Ultrafast Laser Processing Forum (Korea-Germany)

Advaced ps- and fs-Lasers and their Application in Precision Processing

Keming Du
EdgeWave GmbH, Carlo-Schmid-Str. 19, 52146 Würselen
Email: info@edge-wave.com; www.edge-wave.com

About us

Founded: 12.06.2001 as Spin-Off from Fraunhofer Institute of Laser Technology

Locations: Aachen Germany and Office in Shanghai

Facility: 3,200m², 1,000m² clean room

Staff: 43

Missions: *Edge* - Leading *Edge* Technology
Wave - Dynamic via continueous Invention und Innovation

Our Products

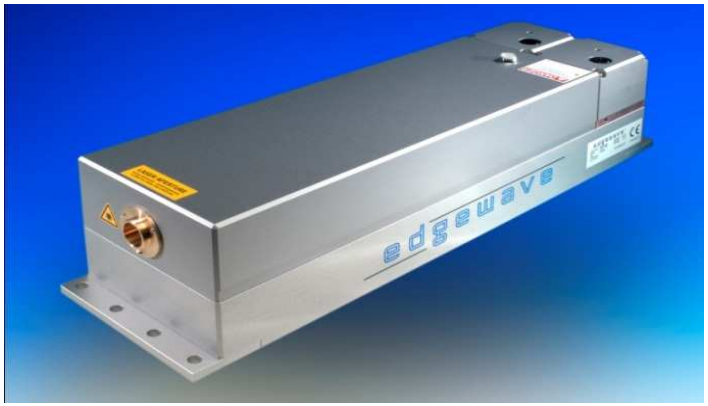
Ultra-short pulse laser: PX-series and FX-series

- beam quality: $M^2 < 2$
- pulse energy: up to 2mJ
- average power: up to 400W
- pulse length: down to 500fs
- repetition rate: up to 50MHz
- wavelength: 1064, 532, 355nm

Short pulse nano second laser: BX-series

- beam quality: $M^2 < 2$
- pulse energy: up to 50mJ
- average power: up to 600W
- pulse length: down to 1ns
- repetition rate: up to 150kHz
- wavelength: 1064, 532, 355nm

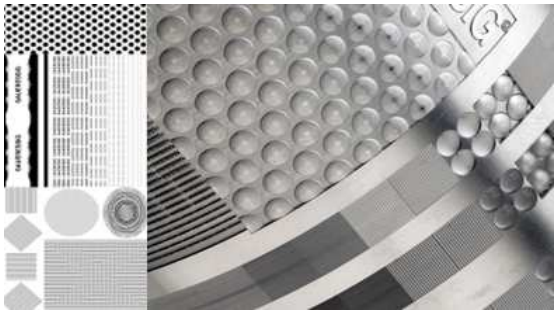
Short pulse nano second laser: IS-series



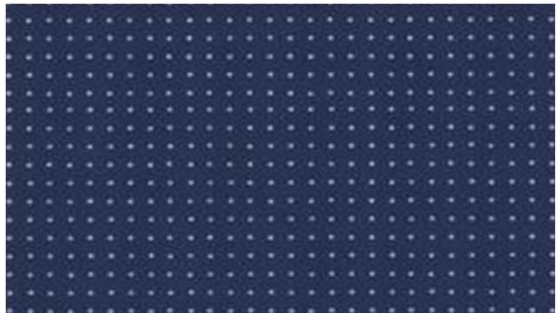
Applications and Market

Consumer Goods

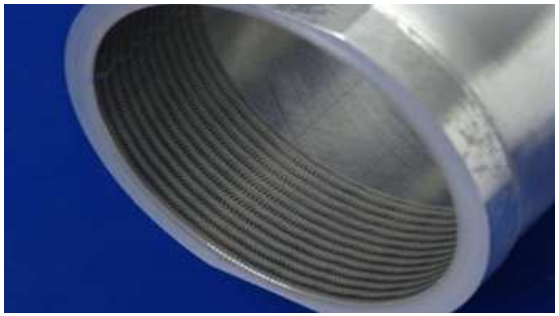
Display



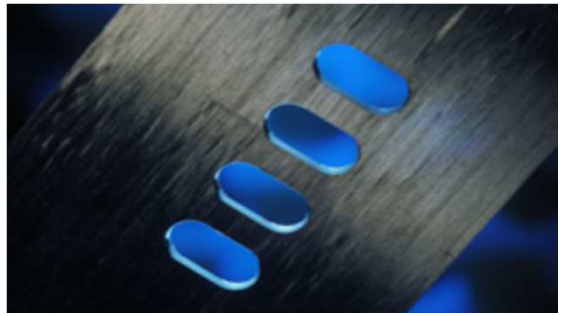
Printing



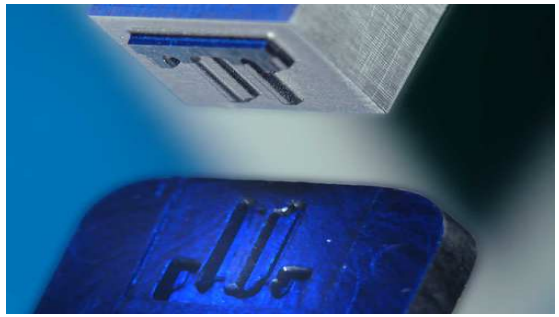
Electronics



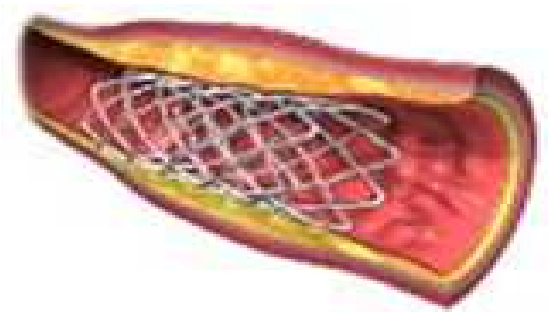
Automobile



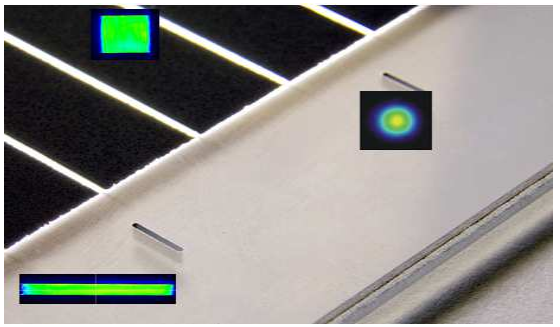
Aerospace



Rapid tooling



Medicine

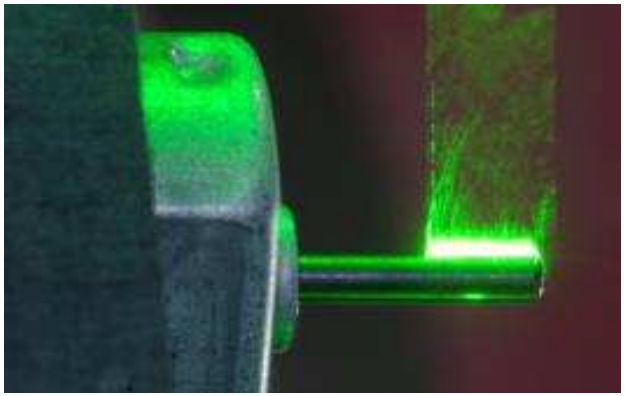


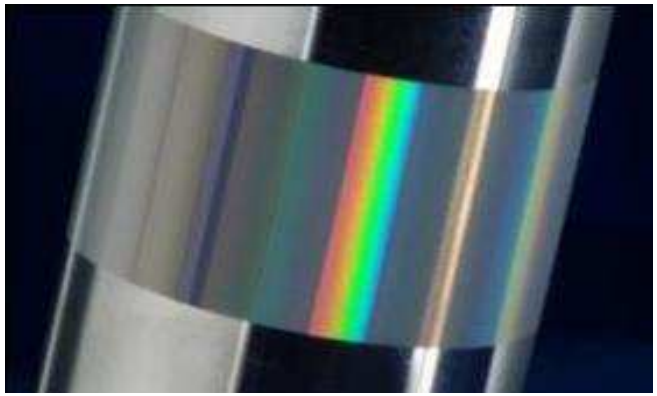
Energy

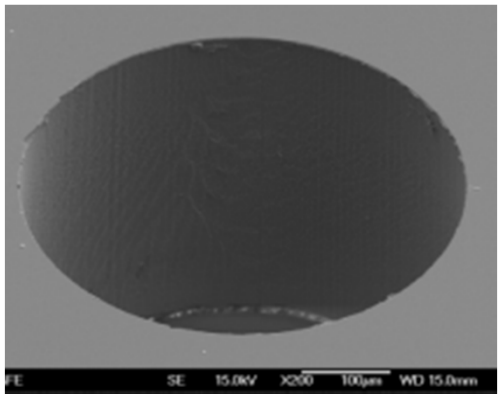
Our lasers have been sold to 41 countries and regions.

Content

Features of ultra-short pulsed Laser Machining

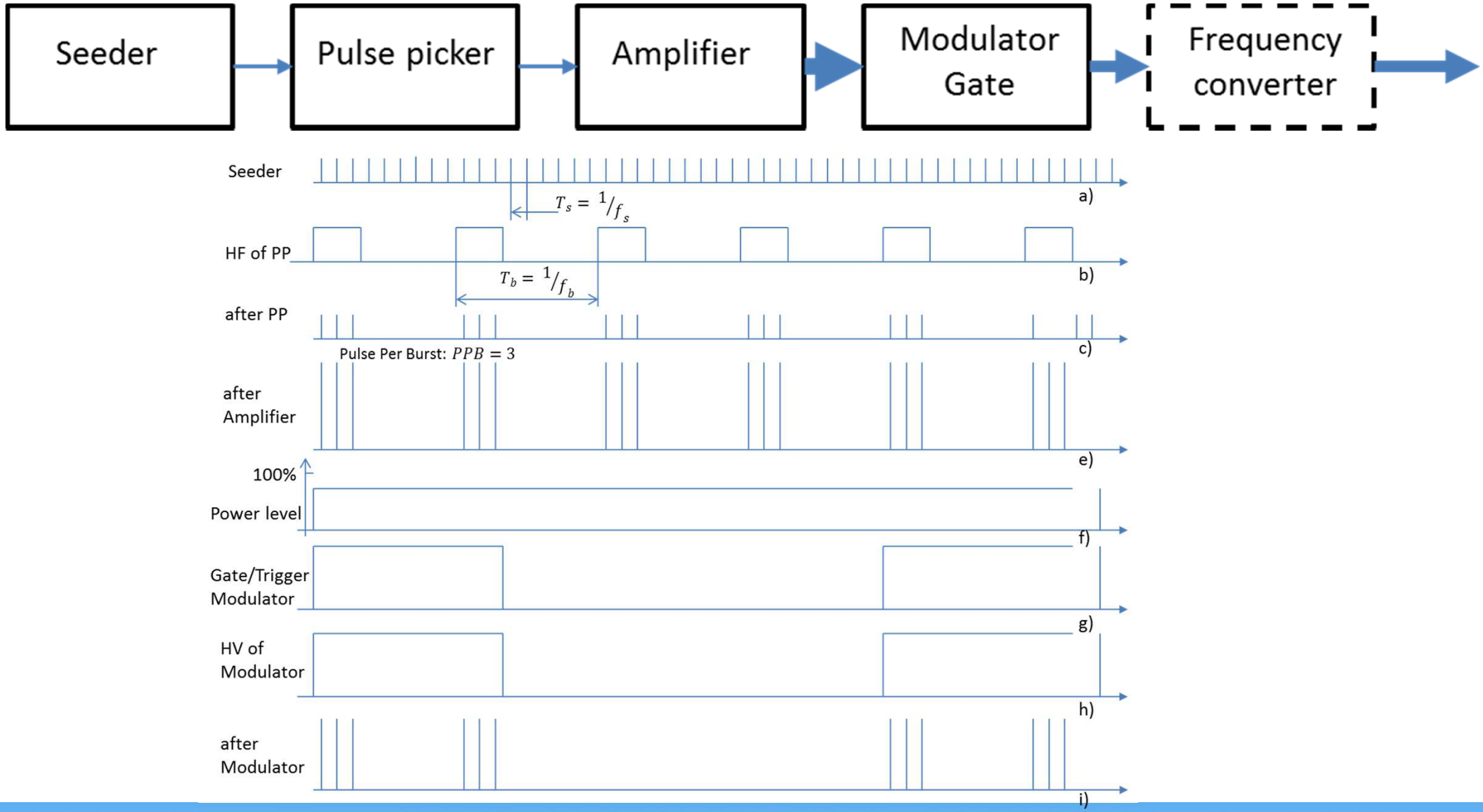






- **Flexible tool with no material dependance**
  - **Wide bandgap materials (Glass, Sapphire, Diamond)**
  - **Semiconductors (Silicon, GaAs, SiC)**
  - **Metals (WC, Steel, Copper)**
  - **Polymers**
  - **Biological materials**
- **High Accuracy**
  - **Sub 100 nm precision in ablation depth**
  - **µm and sub µm precision in lateral resolution**
  - **Material selective processing**
  - **In volume processing**
- **Tool independent processing**
  - **Tool-free, wear-free and resource-efficient**
  - **Almost no lead-time (Digital Photonic Production)**
  - **Universal application (due to high variety of parameters)**

