elementsix™

a De Beers Group Company

William Scalbert

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

# INTRODUCTION

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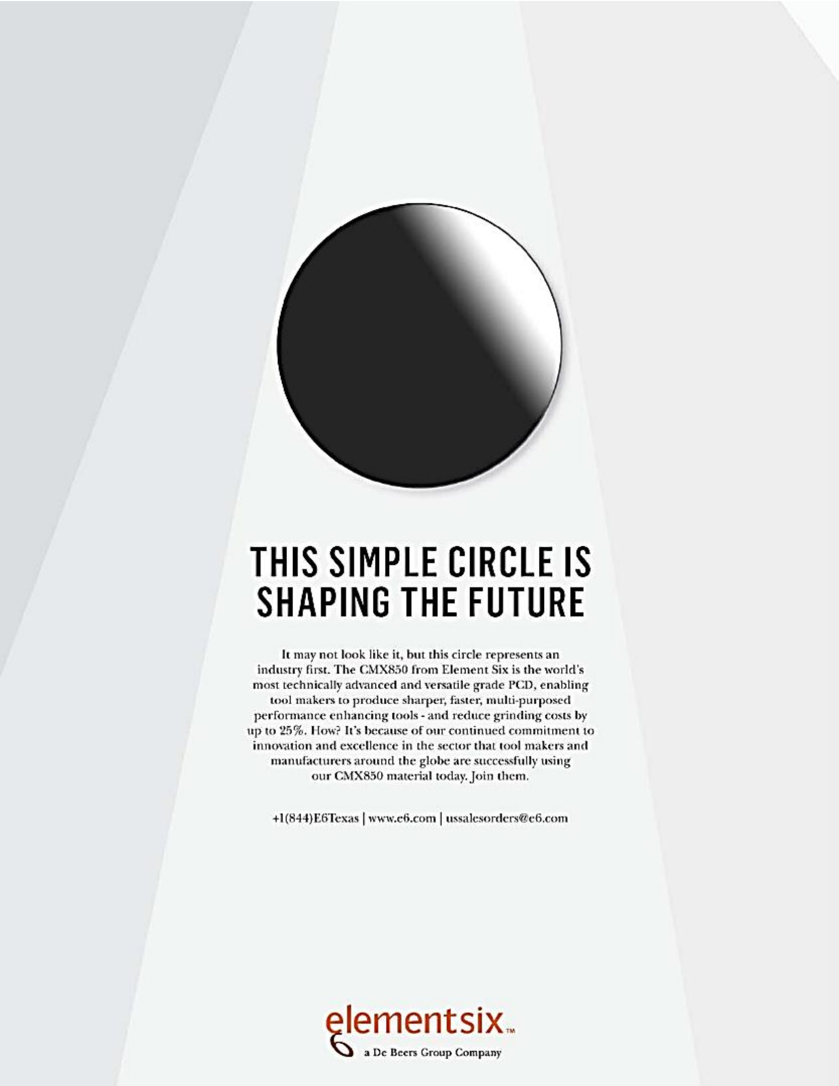


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# SCOPE of HIPERDIAS PROJECT for Element Six

Main scope

Replacement of mechanical polishing machines by Laser machines to Laser ablate PCD up to a mirror surface finish:

- Low processing cost
- Fast processing
- Cold ablation -> no thermal effect
- Laser spot machining with controlled Laser parameters
- Automatic process
- Deal with various topographies thanks to top surface scanner/personalised program

**Higher processing yield**

DEVELOPMENT OF TOP SURFACE SCANNER IN COLLABORATION WITH CLASS 4


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# SCOPE of HIPERDIAS PROJECT for Element Six

Further scope

If capable of polishing a 75 mm diameter disc, extremely wide opportunities arise!

- Polishing flat/non flat segments
- Polishing segment edges
- Polishing Syndrills
- Polishing 3D forms
- Polish other surfaces than PCD (PcBN)

*Oil & Gas Cutters*

*Advanced Material Cutters*

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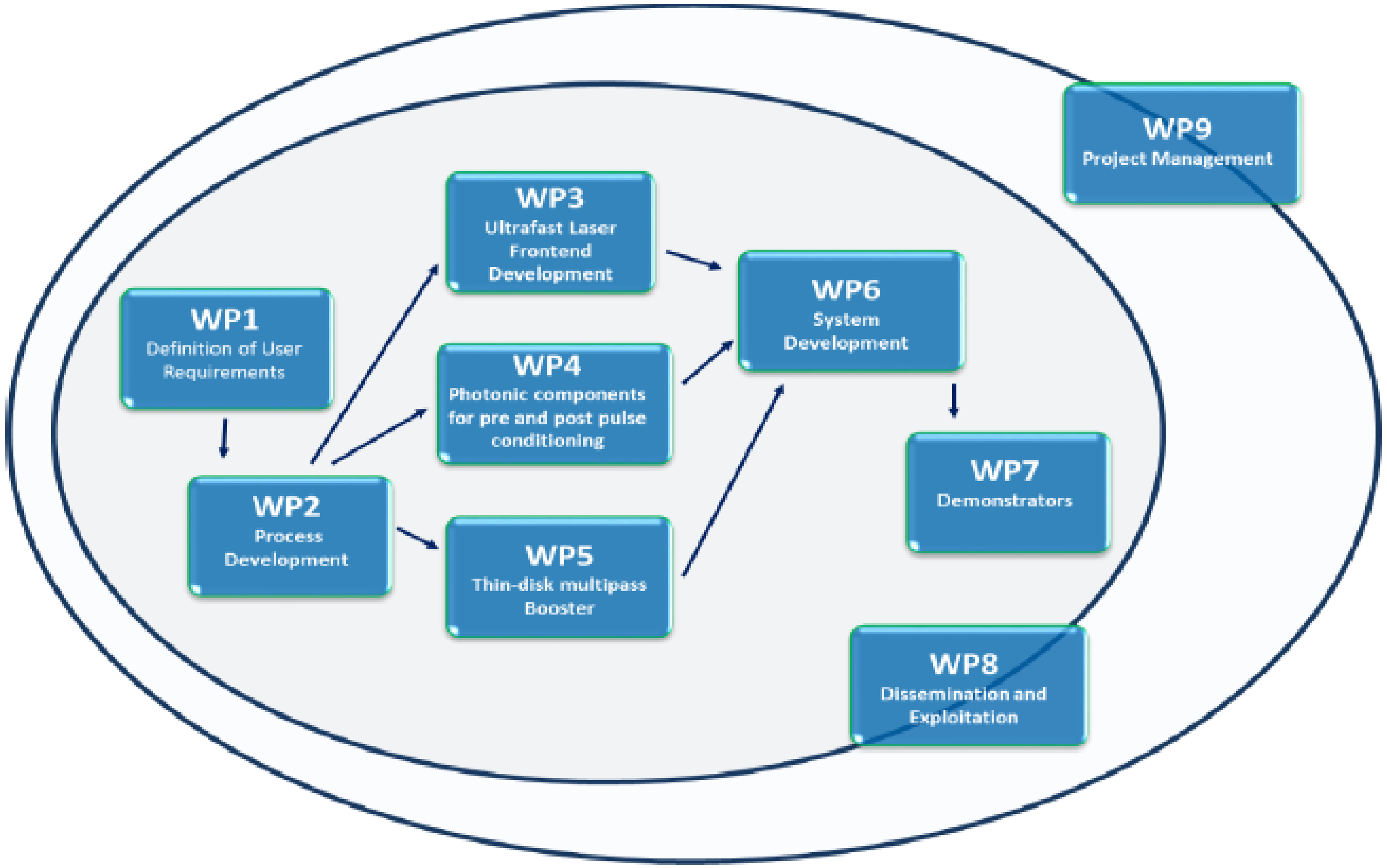
## Work Packages

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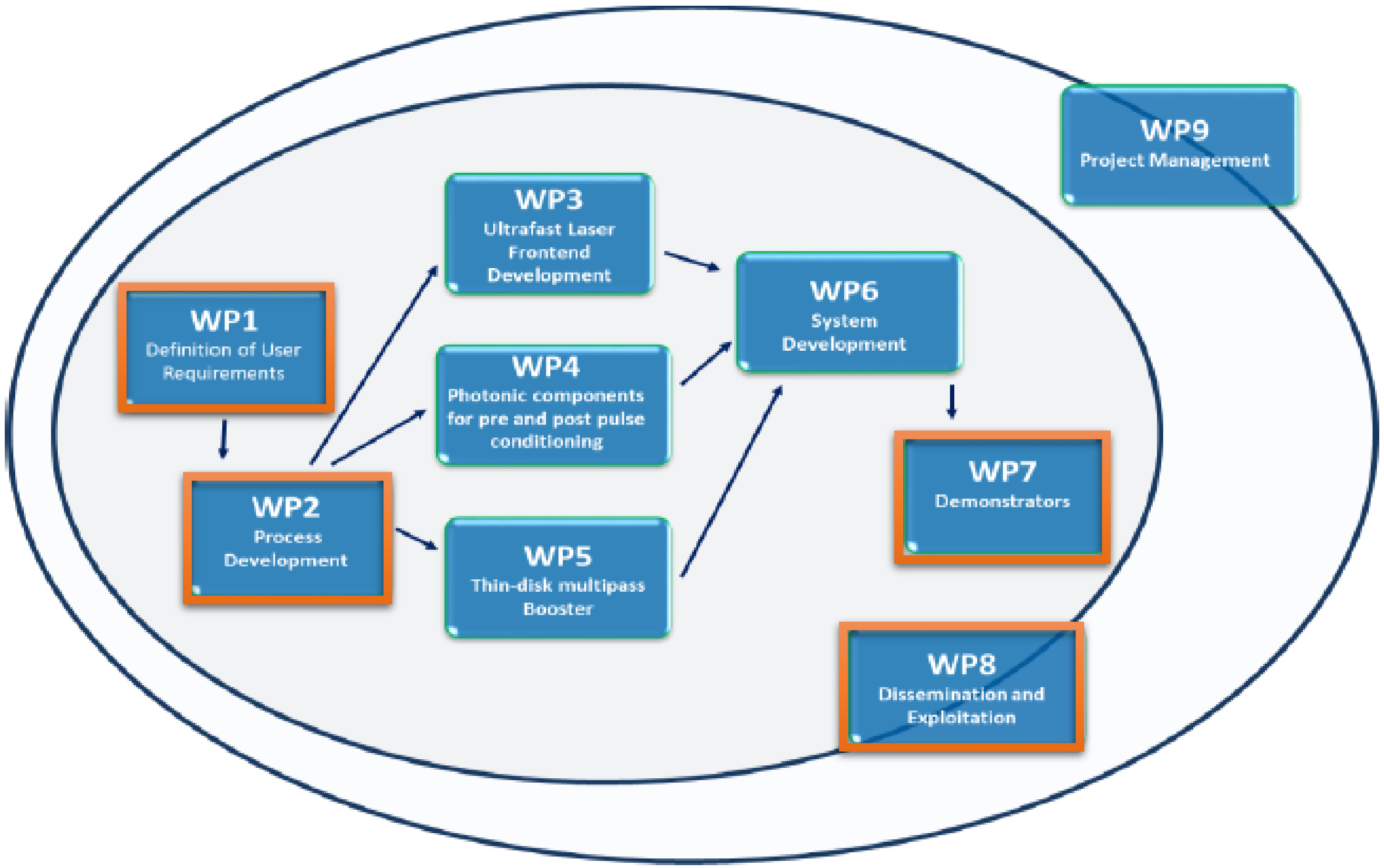
## Element Six Work Packages

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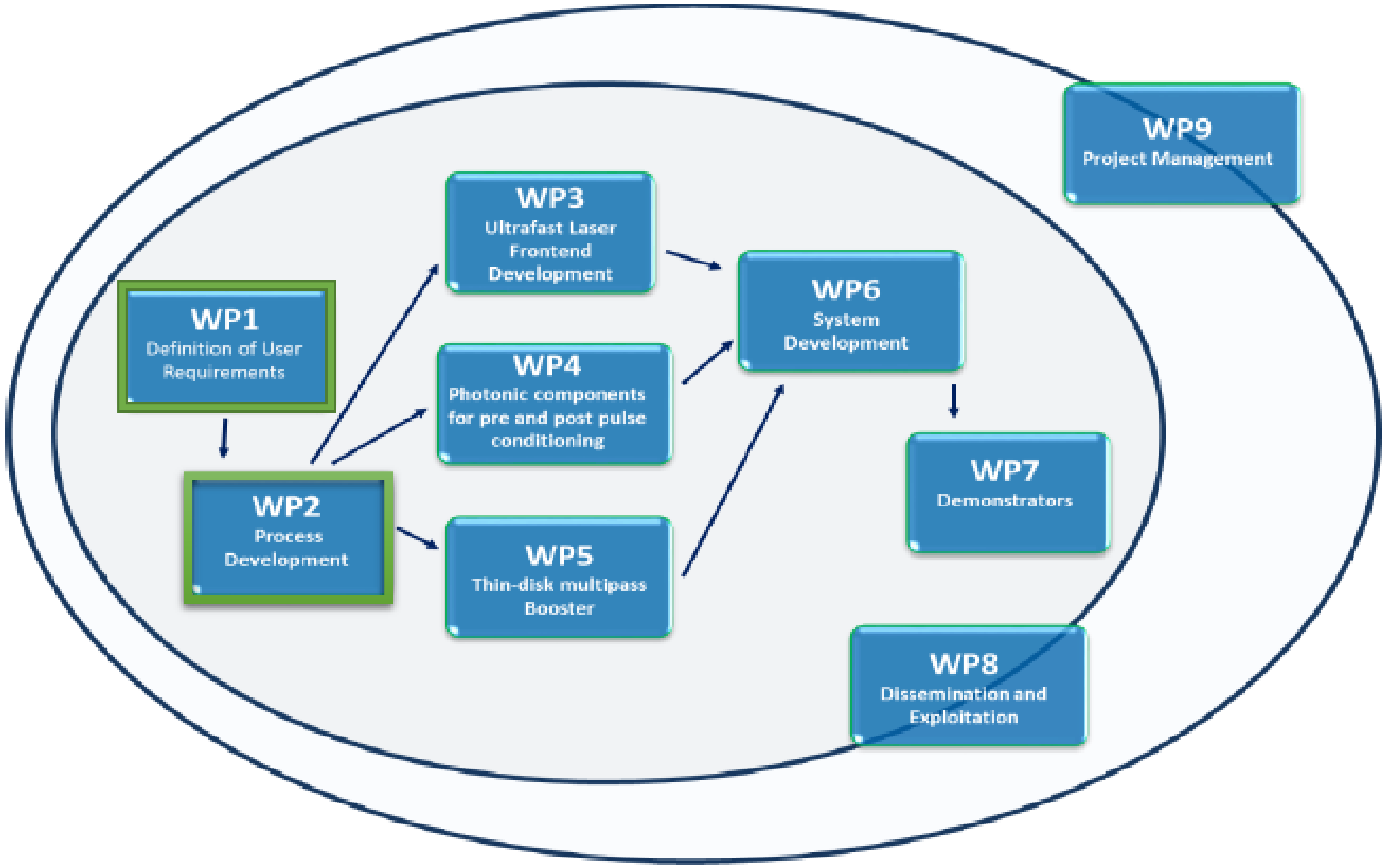
Work Packages presented today

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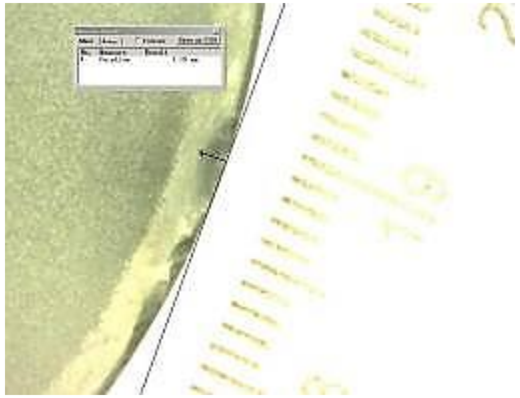
| WP1 | Definition of user requirements |
|---|---|

# Target Application

| Key Performance Indicator | Unit | Target Value |
|---|---|---|
| **Benchmarking product:**<br>• PCD Syndite | |  |
| **Surface roughness** | µm | ≤ 0.01 |
| **Average ablation rate** | $mm^3/s$ | ≥ 0.15 |
| **Shape deviation** | µm | ≤ 2 (waviness) |
| **Edge Chip** | | Must not encroach on the usable area (defined per disc). A maximum of three chips allowed as long as they are separated by the length of the chip. No more than 45° of the periphery can be affected by chipping. Chip-out cannot extend the thickness of the disc. |
| **Pits** | µm | A hole, cavity or small indentation in the PCD polished surface. Pitting is one or more small shallow craters on the surface. It has a definite depth. Typically can be large discrete pits or a scatter of pits smaller than 0.05mm diameter.<br>See table 2 for diameter specifications<br>Pits with a significant* depth are not allowed. |
| **Surface Cracks** | | A crack with a significant depth* is not acceptable. Requires case-by-case review. |
| **Black spot (Binder components leakage)** | | Follow pitting specifications<br>Requires case-by-case review. |



*Edge Chipping*

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# Target Application

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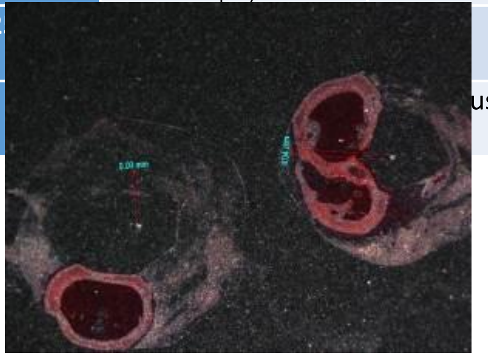
| Ma... dia... | | ...um ...ce ...een ...s |
|---|---|---|
| >200 (XL) | | |
| 200- (XL) | | |
| 100-50 (XS) | Approximately 12 pits per disc<br>0.25pits/cm² | 1 |
| 50-2 (XS) | | |
| <25 | | ...use |

CMX pit > 0.100mm (0.107x0.183mm)



CTH pit < 0.050mm (0.040x0.040mm)

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| WP1 | Definition of user requirements |
|---|---|

# Target Application

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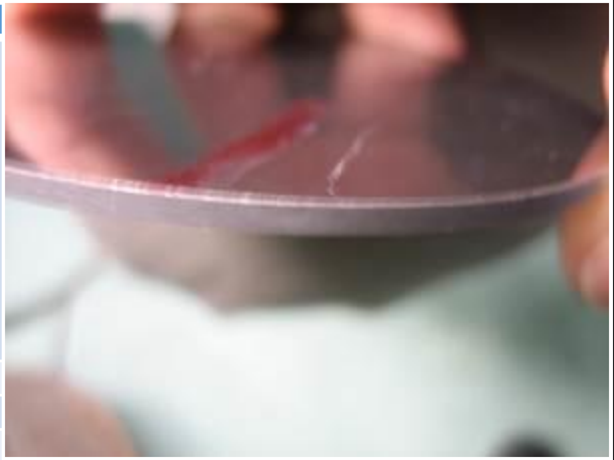

*PCD Crack*

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| WP1 | Definition of user requirements |
|---|---|

# Target Application

| Key Performance Indicator | Unit | Target Value |
|---|---|---|
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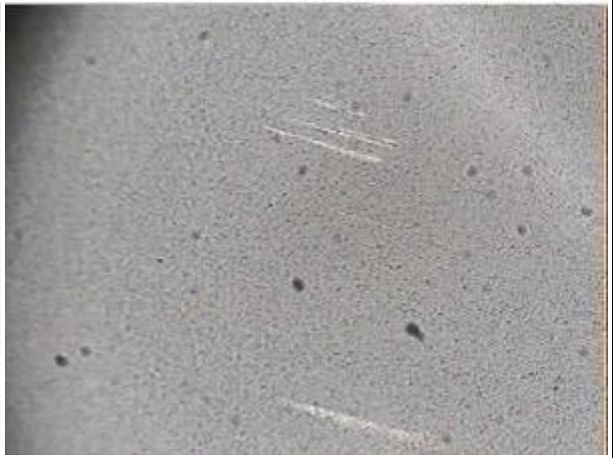

*PCD Black Dots*

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| WP1 | Definition of user requirements |
|---|---|

# Target Application

| Key Performance Indicator | Description | Target Value |
|---|---|---|
| Inhomo | Surface inhomogeneous areas appear different in colour to the normal PCD surface. It has a degree of surface roughness with a definite depth and boundary | Refer to Table 4.2.<br>Follow pitting specifcation (015).<br>Fig 4.07 |
| Outer diameter finish | Outer diameter (OD) quality. | Edge imperfection must not encompass more than 120° of the periphery.<br>Metal swarf must be removed.<br>The metal ring surrounding the PCD shall be continuous and intact and shall not intrude into the PCD surface by more than 1mm. |
| Surface Scratches | PCD surface scratches. Smaller grain grades tend to be more susceptible to scratching. | A scratch with a significant depth is not acceptable. A significant depth is detected by running a sharp edge over the scratch, See Code022. |
| Polish quality | Quality standard of surface finish. A product maybe be partially polished with metal remain | Refer to Table 4.2.<br>Fig 4.15 shows edge polishing fault or not fully polsihed |
| Surface staining | The area can be clearly bounded and is easily observed both by the naked eye | Refer to Table 4.2.<br>Follow pitting (015) specification. |
| Metal Spots | Judged as a bright metallic area. | No contamination is allowed but traces of metal wrap, of negligible depth, are permitted on the periphery. |
| Surface shading | PCD shading defines how dark is the colour of the PCD.PCDshading or toning defines how much grey exists in the colour. | Discs are to be judged on the amount of variation of shading and toning across the product by bare eye. |
| Black spot | Typically found on polished PCD. | Follow Pitting specifications Code 015. |
| Bullet Holes / Grain growth | "Swiss cheese" type structure in the PCD layer.<br>Grain Growth is defined as large crystals that appear on the surface of the disc or interface. | Code 015 |

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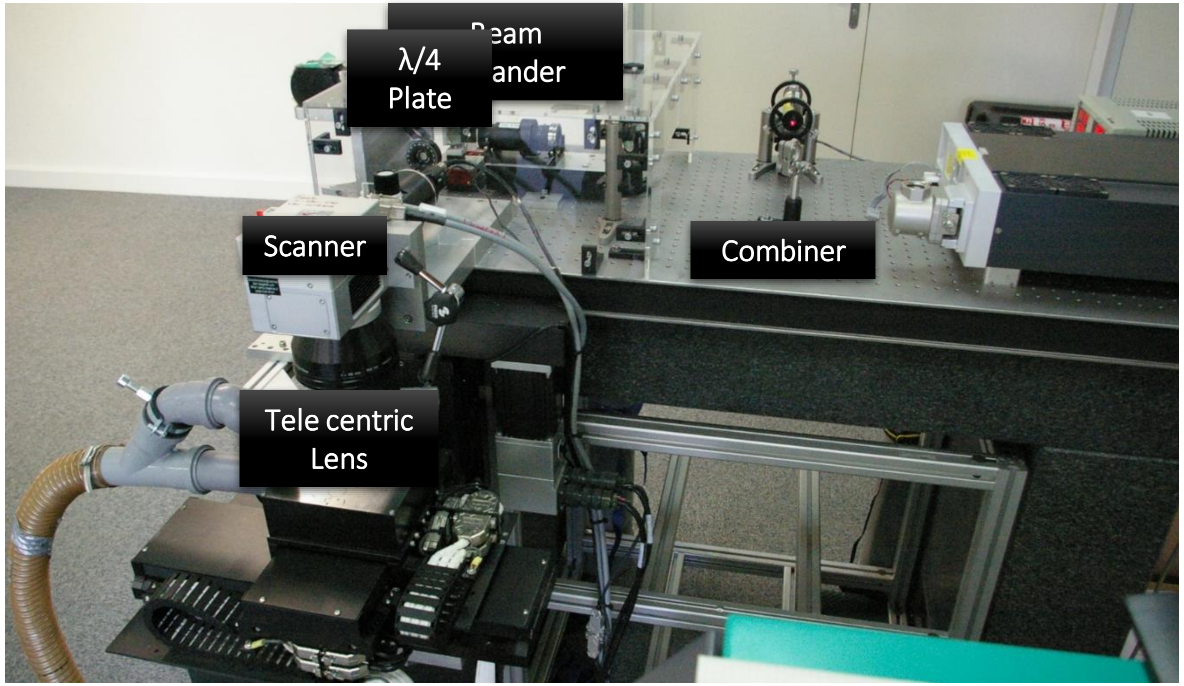
| WP1 | Definition of user requirements |
|---|---|

## Pre Trials Set Up

- 5 W Femtosecond Laser fully set up for pre-trails
- Ablation of PCD surface with 5 W Femtosecond Laser to establish window of parameters required for HIPERDIAS machine development

*In collaboration with*

CLASS 4 LASER
See the light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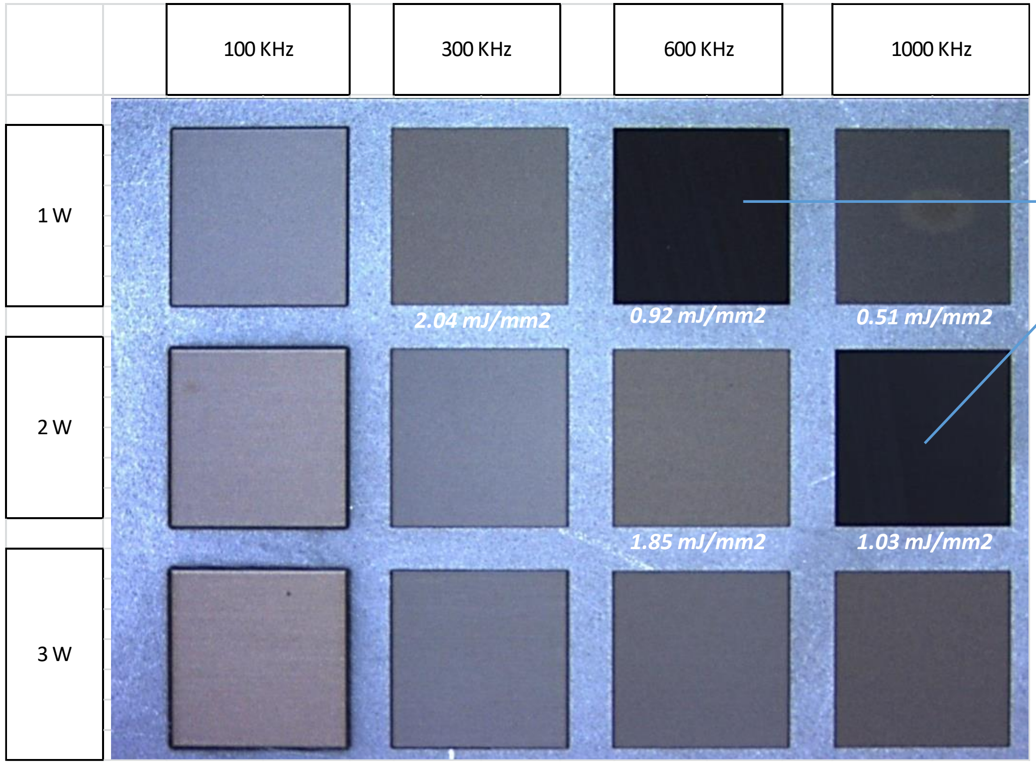
| WP1 | Definition of user requirements |
|---|---|

# Pre Trials

- Fluence threshold measurement at 280 fs




**Graphitisation** → Fluence Threshold between 1 mJ/mm² and 2 mJ/mm²

Parameters Set Up

| | | |
|---|---|---|
| λ | 1030 | ns |
| f' | 100 | mm |
| M^2 | 1.1 | |
| Beam expander | 4 | |
| D | 7.3 | mm |
| ω0 = | 21.74 | µm |

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| WP1 | Definition of user requirements |
|---|---|

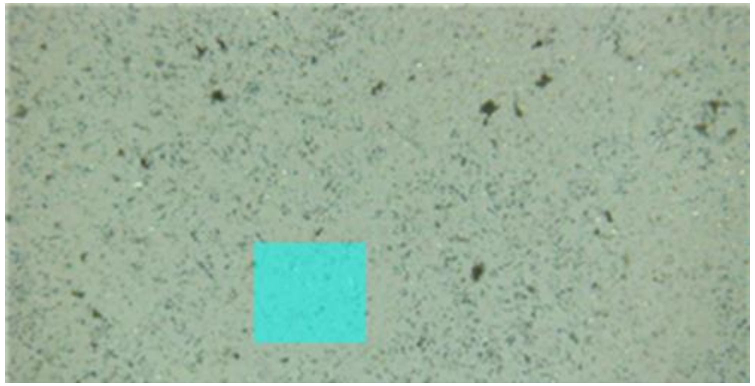
## Pre Trials Results

- Achievement of a surface with surface roughness Ra value between 0.14 – 0.34 µm with intensity of 1.36 mJ/mm²
- Benchmark value = 0.06 – 0.13 µm (mechanically polished surface)

**Mechanically polished PCD surface**

| | Rp | Rv | Rz | Ra | Rq |
|---|---|---|---|---|---|
| Seg.1 | 1.46um | 1.14um | 2.61um | 0.13um | 0.16um |

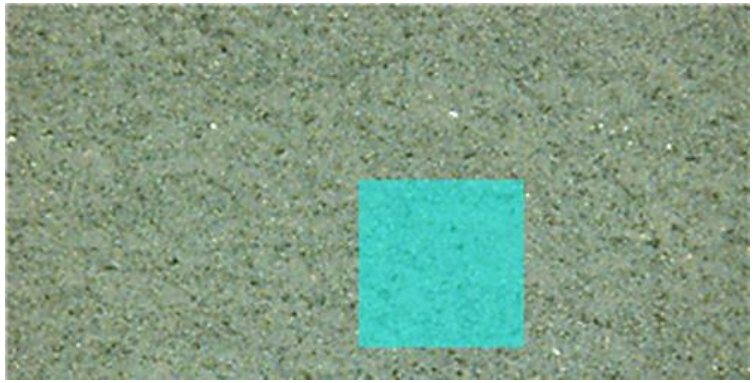
| | Rp | Rv | Rz | Ra | Rq |
|---|---|---|---|---|---|
| Seg.1 | 0.56um | 0.45um | 1.01um | 0.04um | 0.06um |



**Laser ablated PCD surface**

| | Rp | Rv | Rz | Ra | Rq |
|---|---|---|---|---|---|
| Seg.1 | 3.17um | 2.79um | 5.95um | 0.34um | 0.45um |

| | Rp | Rv | Rz | Ra | Rq |
|---|---|---|---|---|---|
| Seg.1 | 0.56um | 0.98um | 1.54um | 0.14um | 0.18um |



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| WP1 | Definition of user requirements |
|---|---|

# Laser Technology Specification

– Two steps processing to achieve high ablation rate

| PARAMETER | 1st step processing | 2nd step processing |
|---|---|---|
| **GOAL** | Highest removal rate while lowering surface roughness of PCD surface | Lower removal rate while achieving lowest surface roughness possible to reach polished surface state |
| **Power Average** | High power average : 200 W<br>Possibility to test 500 W ..? | Lower power average |
| **Pulse Width** | Few hundred femtoseconds to few picoseconds | Few hundred femtoseconds |
| **Frequency** | Over 1 MHz | Over 1 MHz |
| **Wavelength** | 1030 nm (no special requirement) | 1030 nm (no special requirement) |

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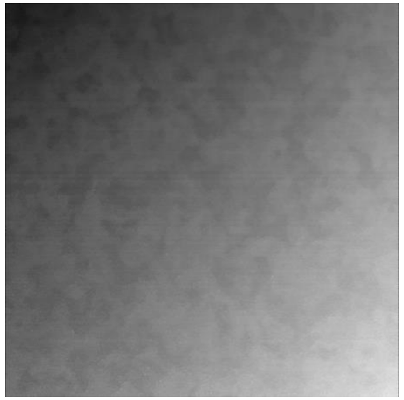
| WP2 | Process Development |
|---|---|

# Scanning Development

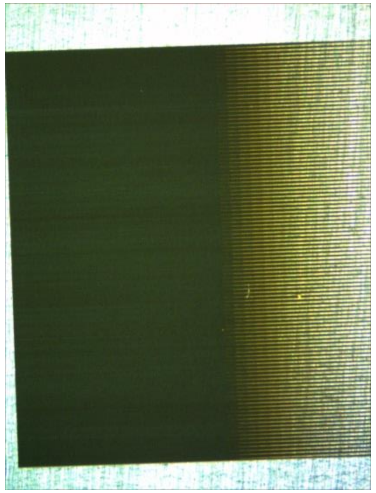
*In collaboration with*

CLASS 4 LASER See the light

- Development of topography sensor to overcome flatness issue and surface defects
- Topography sensor scans surface and creates a BITMAP image as below
- 2.000 x 2.000 pixels picture of a 10 x 10 mm steel surface
- 1 pixel = 5 µm
- Darker = deeper ablation



*BITMAP image of feature to ablate*



*Microscope picture of ablated surface*

- First ablation test =poor result…
- Need more development…

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| WP2 | Process Development |
|---|---|

# Programming Development

*In collaboration with*

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# THANK YOU

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# Contribution of GLOphotonics

GLOphotonics

The Hollow-Core PCF and Photonic MicroCell™ Company

J.Alibert

*GLOphotonics 123 Avenue Albert Thomas 87000, Limoges, France*

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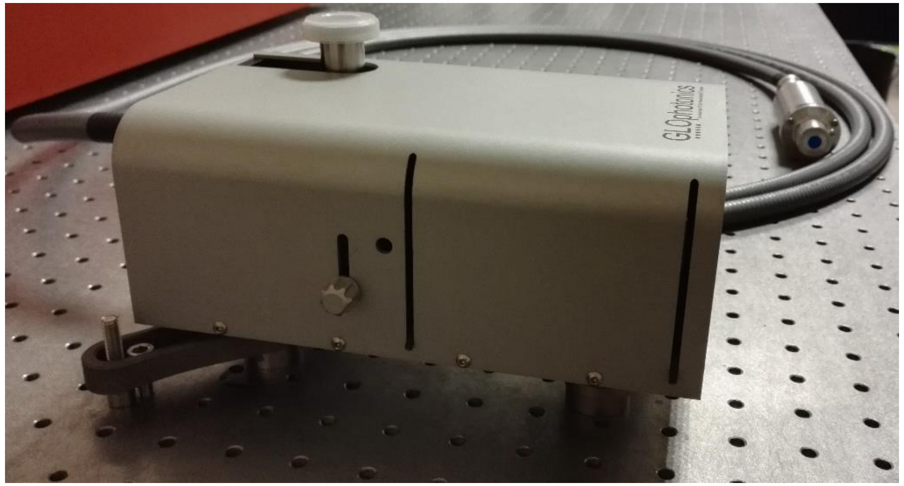
| WP4 | Photonic components for pre and post pulse conditioning |
|---|---|

*D4.4 task / Objective : Design, Fabrication and characterization of PMC module for beam delivery*

Milestone MS4 – (T0+6)

- Design a PMC module including
  - HC-PCF fiber from GLOphotonics standard
  - integrated in coupling optics and compact design
  - Gas & vacuum management
  - Robust fiber housing
- Assembly and test prototype#1
  - Internal characterization with USP laser
  - Specification sheet production



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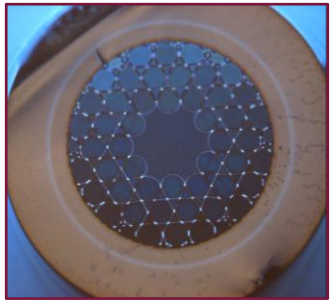
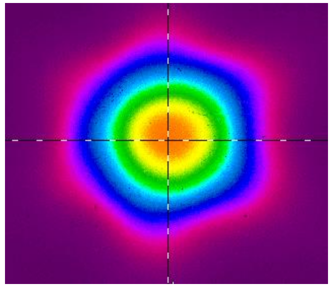
| WP4 | Photonic components for pre and post pulse conditioning |
|---|---|

## Design a PMC module including / HC-PCF fiber from GLOphotonics standard

*PMC-C-Yb-7C*



*Optical micrograph of fiber end facet*



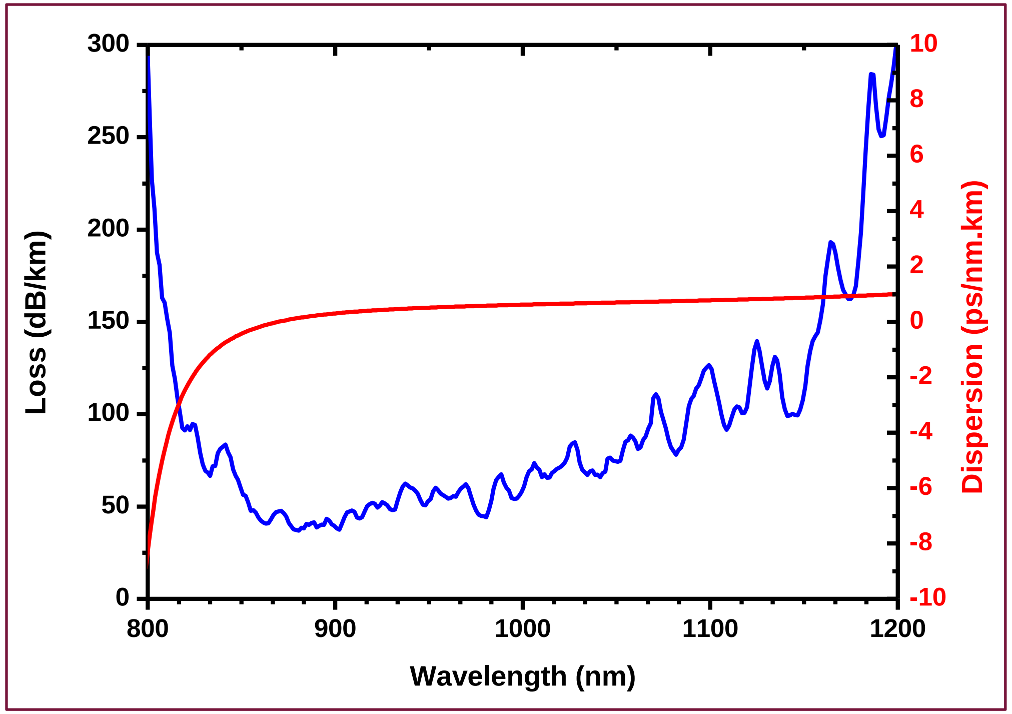
*Typical output near field profile @ 1030nm*

### 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 |

### Optical Properties

| | |
|---|---|
| Center Wavelength | 1030 nm |
| Attenuation @ 1030 nm | 50 dB/km ± 5 |
| Dispersion @1030 nm | 1 ps/nm/km ± 0.5 |
| Transmission band** <br> **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 |

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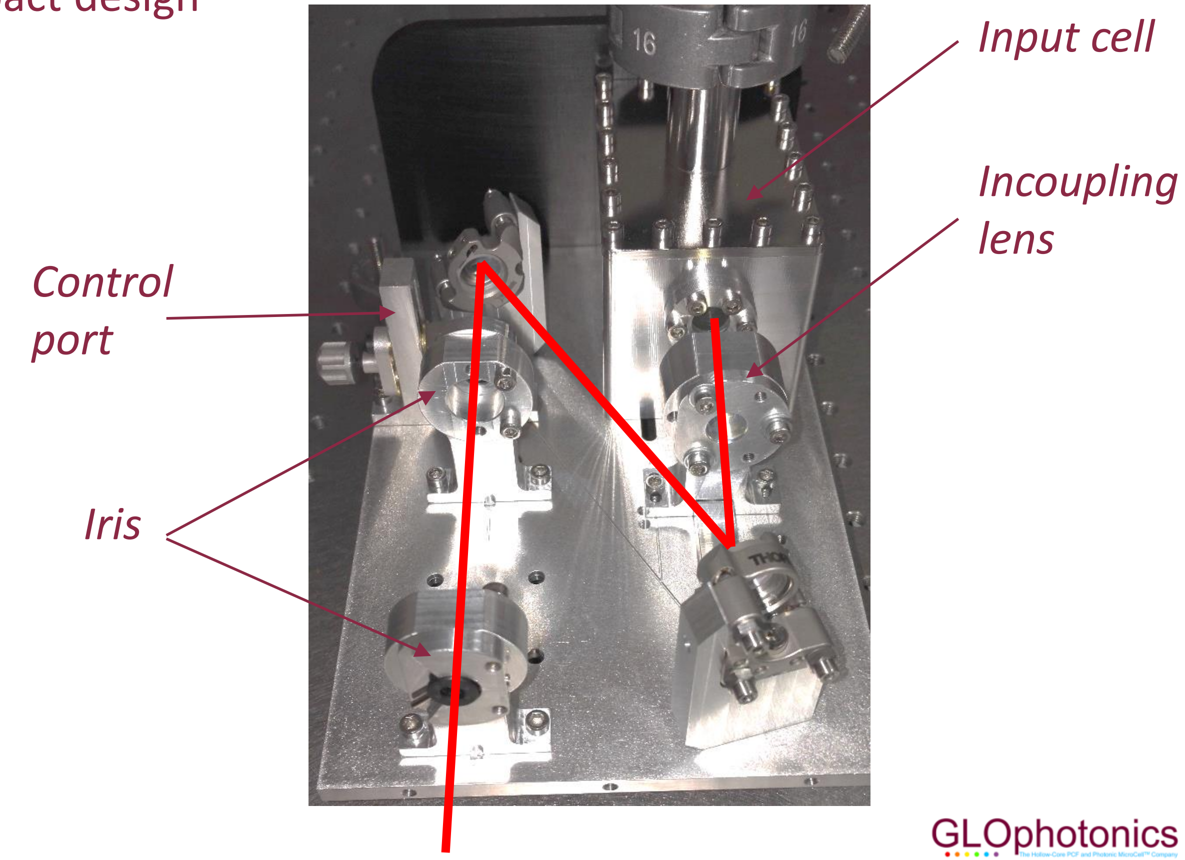
| WP4 | Photonic components for pre and post pulse conditioning |
|---|---|

