Hybrid Laser Processing of Micro-Lens Arrays Using the **FemtoLux 30**

Femtosecond lasers have successfully proven themselves in processing various materials with high precision and quality. Glass, is one of the materials that benefits the most from the ultra-short pulses, allowing to process the material without introducing significant thermal effects, resulting in catastrophic damage.

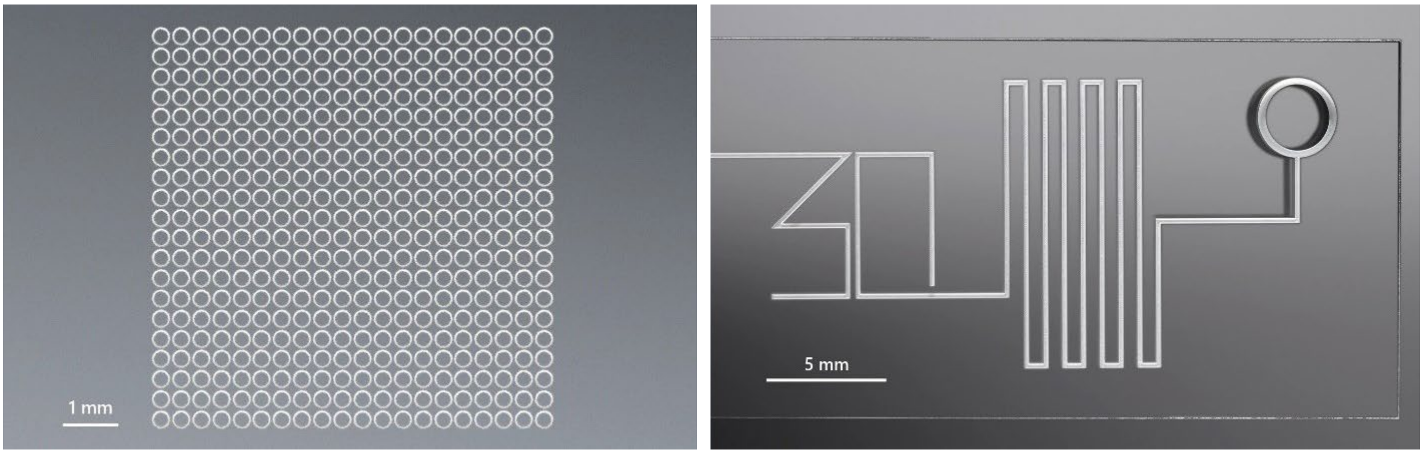

Figure 1. Glass processing with femtosecond laser FemtoLux 30. Left – 300 µm hole drilling in thin borosilicate glass. Right – microfluidic channel milling in soda-lime glass. Courtesy of FTMC

Recent advancements in femtosecond laser technology have been heavily focused on addressing the industry's longstanding challenge – low throughput. **Burst mode processing** has emerged as a breakthrough, not only attracting significant attention but also unlocking new application opportunities for femtosecond lasers.

In burst mode, a single high-energy pulse is divided into multiple lower-energy pulses, allowing for more efficient use of laser power. This prevents excessive energy deposition, which would otherwise degrade processing quality. The high intra-burst repetition rate (ranging from MHz to GHz) ensures that each pulse actively contributes to material removal. Additionally, by adjusting the number of pulses in the burst, the burst duration can be extended up to nanoseconds – an important feature in increasing material removal throughput.