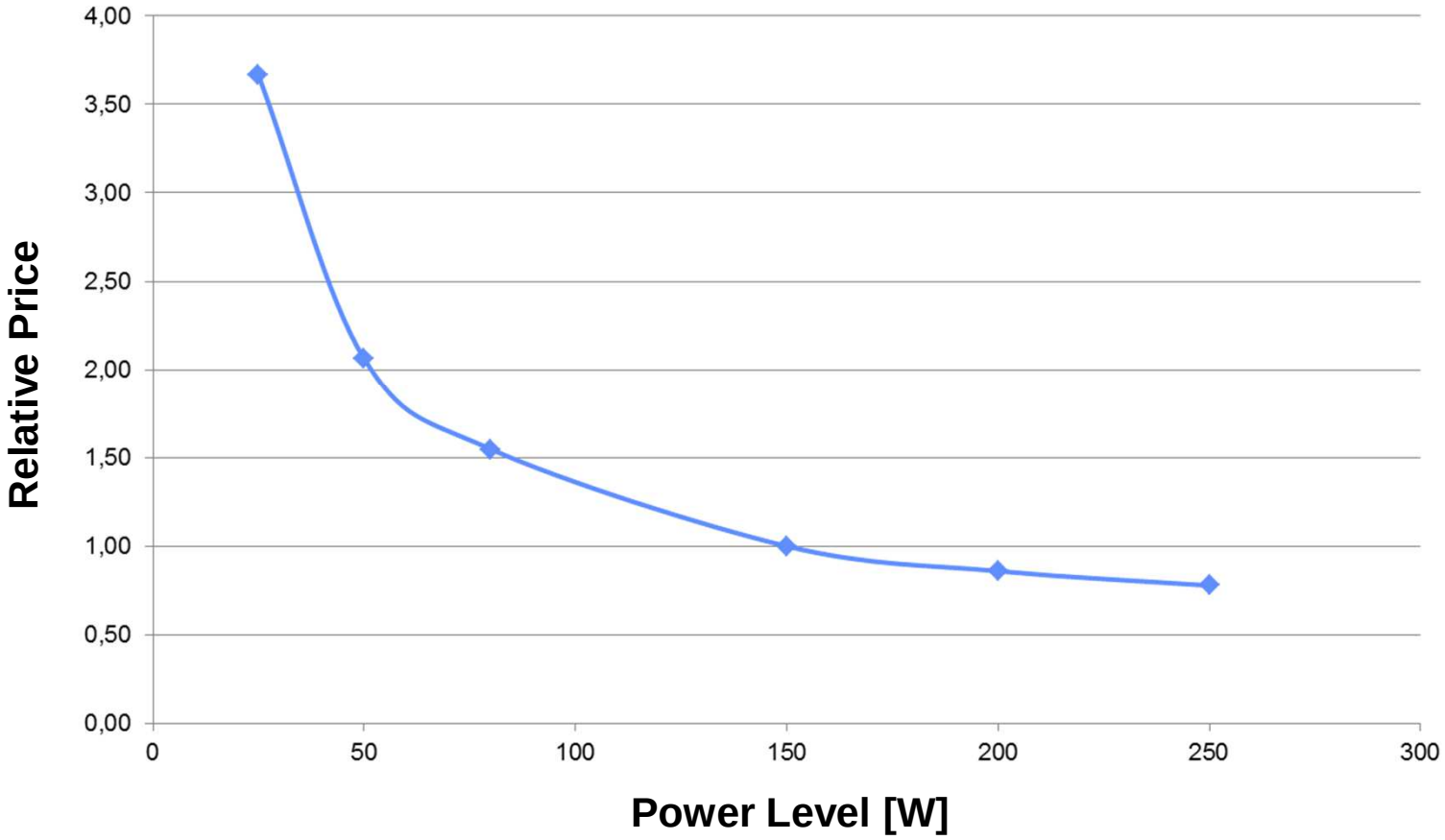
Scheme of High Power Ultra short Pulse Lasers



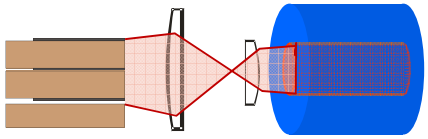
Cost Structure of ultra-short Pulse Lasers

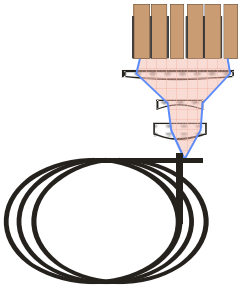
	Seeder	Isolator	Pulse picker	Stretcher	Amplifier	Compressor	Isolator	Modulator
ps-Laser	X	X	X		X		X	X
fs-Laser	X	X	X		X		X	X
fs-Laser h-energy	X	X	X	X	X	X	X	X

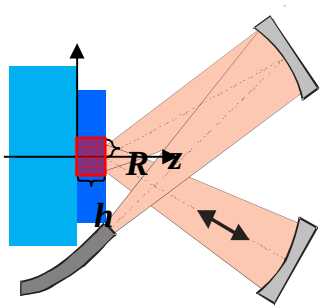
Degression of Price per Watt

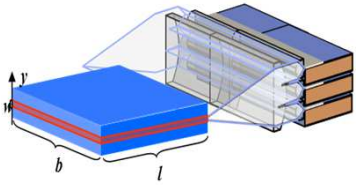


Concepts for Scaling of ultra-short Pulse Lasers



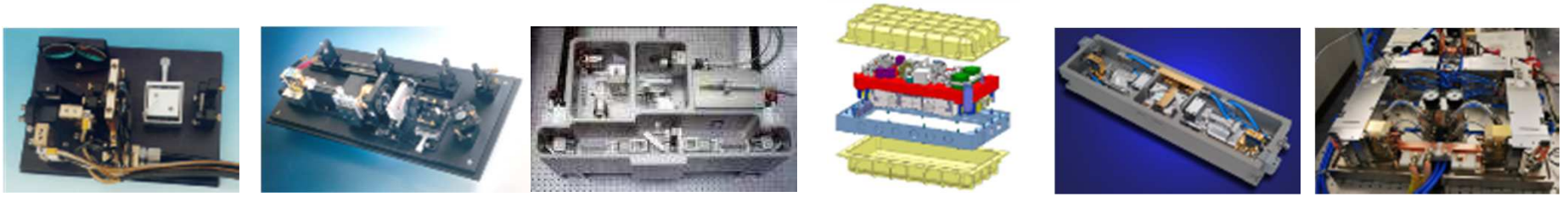




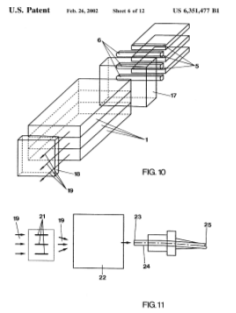


	Rod	Fiber	Thin-Disk	InnoSlab
Power scaling by	multi-rods	length	area	width
Waste heat removal	2D heat flow	large surface	1D axial heat flow	1D heat flow
Pumping	singe/double	fractional	multiple	single/double
Beam cross section	-	- -	+ +	+
Single pass gain	+	+ +	- -	+
Amplification	single/double	single	regenerative	single/multiple
Burst mode	yes	yes	No	yes
Rep rate limitation	no	no	yes	no

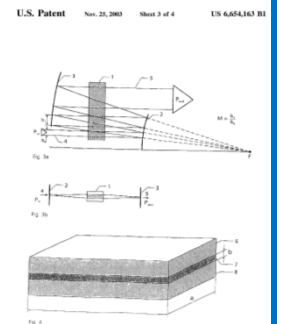
InnoSlab Platform – History



1994 1996 1998 2000 2002 2004 2006 2008 2010 2012



Patent partially pumped slab laser



Patent slab amplifier

edgewave

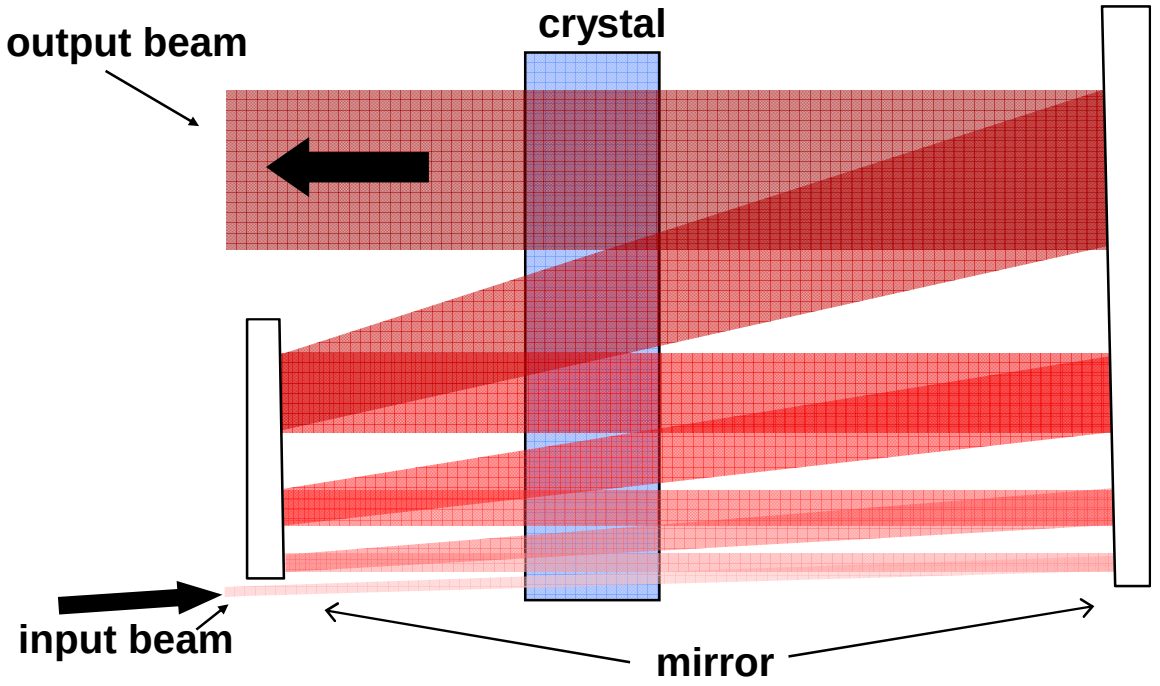
Foundation of EdgeWave 2001

AMPHOS

Foundation of AMPHOS 2010

InnoSlab Amplifier Scheme

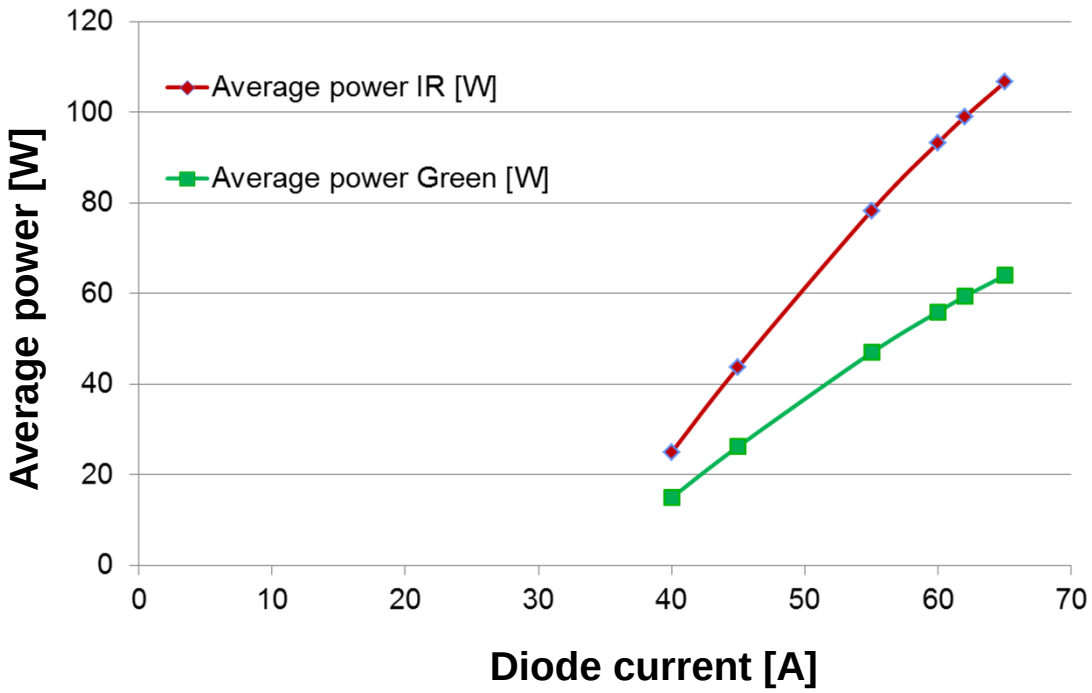
- Multistage amplifier within one single crystal
- High gain in single pass
- Efficient amplification by automatically fitting intensity to saturation
- Constant distance from damage limit

