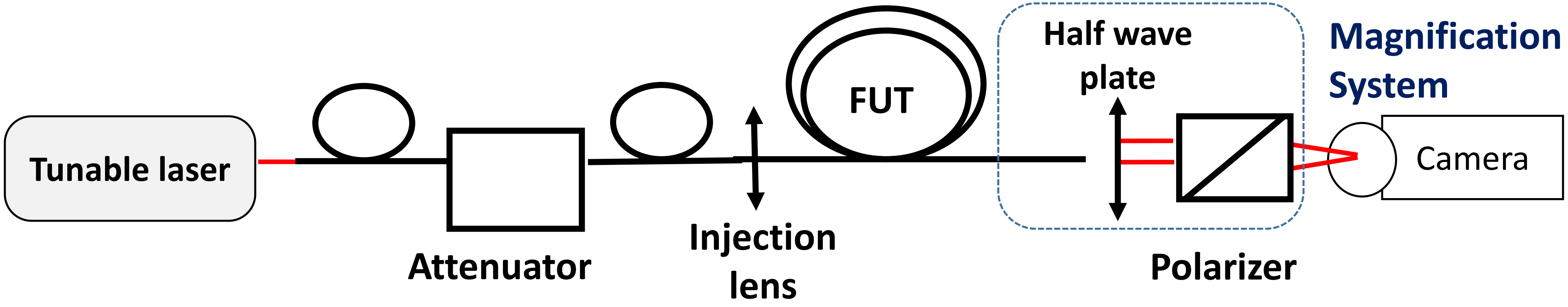


PER measurement (@ 1030nm) :

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

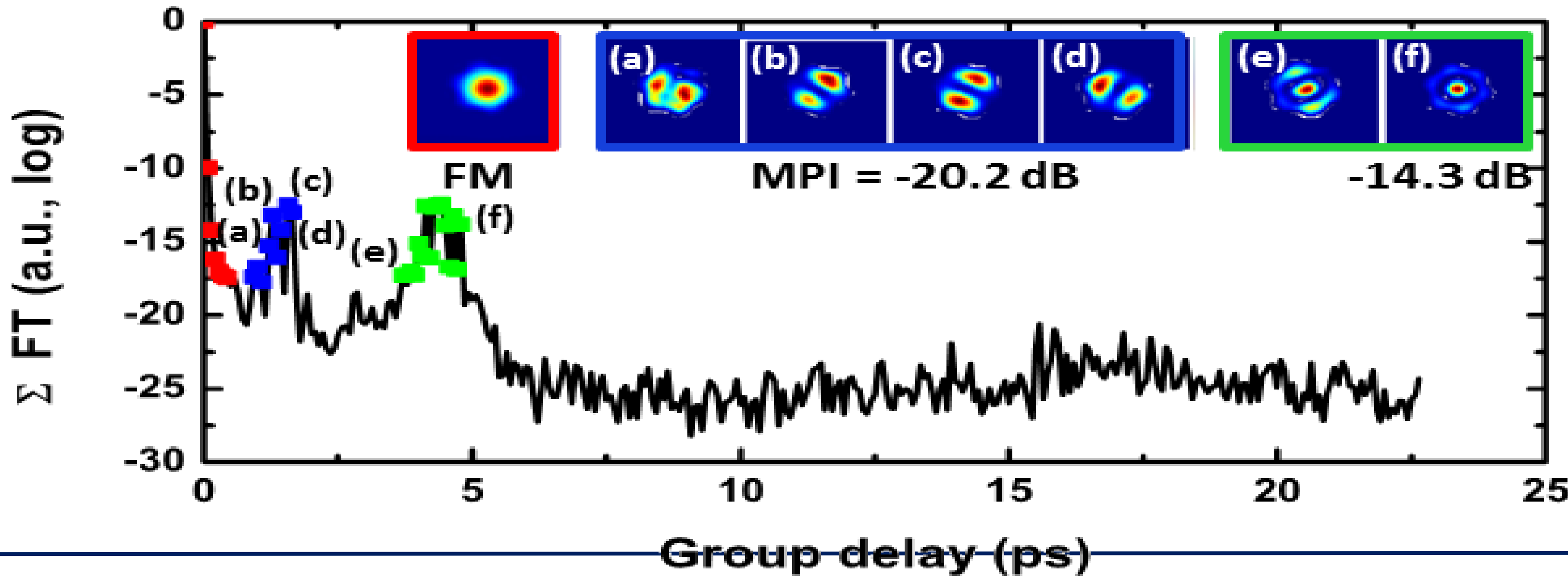
S^2 MEASUREMENTS

*Collaboration CEA Cesta Research Institute



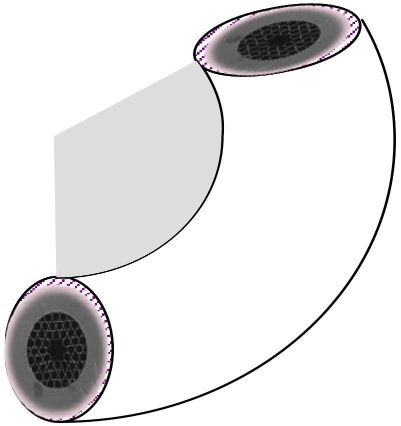
S^2 measurement* :

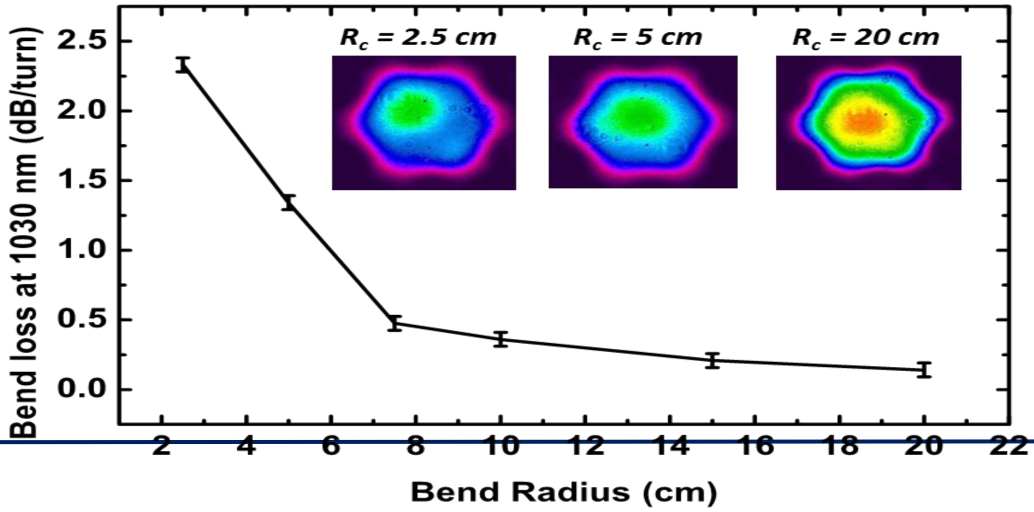
- **Fiber bend: radius** 25 cm
- **Tuning range: (nm)** 1010-1060
- **MPI:** 14.3 dB

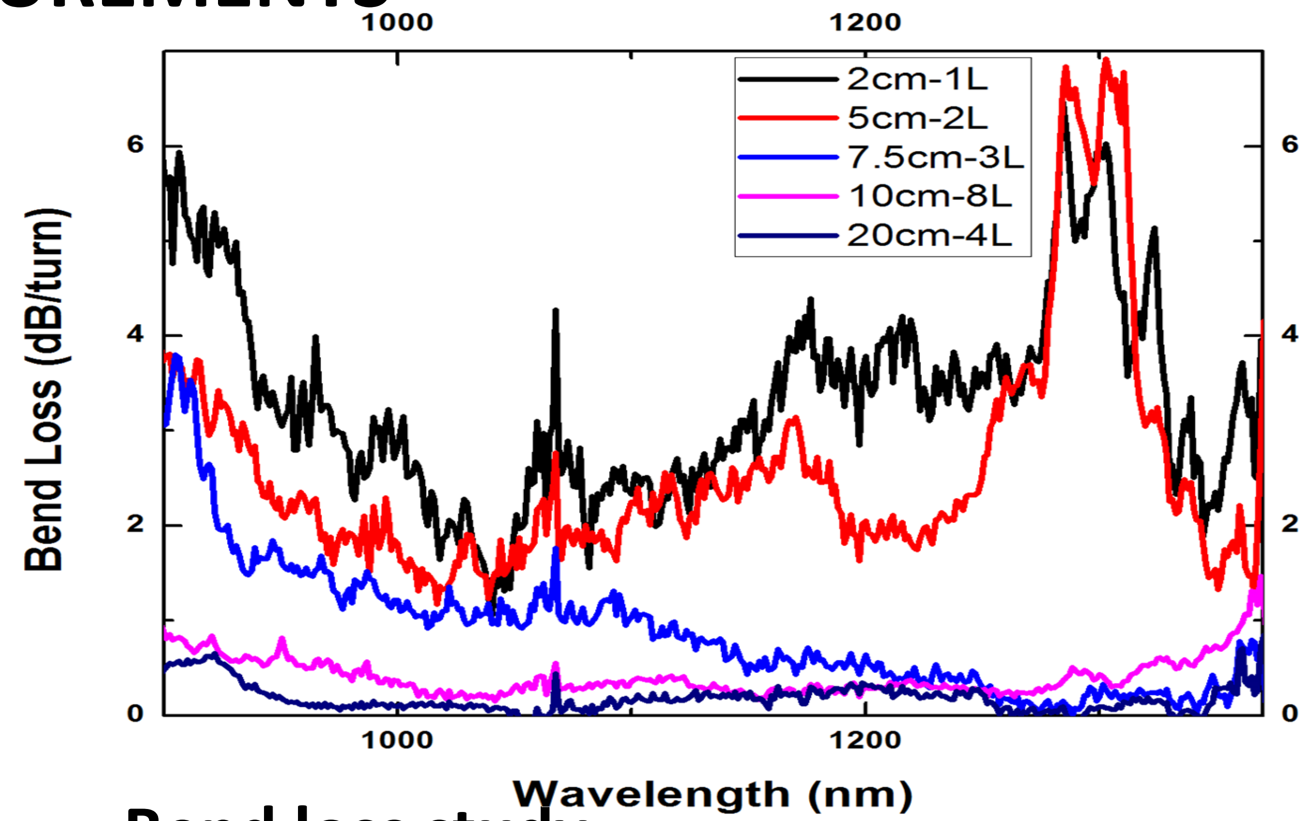


BEND LOSS MEASUREMENTS

Constant radius of curvature



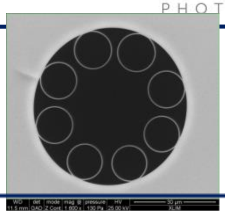




Bend loss study :

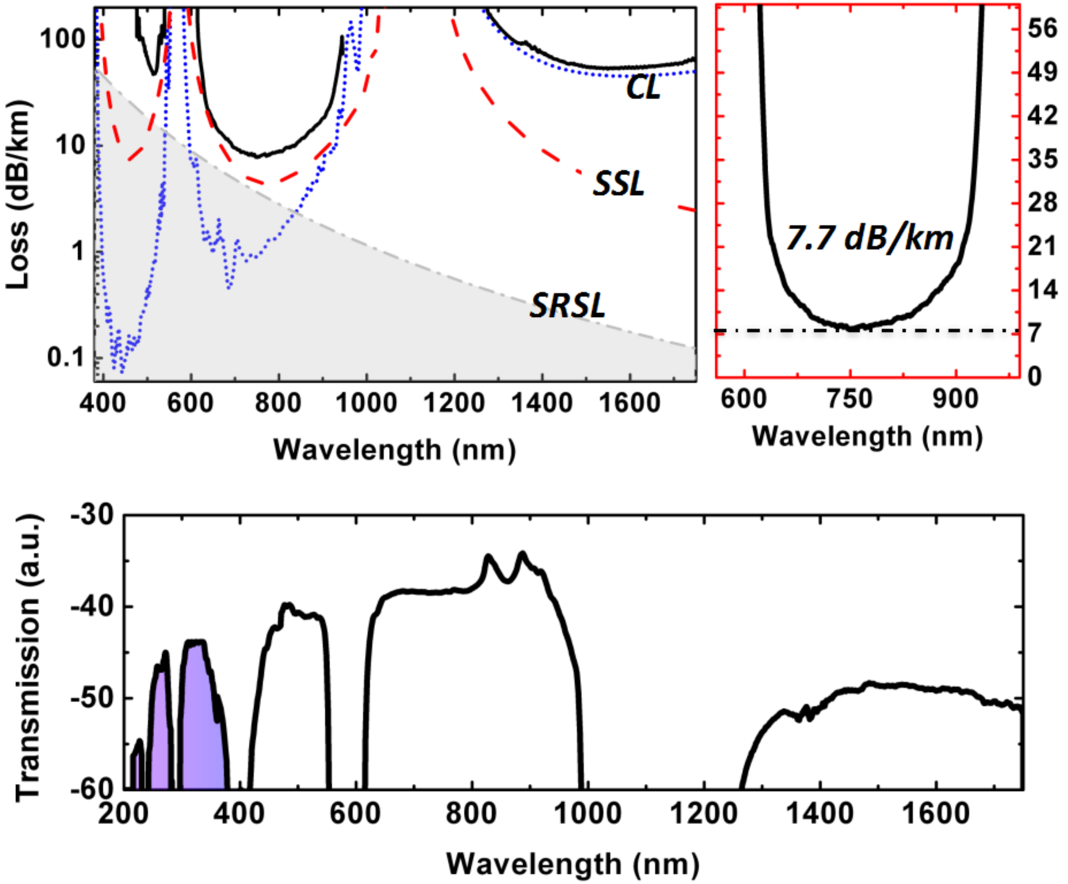
- **Fiber length:** **10 m**
- **Bend radius:** **2.5-20 cm**

DESIGN #2: TUBULAR LATTICE

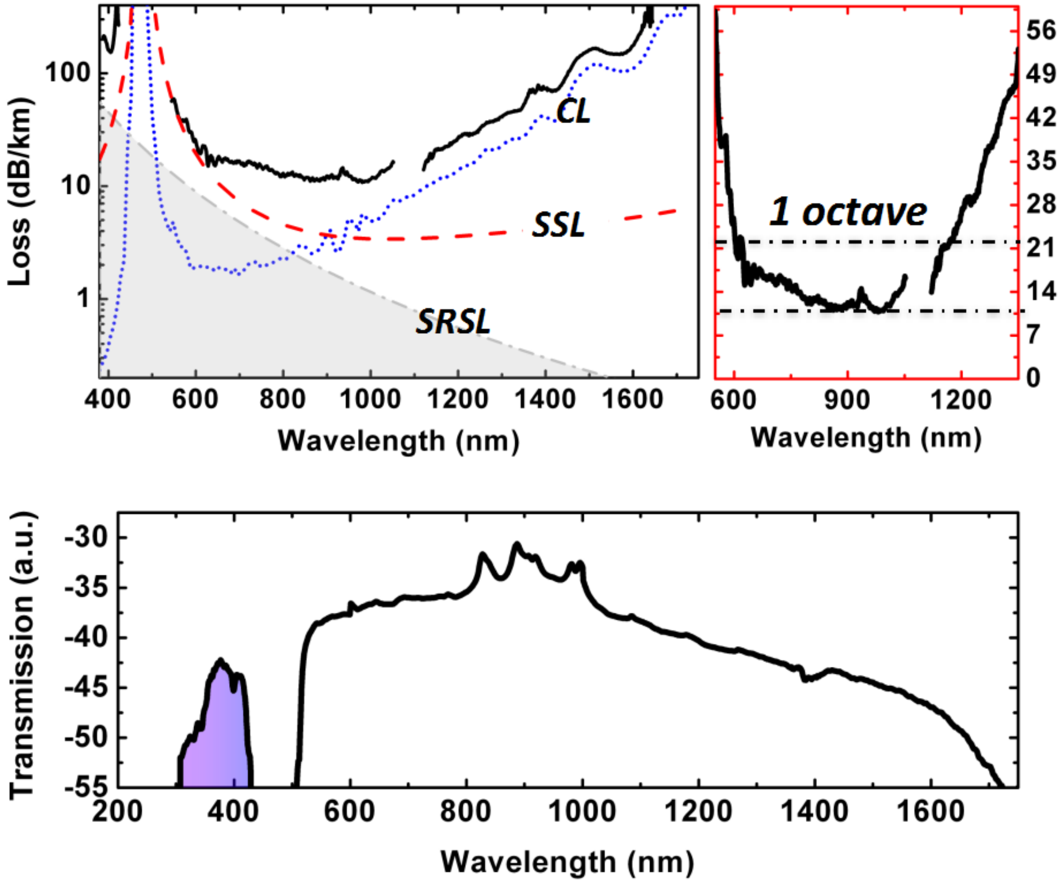


B. Debord et *al.*, CLEO US postdeadline, JTh4C.8 (2016)
B. Debord et *al.*, Optica (2017)

Optimized Fiber #1



Optimized Fiber #2



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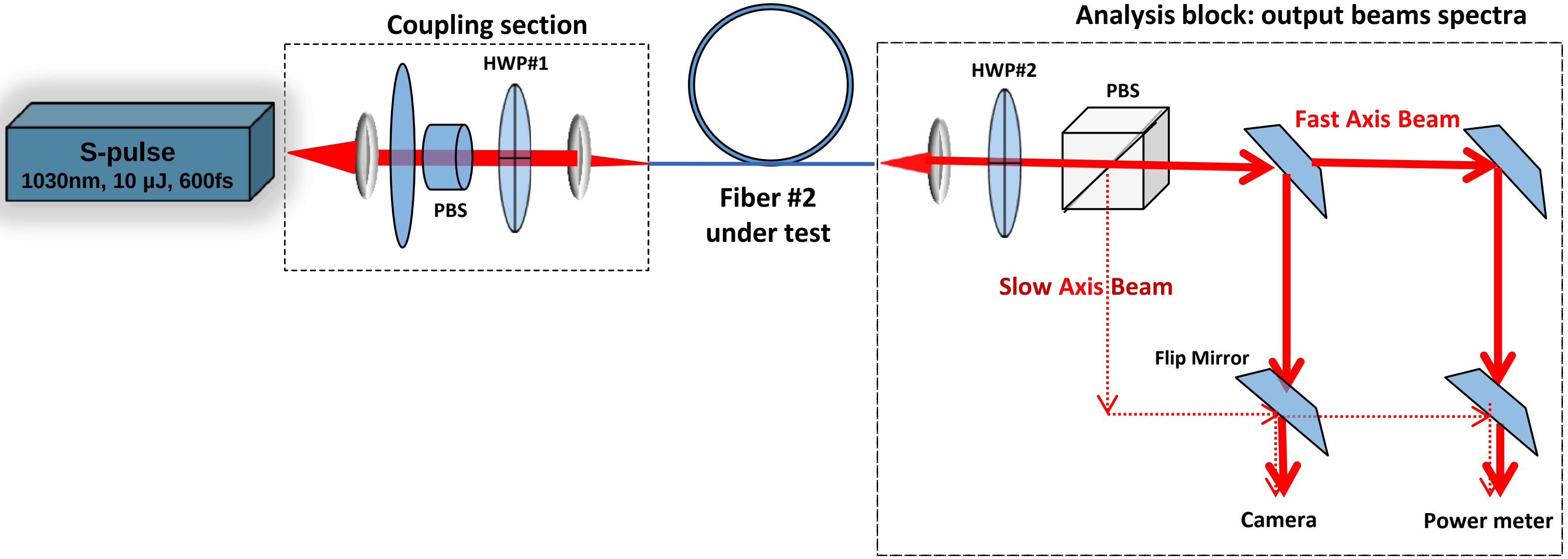
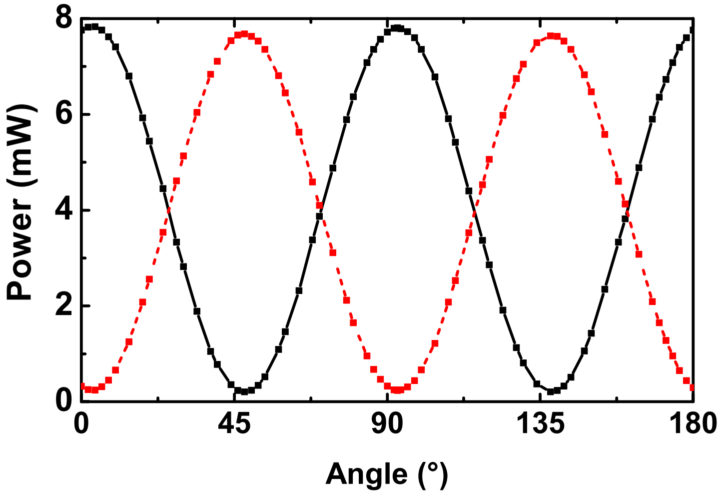
WP4	Photonic components for pre and post pulse conditioning

B. Debord et *al.*, Optica (2017)

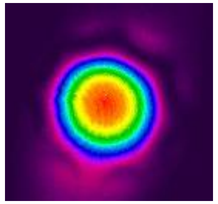
2. IC HC-PCF with a single ring of tubular lattice cladding

2.1. PER measurement

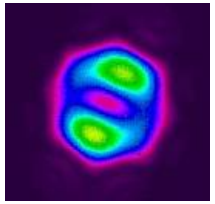




Maximum power



Minimum power



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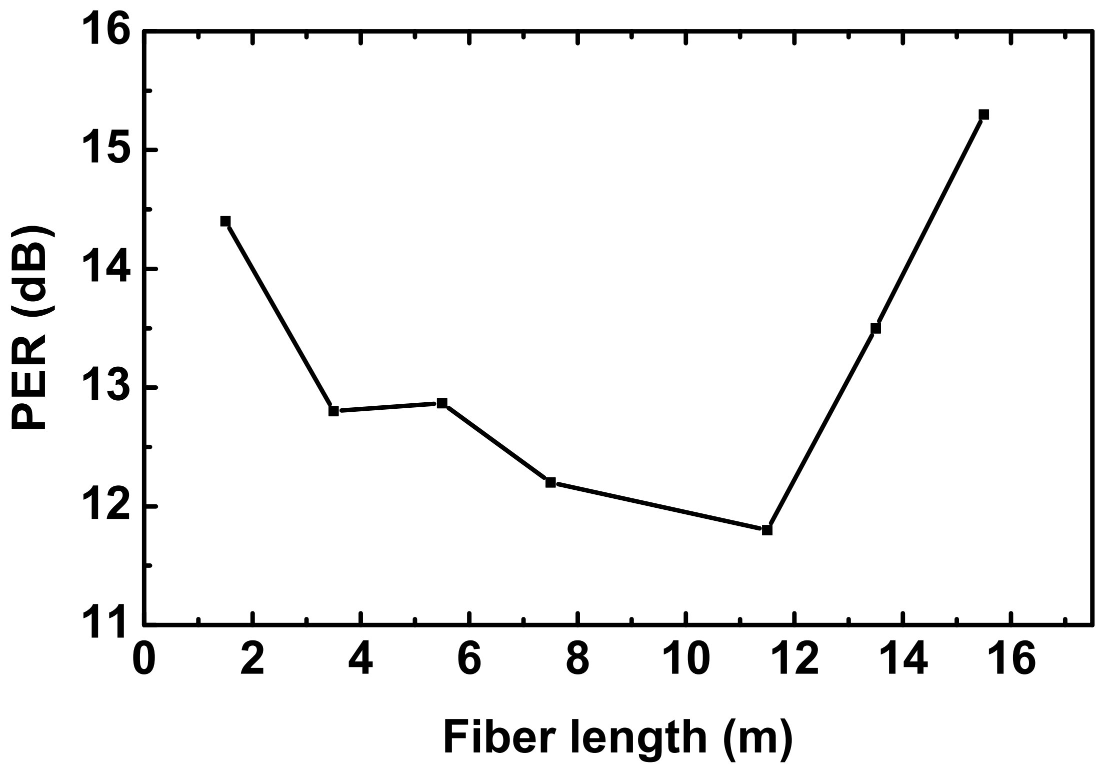
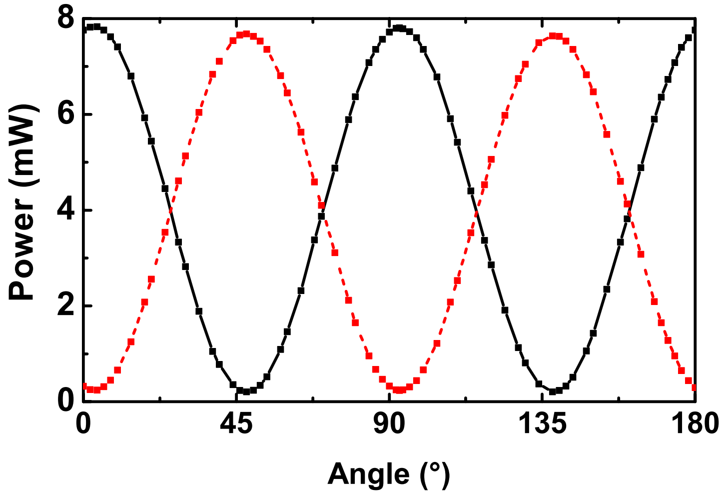
WP4	Photonic components for pre and post pulse conditioning

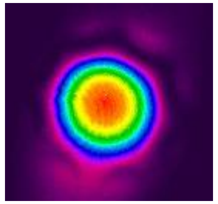
B. Debord et *al.*, submitted to Optica (2016)