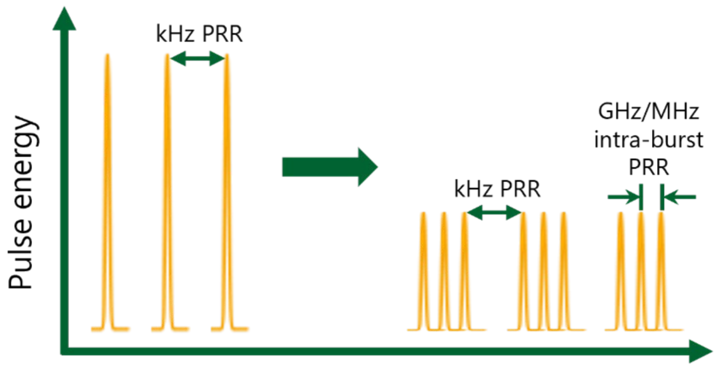

Figure 2. Illustration of burst mode operation

Figure 3. Industrial femtosecond laser FemtoLux

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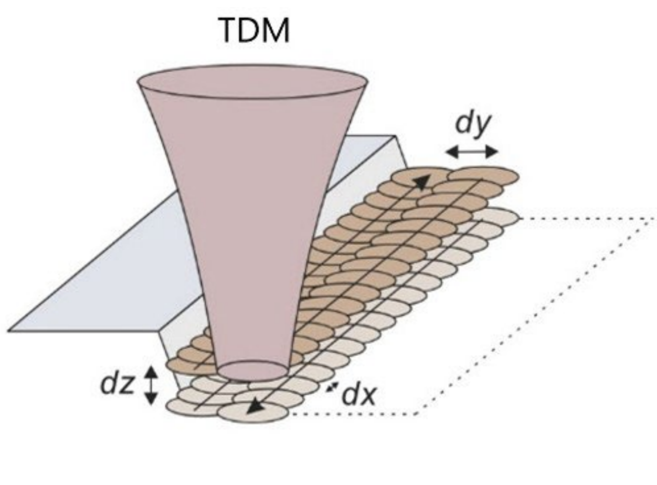


Figure 4. Illustration of TDM and BUM

Glass can be processed in various ways, with the most conventional and widely used method being **top-down milling (TDM)**. This approach removes material layer by layer, making it well-suited for producing fine features. However, its effectiveness is limited when creating high-aspect-ratio geometries, as ablation debris accumulates quickly, restricting further material removal.

An alternative is **bottom-up milling (BUM)**, where the laser is focused at the bottom surface of the sample. This technique not only allows ablation products to be efficiently removed through the backside but also benefits from burst mode processing. By extending the burst duration, material can be removed in larger chips rather than through evaporation, significantly increasing removal throughput.

By utilizing **MHz+GHz burst mode** in combination with BUM, process throughput was significantly increased from 5.17 mm³/min to **619.5 mm³/min**. While this results in a higher surface roughness (S_a=4.3 μm) compared to single-pulse with TDM (S_a=191 nm), it also highlights the versatility of the **FemtoLux 30**. The ability to switch between single-pulse mode for fine feature formation and burst mode for high-speed rough machining provides a powerful advantage, allowing users to optimize the process based on specific application needs.

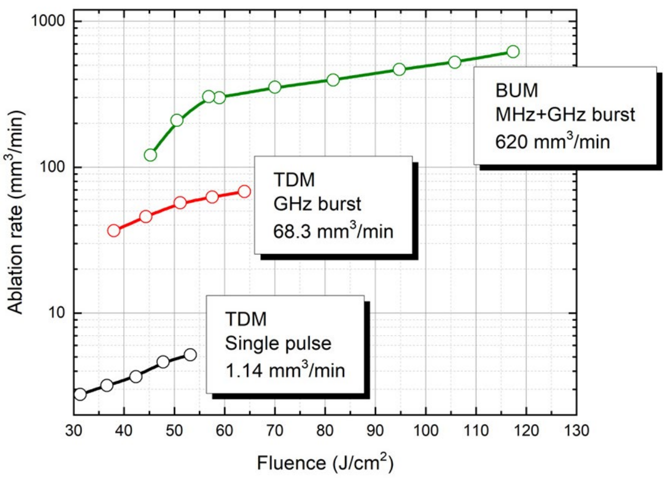


Figure 5. Graphical representation of ablation rate dependence on fluence at different operation modes

Table 1. Ablation efficiency and rate at different operation modes

Operation mode	Ablation efficiency, mm³/min/W	Ablation rate, mm³/min
Single-pulse (TDM)	0.27	5.17
GHz burst (TDM)	3	68.3
MHz+GHz burst (BUM)	27.78	619.5

As a demonstration of the **FemtoLux 30**'s capabilities, a **micro-lens array** was selected for fabrication. The micro-lens array was 25×25 mm^2 with 50 lenses of 5 mm curvature radius. The process involved multiple steps, beginning with the cutting of the device base from a thick fused-silica glass plate. Using burst mode in combination with BUM, the part was processed in just **13 minutes**, achieving an ablation rate of **180 mm^3/min**.