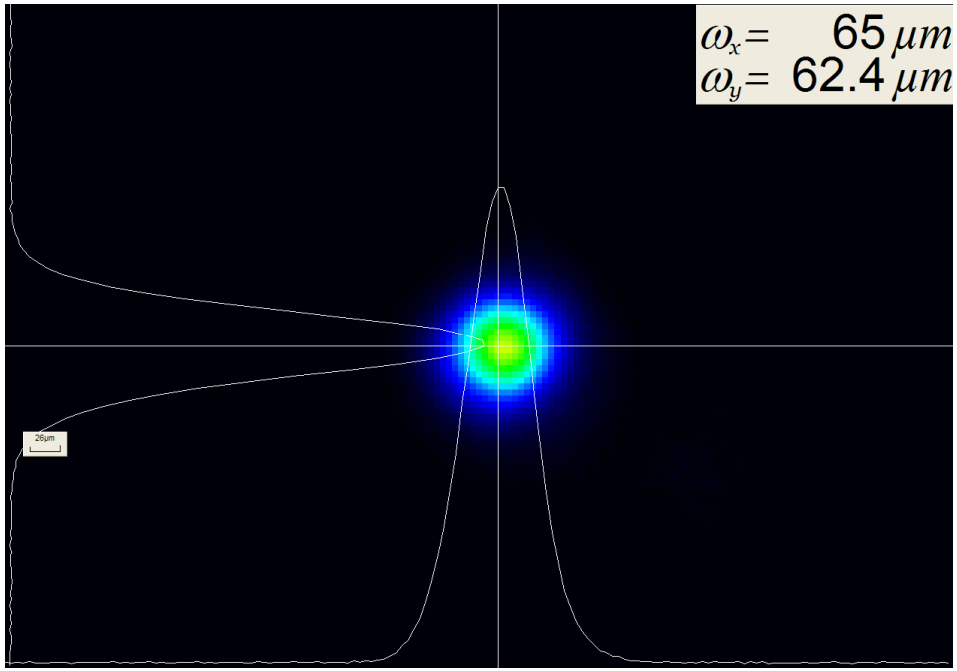


Average Output and beam profile of a ps-Laser PX100-2-GM

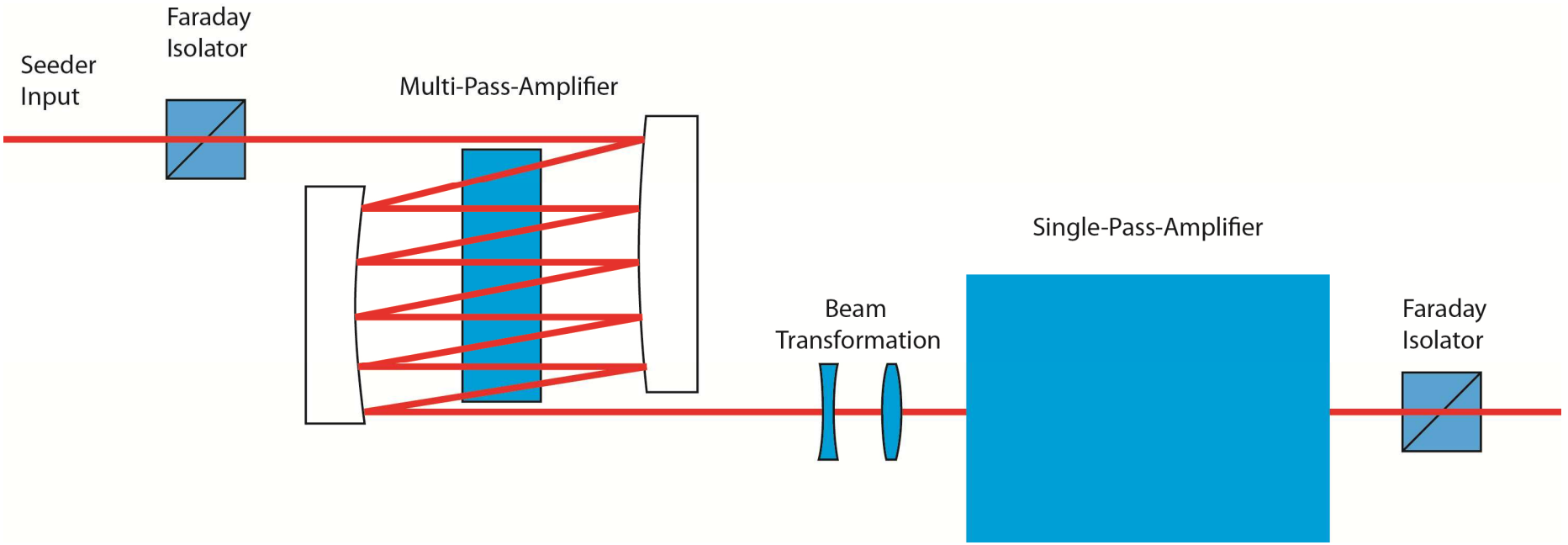
Pulse rep rate 2MHz
IR output power: 100W
Green output power: 60W

Beam quality
M^2 = 1.2 (horizontal)
M^2 = 1.2 (vertical)

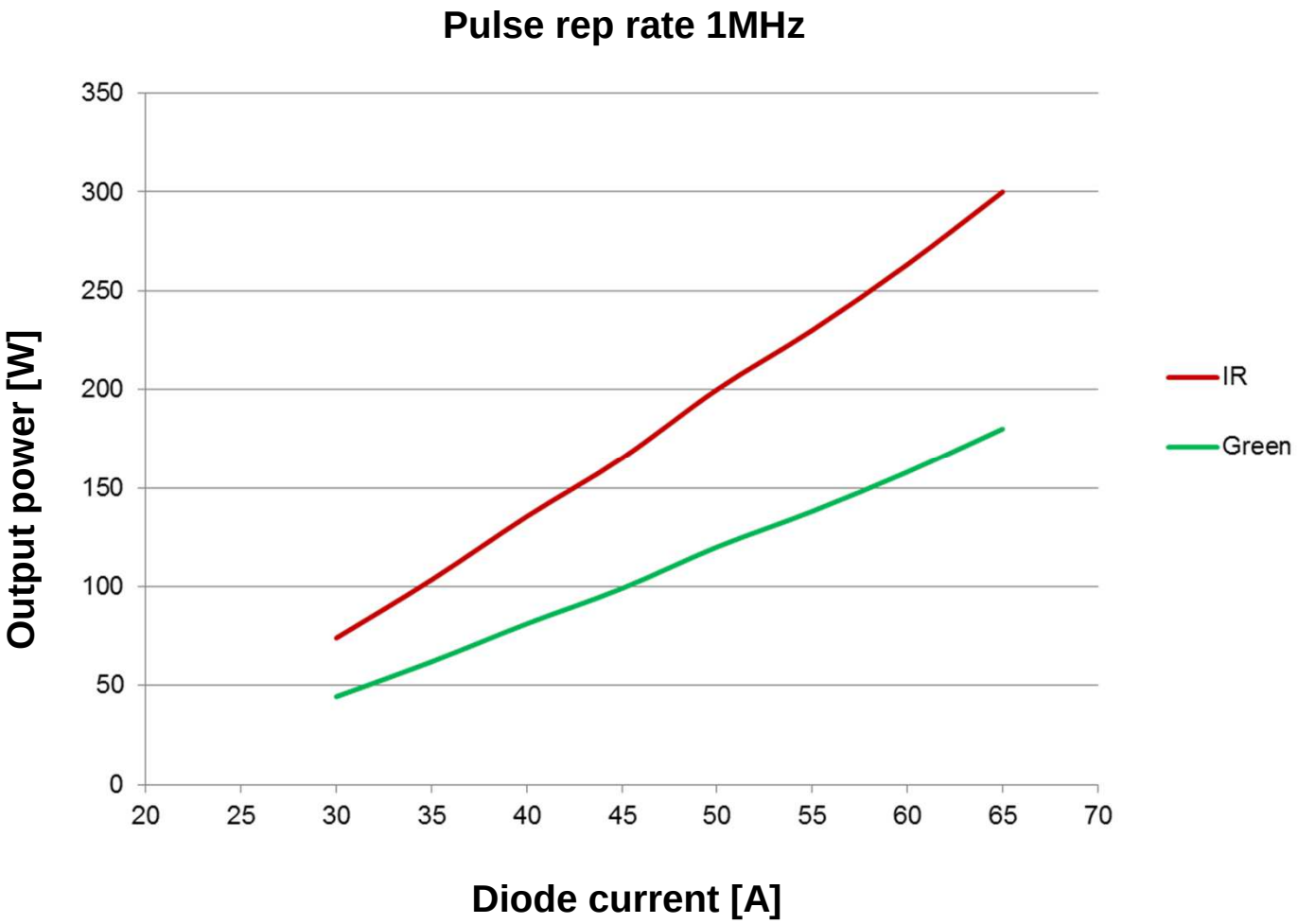


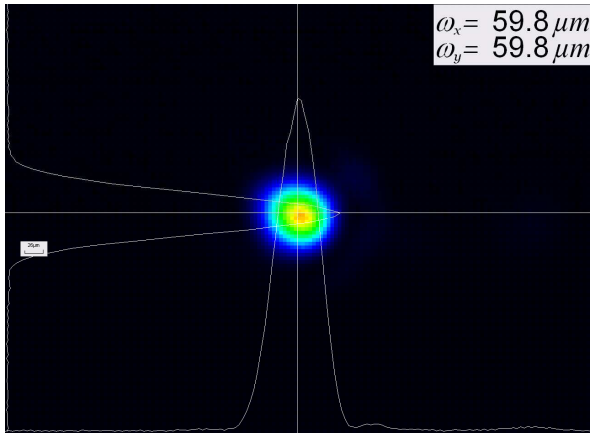


Layout of a 400W ps Laser System based on INNOSLAB Amplifier



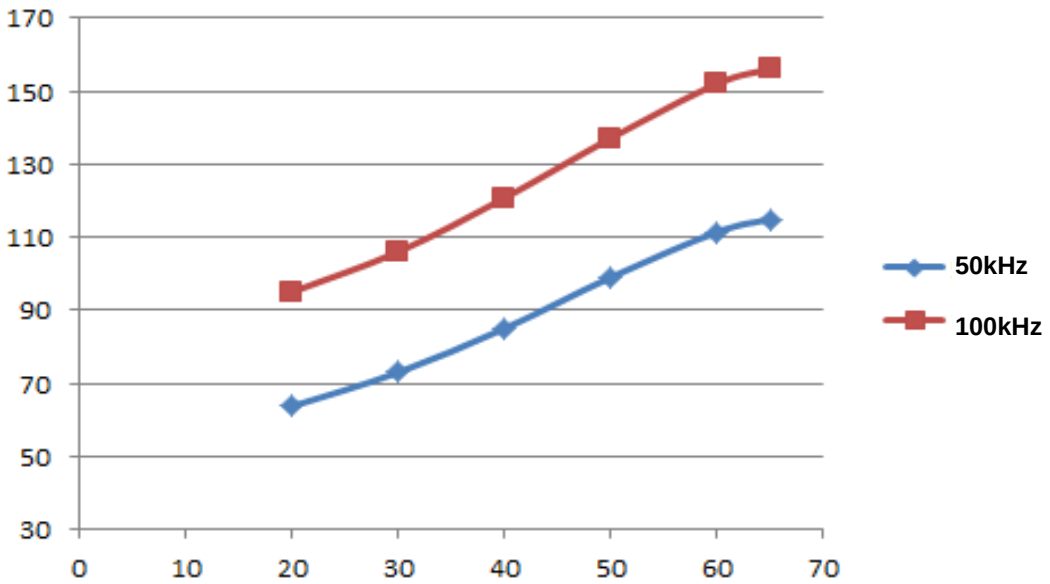
Output Power of PX400-1-GM with circular Gaussian Profile

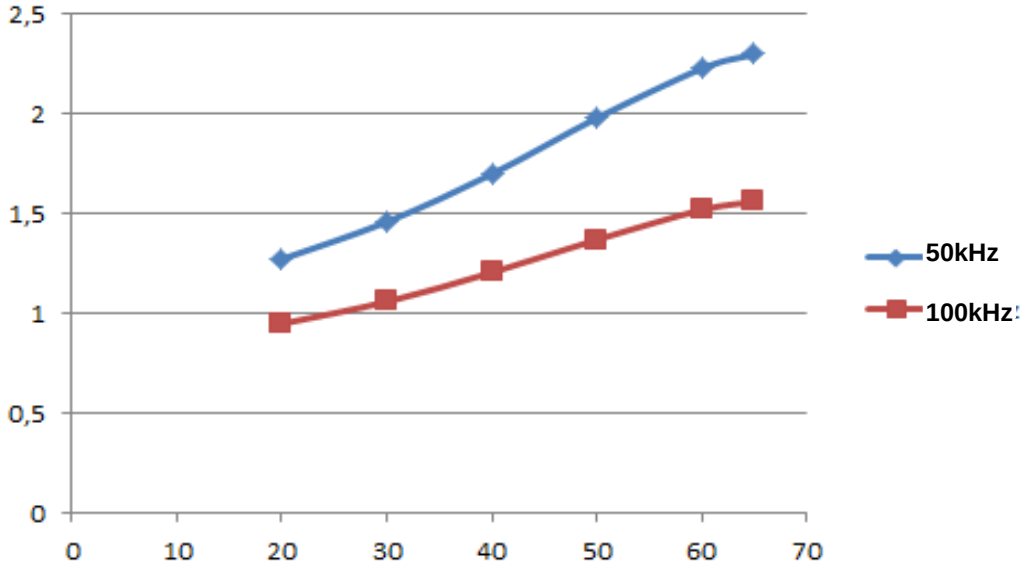




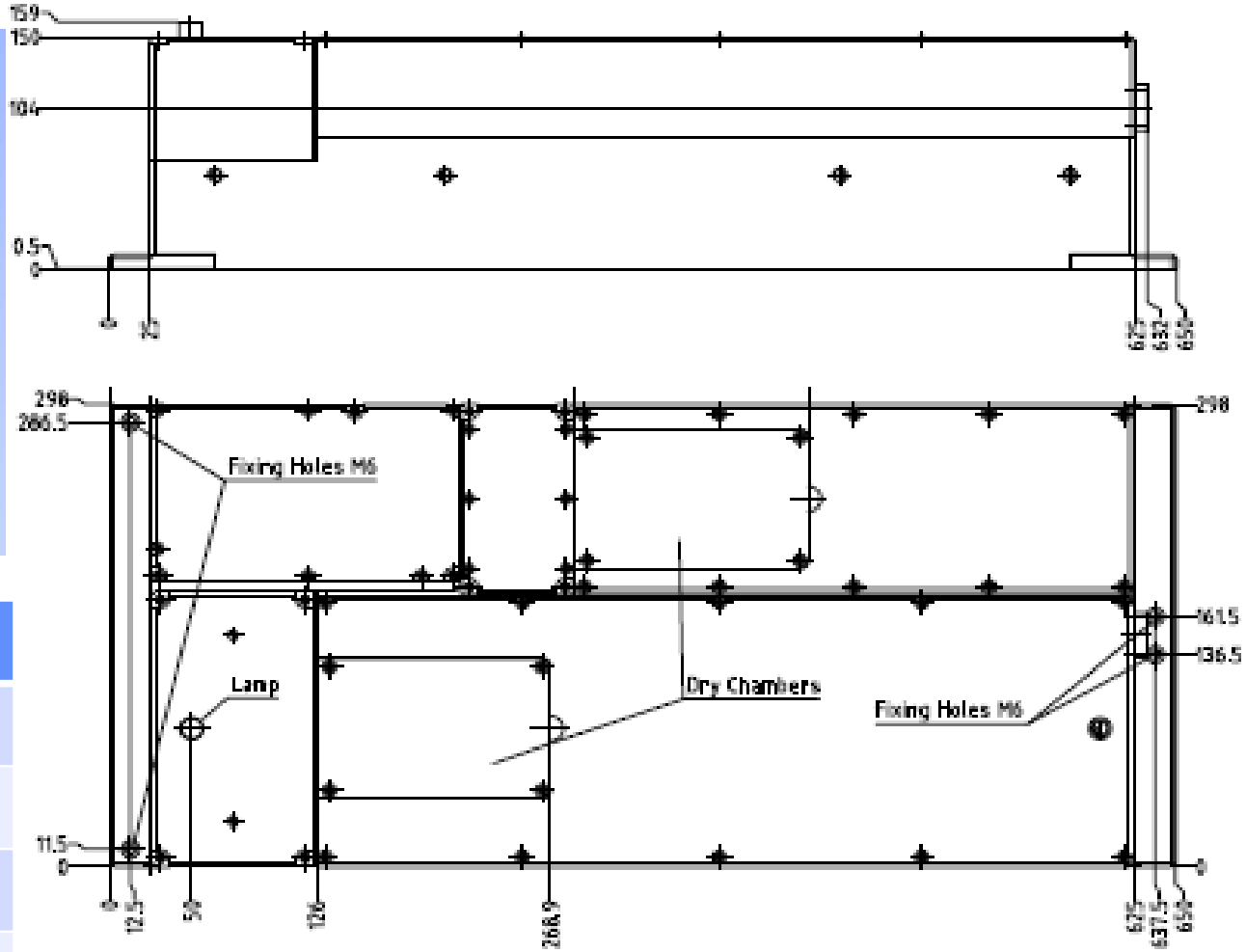
Pulse rep rate 1MHz
IR output power 300W
Green output power: 180W
Beam quality
M^2 = 1.5 (horizontal)
M^2 = 1.5 (vertical)

