Deliverable 6.4: Integration of laser & optics
Deliverable 6.5: System build-up

Dissemination Level: Public

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Context

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Work Package: WP 6

Task: Task 6.4: System layout and build-up
Task 6.5: Integration of laser and optics

Document Status

Version: 1.00

Last modified: 01/10/2019

Status: Released

Approved by: Marwan Abdou Ahmed

Date Approved: 10/10/2019

Declaration: Any work or result described therein is genuinely a result of the HIPERDIAS project. Any other source will be properly referenced where and when relevant

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1 Scope

The objective of this report is to complete the activities of task 6.4: System layout and build-up, and task 6.5: Integration of laser and optics, combining deliverables 6.4 and 6.5 into a joint deliverable to validate the completion of these tasks. The activities of task 6.4 and 6.5 are focused on system building including integration of optics. Thus, the objective of this joint deliverable is to document the 2 systems which will become the demonstrator platforms built at USTUTT by LASEA based on the 500W fs laser (eventually upgraded to 1 kW) and at C4L built by C4L based on the 200 W fs laser.

2 Introduction

This report is structured such that the documentation of each of the systems is treated separately, first the documentation of the 200 W system developed by C4L at C4L is treated, then 500 W system developed by LASEA at USTUTT.

3 Systems

3.1 200 W System

The 200 W demonstrator system has been developed by Class 4 Laser in accordance with the end user requirements for the fine cutting of metals (C4L) and the processing of diamond (E6). The system capabilities and specifications as of January 2019 are documented in this report.

3.1.1 X-Y-Z Axes

The dynamic 3 axis system has been developed by C4L with Aerotech specifically for HIPERDIAS. The system incorporates 2 direct, linear motors (X, Y) and a ballscrew motor (Z) in an X-Z-Y configuration (Figure 1). The performance specifications of the axes are detailed below.

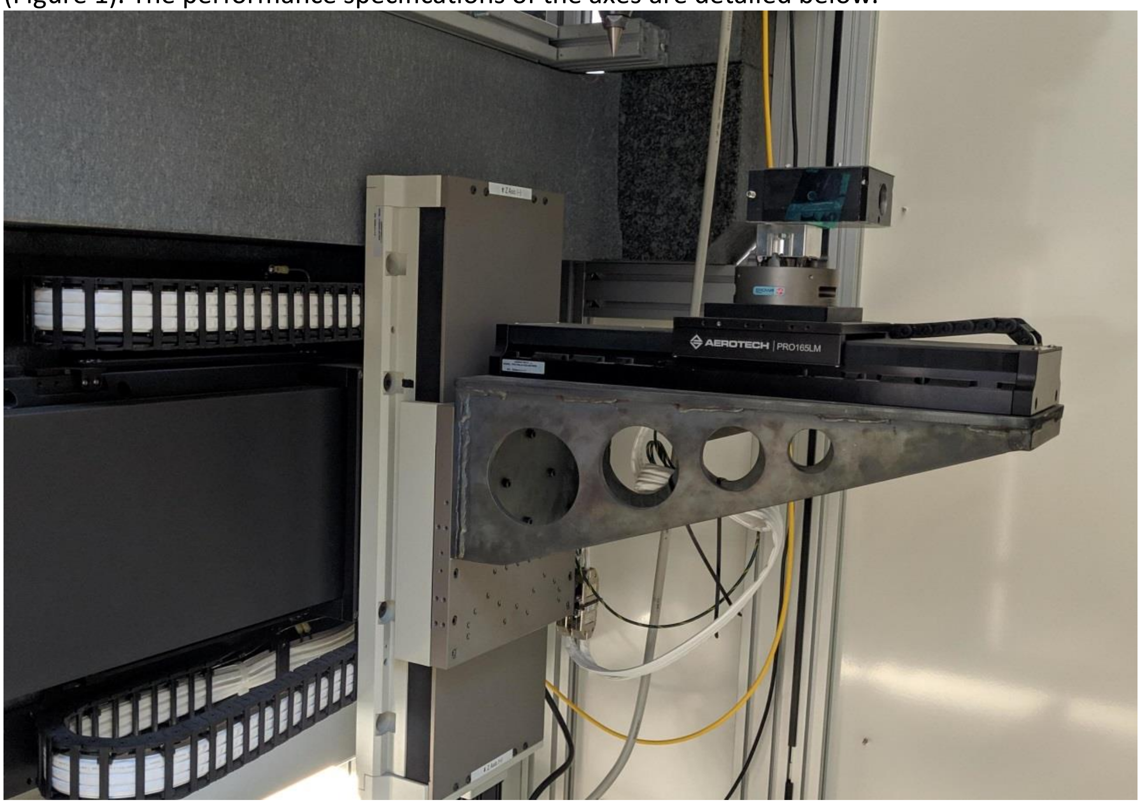

Figure 1: Three axis system implemented on the 200 W system in an X-Z-Y configuration

Y axis:

Max speed [mm/s]	200
Max acceleration [mm/s^2]	2000
Load (test) [kg]	14
Resolution [µm]	0.01

X axis:

Max speed [mm/s]	200

Max acceleration [mm/s^2]	2000
Load (test) [kg]	39
Resolution [µm]	0.01

Z axis:

Max speed [mm/s]	100
Max acceleration [mm/s^2]	1000
Load (test) [kg]	39
Resolution [µm]	0.4

3.1.2 Galvo-scanner

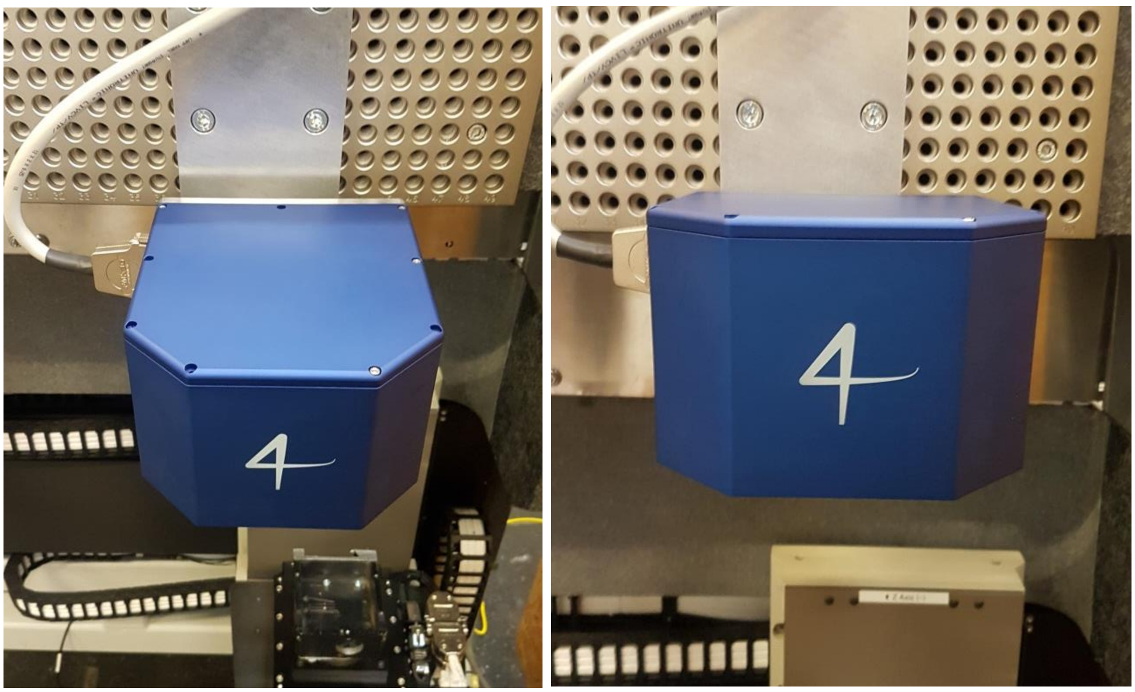

Figure 2: IntelliScan14 unit mounted in C4L housing

The galvo scanner unit; IntelliScan14, Scanlab (De) has been integrated into a custom C4L mounting head (Figure 2). The IntelliScan14 has a 14 mm aperture, which is suitable for the system (3 mm laser output beam diameter, 1-4x beam expansion). The Intelliscan14, used with a 160 mm f-theta objective, has the following specified performance:

Marking speed [m/s]	2.0
Positioning speed [m/s]	5.0
Tracking error [ms]	0.15
Repeatability [µrad]	<0.4
Positioning resolution [bit]	20
Scan angle [rad]	+/- 0.35

3.1.3 Dynamic focal position adjustment

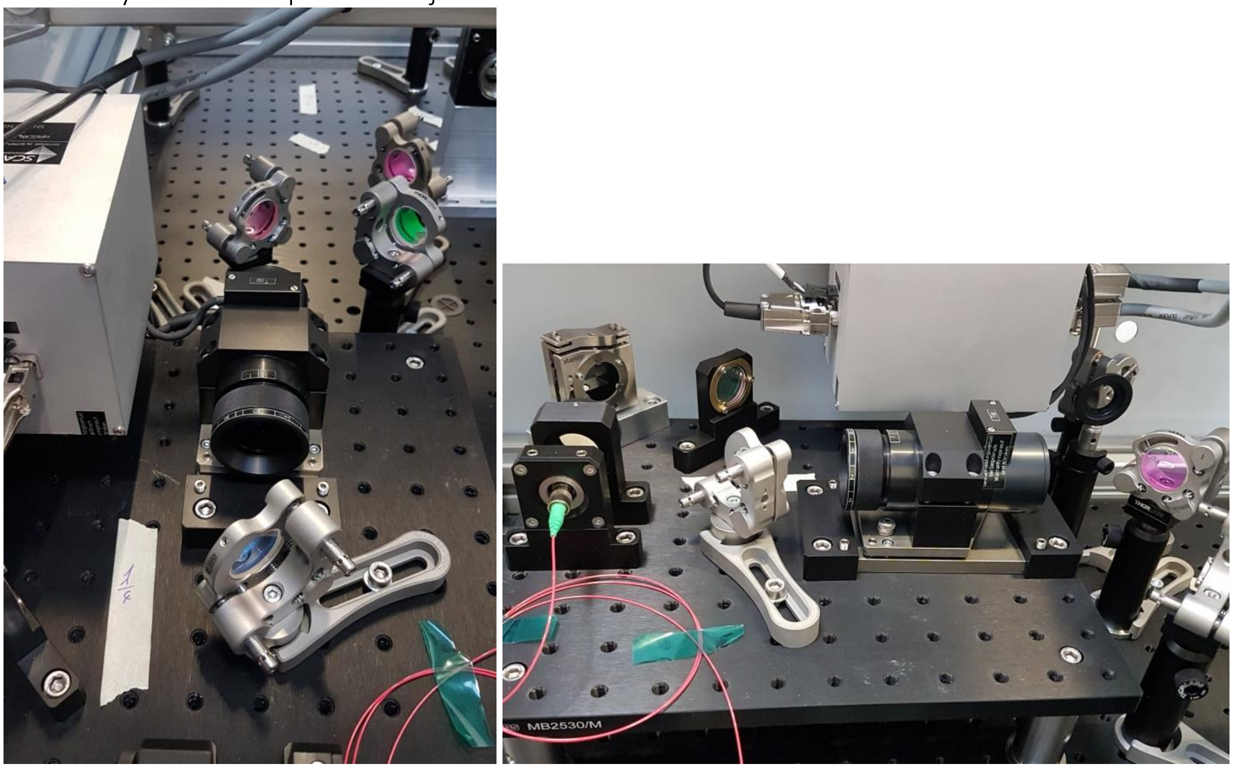

Figure 3: VarioScan$_{de}$ 20i Unit with controller and power supply, mounted in the demonstrator system

Dynamic focal position adjustment is achieved by implementation of a dynamic lens system (focal shift in Z), VarioScan$_{de}$ 20i, Scanlab (De) (Figure 3). The system includes an inherent 2.8 x beam expansion factor which must be considered and compensated where appropriate with a zoom lens or beam expander. The VarioScan$_{de}$ 20i unit has the followed performance specifications when used with a 160 mm f-theta objective:

Input aperture [mm]	8
Output aperture [mm]	20
Focus range (in z) [mm]	+/- 32
Motor repeatability [µm]	<0.5

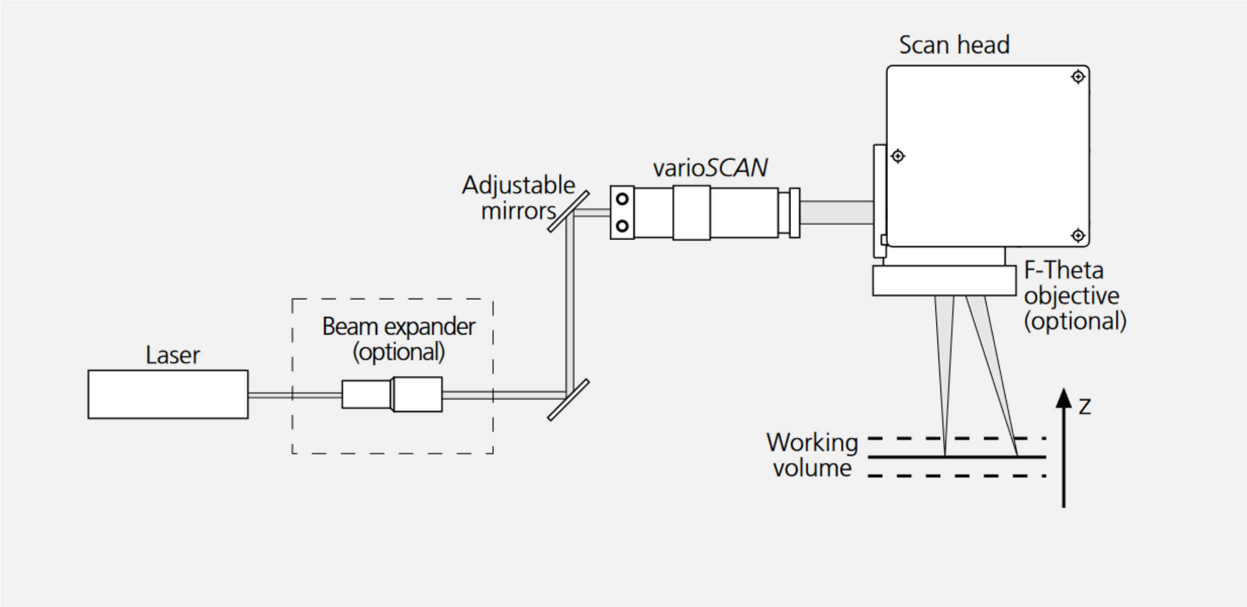

Figure 4: Schematic of dynamic focal adjustment principle

3.1.4 Objective Lens

Two f-theta objectives 32 mm and 167mm (Figure 54) have been mounted and integrated to be used with the galvo-scanner / dynamic focal adjustment system. Both lenses are specified to perform with high average power (200 W), high pulse energy (400 µJ), >200 fs pulsed laser radiation and for a wavelength range of 1000 - 1050 nm. The 32 mm lens has been designed specifically by the lens manufacturer for the 400 fs 200 W 1030 nm pulses from the Tangor system and was taken as a development project by the manufacturer.

