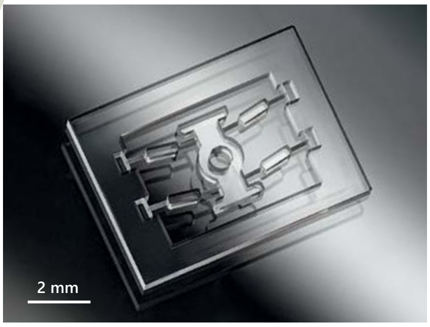
# Material processing examples
## Made with **FemtoLux** laser

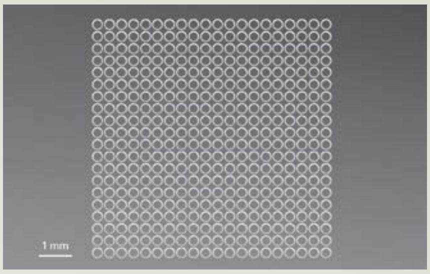



Femtosecond laser induced selective etching of bistable switch. Courtesy of Femtika.

## Glass

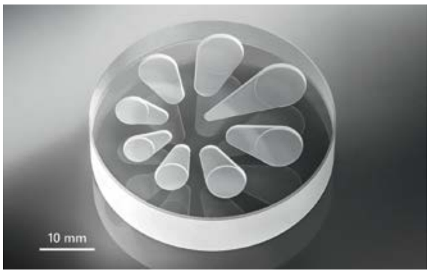
Processing glass substrates presents significant challenges due to their fragility and susceptibility to cracking under excessive thermal loads.

Femtosecond lasers are ideal for processing glass substrates due to their ultra-short pulse duration that minimizes thermal accumulation, resulting in superior quality.

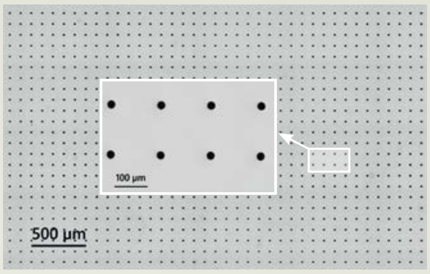



300 µm hole drilling in thin borosilicate glass. Courtesy of FTMC.

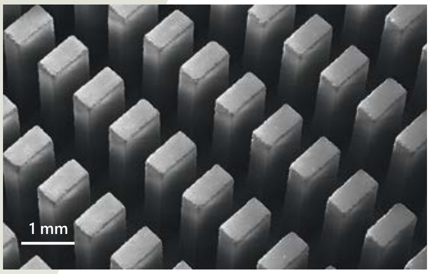
Fused-silica milling. Courtesy of FTMC.



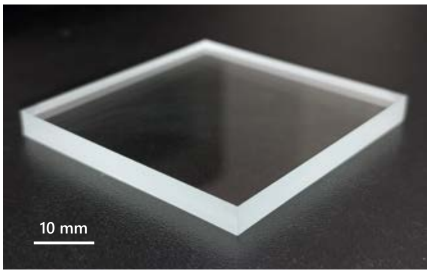

UVFS milling. Courtesy of FTMC.




GHz burst assisted percussion drilling of high aspect ratio holes in EXG glass. Courtesy of Akoneer.




Bottom-up milling of fused-silica glass. Courtesy of FTMC.

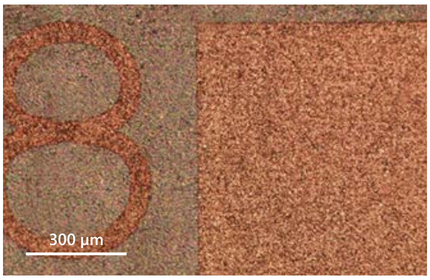



Laser-based Bessel beam scribing of soda-lime glass. Courtesy of FTMC.

## Polymer

Polymers are widely used in various applications, including automotive, medicine, and consumer electronics. However, due to their inherent property of low heat conductivity, polymers are quite sensitive to heat.

Femtosecond lasers, with their very short pulse durations, offer a solution to this problem by enabling the precise machining of polymers while preserving process quality.




Insulation layer removal from PCB. Courtesy of FTMC.

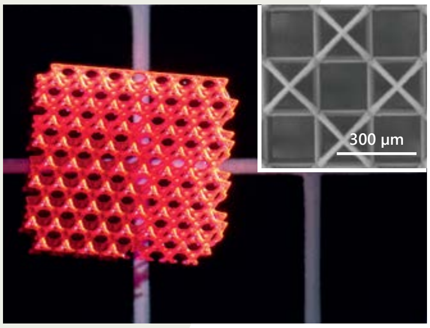



Photo-polymerization. Courtesy of Femtika.

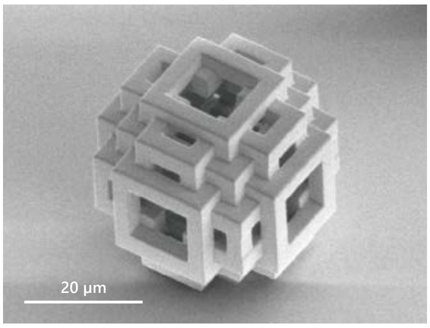
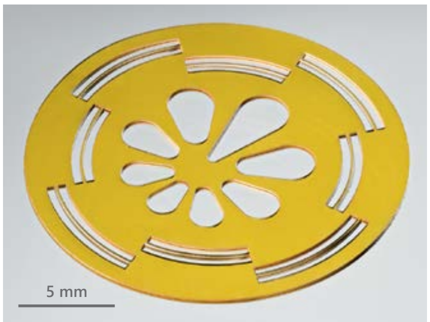



Photo-polymerization. Courtesy of WOP.




Polymide cutting. Courtesy of FTMC.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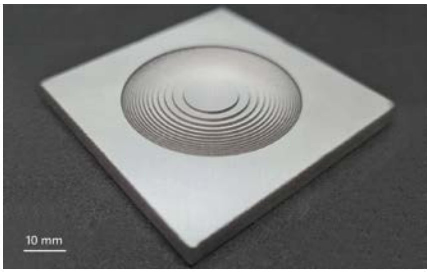
# Material Processing Examples

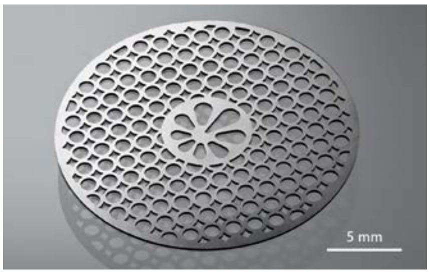
## Metal

Femtosecond lasers enable the production of complex shapes and features, while also providing the capability to perform black/white marking and coloring without the need for chemical additives.


Stainless steel cutting. Courtesy of FTMC.

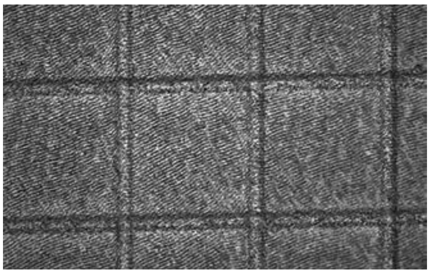



Laser milled aluminium Fresnel lens mould, diameter 35 mm. Courtesy of FTMC.