Scaling of Pulse Energy of ps Laser PX400-1-GM





Compact Ultra short Pulse InnoSlab Laser PX-Series

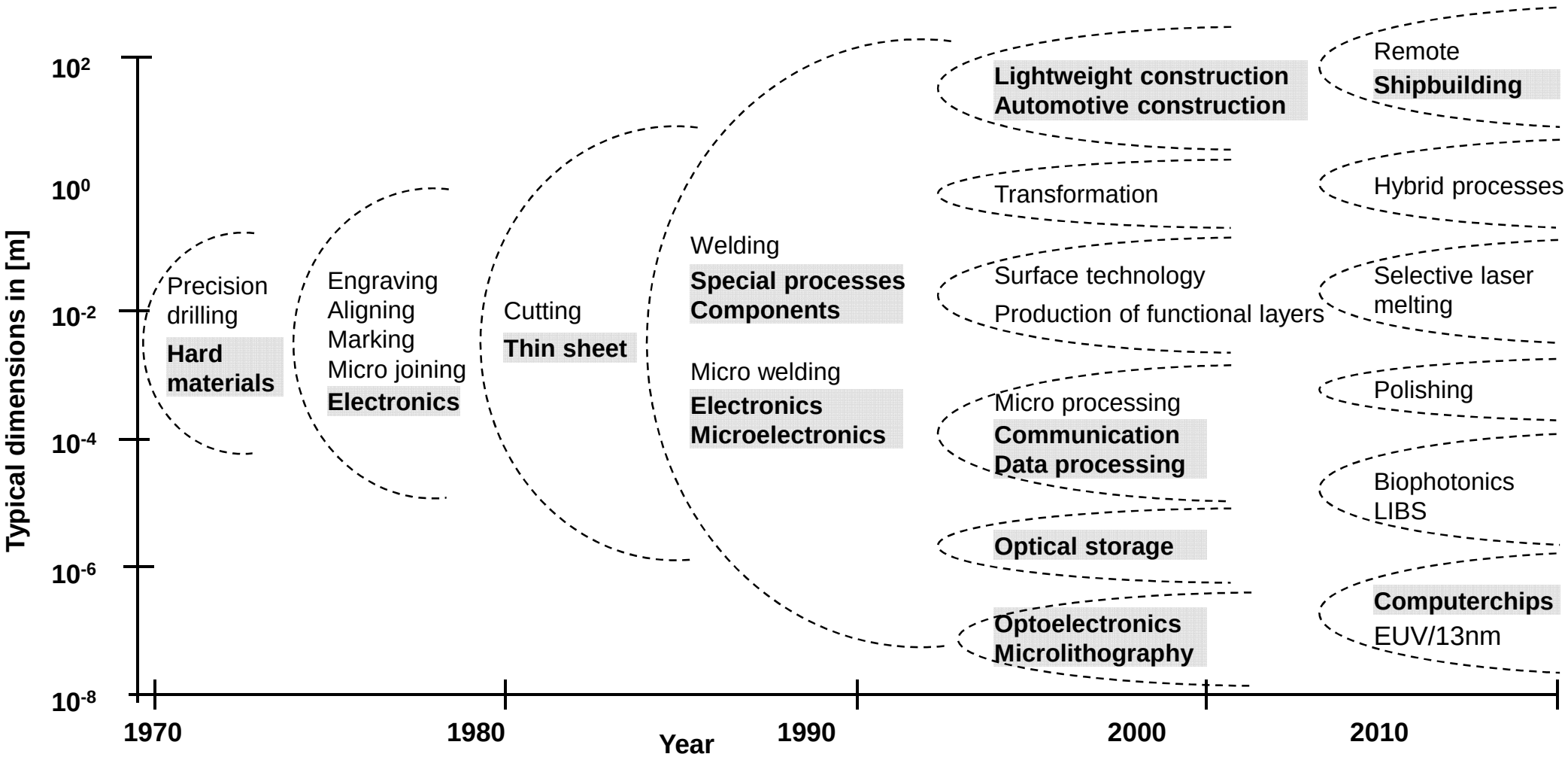


Volume	10W/liter
Weight	5W/kg
Cost	1W/1000€ (> 150W)
Rep rate	Up to 20MHz
Burst Mode	Available

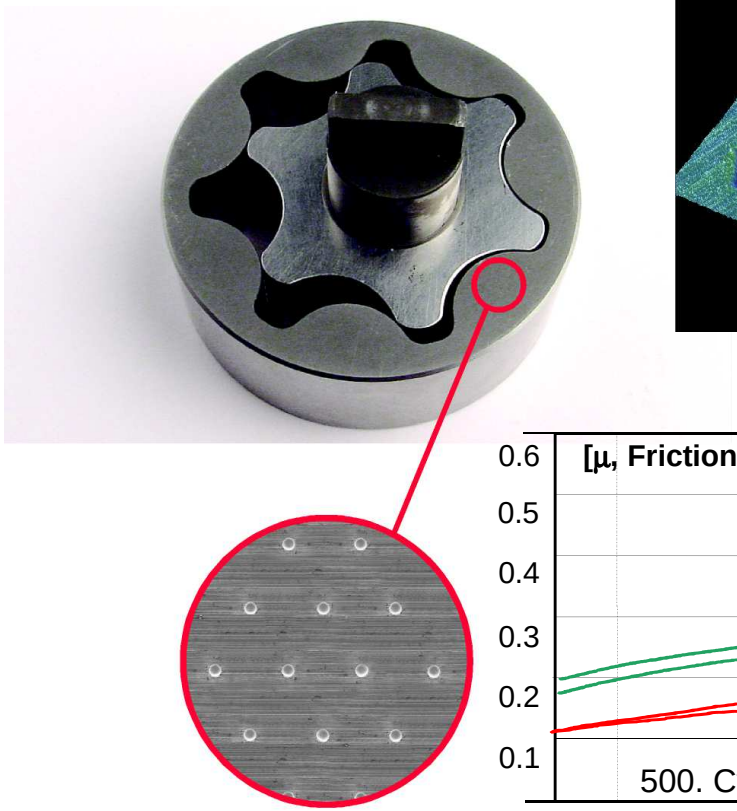
Summary of ultra short Pulse Laser Specifications

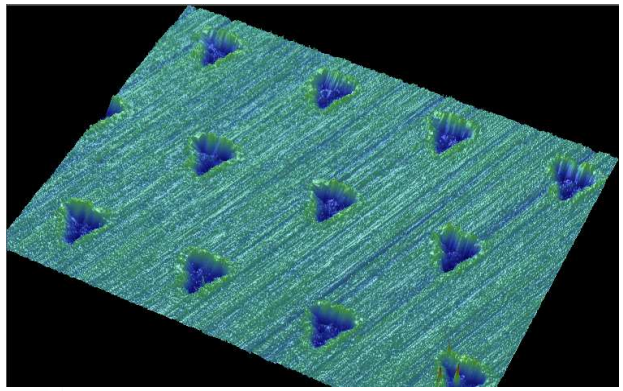
- highest beam quality: $M^2 = 1.1$
- average power: up to 400W
- high pulse energy: up to 2000µJ
- short pulse length: 10ps down to 500fs
- high peak power: up to 200MW
- high pulse rep. rate: up to 100 MHz
- scalability of energy and power
- wavelength: 1064, 532, 355, 266
- efficient nonlinear frequency conversion

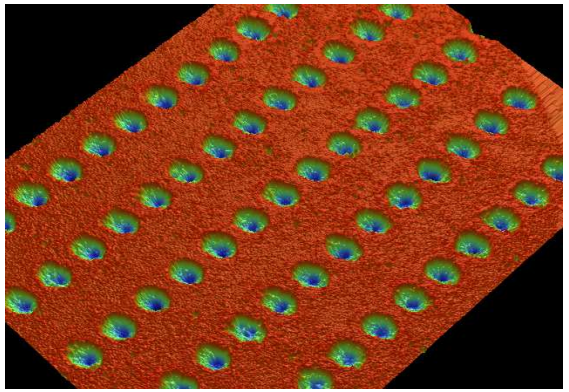
Fields of Application of Laser Material Processing



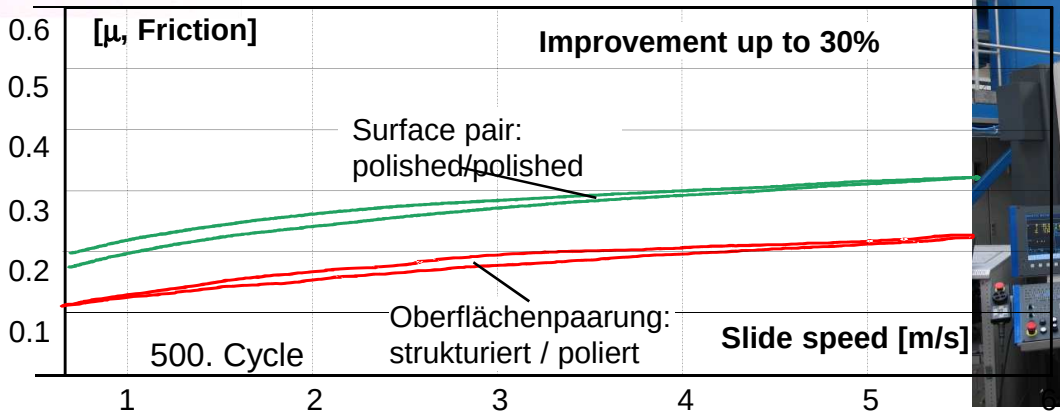
Microstructures for Reducing the Friction



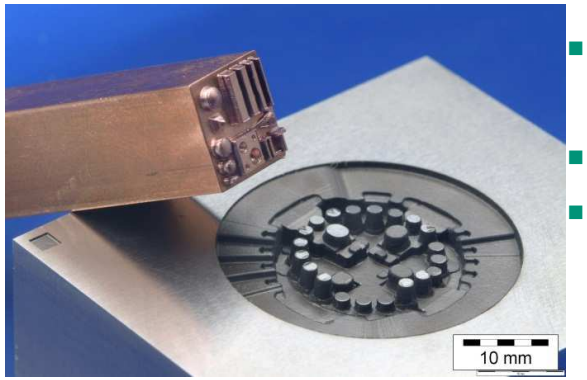




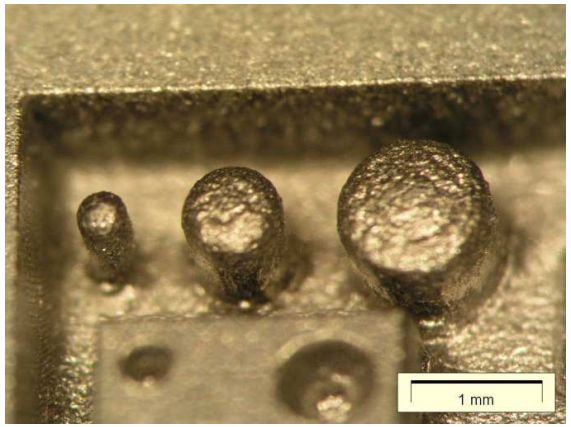
Quelle: Fraunhofer IPT

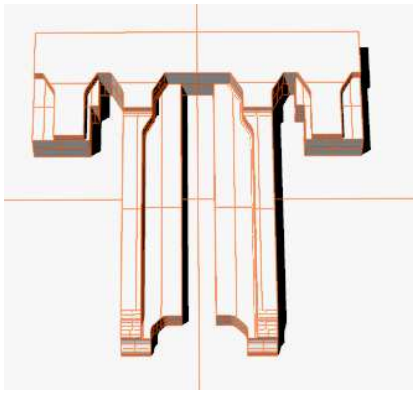


Structuring of Injection Moulding Tools



- Rapid Prototyping of Tool Inserts in Tool Steel and Hardmetals
- Structuring of Tools
- 3D-Processing of hardened and ultrahard Materials