Each of the objectives has the following performance specifications when used in conjunction with the IntelliScan 14 galvo scanner system:

Silll S4LFT7731/450 f-theta objective:

Focal length [mm]	32
Material	fused silica
Scan field [mm]	2.3 x 2.3
Focal spot diameter [µm]	7.6 – 30 µm

Figure 5: Qioptiq 167 mm lens with mounting adjustment and corresponding correction file mounted on C4L galvo-housing

Qioptiq 4401- 513-000-21:

Focal length [mm]	167
Material	Quartz crystal
Scan field [mm]	83 x 83
Focal spot diameter [µm]	40 – 160 µm

3.1.5 Camera

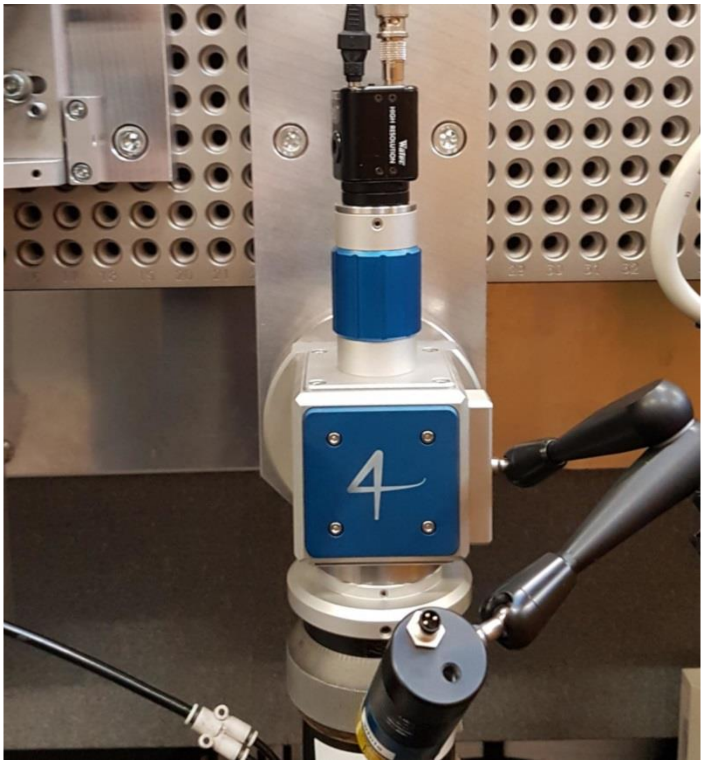

Figure 6: Watec WAT-902B CCD camera mounted on C4L gas assisted cutting head with corresponding light source and adaptable focal lens

A Watec WAT-902B (Watec, JPN) camera is installed on the cutting head working station of the system (Figure 6), the function is primarily for alignment and processing monitoring. The installation set up includes a white light source for work piece illumination, an adjustable objective lens for image focusing and an IR filter to protect the image capture device from laser back reflections from the work piece. The camera set up has the following specifications:

Image capture technology	CCD
Pixels [#]	795 x 595
Pixel size [µm]	8.6 x 8.3
Video output	Analog (composite video)

3.1.6 External manual control unit

The X-Y-Z axis is configured such that the system controller is configurable via a GUI on the system computer. Additionally, the controller of the X-Y-Z axis system can be accessed via a hand - wheel controller (Euchner HBA-100212, EUCHNER, DE) which has up to 5 axis support, speed configuration and an emergency stop button.

3.1.7 Fume extraction system

Figure 7: TBH fume extraction system connected to sample fixation unit

The fume extraction system (TBH FP 150- TBH, DE) (Figure 7) equipped with a polyester high efficiency particulate air (HEPA) filter (H13) removing particles of 0.3 µm with >99.95 % efficiency. The HEPA filter additionally includes activated carbon and BAC granules for physical and chemical absorption of potentially harmful gaseous substances. The filter is cleanable in-situ with compressed air (2 bar).

3.1.8 Sample fixture

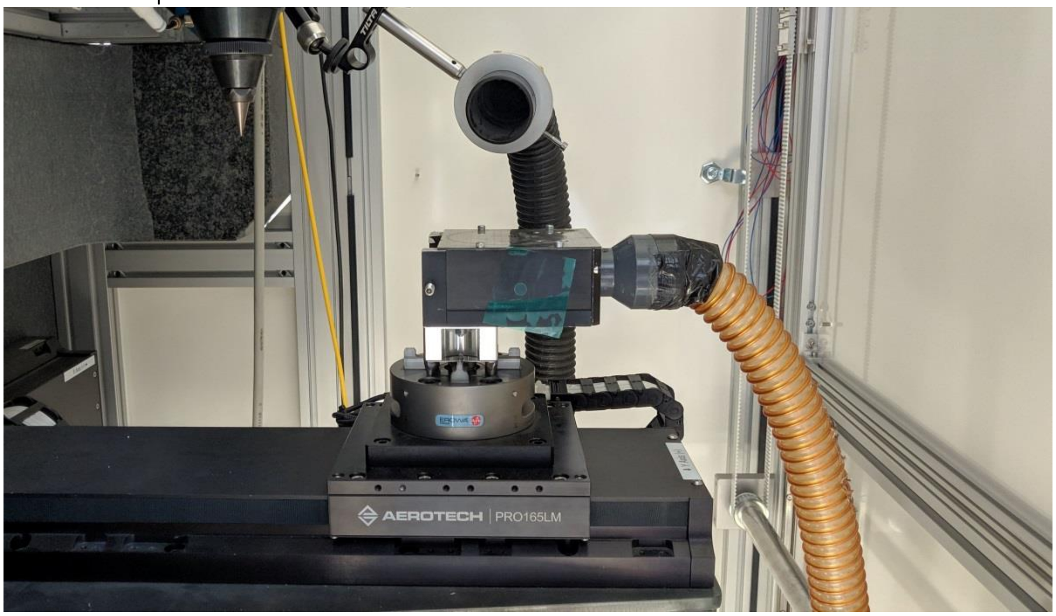

Figure 8: Sample fixation block mounted on QuickChuck system with fume extraction system attached

The work piece fixation block is mounted on a modular clamping system (QuickChuck 100 P, Erowa, CH) (Figure 8) which allows for clamped work piece placement with a repeatability < 4 µm. The work piece block has been manufactured in house at C4L. The mounting block allows for dual action sample fixation and extraction using the vacuum fume extraction system.

3.1.9 Gas assisted cutting

Figure 9: C4L gas assisted cutting head mounted with assist gas connected

The gas assisted cutting head (Figure 9) is an in house C4L designed module capable of processing with up to 20 bar of assist gas (nitrogen, argon, compressed air). The cutting head includes a 100 mm fused silica lens which is capable of focusing the beam to 22 µm spot size (2 w_0).

