Laser Micromachining Solutions and Technologies
**Workshop of Photonics** is all about ultrashort laser micromachining.

We develop instruments and solutions for ultrashort laser micromachining tasks. From feasibility studies to laser micromachining workstations and industrial solutions.

Our services are targeted to both industrial and academic customers.

**Our key competencies:**
- Feasibility studies on ultrashort laser micromachining
- Development of custom ultrashort laser micromachining workstations and optical modules
- Laser system automation software

Our know-how growth is fueled by culture of open innovations and partnership with Lithuanian laser sector companies and worldwide partners.

*Workshop of Photonics* is constantly working on projects connecting scientific inventions with the industry needs.

www.wophotonics.com

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1. Services

*Workshop of Photonics* cooperation with customer usually starts with a demand to perform a specific micromachining task.

The first step is a feasibility study which means that our company prepares samples for a customer to showcase achieved results and prove feasibility of laser processing. Regarding customer requirements it may lead to a small scale production if this is only a one time request. For a more demanding customer feasibility studies would lead to a laser process development - the solution how to prepare the samples would be developed together with a customer.

Pinnacle of the cooperation with the customer is designing and manufacturing custom system for a laser micromachining task. It is a customer’s choice how far to go down the steps of cooperation with *Workshop of Photonics*.

### 1.1. Feasibility Studies

The essence of feasibility study is to demonstrate that customer’s problem can be solved using ultrashort pulsed laser micromachining technology and that it has advantages over competing technologies. *Workshop of Photonics* laboratories are fully equipped and ready to process various materials with femtosecond and picosecond lasers and achieve desired results.

**Feasibility studies are performed in following steps:**

1. Detailed task description
2. Samples received from the customer
3. Processing of samples
4. Evaluation of results
5. Preparation of report and sending it to the customer
6. Feedback from customer

![Fig. 1.1.1. Feasibility study in action](image)
1.2. Laser Process Development

Most of laser micromachining applications are not as straightforward as for example marking. Most of them require development that takes weeks and even months. Not only different laser parameters have to be tested but also various beam shaping and focusing solutions.

A typical approach for a comprehensive process development contains following steps:

- testing of different wavelengths in order to explore light-material interaction
- testing of different focusing conditions
- selecting and testing most suitable positioning solution
- determining what is required for repeatability and required speed of process
- optimizing software functionality for convenient process control

Every customer is welcome to contact us with specific micromachining tasks. We are committed to develop a micromachining process. If a task is more demanding, we are ready to involve our academic partners in search of a solution.

Fig. 1.2.1. Self breaking of glass after laser cutting process

1.3. Small Scale Production

Laser micromachining technologies are perfect solution for specific tasks in material processing. High accuracy, great repeatability, high speed and ability to fabricate difficult objects with submicron resolution are just few advantages of laser processing.

However, if purchasing laser micromachining workstation is not the option at the moment, consider using our laser job shop services. Our laser laboratories are equipped with several laser workstations, using femtosecond and picosecond laser pulses.

We are also able to access laboratories of our partners if different laser capabilities are required for your specific purpose.

A small batch of articles may be fabricated in our laser laboratories according to your requirements.

Fig. 1.3.1. Small scale production examples
1.4. Joint Research Projects

Workshop of Photonics have already participated in several joint research projects using laser technologies with partner companies aiming to develop interdisciplinary products and technologies. Combining our knowledge and abilities with our partners, we are able to put advantages of several scientific fields into a whole.

Our team is open minded, eager to broaden their knowledge, and also interested to get more experience in various fields. Our laboratories are fully equipped with laser micromachining workstations.

Results of joint research projects using laser technologies:

- S-waveplate
- FemtoLAB MPP
- Beam Shaping Unit BSU

Let us know if there is a prospect for joint research projects using laser technologies – we are ready to become your successful partner.

2. Products

2.1. Laser Systems for Laboratories

Workshop of Photonics develops customized laser micromachining workstations - devices that fully meet customer’s requirements in laboratories for scientific research or R&D centers.

System configuration is carefully selected based on customer requirements.