Stainless steel cutting.
Courtesy of FTMC.


Black marking of tweezers.
Courtesy of FTMC.



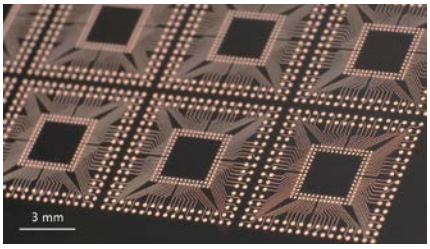
Grid surface texturing with LIPSS of nitinol.
Courtesy of UNIMORE.

Nitinol stent cutting.
Courtesy of Vactronix Scientific

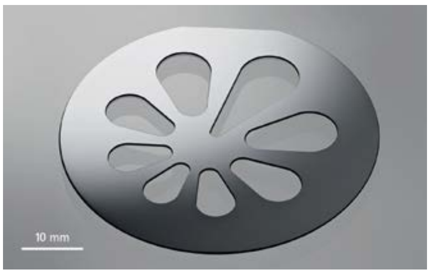

Stainless steel coloring with GHz burst feature.
Courtesy of Akoneer.

## Other materials

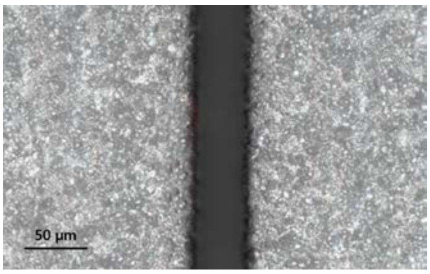
Femtosecond lasers, with pulse durations in the hundreds of femtoseconds, generate high intensities that make it possible to process almost material. Complex 3D structures, as well as non-conventional shapes can be obtained.



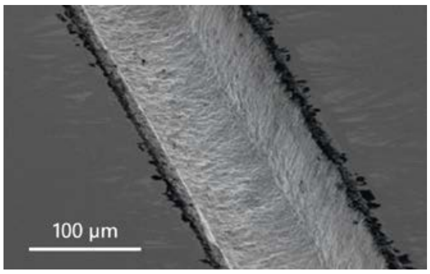

SSAIL technology on PI. Courtesy of Akoneer.



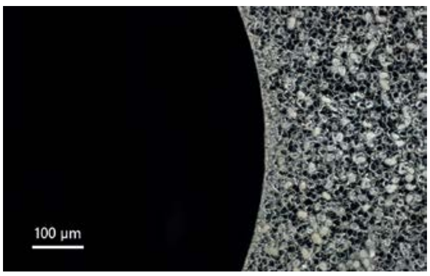

Crystalline silicon cutting.
Courtesy of FTMC.



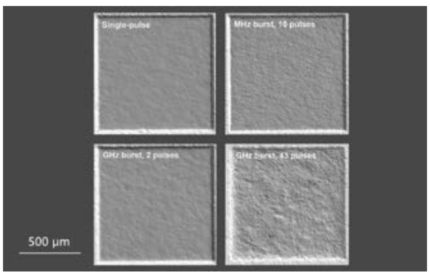

50 µm depth groove formation in ceramic.
Courtesy of FTMC.



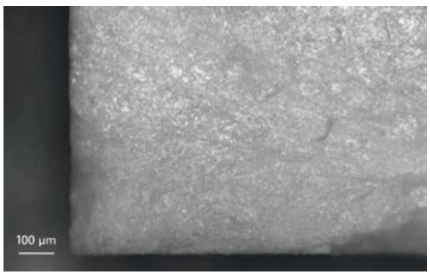

Groove formation in GaAs in water environment.
Courtesy of FMTC.




Crystalline silicon cutting.
Courtesy of FTMC.




Optical 3D profilometer image showing milled square patterns in aluminum oxide ceramics.




Heat-sensitive organic material cutting.
Courtesy of FTMC.

fs Industrial Femtosecond Lasers

# FemtoLux

## Reliability Redefined

## A reliable & versatile tool for micromachining

/ Glass, sapphire and ceramics micro processing

/ Microelectronics manufacturing

/ Glass intra volume structuring

/ Micro processing of different polymers and metals

/ LCD, LED, OLED drilling, cutting and repair

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Rev. 250320

Industrial
Dry Cooled
Femtosecond Laser

# FemtoLux

**Designed from the get-go for maximum reliability, seamless integration and non-stop 24/7/365 zero maintenance operation with innovative "dry" cooling.**

The FemtoLux femtosecond laser has a tunable pulse duration from <350 fs to 1 ps and can operate in a broad AOM controlled range of pulse repetition rates from a single shot to 4 MHz.

The maximum pulse energy is more than 300 µJ operating with single pulses and can reach more than 750 µJ in burst mode, ensuring higher ablation rates and processing throughput for different materials.

The FemtoLux beam parameters will meet the requirements of the most demanding materials and micro-machining applications.

Innovative laser control electronics ensure simple control of the FemtoLux laser by external controllers that could run on different platforms, be it Windows, Linux or others using REST API commands.

This makes easy integration and reduces the time and human resources required to integrate this laser into any laser micromachining equipment.

## Seamless User Experience

**Easy integration** – remote control using REST API via RS232 and LAN.

**Reduced integration time** – demo electronics is available for laser control programming in advance.

**Easy and quick installation** – no water, fully disconnectable laser head. Can be installed by the end-user.

**Easy troubleshooting** – integrated detectors and constant system status logging.

**No periodic maintenance** required.

## Features

Typical max output power
**50 W at 1030 nm,**
**20 W at 515 nm,**
**10 W at 343 nm**

Typical max output energies
**> 300 µJ at 1030 nm,**
**> 50 µJ at 515 nm,**
**> 25 µJ at 343 nm**

**Up to 1 mJ** high energy version available

**MHz, GHz, MHz+GHz burst** modes

**> 750 µJ** in a burst mode

**< 350 fs – 1 ps**

Pulse duration extension **up to 1 ns**

**Single shot – up to 4 MHz** (AOM controlled)

**Pulse-on-demand** (PoD), with jitter as low as 20 ns (peak-to-peak)

<0.5% RMS power long term stability over 100 hours

$M^2 < 1.2$

Beam circularity > 0.85

Zero maintenance / "Dry" cooling

Learn more about FemtoLux
**www.ekspla.com**


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# “Dry“ Cooling

## Direct Refrigerant Cooling System

**The FemtoLux laser employs an innovative cooling system and sets new reliability standards among industrial femtosecond lasers. No additional bulky and heavy water chiller is needed.**

The chiller requires periodic maintenance – cooling system draining and rinsing and water and particle filter replacement. Moreover, water leakage can cause damage to the laser head and other equipment. Instead of using water for transferring heat from a laser head, the FemtoLux laser uses an innovative Direct Refrigerant Cooling method.

The refrigerant agent circulates from a PSU-integrated compressor and condenser, to a cooling plate via armored flexible lines.

The entire cooling circuit is permanently hermetically sealed and requires no maintenance.