Design a PMC module / integrated in coupling optics and compact design

- Compact imprint : 134mm x 212 mm
- Pré-aligned optics
- Iris & control port for user final alignment

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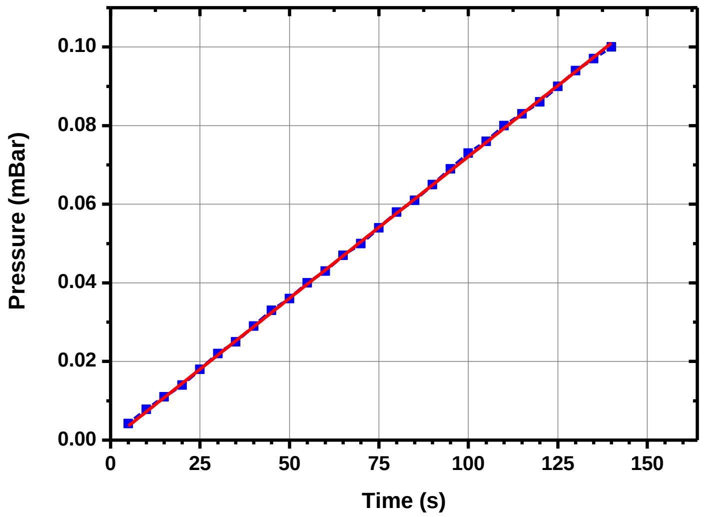
| WP4 | Photonic components for pre and post pulse conditioning |
|---|---|

## Design a PMC module / Gaz & vacuum management

- Standard KF 16 connection on input cell
- Hermetic output standard cell
- <3e-4 mbar.l/s (sensitivity limit of pressure rise test)

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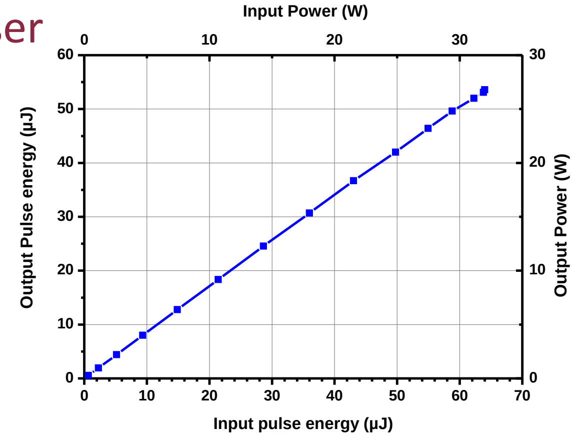
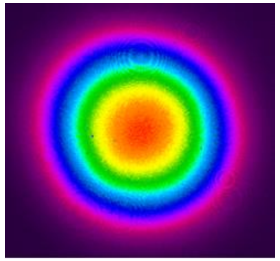
| WP4 | Photonic components for pre and post pulse conditioning |
|---|---|

## Assembly and test prototype#1 / Internal characterization with USP laser

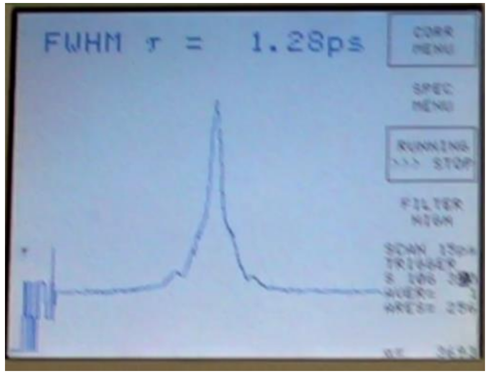
Test with 800fs, 1030nm laser / module prototype#1 (5m)

- >80% overall transmission (high energy, medium average power)
- Near diffraction limited output beam
- Preserved pulse width

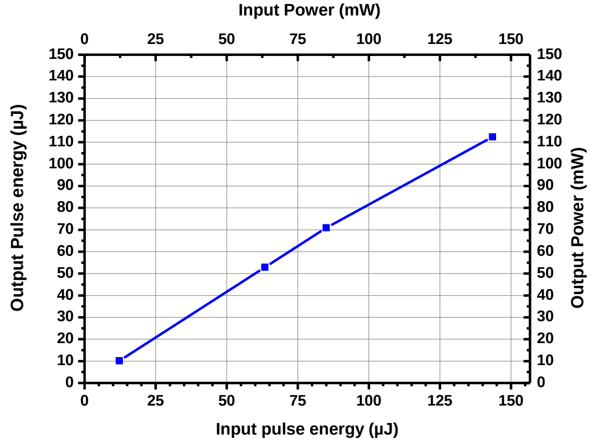


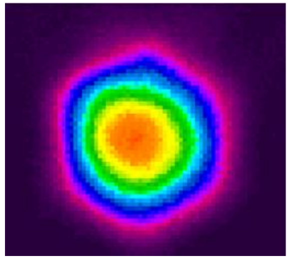



*Output far field profile*




*Autocorrelation trace for $E_{in}$=129µJ*



*Output near field profile*

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| WP4 | Photonic components for pre and post pulse conditioning |
|---|---|

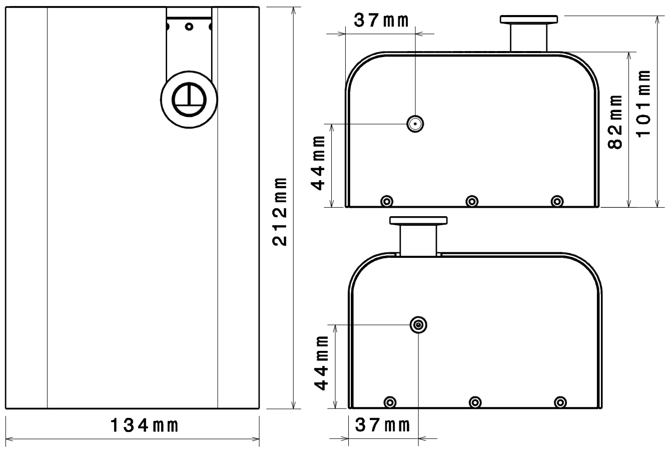
## Assembly and test prototype#1 / Specification sheet production

### Physical Properties

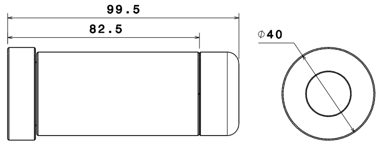
| | |
|---|---|
| Fiber length | 2 m ,3 m, 5 m |
| Output beam quality | $M^2<1.3$ |
| Gas/Vacuum Connexion | KF16 |
| Fiber Protection | Metallic monocoil |
| Monocoil OD[1] | 11.3 mm |
| Output[1] | Sealed rounded cell compatible with optional collimation |

### Optical Properties

| | |
|---|---|
| Center Wavelength | 1030 nm |
| Transmission | >80% |
| Dispersion @ Center Wavelength | 1 ps/nm/km ± 0.5 |
| Transmission band** <br>**Attenuation lower than 100 dB/km | >200 nm |
| Input beam requirment | Collimated 2.5 mm ± 0.1 |
| Min bend radius | 20 cm ± 2 |
| Max input power | 50 W |
| Max input pulse energy | 500 µJ |




*Module dimension*




*Output cell dimension*

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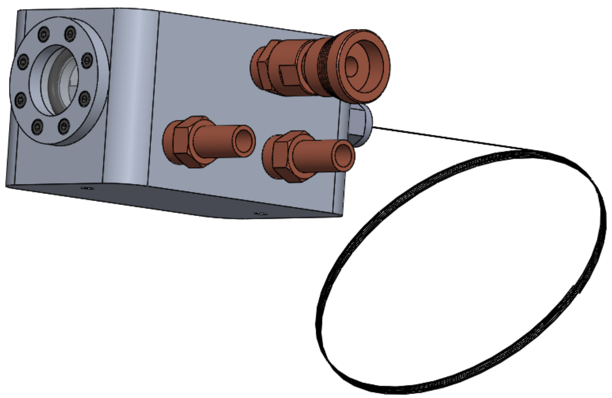
| WP4 | Photonic components for pre and post pulse conditioning |
|---|---|

Next 6 month

- Specification refinement (Laser developer & end user)
- Design and production of prototype#2 (MS14)
- Qualification by a laser developer (MS14)
- Development of water cooled version for high power management



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| WP8 | Dissemination & Exploitation (partner activities) |
|---|---|

## Peer review international conference:

1. Maurel M., Gorse A., Beaudou B., Lekiefs Q., Debord B., Gerome F., Benabid F.: « **Kagome fiber based industrial laser beam delivery**», *Photonic West 2017*, submitted.

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# WP9 Project Management

Julie Devall

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# WP9 Project Management

| | |
|---|---|
| T9.1 | Management and coordination of the project |
| T9.2 | Financial management of the project |
| T9.3 | Management of ethical and gender related issues |
| T9.4 | Establishment of consortium bodies, and of consortium meetings |
| T9.5 | Management of the consolidation of technical and financial reports |
| T9.6 | Monitoring and progress chasing and submission of deliverables and milestones |

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# WP9 Project Management

| Deliverable | Deliverable Title |
|---|---|
| D9.1 | Project management handbook |
| D9.2 | 1st Periodic Report |
| D9.3 | 2nd Periodic Report |
| D9.3 | 2nd Periodic Report |
| D9.4 | 3rd Periodic Report & Final Report |
| D9.4 | 3rd Periodic & Final Reports |

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| | |
|---|---|
| WP9 | Project Management |

## Milestones

| | |
|---|---|
| **MS2** | **Project Handbook** |
| **MS9** | **Completion of financial dry-run with partners** |

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

- Quick overview
- Tasks Started / being monitored
- Deliverables Submitted
- Milestones Achieved

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

- Quick overview
- Tasks Started / being monitored
  - Currently 31 "active tasks"
  - 2 completed
  - 2 to start on the horizon (within the reporting period)
  - Total 35 tasks to report on in our yearly periodic reporting

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

# Consortium Meeting - Stuttgart - 13/09/2016

| WP No | WP Leader | Lead B | Participants | T.no | Task Description | Start | S.Date | Finish | F. Date |
|---|---|---|---|---|---|---|---|---|---|
| WP1 | BOSCH | BOSCH | BOSCH,E6,C4L | T1.1 | Collection of end-user application specifications | 1 | 01/02/2016 | 4 | 31/05/2016 |
| WP1 | BOSCH | LASEA | C4L | T1.4 | Interface requirements | 1 | 01/02/2016 | 12 | 31/01/2017 |
| WP4 | XLIM | USTUTT | AMP,AMO | T4.1 | Design of grating compressors | 1 | 01/02/2016 | 18 | 31/07/2017 |
| WP5 | USTUTT | USTUTT | USTUTT | T5.1 | Design of the thin-disk multipass amplifier | 1 | 01/02/2016 | 6 | 31/07/2016 |
| WP8 | KITE | KITE | ALL | T8.1 | Web site | 1 | 01/02/2016 | 42 | 31/07/2019 |
| WP8 | KITE | KITE | ALL | T8.2 | Dissemination | 1 | 01/02/2016 | 42 | 31/07/2019 |
| WP8 | KITE | KITE | ALL | T8.5 | Management of Intellectual Property | 1 | 01/02/2016 | 42 | 31/07/2019 |
| WP9 | USTUTT | KITE | KITE | T9.1 | Management and coordination of the project | 1 | 01/02/2016 | 42 | 31/07/2019 |
| WP9 | USTUTT | KITE | KITE | T9.2 | Financial management of the project | 1 | 01/02/2016 | 42 | 31/07/2019 |
| WP9 | USTUTT | KITE | KITE | T9.3 | Management of ethical and gender related issues | 1 | 01/02/2016 | 42 | 31/07/2019 |
| WP9 | USTUTT | KITE | KITE | T9.4 | Establishment of consortium bodies, and of consortium meetings | 1 | 01/02/2016 | 42 | 31/07/2019 |
| WP9 | USTUTT | KITE | KITE | T9.5 | Management of the consolidation of technical and financial reports | 1 | 01/02/2016 | 42 | 31/07/2019 |
| WP9 | USTUTT | KITE | KITE | T9.6 | Monitoring and progress chasing and submission of deliverables and milestones | 1 | 01/02/2016 | 42 | 31/07/2019 |

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

# Consortium Meeting - Stuttgart - 13/09/2016

| WP No | WP Leader | Lead B | Participants | T.no | Task Description | Start | S.Date | Finish | F. Date |
|---|---|---|---|---|---|---|---|---|---|
| WP1 | BOSCH | BOSCH | ALL | T1.2 | Process and system specifications | 2 | 01/03/2016 | 12 | 31/01/2017 |
| WP1 | BOSCH | BOSCH | C4L, E6 | T1.3 | Assessment and validation of technical progress | 3 | 01/04/2016 | 12 | 31/01/2017 |
| WP2 | USTUTT | BOSCH | LASEA | T2.1 | Fundamental process development 3D Si processing | 3 | 01/04/2016 | 24 | 31/01/2018 |
| WP2 | USTUTT | C4L | USTUTT | T2.2 | Fundamental process development fine cutting of metals | 3 | 01/04/2016 | 23 | 31/12/2017 |
| WP2 | USTUTT | E6 | C4L | T2.3 | Fundamental process development diamond ablation | 3 | 01/04/2016 | 23 | 31/12/2017 |
| WP3 | AMP | AMP | USTUTT | T3.1 | 50-W, 300-fs laser >1MHz at 1030nm | 3 | 01/04/2016 | 9 | 31/10/2016 |
| WP3 | AMP | AMP | USTUTT, AMO | T3.2 | 200-W, ~500-fs laser >1MHz at 1030nm | 3 | 01/04/2016 | 21 | 31/10/2017 |
| WP3 | AMP | AMP | ALL | T3.3 | Flexible user interface including high speed modulation a high power pulse train | 3 | 01/04/2016 | 21 | 31/10/2017 |
| WP4 | XLIM | AMO | USTUTT | T4.2 | Development of a lithography process for the fabrication of pulse compression gratings | 3 | 01/04/2016 | 30 | 31/07/2018 |
| WP4 | XLIM | GLO | AMP, XLIM | T4.4 | Fabrication and characterization of photonic microcell (PMC) module | 3 | 01/04/2016 | 36 | 31/01/2019 |
| WP6 | C4L | LASEA | AMP,C4L,BOSCH E6 | T6.1 | Definition of interfaces | 3 | 01/04/2016 | 12 | 31/01/2017 |
| WP6 | C4L | USTUTT | AMP, C4L,LASEA,GLO | T6.2 | Definition of laser & optics sizes; optics specifications (incl. fibre) | 3 | 01/04/2016 | 15 | 30/04/2017 |
| WP4 | XLIM | AMO | USTUTT | T4.3 | Development of an etching process for the fabrication of optical components | 5 | 01/06/2016 | 30 | 31/07/2018 |

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# Consortium Meeting - Stuttgart - 13/09/2016

| WP No | WP Leader | Lead B | Participants | T.no | Task Description | Start | S.Date | Finish | F. Date |
|---|---|---|---|---|---|---|---|---|---|
| WP5 | USTUTT | USTUTT | AMP | T5.2 | Assembly & characterization of Yb:YAG thin-disk multipass amplifier | 6 | 01/07/2016 | 22 | 30/11/2017 |
| WP8 | KITE | KITE | ALL | T8.3 | Exploitation | 7 | 01/08/2016 | 42 | 31/07/2019 |
| WP8 | KITE | KITE | ALL | T8.4 | Intellectual property and supply chain | 7 | 01/08/2016 | 42 | 31/07/2019 |
| WP8 | KITE | KITE | ALL | T8.6 | Training | 7 | 01/08/2016 | 42 | 31/07/2019 |
| WP6 | C4L | C4L | LASEA | T6.3 | Development of the interfaces | 8 | 01/09/2016 | 22 | 30/11/2017 |
| WP6 | C4L | C4L | USTUTT,AMP, LASEA | T6.4 | System layout and build-up | 8 | 01/09/2016 | 36 | 31/01/2019 |
| WP6 | C4L | C4L | USTUTT, AMP, LASEA | T6.5 | Integration of laser and optics | 8 | 01/09/2016 | 24 | 31/01/2018 |
| WP4 | XLIM | GLO | AMP, XLIM | T4.5 | Design/Fabrication of photonic microcell module with integrated coupling optics | 12 | 01/01/2017 | 36 | 31/01/2019 |
| WP4 | XLIM | XLIM | GLO | T4.6 | Design and Fabrication of polarization maintaining hollow-core photonic crystal | 12 | 01/01/2017 | 36 | 31/01/2019 |

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

- Quick overview

**Deliverables (retrospective review)**

| Due Month | DoA Month | WP No | Deliverable | Deliverable Title | Lead Beneficiary | Submitted? |
|---|---|---|---|---|---|---|
| 1 | Feb-16 | WP9 | D9.1 | Project management handbook | KITE | Yes |
| 3 | Apr-16 | WP8 | D8.1 | Project website established | KITE | Yes |
| 3 | Apr-16 | WP8 | D8.2 | Communication kit | KITE | Yes |
| 4 | May-16 | WP1 | D1.1 | End-user application specifications | BOSCH | Yes |
| 4 | May-16 | WP4 | D4.1 | Report on simulation of pulse compression gratings with diffraction efficency >=99% over large spectral bandwith (5-10 nm) around 1030 nm | USTUTT | Yes |
| 4 | May-16 | WP8 | D8.3 | Video presentation of the Hiperdias project | KITE | No |
| 6 | Jul-16 | WP5 | D5.1 | Design of the multi-pass amplifier | USTUTT | Yes |

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

- Quick overview

## Deliverables (on horizon in this reporting period)

| Due Month | DoA Month | WP No | Deliverable | Deliverable Title | Lead Beneficiary |
|---|---|---|---|---|---|
| 9 | Oct-16 | WP3 | D3.1 | 50-W, 300-fs,>1-MHz laser for seeding an Yb:YAG amplier (1) | AMP |
| 9 | Oct-16 | WP3 | D3.2 | 50-W, 300-fs,>1-MHz laser for seeding an Yb:YAG amplier (2) | AMP |
| 12 | Jan-17 | WP1 | D1.2 | Process and system specifications | E6 |
| 12 | Jan-17 | WP1 | D1.3 | Prototypes and progress validation | BOSCH |
| 12 | Jan-17 | WP1 | D1.4 | Definition of software-technical Interface | LASEA |
| 12 | Jan-17 | WP4 | D4.2 | Report on first fabrication of pulse compression grating with 98% diffraction efficiency on large area, rectangluar substrate material | AMO |
| 12 | Jan-17 | WP6 | D6.1 | Definition of interfaces | LASEA |
| 12 | Jan-17 | WP8 | D8.4 | Draft exploitation and dissemination plan | KITE |
| 12 | Jan-17 | WP9 | D9.2 | 1st Periodic Report | USTUTT |

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

- Quick overview

## Milestones (achieved so far)

- **MS1 Press Release - WP8 – Kite M01**
- **MS2 Kick-off Meeting and election of Consortium Bodies – WP8 – Kite M02**
- **MS3 First Design high efficient grating mirrors - WP4 – USTUTT M03**
- **MS4 PMC Module for fibre beam delivery prototype -WP4 – GLO M06**

## Milestones (on horizon)

- **MS5 Specification for laser parameters established –WP1 –BOSCH M08 (Due now)**
- **MS6 1st generation grating mirror on large area rectangular substrates fabricated – WP4 –AMO M08 (Due now)**
- **MS7 Interface definition fixed – WP1,WP3, WP6 – LASEA M08 (Due now)**
- **MS8 A 50w, 300 fs at >1mhz seed laser – WP3 - AMP M09**
- **MS9 Completion of financial reporting “dry run” with all partners –WP9 M09**
- **MS10 Key performance indicators for productivity progress specified – WP1 – BOSCH – M10**
- **MS11 Key performance indicators for quality standards specified – WP1 –BOSCH – M12**
- **MS12 Specification for system technology established – WP1 –BOSCH –M12**
- **MS13 Fully optical characterisation of grating mirror regarding diffraction efficiency and LIDT – WP4 –AMO – M12**

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- Quick overview

## Milestones (on horizon continued)

- **MS14 PMC module for fibre beam delivery prototype #2 – WP4 –GLO M12**
- **MS15 Design of HC-PCF with improved PER at 1 um (>20 dB) – WP4 - XLIM M12**
- **MS16 System layout fixed – WP3, WP4, WP5, WP6 – C4L M12**

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

- Quick overview

## Milestones (on horizon continued)

- **MS14 PMC module for fibre beam delivery prototype #2 – WP4 –GLO M12**
- **MS15 Design of HC-PCF with improved PER at 1 um (>20 dB) – WP4 - XLIM M12**
- **MS16 System layout fixed – WP3, WP4, WP5, WP6 – C4L M12**

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| WP9 | Project Management (Periodic Reporting) |
|---|---|

**Technical Report – Project Coordinator's Project Summary (for the period)**

- *Project Summary – to be completed by the coordinator*

*The Project Coordinator is expected to answer the following questions;*

- *Summary of the context and overall objectives of the project*
- *Work performed from the beginning of the project to the end of the period covered by the report*
- *Progress beyond the state of the art and expected potential impact (including the socio-economic and the wider societal implications of the project so far)*
- *Address (URL) of the projects public website*
- *Any supporting documents (images etc.)*

**Technical Report - All WP Leader updates (for the period)**

- *All WP Leaders to provide an overall summary of the progress so far for the period*
- *To break down the summary at task level*
- *Name the participants involved in each of the tasks*
- *Describe any deviations from the Description of Work (resources, timescales, scope)*
- *Describe any corrective actions that took place on the WP to rectify any deviations*

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| | | | | | |
|---|---|---|---|---|---|
| **Work package no.** | **WP 1** | **Plan-Start:** | **1** | **Plan-End:** | **12** |
| **Lead Participant** | **5-BOSCH** | **Actual-Start:** | | **Actual-End:** | |
| **Work package title** | **Definition of User Requirements** | | | | |
| **Activity Type** | **RTD** | | | | |
| **Participant involved** | **BOSCH, USTUTT,AMP, C4L, AMO, XLIM, LASEA, GLO, E6** | | | | |
| **Work package summary of progress towards objectives** | | | | | |
| ***Please provide an overall summary of the period here*** | | | | | |

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| | | | | | |
|---|---|---|---|---|---|
| Task no. | T1.1 | Plan-Start: | M1 | Plan-End: | M4 |
| Lead Participant | BOSCH | Actual-Start: | | Actual-End: | 1 |
| Task title | Collection of end-user application specifications | | | | |
| Participant involved | C4L, E6 | | | | |
| Progress of work; | | | | | |
| *Your update here* | | | | | |

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| WP1 Deliverables and Milestones due in this period | | | | | |
|---|---|---|---|---|---|
| Lead Participant | BOSCH | Date due: | | Date submitted: | |
| Deliverable no. & title | D1.1 End-user application specifications | | | | |
| Participant involved | | | | | |
| Progress of work | | | | | |
| ***Your update here*** | | | | | |

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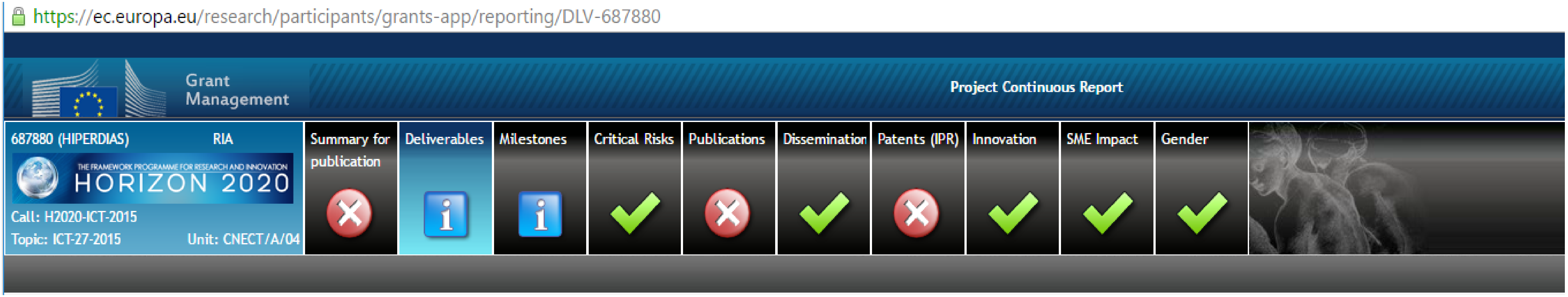
# Consortium Meeting - Stuttgart - 13/09/2016

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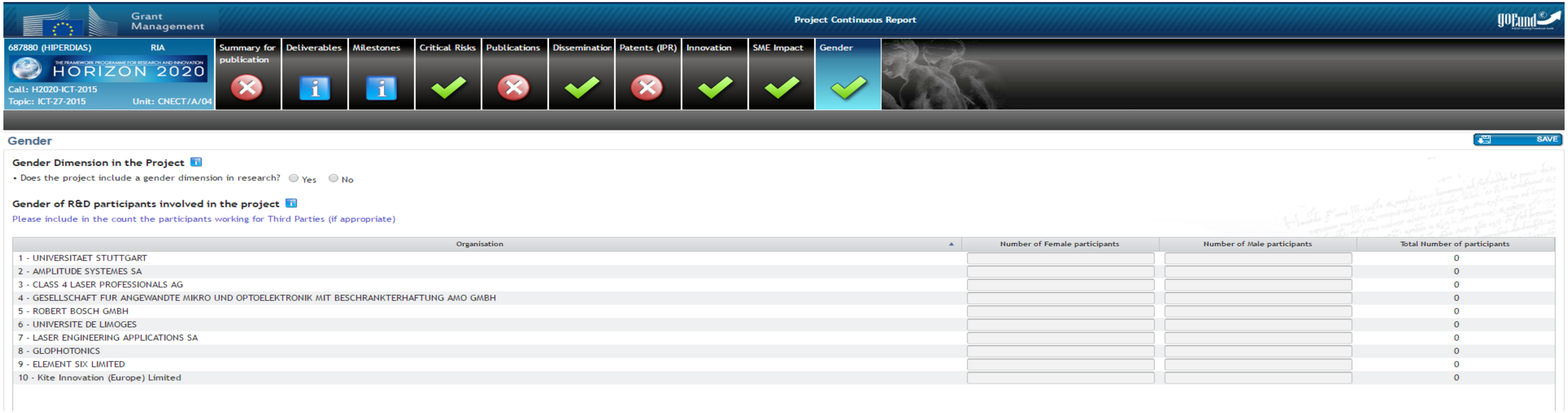
| WP9 | Project Management |
|---|---|

Task 9.3 Management of ethical and gender related issues (USTUTT, KITE M01 – M42)

The HIPERDIAS Consortium takes seriously issues related to ethics in science and gender aspects. Their management is detailed in Section 1.3. Monitoring and reporting will carried out by the CPO. At the end of the project, ethical and gender related issues will be covered in the final report, under the heading 'awareness and wider societal implications'.




Gender

**Gender Dimension in the Project**

• Does the project include a gender dimension in research? Yes No

**Gender of R&D participants involved in the project**

Please include in the count the participants working for Third Parties (if appropriate)

| Organisation | Number of Female participants | Number of Male participants | Total Number of participants |
|---|---|---|---|
| 1 - UNIVERSITAET STUTTGART | | | 0 |
| 2 - AMPLITUDE SYSTEMES SA | | | 0 |
| 3 - CLASS 4 LASER PROFESSIONALS AG | | | 0 |
| 4 - GESELLSCHAFT FUR ANGEWANDTE MIKRO UND OPTOELEKTRONIK MIT BESCHRANKTERHAFTUNG AMO GMBH | | | 0 |
| 5 - ROBERT BOSCH GMBH | | | 0 |
| 6 - UNIVERSITE DE LIMOGES | | | 0 |
| 7 - LASER ENGINEERING APPLICATIONS SA | | | 0 |
| 8 - GLOPHOTONICS | | | 0 |
| 9 - ELEMENT SIX LIMITED | | | 0 |
| 10 - Kite Innovation (Europe) Limited | | | 0 |

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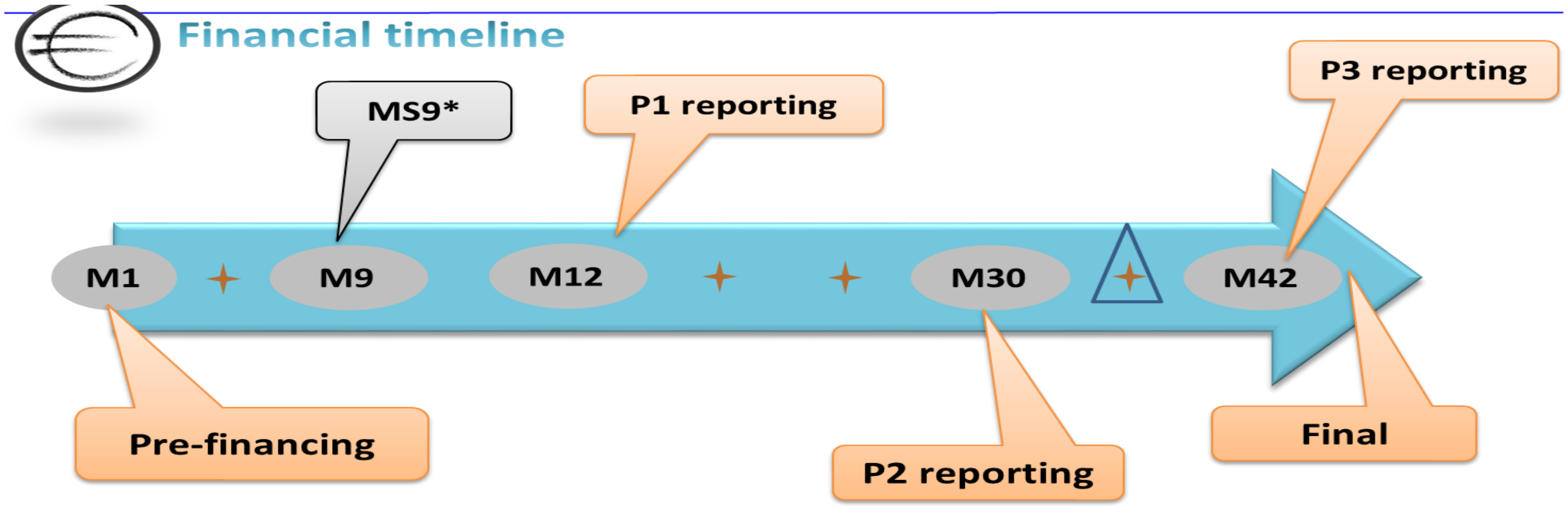
| WP9 | Project Management |
|---|---|

# T9.2 Financial management of the project




✦ – at six monthly intervals, the management board will request updated technical & financial reports

*MS9 – Completion of reporting "dry run" with all partners. T9.2 Means of verification: Draft financial report generated

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| WP9 | Project Management |
|---|---|

| Partner | Partner short Name | Total EU Contribution (€) | Pre-financing distribution: Received | Pre-financing distribution: Guarantee Fund | Pre-financing distribution: Total Net amount transferrable | 90% limit of max grant amount | Max interim payments during project | Max final payment at the end of project | Total check = net pre finance + Period payment + final payment |
|---|---|---|---|---|---|---|---|---|---|
| 1 | USTUTT | € 909,187.50 | € 393,950.94 | € 45,459.38 | € 348,491.57 | € 818,268.75 | € 424,317.81 | € 136,378.13 | € 909,187.50 |
| 2 | AMP | € 555,750.00 | € 240,806.48 | € 27,787.50 | € 213,018.98 | € 500,175.00 | € 259,368.52 | € 83,362.50 | € 555,750.00 |
| 4 | AMO | € 371,742.50 | € 161,076.03 | € 18,587.13 | € 142,488.90 | € 334,568.25 | € 173,492.22 | € 55,761.38 | € 371,742.50 |
| 5 | BOSCH | € 499,002.50 | € 216,217.78 | € 24,950.13 | € 191,267.66 | € 449,102.25 | € 232,884.47 | € 74,850.38 | € 499,002.50 |
| 6 | XLIM | € 299,500.00 | € 129,773.35 | € 14,975.00 | € 114,798.35 | € 269,550.00 | € 139,776.65 | € 44,925.00 | € 299,500.00 |
| 7 | LASEA | € 441,750.00 | € 191,410.28 | € 22,087.50 | € 169,322.78 | € 397,575.00 | € 206,164.72 | € 66,262.50 | € 441,750.00 |
| 8 | GLO | € 289,750.00 | € 125,548.68 | € 14,487.50 | € 111,061.18 | € 260,775.00 | € 135,226.32 | € 43,462.50 | € 289,750.00 |
| 9 | E6 | € 123,417.50 | € 53,476.80 | € 6,170.88 | € 47,305.93 | € 111,075.75 | € 57,598.95 | € 18,512.63 | € 123,417.50 |
| | E6 UK | € 8,832.50 | € 3,827.12 | € 441.63 | € 3,385.50 | € 7,949.25 | € 4,122.13 | € 1,324.88 | € 8,832.50 |
| 10 | KITE | € 141,375.00 | € 61,257.79 | € 7,068.75 | € 54,189.04 | € 127,237.50 | € 65,979.71 | € 21,206.25 | € 141,375.00 |
| **TOTAL** | | **€ 3,640,307.50** | **€ 1,577,345.24** | **€ 182,015.38** | **€ 1,395,329.87** | **€ 3,276,276.75** | **€ 1,698,931.51** | **€ 546,046.13** | € 3,640,307.50 |

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| WP9 | Project Management |
|---|---|

Financial Reporting

**We are reporting on all costs which are eligible**

- Actual and incurred during the project
- Needed solely for work on the project
- Recorded in the accounts
- Salary costs should be backed up by timesheets

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| WP9 | Project Management |
| --- | --- |

Financial Reporting

**Examples of ineligible costs**

- Exchange rate losses
- Costs already considered
- Costs already included in “indirect costs”
- Costs which may be considered excessive

Remember if you exceed 325,000 during the course of the project, you will be required to carry out an audit by an external auditor

Remember to keep all records as the EU at any time can carry out their own audit

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| WP9 | Project Management |
|---|---|

## Indirect Costs

Are costs that are not directly linked to the action implementation and therefore cannot be attributed directly to it.

**Indirect costs** are eligible if they are declared on the basis of the **flat-rate of 25% of the eligible direct costs** (see Article 5.2), from which are excluded:

- costs of subcontracting and
- costs of in-kind contributions provided by third parties which are not used on the beneficiary's premises;

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| WP9 | Project Management |
| --- | --- |

*Financial Dry run – to be complete by 1st Nov*

*Spreadsheet sent out to financial partners, complete by 3rd week of Oct.*

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

LASER ENGINEERING APPLICATIONS

David Bruneel

Jose Antonio Ramos

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

- Please provide an update of the progress made so far on the project by Work package, any deliverables you have contributed to and milestones worked on.
- You may present this by whatever means you see fit (i.e. include photos, link to video etc) but please use this official Hiperdias template.
- It may be the case that you have not worked on all work packages - delete as appropriate
- You may add to the amount of slides here, simply duplicate the format

- Delete this information slide from your final presentation

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| WP1 | Definition of user requirements |
|---|---|

*Work completed*

*T1.4 : Definition of the interfaces :*

*Description of the task: Definition of the requirements of the software/technical interfaces to be developed. These activites will focus on aspects as electrical, mechanical, and optical and software interfaces between the different units (laser, scanner, axis, opto-mechanical element).*

*Create and provide a document that defines and lists all the interfaces between the different components of the system. This document is a living document to be completed during the definition tasks. Every partner has to fill its corresponding tab with the different interfaces details of the component(s) he is in charge, and if necessary to adapt it. This document gathers all information from the different partners for the different interfaces.*

| | *Item* | M1 | M2 | M3 | M4 | M5 | M6 | M7 | M8 | M9 | M10 | M11 | M12 | ... |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **WP1 - Definition of User Requirements** | | | | | | | | M1.1 | | M1.2 | | M1.3 | |
| T1.1 | Collection of end-user application specifications | | | | D1.1 | | | | | | | | M1.4 | |
| T1.2 | Process and system specifications | | | | | | | | | | | | D1.2 | |
| T1.3 | Assessment and validation of technical progress | | | | | | | | | | | | D1.3 | |
| T1.4 | Interface requirements | | | | | | | | | | | | D1.4 | |

Interfaces_require
ıents_USTUTT_AM

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

| WP1 | Definition of user requirements |
|---|---|

*Next 6 months*

*T1.4: Make the document fully completed by all the involved partners. Highlight any mismatch between the different units and propose a solution.*
*The gathered information will then be used in the T6.1 which consists in describing the technical details of interfaces that will have to be developed or modified by the different partners to overcome any mismatch.*

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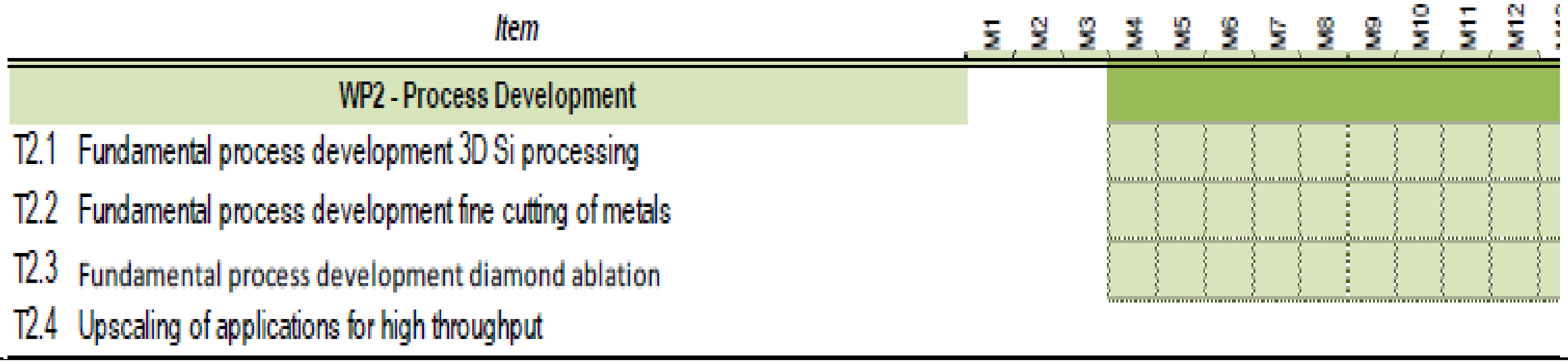
| WP2 | Process Development |
|---|---|

*Work completed*

*T2.1 : Fundamental process development 3D Si processing*

*A study of the process of silicon has been carried out using an actual setup available at LASEA.*
*The goal of this study is to point out the best conditions of machining in terms of laser parameters and quality.*

*This first study revealed that the use of a not too high energy density should be used in order to avoid degradation of the quality with edge burrs appearing. A maximum energy density can be determined which corresponds to the start of the apparition of the burrs.*

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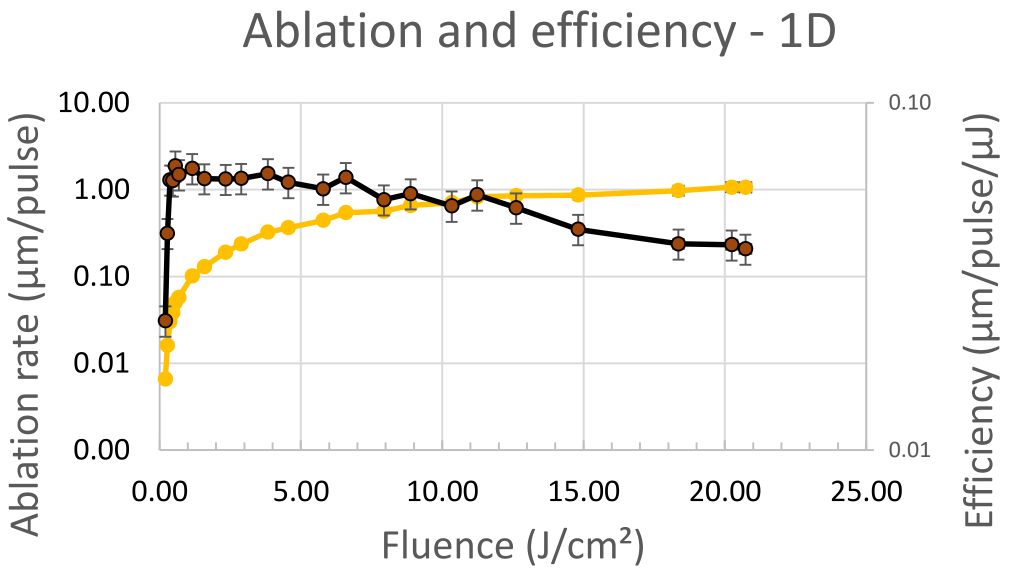
| WP2 | Process Development |
|---|---|