Evaporation and expulsion of molten material in a volume 20 µm x 20 µm x 2 µm

Row-wise scanning of the geometry
overlap 10 - 15 µm

Quelle: Fraunhofer ILT

High Precision Laser Drilling of Steel

- **single pulse drilling:**

  highest efficiency, high volume per pulse, material removal mainly by melting

- **percussion drilling:**

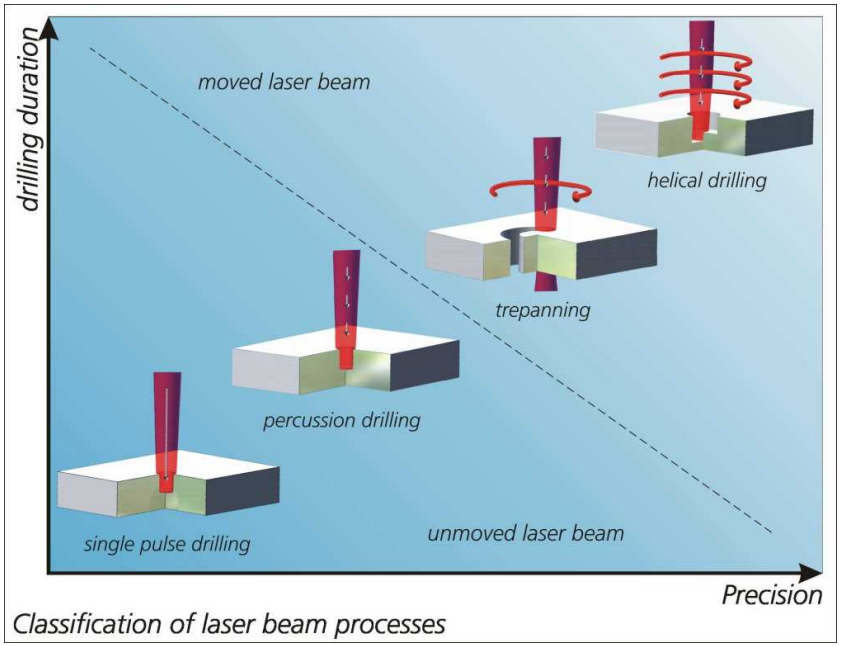
  hole geometry restricted by profile of laser beam, high aspect ratio

- **trepanning:**

  extensive mechanical components, hole diameter restricted by accuracy of the axis, conical and cylindric holes

- **helical drilling:**

  highest precision, low volume per pulse, material removal mainly by vapor, conical and cylindrical holes

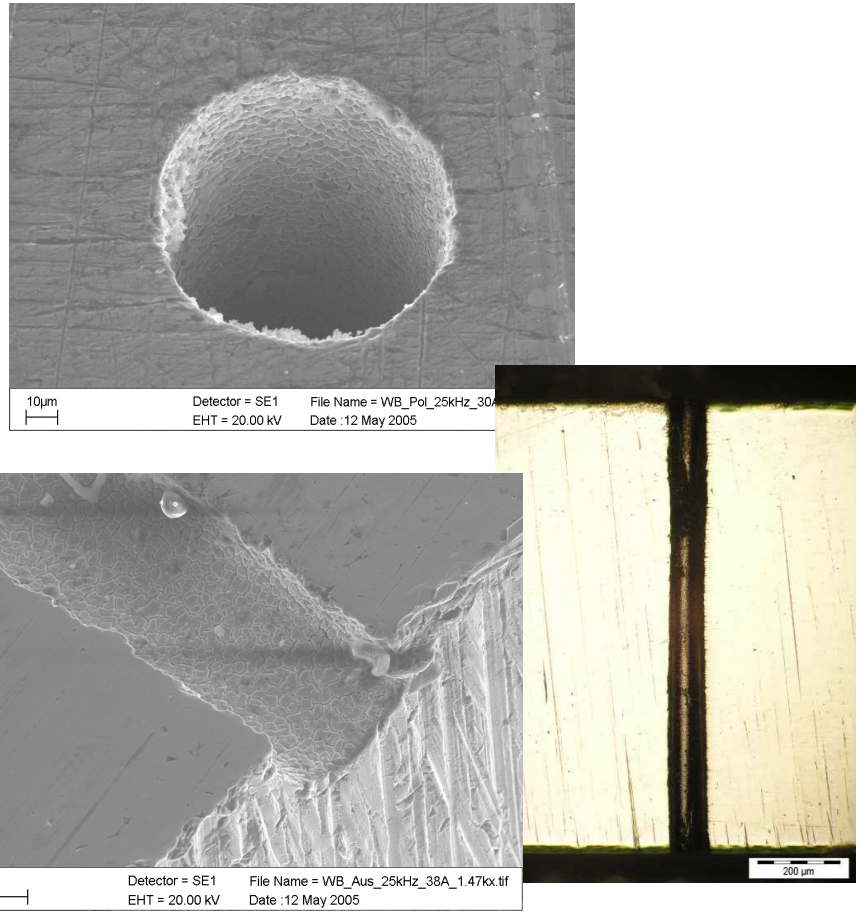


Classification of laser beam processes

High Precision Laser Drilling of Steel

Holes in tooling steel:

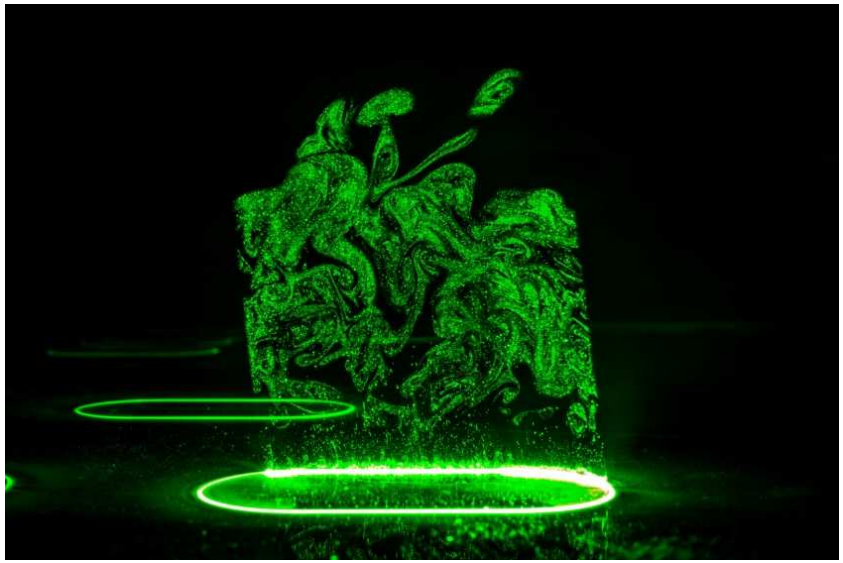
- **material surface almost without ablation particles**
- **hole surface almost without melting layer**
- **circular holes: diameter 30 µm in 1 mm**
  diameter 40 µm in 2 mm
- **holes with positive and negative expansion ratio: 1:2 (30 – 60 µm in 1 mm**
  40 – 80 µm in 2 mm)

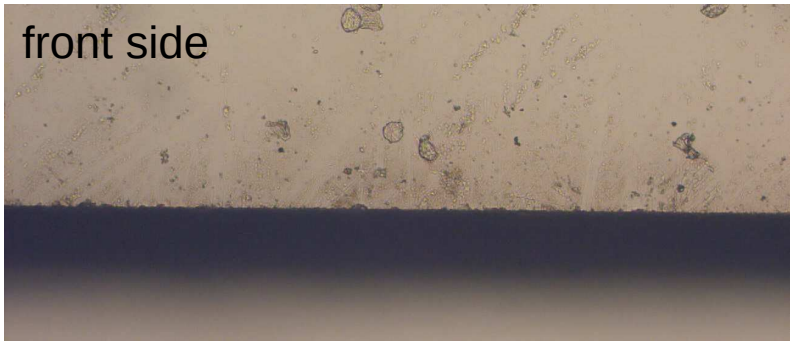


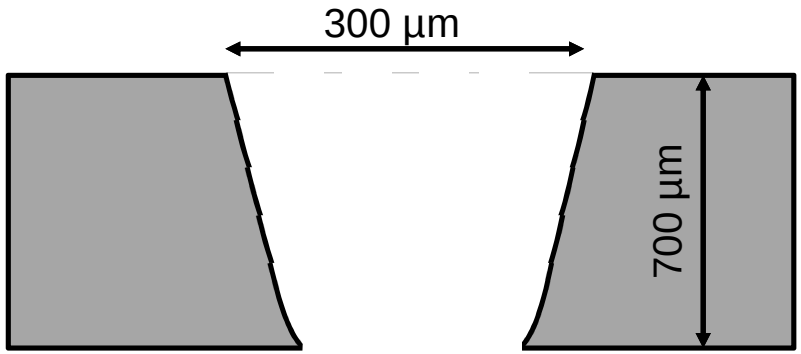
Courtesy of ILT

High Speed Full Body Cutting via Ablation with ps Laser

- Cutting by ablation
- Pulse duration 10 ps
- Wavelength 532nm/1064nm
- Average Power 20W – 300W
- Number of layers 100
- Scan speed 2 – 4 m/s

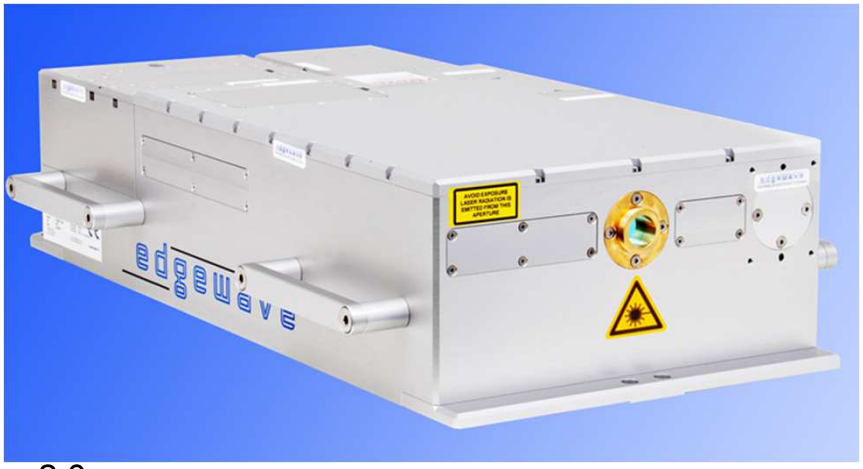


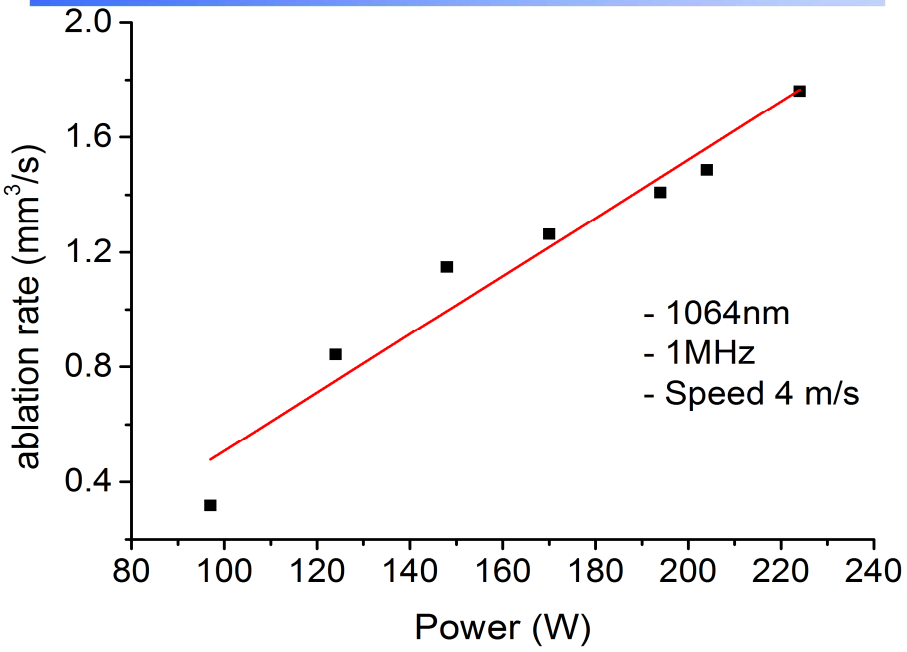




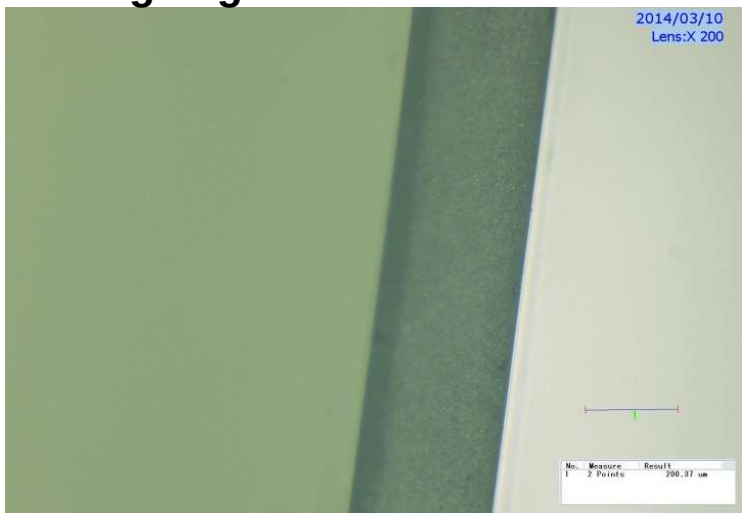
High Speed Ablation of Sapphire with PX300