## Benefits

**Military-grade** reliability

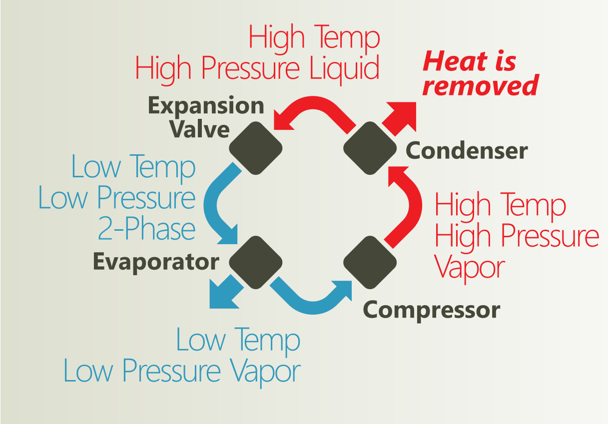
Permanently hermetically sealed system **>90,000 hour MTBF**

**No maintenance**

High cooling efficiency

**>45%** lower power consumption compared to water cooling equipment

**Compact and light**




Compressor picture.
Courtesy of Aspen Systems Inc.

## Simple & Reliable Cooling Plate Attachment

The cooling plate is detachable from the laser head for more convenient laser installation. The laser cooling equipment is integrated with the laser power supply unit into a single 4U rack-mounted housing with a total weight of 15 kg.

**Detachable** cooling plate

**Integrated** cooling equipment with the laser power supply

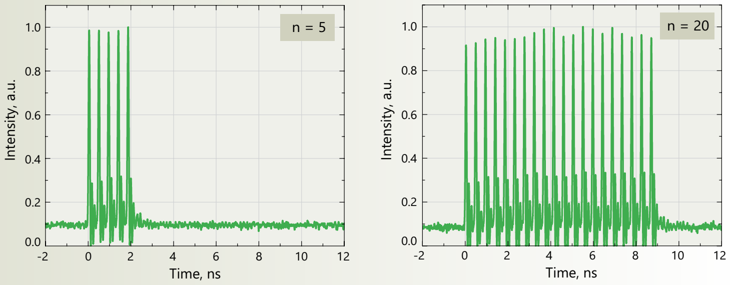

Simple and reliable cooling plate attachment

# GHz Burst Option

## Patent-Pending Method for Ultra-High Rate Bursts

### **Short** GHz burst

**Fig 1.** Measured 2.2 GHz intra-burst PRR burst of pulses containing a different number of pulses of equal amplitudes at 31.5 W average output power




### **Long** GHz burst

**Fig 2.** Measured 2.2 GHz pre-shaped bursts of 1000 pulses at 233 kHz burst repetition rate for the desired rectangular-like burst shape

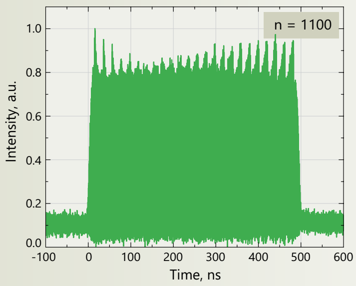
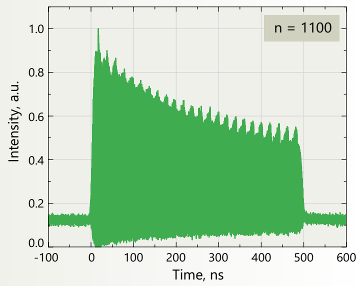



**Fig 3.** Measured 2.2 GHz non-pre-shaped bursts of 1100 pulses at 233 kHz burst repetition rate




### **MHz + GHz** burst mode

**Fig 4.** Measured 4 bursts of 50 MHz BRR containing 4 pulses of 2.5 GHz intra-burst PRR

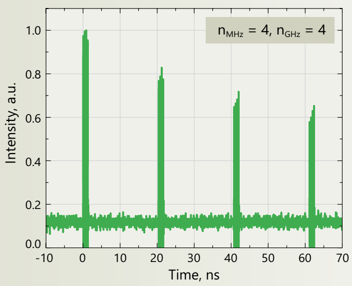
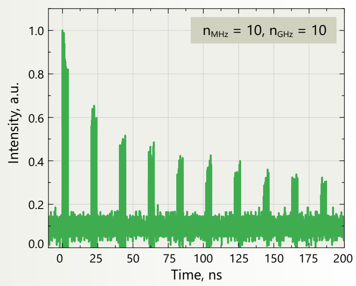



**Fig 5.** Measured 10 bursts of 50 MHz BRR containing 10 pulses of 2.5 GHz intra-burst PRR




## Benefits

The Femtolux laser can operate in the **single-pulse** mode, **MHz burst** mode, **GHz burst** mode, and **MHz + GHz burst** mode.

The burst formation technique based on the use of the AFL is a very versatile method as it allows to overcome many limitations encountered by other fiber- and/or solid-state-based techniques.

**Any desired intra-burst PRR can be achieved** independently from the initial PRR of the master oscillator

**Identical pulse separation** inside the GHz bursts is maintained

**Short- and long-burst formation modes can be provided.**

/ A short burst is up to about 10 ns burst width (from 2 to tens of pulses in the GHz burst).

/ A long burst is from ~20 ns up to a few hundred ns in burst width (from tens to thousands of pulses in the GHz burst)

**MHz+GHz burst** mode

**An adjustable amplitude envelope** of the GHz bursts is provided

**No pre/post pulses** in GHz burst. Pure GHz bursts

**Ultrashort pulse duration** is maintained inside the bursts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**A new versatile patent-pending method to form ultra-high repetition rate bursts of ultrashort laser pulses.**

The developed method is based on the use of an all-in-fiber active fiber loop (AFL). A detailed description of the invention can be found on:

[1] Andrejus Michailovas, and Tadas Bartulevičius. 2021 Int. patent application published under the Patent Cooperation Treaty (PCT) WO2021059003A1.