Main components:

- Laser source
- Sample positioning system
- Beam delivery and scanning unit
- Laser power and polarization control
- Software for system control
- Machine vision
- Sample holders and special mechanics
- Sample handling automation (optional)
- Optical table
- Enclosure
- Dust removal unit

We provide a custom solution for every laboratory. A proven flexibility of FemtoLAB concept allows to further expand and upgrade the system when new requirements arise.
FemtoLAB is a femtosecond laser micromachining system for scientific laboratories. Equipped with high accuracy linear positioning stages, high performance galvanometer scanners and versatile micromachining software SCA, FemtoLAB becomes an entire laser laboratory on an optical table.

**Features:**
- Custom design
- End user selected laser source
- Efficient beam delivery and power control
- Highest quality optical components
- High accuracy positioning stages
- Additional non-standard equipment can be integrated on request

**Specifications:**
- Pulse duration: from 200 fs to 10 ps
- Repetition rate: from 1 kHz to 1 MHz
- Average power: up to 20 W
- Pulse energy: up to 2 mJ
- Wavelengths: 1030 nm, 515 nm, 343 nm, 258 nm, 206 nm
- Positioning accuracy: ±250 nm
- Travel range: from 25x25 mm to 300x300 mm (larger on request)

**Applications:**
- Surface micro and nanostructuring, engraving, drilling, laser lithography and multiphoton polymerization, refractive index modification inside bulk of material, selective layer removal, cutting brittle materials, scribing transparent material, waveguide fabrication, other applications upon request.

FemtoLAB-MPP workstation is optimized for multiphoton polymerization (MPP) technology.

System layout and design is similar to standard FemtoLAB which can also be used for MPP application after minor modifications.

For rapid fabrication we recommend to have synchronized movement of scanner and positioning stages.

**Features:**
- High resolution 3D additive manufacturing (see page 31)
- Rapid prototyping
- Machine vision solution for samples recognition
- Commercially available photoresists
- Wide range of wavelengths with additional OPA
FemtoLAB-KIT

FemtoLAB-KIT is a unique micromachining system which can be installed next to customer’s ultrashort laser source. Depending on laser specifications this system can become a universal tool for micromachining of different materials. Machine vision and user friendly software allows to perform various micromachining tasks.

**Features:**
- XYZ high accuracy sample positioning
- Beam delivery and shaping for selected wavelengths
- Control of entire system through single-window software
- Easily extendable, custom design

**Applications (depends on customer’s laser):**
- Surface micro- and nano-structuring
- Selective ablation
- Micro-drilling
- 3D direct laser writing
- Refractive index modification
- Dicing and cutting
- Multiphoton polymerization (MPP)

Laser Micromachining Software SCA

SCA software makes fabrication tasks easy to write and fine-tune. It is customizable to fit special requirement of scientific or industrial applications.

**Key benefits:**
- Eliminated need to work with G-code
- WYSIWYG interface
- Convenient input of fabrication algorithms and mathematical commands
- Direct control of hardware: laser, positioning stages, galvanometric scanners, power attenuators and power meters, polarization rotators, machine vision and other dedicated peripheral devices

**Features of the software:**
- DXF, PLT, STL, BMP, SVG, AI file format import
- Data import from TXT or XML files
- Slicing and hatching of 3D object for 2.5D fabrication (see figure 2.1.5)
- Digital and analog I/O control
- Fabrication preview window
- Camera view in superposition with fabrication preview
- Machine vision (MV) module for sample position detection
2.2. Laser Systems for Industry

FemtoFAB is a turnkey femtosecond laser machine designed for specific industrial process. Configuration is selected and carefully tuned according to a specific application. System is protected by Class 1 equivalent laser safety enclosure and controlled through advanced SCA engineer software window.

Features:
- High process speed – up to 300 mm/s (more on request)
- Fabrication of complex objects with submicron resolution
- Minimal heat affected zone
- Precise object positioning with submicron accuracy
- High-performance galvanometer scanners
- Pulse density control
- Synchronization of laser pulses with moving object in space and time domains
- Unique software interface for control of all integrated hardware devices

Specifications:
- Pulse duration: from 200 fs to 10 ps
- Repetition rate: from 1 kHz to 1 MHz
- Average power: up to 20 W
- Pulse energy: up to 2 mJ
- Wavelengths: 1030 nm, 515 nm, 343 nm, 258 nm, 206 nm
- Positioning accuracy: ±250 nm
- Travel range: from 25x25 mm to 300x300 mm (larger on request)

Applications:
- Ceramics scribing, glass cutting, sapphire cutting, through glass via (TGV) drilling, solar cell manufacturing, birefringent pattern fabrication, other applications upon request.