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

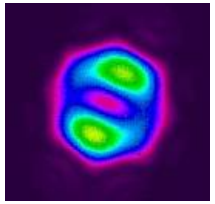




Maximum power



Minimum power



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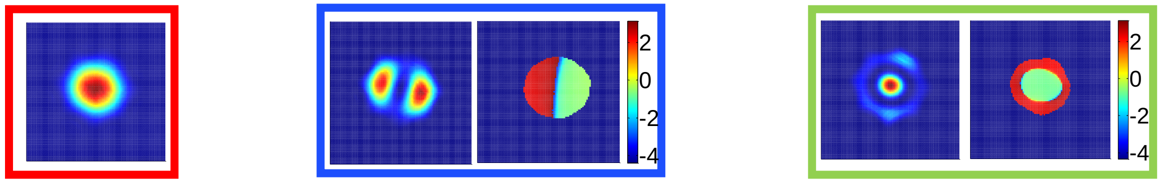
WP4	Photonic components for pre and post pulse conditioning

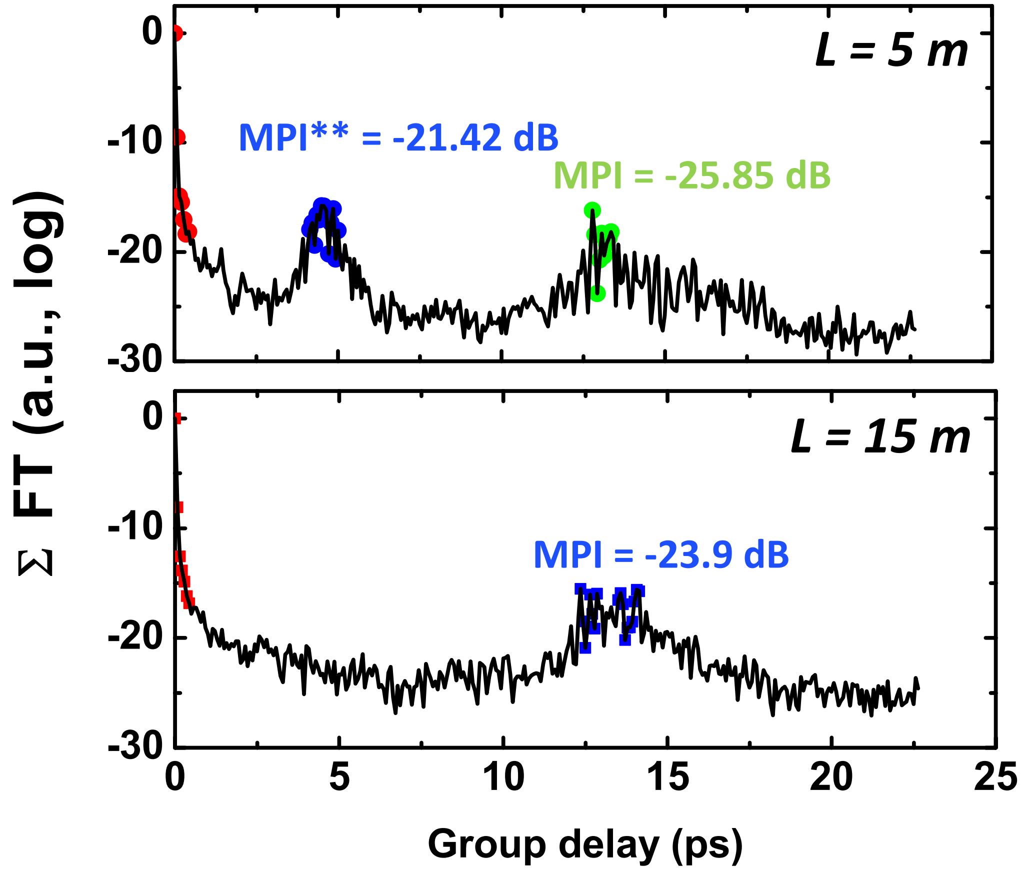
B. Debord et *al.*, submitted to Optica (2016)

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

2.2. S^2 measurement (collaboration)*

Fundamental mode   First HOM   Second HOM





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

**** MPI = Multi-path interference**

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WP4 – The next six months…

1. *High avg power capability for beam delivery (T4.4)*
2. *End-termination spec definition & design (T4.5)*
3. *Investigation of the modal properties of the two IC fibers (T4.6)*
4. *Test of energy handling capabilities of the IC HC-PCF with a single ring of tubular lattice cladding (T4.6)*
5. *Start to set a home-made S^2 set-up (T4.6)*
6. *Continue on the fabrication of IC HC-PCF (T4.6)*
7. *Preliminary characterization of the polarization properties of both fiber designs (T4.6)*

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HIP

Pulse compressors - Pulse compressor gratings are well spread and implemented in most of the high-power laser a systems where the non-linearities can be detrimental due to the high-peak powers in the sub-ps regime. In fact, to circ these issue the chirped pulse amplification (CPA) technique is used. The pulses are first stretched to longer pulses (from or even ns pulses), then amplified and recompressed to the initial pulse duration. However, the overall losses of the co MOPA system can be limited by the performances of the stretcher and compressor elements. For instance, the los compressors device can be typically in the order of 15-20% (4-passes) if the diffraction efficiency is between 95-96%. Thi case of transmission compressor gratings made of pure fused-silica as demonstrated by Clausnitzer et al.[49] with deep gratings and can be commercially provided by Ibsen Photonics, Jenoptik, Alrad, etc….

Oon the other hand fully dielectric grating compressors operating in reflection can exhibit higher diffraction efficiency as high LIDT. Therefore, they represent the most appropriate approach for high-power ultrafast laser systems. Several grou [52] [53] have been reporting on the potential of these elements in a pulse compression architecture. .

Within HIPERDIAS, the pulse compressor gratings which will be developed should target efficiencies of higher or equal tha over a broad spectral bandwidth (10 nm) as well as high LIDT (in the order of the J/cm² at the sub-500 fs regime). AM USTUTT have built a strong experience within this domain within the last years and have very recently, successfully repo grating mirrors with a diffraction efficiency of 99.7% at 1060 nm wavelength which can lead to an overall efficiency comp efficiency of ~98.8%. At a wavelength of 1030 nm, the devices were tested as pulse-compressors, and up to 96.3% ove passes through the gratings i.e corresponding to >99% diffraction efficiency per single-pass) was demonstrated. The LID measured with 2.95 J/cm2 for 12 ns pulses. Based on this experience the further development of these devices will be within HIPERDIAS to implement them within the high average power laser in order to ensure a **high overall efficiency complete MOPA chain**. Furthermore, the approach followed within HIPERDIAS shall exhibit increased fabrication tolera the grating parameter (groove-depth, duty-cycle, etc…) to allow high-yield and efficient implementation in commercia systems

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WP5 Thin-disk Multi-pass Booster

Marwan Abdou Ahmed

USTUTT

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

Work Package 5 Overview

- Main objective: Building multipass amplifier with Seed Source from AMP
  - Task 5.1 Design of the thin-disk multipass amplifier (USTUTT, Due M06)
  - Task 5.2 Amplifier with 500 W, 1 MHz, sub-500 fs (USTUTT, AMP, Due M22)
  - Task 5.3 Second and third harmonic generation (USTUTT, AMP, DUE M28)
  - Task 5.4 Integration of Yb amplifier (AMP, USTUTT, Due M28)
  - Task 5.5 Demonstration of a 1 kW, sub-1ps laser system (USTUTT, AMP, M38)

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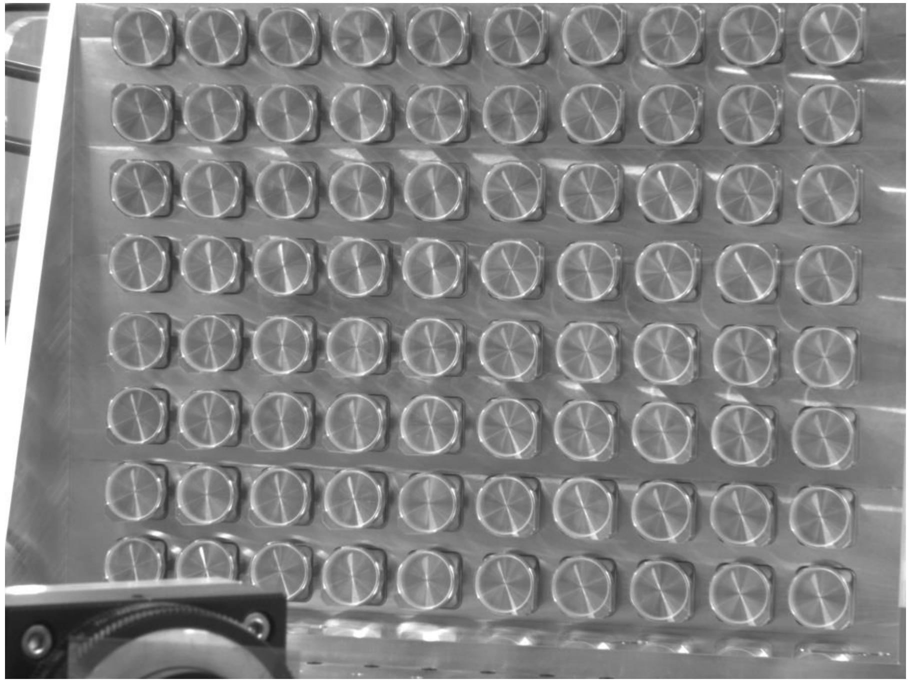
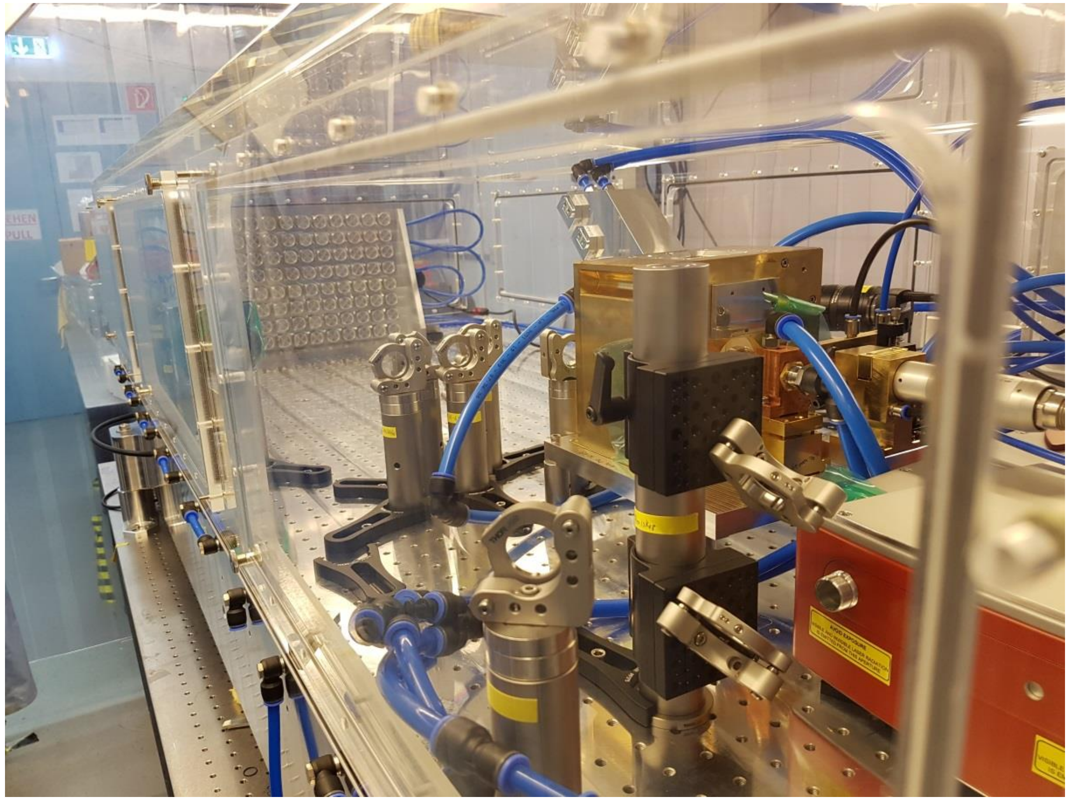
WP5 – Task 5.2: Assembly and characterization of a Yb:YAG thin-disk multipass amplifier (USTUTT, AMP, Due M22)

- All optical and mechanical parts designed in Task 5.1 ordered, delivered and assembled





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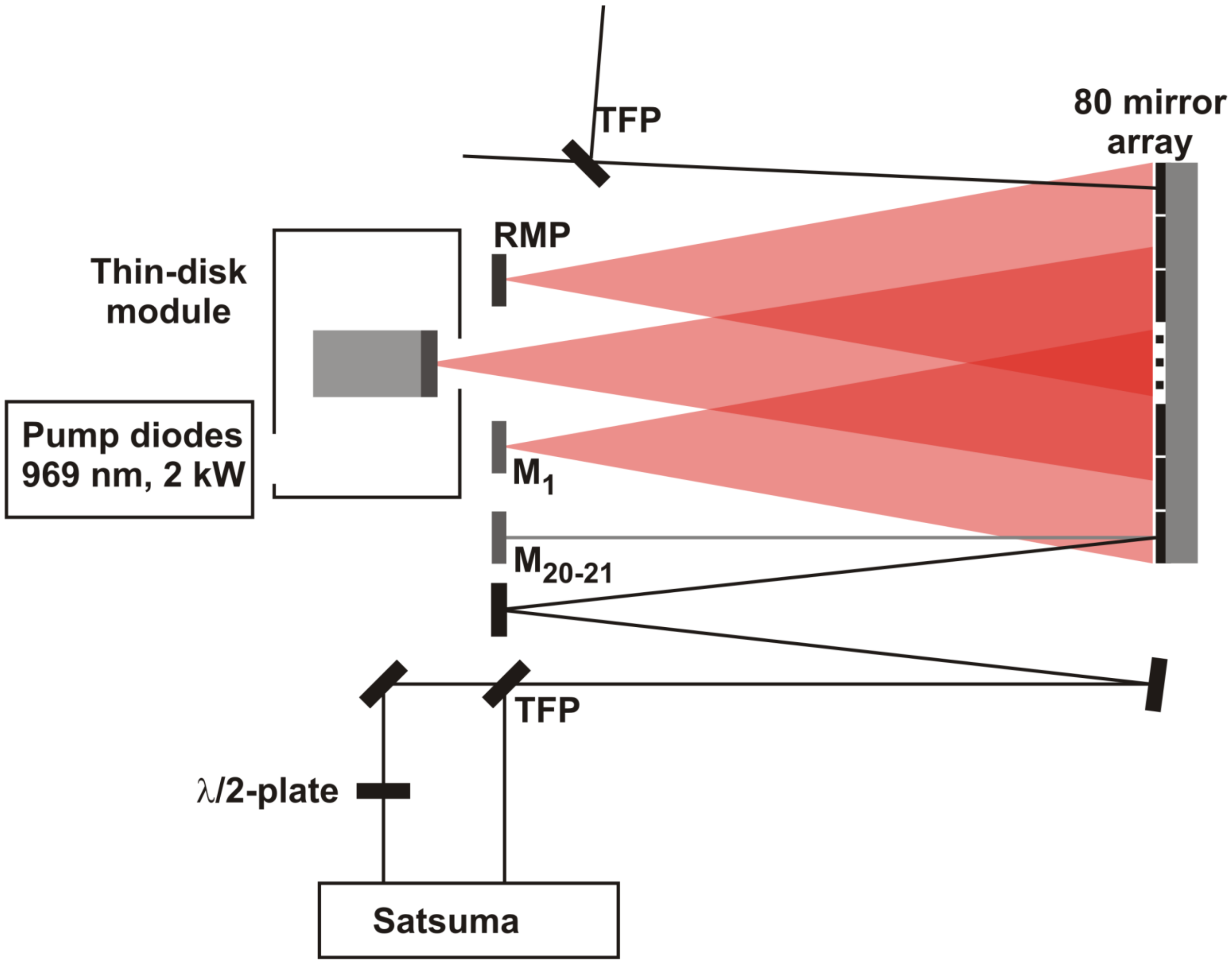
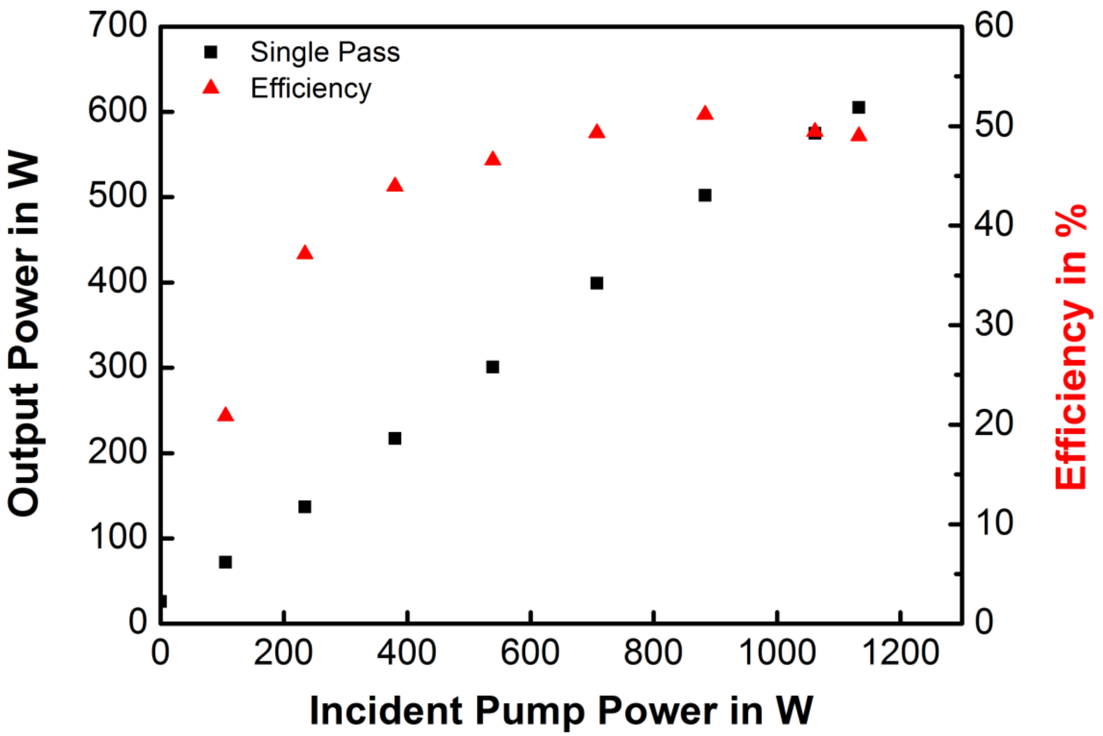
Setup



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

Results – Single pass

- 50 W Seed Power, 330 fs pulses, 1.25 MHz
- Measured output power in single-pass:
  605 W (deliverable goal: 500 W)
- Maximum pulse energy (1.25 MHz): 484 µJ
- No pulse-picking implemented yet



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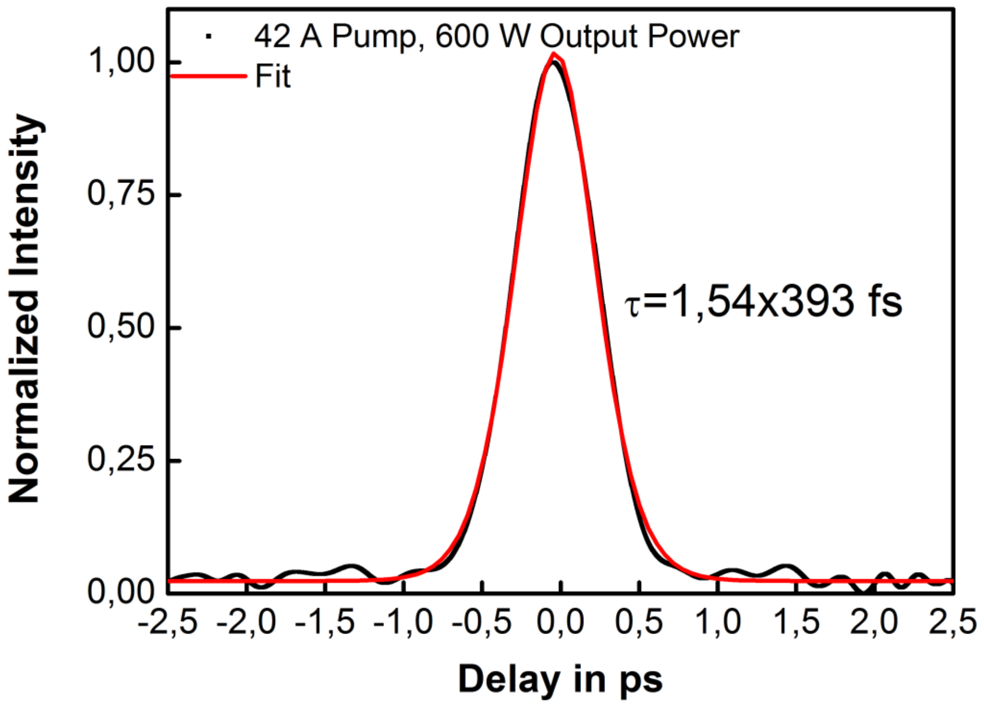
Results – Single pass

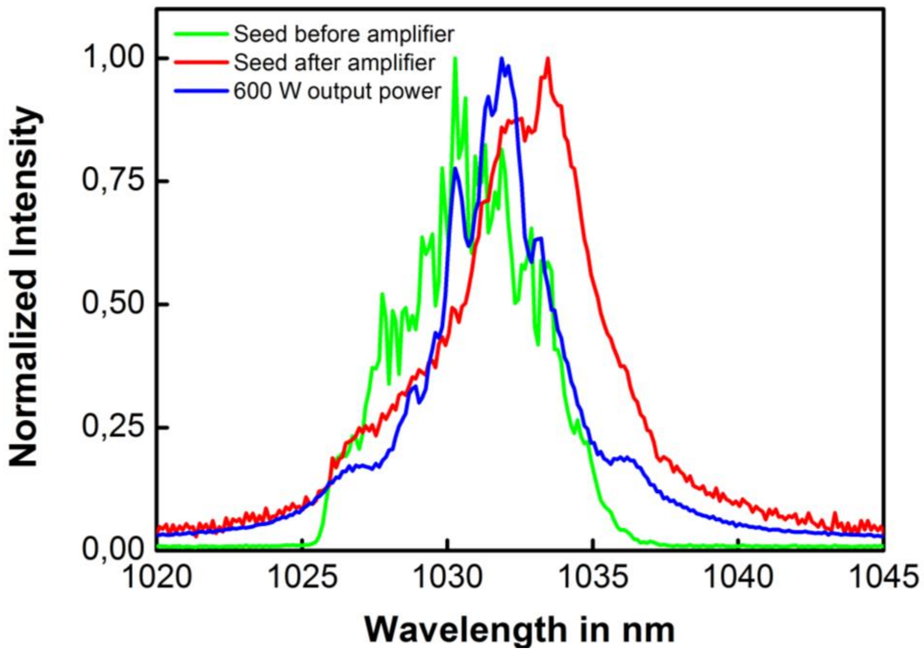
- 330 fs pulse duration of seed laser
- Measured pulse duration at 600 W power: 393 fs
- Peak Power: 1.1 GW

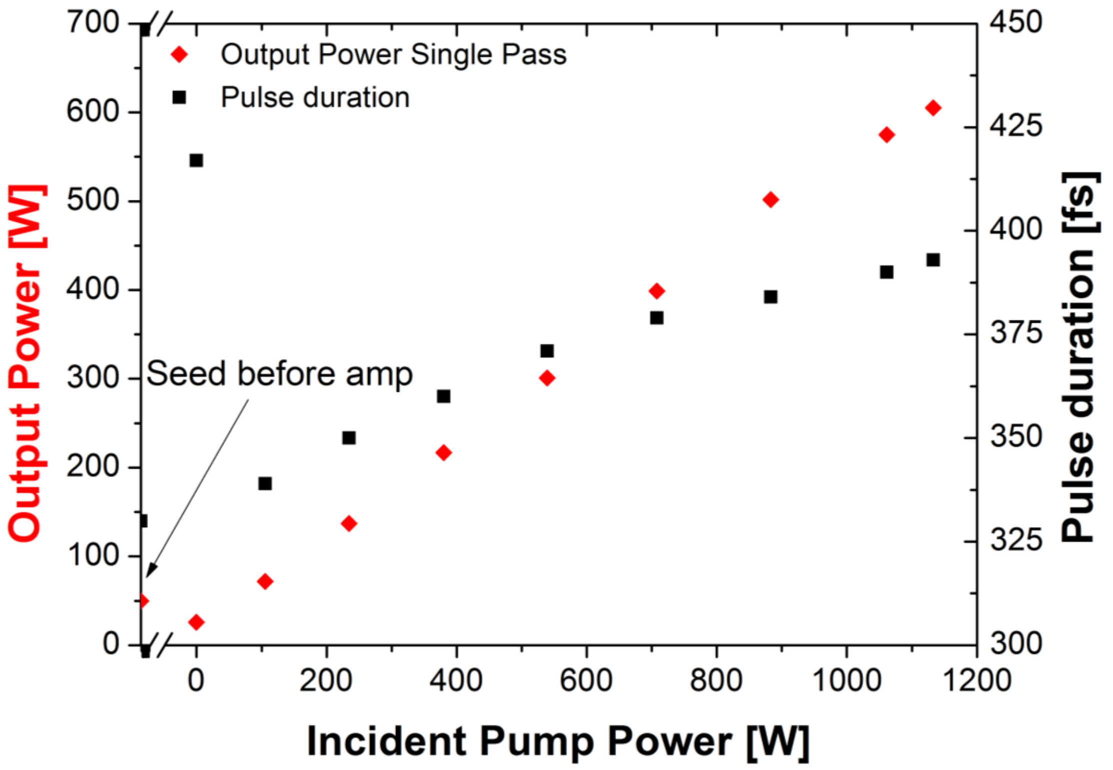


This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 687880

Results – Single pass

- Slight spectral narrowing ➔ very slight temporal broadening
- Sub 400 fs at 600 W output power