3.1.10 Rotating optic

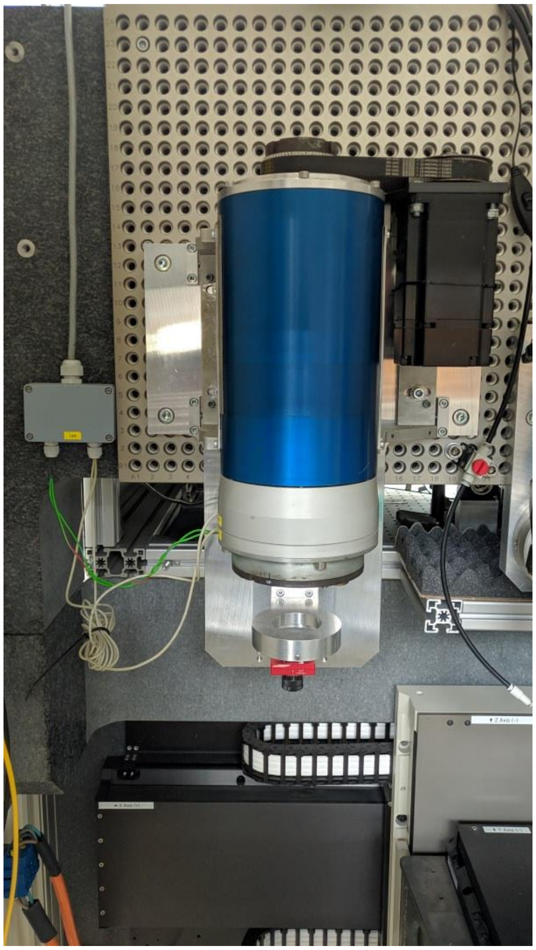

Figure 10: Rotating trepanning optic installed on the demonstrator system

The rotating trepanning optic (Figure 10) which has been developed at the IFSW, creates a rotating beam via two rotating wedge-shaped prisms, the system- which is used in conjunction with a focusing lens is capable of rotation speeds up to 3000 rpm.

3.1.11 Optical path

The optical path has been built in accordance with the end-user requirements and with the specifications of the 200 W Tangor system from Amplitude in mind.

The mirrors (⌀ 25 mm) have been coated with a magnetron sputtered dielectric guaranteed by manufacturer to be suitable for high power >200 fs pulses and for a wavelength range of 970-1090 nm, the reflectivity is specified to be > 99.9% reflection at 1030 nm (reflection spectrum, Figure 11).

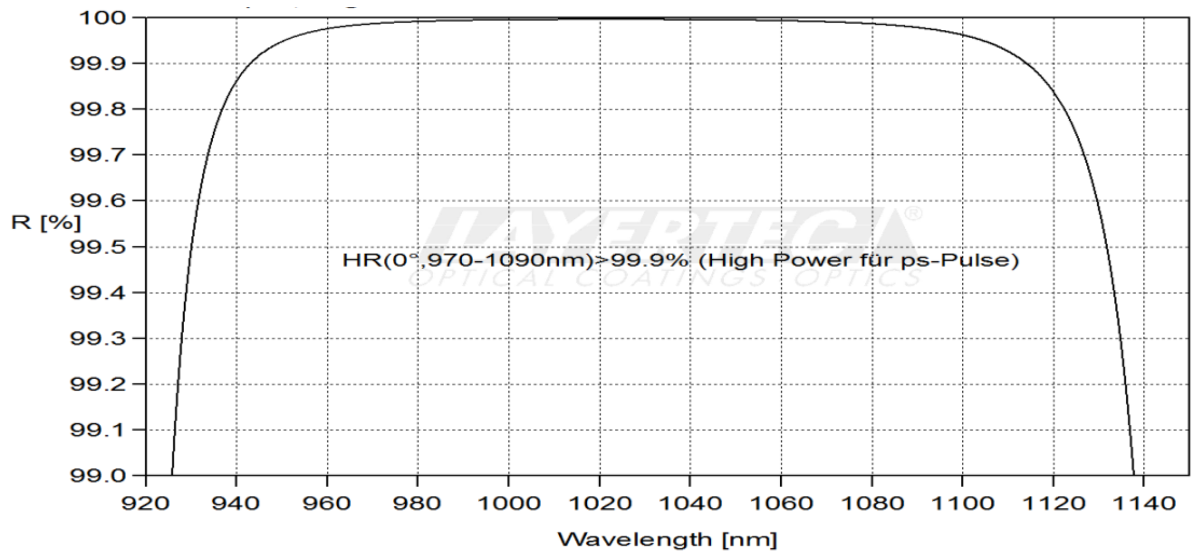

Figure 11: Reflection spectrum of Layertec mirror coating # 100717

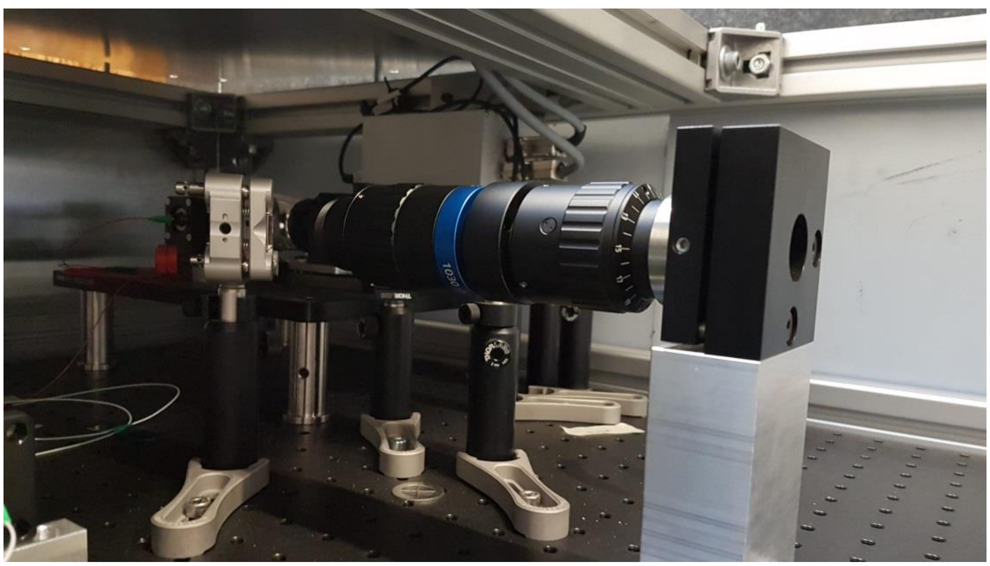

Figure 12: BEX steadfast 1-4x beam expander mounted in C4L adjustable mount

A 1-4x beam expander (BEX Steadfast, Jenoptik, DE) (Figure 12) has been implemented in the system. The beam expander used fused silica lenses with a pulsed LIDT of 1 J/cm^2 and a beam pointing stability of <= 1 mrad.

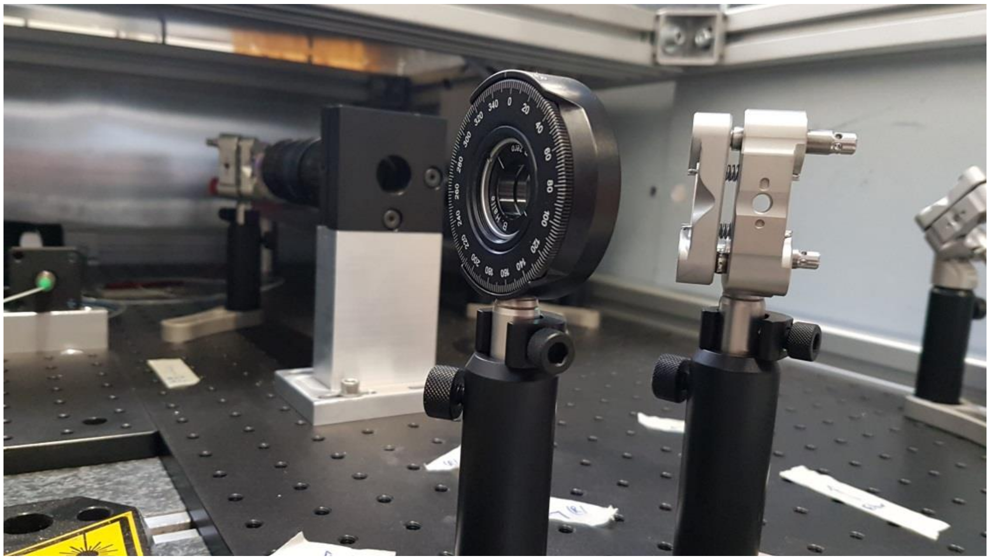

Figure 13: Ring mounted zero order λ/4 wave plate

A ring mounted zero-order λ/4 wave plate (Figure 13) suitable for high implementation with the 200 W fs Tangor system has been implemented in order to process with circularly polarized beam at the workpiece.