PX300-1

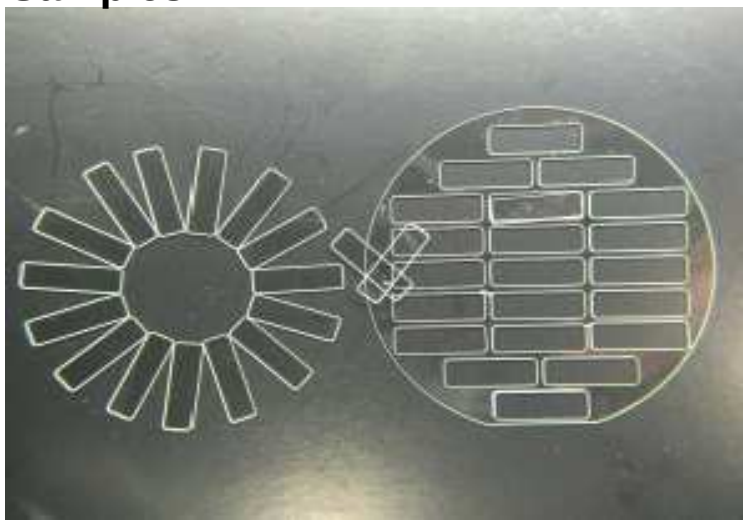




cutting edge

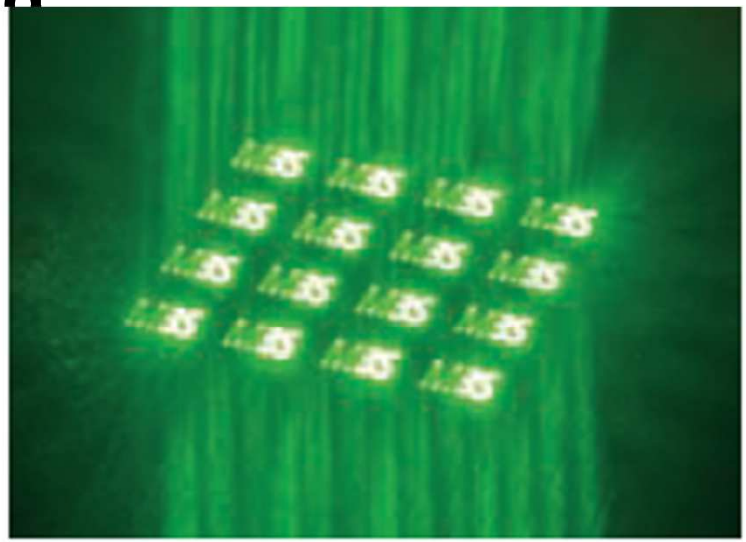


Samples

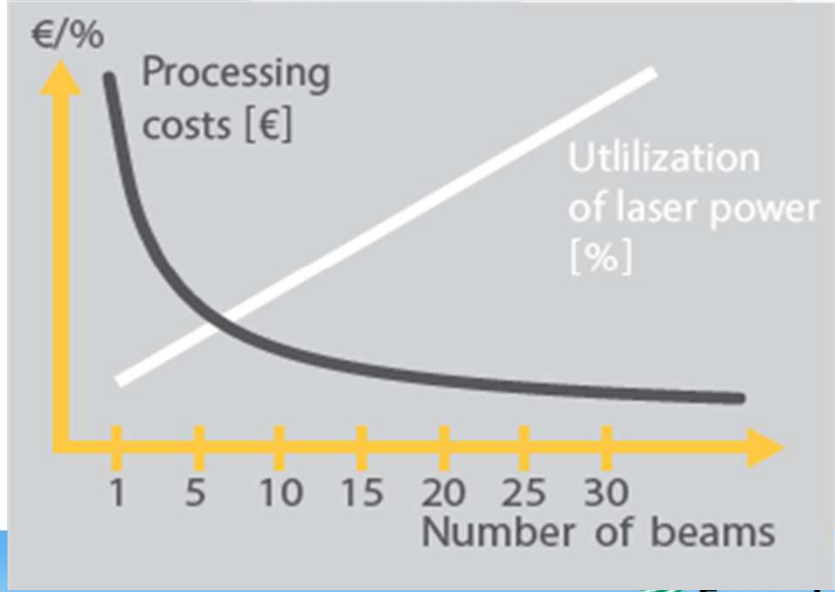


Massive parallel Processing using Beam Splitting by DOE and Scan

- Periodic pattern with n x m spots
- Movement of spot pattern with the scanner system
- Typical period of pattern: 0,3-2 mm
- Optical efficiency >70 %
- Spot uniformity > 93 %
- Semi-automated alignment
- Exchangeable beam splitter
- Masking of unwanted higher orders
- Masking of main orders to reduce number of spots (x and y direction)

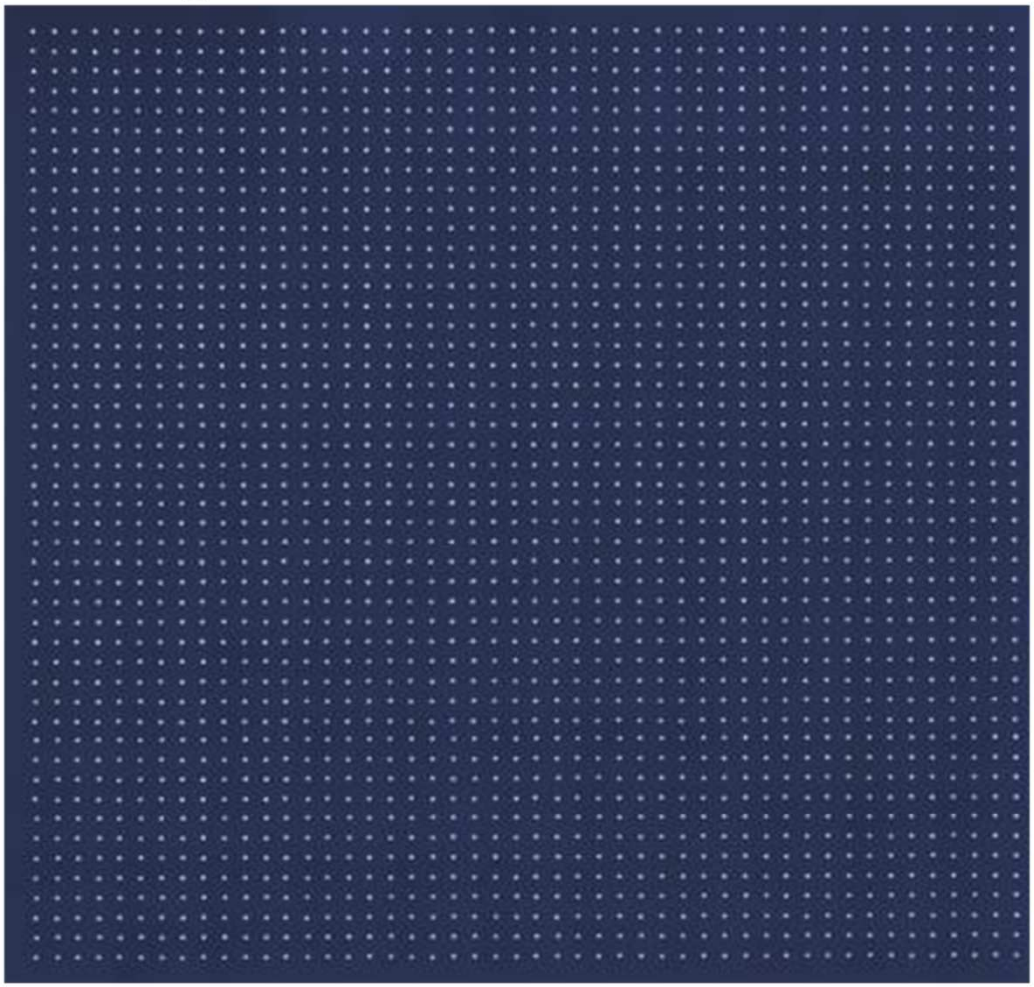


Multi beam laser processing with 16 sub beams



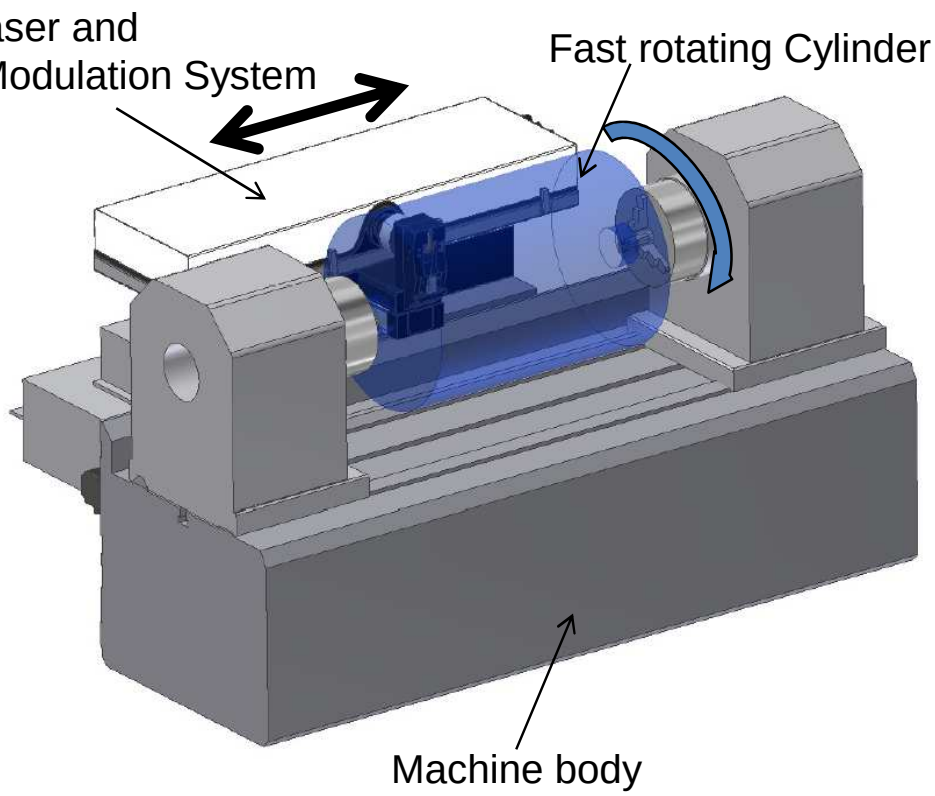
Multibeam Scanner

Drilling of foils



- Drilling speeds
  > 10.000 holes /sec possible
- High reproducibility
- High circularity
- Use of different drilling technologies
  - Single Pulse
  - Percussion
  - Helical drilling
- Possible Applications
  - Filter
  - Via holes
  - masks

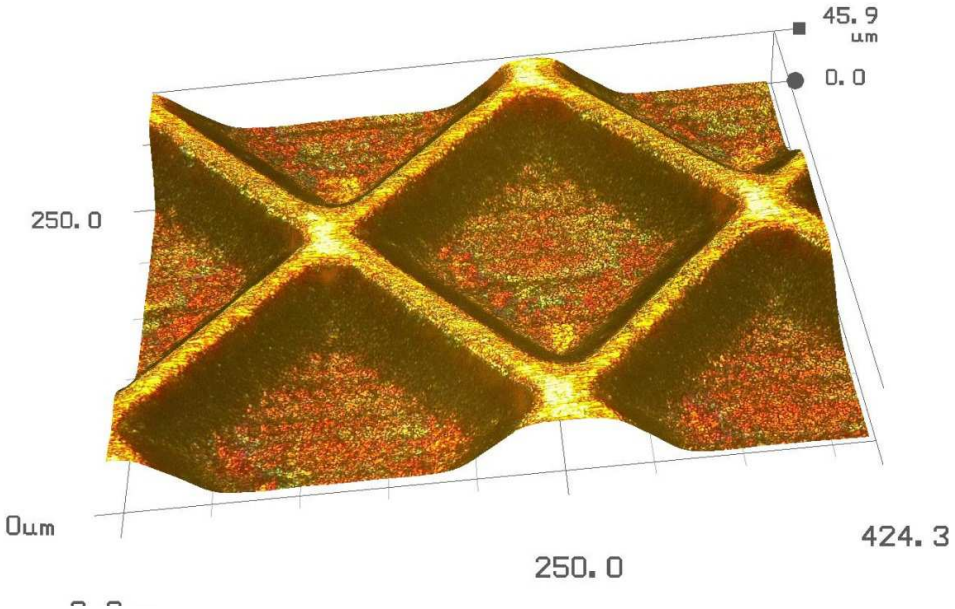
Engraving of Press Cylinder with ps Laser



Contesy of Schepers

Fast spiral scanning via:

- **fast rotating cylinder with surface speed up to 80m/sec**
- **linear motion along cylinder axis**



SPONSORED BY THE
Federal Ministry
of Education
and Research

edgewave

SCHEPERS

SAUERESSIG®

Machine development

Schepers
Laser engraving machine
Digilas

Gefördert von / sponsored by:
Bundesministerium
für Bildung
und Forschung

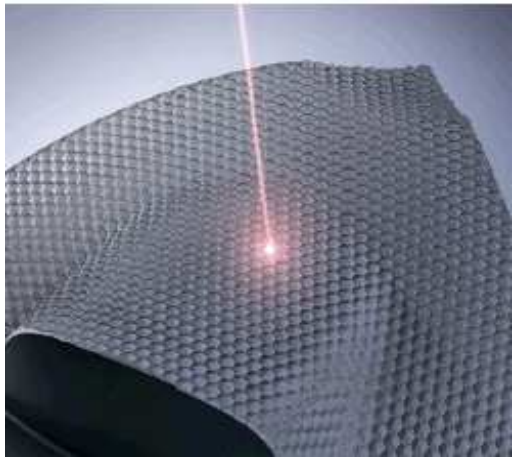
**Großflächenstrukturierung mit
Hochleistungs-Pikosekundenlasern**

Pikoflat - System und Process Technology for Large Area Structuring with High Power Picosecond Lasers

Project objectives

Development of a high speed laser ablation technology based on ultra short pulsed lasers with following specifications

- Ablation rate > 20 mm³/min
- Ablation geometry < 10 µm
- Ablation accuracy < 2 µm
- Laser power: > 200 W,
- Pulse duration: < 10 ps
- Pulse energy: > 10 µJ
- Repetition rate : > 10 MHz



Embossing and injection molding tools

Embossing rolls

Gefördert von / sponsored by:

Bundesministerium für Bildung und Forschung

mabrilas

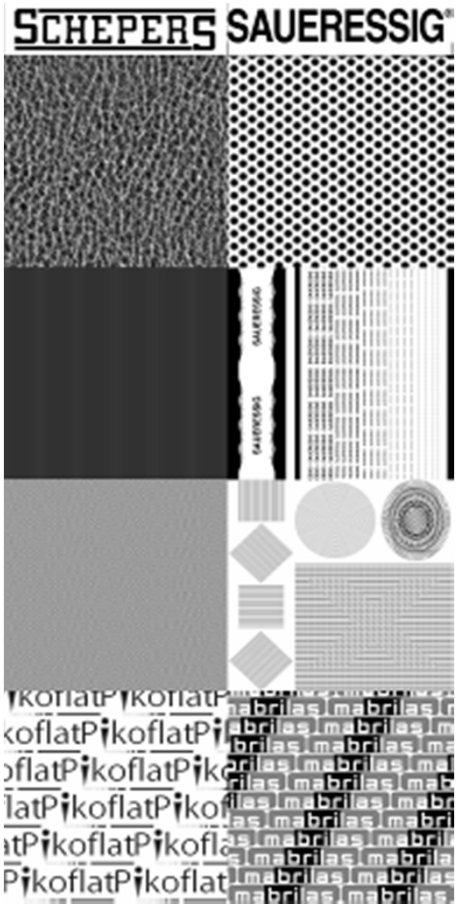
Großflächenstrukturierung mit Hochleistungs-Pikosekundenlasern