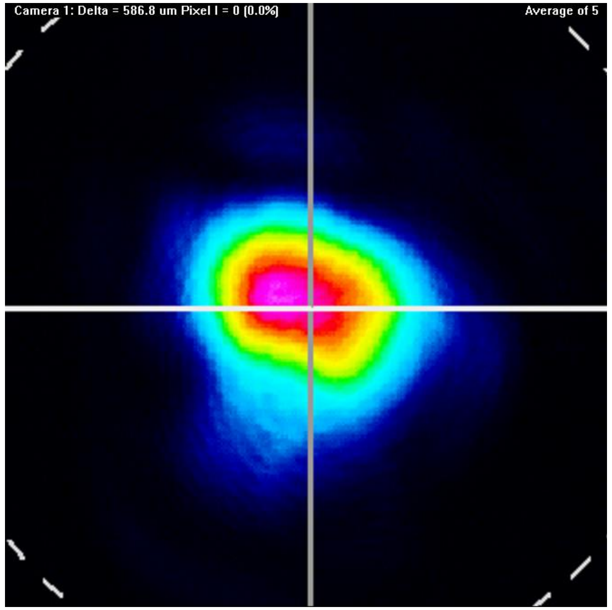


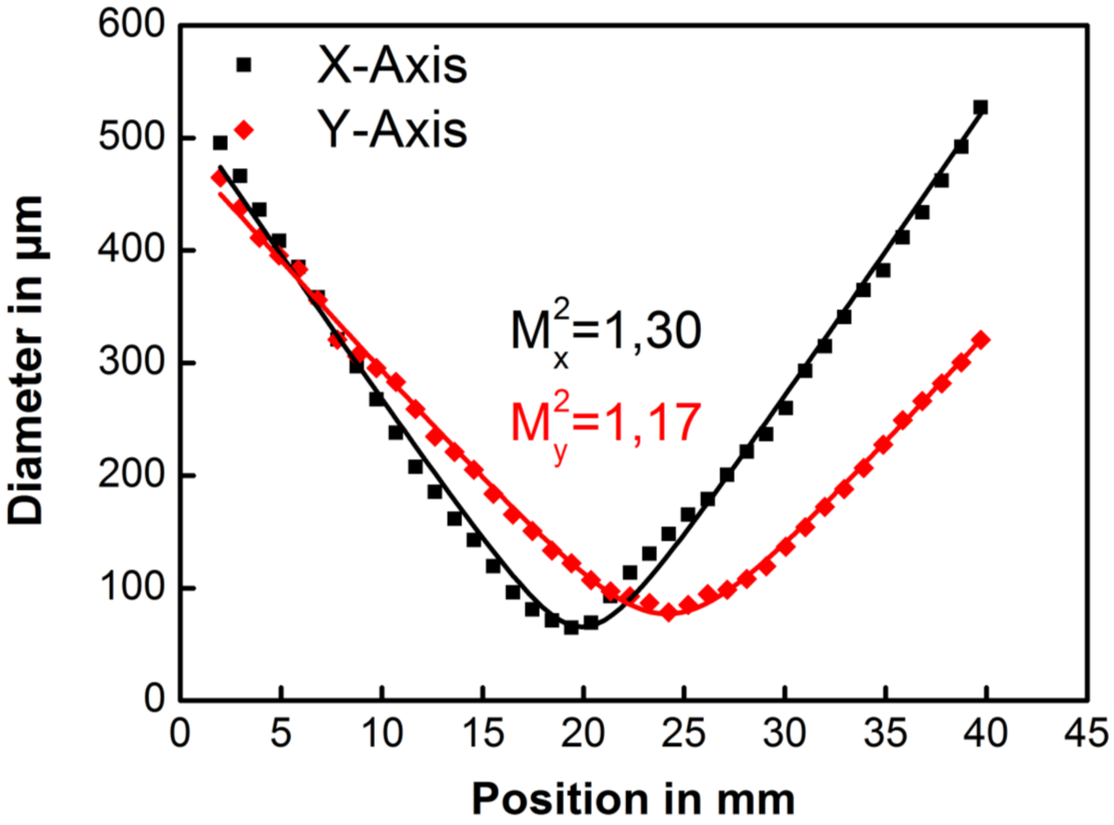


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687880

Results – Single pass

- Beam profile at full output power: only slight aberations visible
- M^2<1.3

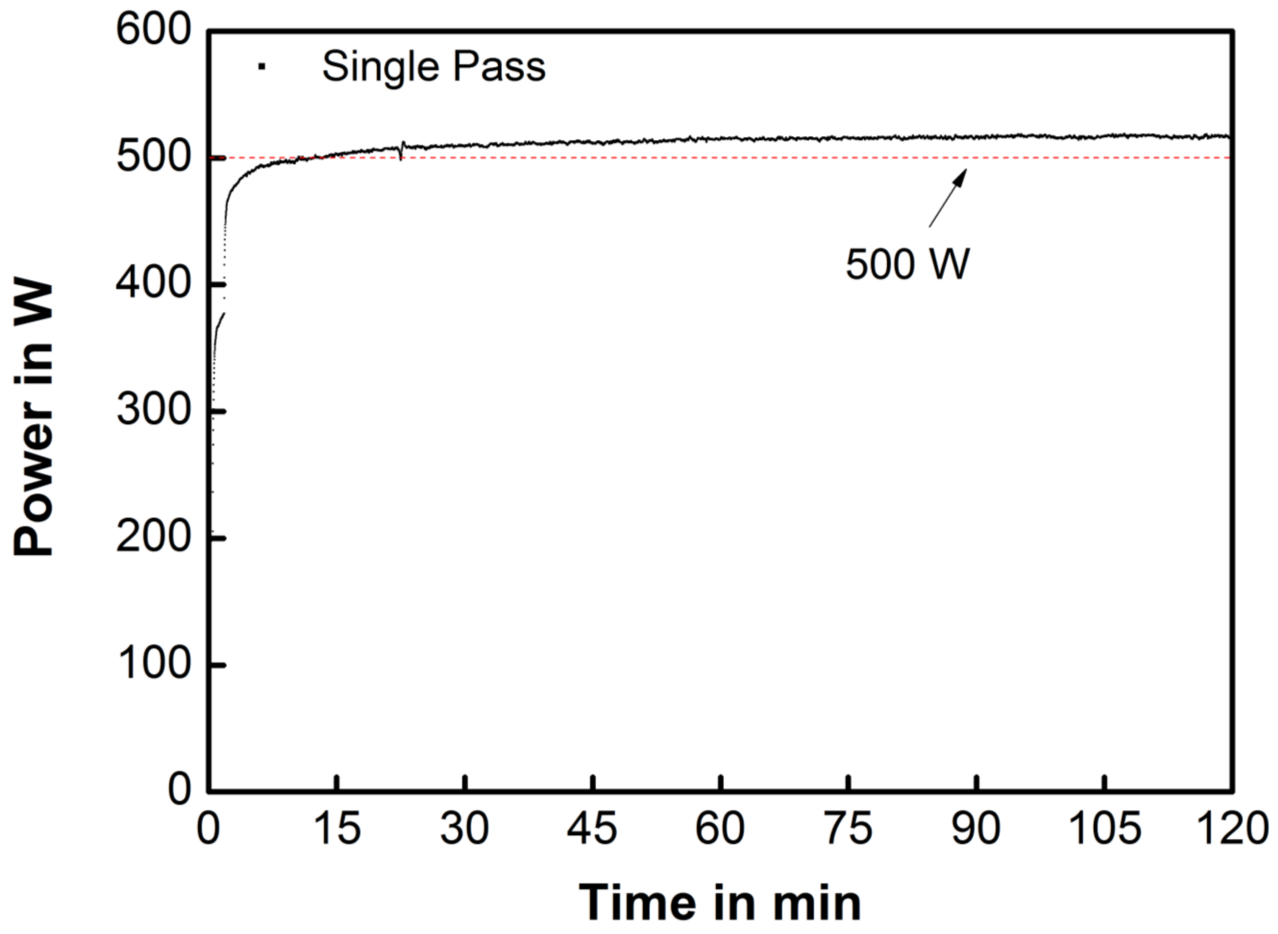




This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 687880

Results – Single pass

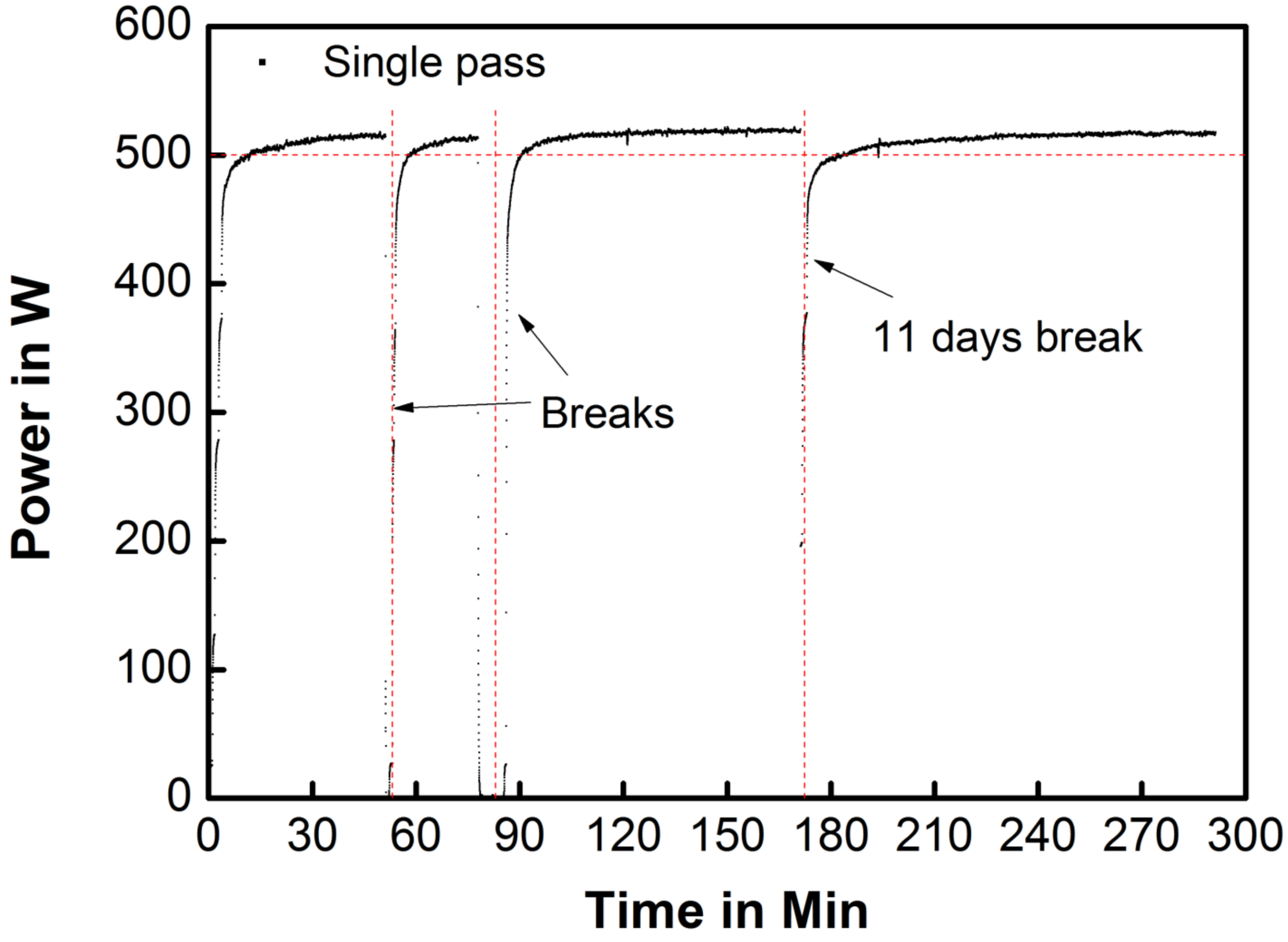
- Thanks to very good thermo-mechanical properties system is very stable after thermalization
- Measurement starting around 500 W
- No power drops observed



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

Results – Single pass

- Reproducable behaviour after breaks
- No realignment after 11 days break



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

Task 5.3 Frequency Conversion (USTUTT, AMP, DUE M28)

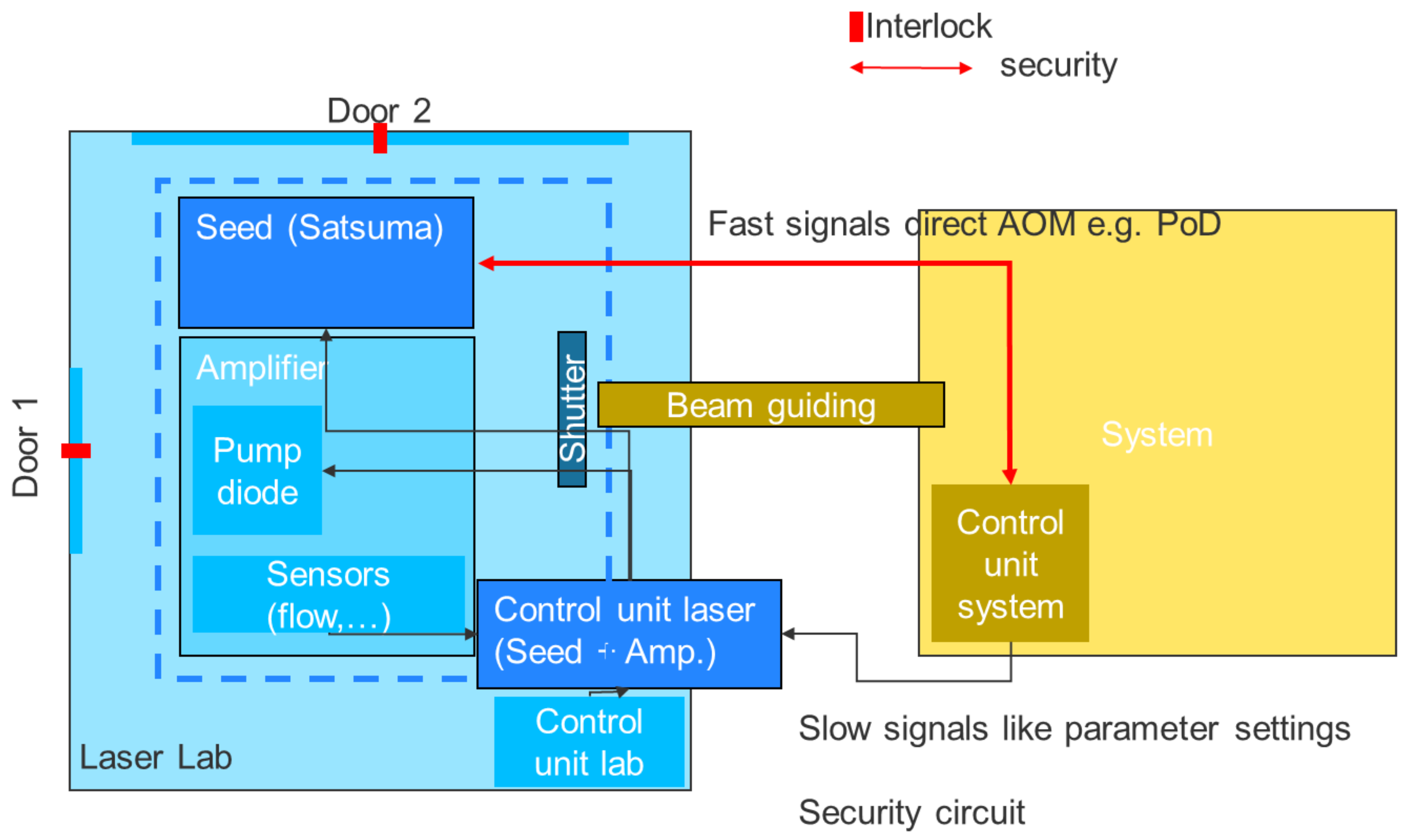
- In progress…
- Designed and most components delivered
- Assembly starts soon
- more to report at next CM.

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

Task 5.4 Integration of multipass amplifier(AMP, USTUTT, Due M28)

- Laser will be placed in a separate room
- Beam guided to workstation (by LASEA)
- Development of controls, interfaces ongoing.
- Room currently being equipped

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



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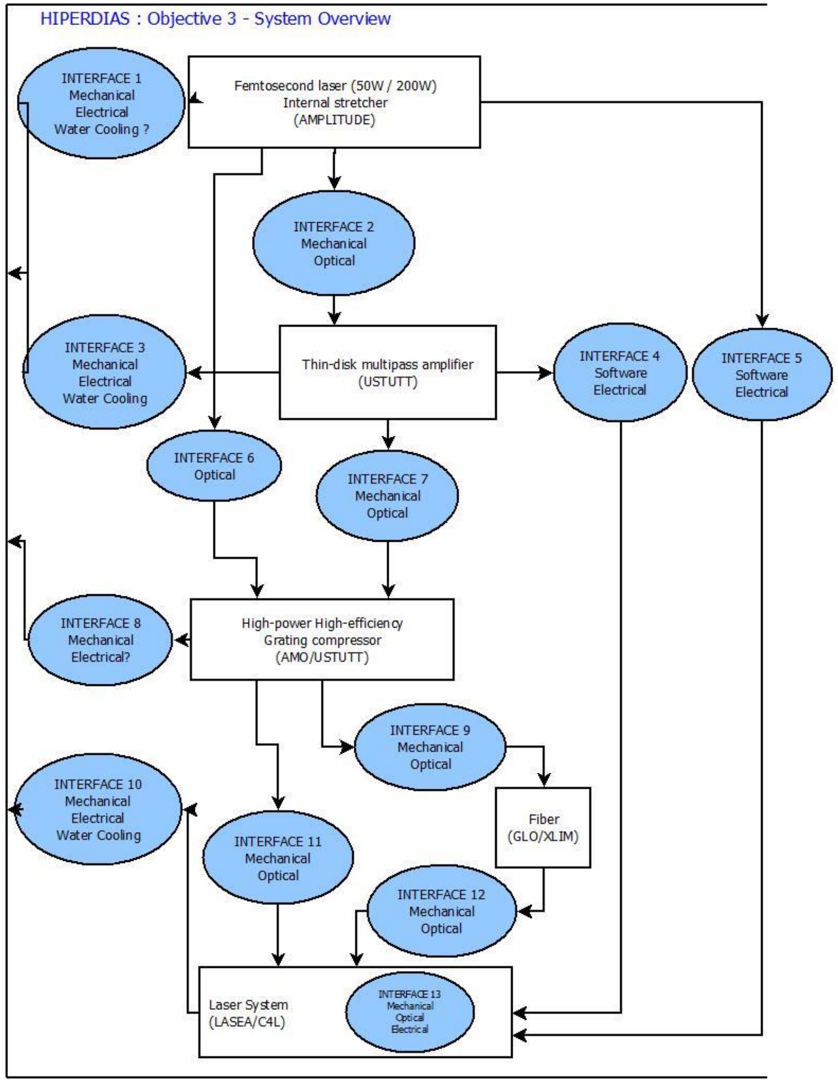
Nr	Partners involved	Type of interface
1	USTUTT <--> AMP	MECHANICAL/ELECTRICAL/WATER/SAFETY
2	AMP <--> USTUTT	MECHANICAL/OPTICAL
3	USTUTT <--> USTUTT	MECHANICAL/ELECTRICAL/WATER
4	USTUTT <--> LASEA/C4L	SOFTWARE/ELECTRICAL
5	AMP <--> LASEA/C4L	SOFTWARE/ELECTRICAL
6	AMP <--> (AMO-USTUTT)	OPTICAL
7	USTUTT <--> (AMO-USTUTT)	MECHANICAL/OPTICAL
8	USTUTT <--> (AMO-USTUTT)	MECHANICAL/ELECTRICAL
9	(AMO-USTUTT) <--> (GLO-XLIM)	MECHANICAL/OPTICAL
10	LASEA/C4L <--> USTUTT/C4L	MECHANICAL/ELECTRICAL/WATER/SAFETY
11a	(AMO-USTUTT) <--> LASEA/C4L	MECHANICAL/OPTICAL
11b	LASEA / C4L <--> LASEA/C4L	MECHANICAL/OPTICAL
12	(GLO-XLIM) <--> LASEA/C4L	MECHANICAL/OPTICAL
13	LASEA/C4L<--> Scanner	MECHANICAL/OPTICAL/ELECTRICAL/SOFTWARE



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

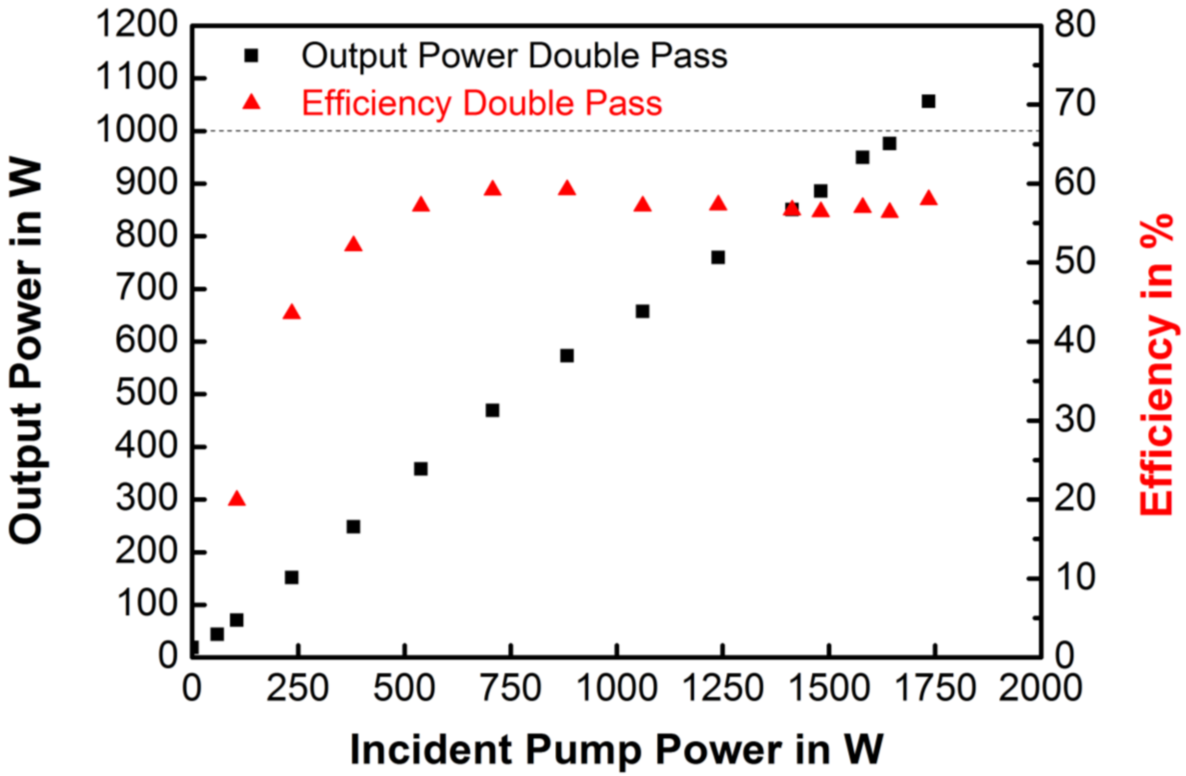
Task 5.5 Demonstration of a 1 kW, sub-1ps laser system (USTUTT, AMP, M38)

- Planned after material processing with 500W
- Seed source:200 W system delivered by AMP

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

New preliminary results – Double pass

- 50 W Seed Power, 330 fs pulses, 1.25 MHz
- Measured output power in double-pass: 1056 W
- Maximum pulse energy (1.25 MHz): 845 µJ
- Further measurements (M^2, AC, …) to follow
- Deliverable 1 kW (but with 200 W seed power in a later stage of the project)



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WP5 – The next six months…

- Implementation of pulse picking (to be implemented, but concept worked in other system)
- Analysis of double-pass experiments (1 kW)
- Pulse compression experiments to go to even shorter pulse durations
- Integration task ongoing in parallel
- First frequency conversion experiments

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

WP5 - Deliverables

Deliverable title	Due date	Status
D5.1 Design of the multipass amplifier	M06 – July 2016	Submitted
D5.2 Thin-disk multipass amplifier with 500 W, 1 MHz, sub-500 fs	M22- November 2017	Not yet submitted, but already fulfilled
D5.3 Demonstration of 200W green and 100W UV laser beams at 1MHz and sub-500 fs pulse	M28- May 2018	Not yet submitted, work ongoing
D5.4 Thin-disk multipass amplifier with 1000W, >=1MHz, sub-1ps	M38- March 2019	Not yet submitted, work ongoing, very confident

- No deviations to report (we are a bit ahead of schedule ☺).

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

WP6 System Development

Noémie Dury

C4L

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

Work Package 6: AMP, BOSCH, C4L, LASEA, USTUTT

- Overview
  - define **interfaces** and system features (2D; 3D), **integrate lasers**, optics and scanner in system for evaluation and **proof of concept** and to define the provision of **demonstrator platform**.
  - the system must be able to be operated in **an industrial frame** for the planned applications within HIPERDIAS.
  - **2 systems** are going to be developed on the basis of existing system at LASEA and C4L.