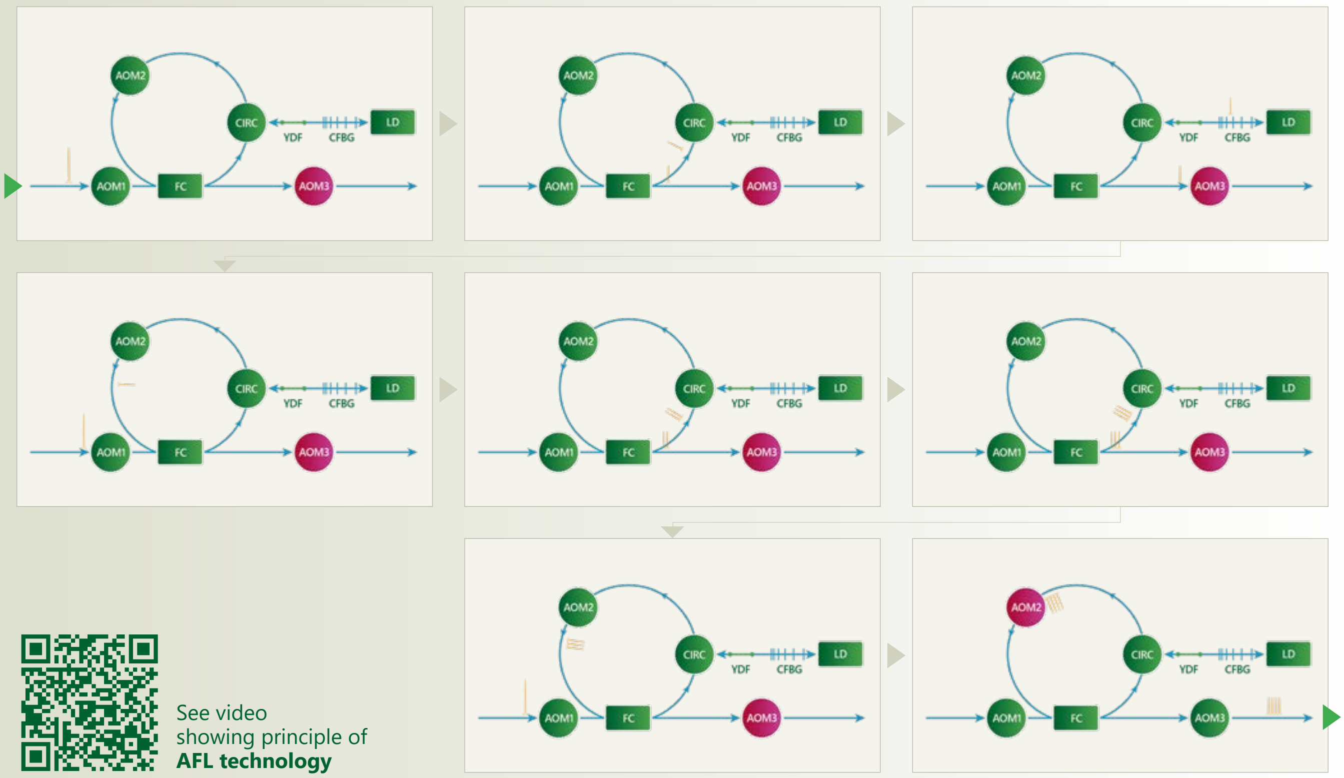
[2] Tadas Bartulevičius, Mykolas Lipnickas, Virginija Petrauskienė, Karolis Madeikis, and Andrejus Michailovas, (2022), "30 W-average-power femtosecond NIR laser operating in a flexible GHz-burst-regime," Opt. Express 30, 36849-36862.

# Specifications

| | | |
|---|---|---|
| Burst repetition rate | up to 650 kHz | |
| Intra-burst pulse repetition rate [1] | 2 GHz | |
| **GHz burst mode** | **short** | **long** |
| GHz burst length | 0.5 – 10 ns | 20 – 500 ns |
| Number of pulses [2] | 2 – 20 | 40 – 1000 |
| Shape | square, rising, falling | falling, pre-shaped [3] |
| **MHz + GHz burst mode** | | |
| Number of pulses in MHz burst | 2 – 10 | |
| Number of pulses in GHz burst [2] | 2 – 20 | |

1) Custom intra-pulse PRR is available upon a request.
2) Depends on the intra-pulse PRR.
3) For more information, please inquire sales@ekspla.com.

# Principle of AFL Technology




See video showing principle of **AFL technology**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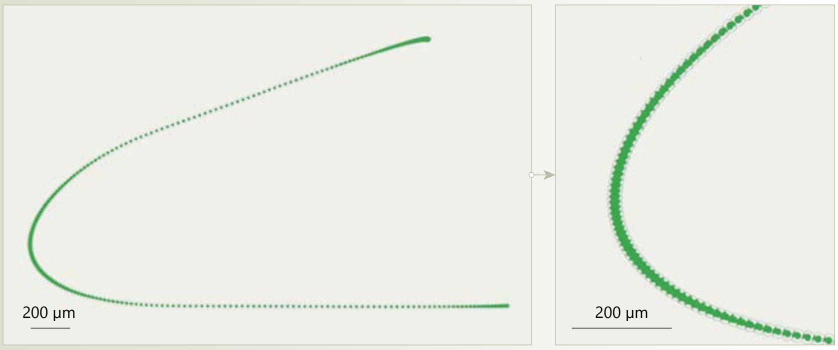
# Pulse-on-Demand (PoD)

Traditional laser triggering techniques struggle to maintain equally spaced pulses at high speeds (Fig.1, 2). Pulse-on-demand feature tackles this challenge and enables high-speed micromachining (Fig. 3).

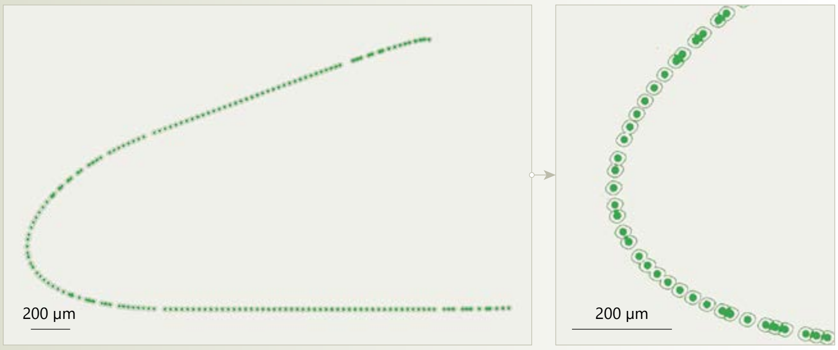
## **Time based** laser triggering

**Fig 1.** Complex shape scanned with time based laser triggering mode with a pulse repetition of 200 kHz and scanning speed of 6 m/s. The scanning started from the top right to the bottom right area. Overlapping pulses result in an overheated area.



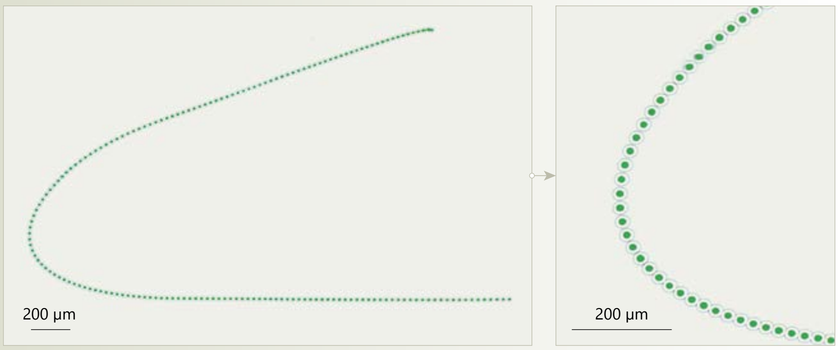

## **Position based** laser triggering

**Fig 2.** Complex shape scanned with position based laser triggering mode with a pitch of 30 µm and scanning speed of 6 m/s. The scanning started from the top right to the bottom right area. Jitter of tens of µs results in random pulse spacing.




## **Pulse-on-demand** (PoD)

**Fig 3.** Complex shape scanned with pulse-on-demand (PoD) and position based laser triggering mode with a pitch of 30 µm and scanning speed of 6 m/s. The scanning started from the top right to the bottom right area. PoD feature preserves equidistant pulse spacing at high speeds.