Pikoflat

Application – Embossing roll

Test structures

- Leather structure
- lense structures
- Micro text
- Moiree-Effect
- 3D-freeform structures
- 3D-Logos



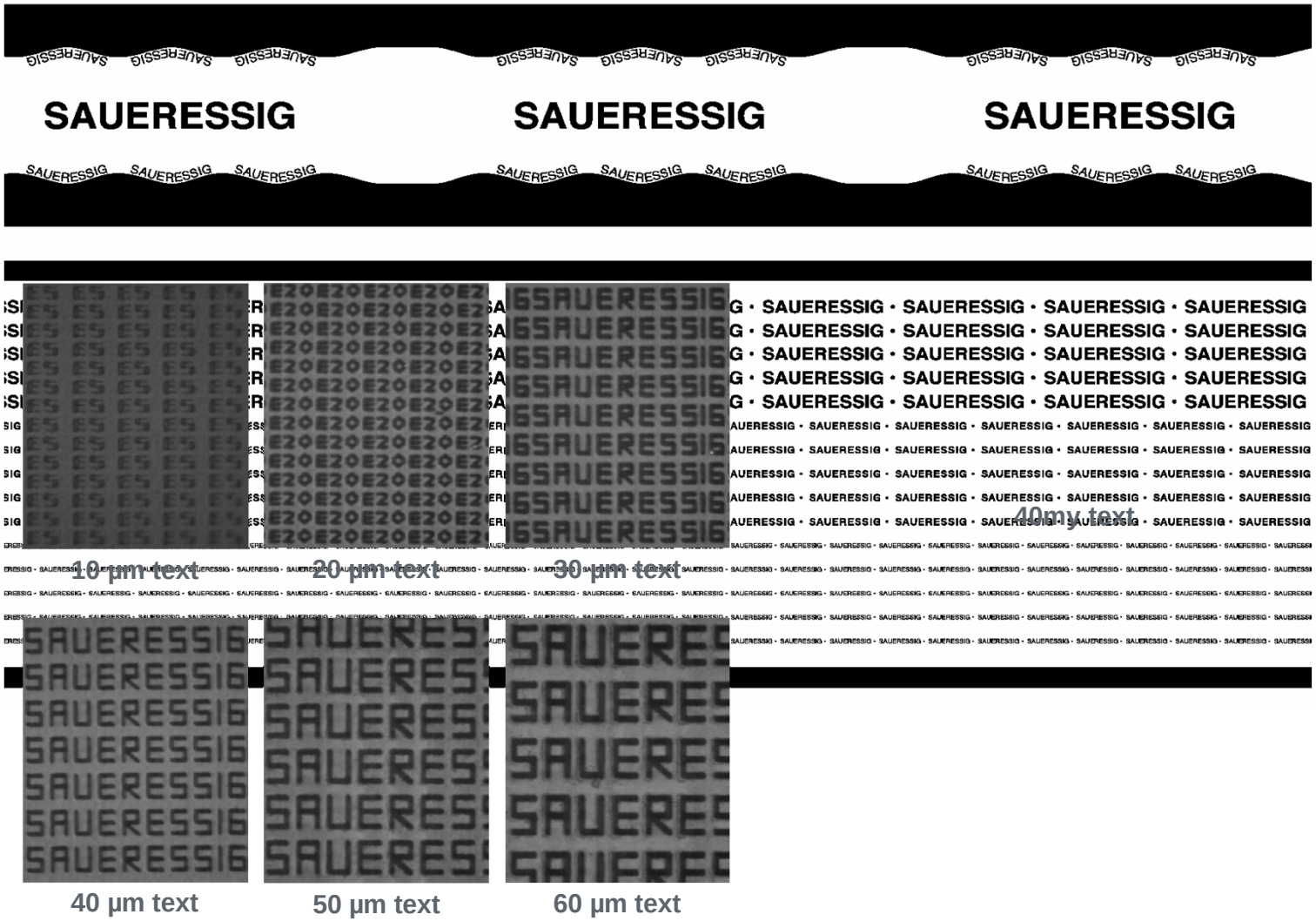
Gefördert von / sponsored by:

Bundesministerium
für Bildung
und Forschung

**Großflächenstrukturierung mit
Hochleistungs-Pikosekundenlasern**

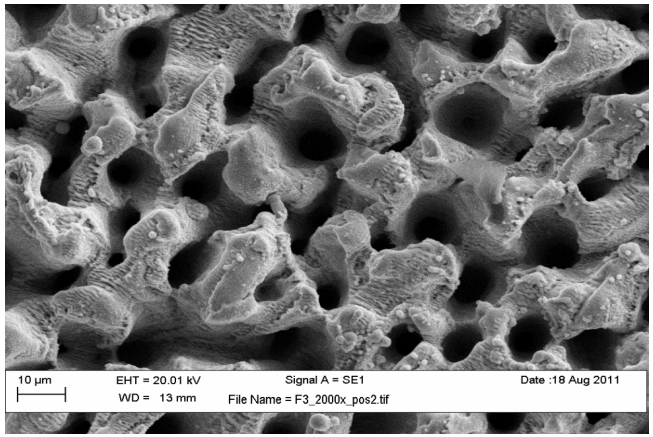
Mikrotext:

Texthöhe



Surface Functionization with ps/fs Lasers Ablation

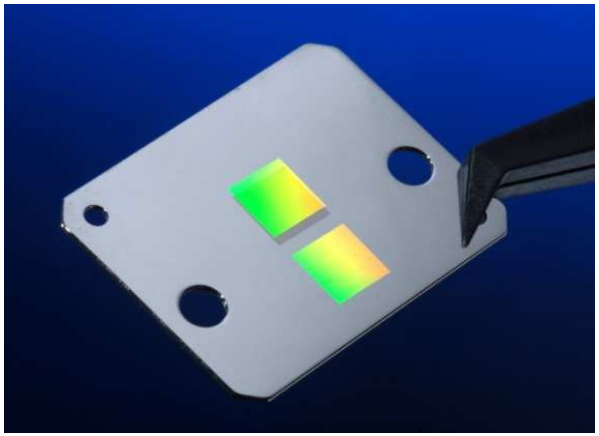
Micro/Nano structures



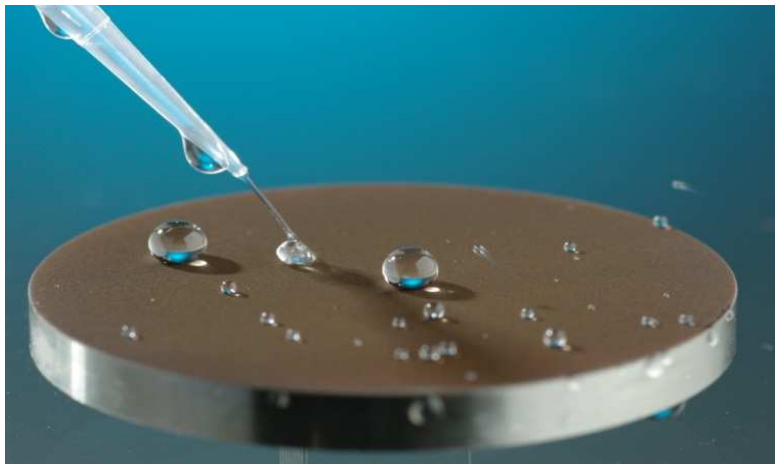
Black copper

Courtesy Tsinghua University

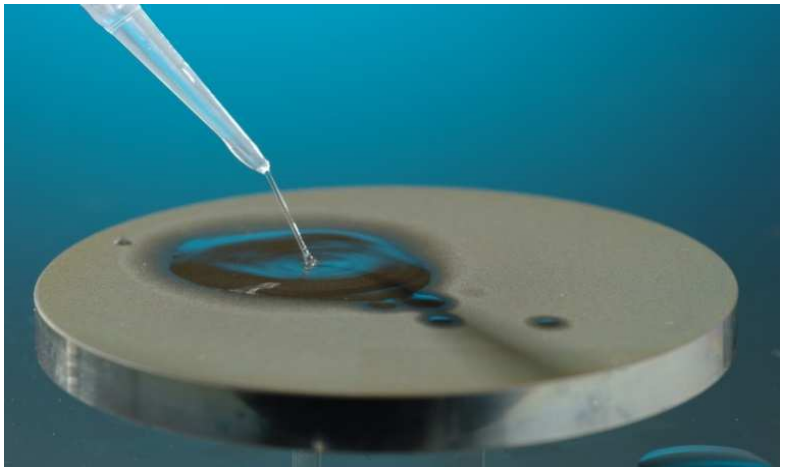
Color marking



Hydrophobic surface

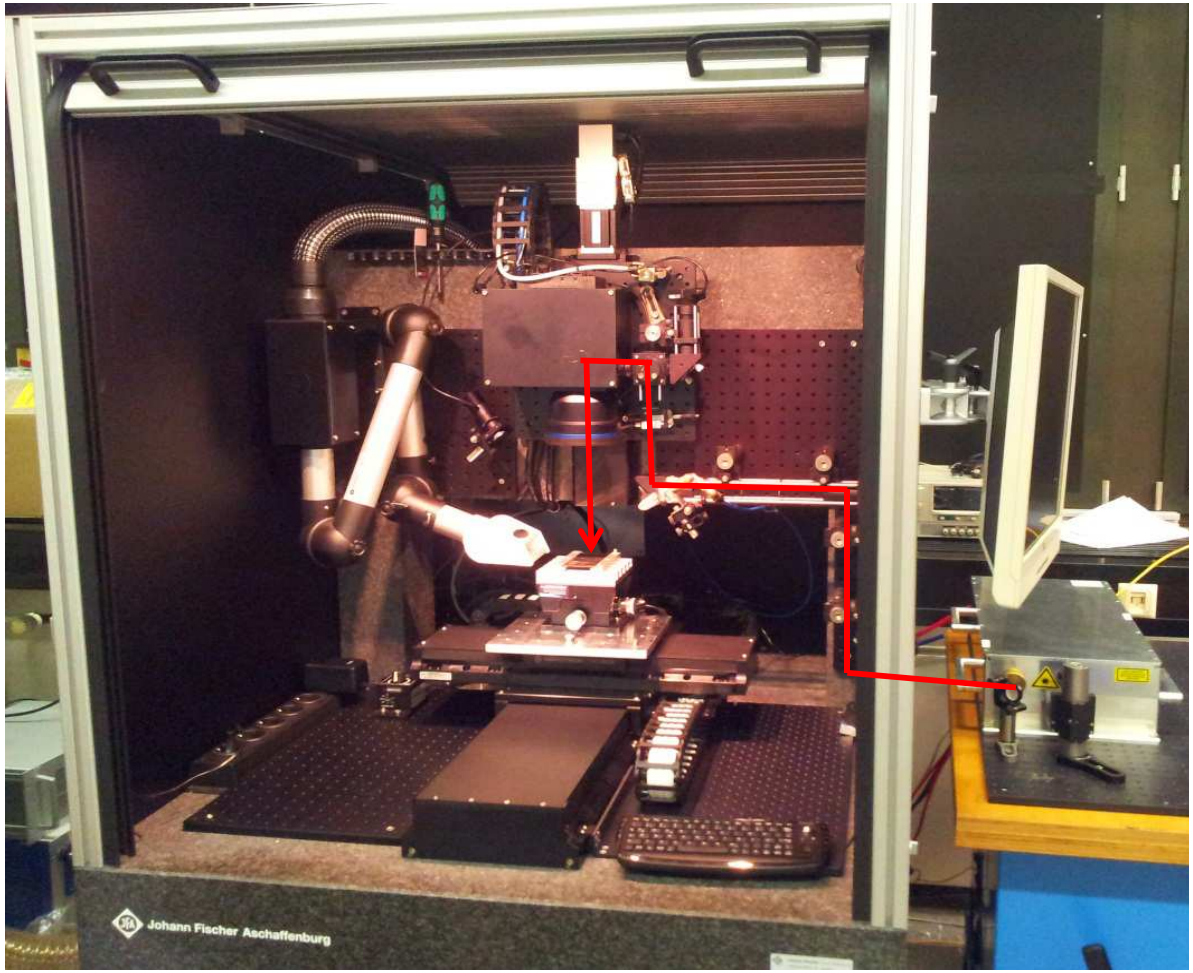


Hydrophilic surface



Courtesy ILT

Versuchsaufbau

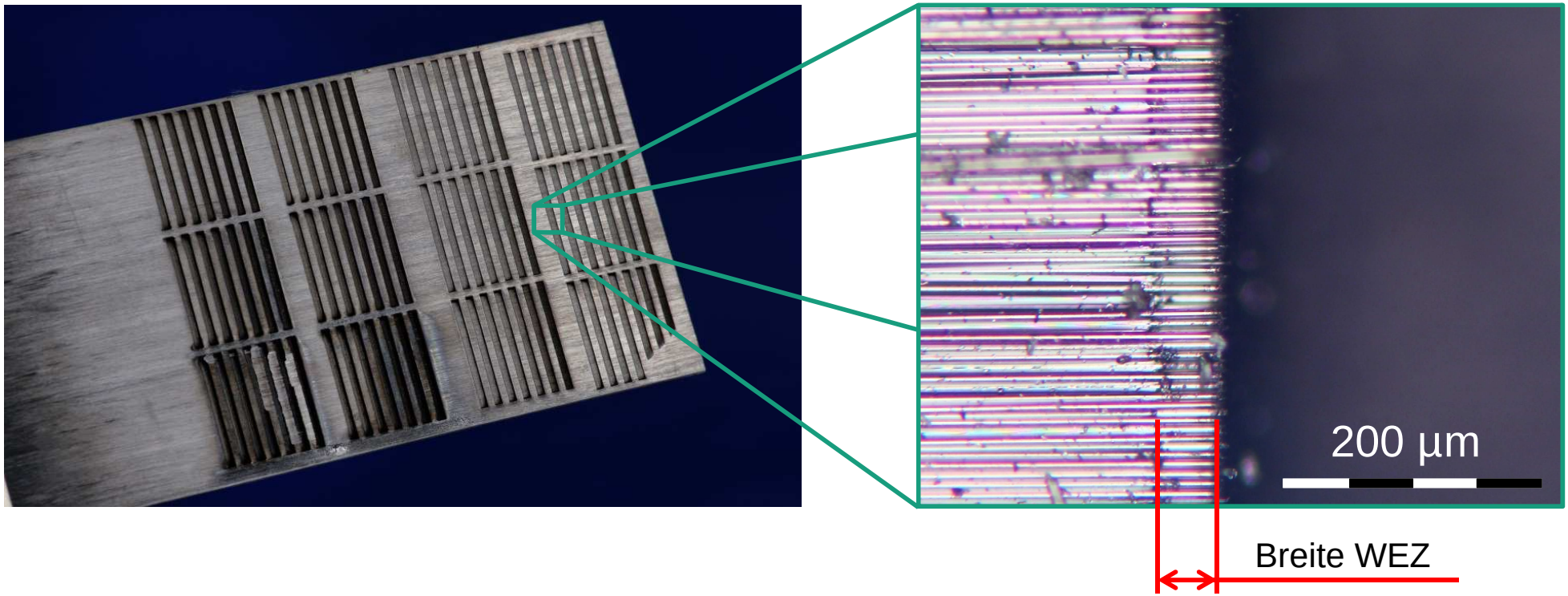


- Edgewave PX Pikosekundenlaser:
  - typische Pulslänge 10 ps
  - mittlere Leistung bis 100 W
  - Repetitionsraten bis 20 MHz
- Galvo Scanner zur Bewegung der Laserstrahlung:
  - max. Geschwindigkeit 15 m/s
  - Positioniergenauigkeit 1 µm
- Aerotech Dreiachssystem zur Bewegung der Probe:
  - max. Geschwindigkeit 2 m/s
  - Positioniergenauigkeit 1 µm