- Achievements
  - **Interfaces** have been defined and validated from all implicated partners.
  - **User requirements** have been defined and validated from all partners
  - **Systems Design** and **Build up** has been started

- Deviations and proposed corrective actions:
  - **No deviations** for the moment

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

WP6 – Task 6.1: Definition of interfaces

- Overview (AMP, BOSCH, C4L, LASEA)
  - Information has been exchanged between partners to define the best the required interfaces from all involved partners. Interfaces means mechanical, optical, as well as electronics and user control interface. Deliverable 1.4 display the defined interfaces.
- Achievements…
  - Definition of interface has been completed. Deliverable 1.4 displays the defined interfaces.
- Deviations and proposed corrective actions
  - **No deviations** for the moment

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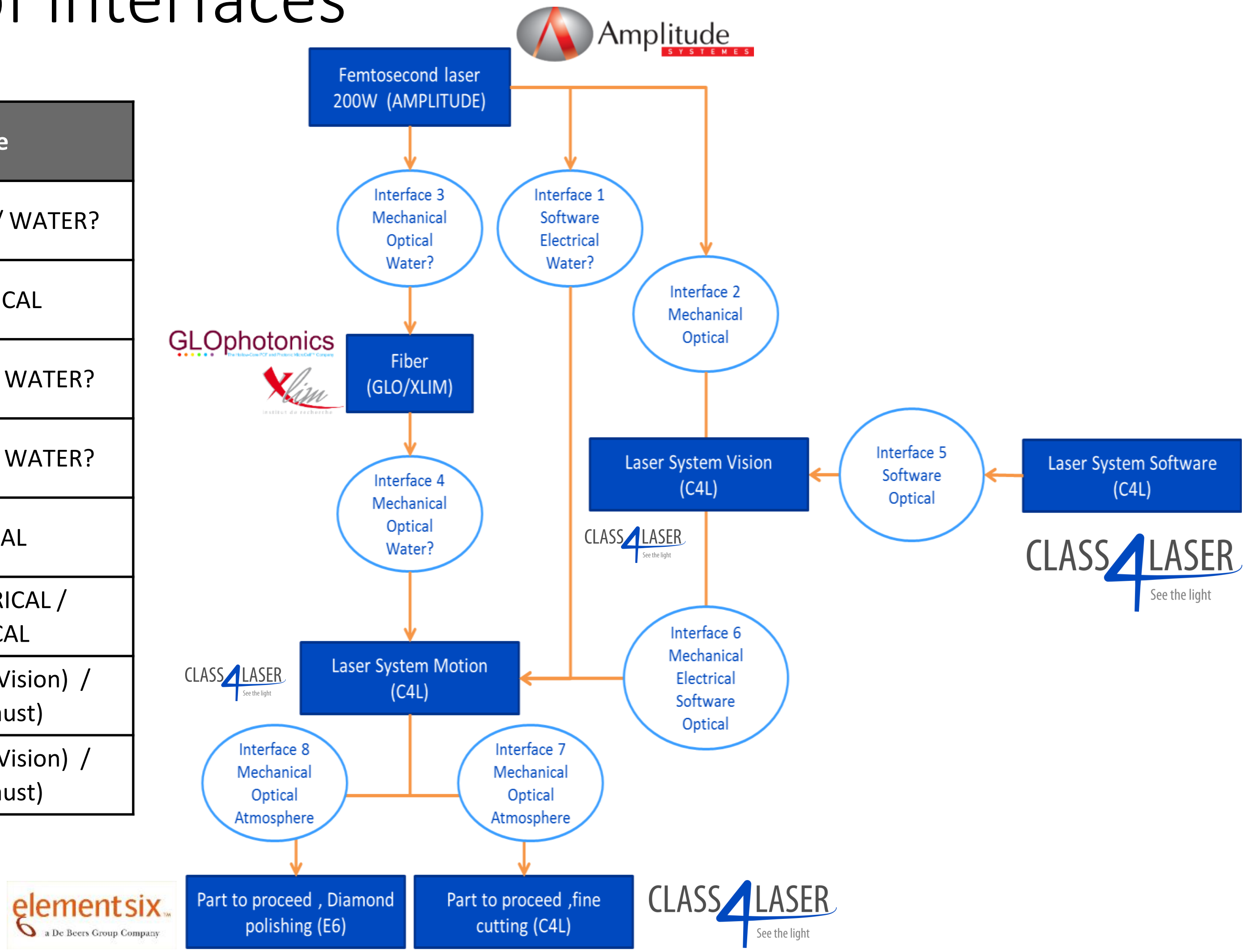
WP6 – Task 6.1: Definition of interfaces

Interface number	Partners involved	Type of interface
1	AMP ◂◂ ▸▸C4L (Motion)	SOFTWARE/ ELECTRICAL/ WATER?
2	AMP ◂◂ ▸▸C4L (Vision)	MECHANICAL/ OPTICAL
3	AMP ◂◂ ▸▸ GLO-XLIM (Fiber)	MECHANICAL/ OPTICAL/ WATER?
4	GLO-XLIM (Fiber) ◂◂ ▸▸ C4L (Vision/Scanner)	MECHANICAL/ OPTICAL/ WATER?
5	(Software) C4L ◂◂ ▸▸C4L (Scanner/Motion/Vision)	SOFTWARE/OPTICAL
6	(Scanner/ Vision) C4L ◂◂ ▸▸C4L (Motion)	MECHANICAL/ ELECTRICAL / SOFTWARE/ OPTICAL
7	(Machine) C4L ◂◂ ▸▸C4L (Part to Proceed)	MECANICAL / OPTICAL (Vision) / ATMOSPHERE (Exhaust)
8	(Machine) C4L ◂◂ ▸▸E6 (Part to Proceed)	MECANICAL / OPTICAL (Vision) / ATMOSPHERE (Exhaust)



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WP6 – Task 6.1: Definition of interfaces

Type of interface	Description	AMP : Laser 50W	USTUTT : Booster
Mechanical	Dimensions	0.5x0.33x0.12 m	2x1x0.7m
	Weight	80 kg	400 kg
	Material	Aluminum	Alu/Cu/Steel
	Cautions	Heavy, To not shock	Very heavy
	Fixings	Clamped feets or screwed baseplate	3 points mounting feet
	Mechanical drawing file (YES/NO)	Yes, is provided with the manual	NO
Electrical	Voltage	N/A	N/A
	Max current	N/A	N/A
	Power	N/A	N/A
	PSU: external/to integrate?	N/A	N/A
	Electrical drawings files	N/A	N/A
Software	Protocol of communication	N/A	N/A
	Table of commands file	N/A	N/A
Optical	Output wavelength	1030 nm	N/A
	Output pulse duration	350 fs	N/A
	Output beam size (1/e2)	2.5mm	N/A
	Output max average power	75W	N/A
	Output max peak power	200 MW	N/A
	Output beam height (mm)	73mm	N/A
	Appropriate safety googles	References will be provided	N/A
	Input wavelength	N/A	1030 nm
	Input Pulse duration	N/A	350fs
	Input Beam size (1/e2)	N/A	4 mm
	Input max average power	N/A	75 W
	Input max peak power	N/A	200 MW
	Input beam Height (mm)	N/A	Flexible height (Lift)
	Appropriate Safety googles	N/A	N/A
Water	Diameter of pipes	N/A	N/A
	Flow rate	N/A	N/A
	additive	N/A	N/A
	Chiller?	N/A	N/A

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WP6 – Task 6.2: Definition of laser & optics sizes; optics specification (incl. fiber)

- Overview (AMP, C4L, GLO, LASEA)
  - The user requirements have been discussed between involved partners and **trials have been completed** from the end user in order to give the most precise information to the laser and system manufacturer. Thanks to these trials and discussions, **specification could be established and described in D1.2 and 1.3.**
- Achievements…
  - **Users requirements have been mostly defined**. Final specifications are due in the next 3 months. Definition of user requirement are summarized in **D1.2 and 1.3**
- Deviations and proposed corrective actions
  - **No deviations** for the moment

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WP6 – Task 6.2: Definition of laser & optics sizes; optics specification (incl. fiber) – **System 1 & 2**

- Achievements…
  - Handle the **very high laser power** without damage to optical elements and without influence of laser power variations on the phase front distribution.
  - suitable for pulse durations down to **1 ps at a pulse energy of 0.5 mJ**
  - Handle the high average power, the **beam should exhibit a large diameter** (e.g. >10 mm). All apertures must be larger than twice the beam passing the aperture to avoid diffraction.

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WP6 – Task 6.2: Definition of laser & optics sizes; optics specification (incl. fiber) – **System 1**

- Achievements…
  - Using a **large focal length** of the focusing device (e.g. 500 mm) may prove beneficial to achieve highest scanning dynamics with large incoming beam sizes.
  - presumably **synchronization of laser performance** (pulse energy, pulse repetition frequency) with scanner dynamics. Thus, fast and flexible triggering (ideal: pulse on demand) and fast power variation are necessary.

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WP6 – Task 6.2: Definition of laser & optics sizes; optics specification (incl. fiber) – **System 2**

- Circular polarized beam
- TEM 00
- Rotation optic (for cutting)
- Galvanometer scanner (Intelliscan from Scanlab)
- 80 mm to 160 mm focal length
- Direct beam cutting optic
- Closed loop Vision System & topography (For Diamond)

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WP6 – Task 6.4: **System 1** layout and build-up

- Overview : (LASEA)
  - The design of the setup N°1 has been started by the design department of LASEA. Different components have been designed and assembled together such the granit, the gantry, mechanical axes, and all the necessary opto-mechanical parts.

Design of the system, choice of the different components :

- Deflecting unit : Scanlab Intelliscan 30 + Varioscan (focusing before scanner)
- Autoalignment system : TEM-MESSTECHNIK Aligna
- Beam expander : really necessary ?, given the use of the Varioscan
- Safety enclosure : made of steel, 1.5mm thick, no window

  → Waiting for more information regarding the risk of generation of X-rays, preliminary calculations announces important risks
- Spatial beam shaping : needed? → under investigation, and for further discussions

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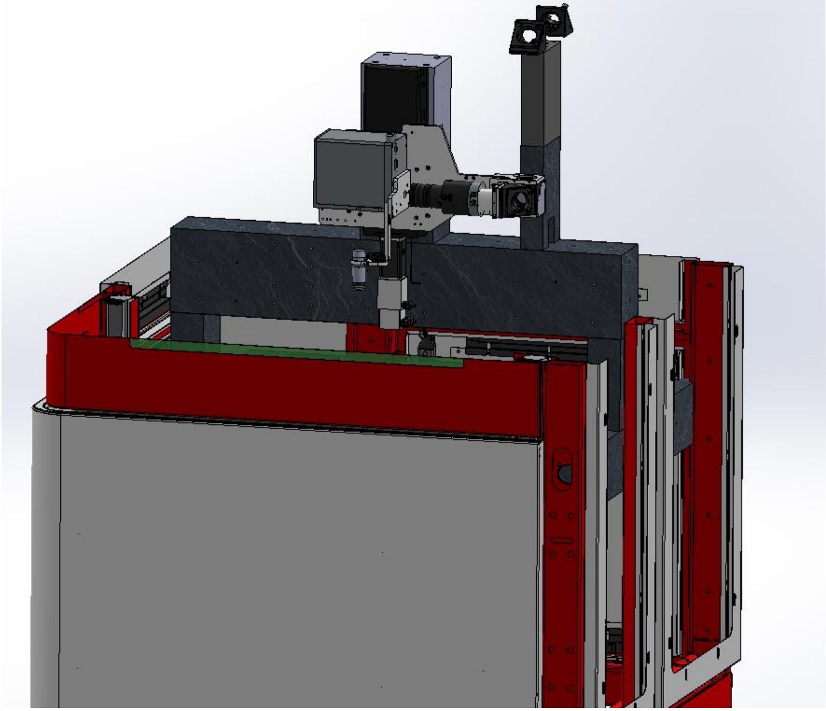
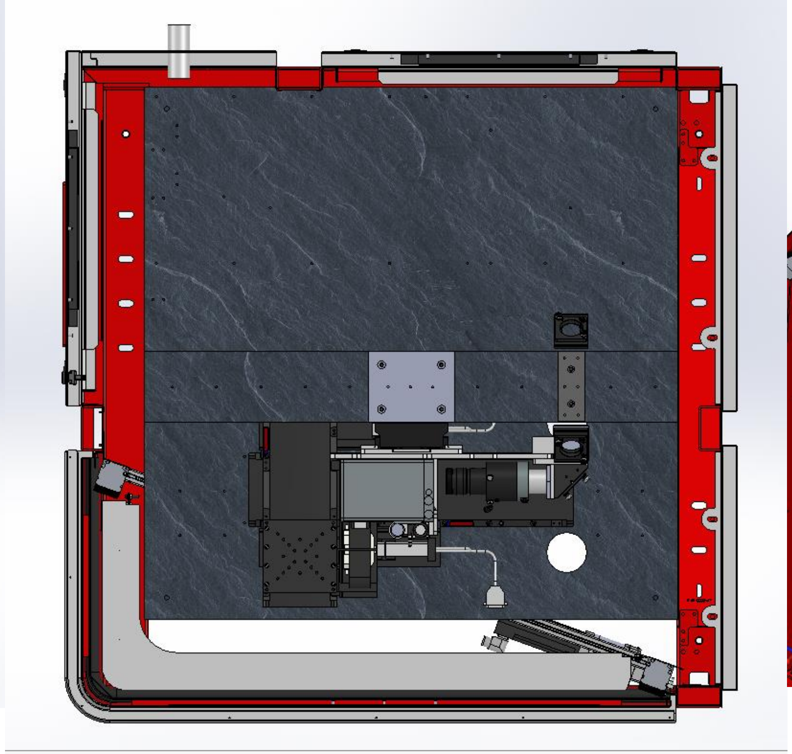
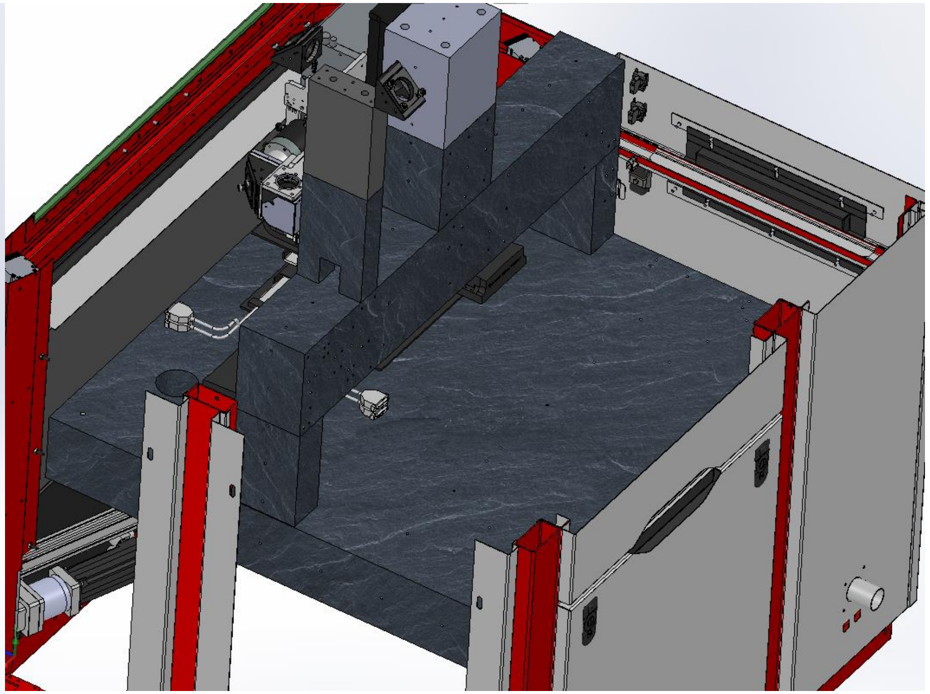
WP6 – Task 6.4: **System 1** layout and build-up

- Achievements: design of the system







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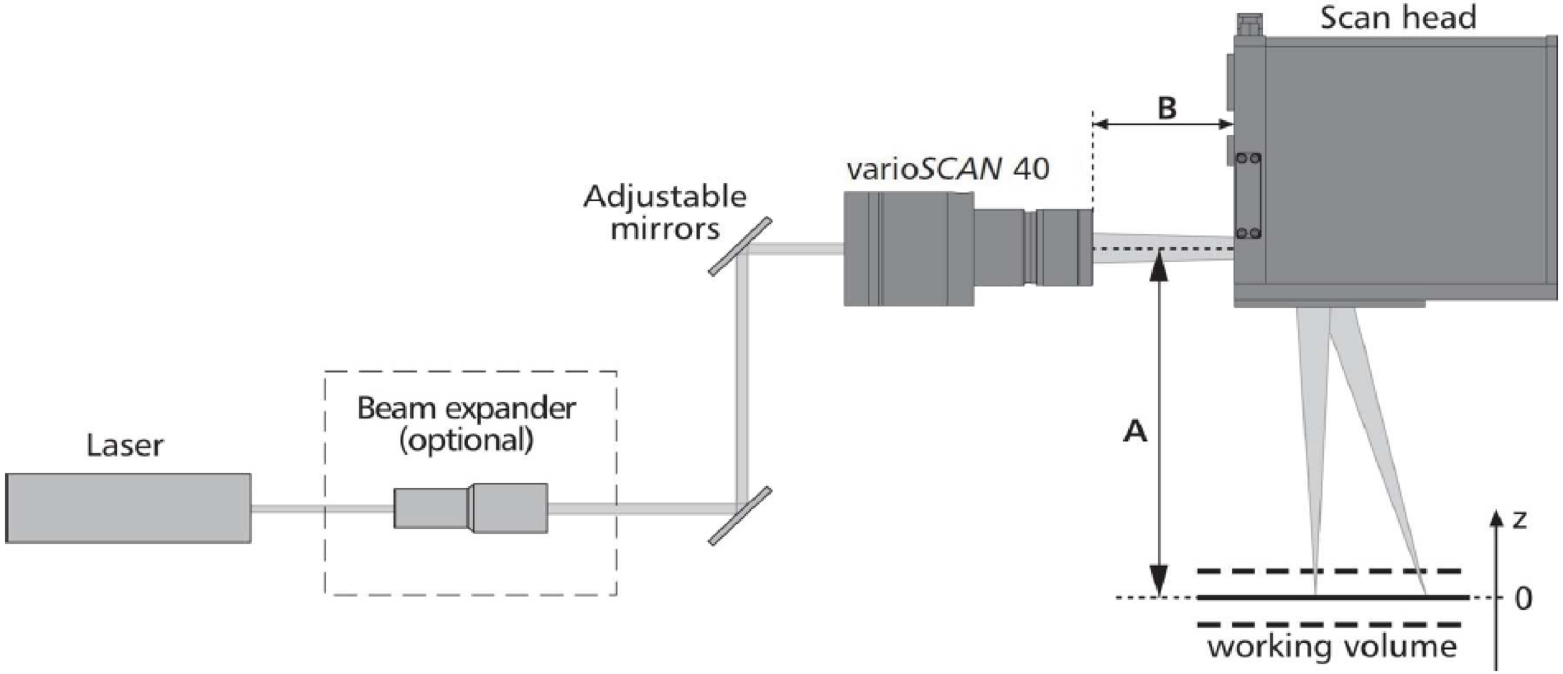
WP6 – Task 6.4: **System 1** layout and build-up

- Achievements: integration of Scanlab Head

- Max avg power : 1000 W
- Spot diameters : 50 – 65µm
- Max marking speed : ~4.5m/s
- Field of view : ~310 x 310 mm²



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WP6 – Task 6.4: **System 2** layout and build-up

- Overview (C4L)
  - The system n°2 layout have been **defined and designed.** The different components have been ordered and a large part of them have been delivered: granite, axes, optical table. **Granite and axes have been built-up**. Software is started. Optical system, most especially the scanning and vision system development have been started and are on going.
  - More information are required concerning the **generation of X-Rays** and the required shielding for the foreseen intensity before starting the design / build up of the shielding.

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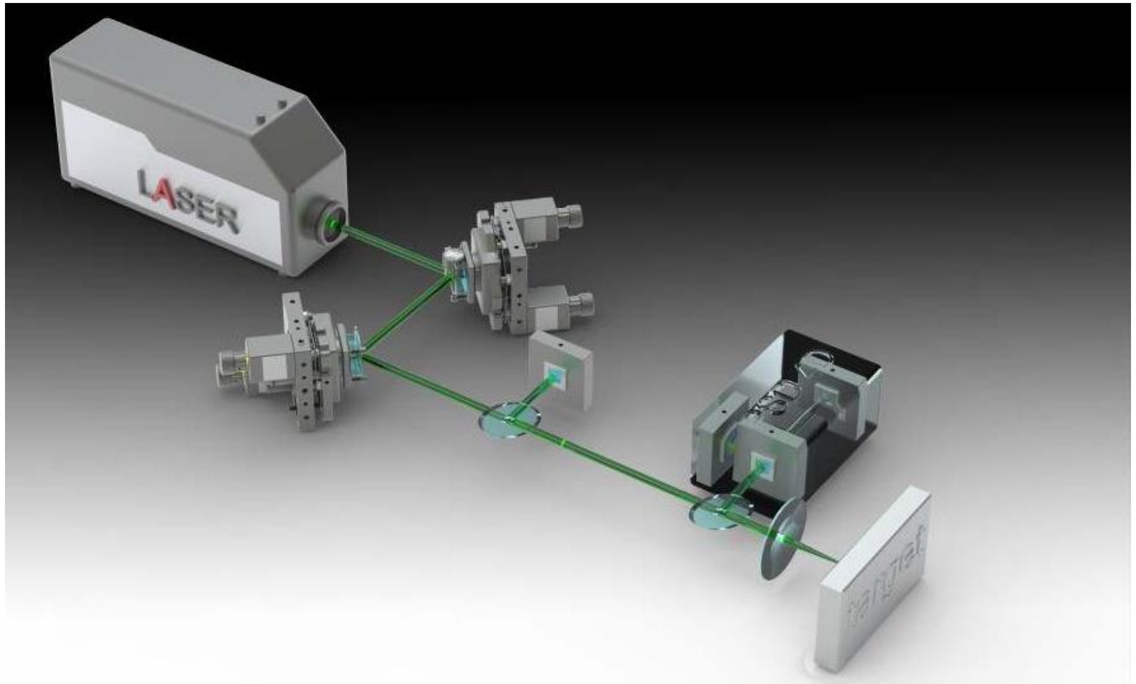
WP6 – Task 6.5: Integration of laser and optics

This task is at its very beginning. The two partners building systems #1 and #2 have started to work on the integration of laser (work on the interfaces, D6.1) and of the optic. Definition of optic as well as the ordering process is on-going and in tracks.

- Achievements : Auto-alignment system
- **System 1**
  - Sampling done with 1mW
  - Measurment resolution : < 1ms
  - Time to move mirrors : tens of ms
  - Often used to compensate air fluctuation (~10Hz)



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WP6 – Task 6.4: **System 2** layout and build-up

- Achievements

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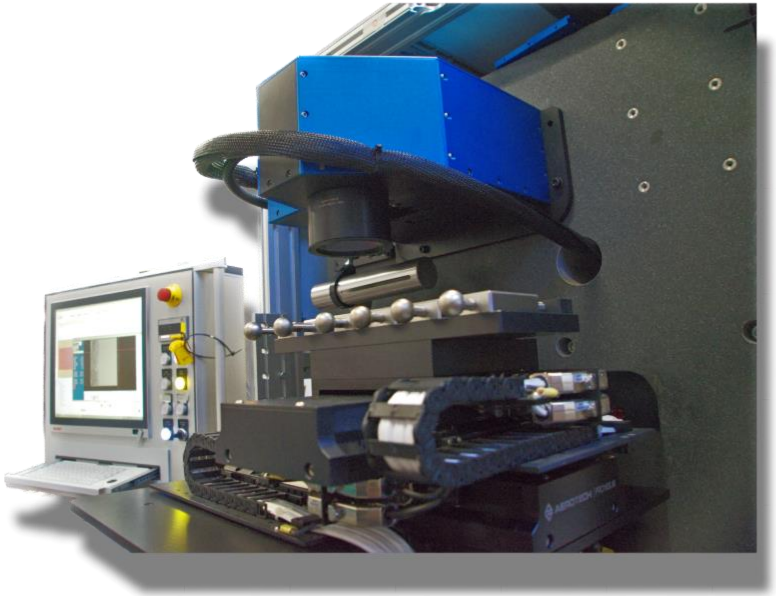
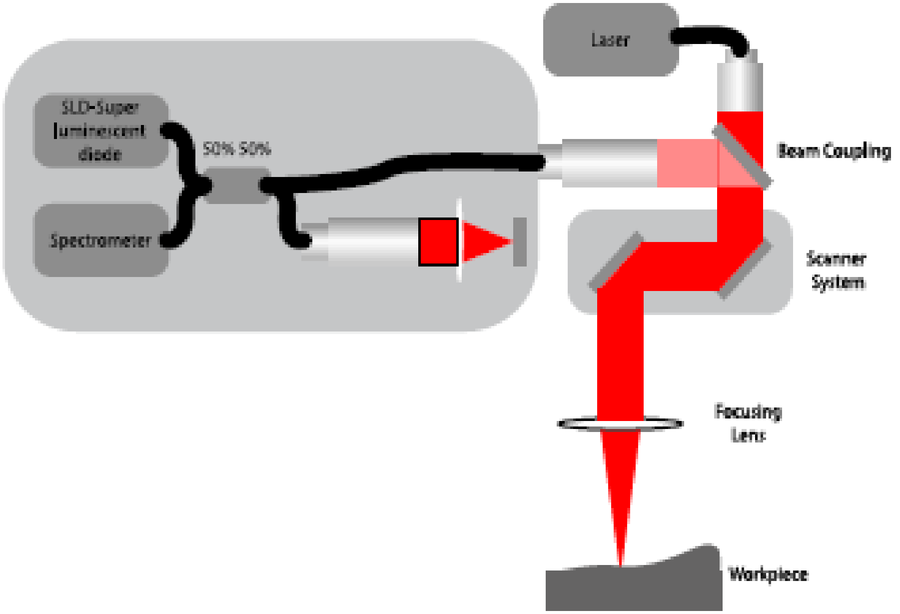
WP6 – Task 6.5: Integration of laser and optics

- Achievements: **System 2**
  - C4L has defined the interfaces required for the integration, the optical tables have partially defined, ordered and delivered. Remaining Optical components have been partially defined and ordered.