*Work completed*
*T2.1 : Fundamental process development 3D Si processing :*

*Spot diameter : 13 µm*
*Speed : 1m/s*
*5 pulses (cumulated)*

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

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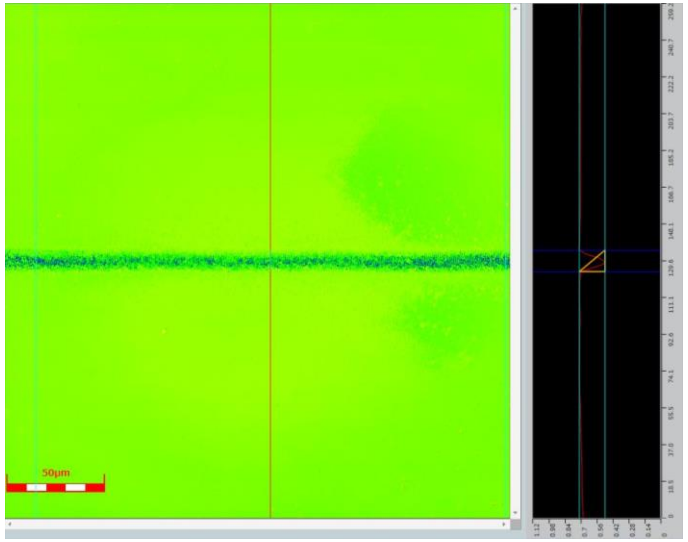
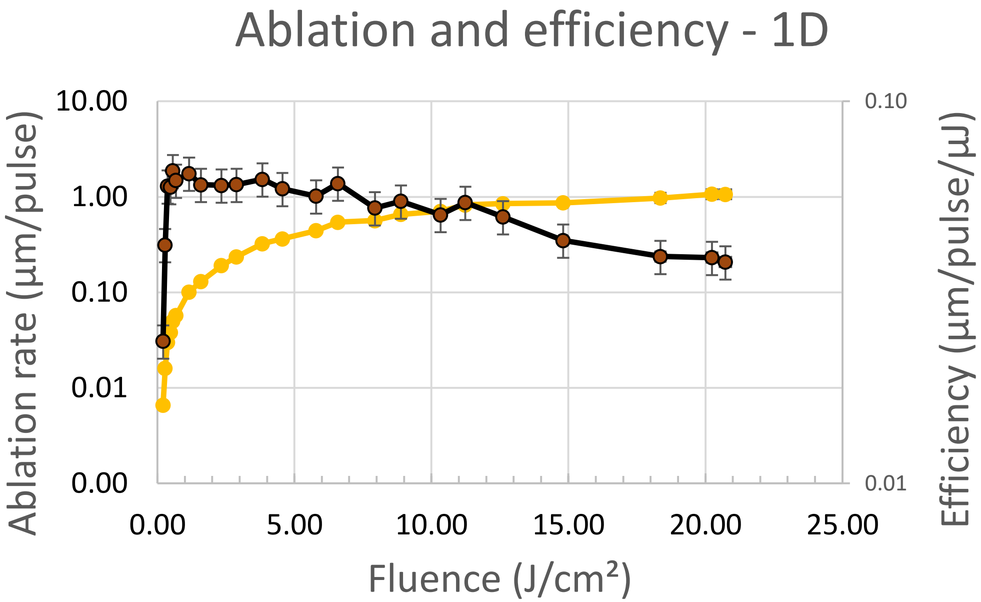
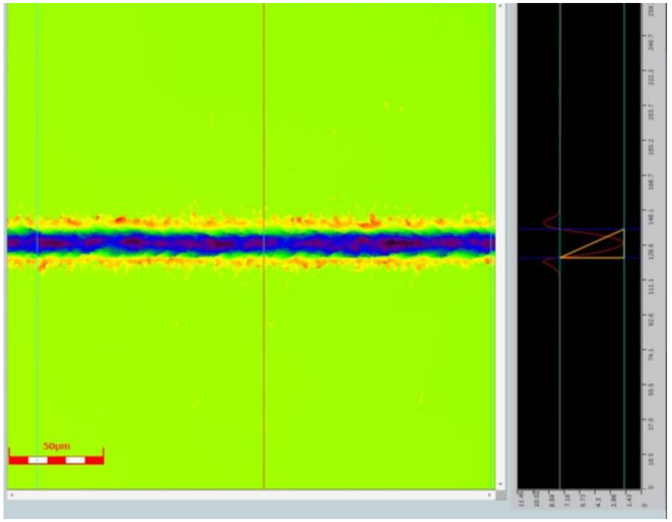
| WP2 | Process Development |
| --- | --- |

*Work completed*

*T2.1 : Fundamental process development 3D Si processing :*





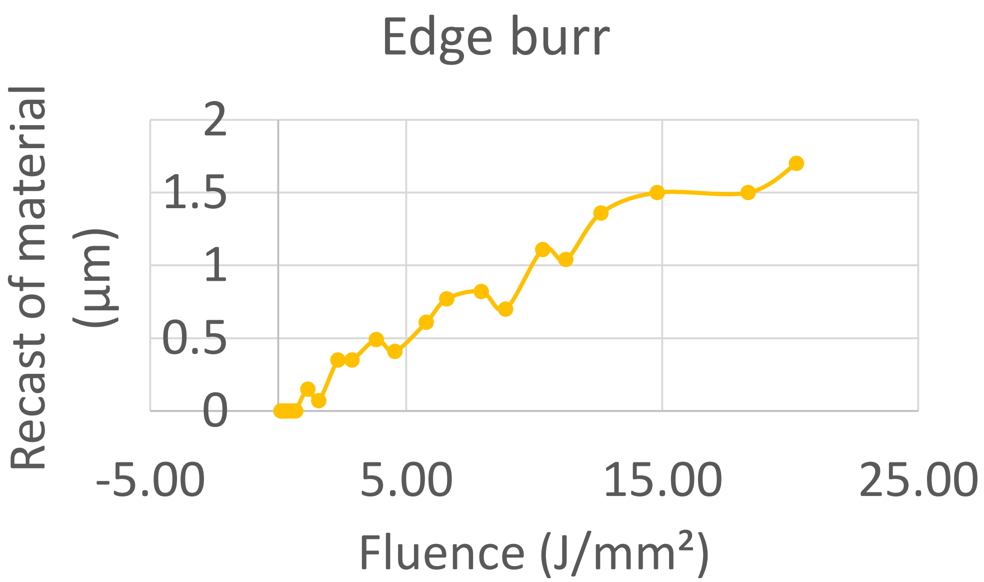



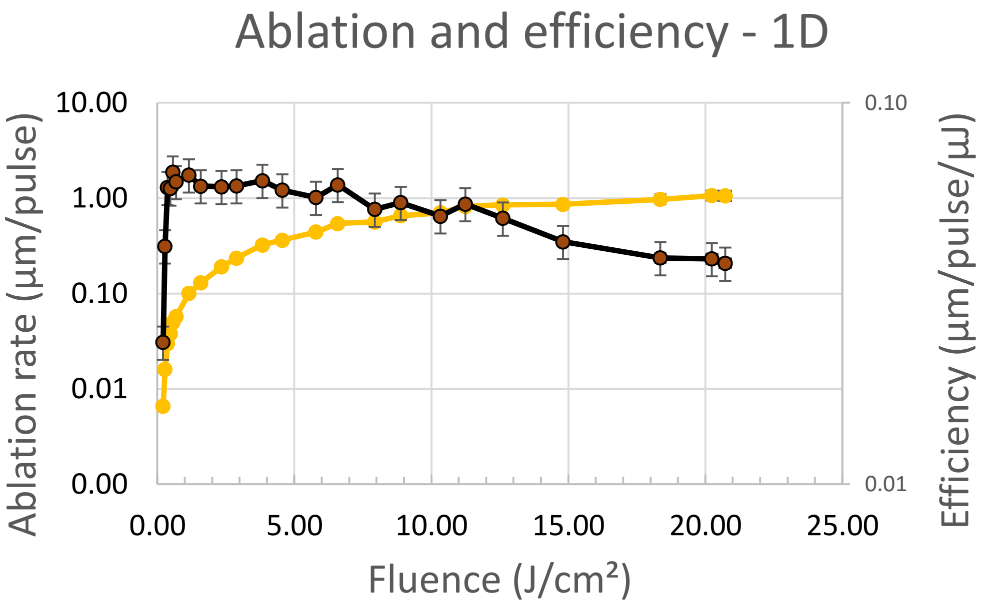
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687880

| WP2 | Process Development |
|---|---|

*Work completed*

*T2.1 : Fundamental process development 3D Si processing :*




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

| WP2 | Process Development |
|---|---|

*During the next 6 months the volumic ablation rate will be investigated.*
*The critical energy density determined allows to give an approximation of the corresponding focal length.*

*Input beam diameter = ~15mm*
*Laser power 500 W – 1000 W @1MHz*

| Power (W) | Pulse energy (mJ) | Pulse energy -20% losses (mJ) | Focal length (mm) | Max. Energy density ($J/cm^2$) | Optical Spot Diameter (µm) |
|---|---|---|---|---|---|
| 500 | 0,5 | 0,4 | 500 | 21 | 50 |
| 1000 | 1 | 0,8 | 500 | 42 | 50 |
| 500 | 0,5 | 0,4 | 1000 | 5 | 100 |
| 1000 | 1 | 0,8 | 1000 | 10 | 100 |

*Next 6 months*
*During the next 6 months more experiments will be carried out in order to develop the processes requested (high speed ablation rate, drilling, edge steepness, …)*

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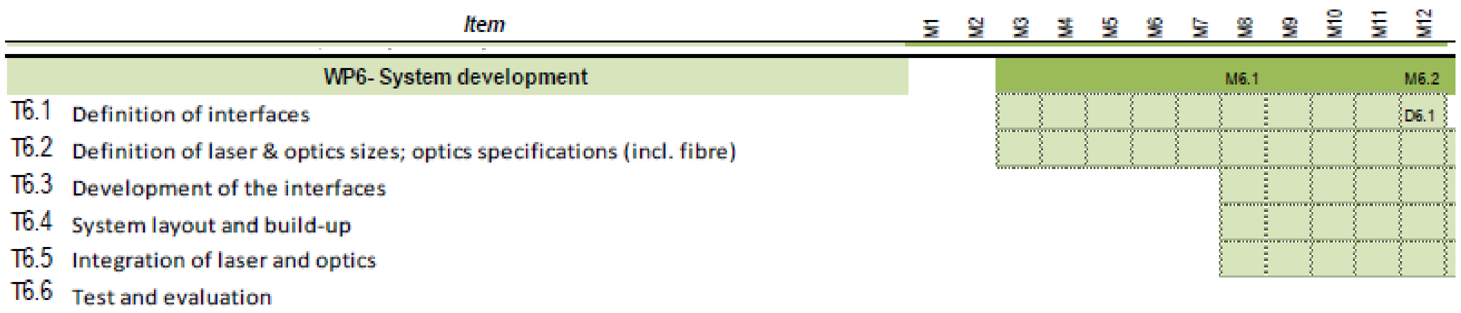
| WP6 | Thin-disk Multi-pass Booster |
|---|---|

*Work completed*
*No work has been carried out during so far.*

*Next 6 months*
*T6.1: Definition of interfaces : highlight mismatches in interfaces.*
*Exchange with the partners in order to propose solutions and/or modifications.*




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

| WP6 | Thin-disk Multi-pass Booster |
|---|---|
| *Next 6 months* | |

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

| WP8 | Dissemination & Exploitation (partner activities) |
| --- | --- |
| What dissemination activities has your organisation taken to promote the Hiperdias project?<br><br>Please list here and you may include images/photos etc. | |

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

# UNIERSITÄT STUTTGART (USTUTT), Institut für Strahlwerkzeuge (IFSW) (WP2, 4, 5 & 7)

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

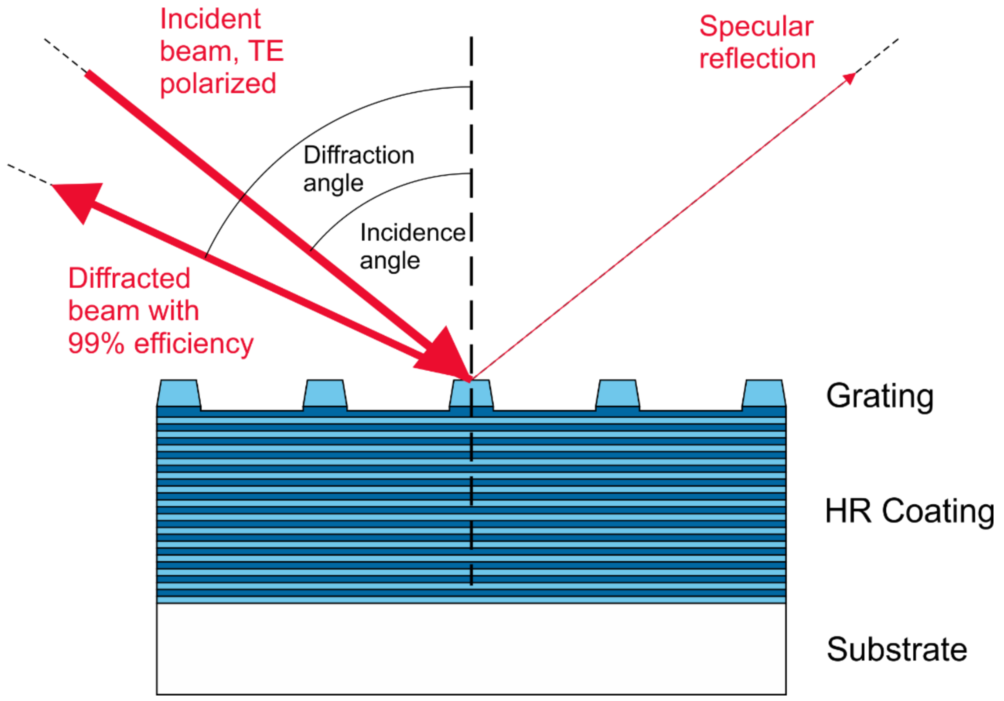
| WP2 | Process Development |
| --- | --- |
| ***Work not yet started for USTUTT*** | |

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

| WP4 | Photonic components for pre and post pulse conditioning |
|---|---|

***Task 4.1: Design of grating compressors***

- *Target parameters (defined together with AMP and AMO*
- → *Period =* ***610 nm (1640 l/mm)***
- → *AOI=51.4° i.e. Separation angle=13.7°*
- → *Diffraction efficiency>99% over >10nm spectral*
- *bandwidth around 1030 nm*
- → *Chosen material for dielectric layers:* $\boldsymbol{Ta_2O_5/SiO_2}$
- *(maybe* $HfO_2/SiO_2$ *at later stage)*
- → *designs were evaluated for 3 different suppliers*
- *(providing layers with slightly different* ***refractive indices****)*

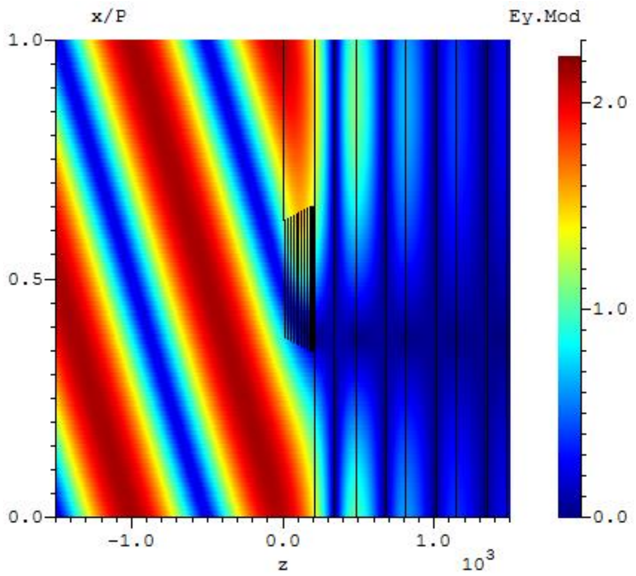


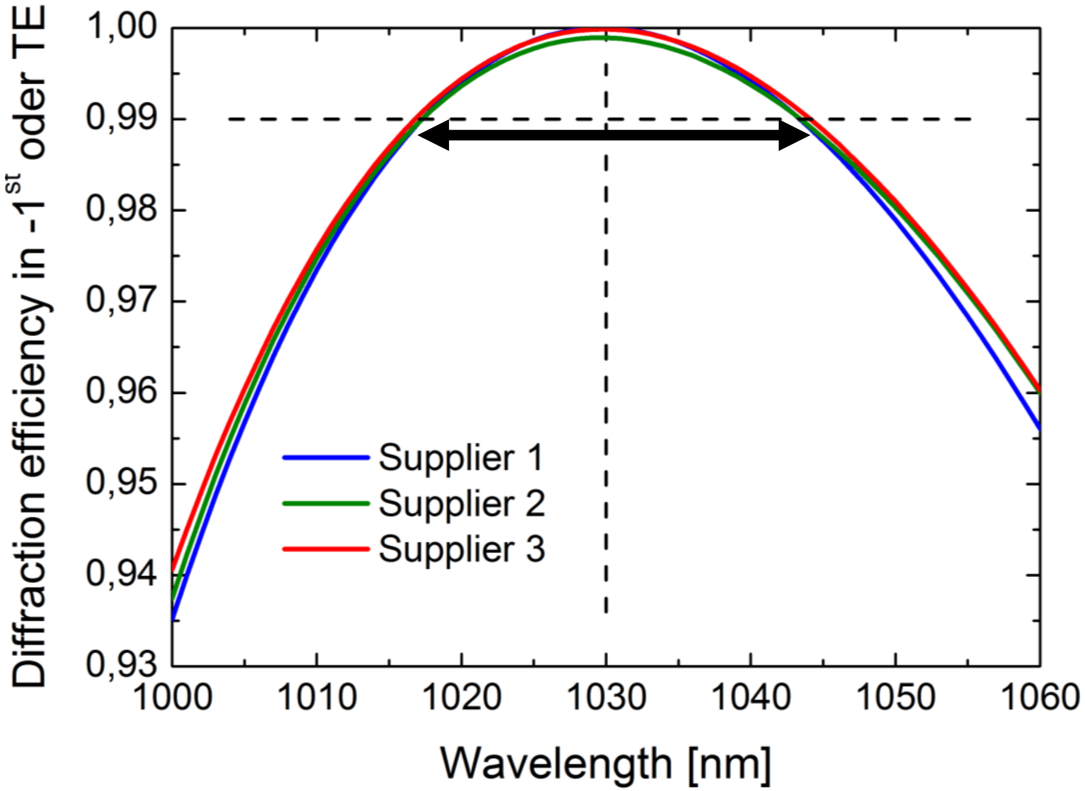

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687880

| WP4 | Photonic components for pre and post pulse conditioning |
| --- | --- |

***Task 4.1: Design of grating compressors (due month 6, completed)***

- *Simulation results: Calculated Diffraction efficiency and LIDT*
- ***→DE (-1st) >99% over >20 nm around 1030nm***
- ***→ LIDT* : 0.35 – 0.5 J/cm²***




*Gallais et.al, APPLIED OPTICS / Vol. 53, No. 4 / 1 February 2014

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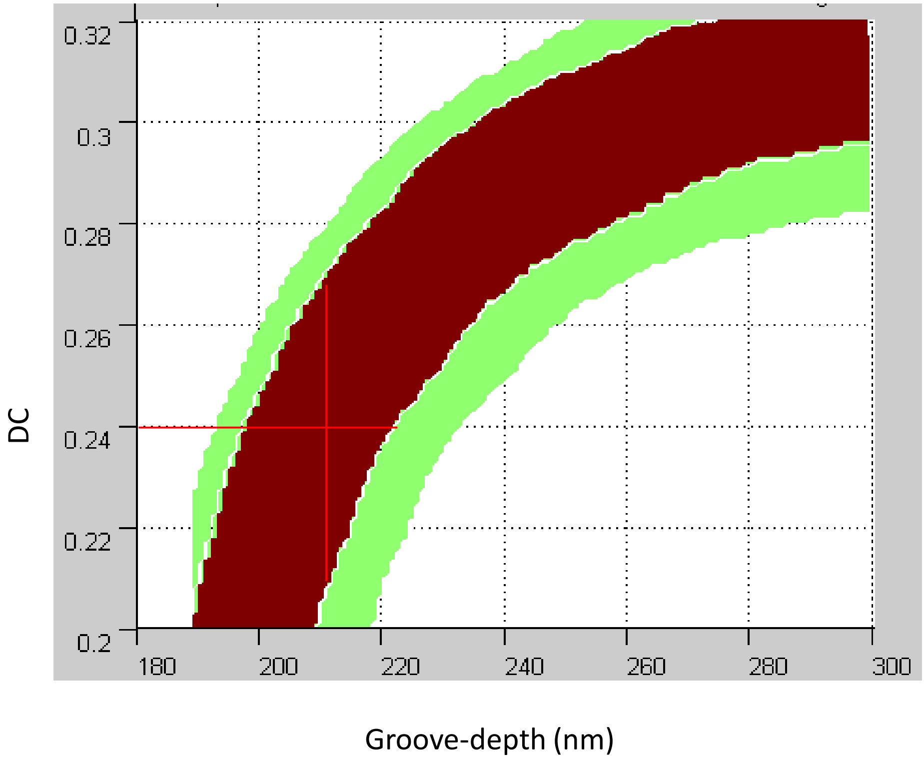
| WP4 | Photonic components for pre and post pulse conditioning |
| --- | --- |

***Task 4.1: Design of grating compressors***

- *Tolerances analysis: Calculated Diffraction efficiency and LIDT*
- *→ Groove depth = 210 nm (+/- 10-20 nm for a fixed DC)*
- *→ Duty-cycle = 24% (+/- 2-3%, for a fixed groove depth)*
- ***Parameters were communicated to AMO for the production of the gratings***

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| WP4 | Photonic components for pre and post pulse conditioning |
|---|---|

***Next 6 months***

- *Task 4.2: Optical characterization of the fabricated gratings by AMO: measurement of diffraction efficiency over a spectral bandwidth of >20 nm around 1030 nm*
- *Design optimization (Task 4.1): design iteration taking into account the measured diffraction efficiency in order to identify the cause of deviations (in case some) from initial design.*
- *LIDT measurements (collaboration with an external partner)*

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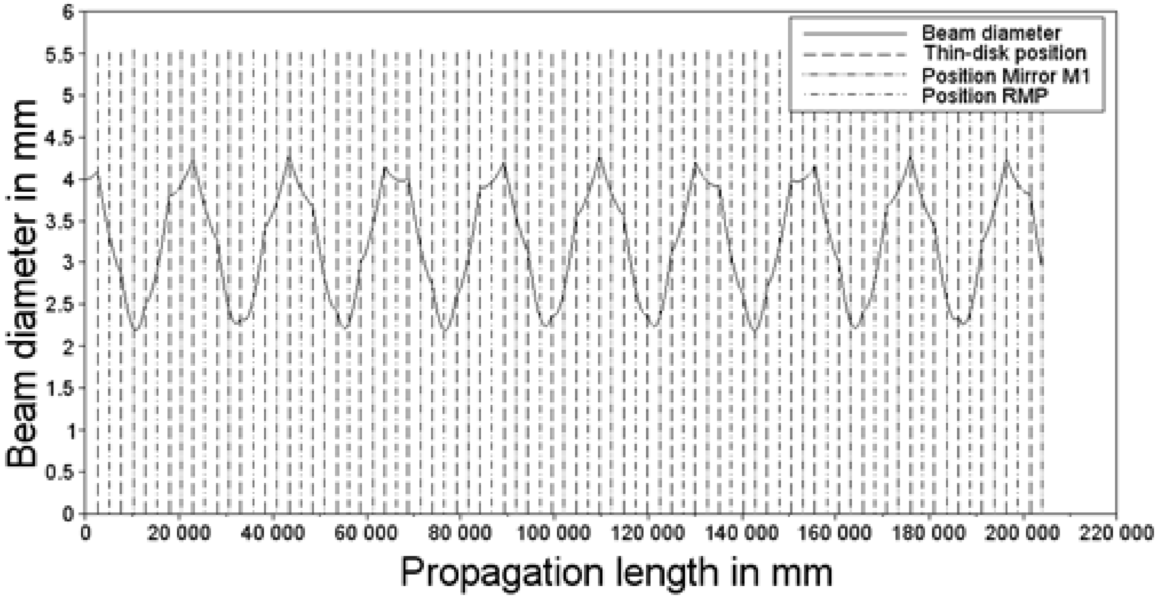
| WP5 | Thin-disk Multi-pass Booster |
|---|---|

- ***Task 5.1 (D 5.1) Design of the multipass amplifier (due month 6, completed)***
  - *Design should be suitable for:*

❖ *Seed (Satsuma) with 50 W, 1.25 MHz, 300 fs (D3.1)*
➔ *Amplification to 500 W, 1.25 MHz, sub-500 fs*

❖ *Seed Satsuma with 200 W, 1.25 MHz, sub-500 fs (D3.3)*
➔ *Amplification to 1000 W, 1.25 MHz, sub-1000 fs*

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| WP5 | Thin-disk Multi-pass Booster |
| --- | --- |

- ***Task 5.1 (D 5.1) Design of the multipass amplifier (due month 6, completed)***
  - *Beam propagation simulated (scheme allows adaption if needed)*
  - *Amplification **factor of >=10** needed!!!*

➔ *We decided (based on previous experiments) on a concept with **80 mirrors** in an array*

➔ *It allows 80 reflections on the disk in double-pass and **40 reflections in single-pass through the a**mplifier*

➔ *Single-pass will be needed to be able to pick single pulses (based on IP USTUTT proposed in the project RAZipol)*

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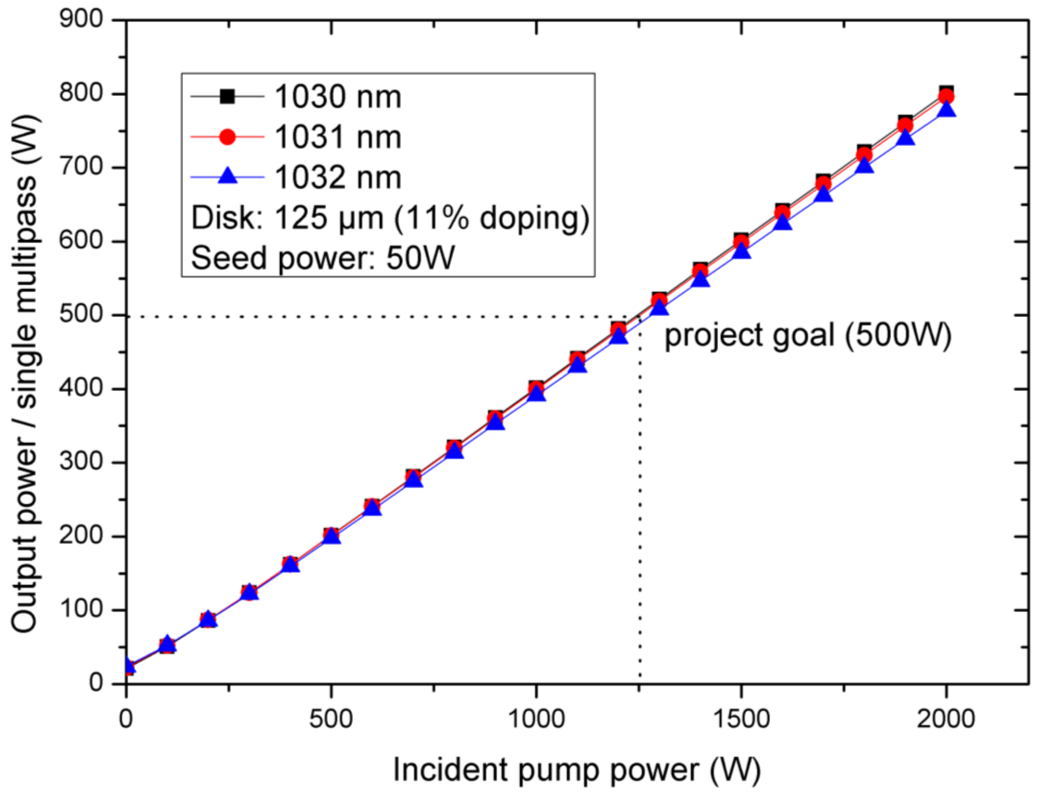
| WP5 | Thin-disk Multi-pass Booster |
|---|---|

- ***Task 5.1 (D 5.1) Design of the multipass amplifier (due month 6, completed)***

  - *First (simplified) Simulation results of amplification*
  - *Slope efficiency ~ 40%*

  ➔ *Challenge: Broad spectrum (6-8 nm) of fs pulses and center wavelength adaption of Satsuma to 1030 nm may influence the amplification process*

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| WP5 | Thin-disk Multi-pass Booster |
|---|---|

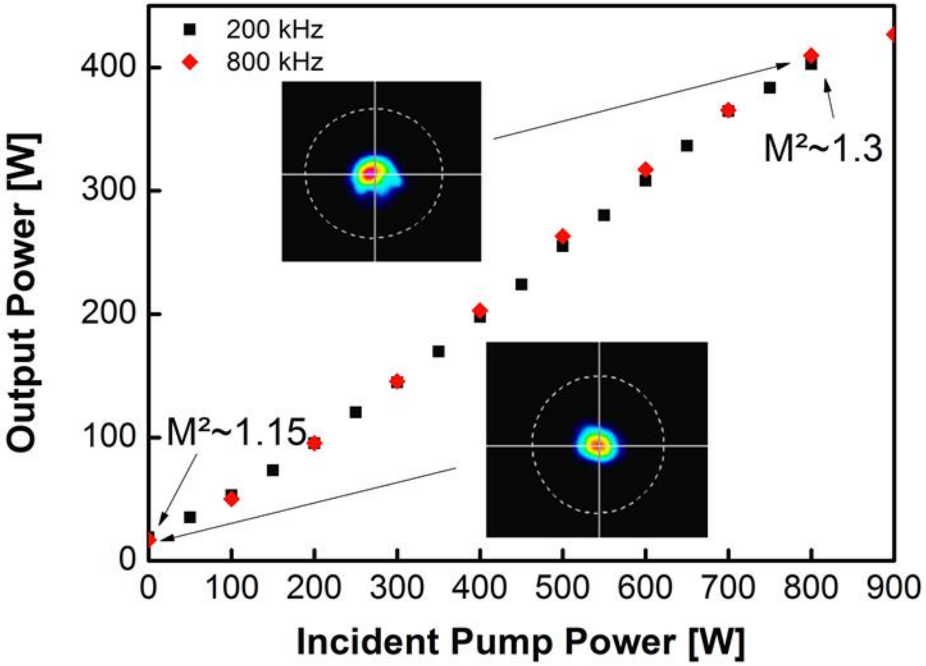
- ***New experimental tests (within project Razipol) on amplification of fs pulses***
  - *40 W Seed power, 200/800 kHz, 805 fs (loaned seed)*
  - *60 passes over the disk ( different disk than disk planed in Hiperdias)*

➔ *400 W of output power, 885 fs, 200/800 kHz*

➔ *Amplification of broad fs pulses is possible*

➔ *We observe spectral broadening at high intensities*

➔ *Here, compression to **sub-200 fs was possible***

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| WP5 | Thin-disk Multi-pass Booster |
|---|---|

***Ongoing work and planned for the next months:***

***Task5.2: Assembly & characterization of a Yb:YAG thin-disk multipass amplifier*** *(Scheduled for M22)*

- *Several components already delivered*
- *Few more parts (optics, custom-designed mechanics and seed source) are still to be delivered*
- *Working on controls and safety of the amplifier*
- *Assembly of amplifier*
- *Measurements and characterization*

***Task 5.3: Second and third harmonics generations*** *(Scheduled for M20-M28):*

- *Design and simulations have started*

***Tasks 5.4: Integration of the Yb:YAG thin-disk multipass amplifier*** *(not yet started)*

***Task 5.5: Demonstration of a 1kW, sub-1ps laser system*** *(not yet start)*

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| WP7 | Demonstrators |
| --- | --- |
| ***Work not yet started for USTUTT*** | |

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## Deliverables

| Number | Deliverable title | Delivery date | Current status |
|---|---|---|---|
| D 4.1 | Report on simulation of pulse compression gratings with diffraction efficiency>=99% over large spectral bandwidth (5-10 nm) around 1030 nm. | M4 | Submitted |
| D 5.1 | Design of multipass amplifier | M6 | submitted |
| D 5.2 | Thin-disk multipass amplifier with 500W, 1MHz, sub-500fs | M22 | Not yet Submitted |
| D 5.3 | Demonstration of 200W green and 100W UV laser beams at 1MHz and sub-500 fs pulse | M28 | Not yet Submitted |
| D 5.4 | Thin-disk multipass amplifier with 1000W, >=1MHz, sub-1ps | M38 | Not yet Submitted |

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| | Milestones | | |
|---|---|---|---|
| **Number** | **Milestone title** | **Estimated date** | **Current status** |
| M 4.1 | First design, high efficient grating mirrors | M3 | Achieved |
| M 4.4 | Fully optical characterization of grating mirror regarding diffraction efficiency and LIDT | M12 | Not yet achieved |
| M 4.8 | Demonstration of optimized grating mirrors, 99% diffraction efficiency | M18 | Not yet achieved |
| M 5.1 | Yb:YAG thin-disk multipass amplifier delivering 500W at a sub-500fs pulse duration and a repetition rate >=1MHz. | M22 | Not yet achieved |
| M 5.2 | Demonstration of a 200W green and 100W UV laser beams at 1MHz and sub-500 fs pulse. | M28 | Not yet achieved |
| M 5.3 | Yb:YAG thin-disk multipass amplifier delivering 1000W at a sub-1ps pulse duration and a repetition rate >=1MHz. | M38 | Not yet achieved |

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# Thank you for your attention

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# Contribution of XLIM-GPPMM

GPPMM
Gas-Phase Photonic & Microwave Materials

F. Gérôme, J. M. Blondy, and F. Benabid

*GPPMM group, Xlim Research Institute, CNRS UMR 7252, University of Limoges, Limoges, France*

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| WP4 | Photonic components for pre and post pulse conditioning |
| --- | --- |

*D4.5 task / Objective : Conception and fabrication of HC-PCF with improved PER (> 20 dB) at 1 µm*

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| WP4 | Photonic components for pre and post pulse conditioning |
|---|---|

*Work completed*

*Two designs investigated (simulations and fabrications):*

1. *Hypocycloid-core Kagomé IC HC-PCF*
2. *IC HC-PCF with a single ring of tubular lattice cladding*

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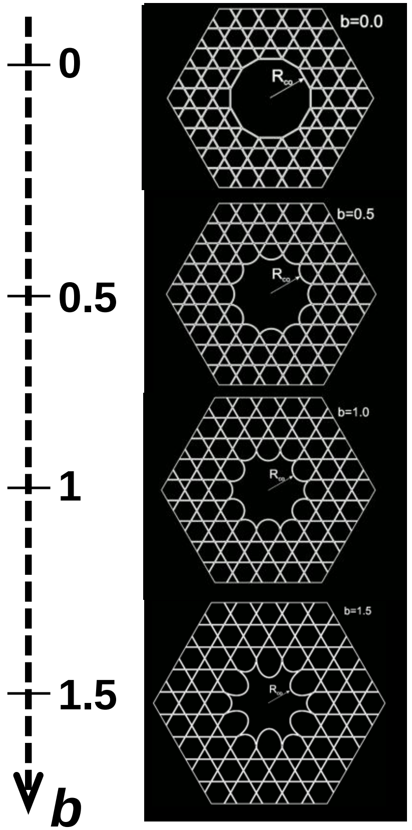
# Consortium Meeting - Stuttgart - 13/09/2016

| WP4 | Photonic components for pre and post pulse conditioning |
|---|---|

B. Debord et *al*. Opt. Express **21**, 28597-28608 (2013)
M. Alharbi et *al*. Opt. Express **21**, 28609-28616 (2013)

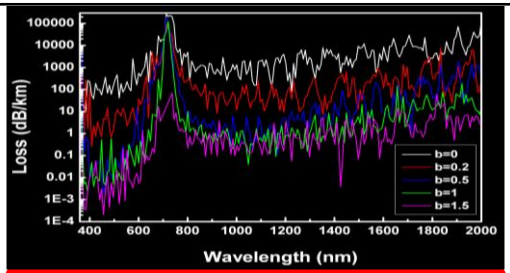
*1. Hypocycloid-core Kagomé IC HC-PCF*

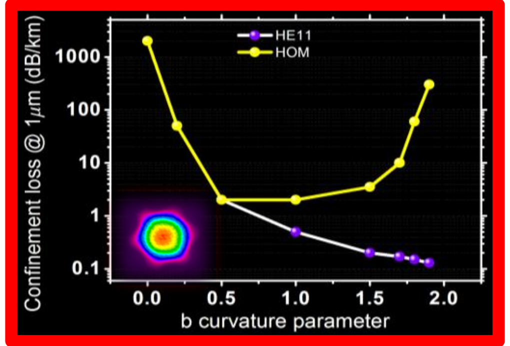


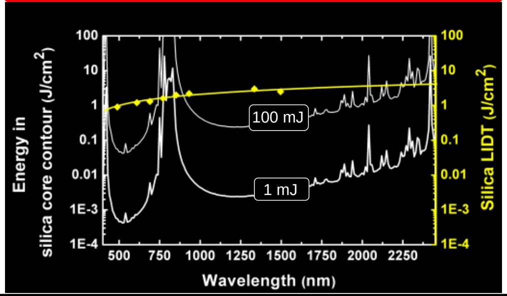

1 **Strong propagation loss decrease ( orders of magnitude )**

2 **Single mode operation with high PER ( Gaussian-like mode)**

3 **Decrease of power overlap with silica surround to a ppm level ( 10000 times lower than PBG )**

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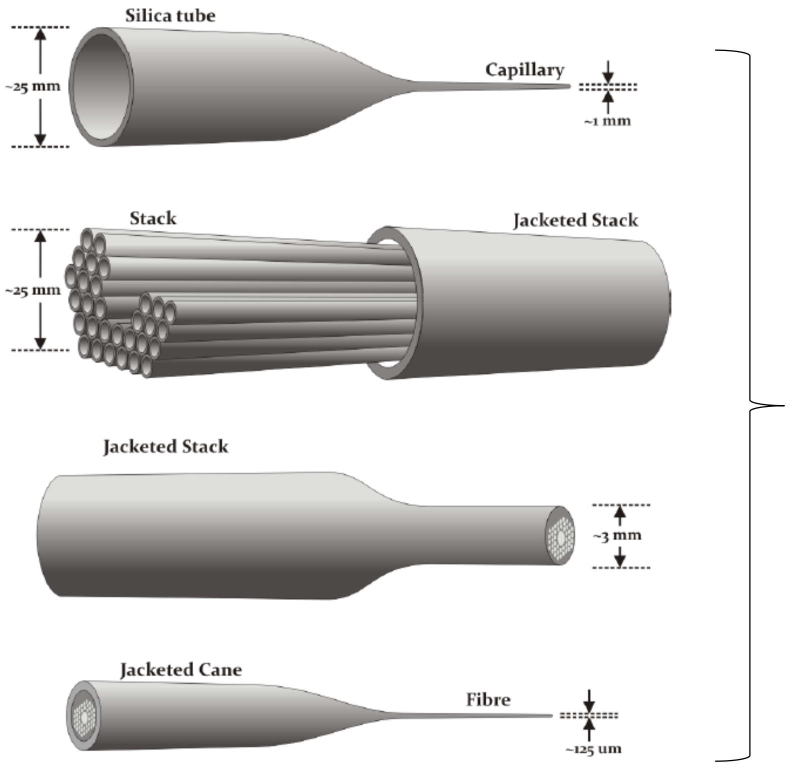
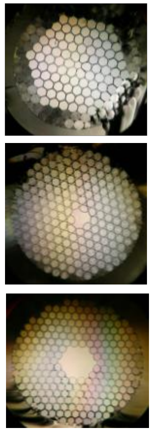
| WP4 | Photonic components for pre and post pulse conditioning |
| --- | --- |