Workshop of Photonics operates femtosecond laser micromachining process and implements it into customer’s production line or designs specialized workstation. System configuration will be selected to assure quality, speed and reliability of execution of the task.

Needs of industrial customers are rather different from those from an academic laboratory: speed, repeatability and efficiency are in focus. The whole system has to be built around the process.
BSU-6000 and BSU-8000

Beam Shaping Unit (BSU) is designed to create round or square laser spots with uniform flattop intensity distribution.

BSU-6000 and BSU-8000 are developed to operate in combination with customer’s scanning optics, but can also be offered as a complete system. It is based on refractive field mapping beam shaper πShaper.

Requirements for the customer’s laser

- **Wavelength**: 257-1064 nm
- **Pulse duration**: ns, ps, fs
- **Mode structure**: TEM₀₀ or multimode
- **Intensity distribution**: Gaussian
- **Input beam diameter**: 6.35 ±0.05 mm
- **Spot shape**: Depends on aperture shape
- **Spot size**: - depends on magnification of the composed imaging system being defined as ratio of focal lengths of F-theta lens and internal collimator, - variable in case of Iris diaphragm

Specifications

- **Power losses**: <15%
- **Flattness**: >95% for TEM₀₀ beam
- **Final spot diameter (on the focus plane of F-theta)**: 100±10 μm

BSU installation

![A principal optical scheme of BSU installation](image)
2.3. Special Optics

S-waveplate - Radial/Azimuthal Polarization Converter (RPC)

S-waveplate is a spatially variable waveplate which converts linear polarization to radial or azimuthal polarization. The product is unique for its high damage threshold 100 times exceeding alternative devices*. Unique results are achieved by forming birefringent nanogratings inside a bulk of fused silica glass. Product developed in collaboration with Prof. Peter G. Kazansky group from Optoelectronics Research Centre at Southampton University.

* According to ISO 11254 – 2 is θ_{1000\text{-ex}} = 22.80 ± 2.74 J/cm², at λ = 1064 nm, τ = 3.5 ns, f = 10 Hz.

Features:
- Converts linear polarization to radial or azimuthal
- Converts circular polarization to optical vortex
- High damage threshold
- 55-90% transmission (wavelength dependent)
- Large aperture (up to 15 mm; standard is 6 mm)
- Continuous pattern - no segments

Standard S-waveplate models are available for 1030 nm, 515 nm, 800 nm and 1550 nm wavelengths. Dielectric anti-reflection coatings can be applied on both converter sides to further increase converter transmission. Custom wavelength (from 400 nm to 2000 nm) converters are available at request.

Applications
- STED microscopy
- Micromachining
- Micromachining high-aspect-ratio channels
- Generate any cylindrical vector vortex
- Multiple particle trapping
- Micro-mill driven by optical tweezers
- Use as intracavity polarization-controlling element in cladding-pumped ytterbium doped
- Observation of photonic spin Hall effect with rotational symmetry breaking
- Realization of polarization evolution on higher-order Poincaré sphere
- Direct transformation of linearly polarized Gaussian beam into vector-vortex beams with various spatial patterns

Fig. 2.3.1. S-waveplate fabricated for 632 nm, clear aperture 8 mm. Cross polarized light photo

Fig. 2.3.2. Measured incident beam intensity distribution (left), S-waveplate (center), radial/azimuth polarization beam intensity distribution after S-waveplate
Custom Spatially Variable Waveplates

We can fabricate custom spatially variable waveplates (half-wave or quarter-wave) for tailored polarization conversion and beam shaping. We can inscribe spatially varying fast axis angle pattern according to your function. Various custom spatially variable waveplates examples are shown in fig. 2.3.3.