- Max avg power : 200 W
- focus diameter : 15 – 30 µm
- Max scanning speed : ~3 m/s
- Max rotating speed: TbD
- Working field: ca. 80 x 80 mm





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WP6 – The next six months…

- Order the remaining components for the systems
- Integrate optics and finalized the systems to be ready to welcome the lasers
- Start to integrate the lasers

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WP6 – The next six months…

Task 6.5: Integration of laser and optics System 1

- Achievements : Delivery planning

	janv-17	févr-17	mars-17	avr-17	mai-17	juin-17	juil-17	août-17	sept-17
Granit									
Axes									
Scanner head									
Auto-alignment									
Caméra									
Enclosure									
Beam shaping (?)									

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WP6 - Deliverables

Deliverable title	Due date	Status
D6.1 Definition of interfaces (LASEA)	M12 – January 2017	SUBMITED
D6.2 Definition of optics constraints (USTUTT)	M15 – April 2017	

WP6 - Milestones

Milestone title	Due date	Status
MS16 System layout fixed	M12 – January 2017	ACHIEVED FOR BOTH SYSTEMS

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WP8 Dissemination & Exploitation Planning

James Clayton
KITE Innovation (Europe) Ltd

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

Presentation Content:

- Overview of Work Completed by M12

Objectives of this meeting:

- Upcoming Conferences and ensure that we follow the IP Management process.
- Training and look at ways of how the Consortium can excel at this Task.
- Interviews - this will form more dissemination videos
- Exploitation Planning – 1st Workshop
  - SQUADRON™ - Segmentation and Quality Requirement
  - PESTLE Analysis

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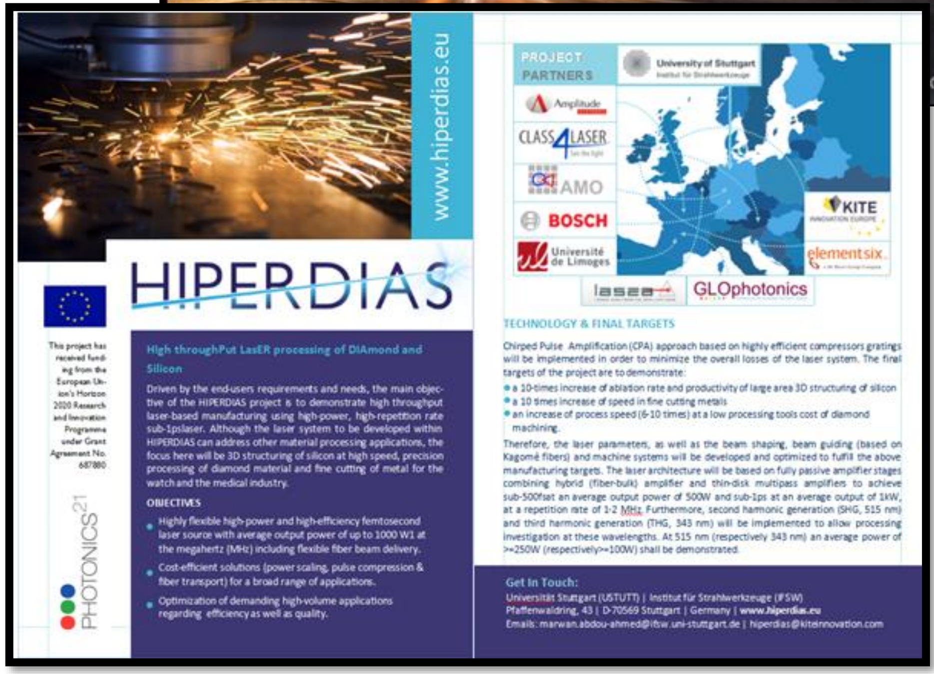
HIPERDIAS – Overview at M12

- HIPERDIAS Website: www.hiperdias.eu
- Press Release
- Two project videos
- Communication Kit
- Initial Dissemination and Exploitation Strategy



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Dissemination Activities / Management of IP

List of upcoming Conferences:

- Photonics 21 Annual Meeting in Brussels, Belgium: 28th and 29th March 2017.
- LPM 2017 in Toyama, Japan: 5th June to 8th June 2017.
- EMT 2017 in Grand-Saconnex, Switzerland: 22nd June 2017.
- CLEO®/Europe-EQEC 2017 in Munich, Germany: 25th June to 29th June 2017.
- LiM 2017. Lasers in Manufacturing Conference in Munich, Germany: 26th June to 29th June 2017.
- **Any more…**

Remember when disseminating Project Results to complete an IP Notification Form (e.g. Publications / Conference Abstracts / Invited Talks etc.).

HIPERDIAS Grant Agreement: 687880

Pre-Publication Intellectual Property Notification	
Lead Author	
Partner Name	
Title	
Reference	*<yymmdd>/<1-n>/USTUTT* e.g. 121106/1/USTUTT
Submitted to	*<name of journal, conference, etc>*
Expected date of publication / conference	
I have reviewed the contents of this submission and … *(select one of the options below)*	
a. It does not contain any intellectual property capable of commercial application	
b. It does or may contain intellectual property capable of commercial application which the beneficiaries will seek to protect	
c. It does or may contain intellectual property capable of commercial application but the beneficiaries will not seek to protect	

I understand that by selecting an option other than (b) subject to the agreement of the HIPERDIAS Technology Transfer Panel, the Co-ordinator (University of Stuttgart) may file the publication with the European Patent Office to obtain a priority date. This will allow the publication to proceed while providing a period of 12 months for further consideration and review of the IP position.

Signed	
Date	

When signed, e-mail a pdf version of this form to the Central Project Office (hiperdias@kiteinnovation.com) along with the draft publication.

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Dissemination Activities

HIPERDIAS

Short Interviews:

An extended video outlining:

1. The aims of the HIPERDIAS Project
2. The roles and responsibilities within the Project
3. The potential applications
4. The importance the EU Funding

Min. 1 person per partner.

Interview questions:

General Questions - About the HIPERDIAS Project (All Partners):

- What is the HIPERDIAS Project about?
- What are the aims and objectives of the HIPERDIAS project?
- How is the Consortium going to achieve its aims and objectives?
- What are the potential end applications and their benefits?

Partner Questions (All Partners):

- What is your organisation/institution role within the HIPERDIAS Project?
- What does your organisation/institution hope to achieve from the HIPERDIAS Project?
- What are benefits of EU Funding to your organisation/institution?
- What are benefits of having partners from across Europe?
- What are the main challenges and risks within the project?

Questions about H2020 & Leading a H2020 Project (USTUTT):

- Why do you think the HIPERDIAS project was originally funded?
- Where did the concept of the HIPERDIAS Project originate from?
- Why is HIPERDIAS such an important Project?
- What makes a successful Consortium/Project?

Applications – (C4L, BOSCH & E6)

- What are the potential applications?
- What are the benefits of this application to stakeholders?
- What are the benefits of these applications to your organisation?

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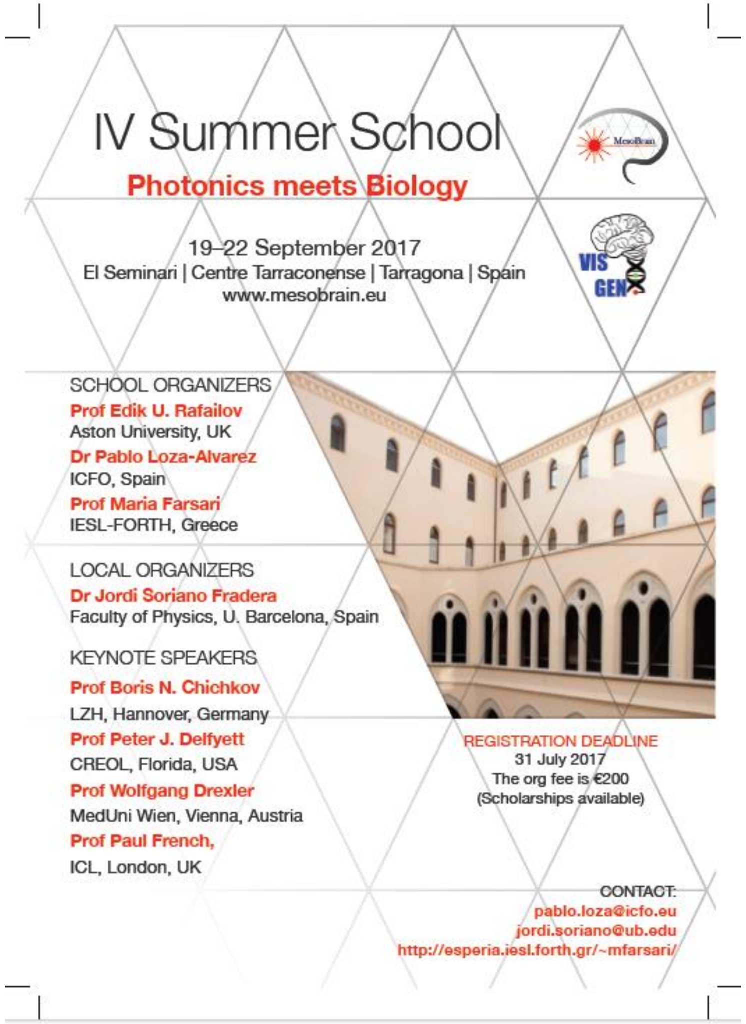
Training / Training Workshops (MS22)

- Training Workshop (2-3 Days)
  - Location/Venue
  - Collaborate with other EU-Funded Projects…
    - TresClean – Coordinated by UNIPR. www.tresclean.eu
    - HiperLAM – Coordinated by ORBTX. www.hiperlam.eu
  - Dates… October/November 2017
  - Target Audience… PhD Students
  - Numbers / Speakers… 50+
  - Budget… 20-30K Euros

- Exchange Opportunities / Short Secondments: Knowledge Transfer between Partners.



Example from the MESO-BRAIN / VISGEN Project

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Exploitation Planning

Recap:

- **Research:** Further research opportunities (Horizon 2020 e.g. ICT 30 – Photonics KET).
- **People:** Career Pathways (PhD Students / Post-Docs). MS22 Training Workshop / Exchange Opportunities.
- **Product and services:** SQUADRON™ Approach

A) Where are we now? → *B) Where are we going?* → *C) How do we get there?* →

PROCESS ELEMENT	1.	2.	3.	4.	5.	6.	7.
	Segmentation – defining market segments for focused development	**Q**uality Requirements	**A**ttractiveness	**D**eliverables	**R**anking	**O**perationalising	**N**ew Income Streams
H2020 PROPOSAL ELEMENT	Concept & Impact	State of the Art (SOA) & Beyond	Impact	Scientific & Technological Methods	The proposal document will not be able to contribute		Post Project

(The SQUADRON is Trademark of Kite Innovation (Europe) Ltd)

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

Exploitation Planning – Segmentation / Quality Attractiveness

"**Segmentation** is a marketing **strategy** that involves dividing a broad target market into subsets of consumers who have common needs and desires as well as common applications for the relevant goods and services".

The **Quality Requirements** are the tech. specification for the identified products and services.

A) Where are we now? *B) Where are we going?* → *C) How do we get there?* →

PROCESS ELEMENT	1.	2.	3.	4.	5.	6.	7.
	Segmentation – defining market segments for focused development	**Q**uality Requirements	**A**ttractiveness	**D**eliverables	**R**anking	**O**perationalising	**N**ew Income Streams
H2020 PROPOSAL ELEMENT	Concept & Impact	State of the Art (SOA) & Beyond	Impact	Scientific & Technological Methods	The proposal document will not be able to contribute		Post Project

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Exploitation Planning – Segmentation / Quality Requirements

PRODUCT / SERVICE	APPLICATION AREA		
Objectives 1 – High-power (kW-Class) ultrafast MOPA System **Objectives 2 –** High efficient compressor gratings **Objectives 3 –** High-power high-efficiency fibre beam delivery system	a) 3D silicon machining	B) Diamond Polishing	c) Fine cutting of metals and glass cutting (e.g. Sapphire)
1. **BOSCH/LASEA –** Laser machining system. Development of the 3D Si processing.	WP1 Presentation Task 1.2 specification & Task 1.3 KPIs.		
2**. E6 –** Laser machining system.		WP1 Presentation Task 1.2 specification & Task 1.3 KPIs.	
3. **C4L –** Laser machining system.			WP1 Presentation Task 1.2 specification & Task 1.3 KPIs.

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Exploitation Planning – Segmentation / Quality Requirements

PRODUCT / SERVICE	APPLICATION AREA				
	a) Micro maching Glass cutting	b) Defractive optics defractive optic elements	c) Ultra fast laser system	d)	e)
AMP – New high power fs laser product and flexible laser control (existing and new products – 50w and 200w laser).	X				
AMO – Further development of manufacturing process and know-how.		X			
XLIM/GLO – Improve and industrialize hollow-core photonic Crystal-Fibre system	X		X		
USTUTT/AMO/AMP - Gratings. (ÙSTUTT) martek photnics spin off company.		X			
USTUTT/AMP – Thin disk Amplifier (>500W)	X				

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PESTEL Analysis

POLITICAL

Will the potential for exploitation of any elements of the project be affected by external policy? Or will the project have an impact on policy?

Exporting of Laser System across the EU. SWISS reform.

Other EU Countries leave the EU.

KITE: *BREXIT and potential access to EU Funding*

ECONOMICAL

What factors will impact on the economic success of the project? What economic impact will the project have on the sector, the EU, globally?

US protectionism. Influences on trade across the world.

KITE: *The strength of the pound sterling against the EURO*

SOCIAL

Is the success of the project dependent on societal acceptance in any way? Will the success of the project have a societal impact?

.

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PESTEL Analysis

TECHNOLOGICAL

What advances might affect the impact of the project? What innovative technologies might the project impact?

.

ENVIRONMENTAL

What legislation/regulation might affect the impact of the project? Might the project have a legislative/regulatory impact - national, EU, globally?

KITE: *BREXIT and potential access to EU Funding*.

LEGAL

Are there any potential environment factors which might affect the impact of the project? What environmental advantages may accrue from the project?

.

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WP8 – The next six months…

- Preparation for the Review Meeting
- Process Interviews
- Training Workshop (MS22)
- Exchange Opportunities / Short Secondments
- Post Exploitation Analysis.
- Start working on D8.5 – Communication Kit. Partners expectations…

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WP8 - Deliverables

Deliverable title	Due date	Status
D8.1 Project website established	M03 – April 2016	Submitted
D8.2 Communication kit	M03 – April 2016	Submitted
D8.3 Video presentation of the HIPERDIAS project	M04 – May 2016	Submitted
D8.4 Draft Exploitation and dissemination plan	M12 – January 2017	Submitted
D8.5 – Communication Kit mid-term update	M24 – January 2018	Ongoing…

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WP8 - Milestones

Milestone title	Due date	Status
MS1 Press release	M01 – February 2016	Achieved
MS17 – Agreement on draft exploitation and use plan	M14 – March 2017	Achieved
MS22 First project workshop held	M18 – July 2017	Ongoing

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WP9 Project Management

USTUTT supported by KITE

Emma Bowden

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

Work Package 9 Overview

- Change in personnel at Kite
  - Project Management - Julie Devall has left, Emma Bowden has moved from other projects to HIPERDIAS
  - James Clayton is Kite Dissemination & Exploitation lead
  - Continue to use hiperdias@kiteinnovation.com for all email communications
- Consortium bodies established
- Communication processes set up
- Consortium meetings organised
- Currently coordinating 1st Periodic Review
- Grant Agreement Amendment awaiting approval of PO

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WP9 – Task 9.1: Management and coordination of the project

- All due Deliverables have been submitted
- The next Deliverables are:

D#	Deliverable name	Lead	Diss. level	M	Due
D9.2	1st Periodic Report	USTUTT	Confidential	14	Mar-17
D6.2	Definition of optics constraints	USTUTT	Confidential	15	Apr-17
D6.3	System layout	C4L	Confidential	17	Jun-17
D4.3	Report on fabrication and optical characterization of optimized gratings with single-pass diffraction efficiency >-99% over large spectral bandwidth (5-10nm) around 1030 nm	AMO	Confidential	18	Jul-17
D3.3	200-W, 500-fs>1-MHz laser (1)	AMP	Confidential	21	Oct-17
D3.4	200-W, 500-fs>1-MHz laser (2)	AMP	Public	21	Oct-17
D5.2	Thin-disk multi-pass amplifier with 500W, 1MHz, sub-500fs (1)	USTUTT	Confidential	22	Nov-17
D5.3	Thin-disk multi-pass amplifier with 500W, 1MHz, sub-500fs (2)	USTUTT	Public	22	Nov-17

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Milestones overview

MS#	Title	WP#	Lead	M#	Status
MS1	Press release	WP8	KITE	1	Achieved
MS2	Kick off meeting and election of members of consortium bodies	WP9	KITE	2	Achieved
MS3	First design, high efficient grating mirrors	WP4	USTUTT	3	Achieved
MS4	PMC module for fibre beam delivery prototype #1	WP4	GLO	6	Achieved
MS5	Specification for laser parameters established	WP1	BOSCH	8	
MS6	1st generation grating mirror on large area, rectangular substrates fabricated	WP4	AMO	8	
MS7	Interface definition fixed	WP1, WP3, WP6	LASEA	8	
MS8	A 50W, 300fs at >1 MHz seed laser	WP3	AMP	9	
MS9	Completion of reporting 'dry run' with all partners	WP9	KITE	9	
MS10	Key performance indicators for productivity progress specified	WP1	BOSCH	10	
MS11	Key performance indicators for quality standards specified	WP1	BOSCH	12	
MS12	Specification system technology established	WP1	BOSCH	12	
MS13	Fully optical characterisation of grating mirror regarding diffraction efficiency and LIDT	WP4	AMO	12	
MS14	PMC module for fibre beam delivery prototype #2	WP4	GLO	12	
MS15	Design of HC-PCF with improved PER at 1µm (>20 dB)	WP4	XLIM	12	
MS16	System layout fixed	WP3, WP4, WP5, WP6	C4L	12	
MS17	Agreement on draft exploitation and use plan	WP8	KITE	14	
MS18	End-capping definition and process design	WP4	GLO	15	
MS19	PMC module for fibre beam delivery prototype #3	WP4	GLO	18	
MS20	Demonstration of optimized grating mirrors, 99% diffraction efficiency	WP4	AMO	18	
MS21	End-capped output PMC module for beam delivery	WP4	GLO	18	
MS22	First project workshop held	WP8	KITE	18	

The first 14 months

The next 6 months

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WP9 – Task 9.2: Financial management including auditing

- All financial information to be included in P1 report

WP9 – Task 9.3: Management of ethical and gender related issues

- Partners need to keep accurate personnel records
- Required aspect of reporting
  - Included in periodic and final reporting

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WP9 – Task 9.4: Establishment of consortium bodies, planning, organisation and administration of consortium meetings

- Consortium Meetings:
  - Bordeaux February 2016
  - Stuttgart September 2016
  - Aachen March 2017
  - Next meeting is the review meeting
  - Next consortium meeting date and location?
- Consortium bodies
  - MB, TTP & STB to meet tomorrow
  - External Advisory Board needed
    - Any suggestions? Interested organisations?

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WP9 – Task 9.5: Management of the consolidation of technical and financial reports and communications with the Commission

- 1st Periodic Report is under way
  - All partners should have completed financial reporting
  - Final information being collated
  - Report to be submitted before end of March
- GA Amendment under way to add CNRS as a linked third party for XLIM
  - Currently with the Commission for approval
  - Should be approved in time for XLIM / CNRS to submit personnel claim this period
  - No action required from other partners

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WP9 – The next six months…

- Review meeting (Brussels)
  - Rehearsal 6th June
  - 7th June 2017
- Internal reporting schedule
  - Technical – quarterly
  - Financial – suggest half way through RP2 – M21
- Continue monthly TCs – recurring appointment in calendar

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WP9 - Deliverables

Deliverable title	Due date	Status
D9.1 Project management handbook	M01 – February 2016	Submitted
D9.2 1st periodic report	M14 – March 2017	In progress!

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

WP9 - Milestones

Milestone title	Due date	Status
MS1 Press release	M01 – February 2016	Achieved
MS17 – Agreement on draft exploitation and use plan	M14 – March 2017	Plan to be distributed and agreement sought from partners
MS22 First project workshop held	M18 – July 2017	

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WP1 Definition of User Requirements

Martin Lustfeld

BOSCH

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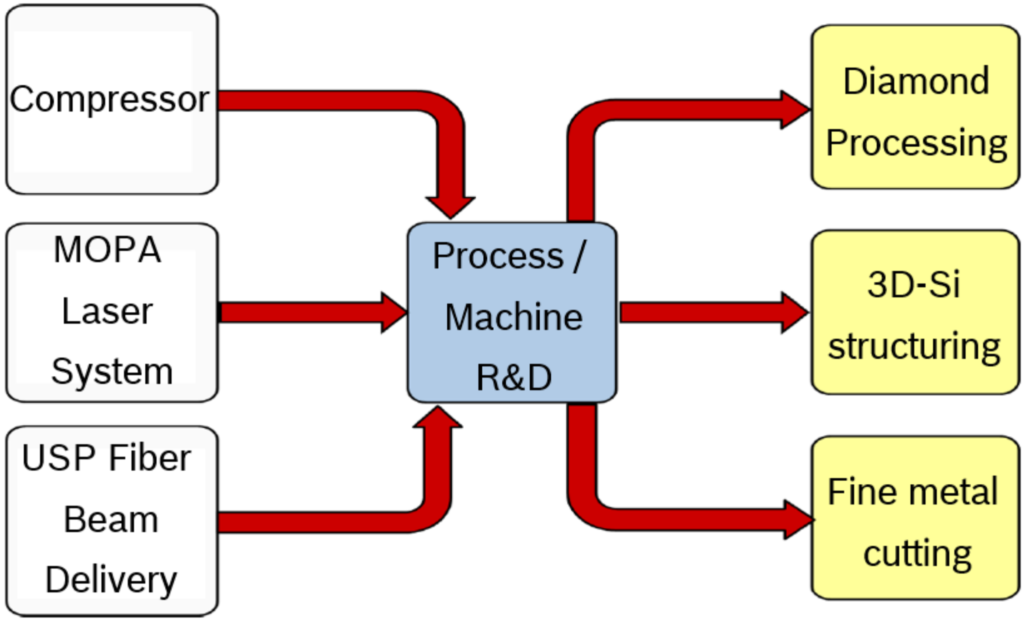
Work Package 1

- 3 applications w/ individual requirements:
  - Quality
  - Cost/Productivity
  - Compatibility to manufacturing environment
- HIPERDIAS objectives/benefits:
  - Product enabling (Si structuring)
  - Product enhancement and cost reduction (diamond processing, fine metal cutting
- WP1 objectives:
  - Align product/process requirements w/ system developers‘ approach
  - Create basis to track progress throughout project



- Partners involved
  - End-users: Bosch, C4L, E6
  - System Development: USTUTT, AMP, AMO, XLIM, LASEA, GLO

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WP1 – Task 1.2: Process and System Specifications (BOSCH, E6, C4L, AMP, AMO, LASEA, USTUTT)

- Scope, objective:
  - Translate end-user requirements into system specifications
  - Expert interviews + scientific literature study at end-users
  - Trial experiments to identify initial parameter set
- Aspects considered:
  - Laser source: power, wavelength, pulse duration
  - Optics: focal length, focal spot size, scanning speed, maximum allowable fluence
  - System design: safety, reliability, compatibility w/ manufacturing environment
  - Process control: beam stabilization, synchronization of scanner / laser
- Achievements
  - Identification of suitable parameter ranges
  - Agreement on design specifications for all HIPERDIAS processes

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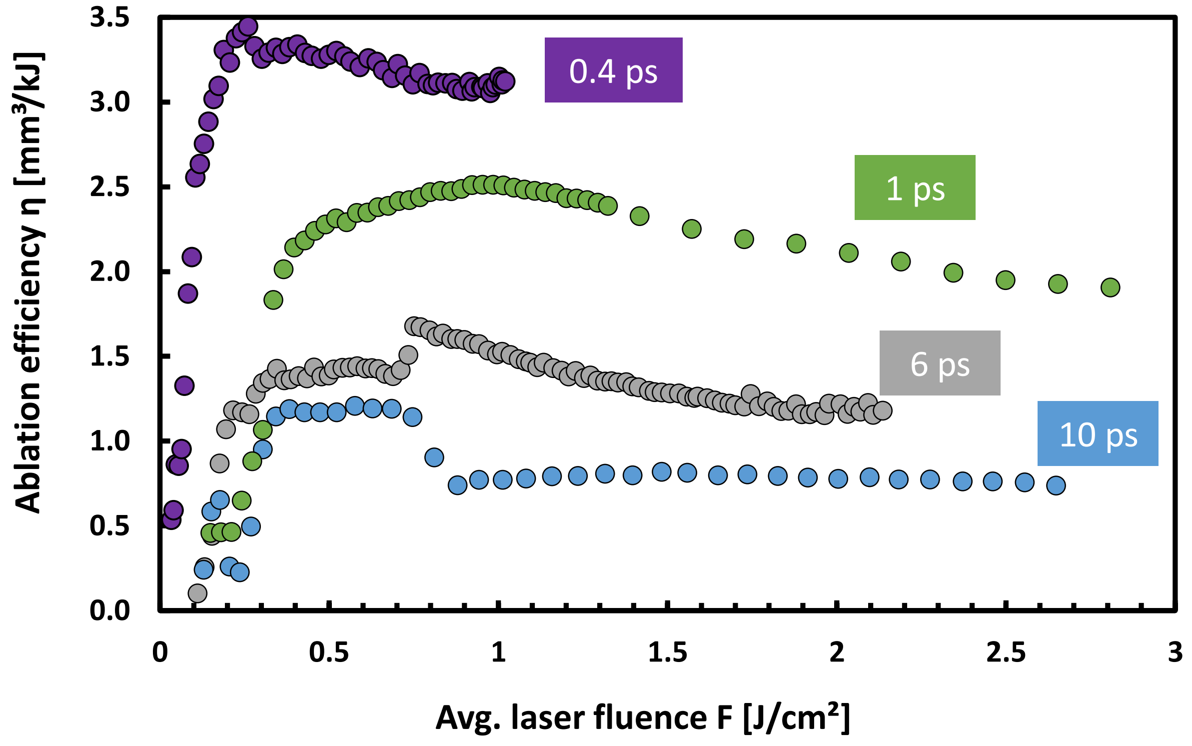
WP1 – Task 1.2: Bosch (3D silicon processing)