## Benefits

**Jitter lower than 20 ns** ensures consistent and equidistant pulse spacing for high-speed micromachining

**Adjustable repetition rate** for processing complex geometries

**Faster processing speeds**, increased productivity

**PoD feature enables the laser to fire a pulse only when required, rather than at a constant rate, enabling precise control over the laser's output and resulting in higher efficiency, accuracy and quality.**

This capability is especially valuable in various micromachining applications where a high processing speed, constant energy, and accuracy are essential. To follow complex curvature at high speed and to maintain equidistant spacing it is necessary to ensure that the repetition rate of the pulses is adjusted. To achieve these requirements, it is necessary to ensure that the repetition rate of the pulses is adjusted to follow complex curvature at high speed and to maintain equidistant spacing. One may try to use position based laser triggering but, due to laser system limitations, the jitter will be from several µs to tens of µs, which will result in random spacing of the pulses. On the other hand, the usage of time based laser triggering results in overheat areas, due to excessive overlap of pulses. The FemtoLux laser has the pulse-on-demand feature with jitter as low as 20 ns (peak-to-peak), and it can therefore tackle all the challenges and maximize process efficiency, precision and quality at high speed.

# Specifications [1]

New!

| Model | | FemtoLux 30 | FemtoLux 50 |
|---|---|---|---|
| **Main specifications** | | | |
| Central wavelength | fundamental | 1030 nm | |
| | with second harmonic option | 515 nm | |
| | with third harmonic option | 343 nm | |
| Pulse repetition rate (PRR) [2] | | 200 kHz – 4 MHz | 100 kHz – 2 MHz |
| Pulse repetition frequency (PRF) after frequency divider | | PRF = PRR / N, N=1, 2, 3, ... , 65000; single shot | |
| Average output power | at 1030 nm [3] | > 27 W (typical 30 W) | > 45 W (typical 50 W) |
| | at 515 nm | > 11 W [4] | > 20 W [5] |
| | at 343 nm | > 6 W [4] | > 10 W [5] |
| Pulse energy | at 1030 nm | > 100 µJ or 1 mJ [6] | > 300 µJ [7] |
| | at 515 nm | > 55 µJ [4] | > 50 µJ [5] |
| | at 343 nm | > 30 µJ [4] | > 25 µJ [5] |
| Number of pulses in MHz burst [8] | | 2 – 10 | |
| Maximal energy in burst mode [9] | | > 450 µJ | > 750 µJ |
| Power long term stability (Std. dev.) [10] | | < 0.5 % | |
| Pulse energy stability (Std. dev.) [11] | | < 1 % | |
| Pulse duration (FWHM) @ 1 MHz | | tunable, < 350 fs [12] – 1 ps [13] | tunable, < 400 fs [12] – 1 ps [13] |
| Optional pulse duration extension | | tunable, up to 1 ns | |
| Beam quality | | $M^2 < 1.2$ (typical < 1.1) | |
| Beam circularity, far field | | > 0.85 | |
| Beam divergence (full angle) | | < 1 mrad | |
| Beam pointing thermal stability | | < 20 µrad/°C | |
| Beam diameter ($1/e^2$) @ 1030 nm | | 2.5 ± 0.4 mm @ 65 cm | |
| Polarization | | vertical | |
| Triggering mode | | internal / external | |
| Pulse output control | | frequency divider, pulse picker, burst mode, packet triggering, power attenuation, pulse-on-demand [14] | |
| Control interfaces | | RS232 / LAN | |
| Length of the umbilical cord | | 3 m, detachable. Custom length option available | |
| Laser head cooling type | | dry (direct refrigerant cooling through detachable cooling plate) | |
| **Physical characteristics** | | | |
| Laser head (W × L × H) | | 434 × 569 × 150 mm | |
| Power supply unit (W × L × H) | | 449 × 496 × 184 mm | |
| **Operating requirements** | | | |
| Mains requirements | | 100 – 240 V AC, single phase, 50/60 Hz | |
| Maximal power rating | | 800 W | |
| Operating ambient temperature | | 18 – 27 °C | |
| Relative humidity | | 10–80 % (non-condensing) | |
| Air contamination level | | ISO 9 (room air) or better | |

1) Due to continuous improvement, all specifications are subject to change without notice. Parameters marked typical are not specifications. They are indications of typical performance and will vary with each unit we manufacture. All parameters are specified for a shortest pulse duration. Unless stated otherwise, all specifications are measured at 1030 nm and for basic system without options.
2) When frequency divider is set to transmit every pulse. Fully controllable by integrated AOM.
3) At 1 MHz.
4) At 200 kHz.
5) At 400 kHz.
6) Other combinations of energy and repetition rate available.
7) At 100 kHz.
8) Oscillator frequency ~50 MHz, ~20 ns separation between pulses.
9) MHz burst mode or MHz+GHz burst mode at 50 kHz PRR.
10) Over 100 h after warm-up under constant environmental conditions.
11) Under constant environmental conditions.
12) At PRR > 500 kHz. At PRR < 500 kHz shortest pulse duration is < 400 fs.
13) Custom pulse duration by request. For example – fixed 50 fs available.
14) Optional feature. Jitter < 20 ns. Trigger-to-pulse delay < 1 µs.

**DANGER:** VISIBLE AND/OR INVISIBLE LASER RADIATION AVOID EYE OR SKIN EXPOSURE TO DIRECT, REFLECTED OR SCATTERED RADIATION
**CLASS 4 LASER PRODUCT**