3.1.12 Laser

Figure 14: Tangor system installed on the demonstrator

The laser which is installed on the system is not the 200 W Tangor, as originally planned. A replacement Tangor laser system from Amplitude with a nominal power of 100 W has been installed (Figure 14).

The calibration curve of the replacement laser is shown in Figure 15: Calibration curve of the replacement laser.

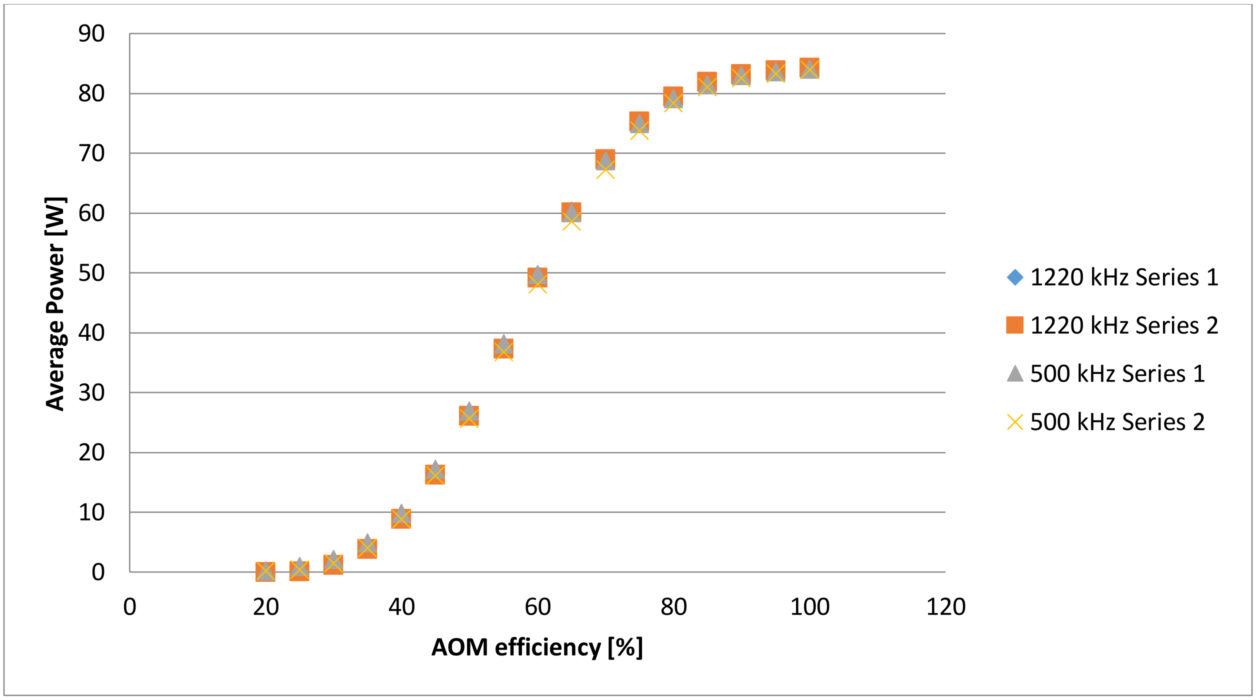

Figure 15: Calibration curve of the replacement laser

3.2 500 W (1 kW) System

3.2.1 System housing

LASEA and USTUTT installed the processing station LASEA LS5-1 for the 3D-Si ablation upscaling experiments described in Task 2.4. Several adaptions had to be conducted by USTUTT to be able to combine the LS5-1 with the thin-disk multi-pass amplifier laser system. The main difference of the setup at USTUTT compared to usual laser processing stations was the spatial separation of the laser system and the processing station. The laser system was installed in a restricted access laboratory which was build up specifically for this system. The processing station was built up in the adjacent hall, close to the laboratory of the laser system. The connection of laser system and processing station was achieved using an aluminum tube, in which the laser beam could propagate from laser station to the processing station (Figure 16).

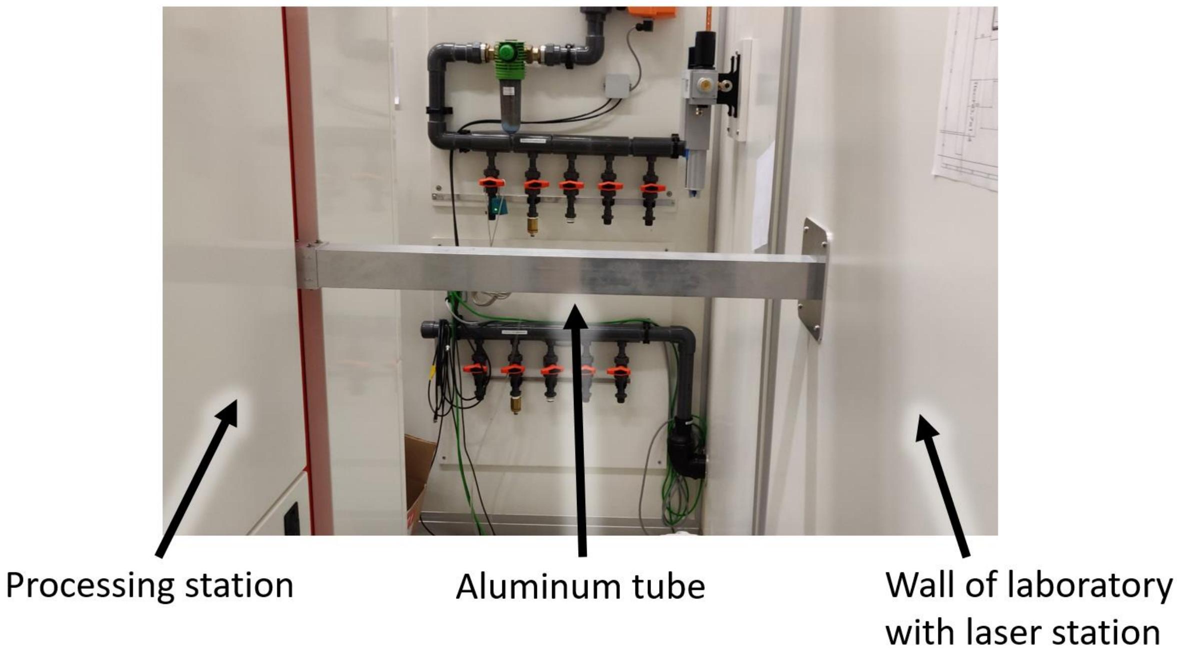

Figure 16: Connection between laser station and processing station via aluminum tube.

3.2.2 Beam Path

As the laser system has to run constantly at full power to be thermally stable, it has to be guaranteed that no light propagates to the processing station while the door of the processing station is opened e.g. to change the samples. For the processing only the 1st order of the laser beam is used, the 0th order is guided to a beam dump within the laser system (compare setup D5.3 Fig. 1). The AOM of the seed laser determines the amount of laser power coming to the processing station which can be adjusted using the PC. However, the correct settings in the AOM alone are not enough to guarantee laser safety, e.g. if the last TFP in the amplifier gets damaged and therefore suddenly transmits all of the power to the processing station. Therefore, an additional two-stage shutter system was developed and installed at USTUTT. The first shutter is the so called high-power shutter, a high-reflective mirror that can be retracted in and out of the beam path of the 1st order (Figure 17).