- Laser source:
  - P = 1000 W
  - f ≤ 2000 MHz
  - E ≥ 0.5 mJ
  - τ = 0.4 … 10 ps (trade off quality ⬄ efficiency, tbc.)
  - Burst capability (≥ 2)
- Beam delivery:
  - Optics w/ high-quality coatings (suitable for E, τ)
  - Large primary beam diameter (≥ 10 mm)
  - Focal spot diameter < 200 µm
  - High scanning dynamics incl. synchronization
- Laser machining system:
  - Safety: Exhaust system, x-ray shielding
  - Handling: State-of-the-art NC system for 200 mm wafers
  - HMI: Easy-to-use hand-wheel operation + batch programming



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WP1 – Task 1.2: C4L (fine cutting of metals)

Laser specification	Symbol	Unit	Value
Wavelength	λ	nm	1030
Pulse duration	τp	fs	290- 500
Repetition rate MAX	frep	kHz	1000
Average power MAX	Pmax	W	5
Pulse energy MAX	Emax	µJ	85
Beam quality factor	M^2	–	1.1
Focus radius (x)	dfx	µm	15-30
Focus radius (y)	dfy	µm	15-30
Focal length	F	µm	80-160

KPI	Benchmark Laser Performances	C4L Specifications for the HIPERDIAS Laser
Average power	5W	200W
Pulse duration	230-20'000 fs	Tuneable around 500 fs (range to be discussed)
Repetition rate	60KHz-1MHz	100KHz-2MHz
Pulse energy	Max 85µJ	200µJ – higher to be disccussed
Wavelength	1030 nm	1030 nm
Beam quality factor	TEM 00 – 1.1	TEM 00 – 1.1
Output Beam diameter (before BE)	5mm	Approx. 5mm

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WP1 – Task 1.2: C4L (fine cutting of metals)

- Laser machining system and beam delivery:
  - Safety: Exhaust system, possibly x-ray shielding
  - Handling: State-of-the-art NC system, flexible system to shift from optic to optic
  - Scanning system
  - Trepaning optic
  - Vision system for identification of parts

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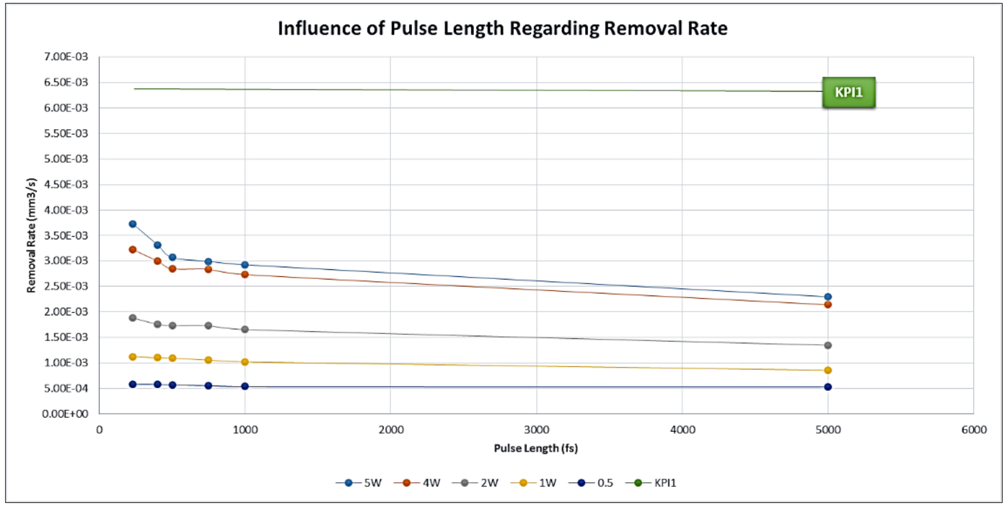
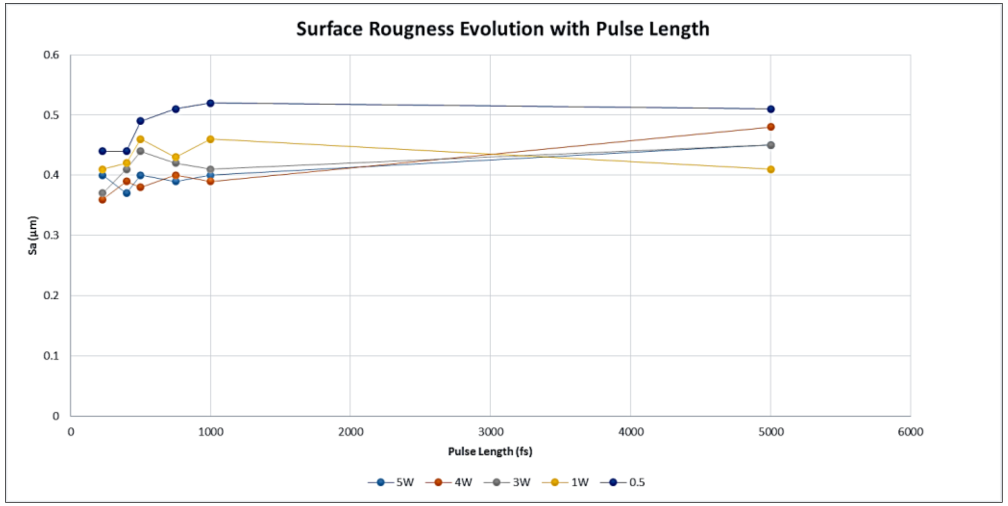
WP1 – Task 1.2: E6 (diamond polishing)

- Pulse Duration
  - Removal Rate
  - Increase of removal rate when pulse duration is reduced
  - Phenomenon with higher importance when average power is increased
  - Surface Roughness
  - Drop when pulse duration below 1 ps
  - Not high variation for femtosecond pulses
  - Conclusion
  - Lowest pulse duration requested (< 500 fs)





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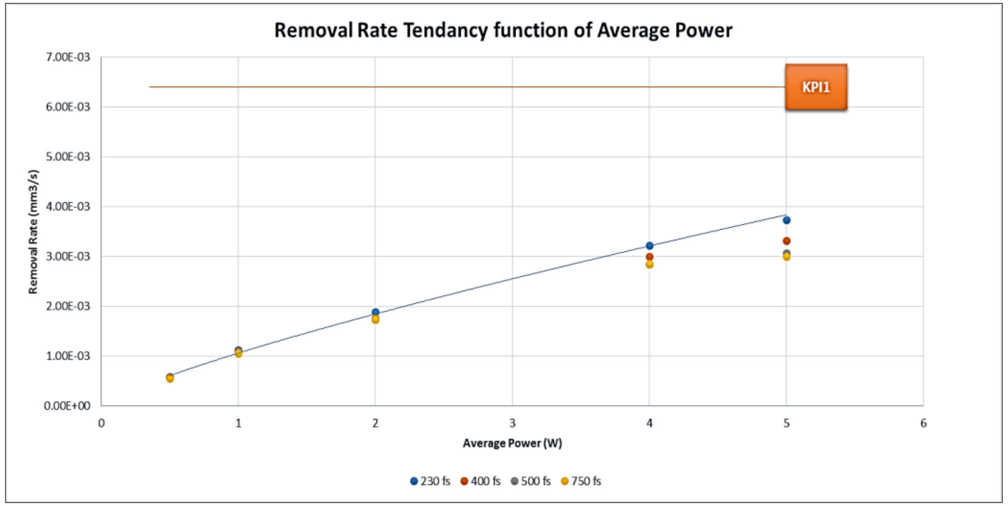
WP1 – Task 1.2: E6 (diamond polishing)

- Average Power
  - Increase of removal rate with average power
  - Higher influence at low pulse duration
  - Best fit (considering same ablation regime)

    → 10 times higher removal rate than current mechanical polishing at 200 W
  - Other ablation regime occurring at high average power and not forecast?
  - Use of pulse burst mode to achieve higher removal rate (WP2)



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WP1 – Task 1.2: E6 (diamond polishing)

- Summary

KPI	Current Laser Performances	Current Validation Status
Material removal rate	0.0035 mm3/s	
Surface Roughness	0.36 µm	

KPI	Current Laser Performances	E6 Specifications for HIPERDIAS Laser
Power	5W	> 200W 500/1000 W
Pulse Length	230 fs	400 fs
Frequency	60KHz-1MHz	< 2MHz Pulse burst (multi pulses mode)
Wavelength	1030 nm	1030 nm

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WP1 – Task 1.3: Assessment and validation of technical progress (Bosch, E6, C4L)

- Scope, objective:
  - Identify most important key performance indicators (KPIs) to track project progress and to compare w/ alternative processes (e.g. mechanical cutting, polishing)
  - Define KPI targets to be achieved within HIPERDIAS
  - Identify suitable analysis methods to evaluate KPIs
- Aspects considered:
  - Quality KPIs
  - Cost, productivity KPIs
  - General KPIs suitable for all applications and application-specific KPIs
- Achievements
  - Comprehensive set of KPIs defined (10 KPIs per application)
  - Suitable measurement systems identified, initial KPI values evaluated, KPI targets specified

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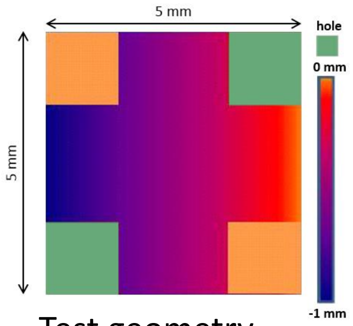
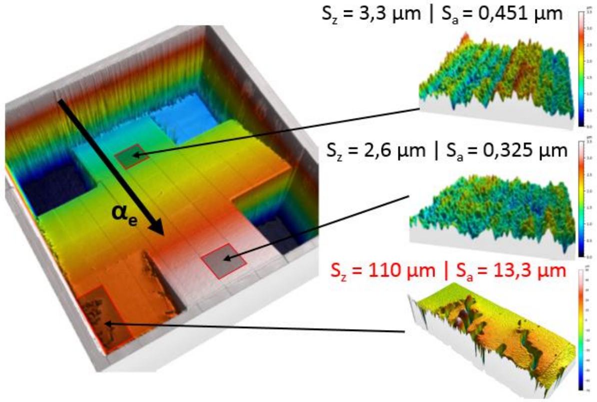
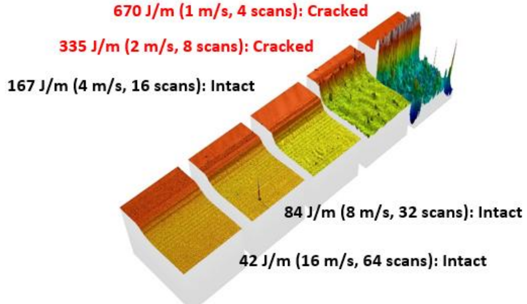
WP2 – Task 2.1: Fundamental process development 3D Si processing



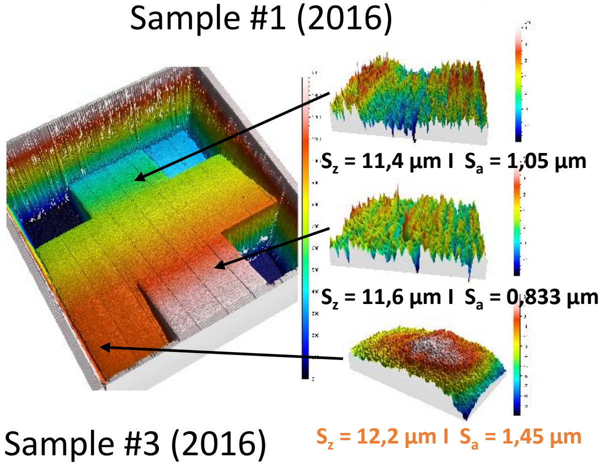
Test geometry



Sample #1 (2016)



Sample #2‘ (2016 @ IFSW)



Sample #3 (2016)

KPI	Unit	Target	#1	#2‘	#3
Average ablation rate	mm³/s	≥1	0,045	0,3	0,05
Peak ablation rate	mm³/s	≥3	0,049	0,7	0,054
Shape deviation	µm	≤10	110	(8)	12,2
Average surface roughness	µm	≤1	1	(0,6)	1,1
Surface damage thickness	µm	≤1	n.a.	n.a.	n.a.
Surface defects > 1 µm	mm²/mm²	none	0,42	n.a.	0,05
Min. edge radius	µm	≤ 200	80	n.a.	60
Max. edge-steepness	degree	≥ 70	81	n.a.	82

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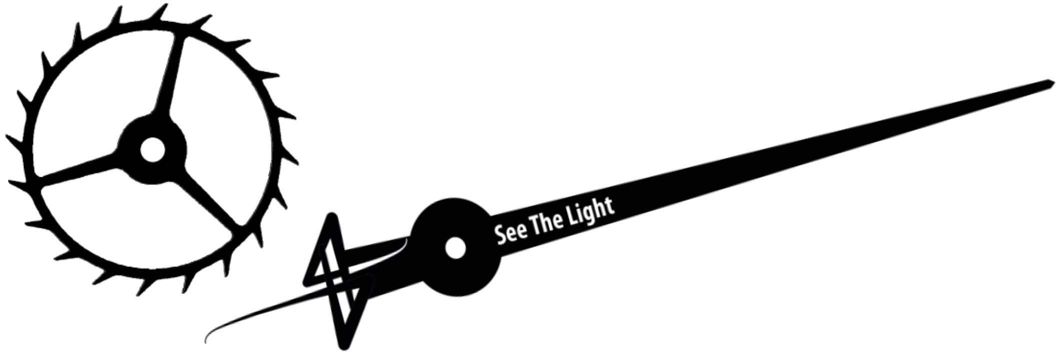
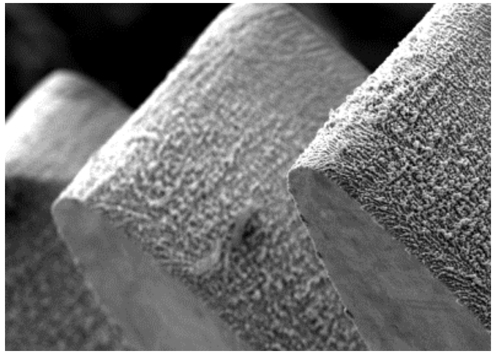
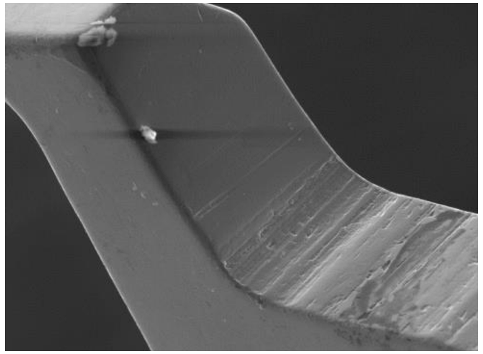
WP1 – Task 1.3: C4L (fine cutting of metals)



Product geometry features


Laser-machined part


Conventionally machined part w/ post-processing

KPI	Unit	current process value
Part thickness	mm	0.1 – 0.3
Part dimensions	mm	Gear diameter: 5-10 Watch arm length: ca. 20
Material covered		Metal, ceramic, sapphire, carbon
General dimensions tolerances	mm	From ± 5 to ± 20
Specific dimensions tolerances	mm	+- 5
Smallest holes	mm	From 50 to 100
Maximal side steepness (taper)		0 to 10°
Average cutting speed (relative to shape and thickness)	mm/min	USP laser: ≤50 Fiber laser: 300
Shape deviation	µm	+- 5
Surface roughness (non-functional)	µm	0.4 (N5)
Surface roughness (functional)	µm	0.1 (N3)

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WP1 – Task 1.3: E6 (diamond polishing)

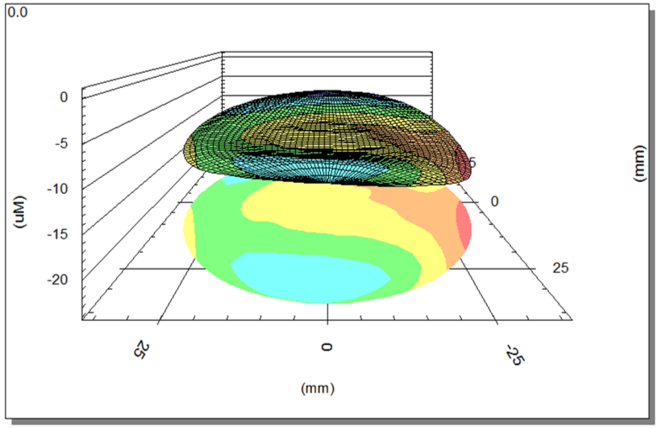
A—Polishing Wheel

B—Pneumatic Head

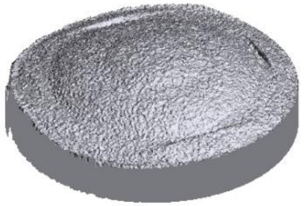
C—Cooling Pipes

D—Copper Head

Conventional polishing machine



Measurement of thickness variation



Flatness measurement of domed surface

KPI	Target
Material Removal Rate	> 0.150 mm^3/s per disc
Total Handling Time	< 10 min per disc
Post Processing/Cleaning Time	no post processing
Production Running Cost	< 5$ per disc
Surface Roughness	Sa < 0.010 µm, Sz < 0.12 µm
Shape Deviation	< +/- 2 µm
Visual Defects	pass rate 100%
Cobalt Depletion	0 %
Graphitization	No micro-structure modification
Colour	L* < 15

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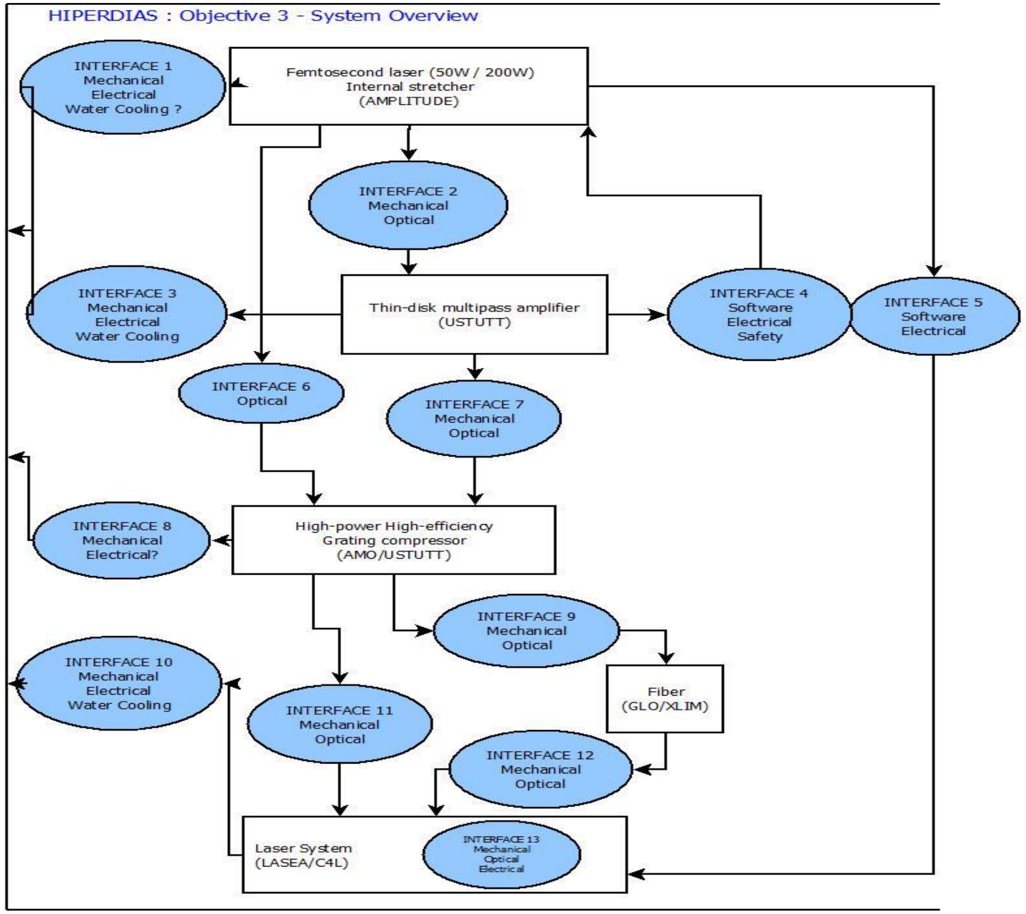
WP1 – Task 1.4: Interface requirements (LASEA, 4CL)

- Scope, objective:
  - Specify interfaces between different system units (laser, scanner, axes, opto-mechanical elements)
- Aspects considered:
  - Electrical, mechanical, optical and software interfaces
  - Interface: limit layer between 2 components
- Achievements
  - Identified all different system interfaces relevant for each partner
  - Specification of interface requirements both from end-user and system side



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WP1 - Deliverables

Deliverable title	Due date	Status
D1.1 End-user application specifications	M04 – May 2016	✓
D1.2 Process and system specifications	M12 – January 2017	✓
D1.3 Prototypes and progress validation	M12 – January 2017	✓
D1.4 Definition of software-technical interface	M12 – January 2017	✓

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WP1 - Milestones

Milestone title	Due date	Status
MS5 Specification for laser parameters established	M08 – September 2016	✓
MS10 Key performance indicators for productivity progress specified	M10 – November 2017	✓
MS11 Key performance indicators for quality standards specified	M12 – January 2017	✓
MS12 Specification for system technology established	M12 – January 2017	✓

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WP2 Process Development

Status Update

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

Task 2.1

BOSCH

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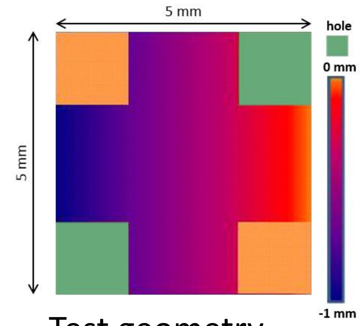
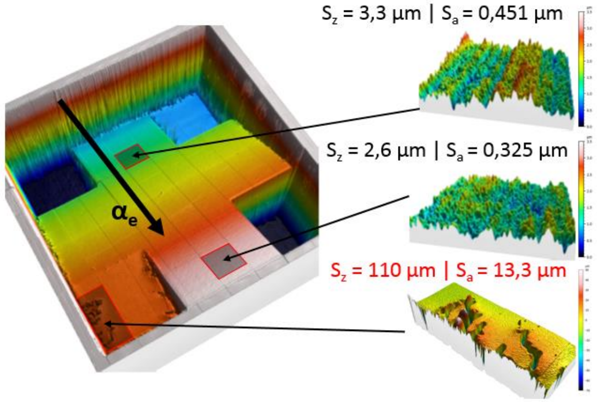
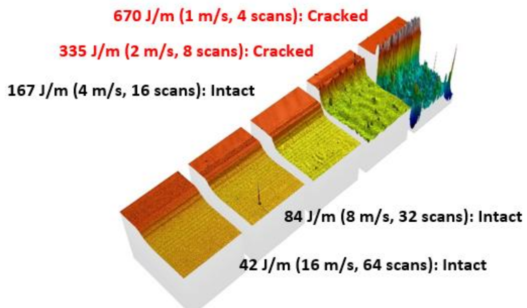
WP2 – Task 2.1: Fundamental process development 3D Si processing



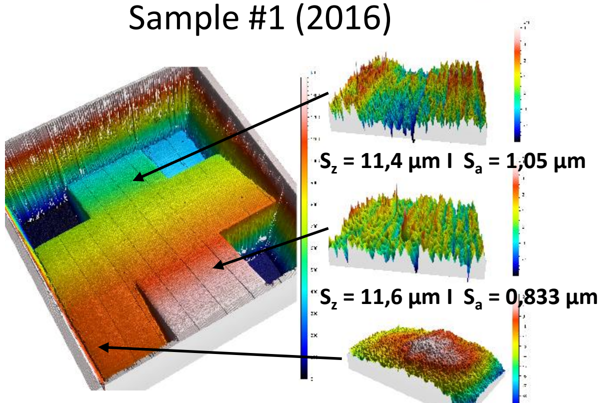
Test geometry



Sample #1 (2016)



Sample #2‘ (2016 @ IFSW)



Sample #3 (2016)

KPI	Unit	Target	#1	#2‘	#3
Average ablation rate	mm³/s	≥1	0,045	0,3	0,05
Peak ablation rate	mm³/s	≥3	0,049	0,7	0,054
Shape deviation	µm	≤10	110	(8)	12,2
Average surface roughness	µm	≤1	1	(0,6)	1,1
Surface damage thickness	µm	≤1	n.a.	n.a.	n.a.
Surface defects > 1 µm	mm²/mm²	none	0,42	n.a.	0,05
Min. edge radius	µm	≤ 200	80	n.a.	60
Max. edge-steepness	degree	≥ 70	81	n.a.	82

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WP2 – Task 2.1: Fundamental process development 3D Si processing

Used Laser Sources			
Sample	**#1**	**#2‘**	**#3**
Laser	**Trumpf TruMicro**	**Experimental @ USTUTT**	**Lumentum PicoBlade**
λ	1030 nm	1030 nm	1064 nm
τ_p	6 ps	6 ps	10 ps
f_{rep}	400 kHz	300 kHz	400 kHz
P_{max}	50 W	670 W	40 W
M^2	1,1	3	1,1
burst	no	no	*yes*
F	255 mm	340 mm	255 mm
d_0	80 µm	140x420 µm²	55 µm