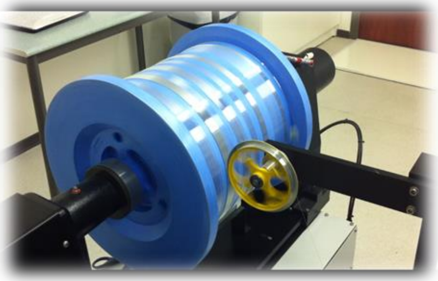
*1. Hypocycloid-core Kagomé IC HC-PCF*




Stack and draw process


State-of-the-art drawing towers

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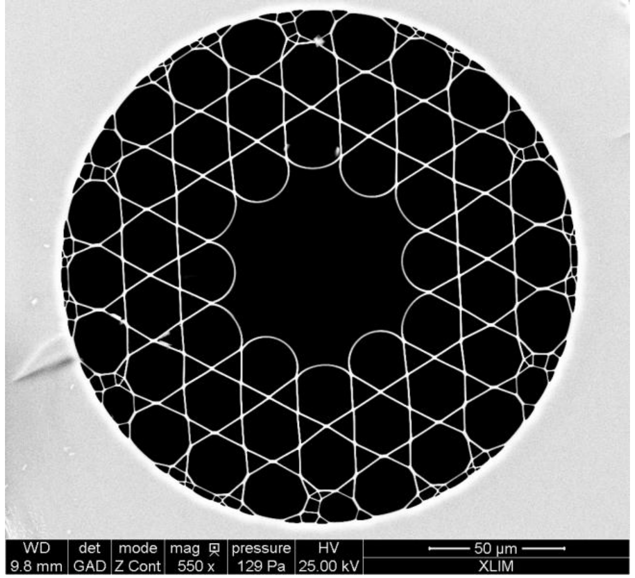
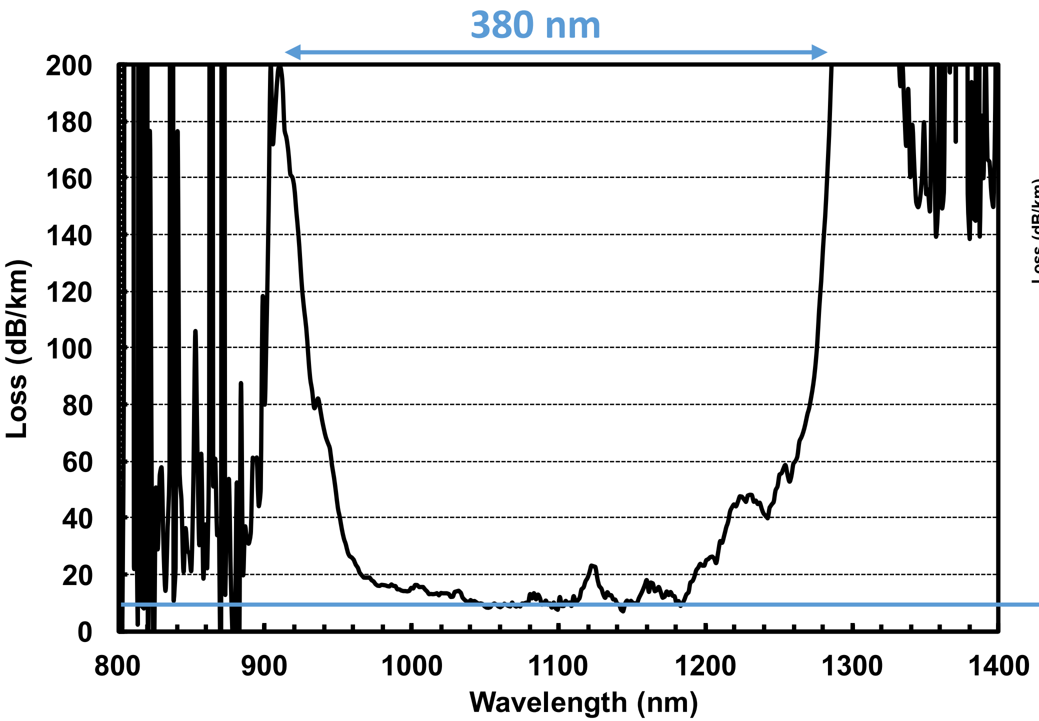
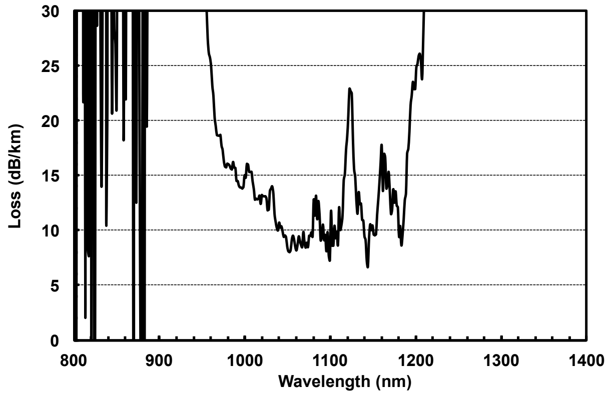
| WP4 | Photonic components for pre and post pulse conditioning |
|---|---|

B. Debord et *al*. submitted to Photonic West (2017)

*1. Hypocycloid-core Kagomé IC HC-PCF*




Min loss: 8.5 dB/km *

**Core Diameter......... 60-72 µm**

**MFD...................... 42 µm**

***b*......................... 0.9**

* Cut-back done between 106 m and 3.8 m

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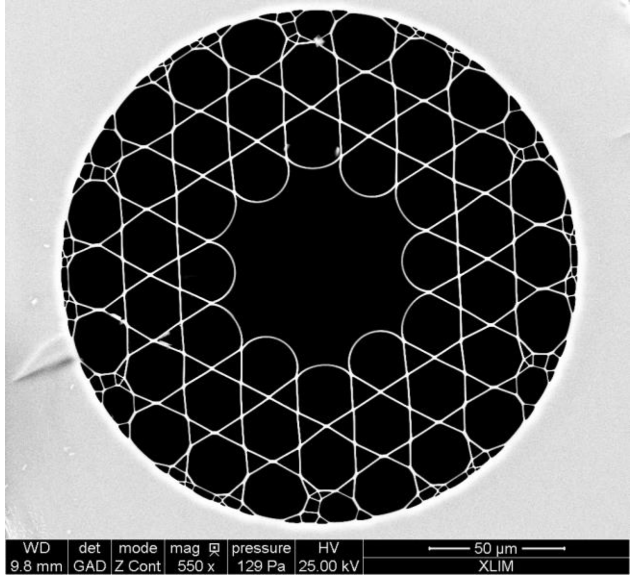
| WP4 | Photonic components for pre and post pulse conditioning | B. Debord et *al*. submitted to Photonic West (2017) |
|---|---|---|

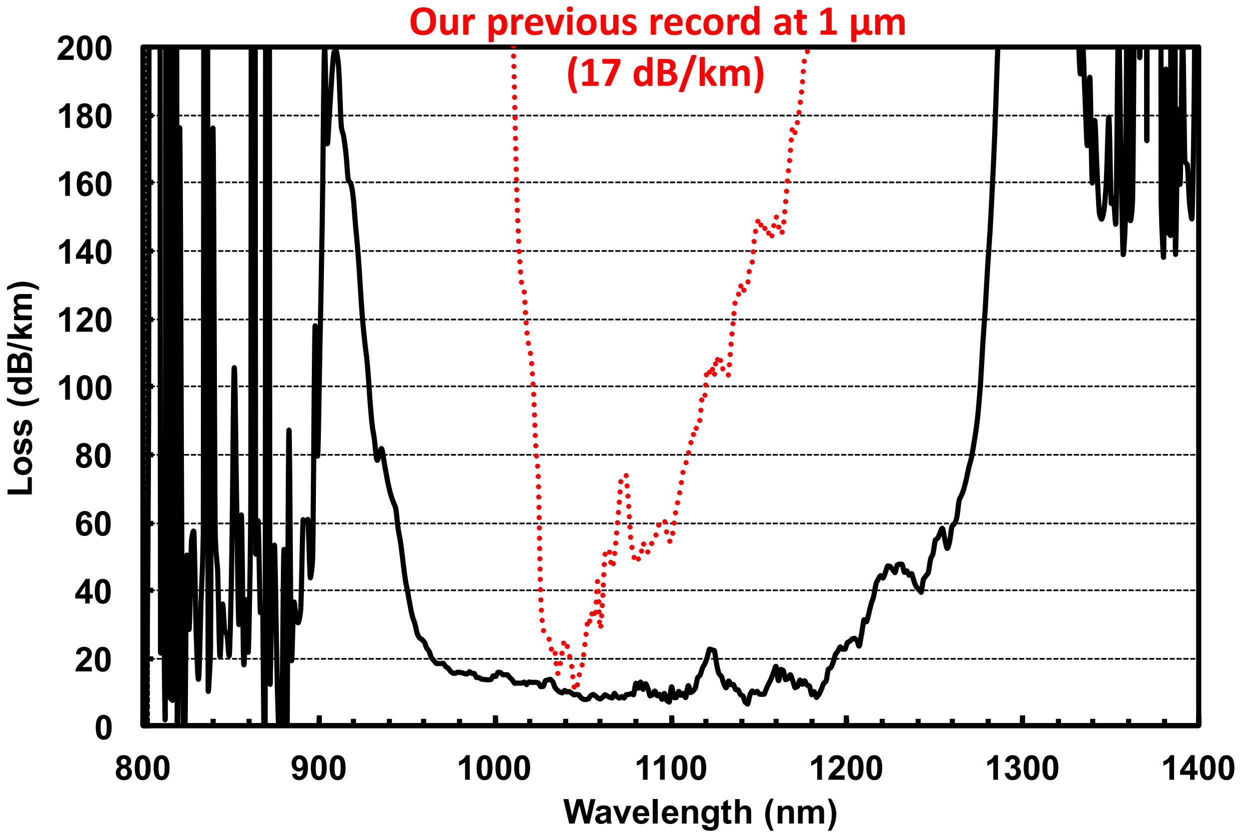
*1. Hypocycloid-core Kagomé IC HC-PCF*




**Core Diameter......... 60-72 µm**

**MFD....................... 42 µm**

***b*........................... 0.9**

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| WP4 | Photonic components for pre and post pulse conditioning B. Debord et *al*. submitted to Photonic West (2017) |
|---|---|

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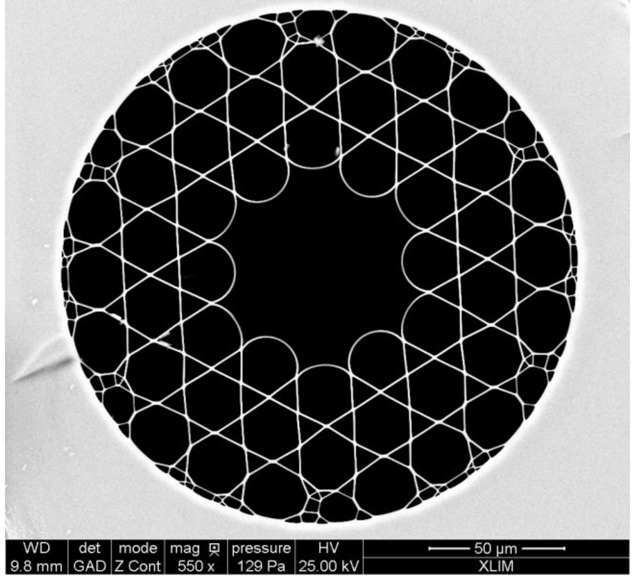


**Core Diameter......... 60-72 µm**

**MFD....................... 42 µm**

***b*.......................... 0.9**

***« Modal properties ($S^2$ and PER) under progress »***

***See Next 6 months plan***

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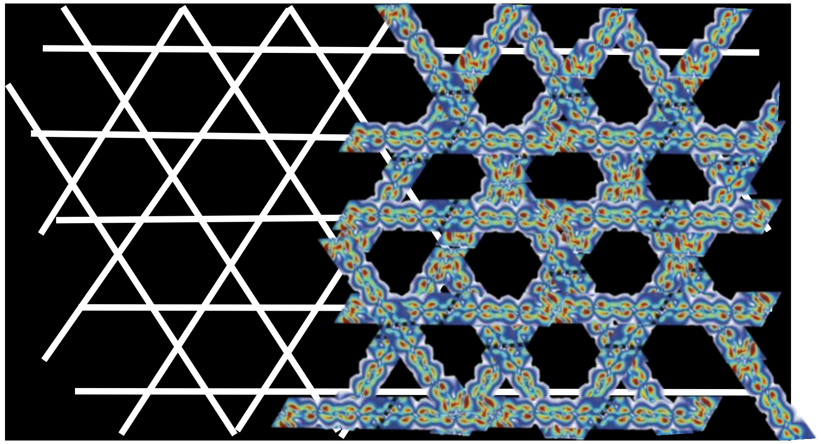
| WP4 | Photonic components for pre and post pulse conditioning |
|---|---|

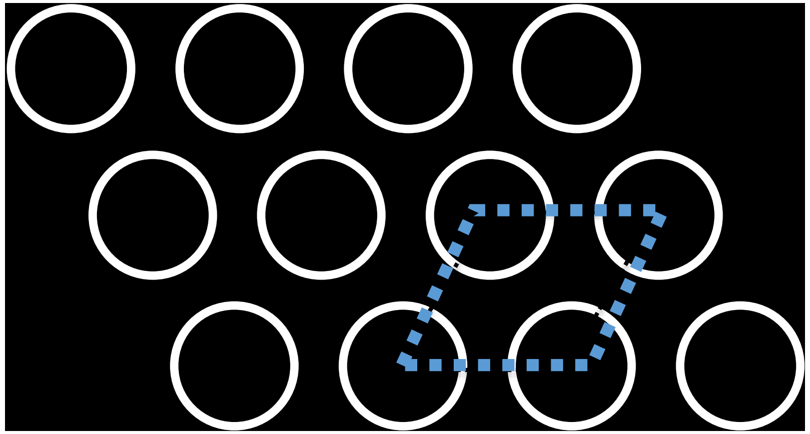
*2. IC HC-PCF with a single ring of tubular lattice cladding*

## ➘ Kagome lattice



✓ Long silica struts
✓ Typical azimuthal number $m \approx 200$

## ➘ Tubular lattice



✓ No connecting nodes

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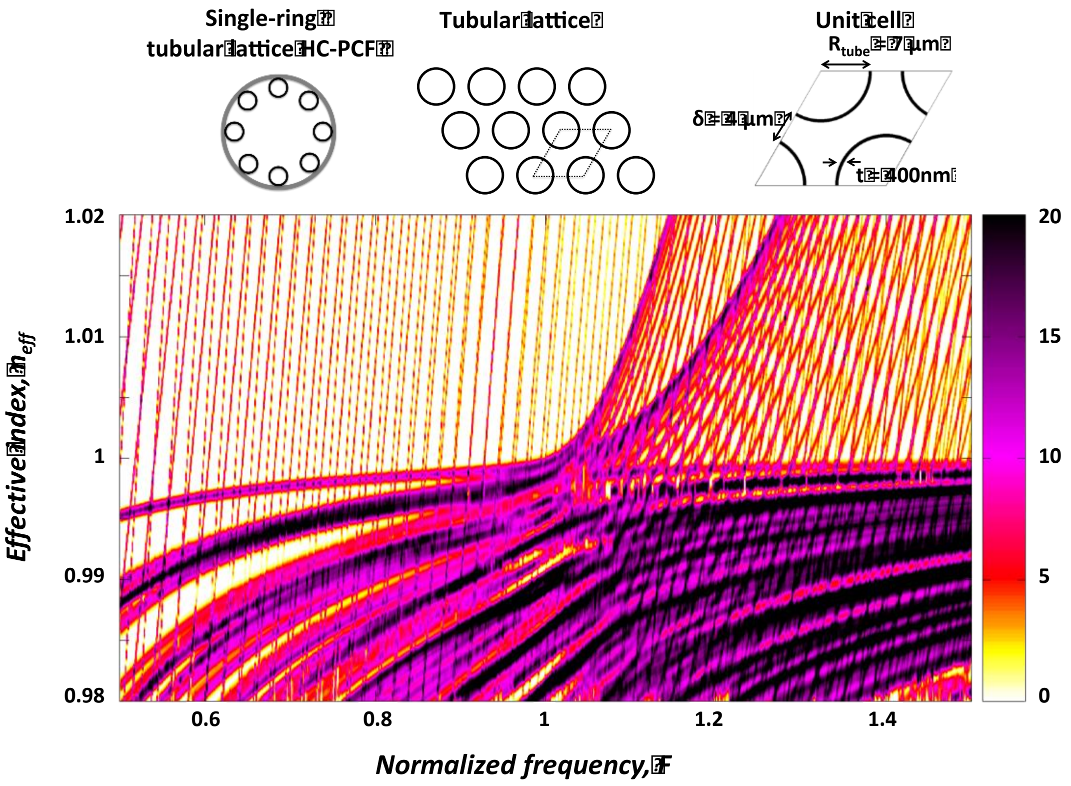
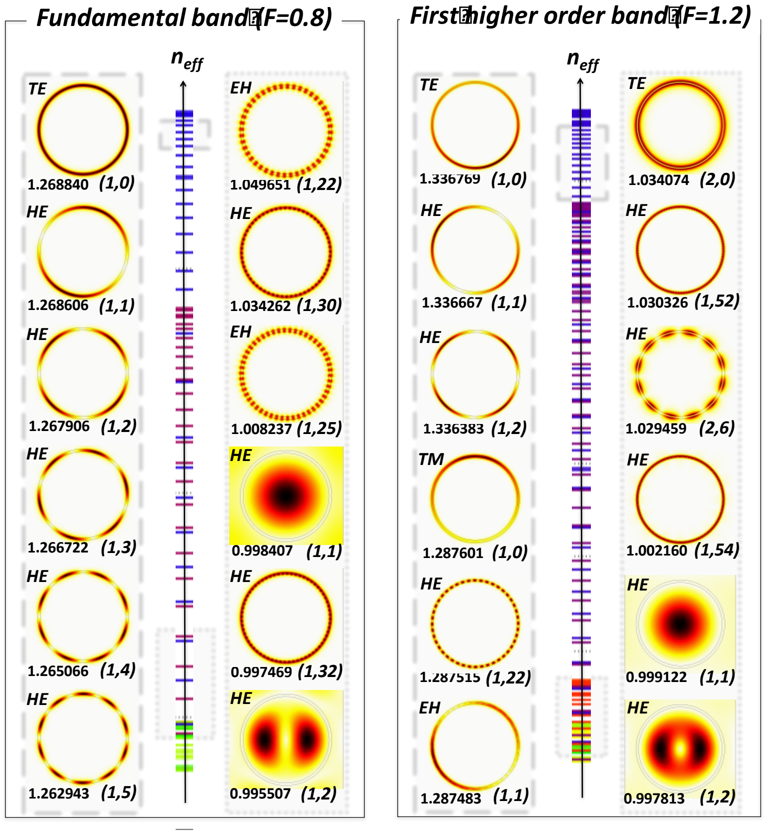
| WP4 | Photonic components for pre and post pulse conditioning |
| --- | --- |

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

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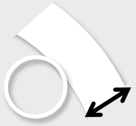
| WP4 | Photonic components for pre and post pulse conditioning |
|---|---|

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

| | Geometrical parameters | | | Scaling laws | Limitations |
|---|---|---|---|---|---|
| **Core** | Core radius | $R_{co}$ |  | Large *Rco* ↗ IC (loss ~ $R_{co}^4$) | Ratio between *Rco* and *Rt* for single mode operation |
| **Cladding** | Tube radius | $R_t$ |  | $R_t$ ↗ IC | - If too large: Coupling between core and tube mode<br>- Keeping the circular shape of the tube |
| | Strut thickness | $t$ |  | Thin struts ↗ IC | Induced surface roughness |
| | Gap between two tubes | $\delta$ |  | - Large: avoid mode coupling between 2 adjacent tubes | - If too large: Core mode not sufficiently confined |
| | Number of tubes | $N$ |  | | |

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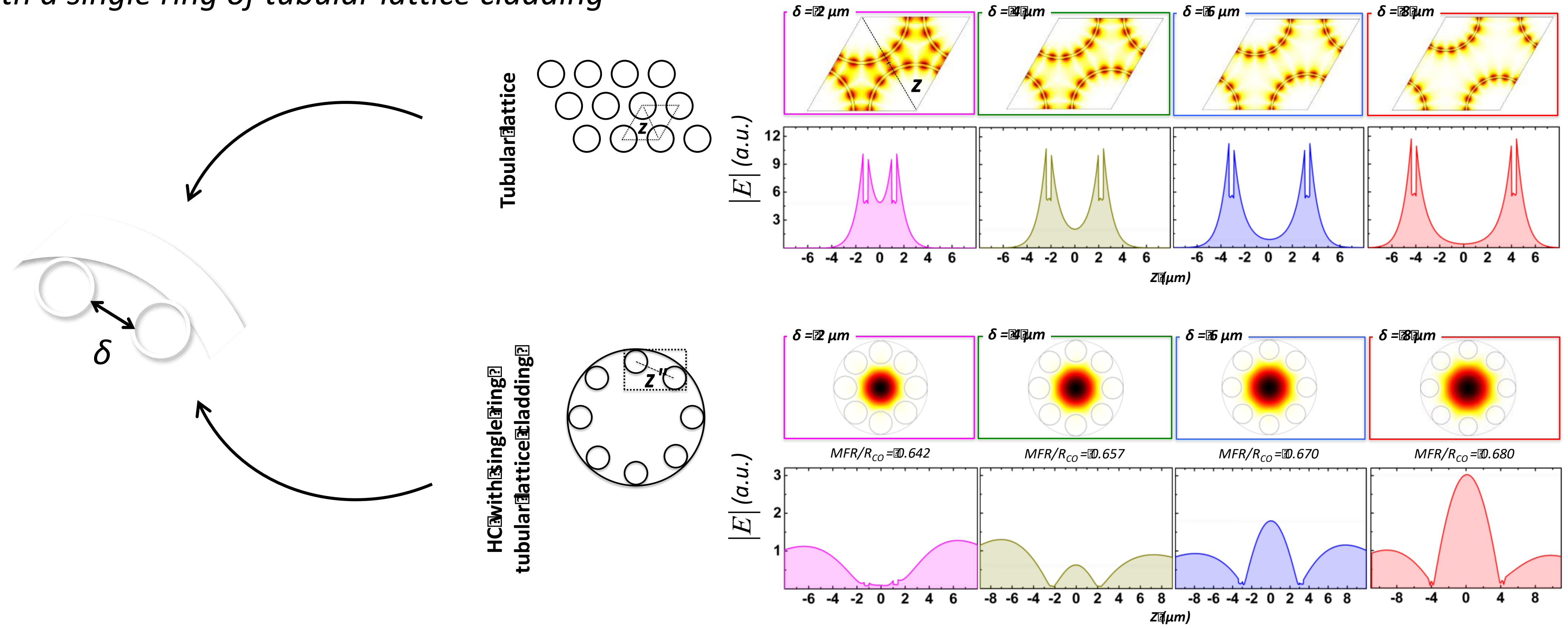
| WP4 | Photonic components for pre and post pulse conditioning |
|---|---|

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

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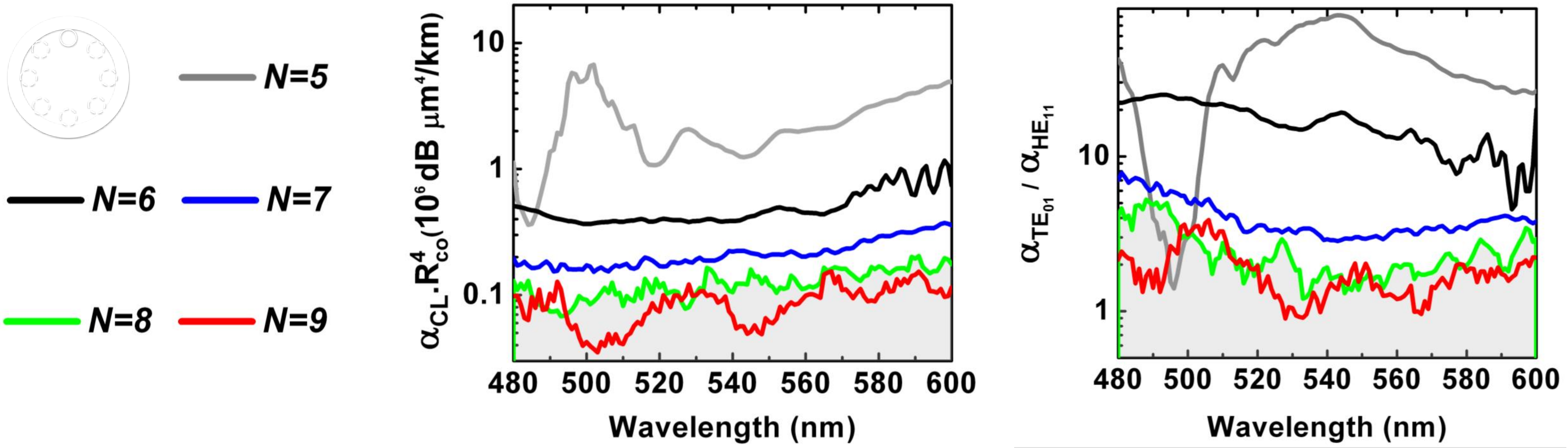
| WP4 | Photonic components for pre and post pulse conditioning |
|---|---|

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

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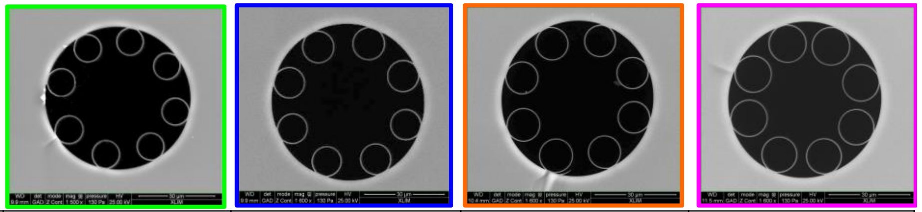
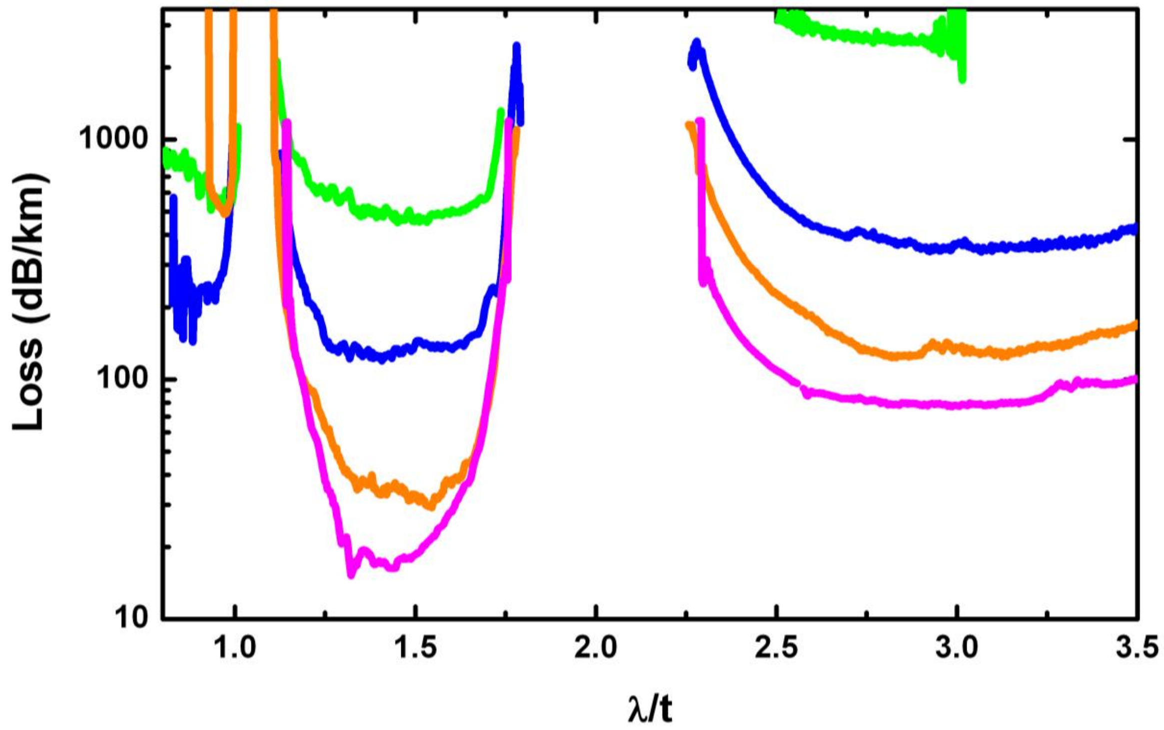
| WP4 | Photonic components for pre and post pulse conditioning |
|---|---|

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



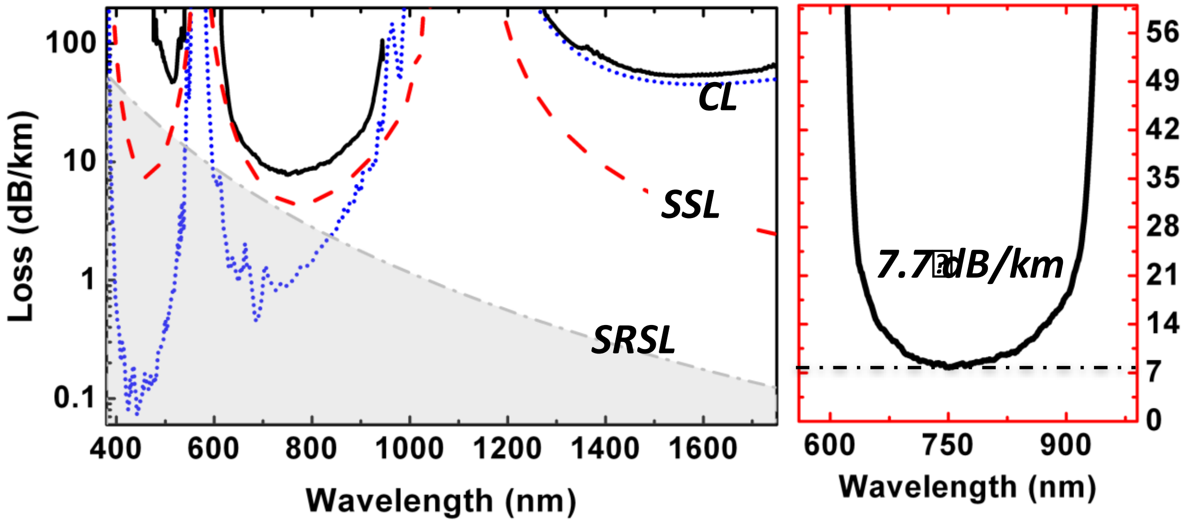
| | | | | |
|---|---|---|---|---|
| $\delta$ [$\mu m$] | 8 | 5 | 3.7 | 2.7 |
| $R_t$ [$\mu m$] | 5.1 | 5.54 | 5.88 | 6.15 |
| $t$ [$nm$] | 580 | 500 | 465 | 415 |
| $R_c$ [$\mu m$] | 18.5 | 16.5 | 15.25 | 13.75 |

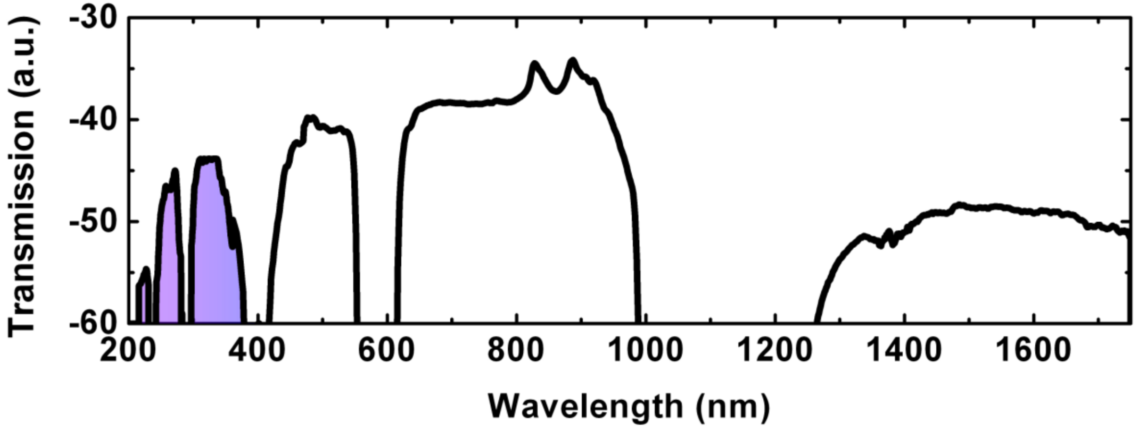



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687880

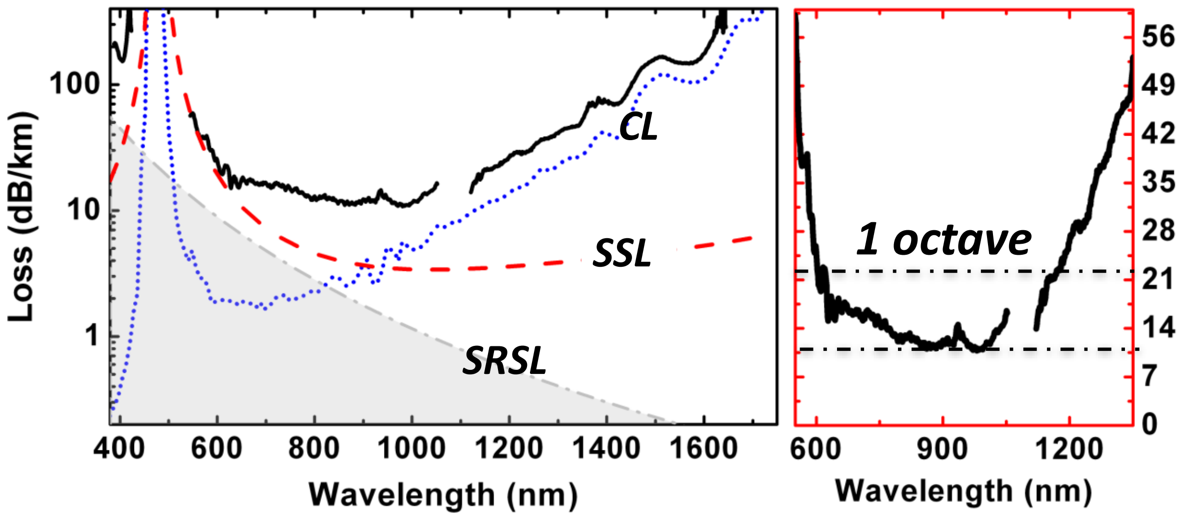
## Optimized Fiber #1

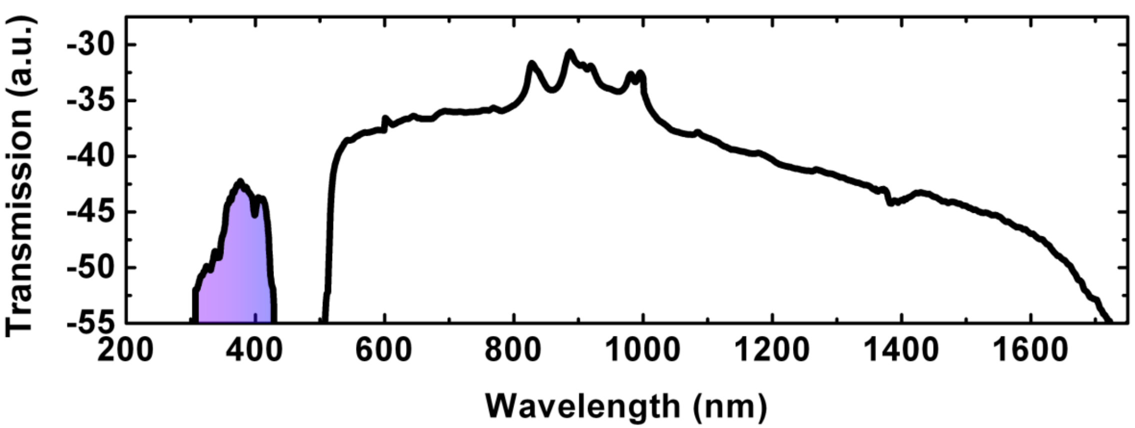
B. Debord et *al.*, CLEO US postdeadline, JTh4C.8 (2016)




## Optimized Fiber #2



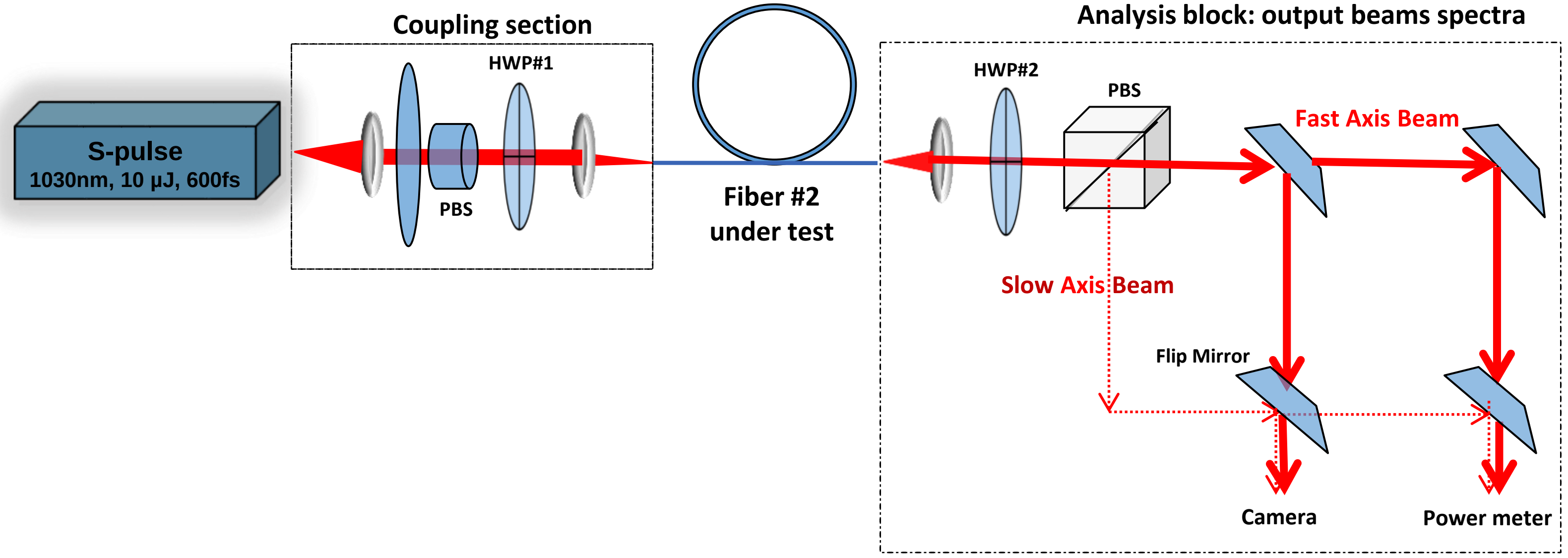

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687880

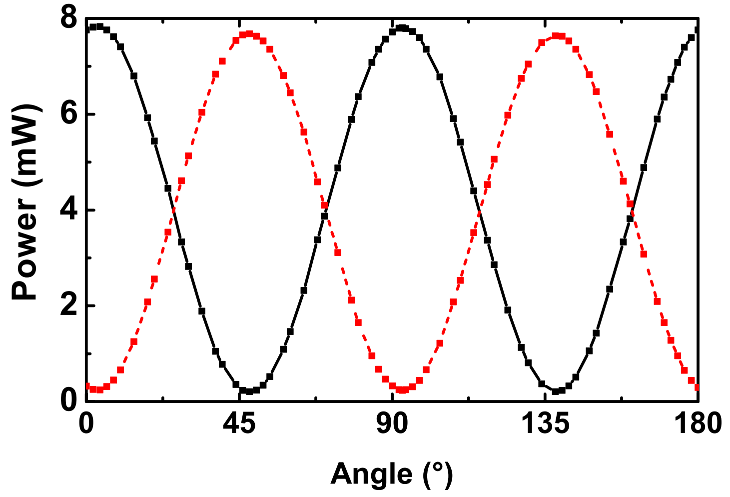
| WP4 | Photonic components for pre and post pulse conditioning |
|---|---|

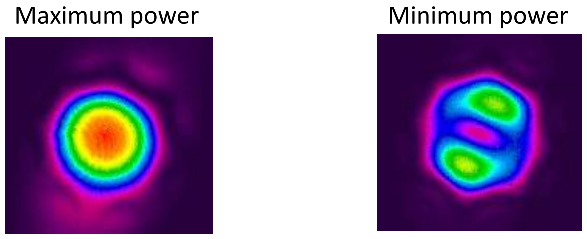
B. Debord et *al.*, submitted to Optica (2016)

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

### *2.1. PER measurement*

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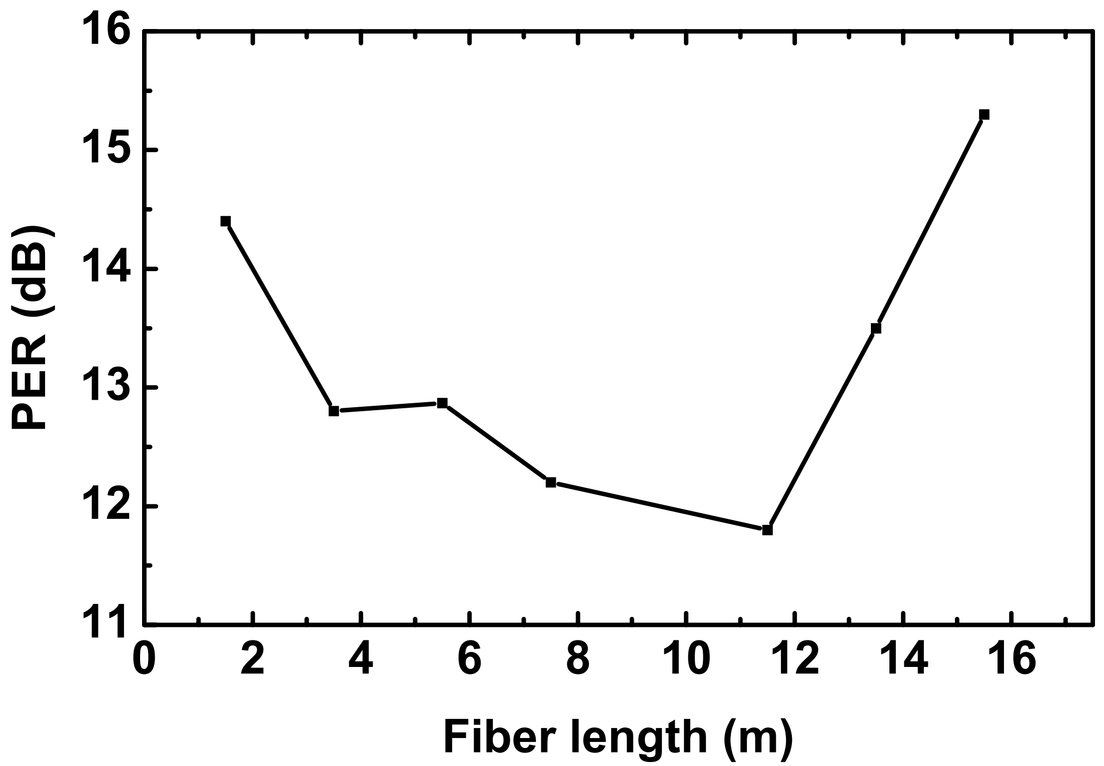
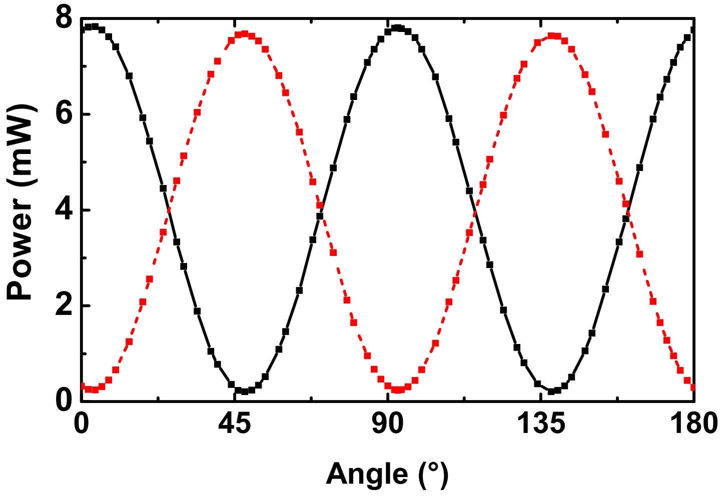
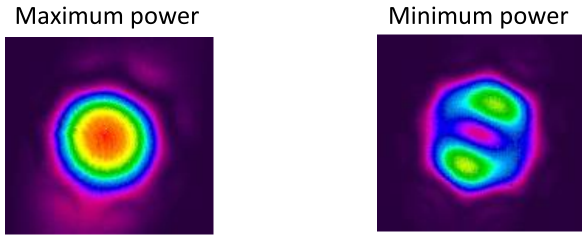
| WP4 | Photonic components for pre and post pulse conditioning |
|---|---|