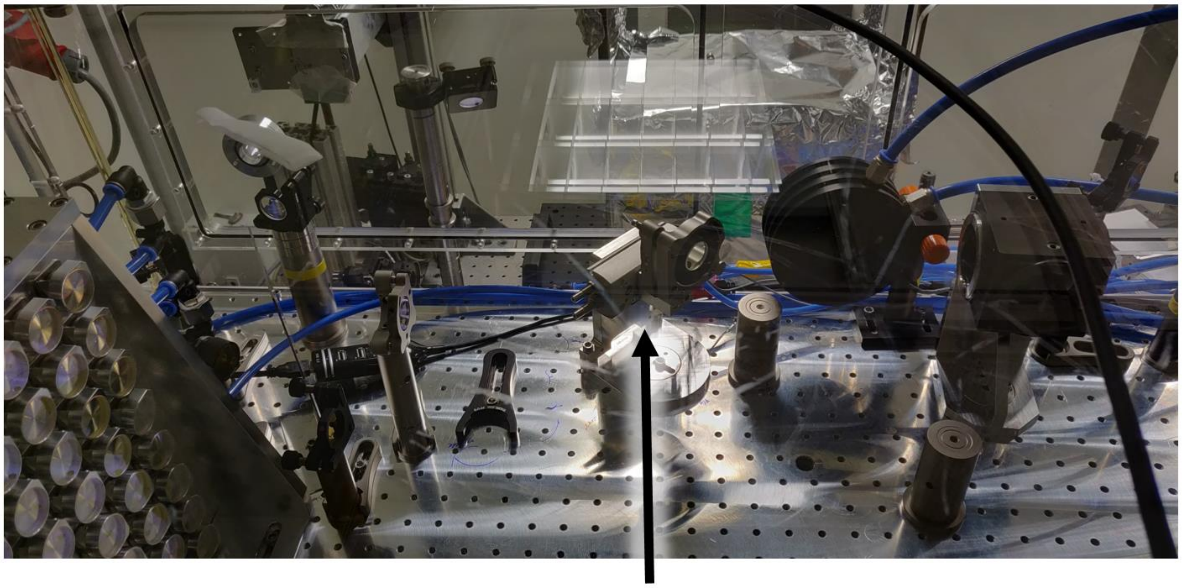

Figure 17: High-power shutter in the amplifier laser system.

When the mirror is in the beam path, it reflects the light in the 1st order to a beam dump within the amplifier. When the mirror is retracted out of the beam path, the light in the 1st order can propagate through the output coupler window to the aluminum tube. The second shutter is the so called low-power shutter, a retractable aluminum plate that closes the aluminum tube when in the beam path to avoid stray light in the processing station (Figure 18). This shutter cannot handle the high power but is equipped with a meander of an electrical circuit. If the electrical circuit is disturbed, e.g. due to laser radiation, the whole laser system will be shut off. This improves the laser safety in the case that the high-power shutter fails to reflect the light to the beam dump, e.g. due to a damaged surface.

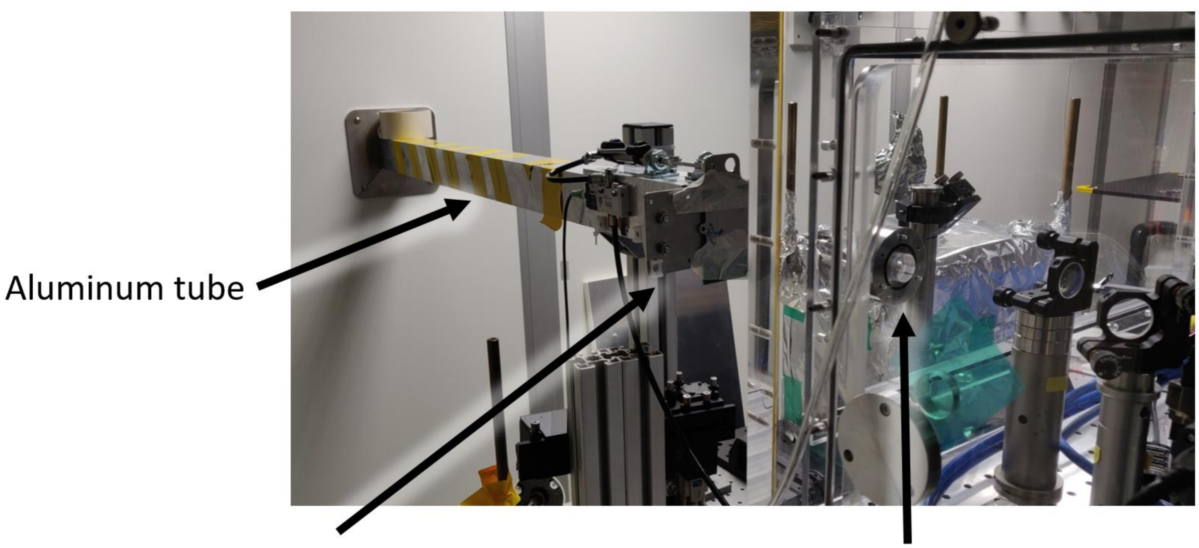

Figure 18: Low-power shutter applied to the aluminum tube at the exit of the laser system.

After propagating through the aluminum tube, the laser beam enters the processing station through a drilled hole (Figure 19) and is the reflected to the processing zone by several mirrors.

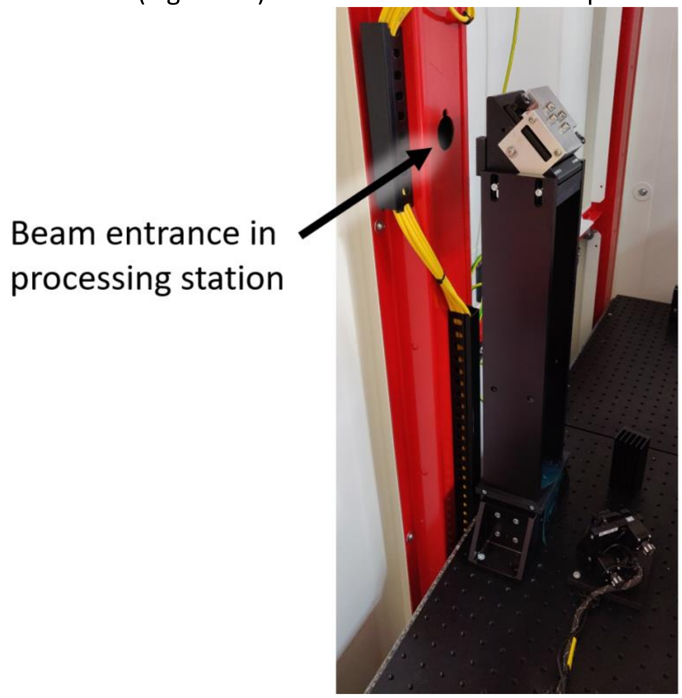

Figure 19: Beam entrance in the processing station.

The beam stabilisation system from TEM should not be used as such in case of high powers as it cannot be guaranteed to work reliably in pulsed laser processing and with varying laser power. However, the TEM system can be used to adjust the beam in the processing station at low power, e.g. for the daily adjustment. After adjusting at low power an aluminum block has to be placed before the TEM detector to avoid damaging it at high power.
The suction system was installed to protect the operator and the optics from ablated material (Figure 20). The equipped camera can be used to supervise the ablation process.