**Features**
- custom spatially variable fast axis and/or retardance patterns
- wavelength range from 400 nm to 2000 nm
- half-wave or quarter-wave converters available
- size from 1 mm to 20 mm
- transmission from 40% to 90% (wavelength dependent)

Spatially Variable Waveplate for Flat-Top Conversion

Combination of a spatially variable waveplate and a polarizer acts as a spatially variable transmission filter and can be used to transform an initially Gaussian beam to a flat-top beam. It is a spatially variable phase retardation plate inscribed inside bulk of fused silica glass by femtosecond laser pulses. Combination of a spatially variable waveplate and a polarizer acts as a spatially variable transmission filter (patent pending) and can be used to transform an initially Gaussian beam to a flat-top beam with efficiency of more than 50% of initial laser power.

Converter allows for on-the-fly adjustment of the beam shape from flat-top to a shape with a dip in the middle. Converter is compatible with high power ultrashort lasers.

**Features:**
- Conversion of Gaussian beam to a flat-top beam
- High damage threshold
- Conversion efficiency up to 60% (wavelength dependent)
- Large aperture (up to 15 mm; standard is 6 mm)

**Applications:**
- Laser micromachining
- Laser pump shaping
3. Technologies

3.1. WOP Laser Technology for Cutting Glass and Sapphire

Workshop of Photonics has developed a state of the art glass and sapphire cutting technology to meet new challenges arising from new materials and requirements. Our technology enables dicing glass or sapphire from 30 μm to 1.3 mm thick with process speed from 100 mm/s to 1000 mm/s. Straight and curved cuts can be performed in the same step.

Processing steps for tempered glass:
1. A flat sheet of glass has to be positioned under the laser beam in the approximate beam focus distance.
2. Depending on the thickness of glass, one or two passes per trajectory might be needed.
3. Surface position tracking is advised for large area samples.
4. Sheet of glass is removed from the machine. Two alternatives are possible for cleaving:
   a. Initiation of self cleaving, by creating temperature gradient in the sample – slightly heating or cooling one side of the sample.
   b. Sample can be left for several minutes untill self-cleaving happens without initiation.

Processing steps for non tempered glass and sapphire:
1. A flat sheet of glass/sapphire has to be positioned under the laser beam in the approximate beam focus distance.
2. Depending on the thickness of sample, one or two passes per trajectory might be needed.
3. Surface position tracking is advised for large area samples.
4. Since non tempered glass and sapphire do not have internal tension, cleaving does not happen on itself and has to be initiated. This can be done mechanically (bending sheet along the scribing lines) or a different method might be developed.

Technology was tested on a variety of glass and sapphire samples provided by various suppliers.

Processing parameters
Process is optimized for each type of glass/sapphire that is used. Processing window is quite wide and can be set up easily according to these parameters:

- Straight and round cut trajectories
- Thickness of tempered glass: 0.3 – 1.3 mm
- DOL of tempered glass: 10 – 80 µm
- Thickness of non-tempered glass: 0.03 – 1 mm
- Thickness of sapphire: 100 – 760 µm
- Speed of cutting (tested): 200 mm/s
- Speed of cutting (extrapolated): 800 mm/s
- Cut surface roughness: R<sub>a</sub> < 1 µm

Different processing parameters might be developed for specific inquiries.
3.2. Heat Sensitive Materials Scribing

Ultrashort laser scribing shows the best results for heat sensitive materials fabrication. Ablated grooves seem to be homogeneous, and the wall of the groove least affected, when using special technology developed especially for this kind of materials.

**The fabrication features:**
- No heat affected zones and melting layers
- Grooves of less than 15 µm widths and more than 25 µm depth
- No overshooting in intersections
- Better than 0.5 µm accuracy within 40 mm area
- Fabricating up to 9 samples without any operator interference
- Controlling the fabrication process for up to 24 hours long and maintaining needed accuracy, compensating beam and mechanical drift within 0.5 µm.

3.3. Laser Micro Drilling

A solution has been developed at Workshop of Photonics that enables machining of holes with controlled (positive, zero, negative) taper in various materials at high drilling speed, good surface quality and a wide range of diameters (tens of micrometres to millimetres). Both transparent and absorbing materials can be drilled using femtosecond laser technology.