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

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



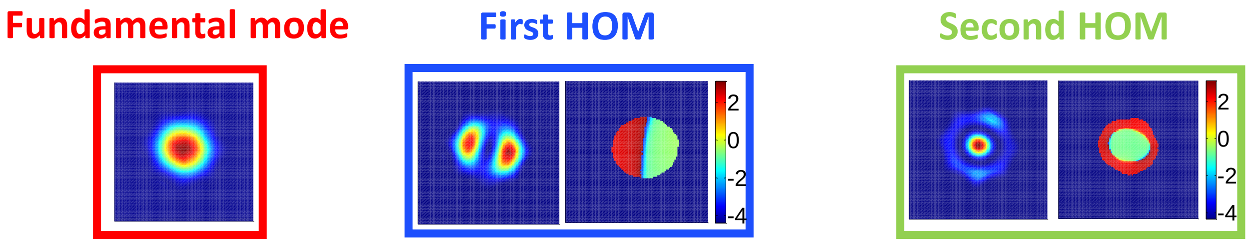

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687880

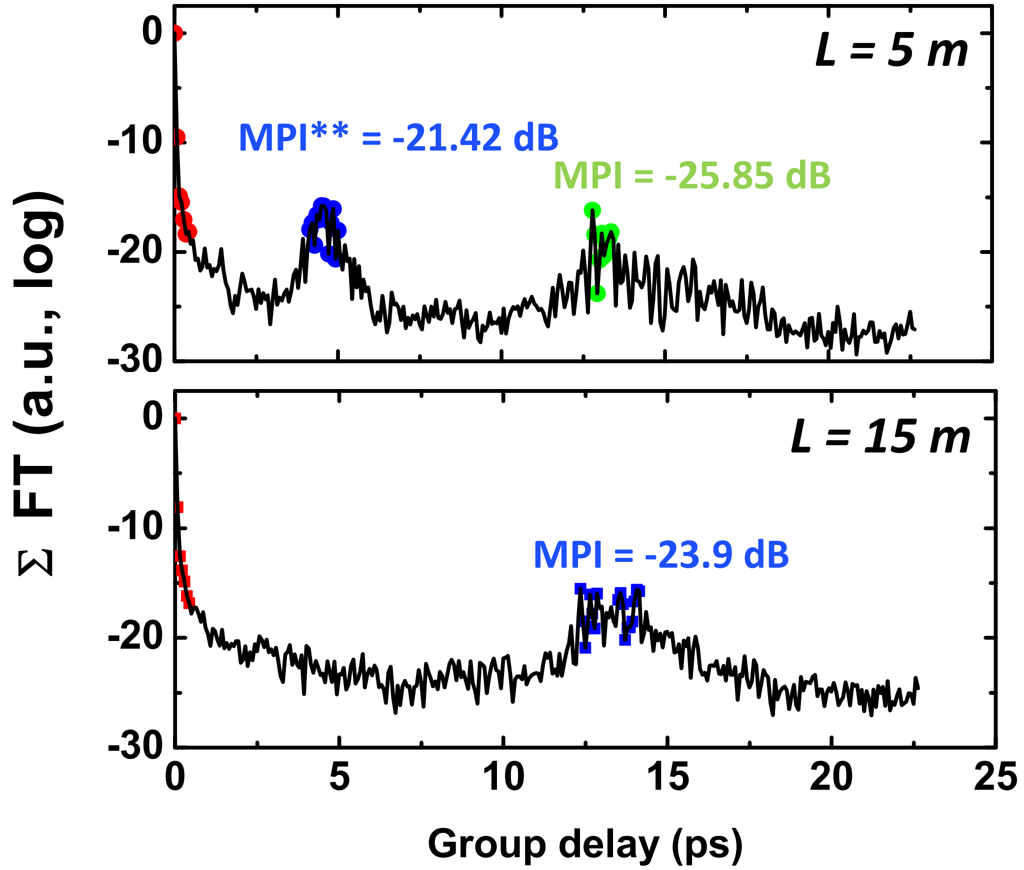
| WP4 | Photonic components for pre and post pulse conditioning |
| --- | --- |

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

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

*2.2. $S^2$ measurement (collaboration*)*




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

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

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| WP4 | Photonic components for pre and post pulse conditioning |
| --- | --- |

*Next 6 months*

1. *Investigation of the modal properties of the hypocycloid-core Kagomé IC HC-PCF*
2. *Test of energy handling capabilities of the IC HC-PCF with a single ring of tubular lattice cladding*
3. *Start to set a home-made $S^2$ set-up*
4. *Continue on the fabrication of IC HC-PCF*

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| WP8 | Dissemination & Exploitation (partner activities) |
|---|---|

## Peer review journal:

1. DEBORD B., AMSANPALLY A., CHAFER M., BAZ A., MAUREL M., BLONDY J-M., HUGONNOT, E., SCOL, F., VINCETTI L., GEROME F., BENABID F.: « **Ultra-low transmission loss (7.7 dB/km @750 nm) inhibited-coupling guiding hollow-core photonic crystal fibers with a single ring of tubular lattice cladding** », *Optica*, submitted in september 2016.

## Peer review international conference:

1. DEBORD B., AMSANPALLY A., CHAFER M., BAZ A., VINCETTI L., BLONDY J-M., GEROME F., BENABID F.: « **7.7 dB/km losses in inhibited coupling hollow-core photonic crystal fibers** », *CLEO US*, Postdeadline, JTh4C.8, San Jose, California, 5 - 10 June 2016.
2. BENABID F.: « **Hollow core photonic crystal fibre: Novel light guidance and myriad of gas-photonic applications**», *XXI Rinem*, invited talk, Parma, Italy, 12 - 14 September 2016.
3. DEBORD B., Maurel M., AMSANPALLY A., ADNAN M., BEAUDOU B., BLONDY J-M., VINCETTI L., GEROME F., BENABID F.: « **Ultra-low loss (8.5 dB/km @ Yb-laser region) inhibited-coupling Kagome HC-PCF for laser beam delivery applications** », *Photonic West 2017*, submitted.
4. Maurel M., GORSE A., BEAUDOU B., LEKIEFS Q., DEBORD B., GEROME F., BENABID F.: « **Kagome fiber based industrial laser beam delivery**», *Photonic West 2017*, submitted.

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

# AMO GmbH

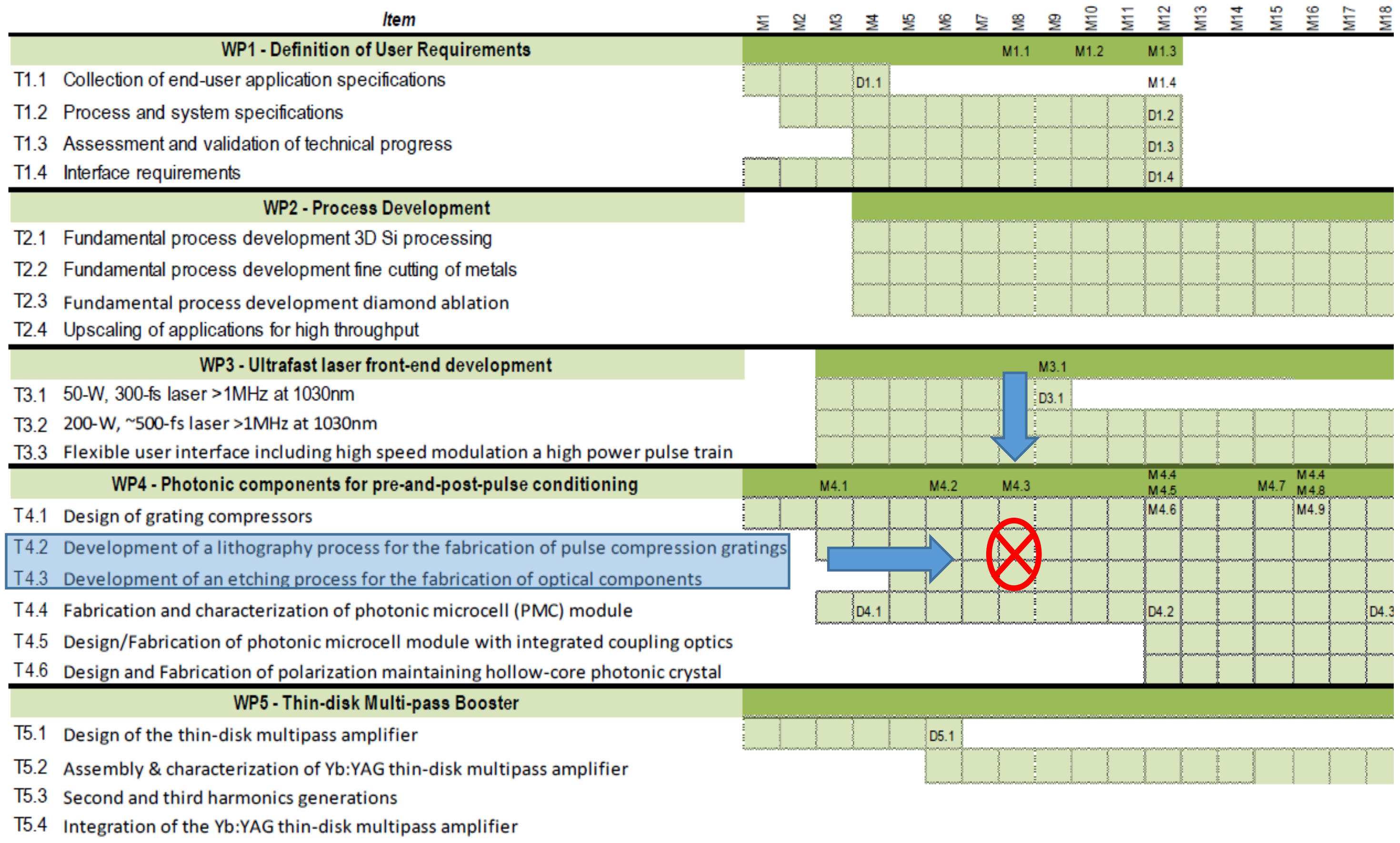
Michael Moeller

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

## Our role:

- AMO mainly active in WP4 (T4.2 and T4.3)
- Process development PC-grating fabrication

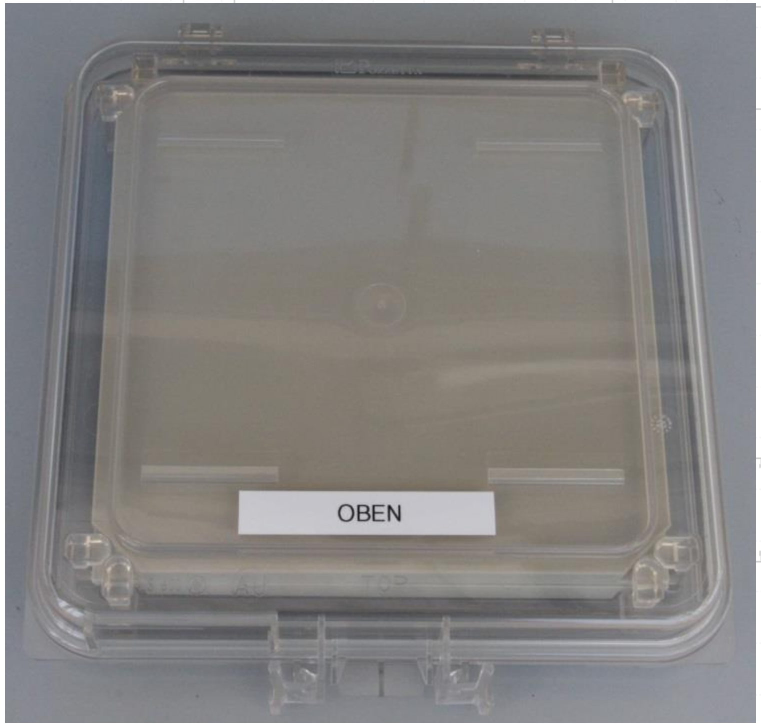
## Gantt chart:



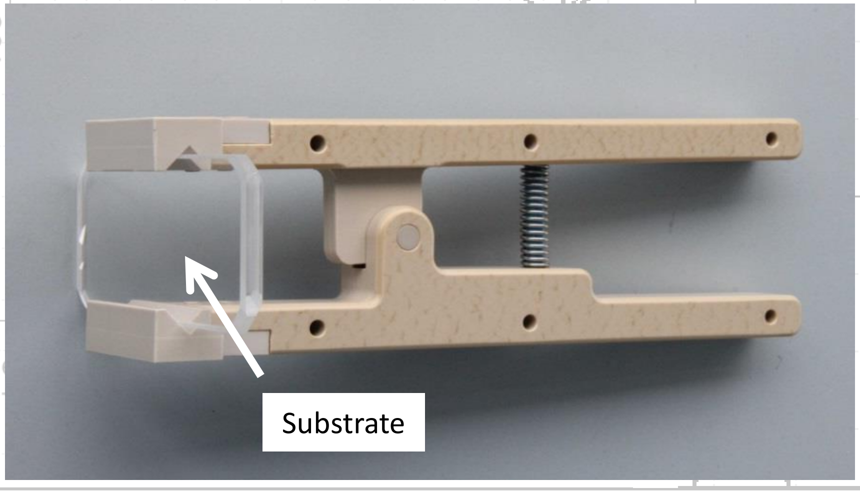

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687880

| WP4 | Photonic components for pre and post pulse conditioning<br>***Processing equipment*** |
|---|---|

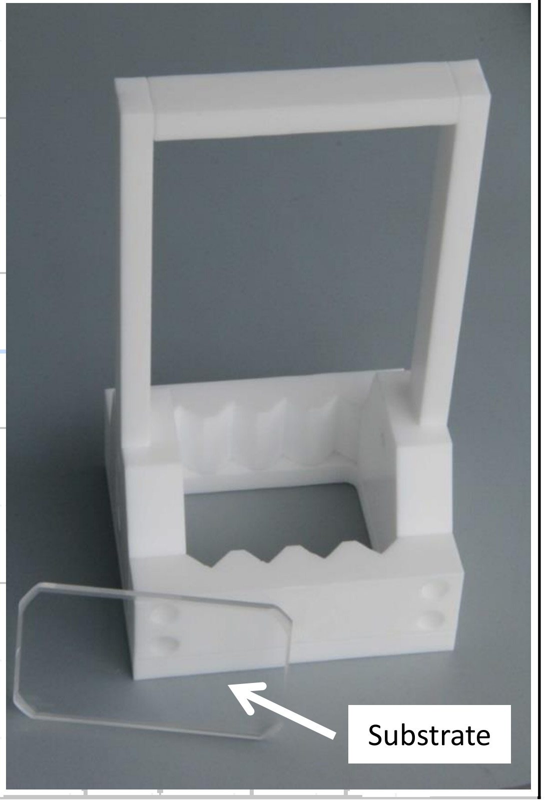
**Storage box**




**Tweezers for single-item processing**



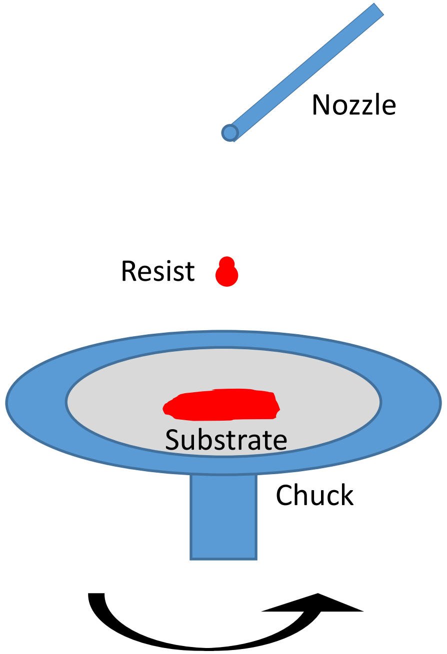

**Batch processing**



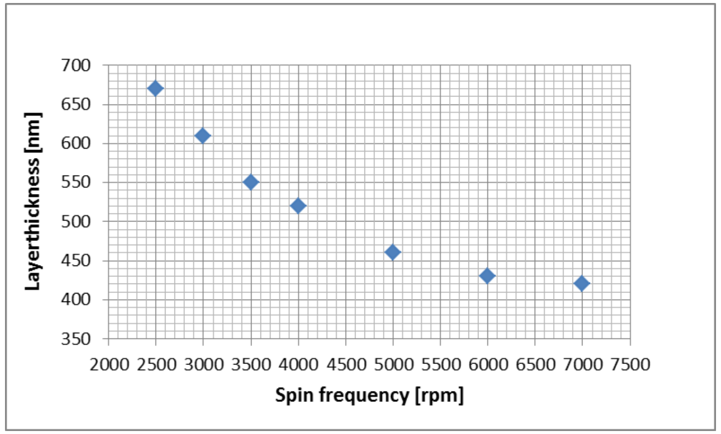

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687880

| WP4 | Photonic components for pre and post pulse conditioning<br>***Modification spin coater Suess Microtec RCD8*** |
|---|---|

**Spin coating**

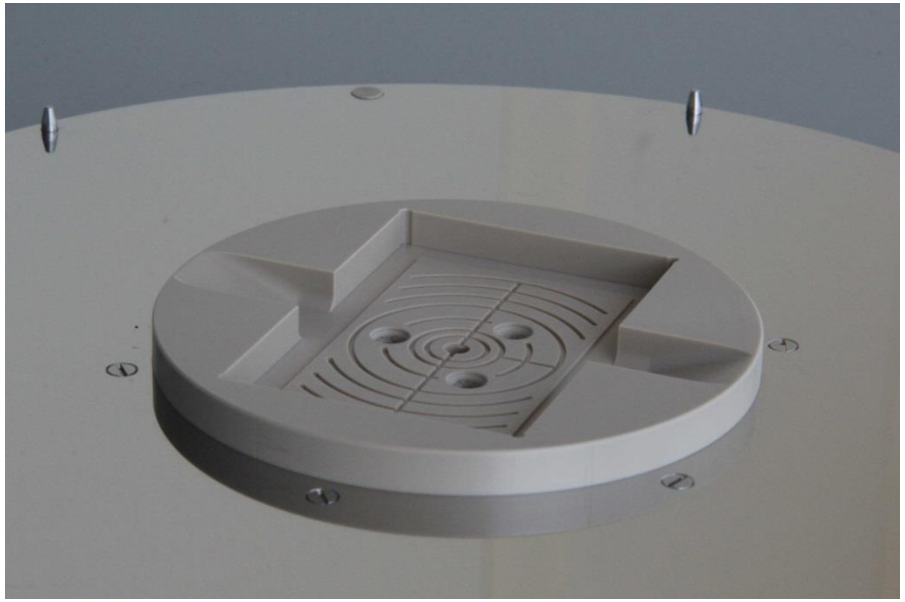



**Spin curve**




f(viscosity, rotation frequency, acceleration, duration)

**New chuck system + Gyrset system for square substrates**



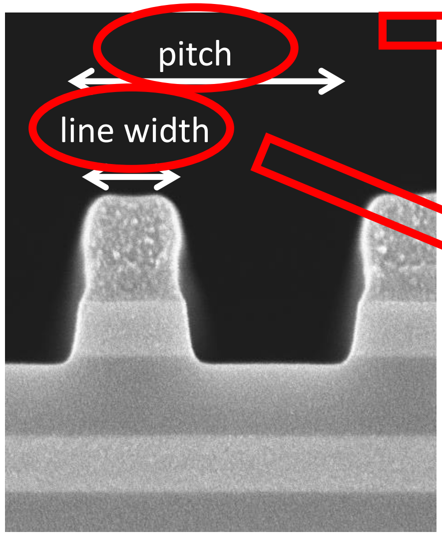
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687880

| WP4 | Photonic components for pre and post pulse conditioning<br>***Lithography process development*** |
|---|---|

**Lithography process steps**

- Cleaning
- Spin-coating BARC + Resist
- Softbake
- Exposure
- Post exposure bake
- Development

**Geometric design parameter from IFSW for the PC gratings**




**Controlling the design parameter during the lithography process**

- pitch → Lithography system calibration
- line width → Exposure dose + Post exposure bake temperature and duration

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

| WP4 | Photonic components for pre and post pulse conditioning<br>***Lithography system pitch calibration*** |
|---|---|

**Reference grating** → **Extern calibration service** → **Optical diffraction measuring setup**

- substrate preparation
- grating definition
- pattern transfer
- Al covering

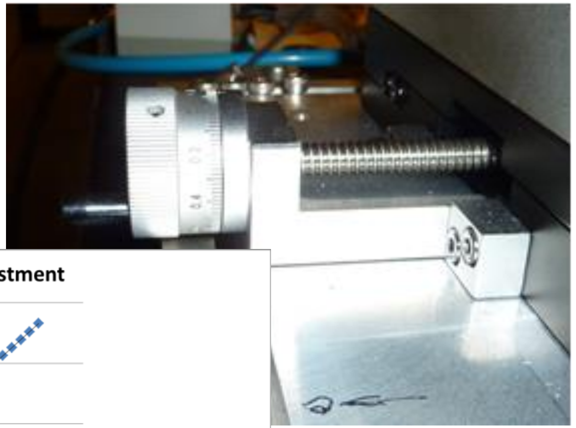
Carl Zeiss Jena GmbH
Kompetenzzentrum Qualität

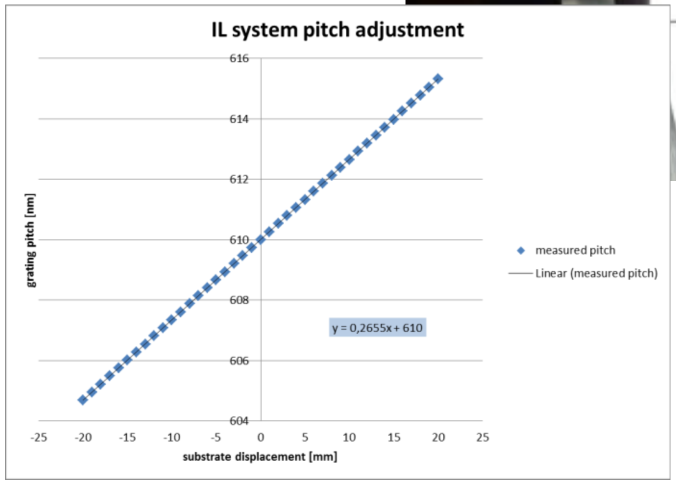
**Kalibrierzertifikat**
*Calibration certificate*

P-QK 0542/2016

| | |
|---|---|
| **Gegenstand:** *Object:* | Beugungsgitter |
| **Hersteller:** *Manufacturer:* | unbekannt |
| **Ident-Nr.:** *Ident number:* | BG160401 |
| **Auftraggeber:** *Customer:* | AMO GmbH<br>Gesellschaft für angew. Mikro- u. Optoelektronik<br>Otto-Blumenthal-Str. 25<br>D-52074 Aachen |
| **Auftragsnummer:** *Order No.:* | 201603171 |
| **Auftrags-/Eingangsdatum:** *Date of order/receipt:* | 17.03.2016 |
| **Kalibrierzertifikat besteht aus:** *Calibration certificate consists of:* | 2 Seiten / pages<br>0 Anlage(n) / enclosure(s) |
| **Datum der Kalibrierung:** *Date of calibration:* | 05.04.2016 |

| Stempel *Seal* | Datum *Date* | Mess- und Kalibrierzentrum *Measuring and Calibration Centre* | Bearbeiter *Responsible originator* |
|---|---|---|---|
| | 11.04.2016 | Dr. Meoß | Terf |

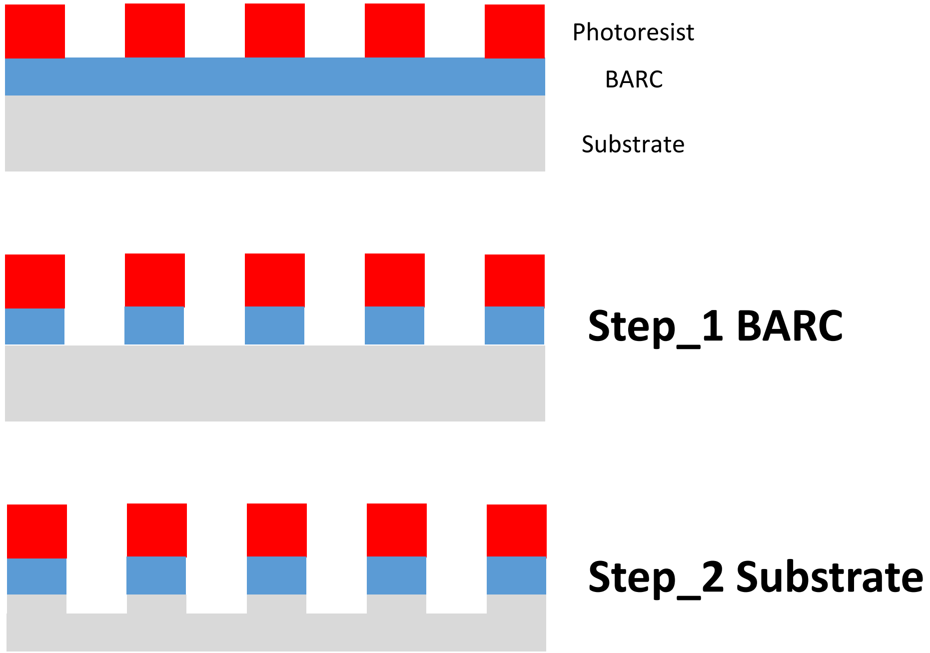




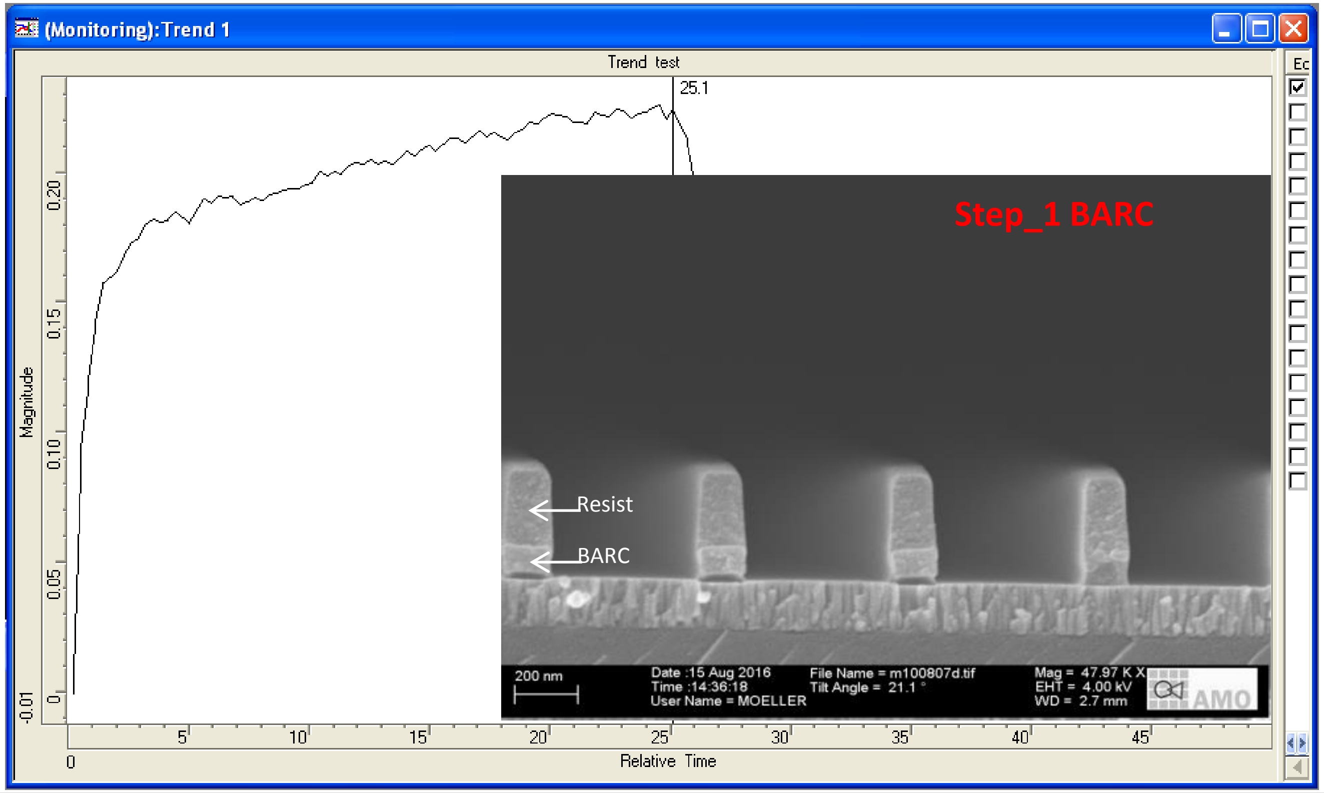

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687880

| WP4 | Photonic components for pre and post pulse conditioning<br>***Etch process development*** |
|---|---|

## Etch process




## Automatical endpoint detection via plasma spectroscopy

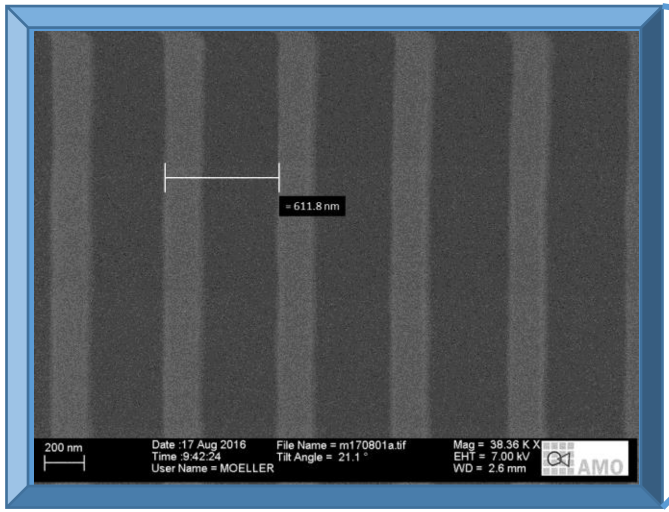


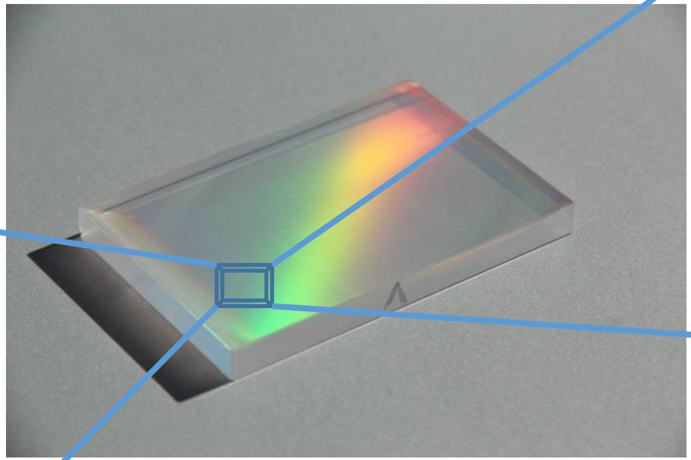

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687880

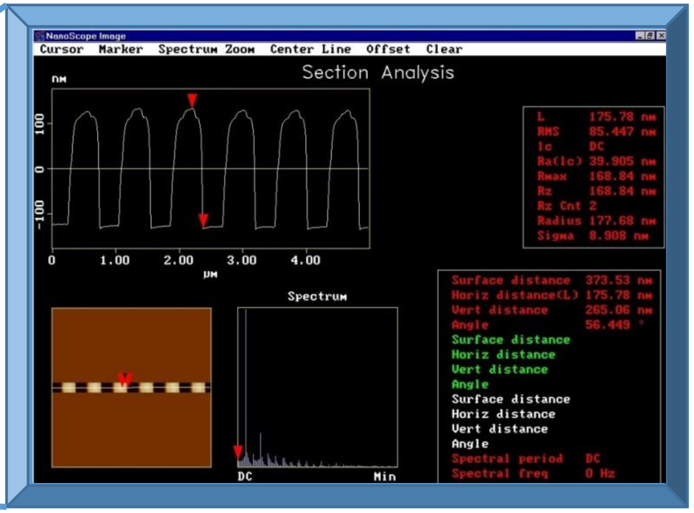
| WP4 | Photonic components for pre and post pulse conditioning |
|---|---|

**1st generation grating mirror on large area, rectangular substrates fabricated according to HIPERDIAS design No. 1**

SEM photograph






AFM analysis

Milesstone 4.3 successfully completed

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| WP4 | Photonic components for pre and post pulse conditioning |
|---|---|

***Summary:***

- *Processing equipment developed and tested successfully*
- *New customized mechanical chuck and software for the spin coater RCD8 was installed*
- *Fabrication of a reference grating is completed*
- *Pitch adjustment from lithography system verified*
- *Automatic endpoint detection tested in combination with etch process Step_1 BARC*
- *Milestone 4.3 fulfilled*

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| WP4 | Photonic components for pre and post pulse conditioning |
|---|---|

***Next 6 months***

*Spin coating:*

- *Integration and start-up of the Gyrset system for the coating of square substrates*
- *Process development and optimization with focus on uniformity and reproducibility*

*Lithography process:*

- *Influence of exposure dose and PEB on linewidth of the grating*
- *Strategies to improve linewidth reproducibility*

*Etch process:*

- *Endpoint detection system compatibility to etch process Step_2 Substrate*

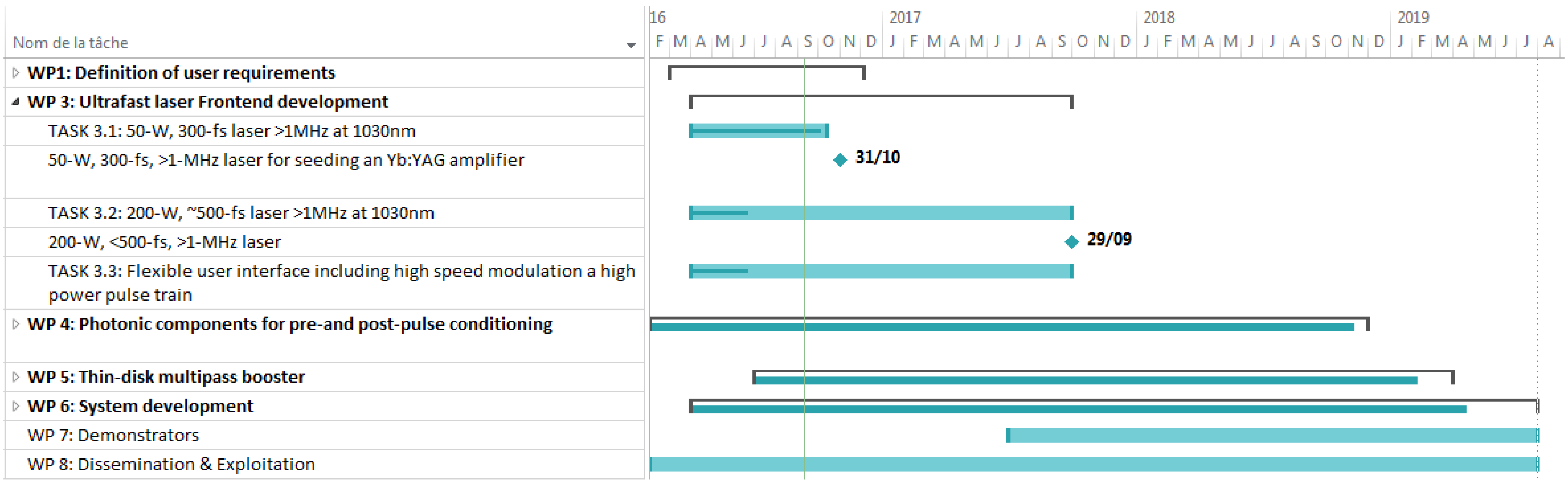
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687880

# Amplitude Systèmes

**B. Weichelt, M. Delaigue, J. Pouysegur, F. Morin, C. Hönninger**

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

# • WPs with contributions from Amplitude




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

CONFIDENTIAL

# WP 1: Definition of user requirements

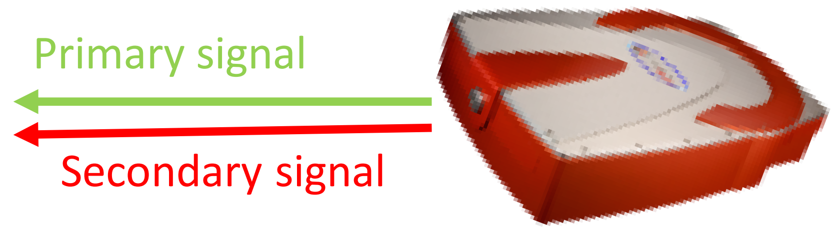
- Participation in the definition of process and system specifications
  - Discussions with and input from Bosch and C4L
  - This input is taken into account in Amplitude's user interface development (task 3.3) and as far as possible anticipated in the deliverables D3.1 (50-W femtosecond laser) and D3.2 (200-W femtosecond laser)
    - <1ps pulse duration
    - Max. pulse energy ~500µJ
    - Typical pulse repetition rate ranges (< 2 MHz)

    - Flexible burst mode
    - Synchronisation to scanner
    - Real pulse on demand & triggering by scanner control or…
    - …fast changing of pulse divider or…
    - …other approaches

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

# WP 3: Ultrafast laser Frontend development

- T3.1: 50-W femtosecond laser
  - Task ~95% finished
  - 50-W laser should be shipped to IFSW this week




  - Further specific laser features:
    - Zero diffraction order output to ensure saturation of downstream thin disk amplifier and avoid first pulse problematic or damage
    - Synchronisation to scanner (supersync), synchronisation scheme follows below
    - Burst mode possible

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

# WP 3: Ultrafast laser Frontend development

- T3.1: 50-W femtosecond laser

| | Laser Parameters | | Unit | Target | | Measurement | |
|---|---|---|---|---|---|---|---|
| | | | | 1250 kHz | 2 MHz | 1250 kHz | 2 MHz |
| IR | *Energy per pulse | | µJ | ≥ 40 | ≥ 25 | 40.8 | 25.8 |
| | *Average power | | W | ≥ 50 | ≥ 50 | 51.02 | 51.6 |
| | Center wavelength | | nm | 1030 +/- 5 | | 1031.3 | 1031.3 |
| | Bandwidth FWHM | | nm | ≤ 10 | | 6.8 | 6.7 |
| | *Pulse duration | | fs | < 400 | | 320 | 310 |
| | Pulse energy over 12h | *Average* | µJ | ≥ 40 | N/A | 40.8 | N/A |
| | | *RMS* | % | < 2 | | 0.10 | |
| | Polarization ratio | | - | > 100:1 | | 2516:1 | |
| | $M^2$ | *$M^2x$* | - | < 1.30 | | 1.15 | |
| | | *$M^2y$* | - | | | 1.08 | |
| | Beam diameter | *$W_0x$* | mm | 2.5 +/- 0.5 | | 2.35 | |
| | | *$W_0y$* | mm | | | 2.09 | |
| | Beam ellipticity | | % | < 13% | | 11.1 | |
| | Astigmatism | | % | < 50% | | 8 | |
| | Waist ellipticity | | % | < 13% | | 3.0 | |
| | Pointing stability | | µrad | < 100 | | x: 37 | y: 48 |