KPI	Unit	Target	#1	#2‘	#3
Average ablation rate	mm³/s	≥1	0,045	0,3	0,05
Peak ablation rate	mm³/s	≥3	0,049	0,7	0,054
Shape deviation	µm	≤10	110	(8)	12,2
Average surface roughness	µm	≤1	1	(0,6)	1,1
Surface damage thickness	µm	≤1	n.a.	n.a.	n.a.
Surface defects > 1 µm	mm²/mm²	none	0,42	n.a.	0,05
Min. edge radius	µm	≤ 200	80	n.a.	60
Max. edge-steepness	degree	≥ 70	81	n.a.	82

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WP2 – Task 2.1: Fundamental process development 3D Si processing

- Insights from samples
  - High average power (Approx. 1000 W) required to reach ablation rate goals
  - High thermal load require fast scan systems
  - Vectorial scanning → high jump time losses
  - Good Quality at high average power achievable
  - Burst modus: Shape deviation and surface defects can be significantly reduced
  - Edge radius ≈ spot diameter

KPI	Unit	Target	#1	#2‘	#3
Average ablation rate	mm^3/s	≥1	0,045	0,3	0,05
Peak ablation rate	mm^3/s	≥3	0,049	0,7	0,054
Shape deviation	µm	≤10	110	(8)	12,2
Average surface roughness	µm	≤1	1	(0,6)	1,1
Surface damage thickness	µm	≤1	n.a.	n.a.	n.a.
Surface defects > 1 µm	mm^2/mm^2	none	0,42	n.a.	0,05
Min. edge radius	µm	≤ 200	80	n.a.	60
Max. edge-steepness	degree	≥ 70	81	n.a.	82

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WP2 – Task 2.1: Fundamental process development 3D Si processing

- Influence of high thermal load
  - Stable process for first number of passes
  - Process gets instable as heat accumulation gets thermal effects to significant level
  - → Cracks, Holes, Permanent Change of Reflectivity
- Laser parameters
  - P_{av} = 32 W
  - f_{rep} = 200 kHz
  - d_{Spot} = 56 µm
  - v_{scan} = 1 m/s

Video

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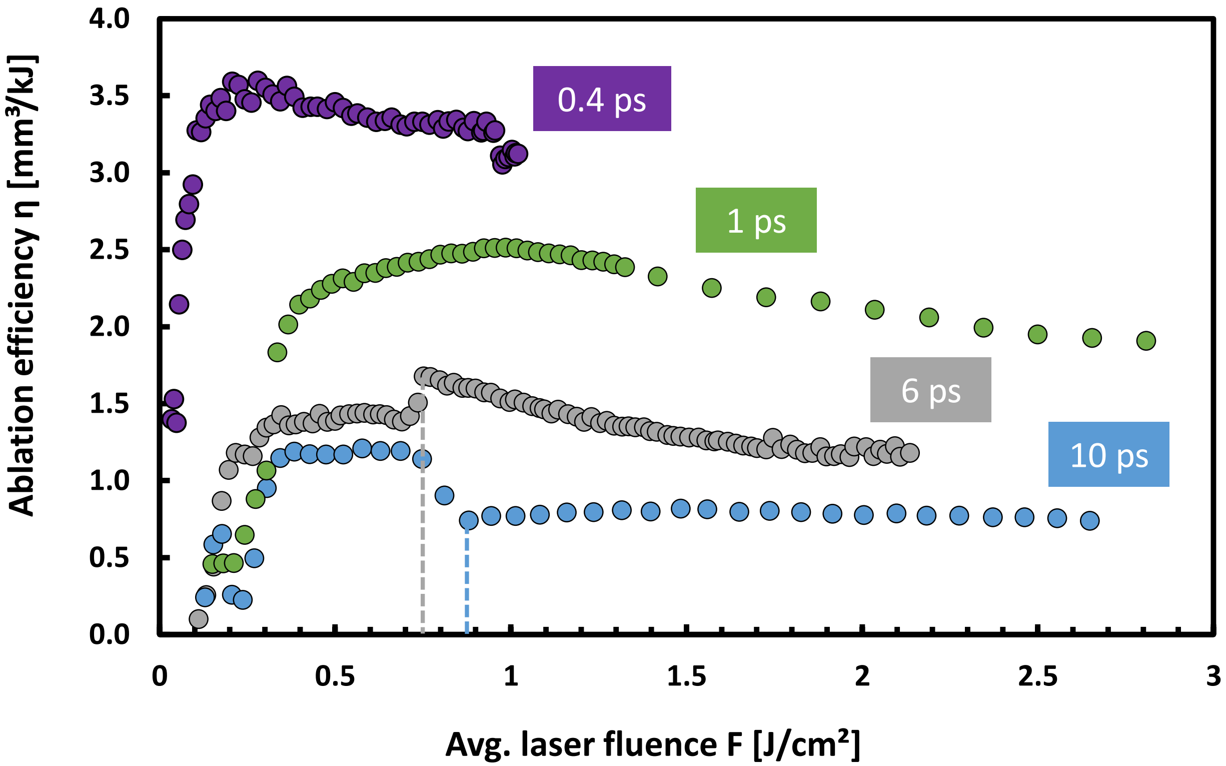
WP2 – Task 2.1: Fundamental process development 3D Si processing

- Decisive characteristic for Si ablation processes: Ablation efficiency
  - Primarily affected by laser fluence
    - *Strong increase* of efficiency slightly above ablation threshold
    - *Maximum* efficiency at moderate fluences
    - *Decreasing* efficiency at high fluences
  - Trends with shorter pulse durations
    - Maximum efficiency increases
    - Form of efficiency-function changes
  - Predictions? Applicable models?



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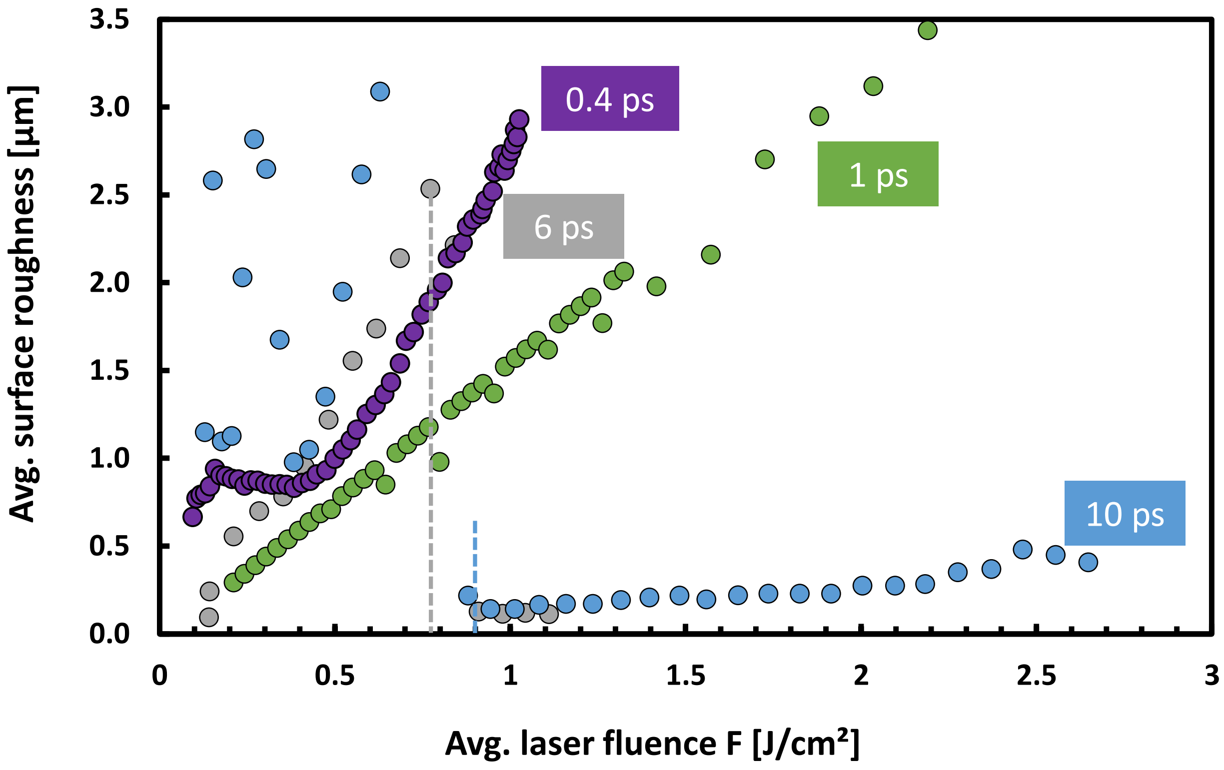
WP2 – Task 2.1: Fundamental process development 3D Si processing

- Decisive characteristic for Si ablation processes: Surface roughness
  - Primarily affected by laser fluence
    - ***Strong increase*** of roughness slightly above ablation threshold
    - ***Maximum*** roughness
      - around efficiency maximum (τ_p = 6, 10 ps)
      - Monotonous increase (τ_p = ≤ 1 ps)
    - ***Strong reduction*** of roughness
      - *F* larger than ≈ 1 J/cm² (τ_p = 6, 10 ps)
      - *F* > 3 J/cm² (τ_p = ≤ 1 ps, not shown)
  - Trends with shorter pulse durations
    - Threshold for good surface quality at higher fluence
  - Impact for process development?



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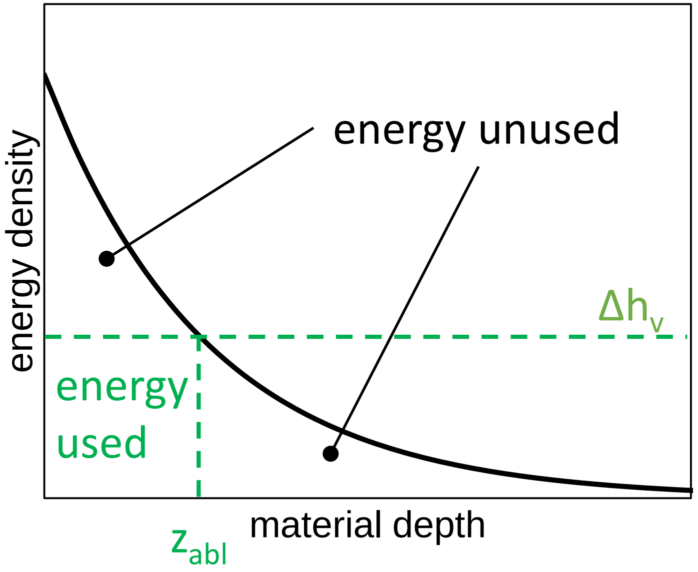
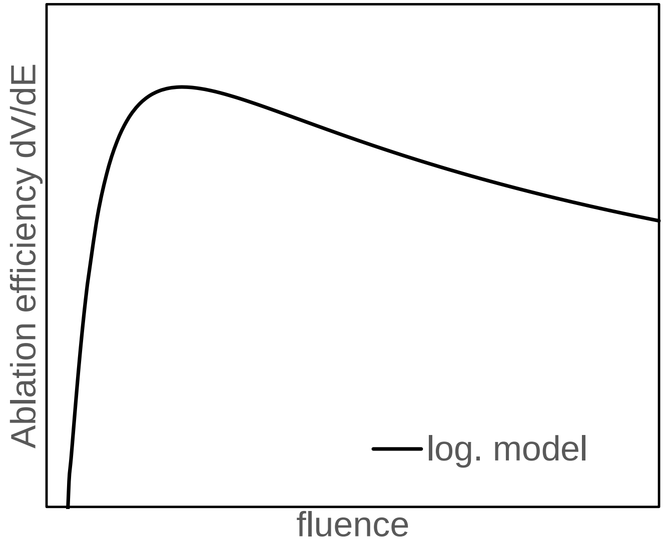
WP2 – Task 2.1: Fundamental process development 3D Si processing

- Frequently used model in scientific community
  - Based on logarithmic ablation law
  - Energy absorption according to ***lambert-beers' law***
  - No thermal diffusion of energy during ablation process
  - Constant ablation threshold H_{th}, energy penetration depth δ





$$z_{abl} = \delta \cdot \ln\left(\frac{H}{H_{th}}\right)$$

→ Gaussian intensity distribution

$$\frac{dV}{dE} = \frac{\delta}{4 \cdot H} \cdot \ln^2\left(\frac{H}{H_{th}}\right) \quad [1]$$

[1] B. Neuenschwander et al.: *Optimization of the volume ablation rate for metals at different laser pulse-durations from ps to fs*.In: SPIE LASE, International Society for Optics and Photonics, 2012. S. 824307-824307-13.

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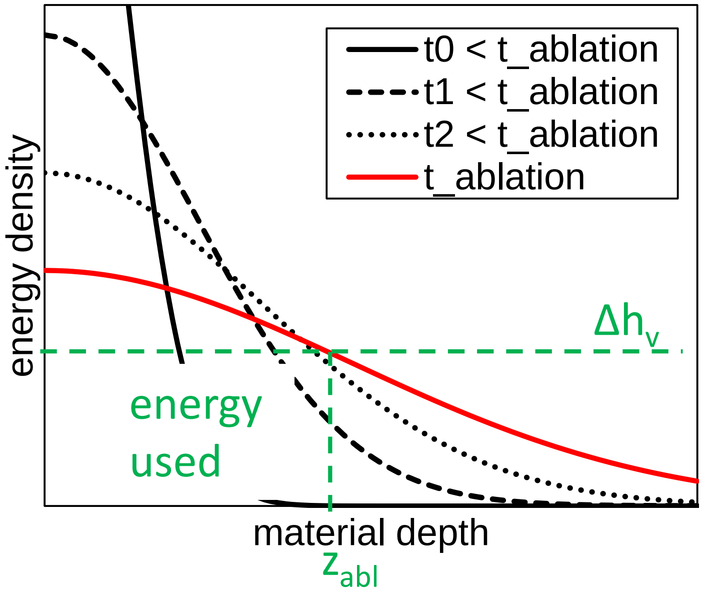
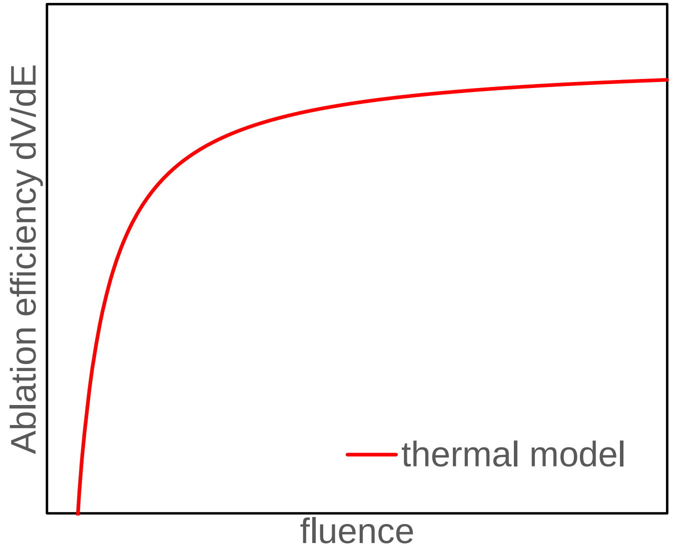
WP2 – Task 2.1: Fundamental process development 3D Si processing

- Thermal ablation model
  - Analytic approximation of numerical solution for ***two temperature model***
  - Thermal diffusion of energy during ablation process takes place
  - Temperature dependent material properties are taken into account





$$z_{abl} = \sqrt{\frac{2}{\pi e} \cdot \frac{H}{\Delta h_v}} \quad [2]$$

→ Gaussian intensity distribution

$$\frac{dV}{dE} = \sqrt{\frac{1}{2\pi e}} \cdot \frac{\delta}{H} \cdot \left(\frac{2 \cdot H}{H_{th}} - 1\right)$$

[2] B.H. Christensen, K. Vestentoft, P. Balling: *Short-pulse ablation rates and the two-temperature model*, Applied Surface Science 253 (2007) 6347–6352

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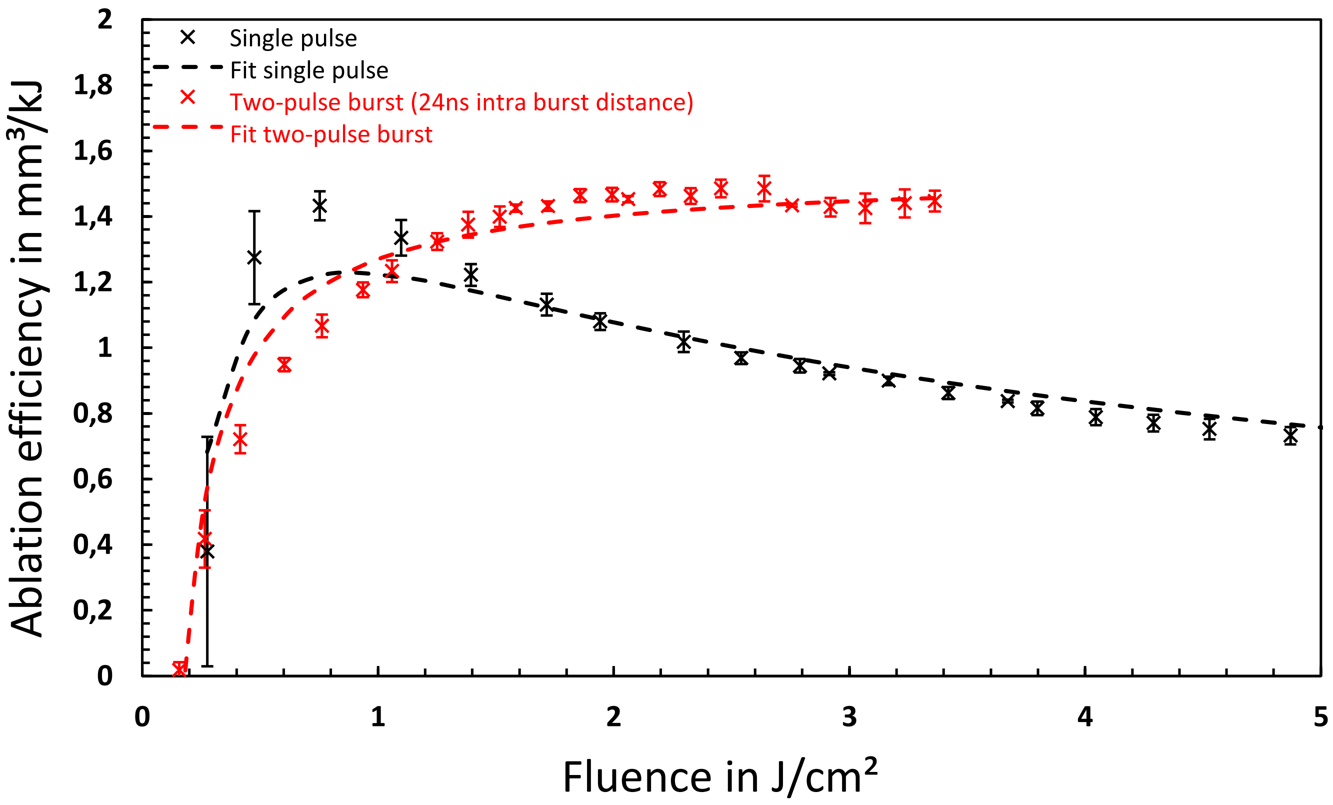
WP2 – Task 2.1: Fundamental process development 3D Si processing

- Comparison of ablation models with experimental data
  - *Logarithmic* model → Best fit for ***single pulse*** ablation
  - ***Thermal Model*** → Best fit for ***burst-ablation***
- Chance for Si-Ablation
  - Efficiency increases with laser fluence



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WP2 – Task 2.1: Fundamental process development 3D Si processing

- Conclusions / Consequences for Laser and Machine
  - High average power (Approx. 1000 W) required to reach ablation rate goals
  - High thermal load require fast scan systems
  - Vectorial scanning → high jump time losses
  - Good Quality at high average power achievable
  - Burst modus
    - Shape deviation and surface defects can be significantly reduced
    - *Energy efficiency can be increased*
  - Edge radius ≈ spot diameter
- Next steps
  - Continue studies on process fundamentals, processing with burst mode in particular
  - Design of experimental Strategy for up-scaling of the laser process
  - Identification of phenomena occurring specifically at very high laser power
  - Optimization of overall process

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Task 2.1

lasea
LASER ENGINEERING APPLICATIONS

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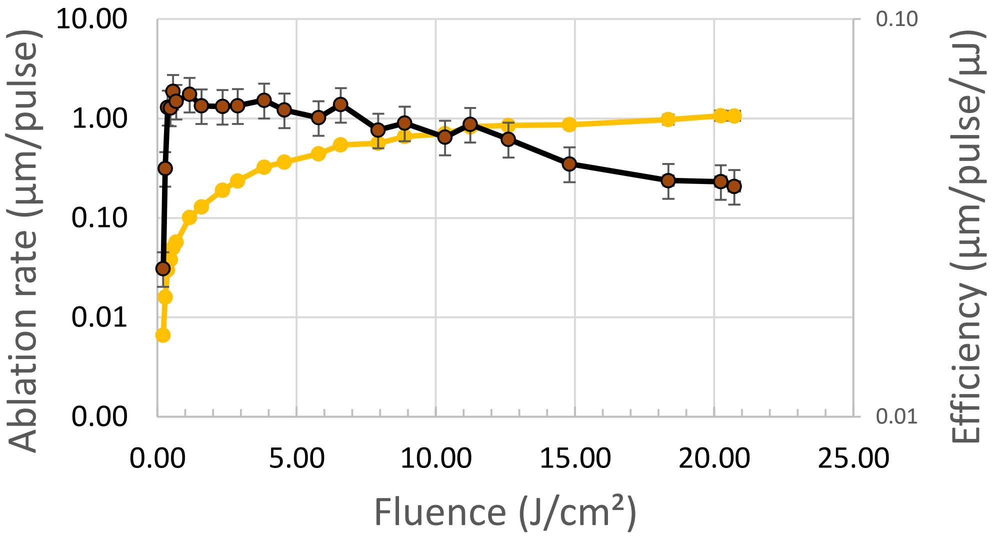
WP2 – Task 2.1: Fundamental process development 3D Si processing

- Achievements :
  - Low power (20W) laser preliminary trials at LASEA to study the ablation of Si
  - Define preliminary best process conditions
  - Influence of the process on the system design

  - Critical energy density : ~0.7 J/cm²
  - Ablation rate : 60 nm/pulse
  - Efficiency : 62nm/pulse/µJ

  → big spot size of ~50µm

Ablation and efficiency - 1D



Power (W)	Pulse energy (mJ)	Pulse energy -20% losses (mJ)	Max. Energy density (J/cm²)	Optical Spot Diameter (µm)
500	0,5	0,4	21	50
1000	1	0,8	42	50

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Task 2.2

CLASS 4 LASER
See the light

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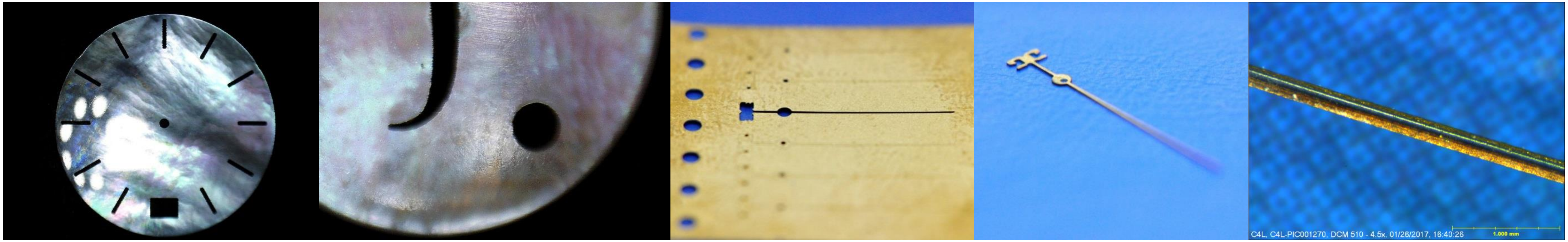
WP2 – Task 2.2: Fundamental process development fine cutting of metals

- Partner involved: C4L
- Until now trials have been done thanks to the carbide laser (85µJ, 5W, 1MHz) available at C4L using scanner optics on metals and organic materials: Brass, Glass, mother of pearl. Main goal has been to define a rough parameters window in order to give required specifications feedback to the laser manufacturer.
- Deviations : No deviation

Example: Cutting of 0.15mm brass with 5W femto second laser: 9s



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WP2.2 – The next six months…

- Fine cutting of metals:
  - Systematic process development
  - Cutting with trepanning optic
  - Exploring the maximal speed and thickness