For reliable controlled taper drilling the depth to diameter ratio of 8:1 has been demonstrated so far, but every material has its own limitations and possibilities. Single point drilling or usual helical path drilling can produce holes of much higher aspect ratios than 6:1 (usually limited only by ablated material evacuation from extremely deep narrow holes) with typical taper angles of 4 deg. per side. Limited depth wells can also be machined with good bottom and sidewall quality depending on material and hole geometry.
3.4. 3D Additive Manufacturing

Fig. 3.4.1. Example of 3D microstructure

3D additive manufacturing, or multiphoton polymerization (MPP) is a unique technology for 3D structuring of micron scale objects with nanometer resolution developed with Vilnius University Laser Research Center. Femtosecond laser beam is focused inside a drop of photoresist polymer and desired pattern is “written” precisely. After photoresist is washed away the fabricated microstructures remains on the substrate (Fig. 3.4.2).

Features:
- Writing resolution: 200 nm – 10 μm
- Variety of polymers available
- Transparent 3D objects fabrication

Materials tested at Workshop of Photonics currently include but are not limited to:
- Polyimide
- Ruby
- Sapphire
- Schott AF32 glass
- Soda-lime glass
- Fused silica
- Various steels (stainless, chromium steel, plain carbon steel)
- Molybdenum alloy
- Hard ceramics (alumina, silicon nitride, CBN, others)

Examples of achieved results

<table>
<thead>
<tr>
<th>Thickness</th>
<th>Material</th>
<th>Hole diameter</th>
<th>Ellipticity</th>
<th>Taper</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 μm</td>
<td>glass</td>
<td>60 μm</td>
<td>&lt; 4 μm</td>
<td>~3 deg</td>
<td>0.25 s/hole</td>
</tr>
<tr>
<td>50 μm</td>
<td>glass</td>
<td>30 μm</td>
<td>&lt; 4 μm</td>
<td>~3 deg</td>
<td>0.25 s/hole</td>
</tr>
<tr>
<td>100 μm</td>
<td>sapphire</td>
<td>60 μm</td>
<td>&lt; 5 μm</td>
<td>~3.5 deg</td>
<td>0.22 s/hole</td>
</tr>
</tbody>
</table>

Fig. 3.3.3. 100 μm hole in ruby disc

Fig. 3.3.4. Square holes in SiN

Fig. 3.4.2. Fabrication process
Photoresist polymer materials

- Variety of photoresist materials with required features can be chosen
- No structural distortions
- Certain wavelength absorption
- Refractive index matching

Precise and controllable self-polymerization

Standard direct writing is able to make repeatable structures as small as 200 nm, though by employing self-polymerization effect, the smallest lines can be around 90 nm.

Identical structures can be fabricated by direct laser writing process but in order to save time and work for large area patterning stamping technique can be used.

Fabrication examples

1. Conventional minimized optical components

![Lenses](image1.png)
![Prisms](image2.png)
![Gratings](image3.png)
![Axicons](image4.png)

2. Free form 3D elements

![Spiral phase plates](image5.png)
![Segmented phase plates](image6.png)
![Fresnel lenses fraxicons](image7.png)

3. Arbitrary shape arrays of the micro optical components with 100 % fill factor

![Micro grids](image8.png)


![Example of fabricated grid](image9.png)
![Example of fabricated grid](image10.png)
3.5. Surface Texturing

Surface texturing can be applied to enhance various properties of surfaces or even induce new properties that material does not possess by itself, for example:

- Friction reduction/lubricant retention
- Diffractive structures for optical applications
- Micromolds for micro/nano feature replication
- Roughness modification
- Hydrophobicity/hydrophilicity
- Marking

Using femtosecond lasers texturing can also be performed on a variety of transparent materials both on the surface and in the volume.

4. Micromachining Examples

Processing of solar cells

Applications:
- Front contact formation
- Back contact formation

Edge isolation for solar cells

Selective dielectric layers removal for solar cells
- For novel emitter side metalization technologies
- For PERC technology

Laser marking of solar cells
Surface micro/nano structuring
- Up to 200 nm ripple period fabricated
- Individual nano-feature size on ripples: 10 – 50 nm
- Controlled period, duty cycle and aspect ratio of the ripples

Applications:
- Detection of materials with increased sensitivity using surface-enhanced Raman scattering (SERS)
- Bio-sensing, water contamination monitoring, explosive detection etc.