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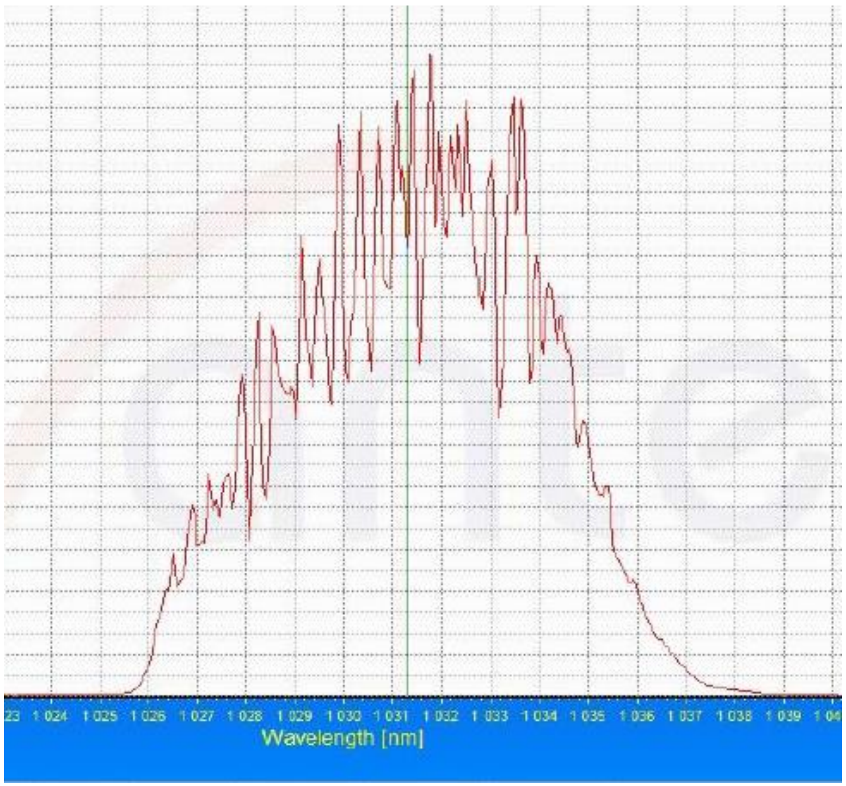
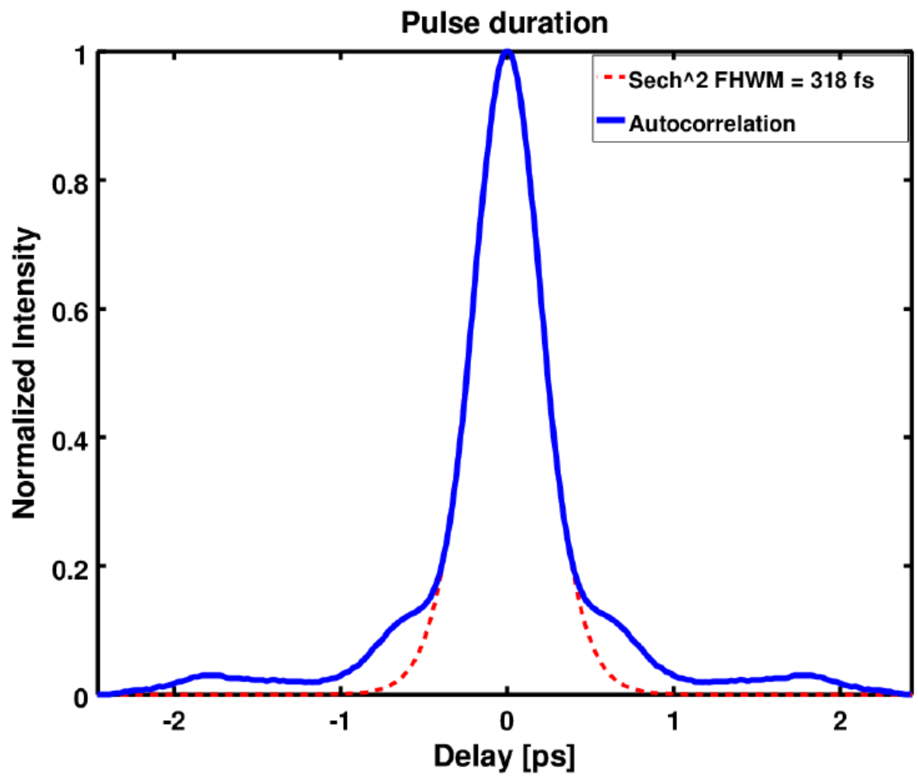
# WP 3: Ultrafast laser Frontend development

- T3.1: 50-W femtosecond laser

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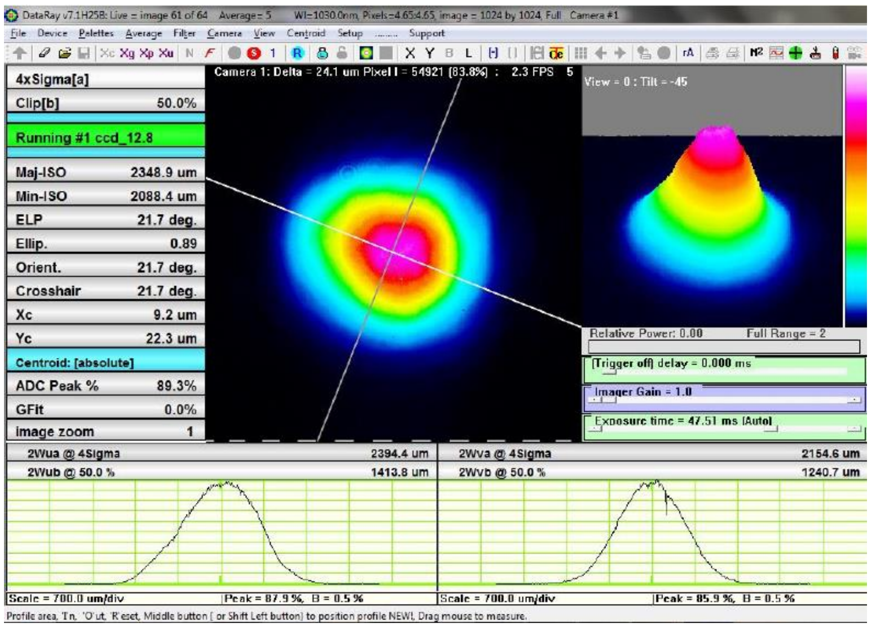
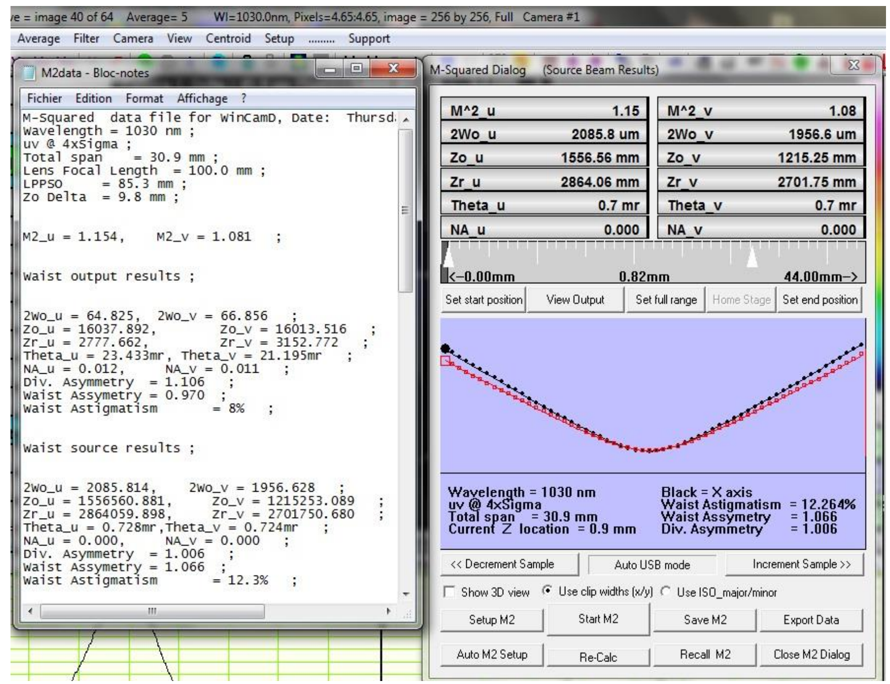
CONFIDENTIAL

# WP 3: Ultrafast laser Frontend development

- T3.1: 50-W femtosecond laser

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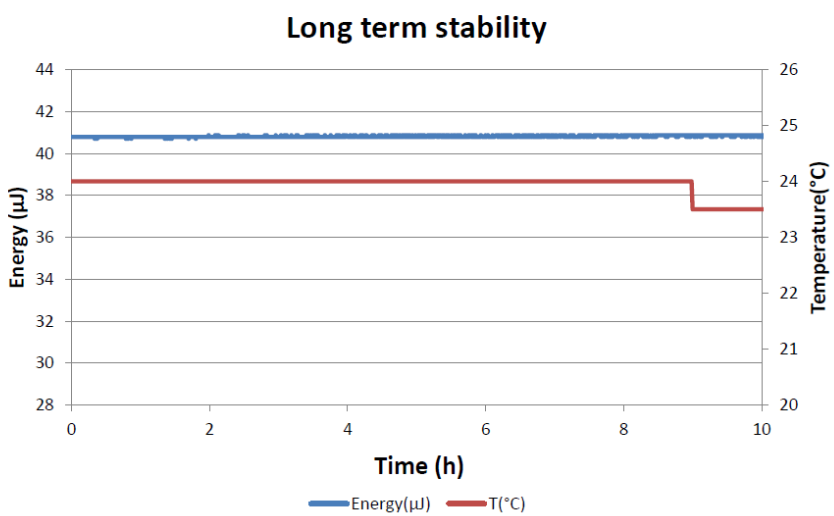
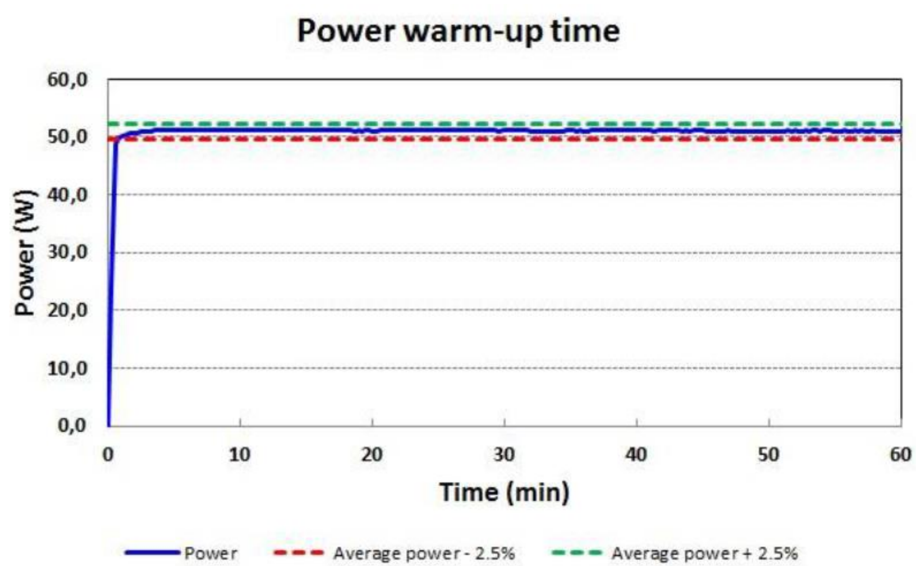
# WP 3: Ultrafast laser Frontend development

- T3.1: 50-W femtosecond laser

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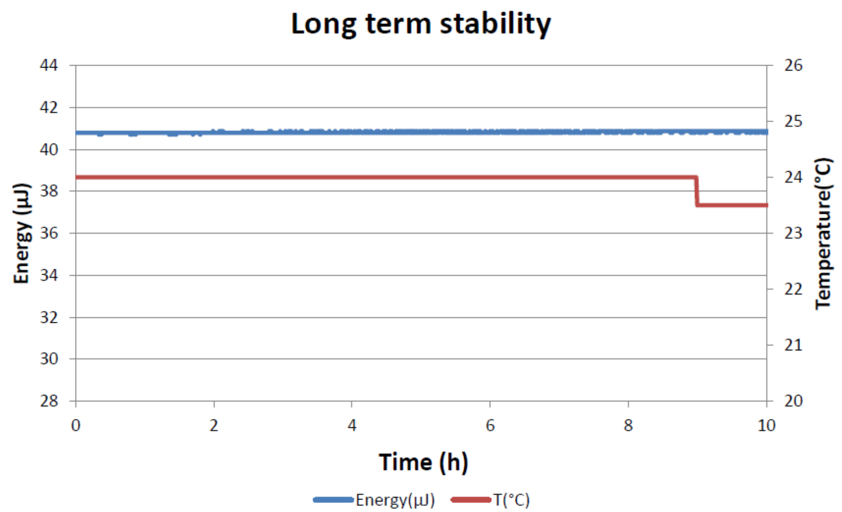
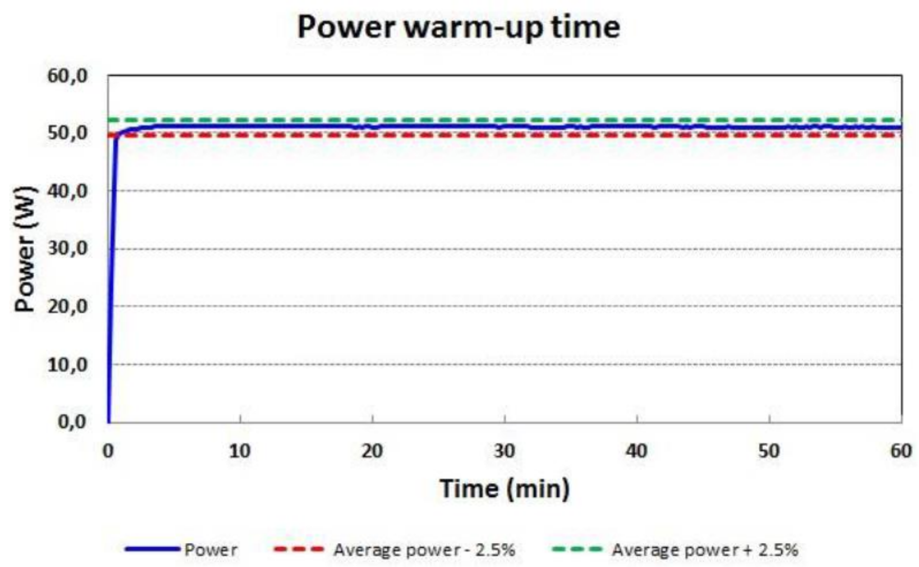
# WP 3: Ultrafast laser Frontend development

- T3.1: 50-W femtosecond laser

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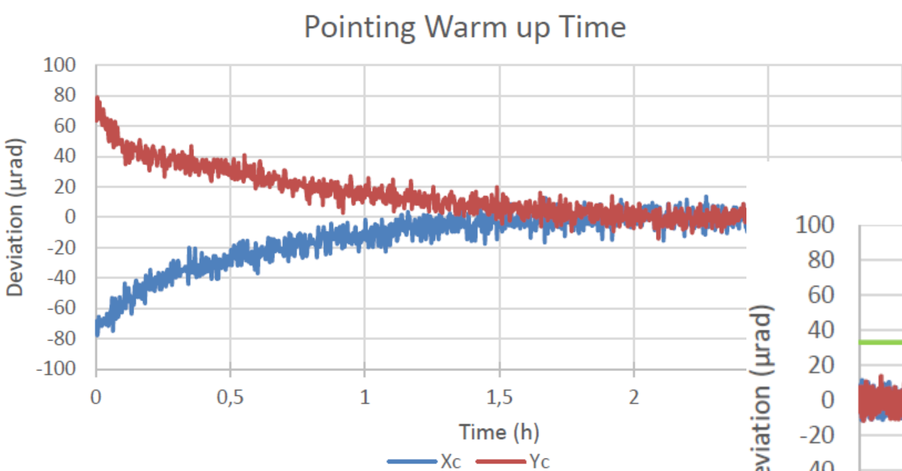
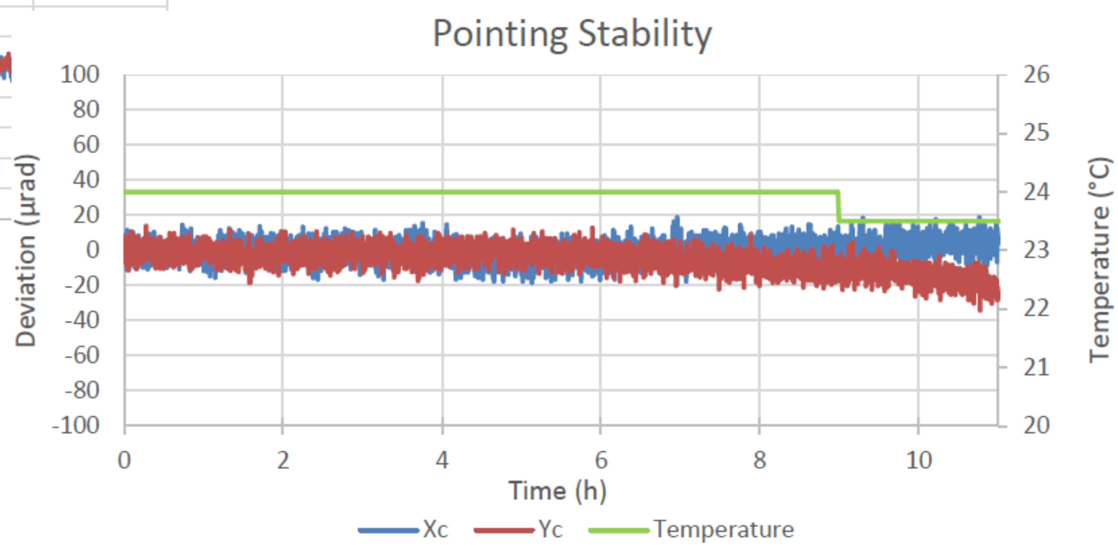
# WP 3: Ultrafast laser Frontend development

- T3.1: 50-W femtosecond laser

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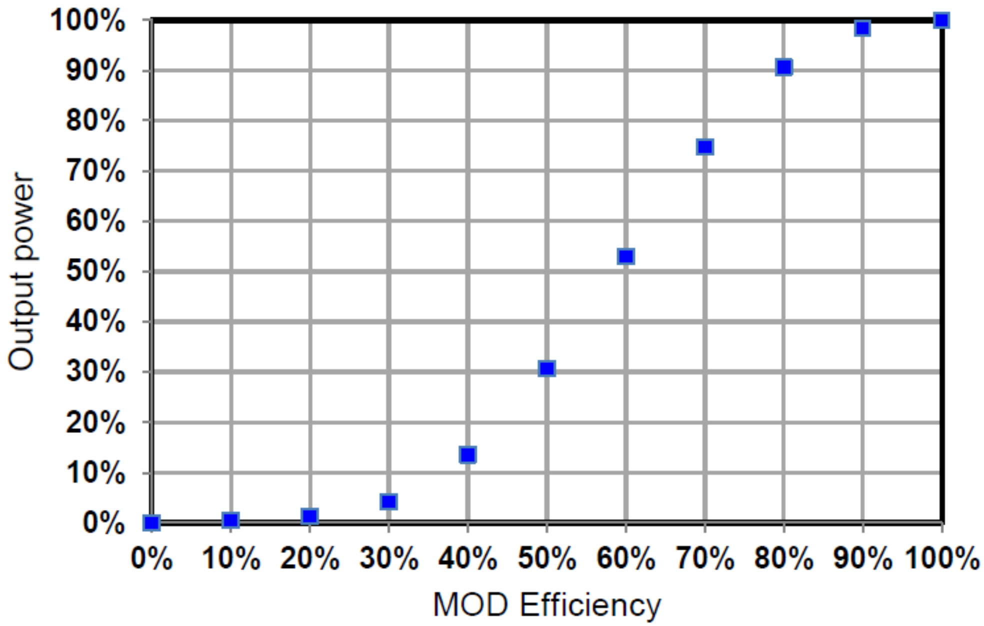
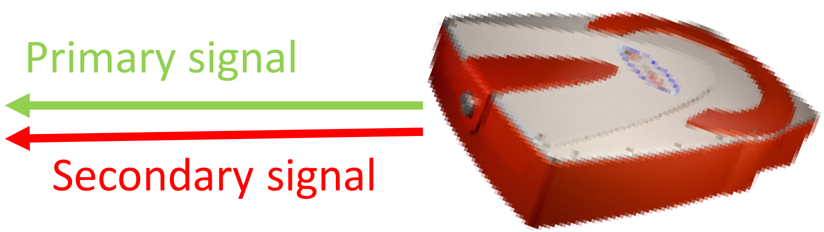
# WP 3: Ultrafast laser Frontend development

- T3.1: 50-W femtosecond laser

External modulator attenuation:

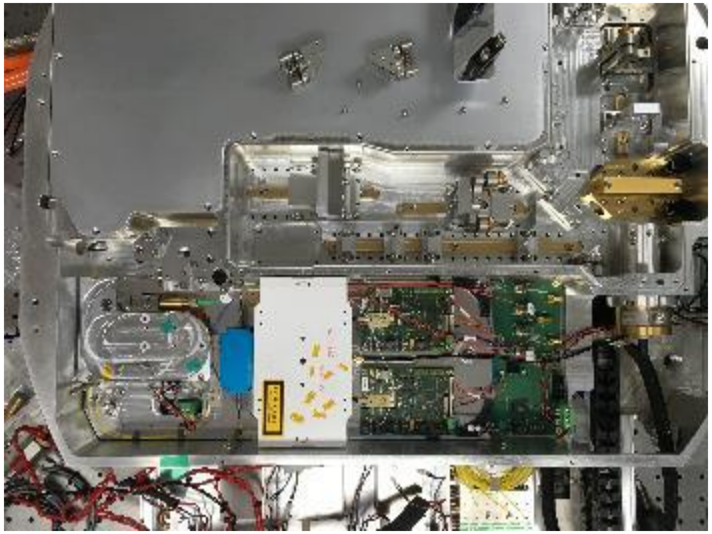


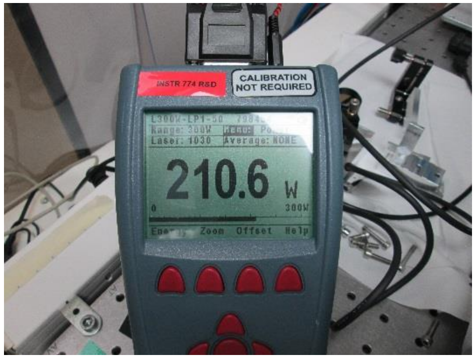




This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687880

# WP 3: Ultrafast laser Frontend development

- T3.2: 200-W femtosecond laser
  - Task started (~10 to 15% estimated)
  - Buying of components and testing of concepts
  - Preliminary results, but too early to conclude for best concept






- not fully characterized
- not compressed

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# WP 3: Ultrafast laser Frontend development

- T3.3: Flexible user interface including high speed modulation a high power pulse train
  - Task started (~10% estimated)
  - Typical pulse repetition rate ranges (< 2 MHz)
  - Flexible burst mode
  - Synchronisation to scanner
  - Real pulse on demand & triggering by scanner control or…
  - …fast changing of pulse divider or…
  - …other approaches

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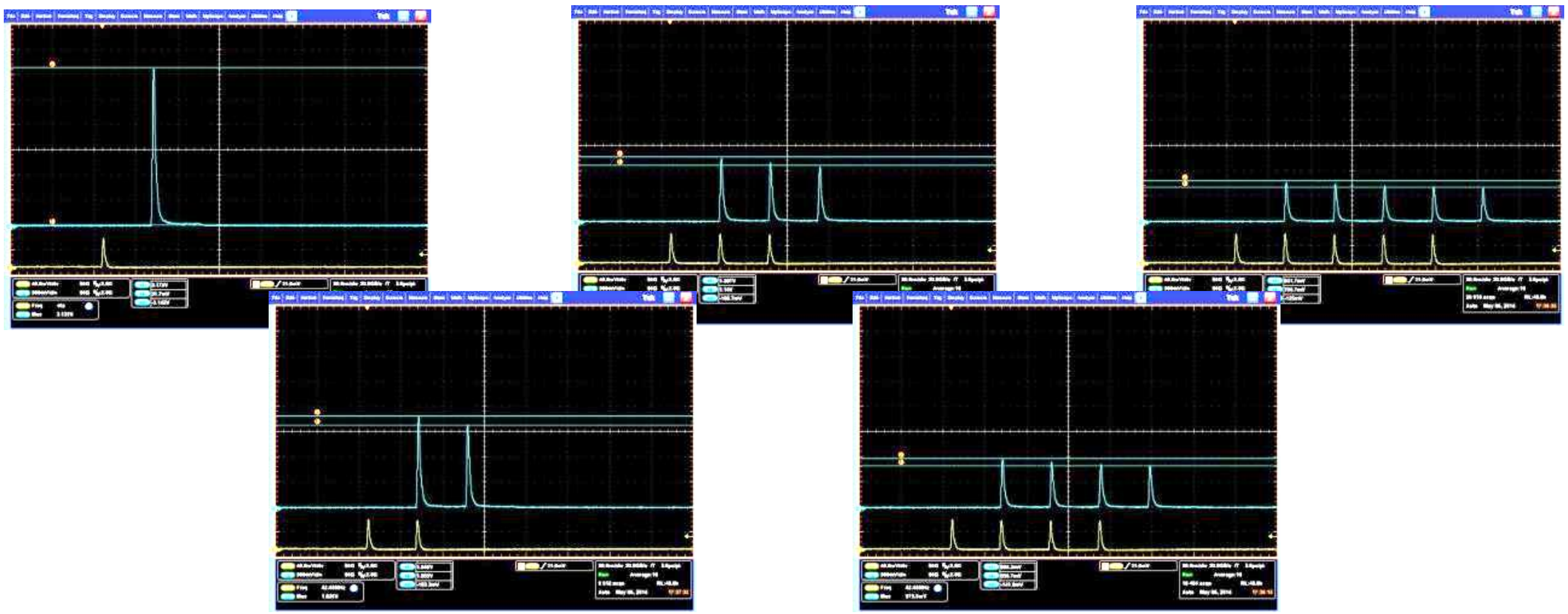
# WP 3: Ultrafast laser Frontend development

- T3.3: Flexible user interface including high speed modulation a high power pulse train



  - Pulse separation within burst = oscillator periode: 25 ns
  - Burst repetition rate flexible

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# WP 3: Ultrafast laser Frontend development

- T3.3: Flexible user interface including high speed modulation a high power pulse train
  - User access to Pulse picker
  - Synchronisation between Laser and Scanner for high speed processing


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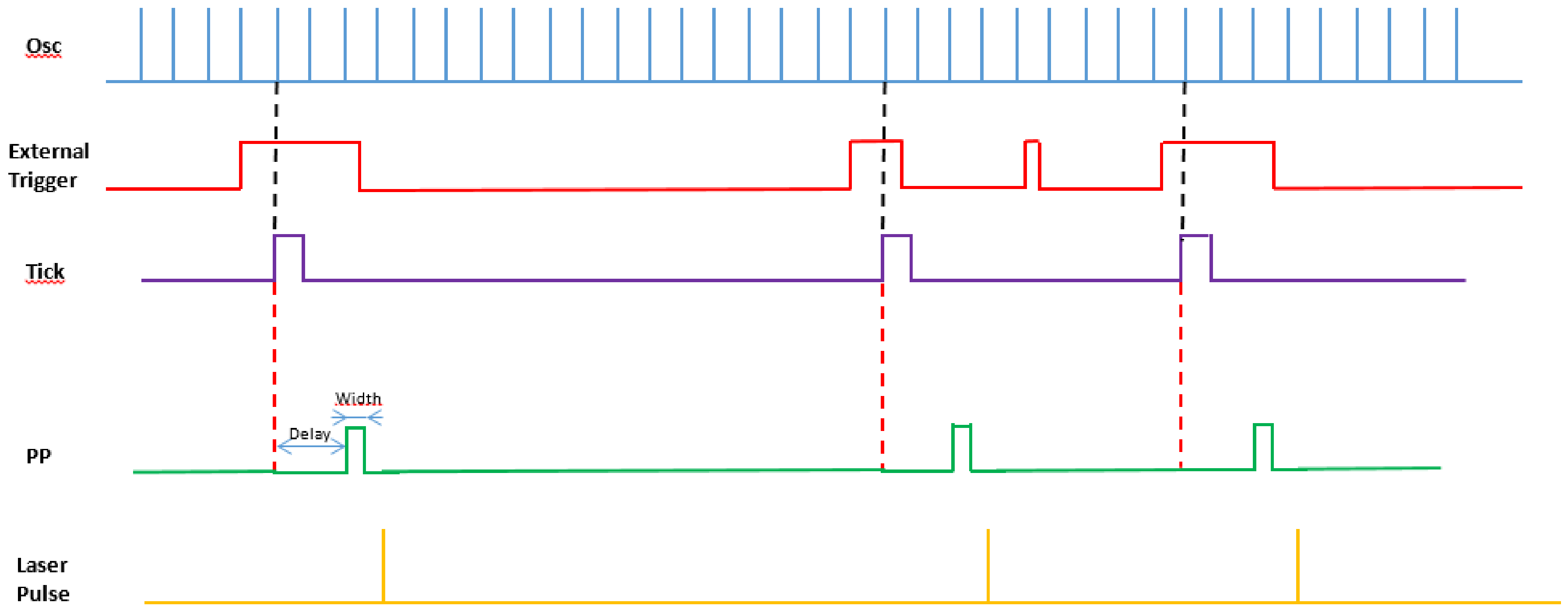
# WP 3: Ultrafast laser Frontend development

- T3.3: Flexible user interface including high speed modulation a high power pulse train

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# WP 3: Ultrafast laser Frontend development

- T3.3: Flexible user interface including high speed modulation a high power pulse train
  - Identify all critical system delay times
  - Suggest concepts for pulse-on-demand without "dead times" to endusers, discuss, decide, realize

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# • WP 4, 5, 6:

## – WP 4: Photonic components

- Specifications for high efficiency diffractions gratins communicated to partners IFSW and AMO

## – WP 5: Thin disk multipass booster

- first seed laser to be provided soon
- Additional features integrated to facilitate thin disk multipass amplifier (zero order of ext. Mod OUT)
- Discussions on control interface started but needs to become more concrete

## – WP 6: System development

- Interfaces of seed lasers communicated to integrator LASEA (as far as possible at this stage)

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- Next steps:
  - WP 3:
    - Ship and install 50-W laser (this month)
    - R&D work on 200-W laser, validate concept, and start demonstrator fabrication (should be in plan)
    - R&D work on user interface and pulse-on-demand requirements
      - Close contact to end users required in order to develop the right thing

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# High-Volume 3D Processing of Silicon – Process Development

M. Lustfeld, A. Michalowski, M. Ametowobla,
G. Kunz, D. Brinkmeier, S. Karg

BOSCH
Invented for life

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

## BOSCH team involved in HIPERDIAS


- Martin Lustfeld / martin.lustfeld@de.bosch.com / +49 (0) 711 811 43990
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# Timeline of BOSCH involvement in HIPERDIAS

| Task | H1/16 | H2/16 | H1/17 | H2/17 | H1/18 | H2/18 | H1/19 |
|---|---|---|---|---|---|---|---|
| **1.1** Application specs | | D1.1: End-user application specs R: BOSCH; turned in: 06/16 | | | | | |
| **1.2** Process & system specs | | | D1.2: Process & system specs | | | | |
| **1.3** Validation of progress | | | D1.3: Prototype & progress validation R: BOSCH | | | | |
| **2.1** Process development | | | | | D2.1: Process limits 3D Si processing; R: BOSCH | | |
| **2.4** Process upscaling | | | | | | D2.4: Strategy for high power processing; R: BOSCH | |
| **6.1** Definition of interfaces | | | D6.1: Interface definition | | | | |
| **6.6** Test and Evaluation | | | | | | D6.6: System test & validation | |
| **7.4.1** Reference samples | | | | | D7.5: Performance of the 500 W demonstrator; R: BOSCH | | |

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| WP1 | Definition of user requirements |
|---|---|

***Work completed in period 02/16 – 08/16***

**Task 1.1: Collection of end-user application specifications**

- Specified demonstrator geometry containing all end-user requirements
- Completed Deliverable 1.1

**Task 1.2: Process and system specifications**

- Deduced system requirements from product requirements
- Defined additional system requirements based on experience in Task 2.1
- Discussed requirements with partners in WP3-7

**Task 1.3: Assessment of technical progress**

- Deduced KPI’s from demonstrator geometry
- Identified assessment methods to validate KPI’s

***Work in progress until 01/17***

- Establish iterative feedback loop with partners in WP3-7 to adapt system requirements
- Adapt demonstrator geometry accordingly
- Qualify assessment methods for validation of KPI’s

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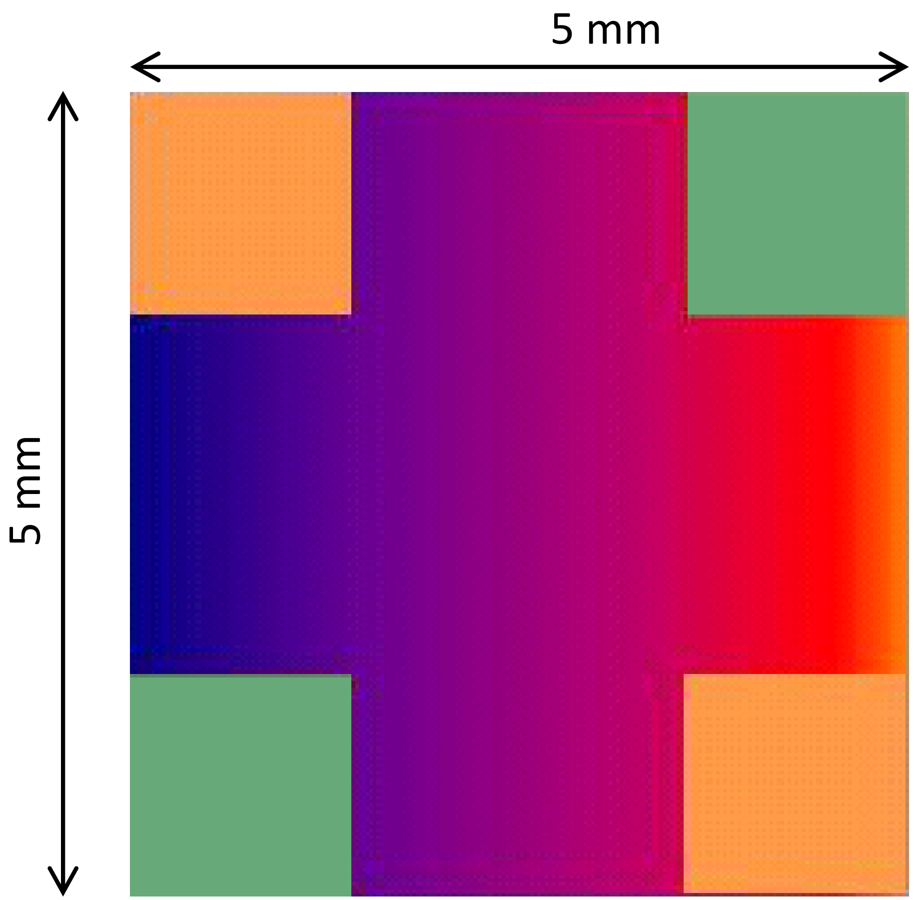
| WP1 | KPI's and their validation using the demonstrator geometry |
|---|---|

**KPI 1 (WLI):**
average ablation rate

**KPI 2:**
peak ablation rate

**KPI 3 (WLI):**
contour accuracy

**KPI 4 (WLI, LSM):**
surface roughness $S_a$




**KPI 5 (SEM):**
thickness of surface damage

**KPI 6 (SEM):**
surface defects, e.g. pores > 1 µm

**KPI 7 (OM):**
edge radius

**KPI 8 (LSM):**
edge steepness


## KPI's

| name | target |
|---|---|
| av. ablation rate | 1 $mm^3/s$ |
| peak ablation rate | 3 $mm^3/s$ |
| contour accuracy | < 10 µm |
| surface roughness Sa | < 1 µm |
| surface damage | tbd. |
| surface defects > 1µm | none |
| edge radius | < 200 µm |
| edge steepness | > 70° |

WLI: White Light Interferometry
SEM: Scanning Electron Microscopy
LSM: Laser Scanning Microscopy
OM: Optical Microscopy

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| WP1 | Implications of process requirements for the laser production system |
|---|---|

**Performance and quality: Laser source and interface features**

- Pulse duration $\tau_p < 1$ ps (increased ablation efficiency for reduced pulse duration)
- Max. pulse energy $E_p \geq 500$ µJ
- Pulse repetition frequency $f_{rep} \leq 2$ MHz (estimate)
- Min. 2 pulse burst desirable, flexible burst desirable
- Pulse divider from base frequency (variable repetition rate, unchanged pulse parameters)
- Synchronization with scanner (→ use of skywriting) → e.g. precision switching of gate
- **Ideal**: synchronization of scanner speed and pulse repetition frequency ➔ increase processing speeds

**Safety**

- High total ablated volume → heavy-duty exhaust system
- Very high power densities → x-ray shielding?
- High power input: wafer cooling to avoid cracking?