Next, the lens array was ablated on the surface of the substrate by using a **finer machining parameter set**, leveraging the **FemtoLux 30**'s flexible burst mode configuration to achieve a surface roughness of **0.5 µm (Sa)**. Finally, CO_2 laser polishing was applied to polish the surface to optical quality, achieving a surface roughness of **23 nm**.

This application note highlights the **versatility** of the **FemtoLux 30**, demonstrating how various processing modes can be effectively combined to manufacture **free-form micro-optical elements** with both high precision and high throughput.

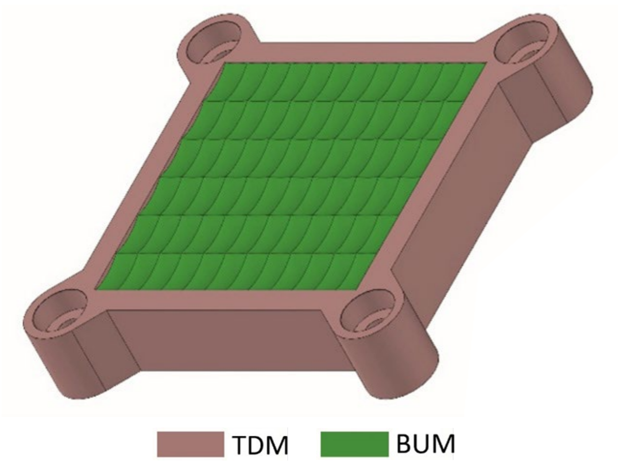


Figure 6. Schematic of micro-lens array

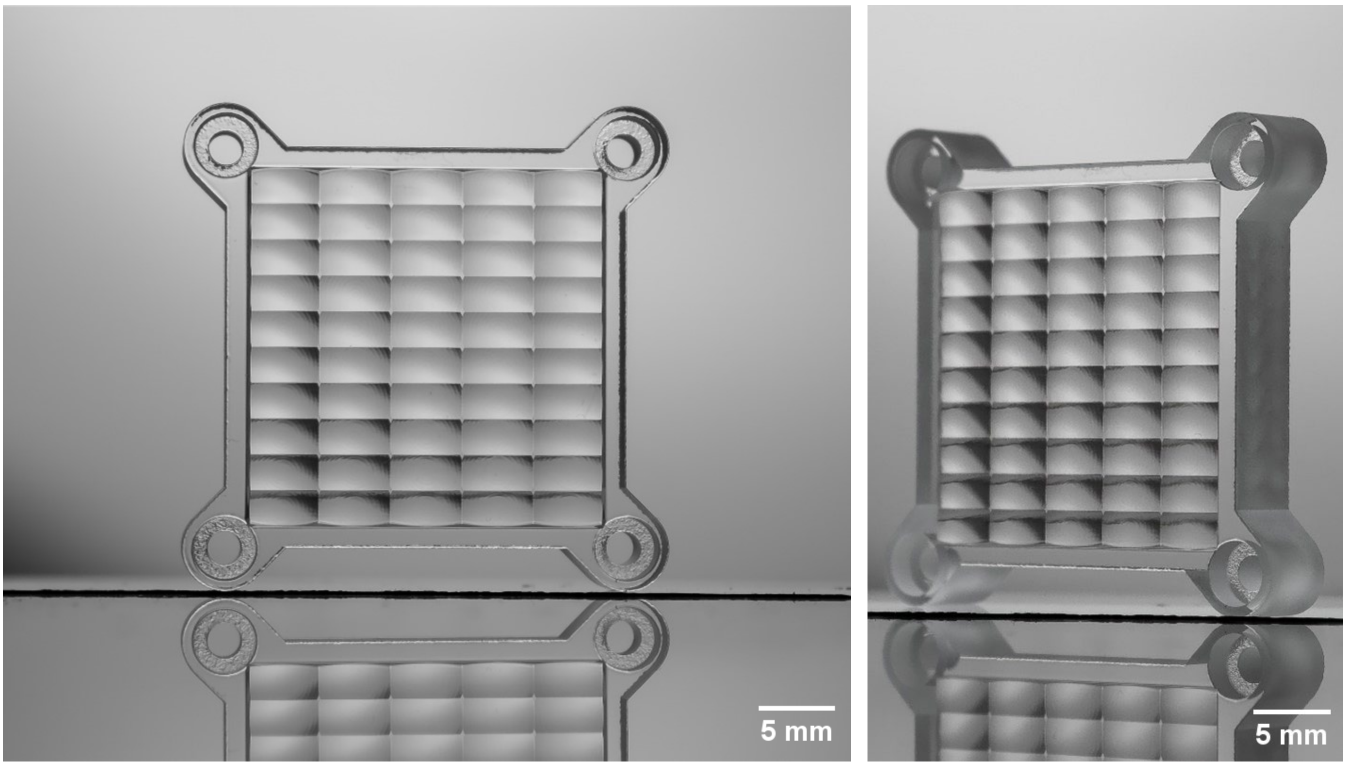
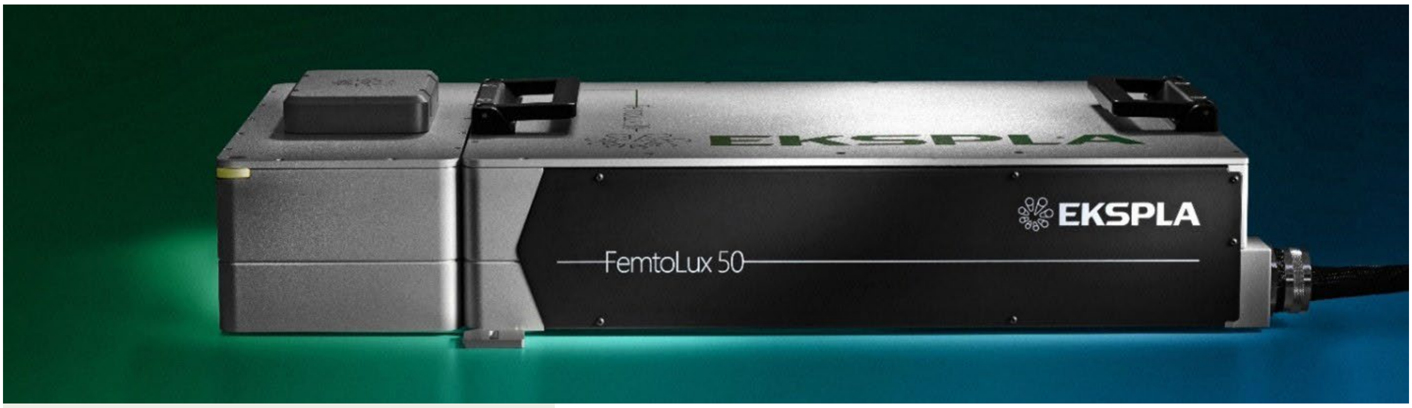


Figure 7. Micro-lens array fabricated with hybrid laser processing method using the FemtoLux 30

FemtoLux – Industrial Femtosecond Lasers



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)

$M^2 < 1.2$

Beam circularity > 0.85

FemtoLux is designed from the get-go for maximum reliability, seamless integration and non-stop **24/7/365 zero maintenance operation** with innovative dry cooling. Wide range of options enable to tailor this ultrafast laser for desired material processing tasks.

Application fields

/ Through glass vias (TGVs) manufacturing

/ Thin glass cutting

/ Nitinol stent processing

/ Microelectronics manufacturing

/ Heat-sensitive polymer cutting

/ Scribing of thick glasses

/ Black/color marking of medical tools

Ready to take your application to the next level?
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