# Performance of FemtoLux 50

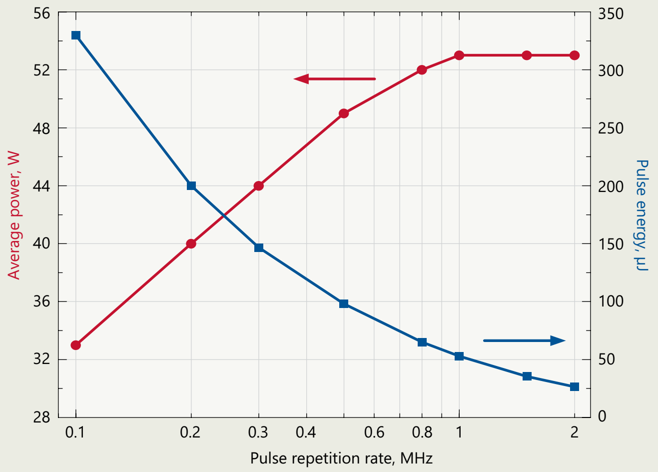



**Fig 1.** Typical dependence of output power and pulse energy of FemtoLux 50 laser at 1030 nm on pulse repetition rate

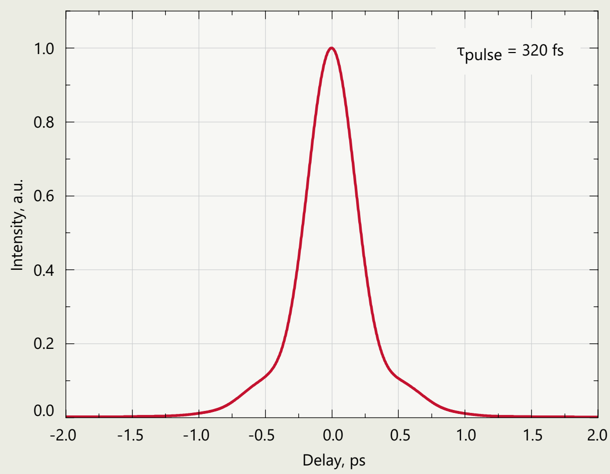



**Fig 2.** Typical FemtoLux 50 laser output pulse autocorrelation function at 1030 nm @ 1 MHz

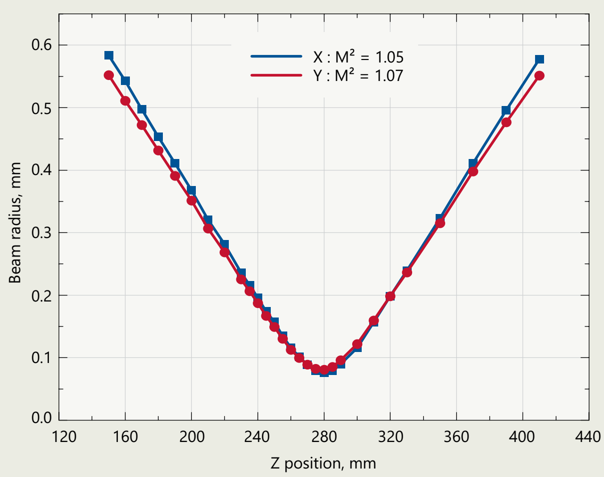



**Fig 3.** Typical M$^2$ measurement of FemtoLux 50 laser at 1030 nm

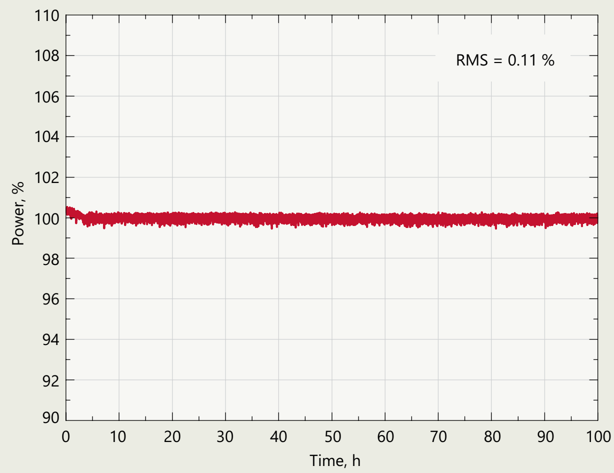



**Fig 4.** Typical long term average power stability of FemtoLux 50 laser at 1030 nm under constant environmental conditions