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| WP2 | Process Development |
| --- | --- |

***Work completed in period 02/16 – 08/16***

**Task 2.1: Fundamental process development 3D Si processing**

- Performed literature study on:
  - State of the art in laser processing of Si
  - Comparison to alternative Si micro structuring processes (mechanical, chemical)
- Ablated 3D Si demonstrator geometry
  - Qualified assessment methods of KPI's
  - Determined current state of KPI's
- Determined ablation efficiency as a function of fluence at medium laser power
  - 3 different laser sources (40 W – 50 W)
  - Pulse duration (1 ps, 6 ps, 10 ps)
  - Laser fluence: 0.1 $J/cm^2$ – 3 $J/cm^2$
- Performed ablation experiments at high power (670 W) @ USTUTT

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| WP2 | Process Development |
|---|---|

***Work in progress***

***Short-term: until 03/17***

- Continue literature study
- Continue studies on process fundamentals
  - Impact of processing in burst mode
  - Impact of very short pulse duration (< 1 ps)
  - Phenomena occurring during processing at very high fluence
- Proposal of set of optimum laser process parameters

***Long-term (including WP 6.6 and WP 7.4.1)***

- Design of experimental strategy for upscaling of the laser process
- Implementation of experimental strategy in collaboration with WP3-7
- Identification of phenomena occurring specifically at very high laser power
- Optimization of overall process

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| WP2 | Literature Study |
|---|---|

**Alternative Si removal processes:**

- **Mechanical milling:** High finishing quality requires ductile processing regime at very low feed rate
  → currently available technology too slow by several orders of magnitude [1] [2]
- **Chemical etching:** Challenge: Si texture causes anisotropic removal rates;
  3D ablation requires elaborate masking setup → very slow processing

**Laser processing of Si: Exemplary studies, recently published:**

- [3]: ps-laser texturization of Si for photovoltaics at UV, VIS, IR wavelength
  → Sub-surface damage of Si (amorphization) to a depth of up to 2 µm below the ablated surface
- [4]: Minimizing the surface roughness for Si ablation with USP lasers
  → Trade-off between laser-induced surface structures (low fluence) and melt ejections (high fluence)
  → Surface roughness depends strongly on scanning strategy
- [5]: Quality & efficiency enhancement by processing in burst mode ("ablation-cooled material removal")

[1] T.J.K. Rusnaldy, H.S. Kim, INT J MACH TOOL MANU 47:52 (2007); [2] M. Arif, M. Rahman, W.Y. San, J MANUF PROCESS 14:52 (2012)
[3] S. Binetti *et al.*, APPL SURF SCI 371:196 (2016); [4] M. Domke *et al.*, J LAS MICRO/NANO ENG 11:100 (2016); [5] C. Kerse *et al.*, NATURE 537:84 (2016)

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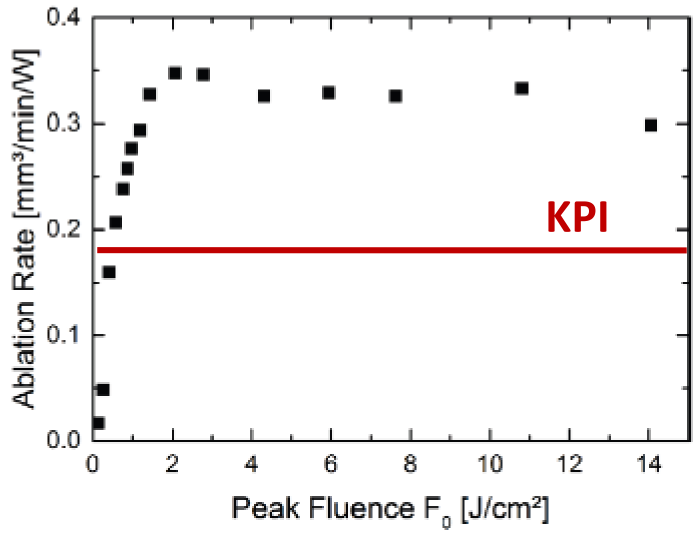
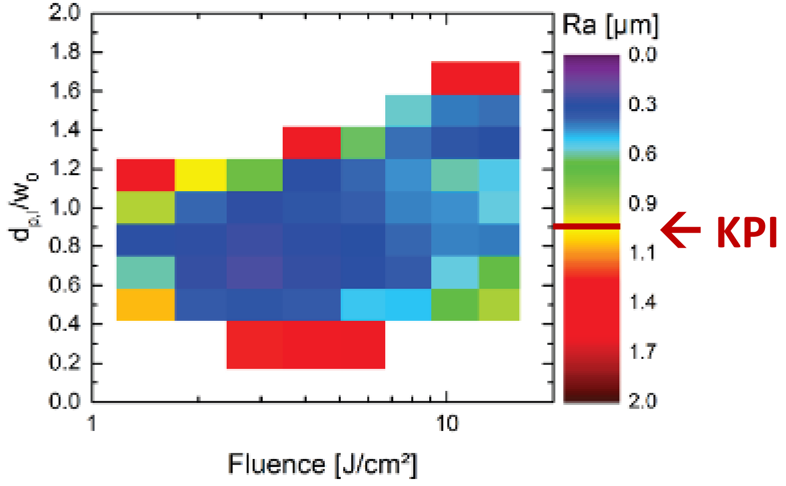
| WP2 | Literature Study: Exemplary available data |
| --- | --- |

**Minimizing the surface roughness for Si ablation with USP lasers [4]**

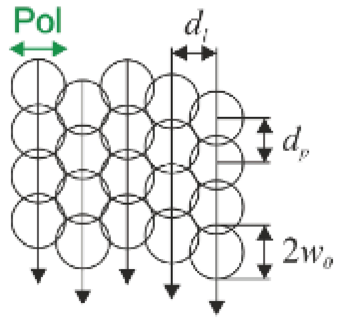
- Non-linear relation between fluence and ablation depth
- Surface roughness: Function of fluence and scanning strategy




| Parameters | | |
| --- | --- | --- |
| wavelength | $\lambda$ | 520 nm |
| pulse duration | $\tau_p$ | 380 fs |
| repetition rate | $f_{rep}$ | 200 kHz |
| maximum power | $P_{max}$ | 2 W |
| focus radius | $d_0$ | 6 µm |

**Scanning strategy**




➔ **Scalability to high power ablation (> 2 orders of magnitude)?**

[4] M. Domke *et al.*, J LAS MICRO/NANO ENG 11:100 (2016)

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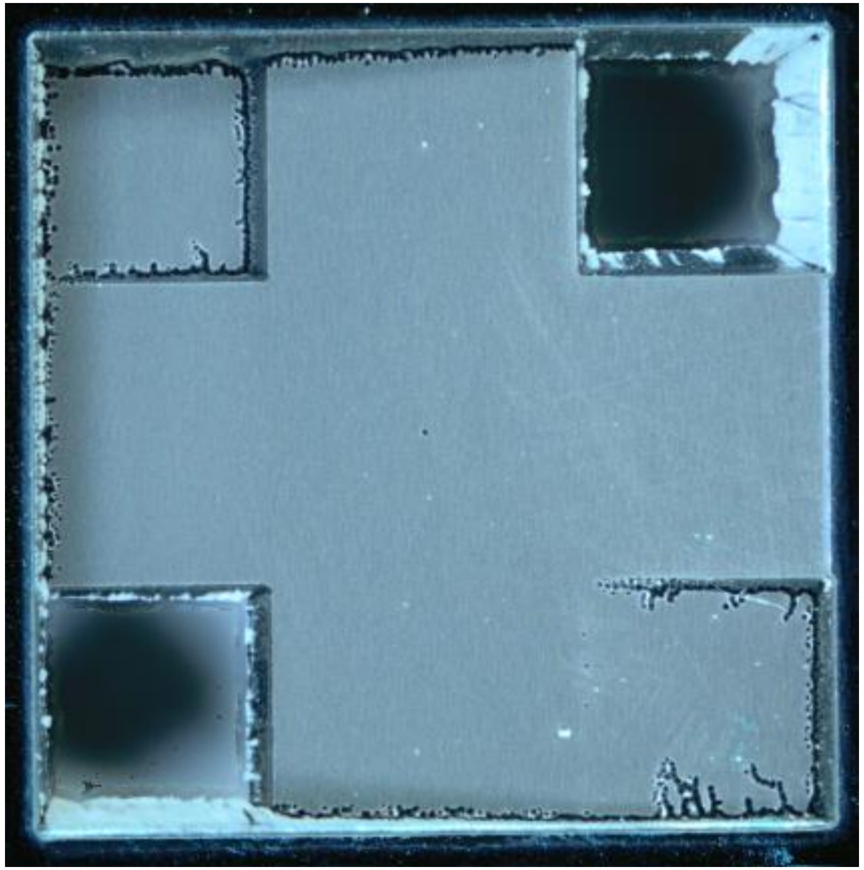
| WP2 | Experimental work at BOSCH: Ablation of demonstrator geometry (laser source: TruMicro) |
|---|---|



| Parameters | | |
|---|---|---|
| wavelength | $\lambda$ | 1030 nm |
| pulse duration | $\tau_p$ | 6 ps |
| repetition rate | $f_{rep}$ | 400 kHz |
| maximum power | $P_{max}$ | 50 W |
| focus radius | $d_0$ | 70 µm |

**Selected KPI's**

| name | measured | target |
|---|---|---|
| av. ablation rate | 0,045 mm³/s | 1 mm³/s |
| edge steepness | 81° | > 70° |
| surface roughness $S_a$ | < 1 (15) µm | < 1 µm |
| edge radius | 80 µm | < 200 µm |

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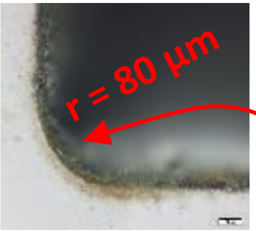
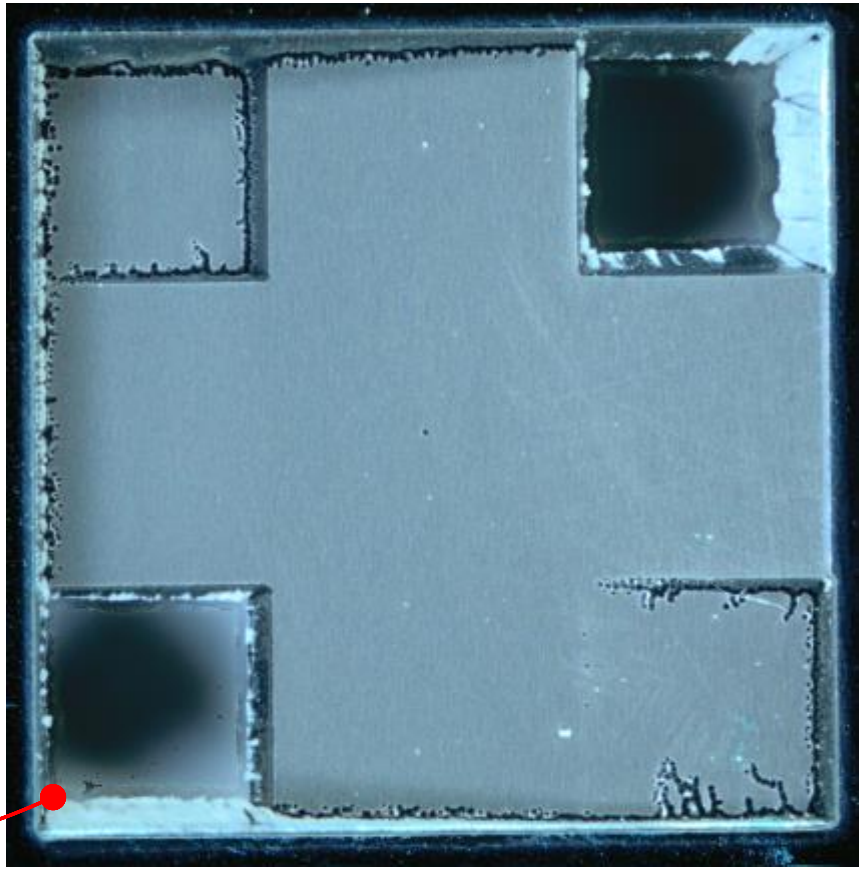
| WP2 | Experimental work at BOSCH: Ablation of demonstrator geometry (laser source: TruMicro) |
|---|---|



| Parameters | | |
|---|---|---|
| wavelength | $\lambda$ | 1030 nm |
| pulse duration | $\tau_p$ | 6 ps |
| repetition rate | $f_{rep}$ | 400 kHz |
| maximum power | $P_{max}$ | 50 W |
| focus radius | $d_0$ | 70 µm |

**Selected KPI's**

| **name** | **measured** | **target** |
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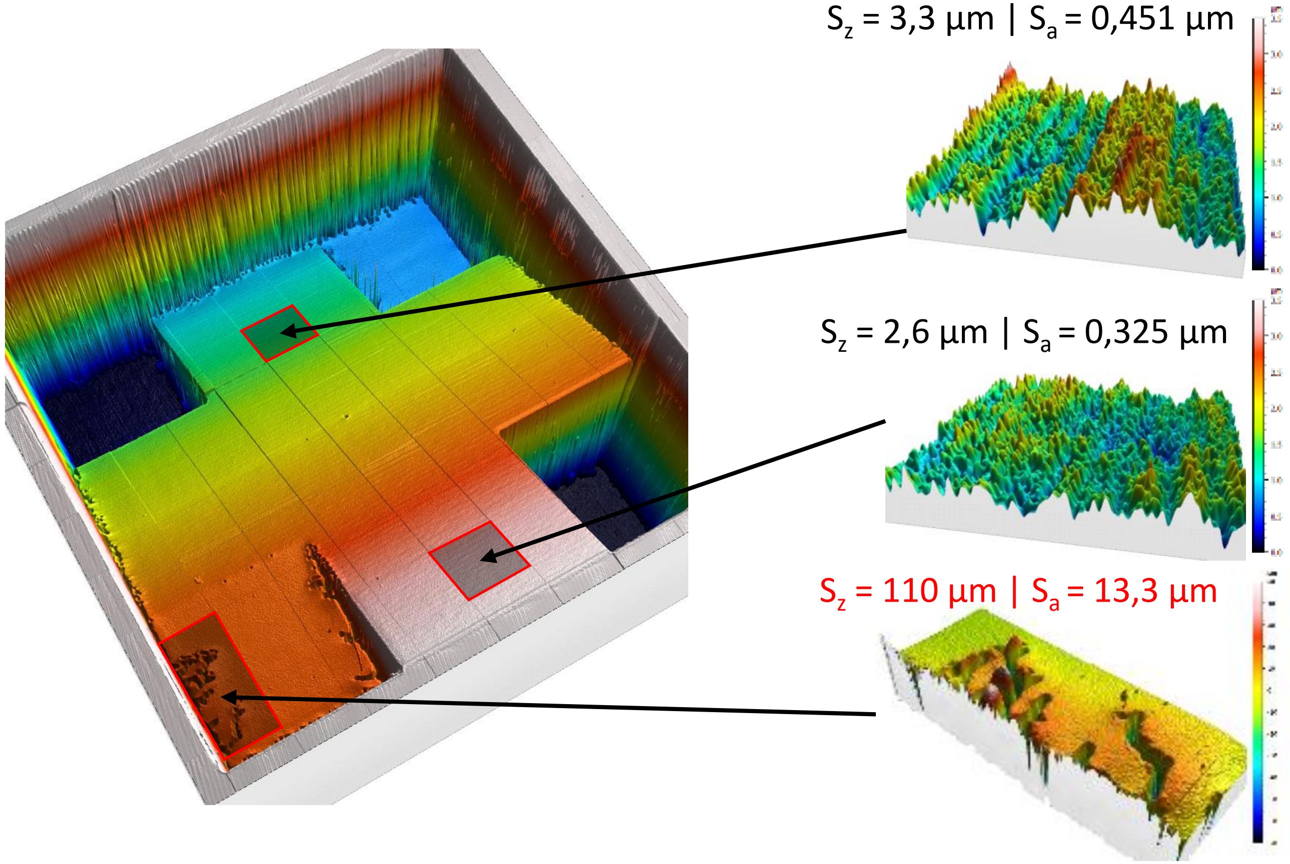
| WP2 | Experimental work at BOSCH: Ablation of demonstrator geometry: surface roughness |
|---|---|




| Parameters | | |
|---|---|---|
| wavelength | $\lambda$ | 1030 nm |
| pulse duration | $\tau_p$ | 6 ps |
| repetition rate | $f_{rep}$ | 400 kHz |
| maximum power | $P_{max}$ | 50 W |
| focus radius | $d_0$ | 70 µm |

| Selected KPI's | | |
|---|---|---|
| **Name** | **measured** | **target** |
| av. ablation rate | 0,045 mm³/s | 1 mm³/s |
| edge steepness | 81° | > 70° |
| surface roughness $S_a$ | < 1 (15) µm | < 1 µm |
| edge radius | 80 µm | < 200 µm |

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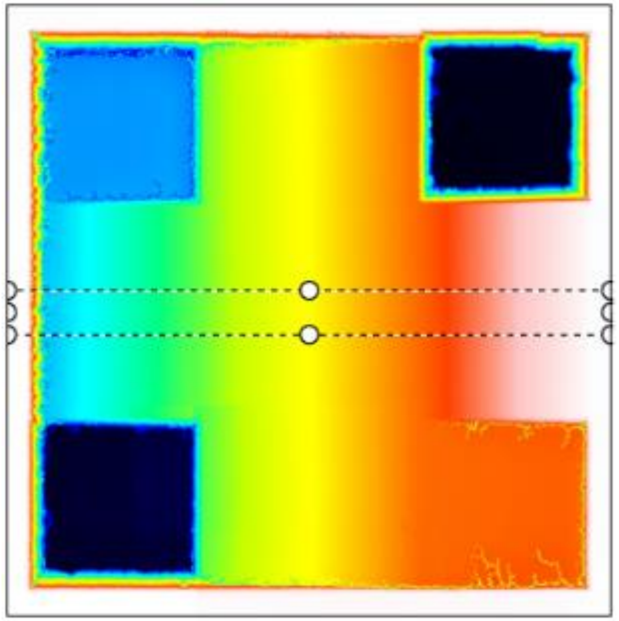
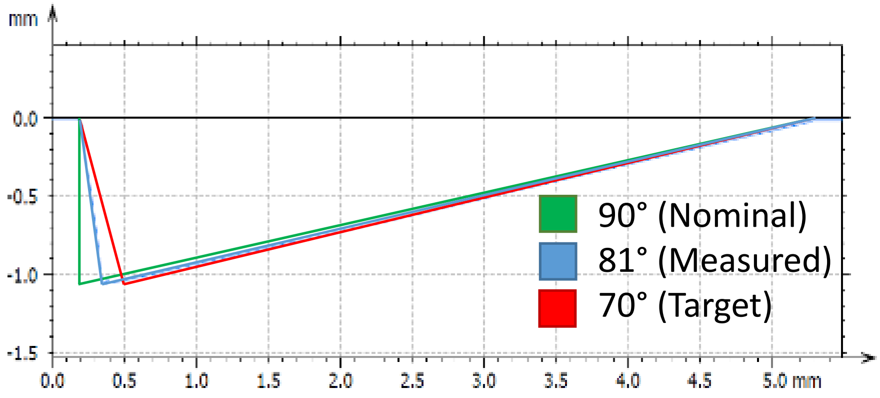
| WP2 | Experimental work at BOSCH: Ablation of demonstrator geometry: edge steepness |
|---|---|



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**Selected KPI's**

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| WP2 | Experimental work at BOSCH: Fundamental studies |
|---|---|

**Objectives of fundamental studies:**

- Suitability of laser sources (3 USP lasers):
- Determined relation: laser fluence – ablation efficiency
- Determined relation: ablation rate – surface quality
- Determined scalability of literature values to medium laser power

**Used Laser Sources**

| | A: TruMicro | B: Picoblade | C: TruMicro FE |
|---|---|---|---|
| λ | 1030 nm | 1064 nm | 1030 nm |
| $\tau_p$ | 6 ps | 10 ps | 1 ps |
| $f_{rep}$ | 400 kHz | 1000 kHz | 400 kHz |
| $P_{max}$ | 50 W | 40 W | 40 W |
| $d_0$ | 80 µm | 55 µm | 55 µm |
| burst | no | yes | no |

**Procedure:**

- Efficiency curve:
  - Ablated square geometry (1 mm²): 20 – 50 samples (0.1 – 3 J/cm²) per parameter set
  - Measured ablation depth by WLI
- Surface quality (roughness $S_a$):
  - Assessed ablated surface quality by LSM/WLI

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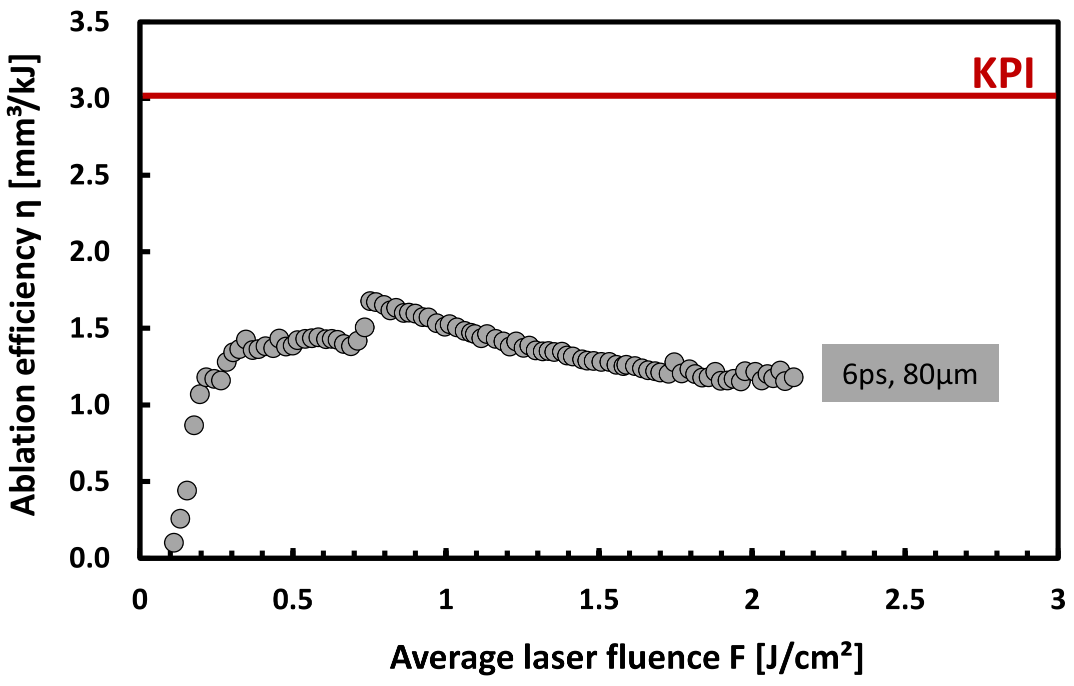
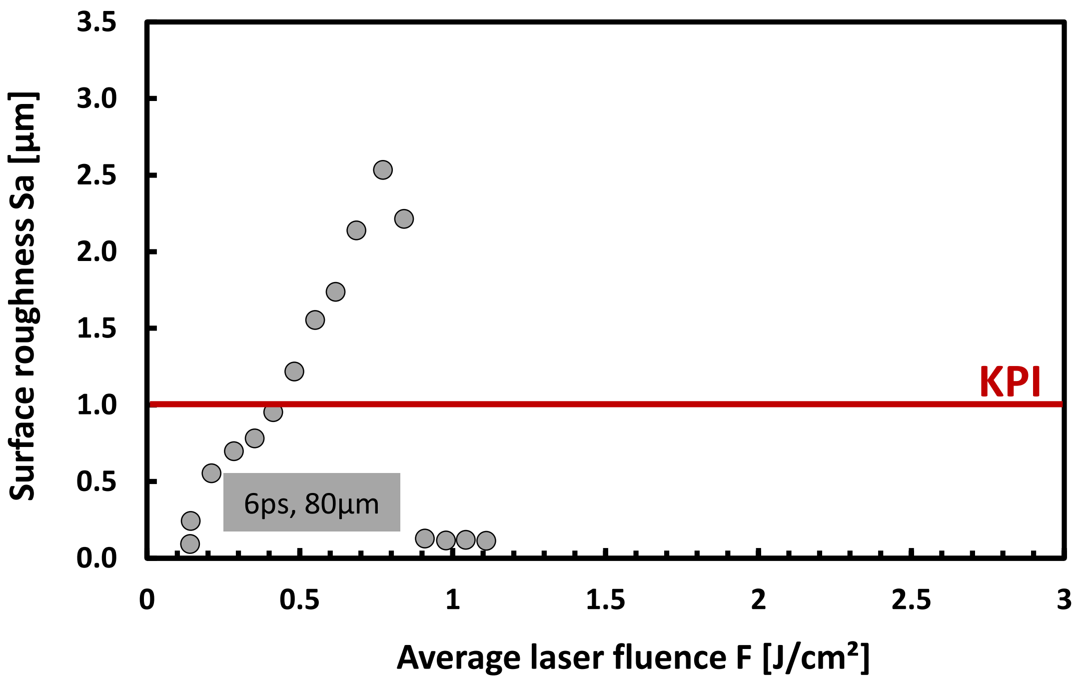
| WP2 | Experimental work at BOSCH: Fundamental studies |
|---|---|

**Experimental series A: TruMicro 5050, $\tau_p$ = 6 ps, $\lambda$ = 1030 nm, $d_0$ ≈ 80 µm**

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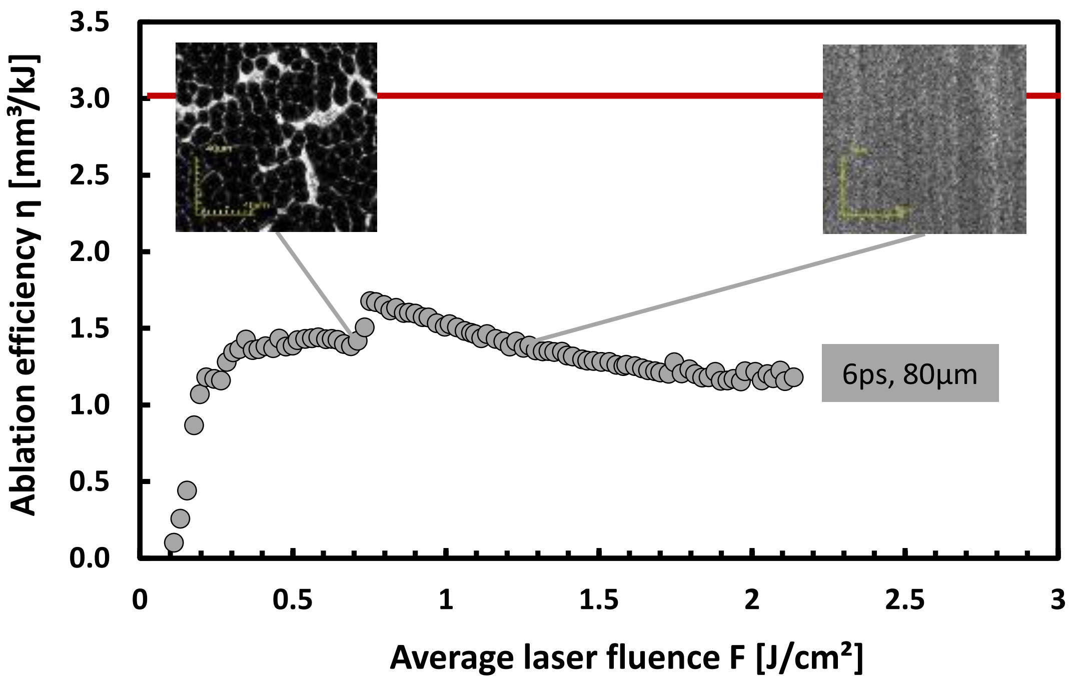
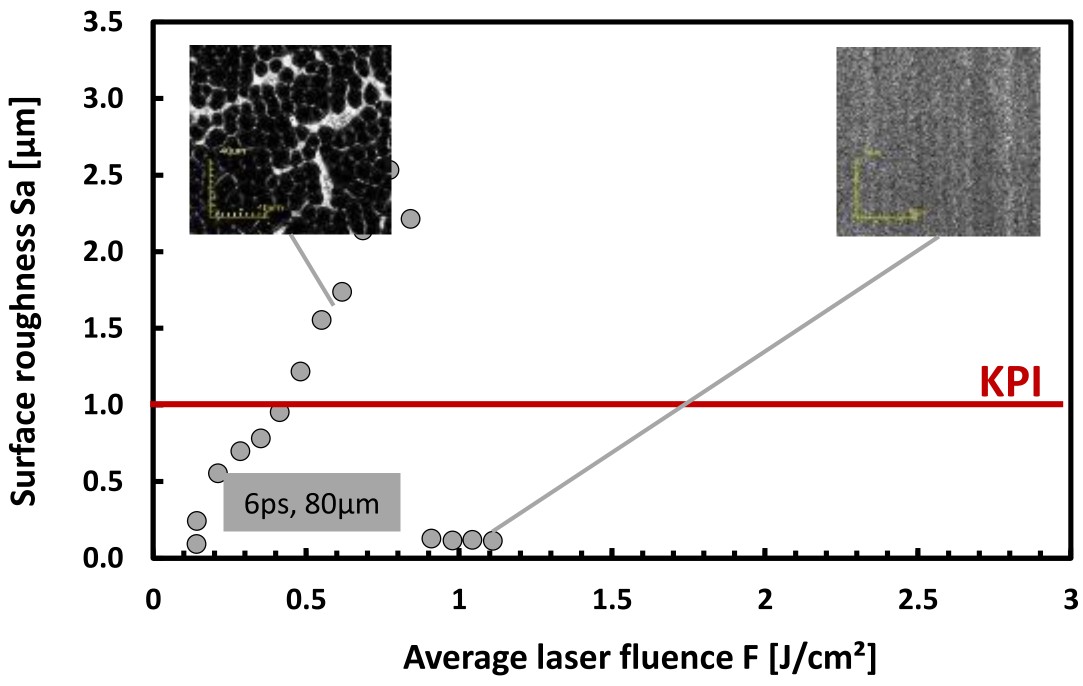
| WP2 | Experimental work at BOSCH: Fundamental studies |
|---|---|

**Experimental series A: TruMicro 5050, $\tau_p$ = 6 ps, $\lambda$ = 1030 nm, $d_0$ ≈ 80 µm**

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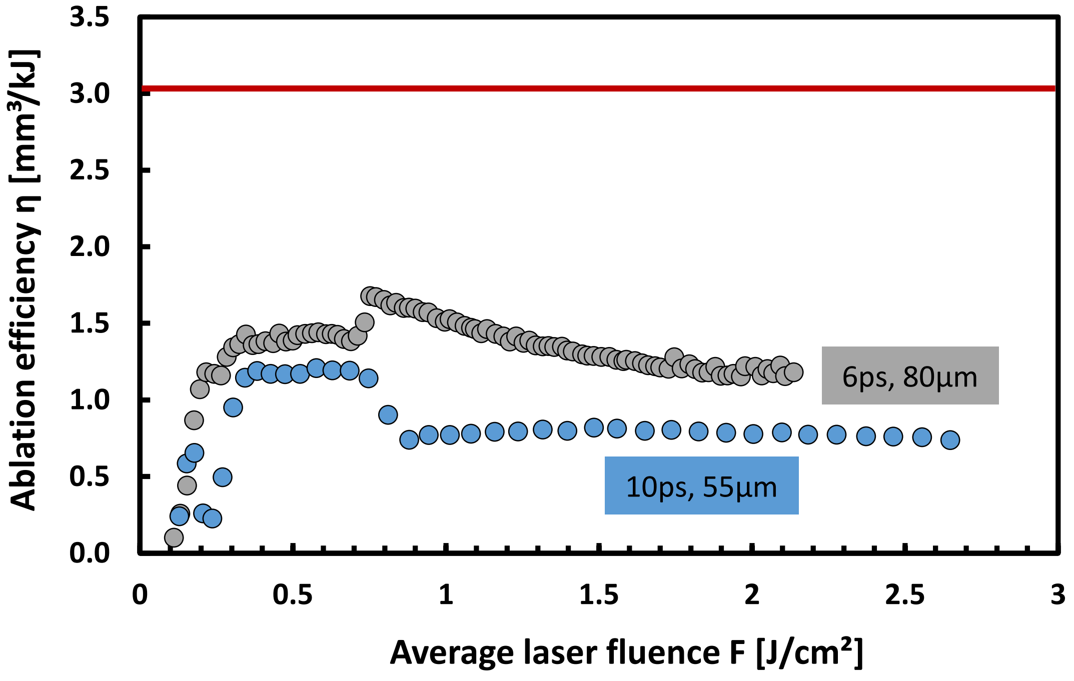
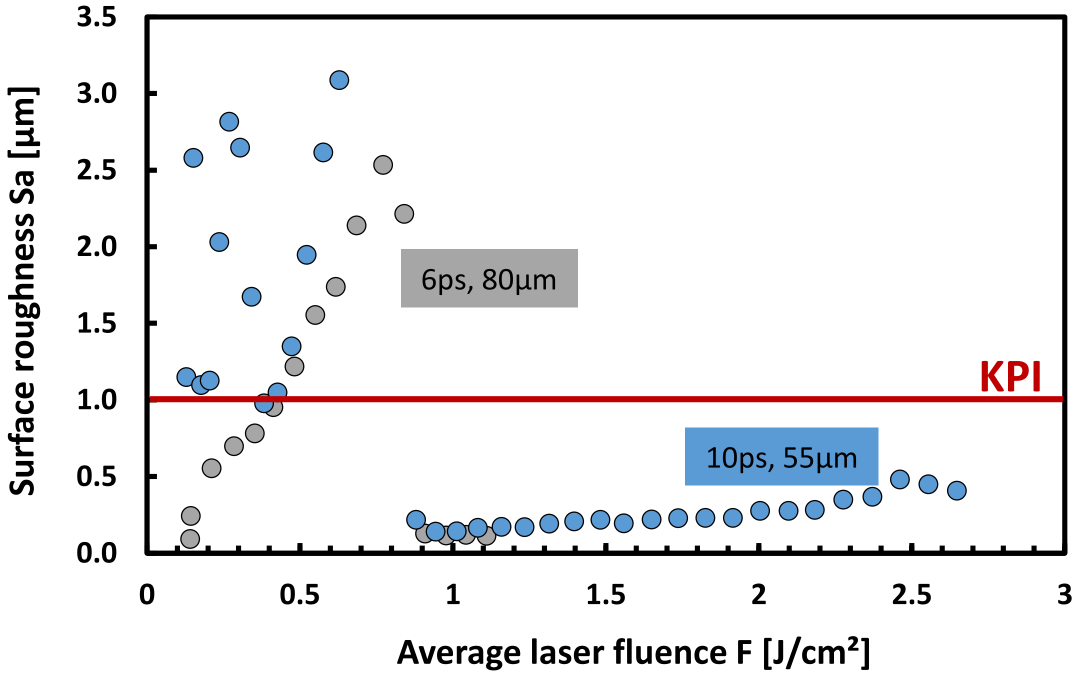
| WP2 | Experimental work at BOSCH: Fundamental studies |
| --- | --- |

**Experimental series B: Lumentum PicoBlade, $\tau_p$ = 10 ps, $\lambda$ = 1064 nm, $d_0$ ≈ 55 µm**

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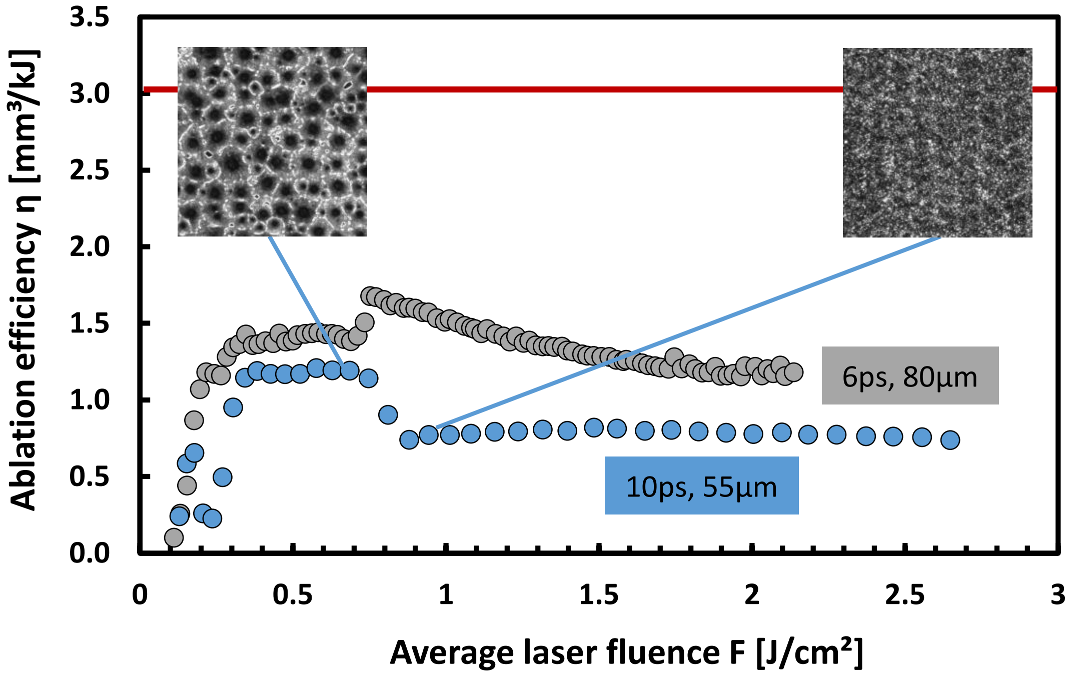
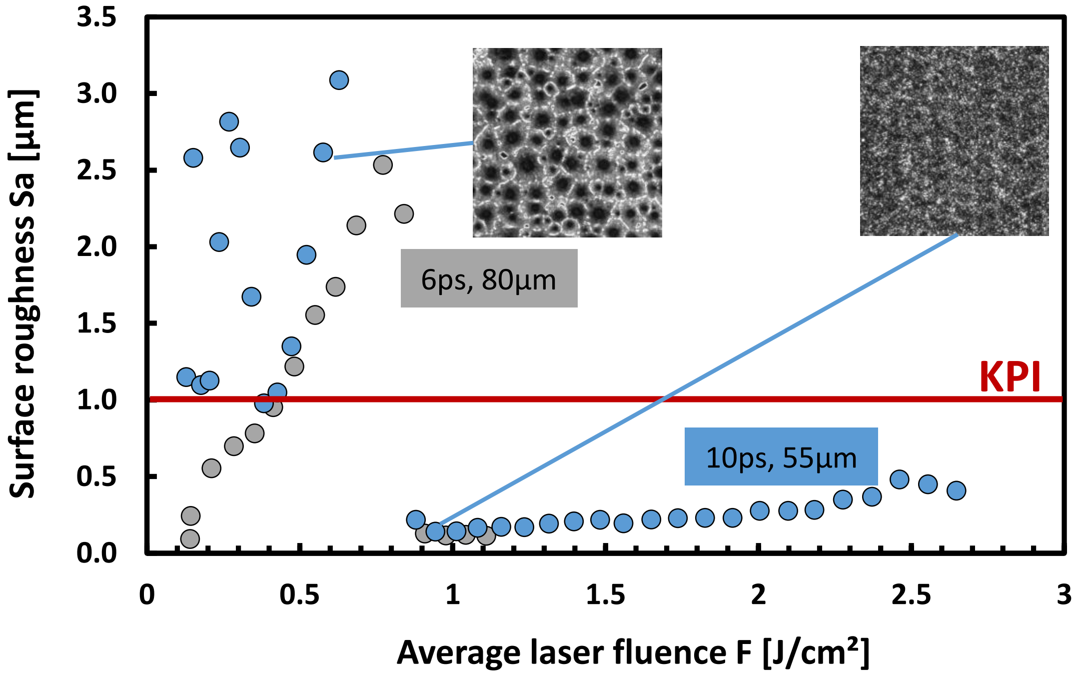
| WP2 | Experimental work at BOSCH: Fundamental studies |
|---|---|

**Experimental series B: Lumentum PicoBlade, $\tau_p$ = 10 ps, $\lambda$ = 1064 nm, $d_0 \approx$ 55 µm**

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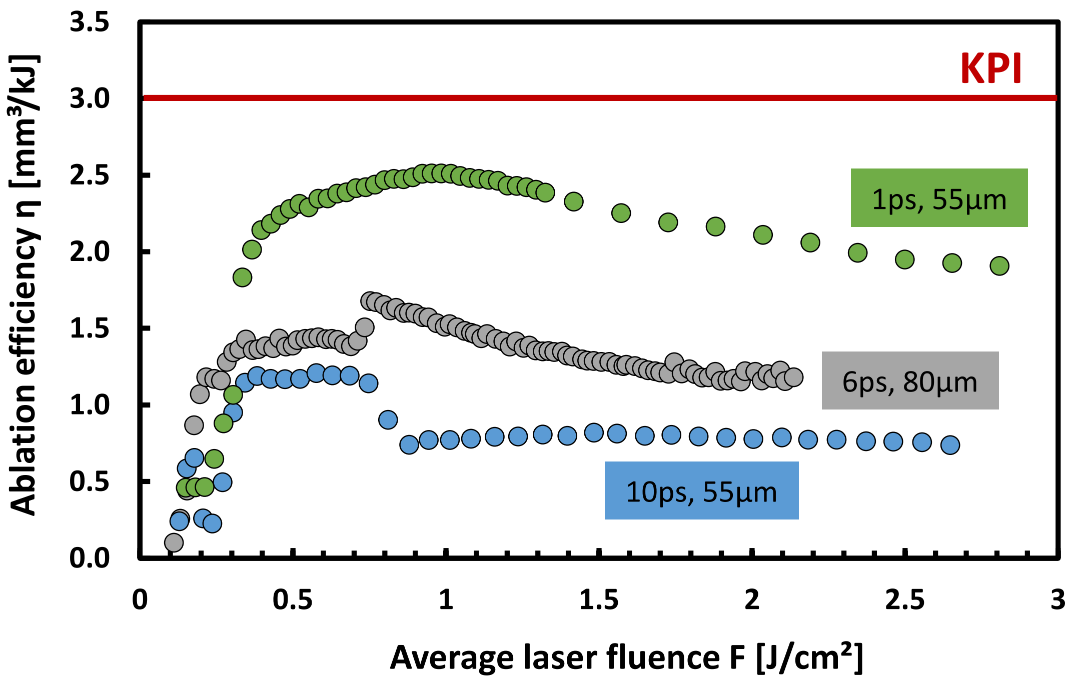
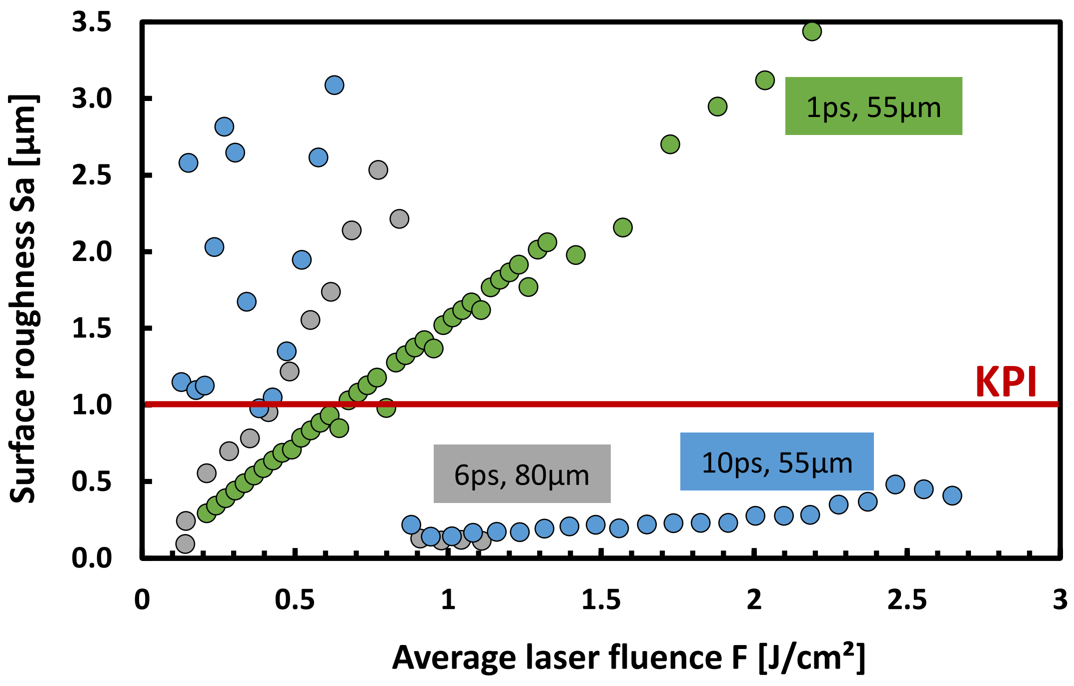
| WP2 | Experimental work at BOSCH: Fundamental studies |
|---|---|