Metal surface structuring
- 3D structures formed on steel surface
- High precision and surface smoothness achieved

Cast iron surface ablation
- Surface texturing with micro holes and grooves
- Minimum heat affected zone

Application:
- Friction reduction between moving metal parts

Micromachining inside transparent materials
- Marking made inside a bulk of contact lens, preserving surface of lens and distortions
- Exact positioning of markings – 3D text format

Applications:
- Product counterfeit protection

Micro channel formation
- Wide range of materials – from glass to polymers

Applications:
- Microfluidic sensors
- Waveguides

Polycrystalline diamond (PCD) cutting
- Low carbonization
- Minimum heat affected zone
- Low material loss

Applications:
- Diamond sheet cutting
- Diamond texturing/patterning

Ablation of polycrystalline diamond (PCD)
- Ablated circle crater on the surface of PCD
- Smooth and even bottom of the crater

Application:
- Component of PCD cutting tools

Steel foil micro drilling
- No melting
- Micron diameter

Applications:
- Filters
- Functional surfaces
Datamatrix
- Data inscribed on a glass surface
- Extremely small individual elements, 5 µm in size

Application:
- Security marking

Micro drilling
- Borosilicate glass
- 150 µm thickness
- ~900 holes per mask
- Mask diameter 25.4 mm

Application:
- Selective coating
- Mask for beam splitter pattern deposition

Glass tube drilling
- Controlled damage and depth

Application:
- Medical needles

Ruby Drilling
- Precise control of hole geometry, diameter and taper angle
- High processing speed
- No cracks or burning effects

Glass holes drilling
- Various hole sizes with routine taper angle better than 5 deg
- Minimal debris around the edges of holes

Stent cutting
- Holes in stent wall, cross-section view
- Polymer stent
- No heat effect, no debris
- Minimal taper effect

Application:
- Vascular surgery

Fuel Nozzle drilling
- Controllable taper angle
- Variable geometry
Selective metal coating ablation
- Selective ablation of metal coatings from various surfaces

Applications:
- Beam shaping elements
- Optical apertures

![Chrome ablation from glass substrate](image)

Optical fiber drilling
- Diameter from <10 μm
- Various hole profiles possible
- Depth control

Applications:
- Optical fiber sensors

![Au layer ablation without damaging MgO substrate](image)

Optical fiber volume fabrication
- Light scattering
- No surface damage
- Even light dispersion

Applications:
- Medical fibers
- Oncology

![Micro marking inside a bulk or surface of transparent material](image)

Glass and sapphire cutting
- Minimum chipping
- High bending strength
- Crack direction control

![Glass and sapphire cutting](image)

Micro marking inside a bulk or surface of transparent material
- Very small or no cracks near markings
- Low influence on strength of the substrate

![Micro marking inside a bulk or surface of transparent material](image)

Micro lens fabrication on tip of fiber
- Matching refractive index
- Shape flexibility

Applications:
- Medical fibers
- Fiber collimators

![Micro lens fabrication on tip of fiber](image)
Micro cutting

- Submicron precision micro parts made of polycarbonate / polypropylene / poly (ethylene terephthalate)
- Minimal or no signs of heat affected deformation
- Excellent cut surface quality, sub-micron precision of shape

Glass micro-hole drilling

- Glass up to 320 µm thickness
- Hole entry diameter: 50 µm
- Hole exit diameter: 25 µm

Bragg grating fabricated in fused silica substrate

- Absolute diffraction efficiency up to 99%
- Refractive index modulation of up to 0.003
- Up to 1000 lines/mm
- Thickness of the grating of up to few millimeters
- Custom shape and size of the grating is available on request

Partners

Commercial partners

Academic partners
Participation in Exhibitions

**SPIE. PHOTONICS WEST**

13-18 February 2016
San Francisco, USA
**Stand** 5262, North hall D

**LASYS**

15-17 March, 2016
Shanghai, China
**Stand** 5232

**OPTICS & PHOTONICS International Exhibitor**

18-20 May 2016
Pacifico Yokohama, Japan

31 May - 2 June 2016
Stuttgart, Germany
**Stand** 4E59