# Performance of FemtoLux 30

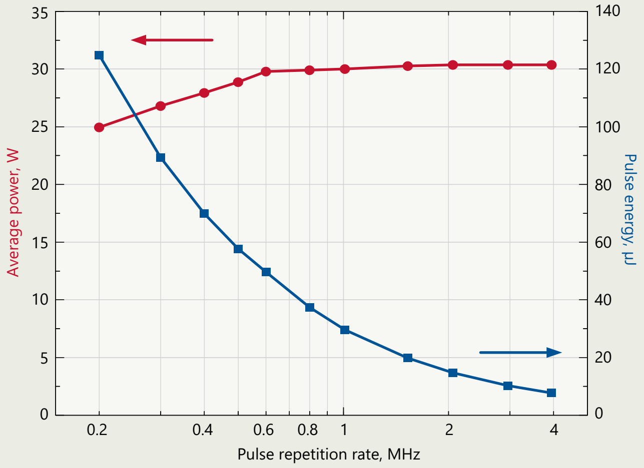



**Fig 5.** Typical dependence of output power and pulse energy of FemtoLux 30 laser at 1030 nm on pulse repetition rate

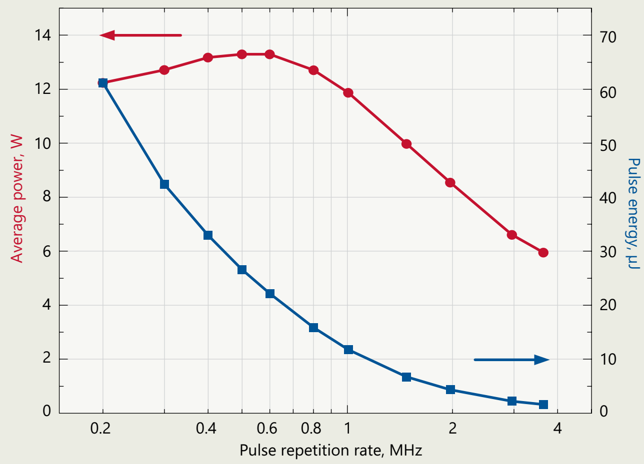



**Fig 6.** Typical dependence of output power and pulse energy of FemtoLux 30 laser at 515 nm on pulse repetition rate

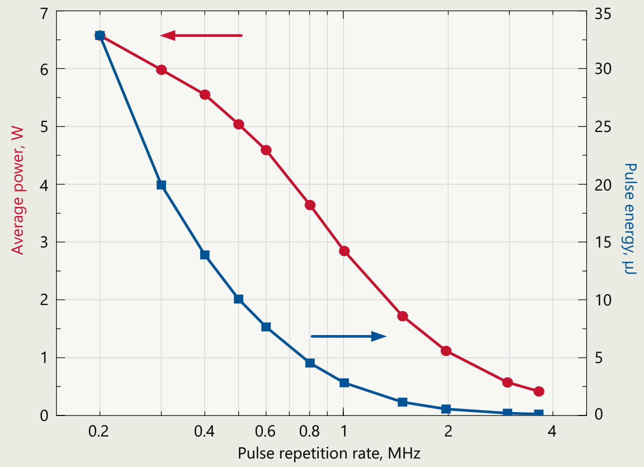



**Fig 7.** Typical dependence of output power and pulse energy of FemtoLux 30 laser at 343 nm on pulse repetition rate

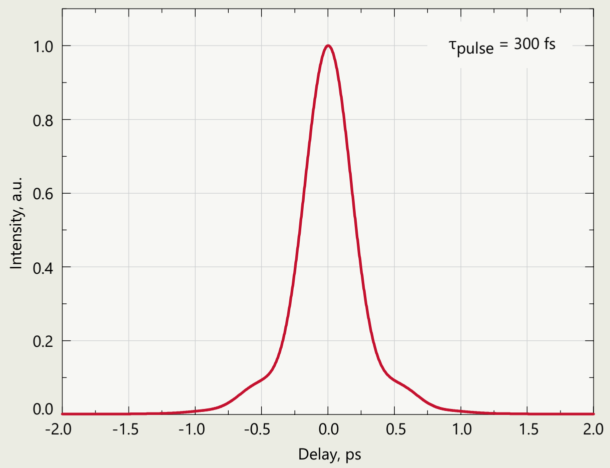



**Fig 8.** Typical FemtoLux 30 laser (at 1030 nm) output pulse autocorrelation function

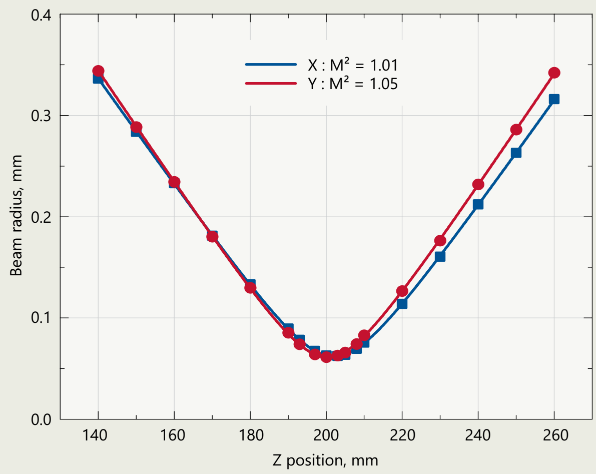



**Fig 9.** Typical $M^2$ measurement of FemtoLux 30 laser at 1030 nm

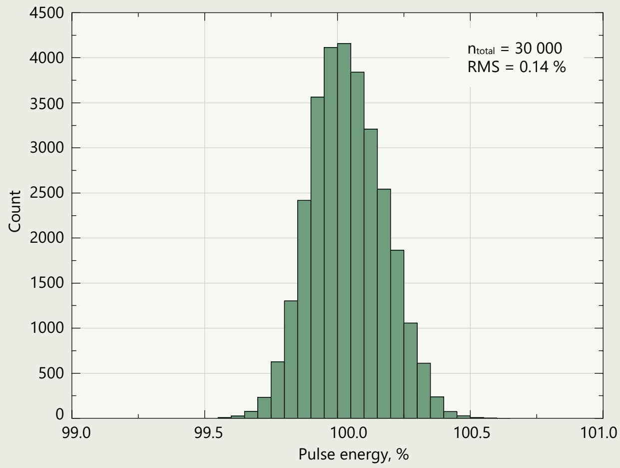



**Fig 10.** Typical pulse-to-pulse energy stability of FemtoLux 30 laser at 200 kHz over 30 000 pulses. RMS was calculated by using a set of mean values of 10 consecutive laser shots

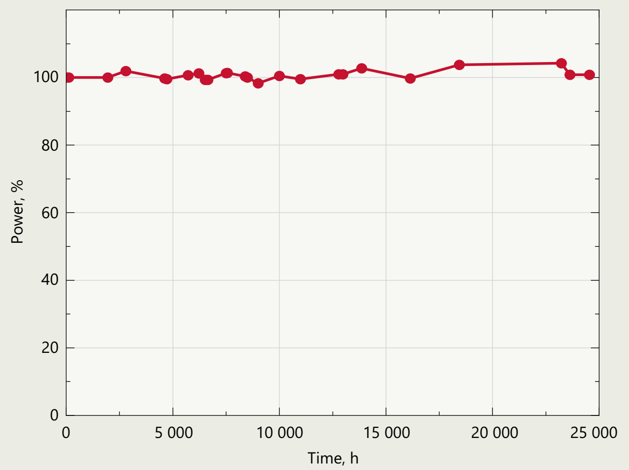



**Fig 11.** Long-term average power stability of the FemtoLux 30 laser at 1030 nm under constant environmental conditions over an extended duration of 25,000 hours

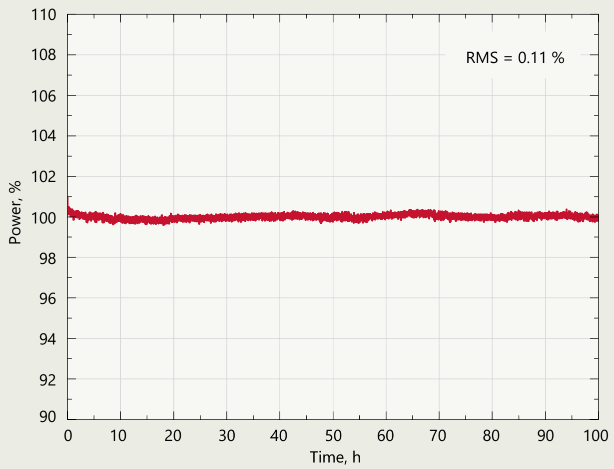



**Fig 12.** Typical long term average power stability of FemtoLux 30 laser at 1030 nm under constant environmental conditions