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Task 2.3

elementsix™
a De Beers Group Company

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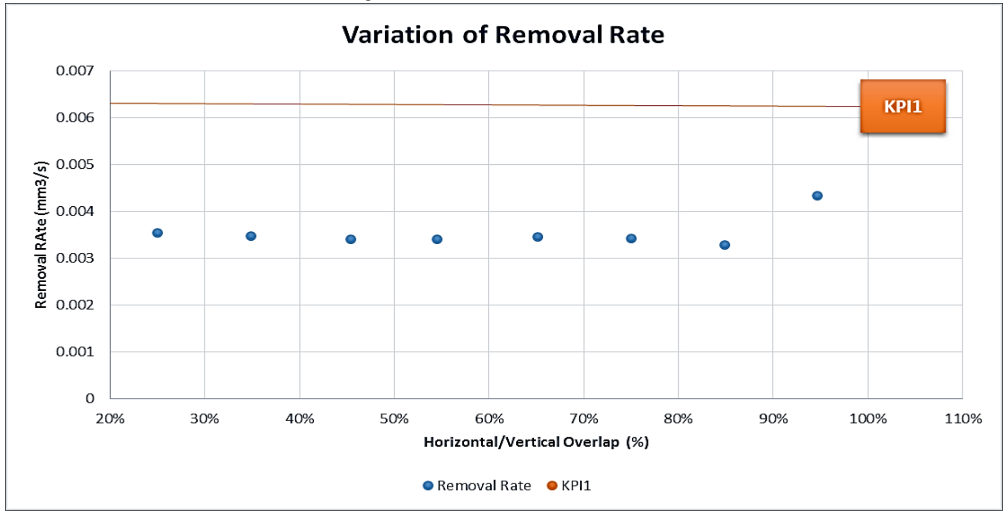
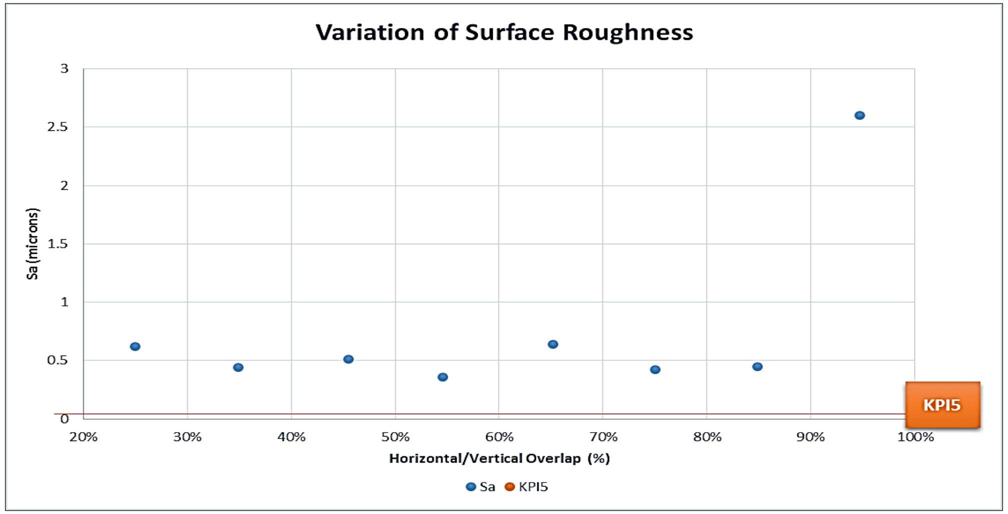
WP2 – Task 2.3: Fundamental process development diamond ablation

- Overlap testing
  - No variation of removal rate/surface roughness with overlap between 25% - 85%
  - Variation at extremely high overlap only
    - →Thermal effects..?
    - →Possible thermal effects at 200 W ?
  - Possible to work on a large window of overlap without influence on removal rate





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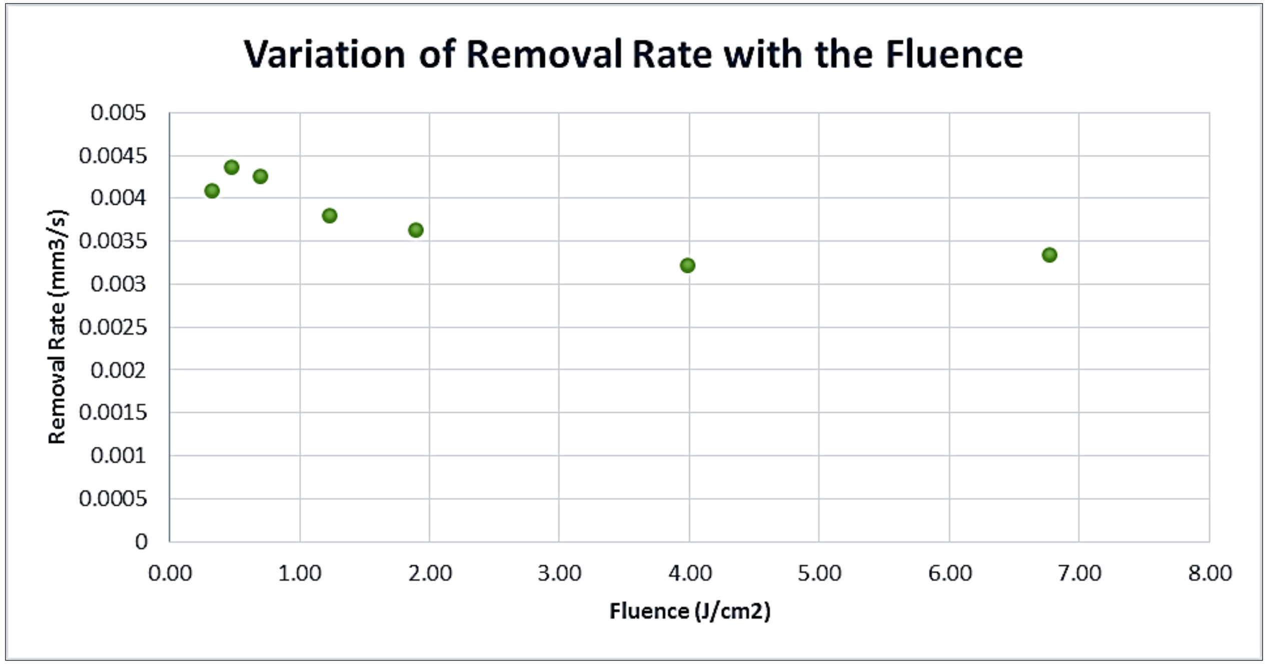
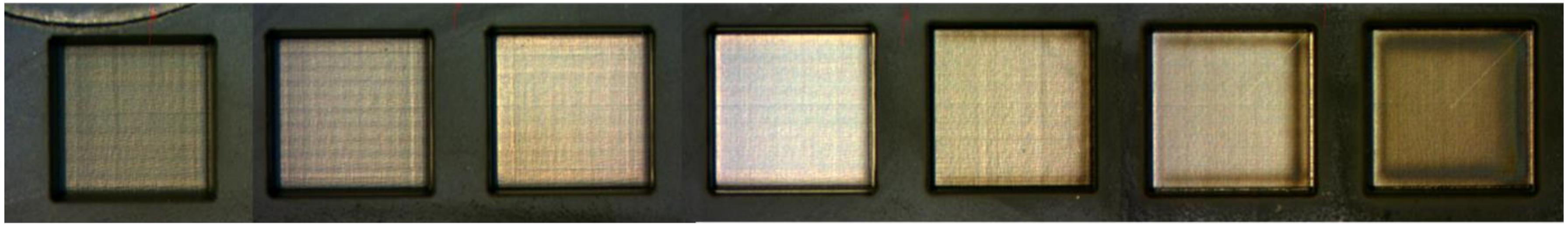
WP2 – Task 2.3: Fundamental process development diamond ablation

- Fluence analyses
  - Previous pre-analyses in WP1 showed fluence threshold around: $\Phi th \simeq 0.1$ J/cm2
  - Optimal fluence at 5 W average power : $\Phi \simeq 0.48$ J/cm2
  - PCD similar behavior as metal regarding ultra-short pulses?





0.32 J/cm2 | 0.48 J/cm2 | 0.70 J/cm2 | 1.23 J/cm2 | 1.90 J/cm2 | 3.99 J/cm2 | 6.77 J/cm2

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WP2 – The next six months…

Element Six

- Work at low fluence: Φ < 1 J/cm2
- Reproduce optimal fluence search for different average power to generate best fit and forecast at 200 W
- Test pulse burst mode to achieve higher removal rate (KPI1)
- Carry out material surface analyses
  - Composition: Cobalt depletion (KPI8)
  - Microstructure: Graphitization (KPI9)
- Installation and set up of the 200 W Laser system

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Task 2.4

IFSW

Not yet started.

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WP3 Ultrafast laser front-end development

Clemens Hönninger

AMP

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

Work Package 3 Overview

- Objective: Develop ultrafast laser frontend for further amplification to a 500-W and 1-kW average power femtosecond laser
- Achievements in period:
  - Ultrafast laser frontend development is on track
    - First 50-W fs laser was realized and delivered to partner USTUTT
      - “gain limiting” option was delivered in addition to facilitate the multipass thin disk amplifier architecture
    - Work on 200-W laser development was started, parts ordered, experiments started, first results obtained
    - Fast modulation concepts have been developped and must now be consolidated.
      - Discussions with end users started and requirements taken into account for modulator concept and user interface.

- Involved partners: AMP, USTUTT so far, AMO to come (test of high efficiency gratings)

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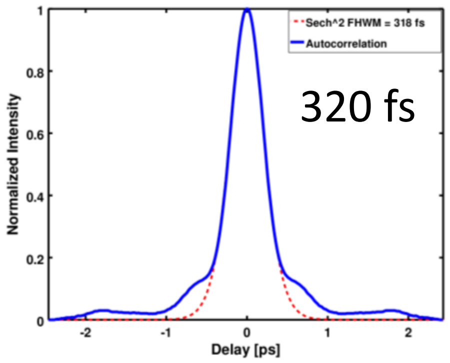
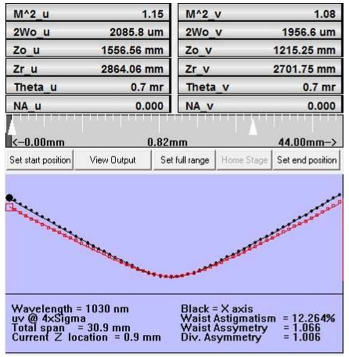
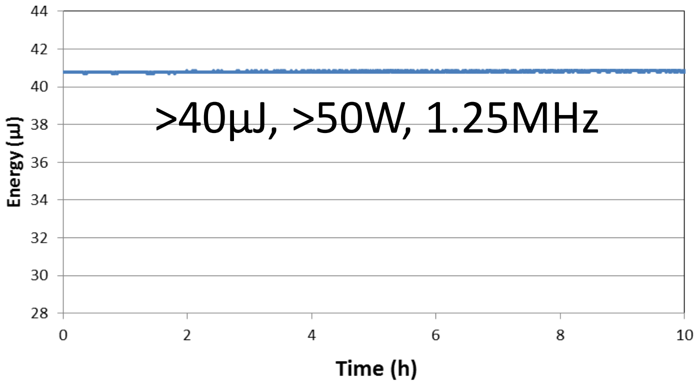
WP3 – Task 3.1: 50-W, 300-fs laser >1MHz at 1030nm

- partners involved: AMP, USTUTT
- Achievements:
  - 50-W laser optimized for spectrum @ 1030nm
  - 50-W laser output with modulator option: primary and secondary signal, primary signal is used signal, secondary signal can be used to limit stored energy in the thin disk amplifier for simpler system architecture
  - 50-W laser delivered to USTUTT (D3.1)







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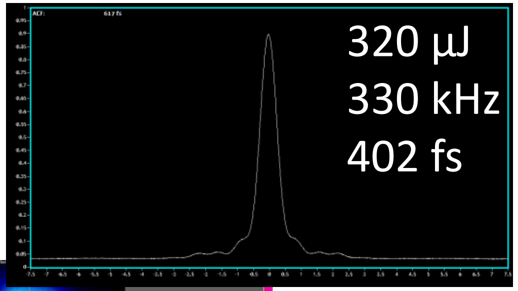
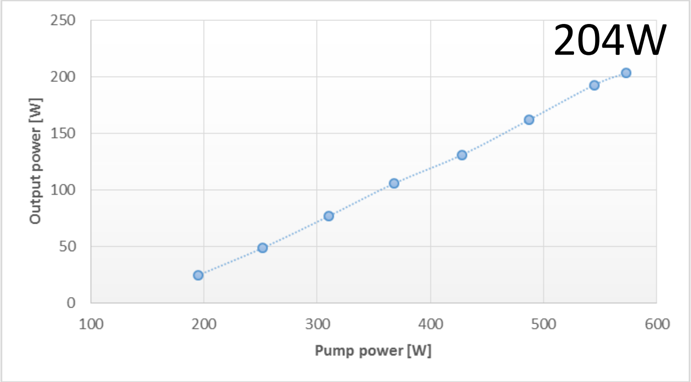
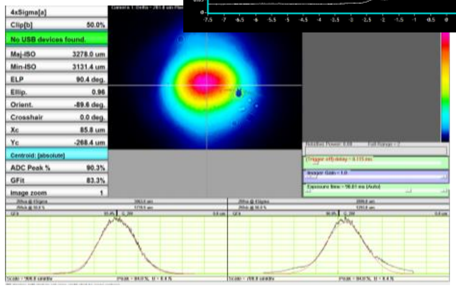
WP3 – Task 3.2: 200-W, ~500-fs laser >1MHz at 1030nm

- partners involved: AMP, USTUTT, AMO
- Achievements:
  - Hybrid fiber-seeded/crystal-amplifier architecture, Tangor platform
  - Short pulse duration ~400fs demonstrated
  - >200W output power achieved with good beam quality
  - Still before compression!







- Task on track so far. Worst case scenario: slightly <200W after compression

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WP3 – Task 3.3: Flexible user interface including high speed modulation a high power pulse train

- Overview:
  - The objective of the task is nicely summarized in its title
  - User requirements out of the consortium are taken into account in order to develop the most appropriate user interface
  - Synchronisation with a scanner or axes is taken into account – as far as possible with a “master oscillator”-based laser
  - The aspects of modulating high average power and high pulse energies are taken into account

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WP3 – Task 3.3: Flexible user interface including high speed modulation a high power pulse train

- partners involved: AMP
- Achievements:
  - Different concepts worked on
    - 1: based on existing user interface, but introduced new options for externally triggering the pulse picker (and not only the GATE) to allow synchronisation with the scanner. This concept works up to 2MHz with the GATE and up to 20MHz with only the pulse picker.
    - 2: proof of principle of new modulator/gain limiter concept to gain higher flexibility than option1 for certain cases. Advantages:
      - Higher speed possible (but only relevant for higher repetition rate oscillators, not the case in Hiperdias)
      - Easily extensible to higher average powers (multi-100-W concepts)
    - Both concepts are compatible with burst mode operation
- Most likely, concept 1 will be integrated to the 200-W laser, because very high pulse repetition rates seem not necessary.

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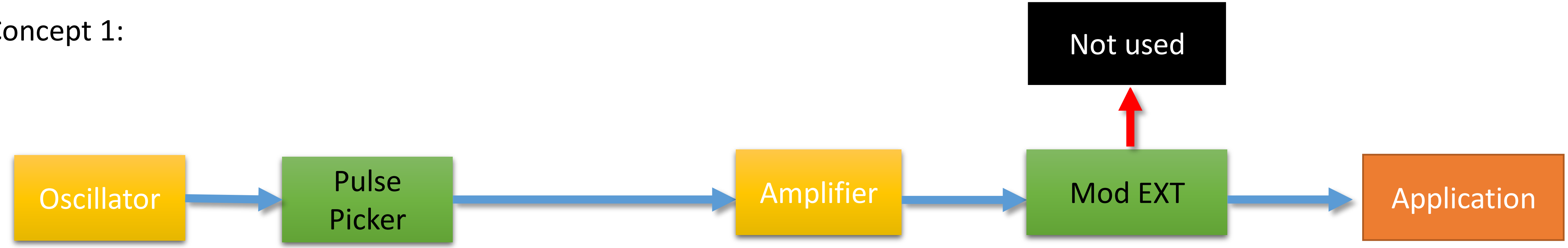
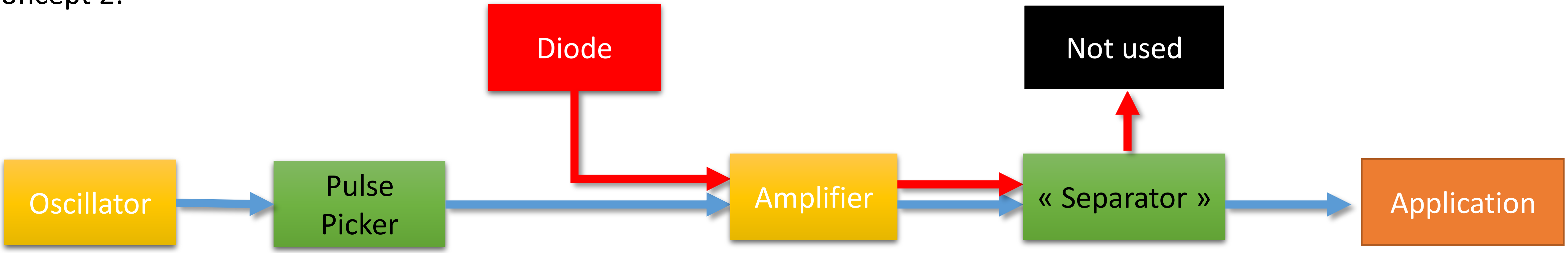
Schematics of the modulation concepts:

Concept 1:



Concept 2:



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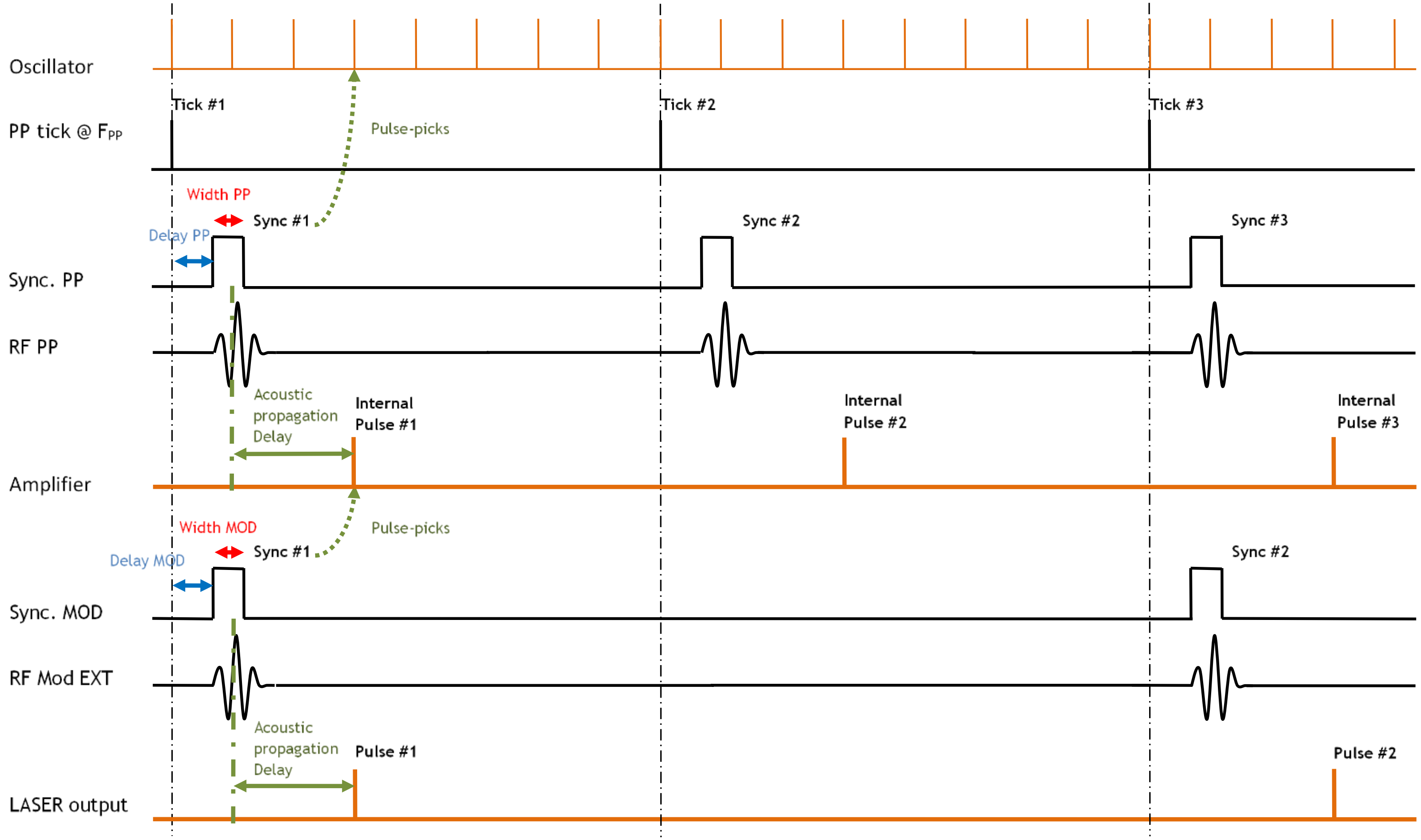
Synchronisation scheme with pulse picker and external modulator:



Oscillator: 40MHz
PP: up to 20MHz

- PP signal can be generated internally or externally (by user: « pulse on demand »)

Attention:

- Latency of AOMs to be taken into account! (acoustic propagation)
- AOM2 (Mod EXT) is limited to 2MHz (by rise time)
- If PP and ModEXT are used in external mode, then the user has to provide ALL TRIGGER signals!

- **Let's discuss the different user profiles together!**

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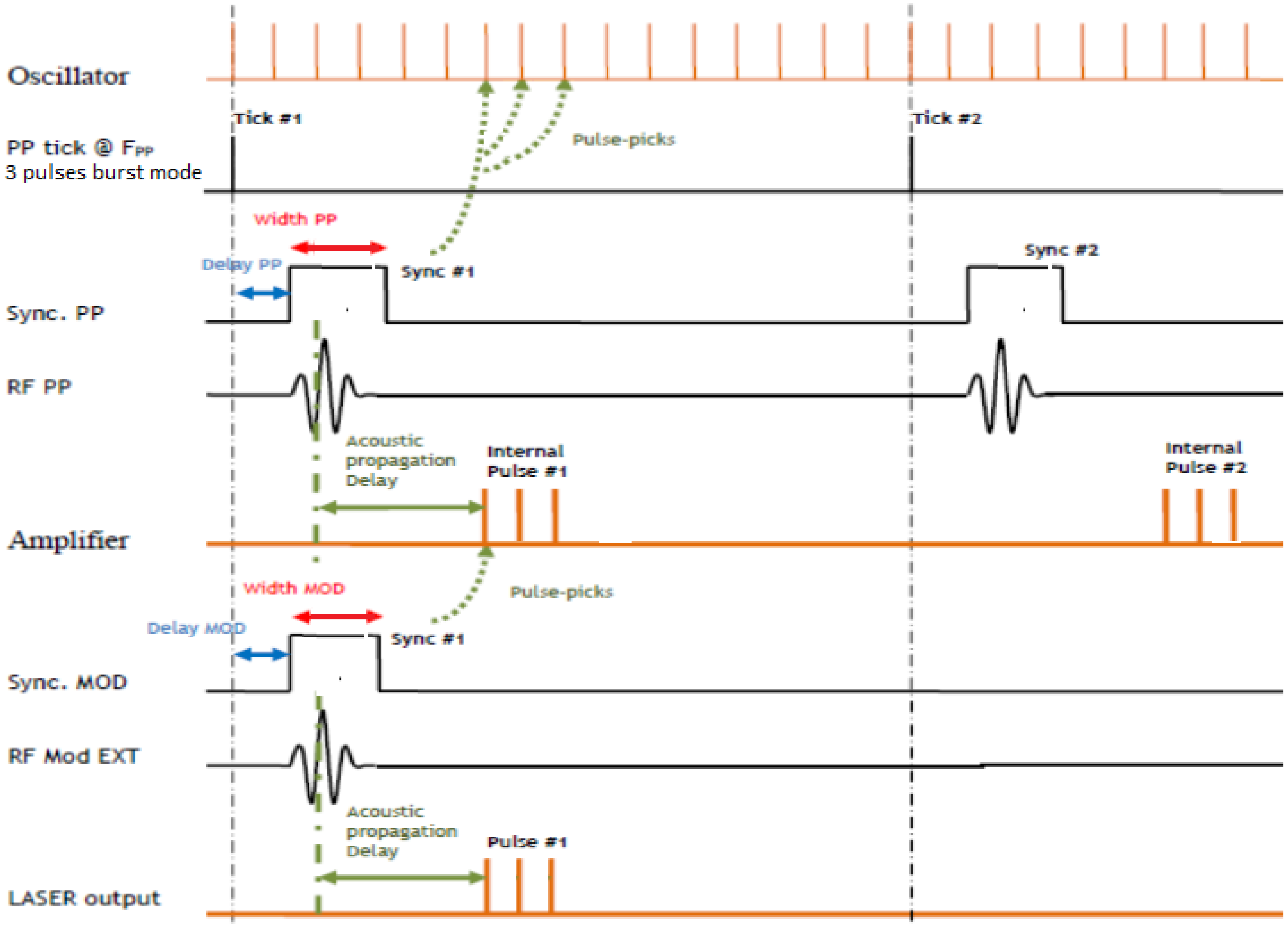
Synchronisation scheme with burst mode:



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WP3 – The next six months...

- Task 3.2: 200-W, ~500fs laser, >1MHz @ 1030nm
  - Consolidate laboratory demonstration and final architecture
  - Implement tuning of pulse duration
  - Test high reflectivity AMO gratings and evaluate possible integration in demonstrator
  - Exchange interface information with partners/endusers
  - Start realizing the demonstrator in its final package

- Task 3.3: Flexible user interface including high speed modulation
  - Consolidate proof of concept of high speed modulation at high average power
  - Decide for the concept to best match partner/user requirements
  - Implement this concept to the 200W demonstrator

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WP3 - Deliverables

Deliverable title	Due date	Status
D3.1 50-W, 300-fs, >1-MHz laser for seeding an Yb:YAG amplifier (1)	M09 – October 2016	✓
D3.2 50-W, 300-fs, >1-MHz laser for seeding an Yb:YAG amplifier (2)	M09 – October 2016	✓

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WP3 - Milestones

Milestone title	Due date	Status
MS8 A 50W, 300fs at >1 MHz seed laser	M09 – October 2016	✓

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