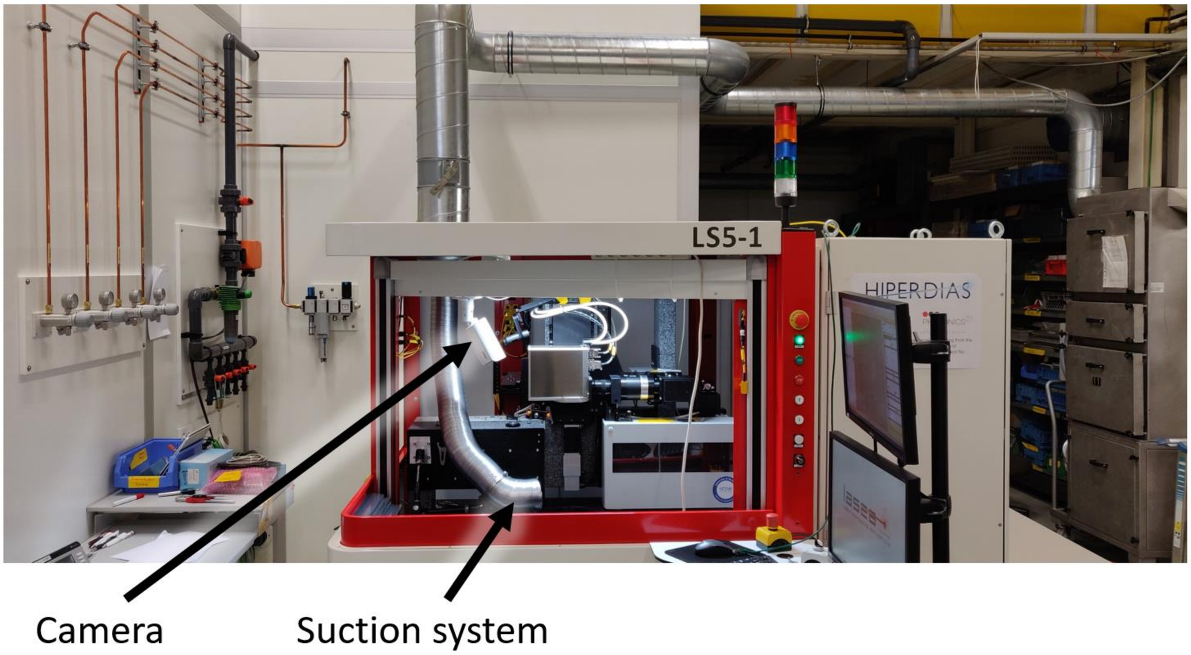

Figure 20: Camera and suction system installed in the processing station.

3.2.3 Laser signals:

The machine is located in another room than the 500 W laser system. As the cable to use between the machine and the laser will be quite long, a check of the gate and trigger signals was performed. The cable used were 10 m long coaxial cables. The tests were done for a TTL signal with a frequency of 3 MHz, higher than the frequency of the laser. We did not observe any significant distortion or electronic noise. Figure 21 Figure 22 and Figure 23 below illustrate the tests and the results:

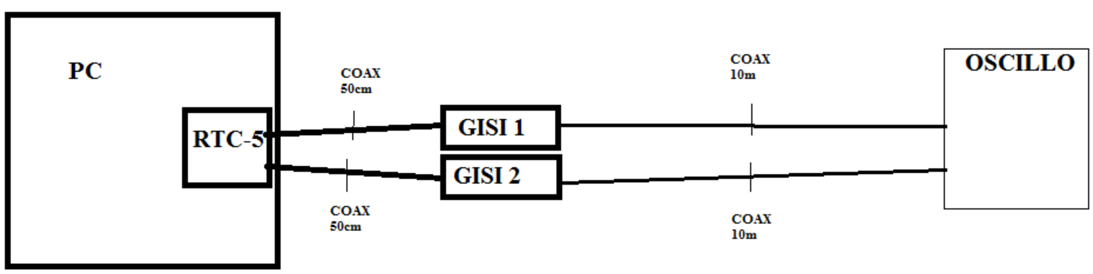

Figure 21 Sketch of the electronic setup used to check the gate and Trigger signals

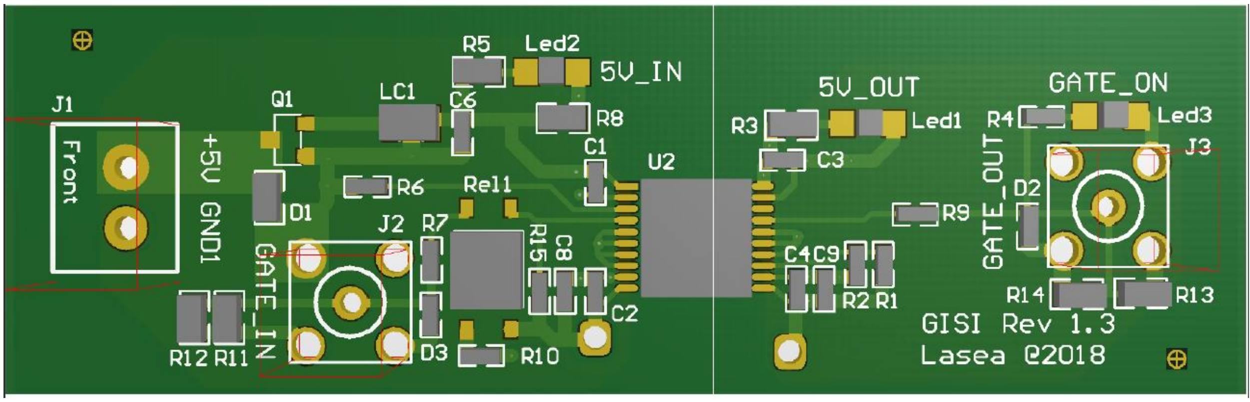

Figure 22 Detailed view of the electronic board interfacing the Scanlab RTC5 board and the laser controller

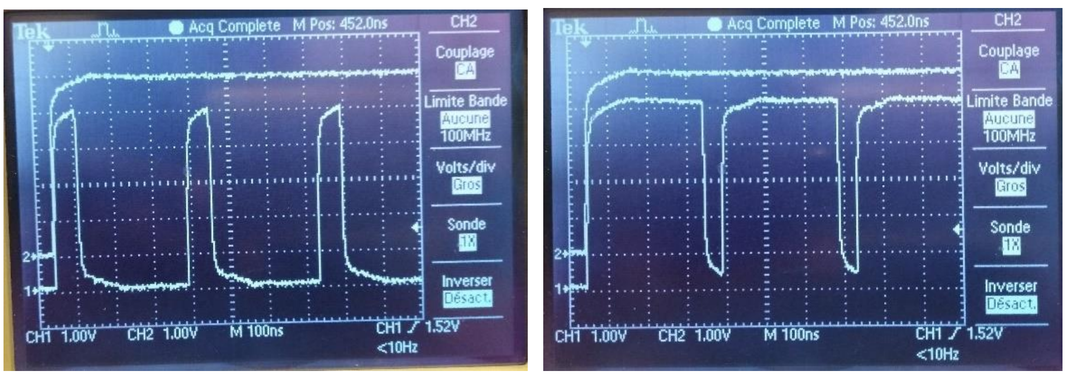

Figure 23 Examples of results for 2 trigger signals of 3MHz, one with a duty cycle of 10% and another one with a duty cycle of 90%

3.2.4 Motion axis:

The motion of the part will be managed by 3 axes X, Y and Z as illustrated by the Figure 24 with a travel of 500 mm, 300 mm and 200 mm respectively which will allow to move the work-piece (in this case a wafer) from the laser machining area to the camera. Those axes are driven by 3 drives “Ensemble” from Aerotech. Those axes are controllable with the LASEA software Kyla. Here is a screenshot of the control section of the axes as described above.