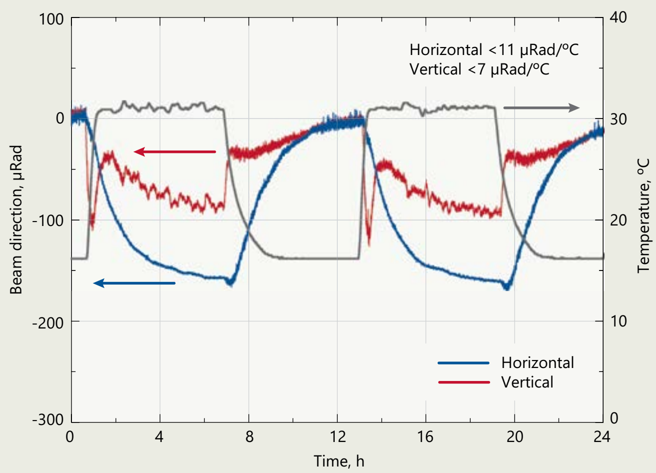



**Fig 13.** Typical beam direction stability of FemtoLux 30 under harsh environmental conditions

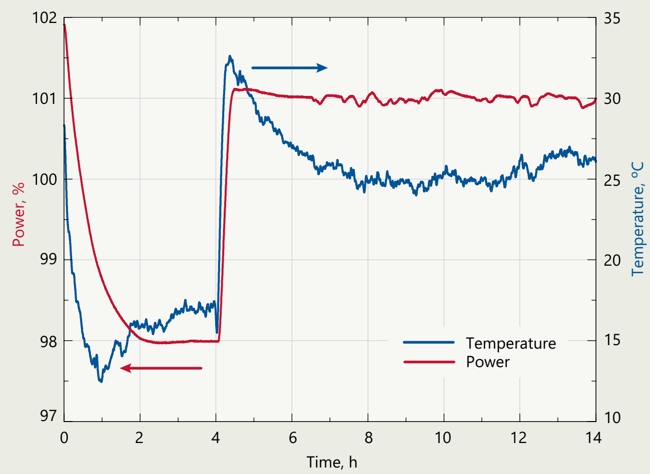



**Fig 14.** Average output power dependance of FemtoLux 30 laser on ambient temperature at 1030 nm


FemtoLux with harmonics module and power supply

# Drawings

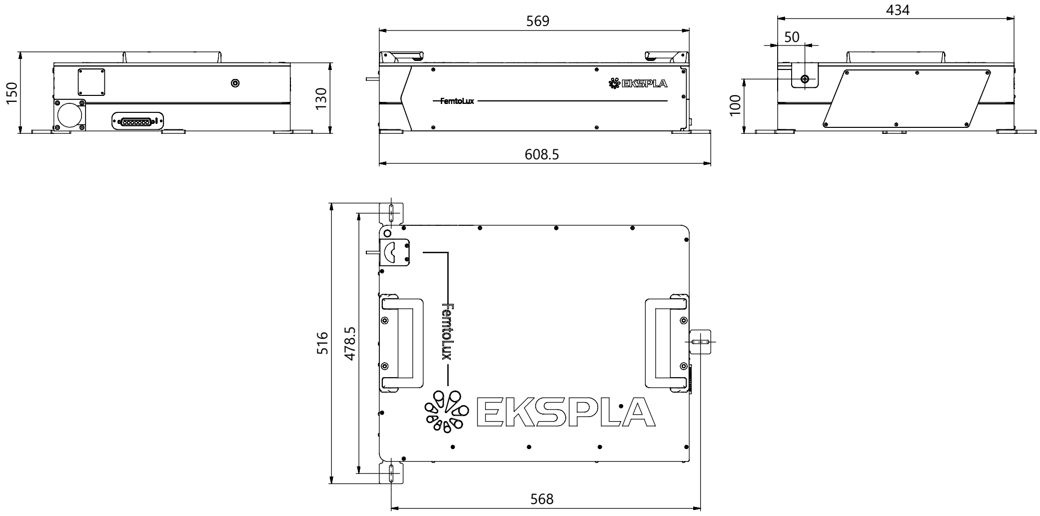



**Fig 11.** FemtoLux laser head outline drawing

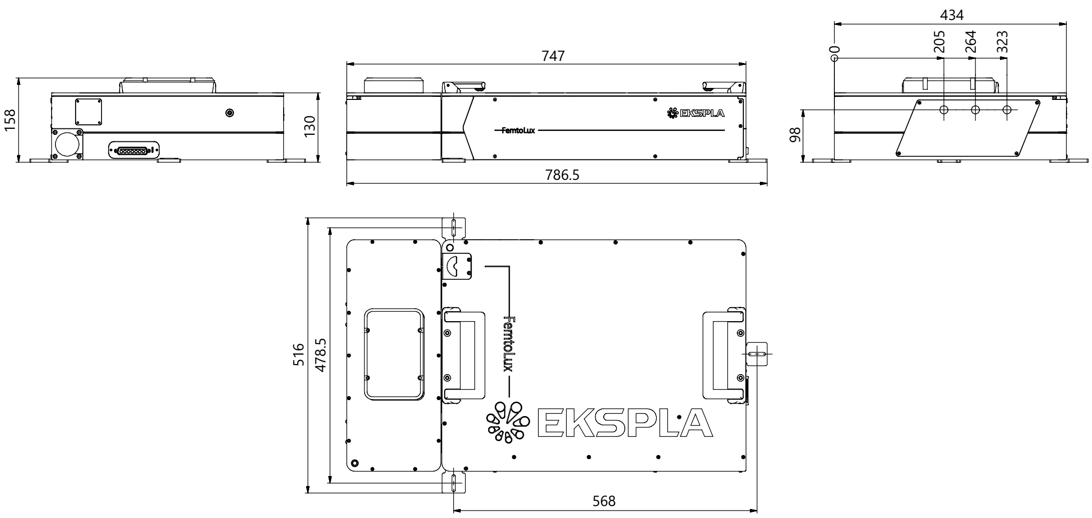



**Fig 12.** FemtoLux with harmonics module. Laser head outline drawing

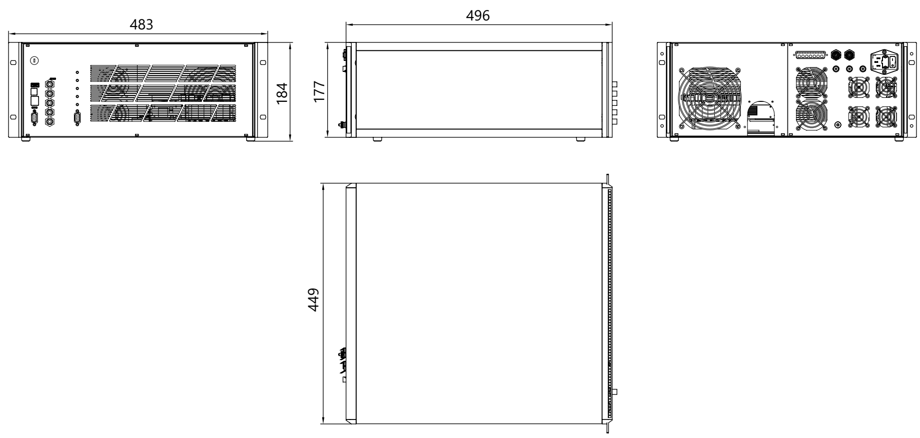
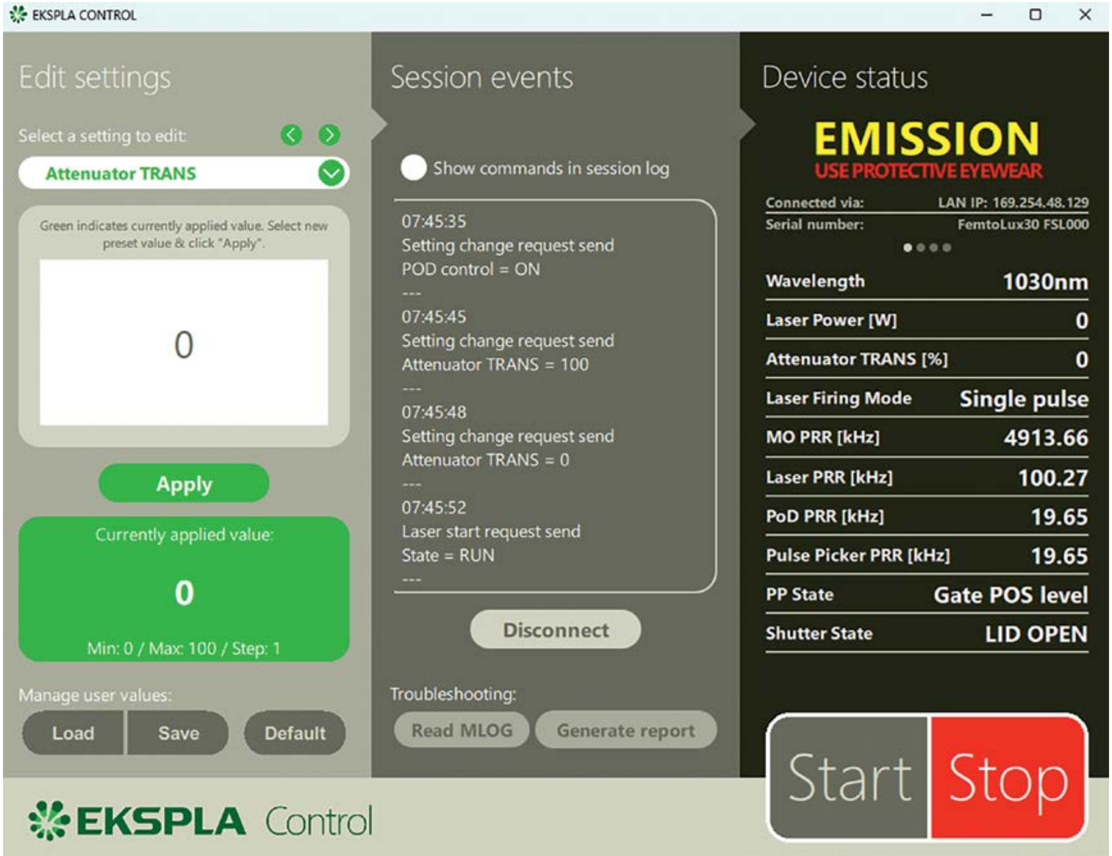



**Fig 13.** Power supply outline drawing

# Laser control application

Ekspla Control Application is a software tool intended for day-to-day routine operation control. It is used to control the laser in API level through LAN or RS-232 communication types, the control capabilities are stored in the laser system itself, software is self-adaptive to the system, one application can be used with multiple systems and can run on different platforms – be it Windows, Linux or others using REST API commands.






Savanoriu Av. 237, LT-02300 Vilnius, Lithuania | ph. +370 5 2649629 | e-mail: sales@ekspla.com | **www.ekspla.com**

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