**Experimental series C: Trumpf TruMicro 5050 Femto Edition, $\tau_p$ = 1 ps, $\lambda$ = 1030 nm, $d_0 \approx$ 55 µm**

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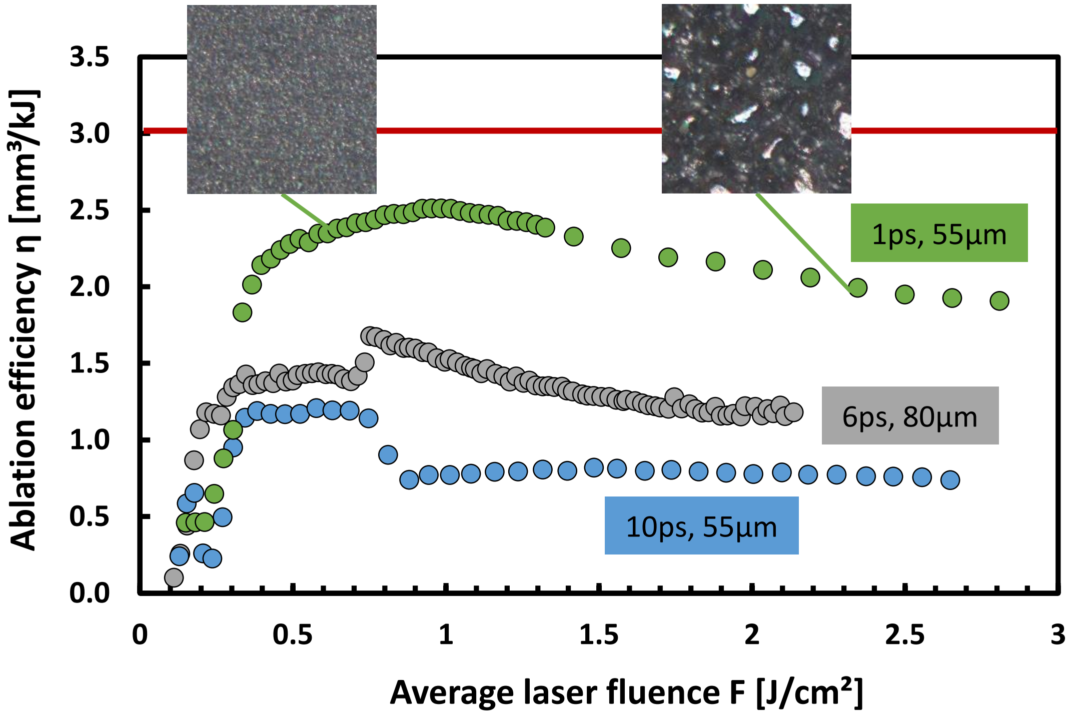
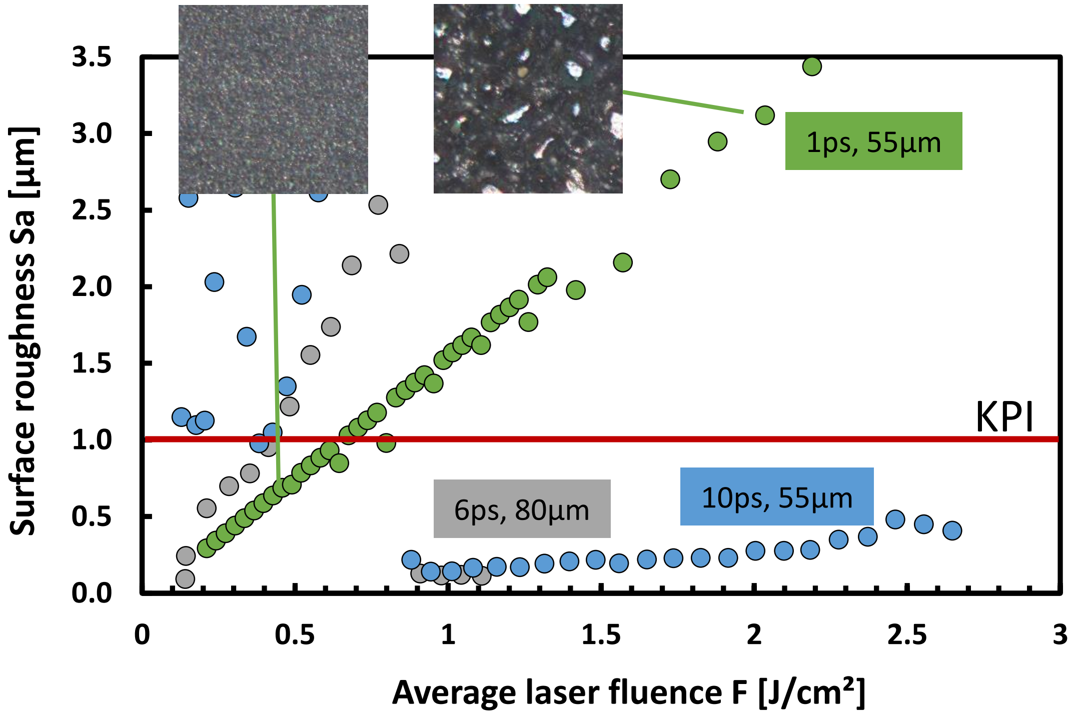
| WP2 | Experimental work at BOSCH: Fundamental studies |
|---|---|

**Experimental series C: Trumpf TruMicro 5050 Femto Edition, $\tau_p$ = 1 ps, $\lambda$ = 1030 nm, $d_0$ ≈ 55 µm**

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| WP2 | Experiments conducted by BOSCH at USTUTT |
|---|---|

**High-volume ablation on amplified TruMicro5000 @ USTUTT**

- Objective: Assess process scalability to high laser power
- Amplified high-power laser system (670 W)
- Short total experimental times (max: 30 s)
- High max. scan speed (16 m/s)
- No wafer cooling applied
- High energy input causes wafer cracking above threshold values of:
  - max. specific line energy: 170 J/m at 4 m/s scan speed
  - max. energy input on 10x10 mm² square: approx. 3.5 kJ
- **Achieved average ablation rate: 0.29 mm³/s (including down times)**

| Parameters (source: USTUTT) | | |
|---|---|---|
| wavelength | $\lambda$ | 1030 nm |
| pulse duration | $\tau_p$ | 6 ps |
| repetition rate | $f_{rep}$ | 300 kHz |
| maximum power | $P_{max}$ | 670 W |
| focus radius (x) | $d_{fx}$ | 140 µm |
| focus radius (y) | $d_{fy}$ | 420 µm |
| focal length | F | 340 mm |
| beam quality factor | $M^2$ | 3 |
| Si wafer diameter | D | 200 mm |
| Si wafer thickness | h | 1.35 mm |
| optics | Intelliscan20 | |

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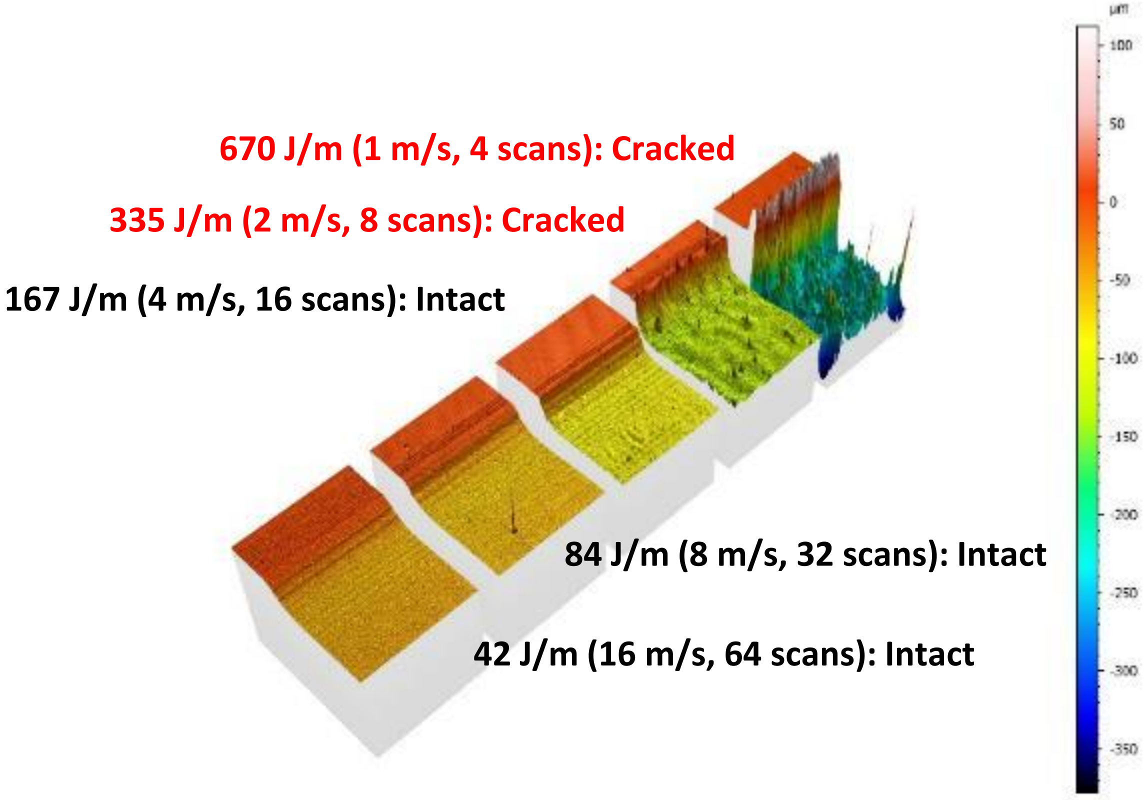
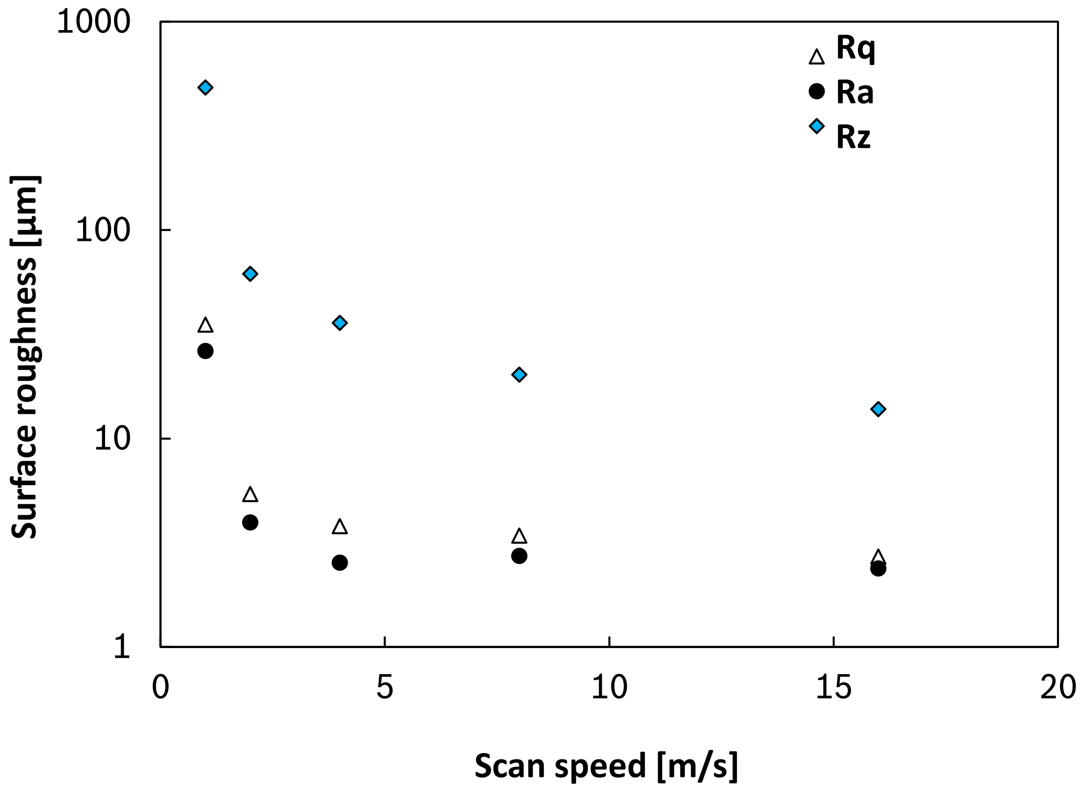
| WP2 | Experiments conducted by BOSCH at USTUTT |
|---|---|

**Result: Surface quality depends on specific line energy (J/m)**

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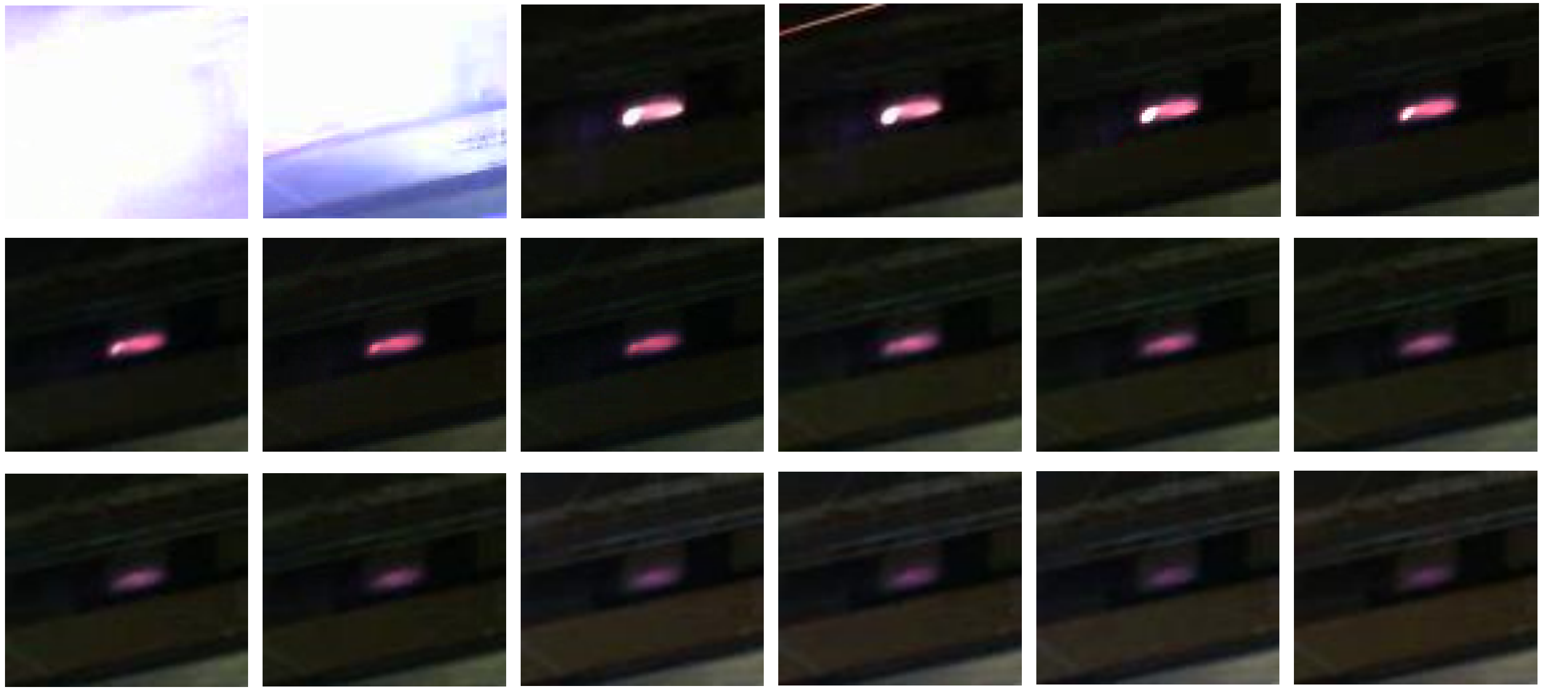
| WP2 | Experiments conducted by BOSCH at USTUTT |
|---|---|

Camera pictures (Δt = 40 ms) → ablated surface continues to glow subsequently to processing



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| | Conclusion & Outlook |
|---|---|

**Summary**
- Laser ablation: potential, but challenging process for 3D Si structuring
- 8 KPI's to determine process maturity
- Demonstrator geometry allows to track progress of KPI's
- Laser fluence: significant process parameter:
  - Ablation efficiency optimum between 0.5 and 1.0 J/cm²
  - Surface quality deteriorates above efficiency optimum
  - But: above threshold fluence, surface quality improves substantially
- Major challenge: Upscaling of process to reach productivity KPI (average ablation rate of 1 mm³/s)
- High-power laser experiments (BOSCH at USTUTT): heat accumulation results in wafer cracking

**Focus on short- and medium term R&D work @ Bosch:**
- Continue fundamental research on KPI enhancement
  → Include burst mode, fs ablation, investigate high-fluence ablation
- Specify system requirements based on experimental experience
- Design of experiments for process upscaling

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# Class 4 Laser Professionals AG

CLASS 4 LASER
See the light

Noémie Dury

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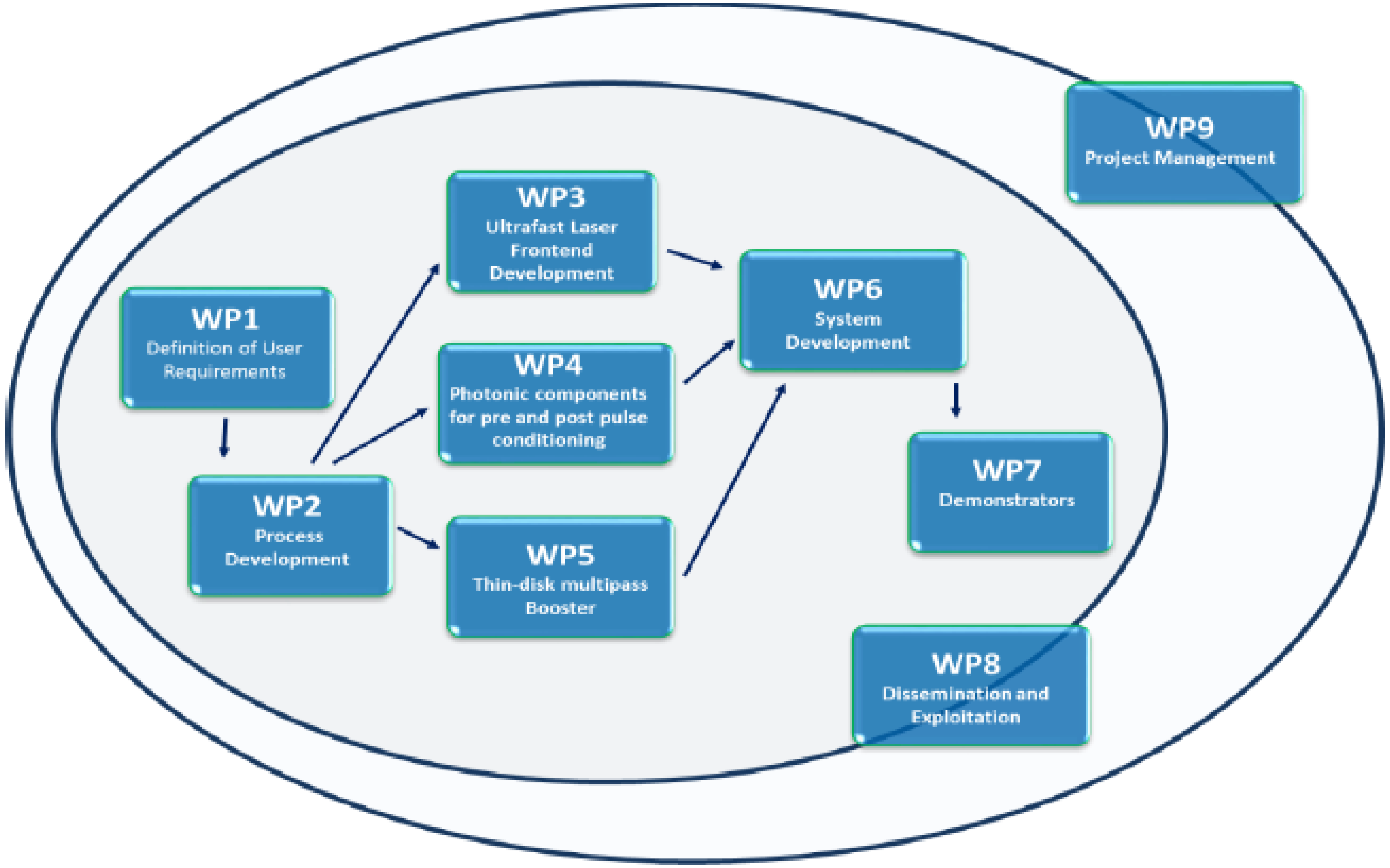
## Work Packages

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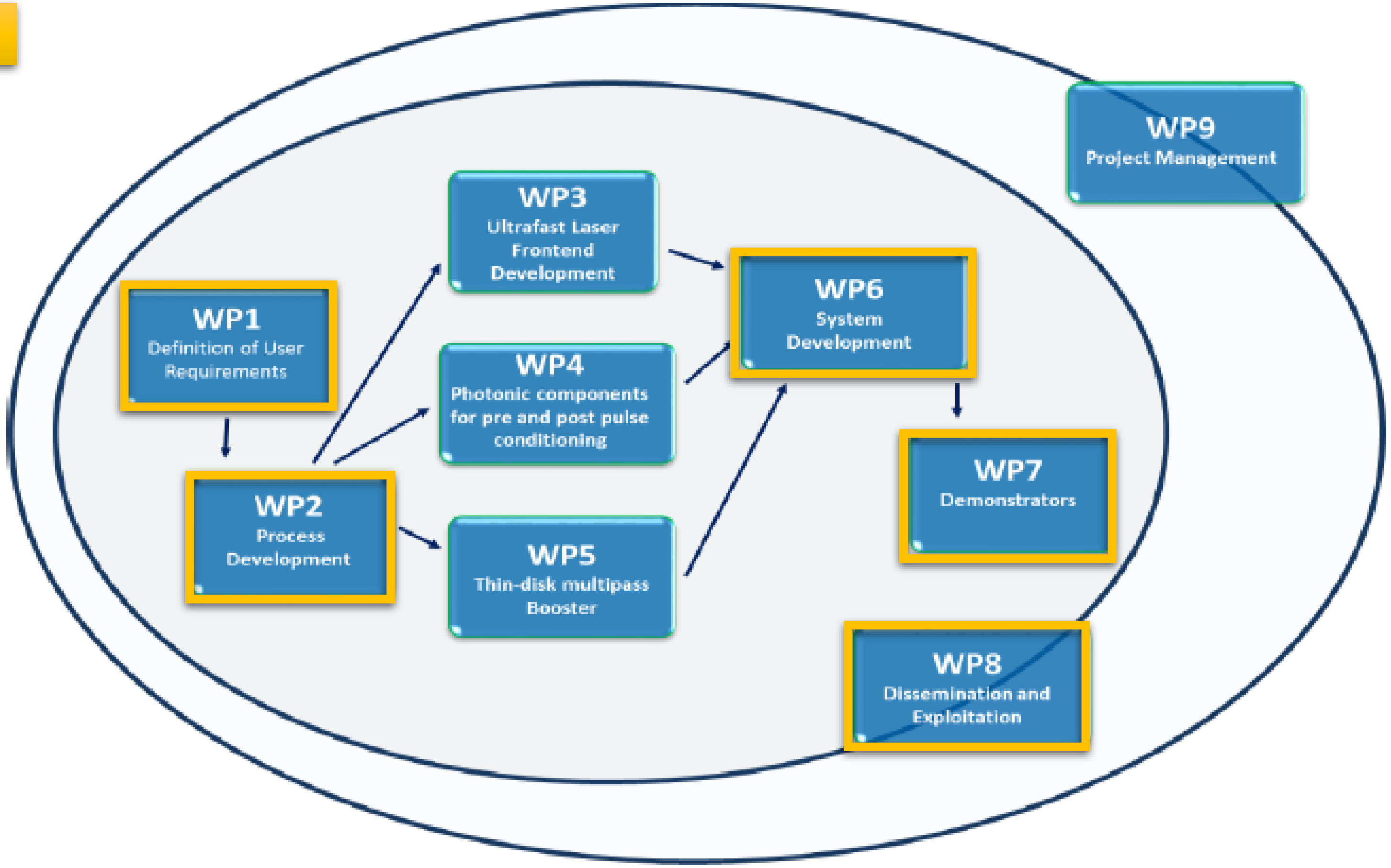
Class 4 Laser's Work Packages

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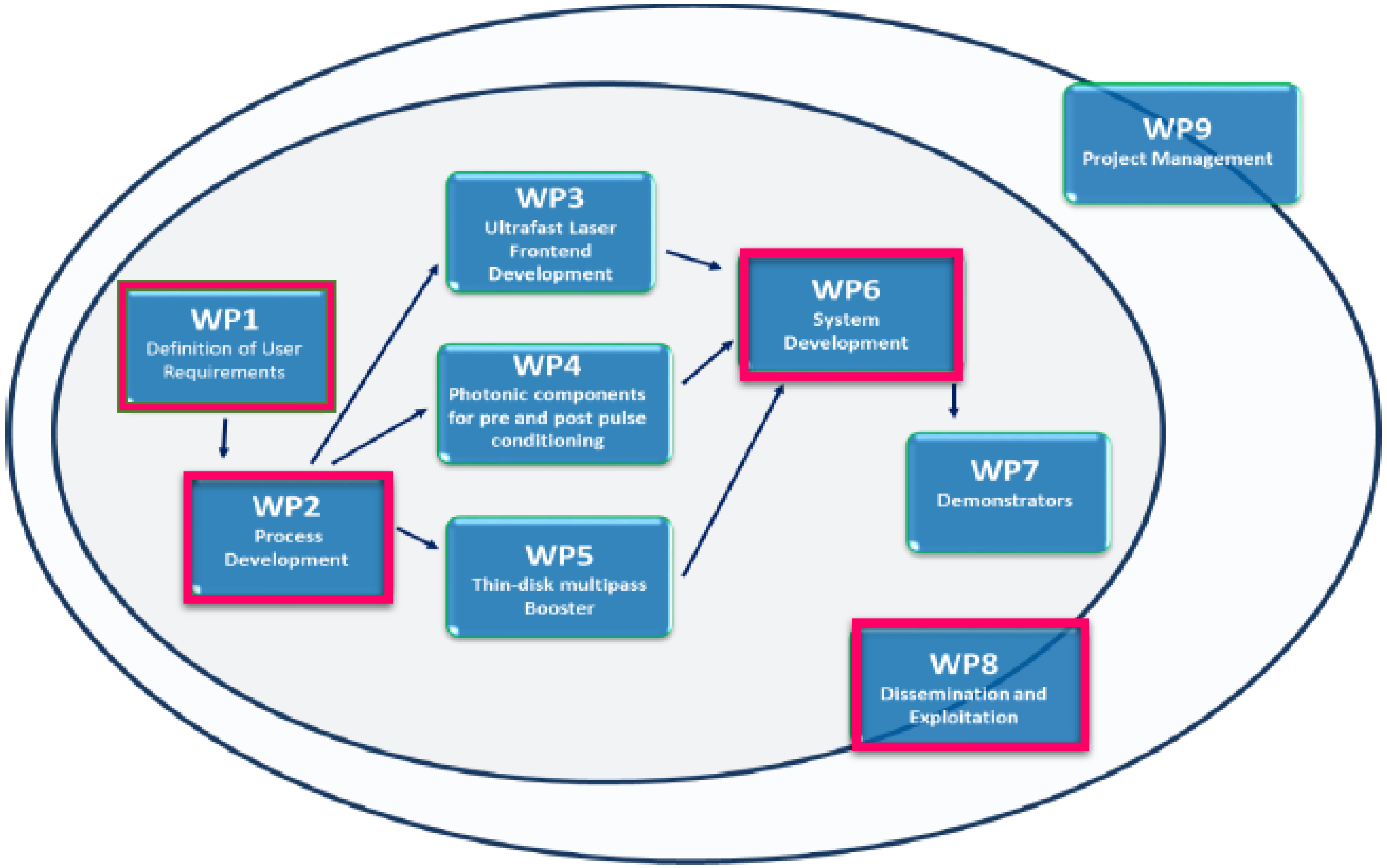
Work Packages presented today

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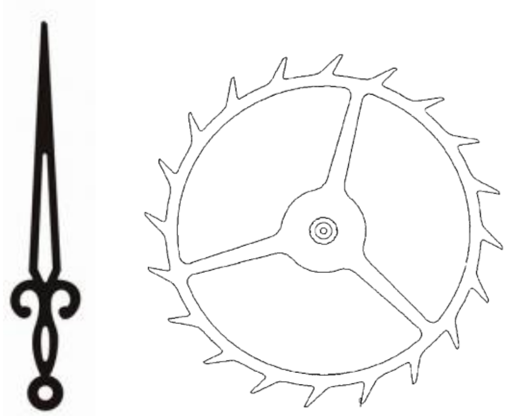
# HIPERDIAS Consortium Meeting - Stuttgart - 13/09/2016

| WP1 | Definition of user requirements |
|---|---|

Benchmarking shape
Standardized watch arm
Standardized Gear



| Key Performance Indicator | Unit | Target Value |
|---|---|---|
| Parts thickness | mm | 0.1 – 0.5 |
| Material covered | Metal, ceramic, sapphire | |
| General dimensions tolerances | µm | From ± 5 to ± 20 |
| Specific dimensions tolerances | µm | From ± 2 to +-5 |
| Smallest holes | µm | From 50 to 100 |
| Maximal side steepness (taper) | Relative to dimension tolerances | |
| Average cutting speed (relative to shape and thickness) | mm/min | ≥ 300 |
| Shape deviation | µm | +- 2 |
| Surface roughness (non-functional) | µm | 0.4 (N5) |
| Surface roughness (functional) | µm | 0.1 (N3) |

Informal partnership with a big watch making company for validation of the parts

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| WP1 | Definition of user requirements |
|---|---|

| | | | |
|---|---|---|---|
| **WP1 - M01-M12 (January 17) - Definition of User Requirements**<br>**C4L - 2.5 MM = 446.25 H** | | | |
| **Definition of application requirements**<br>**Process development pre tests** | | | |
| Task 1.1 : M01- M04 (May 16)<br>Collection of application specifications | Task 1.2 : M02 - M12 (January 17)<br>Process and system specifications | Task 1.3: M04 - M12 (January 17)<br>Assessment and validation of technical progress | Task 1.4: M01 - M12 (January 17)<br>Interface requirements |
| Installation of the laser needed for the trials at C4L<br>Assistance of E6 for the first trials to define the laser specs | Started in March : cutting and ablation trials for benchmarking for diamond ablation and cutting of watch parts .<br>Calculation of the forseen needed laser parameters | C4L & E6 Define necessary characterization and measurement methods. Define benchmark processes; define key performance indicators (KPI) for quantitative progress assessment.<br><br>September 16 | C4L sends AMP the dimensions and already known spec of the machine --> **KW8** |
| E6 make a document to summerize their need for diamond polishing | C4L & E6 - first ablation trials to determine the ablation threashold / required / pulse duration / laser parameters for th diamond ablation | | What do the customer need. Will feed the WP6 T6.1 - E6 |
| C4L make a document to summerize their need for cutting of watch parts. | the cutting trials for the watch componants will be started when the system to combine axes with rotating optic is available at C4L : planned october/ November 2016 | | fill in the table from Lasea |
| **Delivrable sent CW26** | C4L & E6 prepare a common document with enduser requirement and system manufacturer requirement this document is then sent to AMP with cc USTUTT and BOSCH. | | |
| | fill in the table from Lasea | | |
| | | | |

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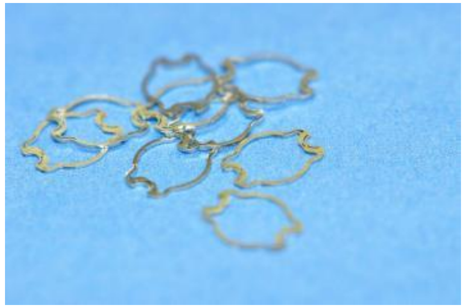
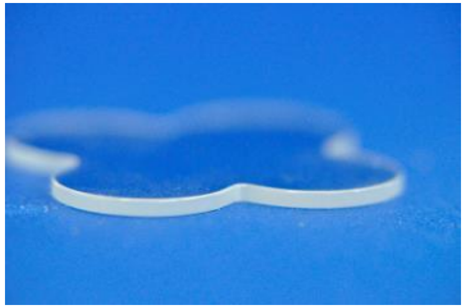
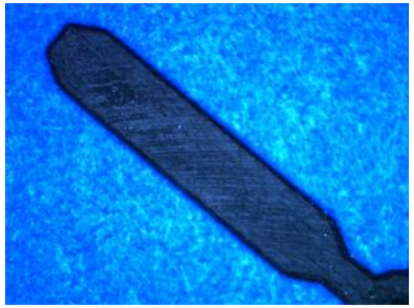
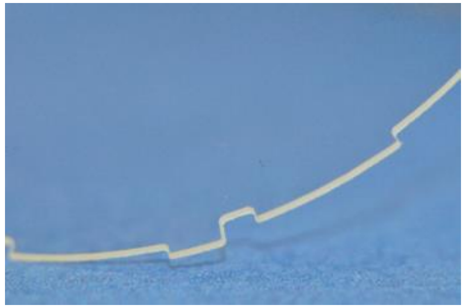
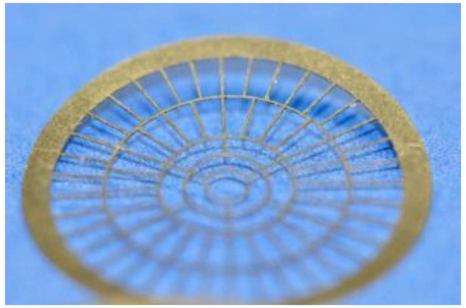
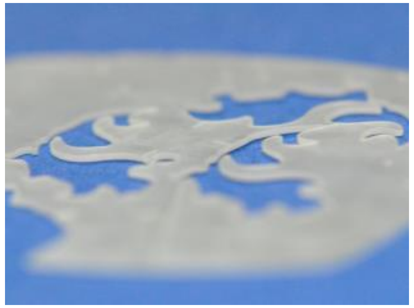
| WP2 | Process Development |
|---|---|

*Work completed*

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| WP2 | Process Development |
|---|---|

| | | |
|---|---|---|
| **WP2 - M04 (May 16) - M30 (July 18) - Process Development<br>C4L - 13 MM = 2320.5 H** | | |
| **Process developement for watch parts cutting and diamond polishing** | | |
| Task 2.2 : M04-M24 (January 18)<br>Fundamental process development fine cutting of metals **(LEAD)** | Task 2.3 : M04 - M24 (January 18)<br>Fundamental process development diamond ablation | Task 2.4: M22 (November 17) - M30 (July 18)<br>Upscaling of applications for high throughput |
| Start in March : cutting trials for benchmarking. Calculation of the forseen needed laser parameters | Start in March : ablation trials for benchmarking. Calculation of the forseen needed laser parameters | |
| the cutting trials for the watch componants will be started when the system to combine axes with rotating optic is available at C4L : planned october 2016 | C4L & E6 - first ablation trials to determine the ablation threashold / required / pulse duration / laser paameters for th diamond ablation | |
| | | |

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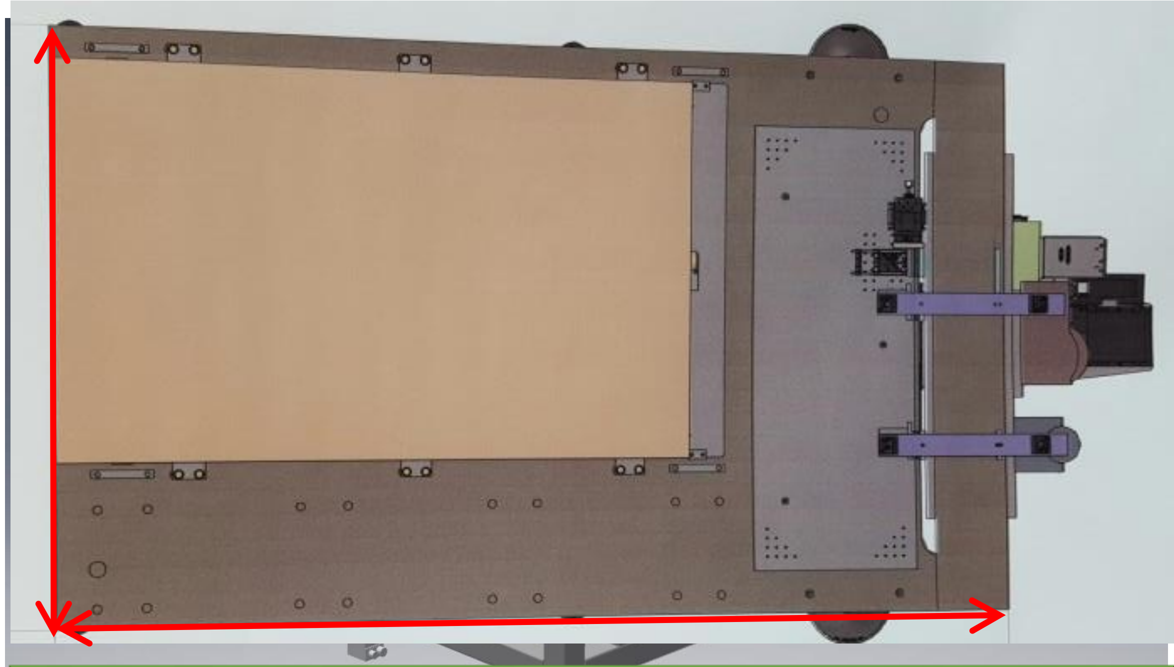
| WP6 | System development |
| --- | --- |

*Work completed*

**Dimensions of the table: 2200 x 1500 mm**

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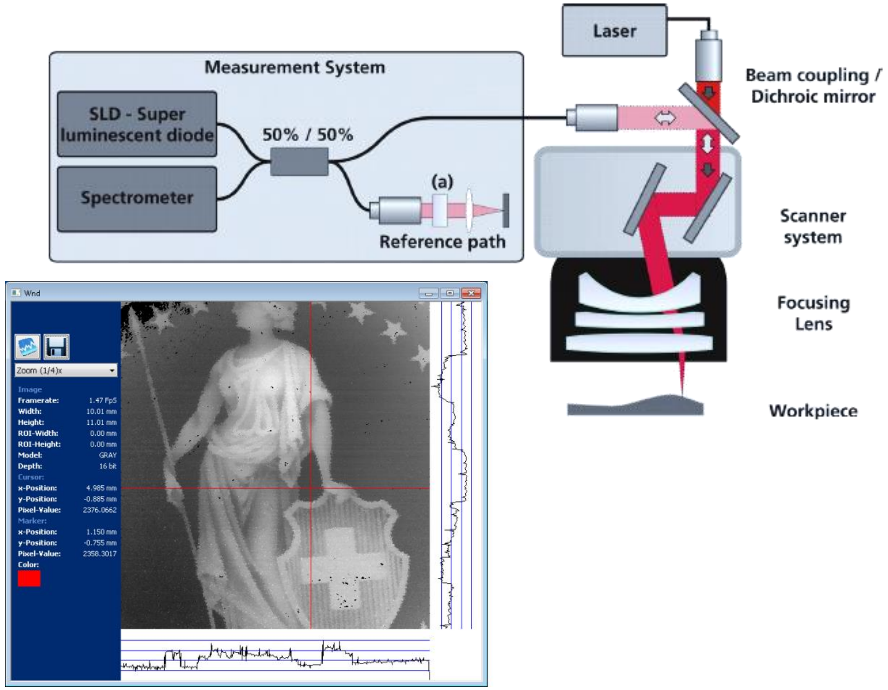
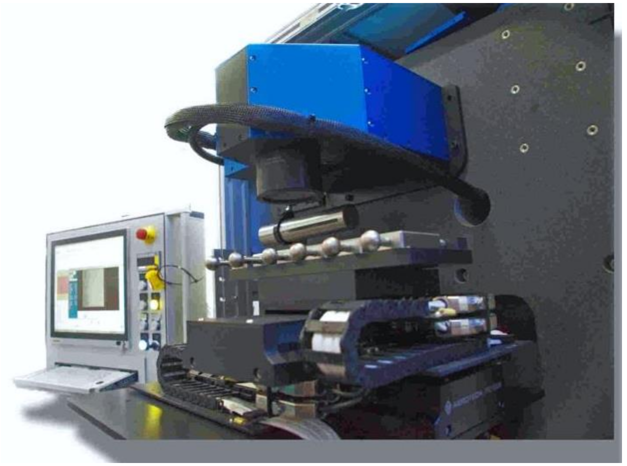
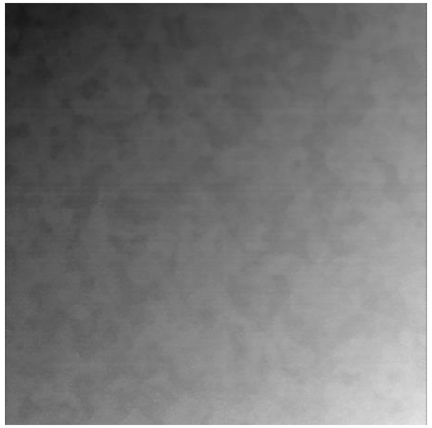
| WP6 | System development : Scanning system |
|---|---|

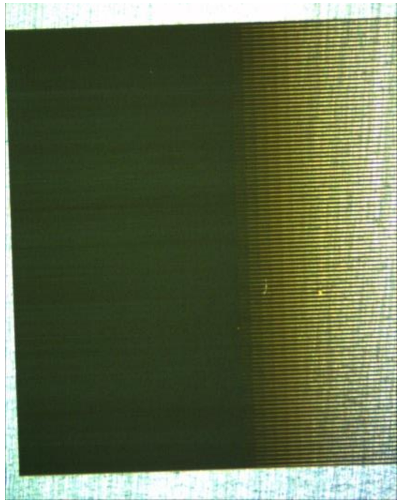
- Development of topography sensor to overcome flatness issue and surface defects
- Topography sensor scans surface and creates a BITMAP image as below





*BITMAP image of feature to ablate*



*Microscope picture of ablated surface*

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| WP6 | System development |
|---|---|

*Next 6 months*

# WP6 - M03-M42 - System development (LEAD)
# C4L - 28.5 MM = 5087.25 H

**Development of the system for Watch parts cutting and diamond polishing**

| | | |
|---|---|---|
| Task 6.4: M08 - M36 (January 19) System layout and build-up **(LEAD)** | Task 6.2 : M03 - M15 (April 17) Definition of laser & optics sizes, optics specifications (incl. fibre)<br>Task 6.5: M08 - M24 (January 18) Integration of laser and optics **(LEAD)** | Task 6.3: M08 - M22 (November 17) Development of the interfaces **(LEAD)**<br>Task 6.6: M12 - M42 (July 19) Test and evaluation |
| 5 axes system design for 3 optical stations and 2 different lasers | optimisation of the OCT vision and scanning divice for diamond polishing | |
| System build up | | |

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| WP8 | Dissemination & Exploitation (partner activities) |
| --- | --- |

One talk during the
EPMT / EPHJ / SMT fair in Geneva,
presenting Hiperdias


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