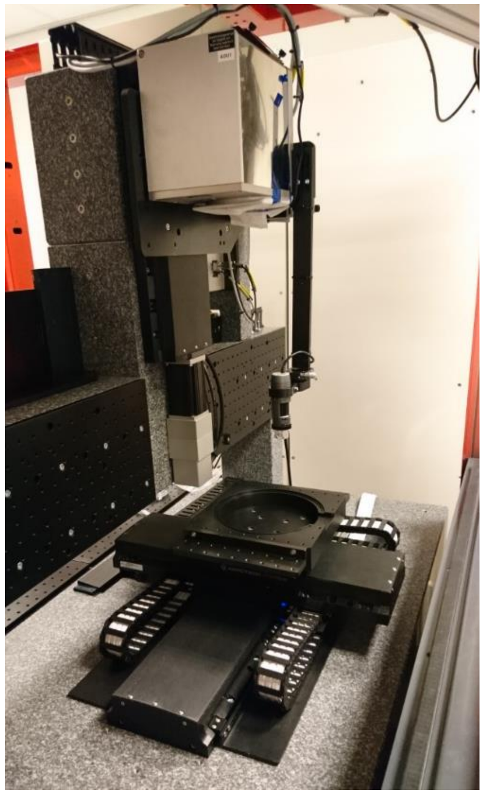

Figure 24 Picture illustrating the axes implemented on the machine.

Those axes carry a jig specially designed to support a 200 mm diameter and 2 mm thick silicon wafer. There is the possibility to bring some vacuum sucking in this jig in order to help in the fixing of the wafer on the jig.

3.2.5 Scanner system + varioscan:

The choice was made to use an Intelliscan de 30 with a Varioscan de 40i from Scanlab as illustrated by the Figure 25. The input beam will be set with a diameter between 5 and 15 mm to avoid any clipping of the beam as defined by the end-user. No lens will be used in order to avoid any ghost that will damage the galvo mirrors. The focusing of the beam is achieved with the Varioscan. Two different calibration files are provided giving two possible and different effective focal lengths i.e. 275 mm and 320 mm.
The lenses used in the Varioscan 40i are made of fused silica in order to allow high power lasers to go through.

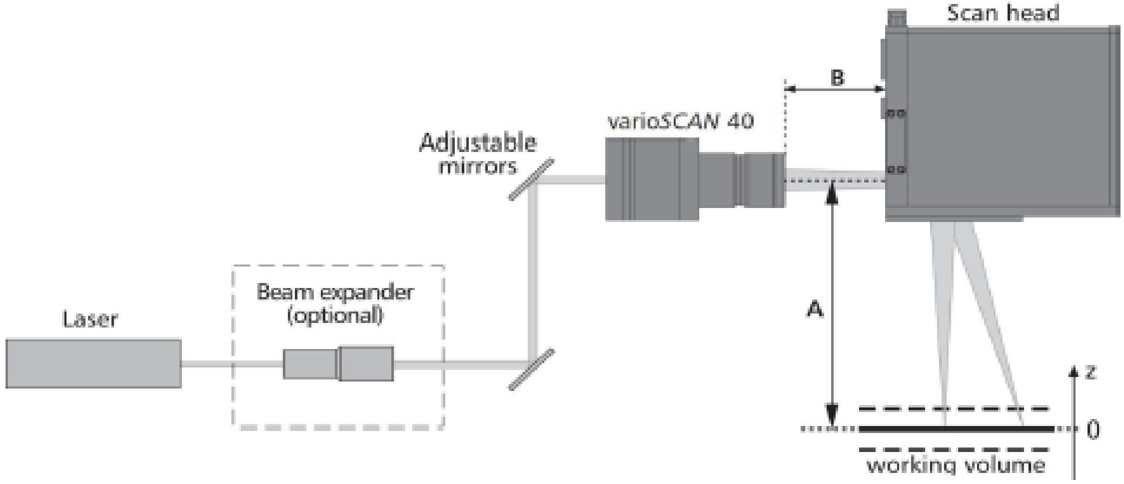

Figure 25 : Sketch of the intelliscan 30 de + varioscan 40i assembly

3.2.6 Mirrors:

In the standard free space guiding of the beam, the mirrors are a key component. In order to manage the very high power, they must have a very high reflectivity i.e. very low absorption. One of the most important specification is about the Limit Induced Threshold damage (LIDT) which must be above of the peak fluence of the input beam. According to the specifications of the laser beam, the beam size will be of 4 mm of diameter at minimum, which corresponds to a peak fluence of 15 mJ/cm² for a pulse energy of 1 mJ. The mirrors chosen are provided by the company Layertec. The LIDT of the mirrors is calculated to be of 400 mJ/cm² for a corresponding pulse duration of 400fs. There are made of fused silica. In addition, the reflectivity given by the supplier is >99.9% at 1030nm for an AOI (Angle Of Incidence) of 45°. The reflectivity versus wavelength spectrum is illustrated in the Figure 26 in the second demonstrator part below.

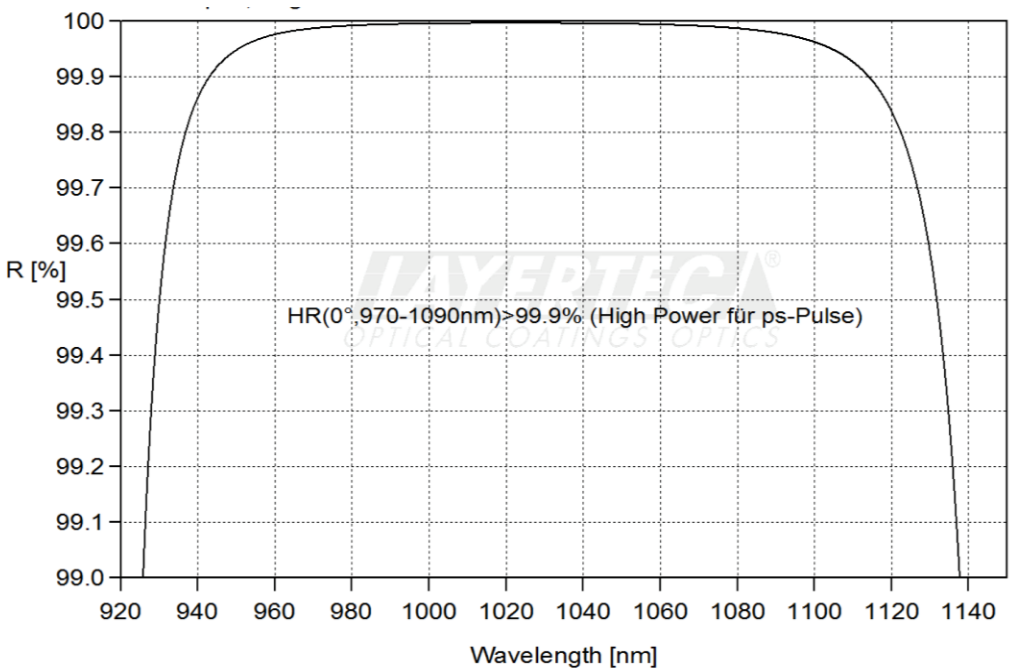

Figure 26 : reflectivity of the mirrors depending on the wavelength. At 1030 nm reflectivity is above 99.99%

4 Conclusions

Both the 200 W and 500 W (1 KW) systems have been developed and built by C4L and LASEA (USTUTT) according to the end user requirements of E6, C4L and Bosch (USTUTT). The finalised systems with performance capabilities suitable to reach the end user requirements (excepting the power drop on the 200 W system from 200 W to 85 W, which has been documented) will now become the demonstrator platforms 1 & 2.