edgewave

Fraunhofer ILT

Versuchsdurchführung

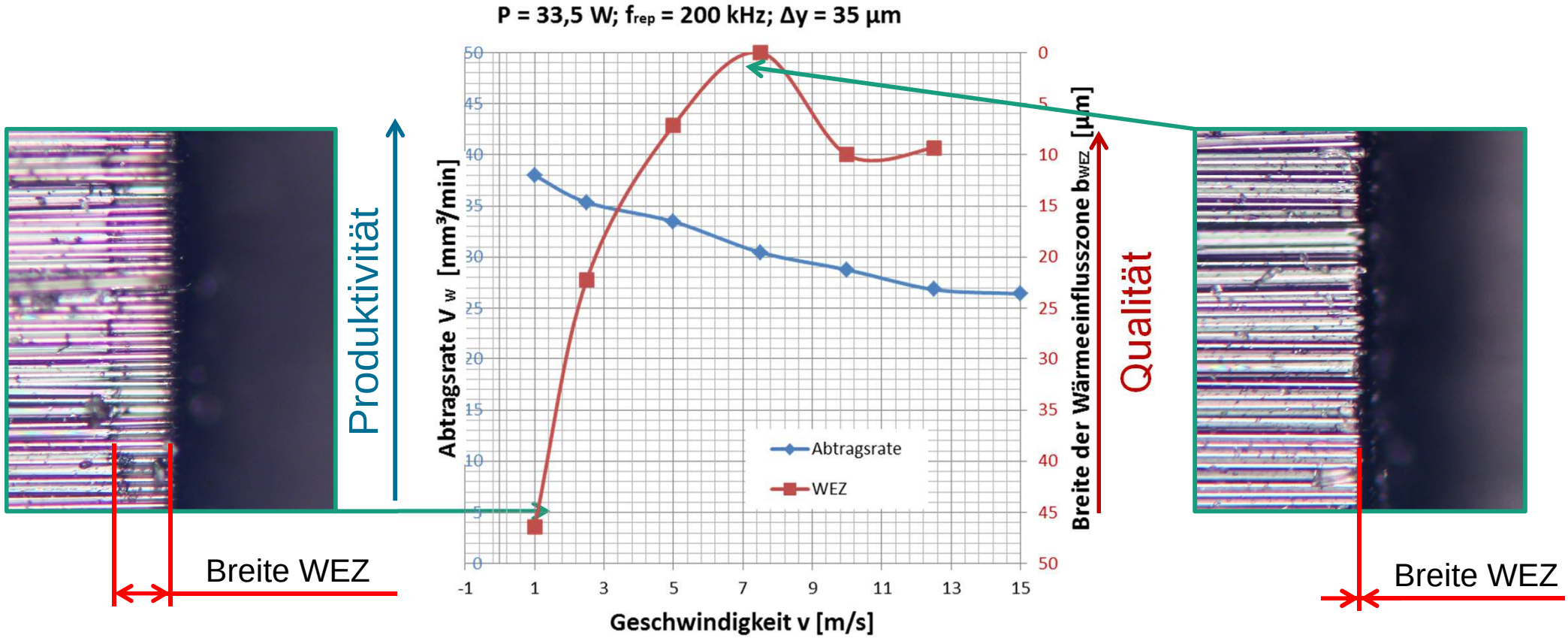


- Probenabmessungen 100 x 50 mm
- Dicke 2 mm
- Variation von Leistung, Geschwindigkeit, Bahnabstand
- Messung der Breite der Wärmeeinflusszone
- Bestimmung von Abtragsraten

edgewave

Fraunhofer ILT

Qualität der Schnittkante

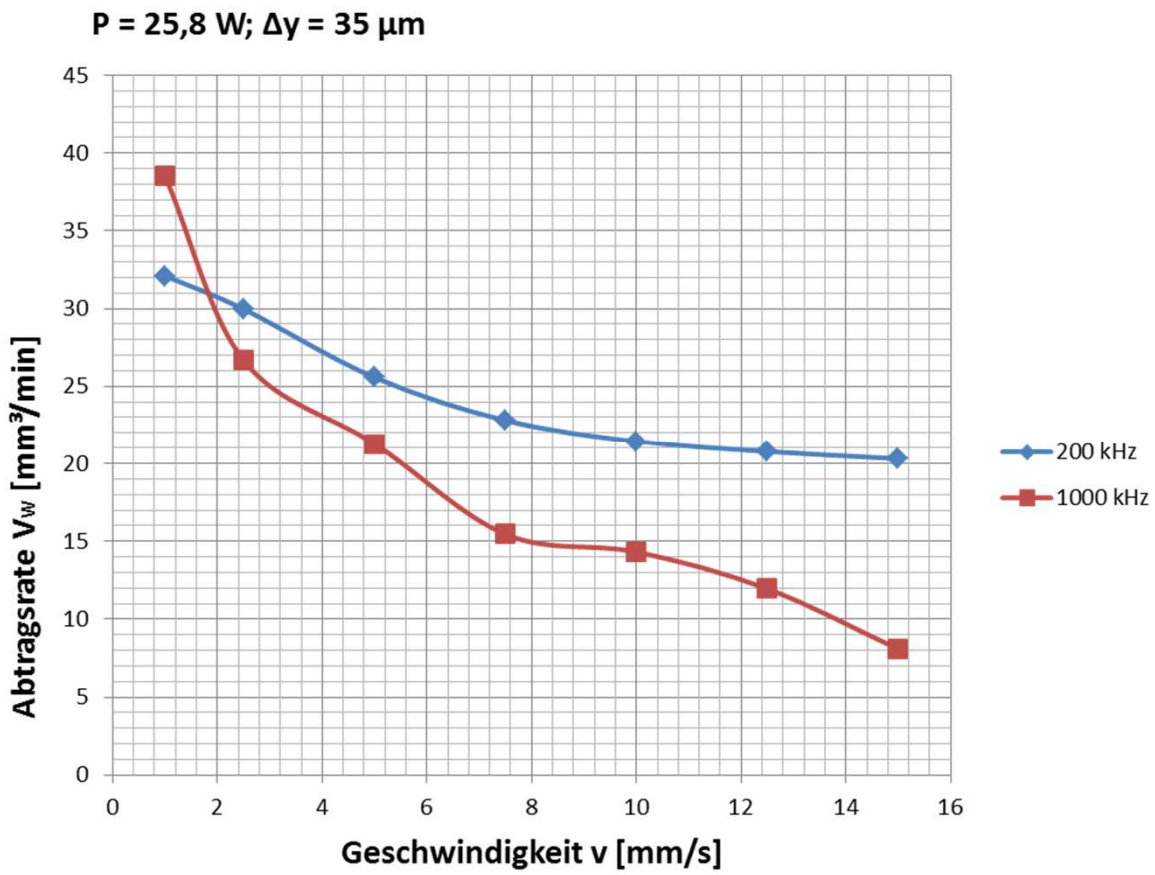


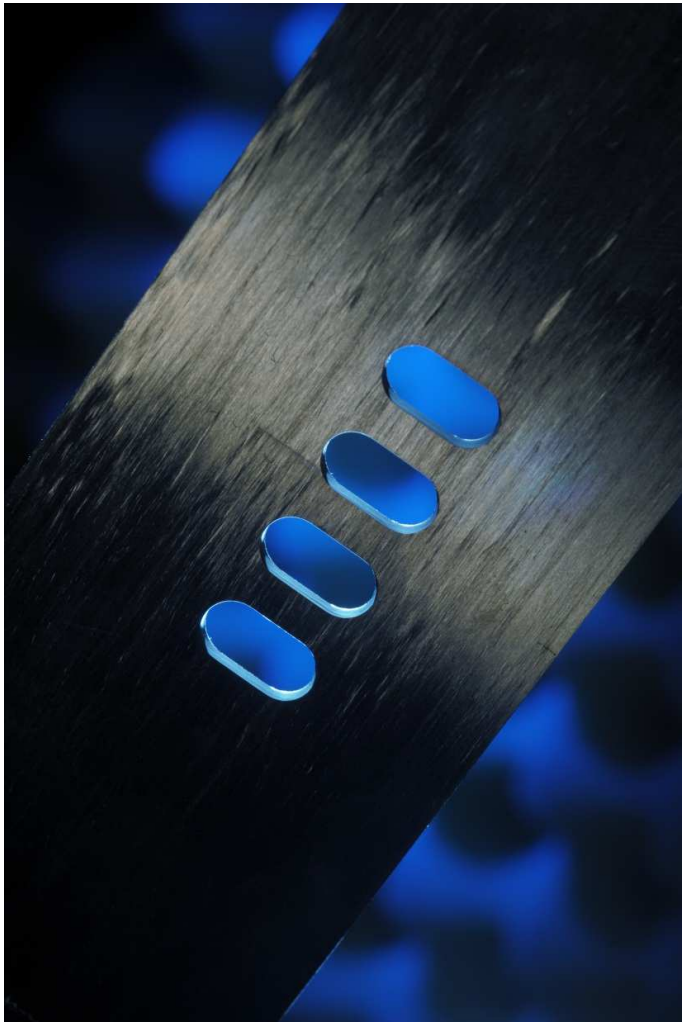
- Keine Wärmeeinflusszone bei 7,5 m/s

edgewave

Fraunhofer ILT

Abtragsrate vs. Geschwindigkeit



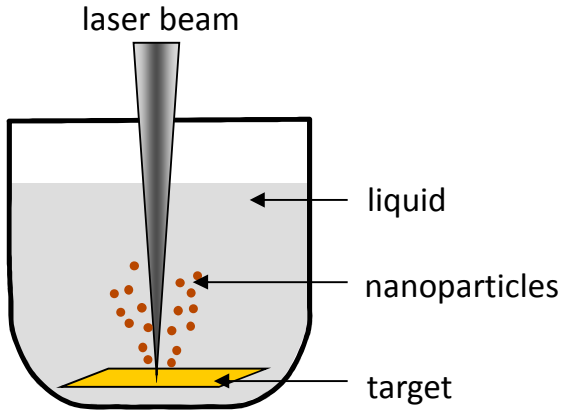


- Kleinere Repetitionsraten f_{rep} nutzen eingesetzte Leistung P effizienter

edgewave

Fraunhofer ILT

Laser-Generated Nanoparticles



- 100% pure
- material and liquid variation
- stable
- occupational safe

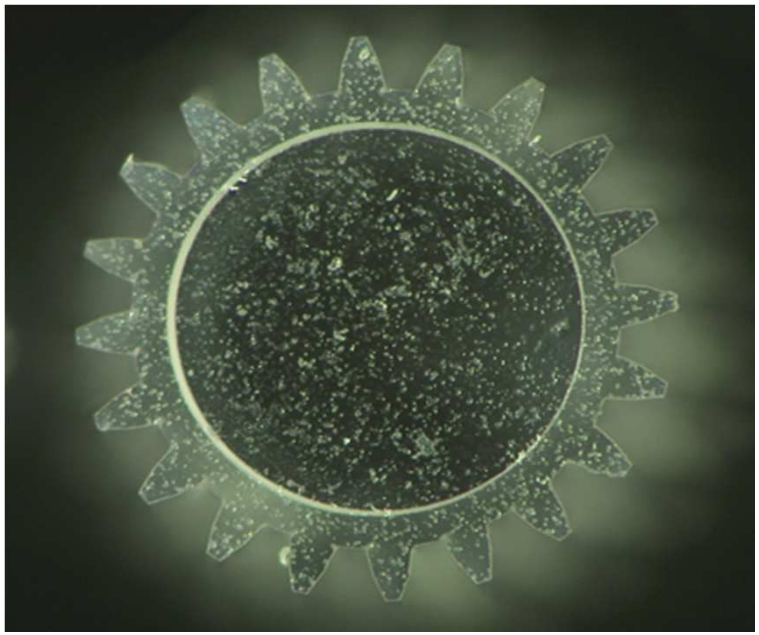
Special Issue
"Laser Ablation and Nanoparticle Generation in Liquids"
J. Phys. Chem. C (2011), 115, 2447-2668

Guest Editors: Stephan Barcikowski and Fumitaka Mafuné

Examples for High Speed In-volume Micro Structuring

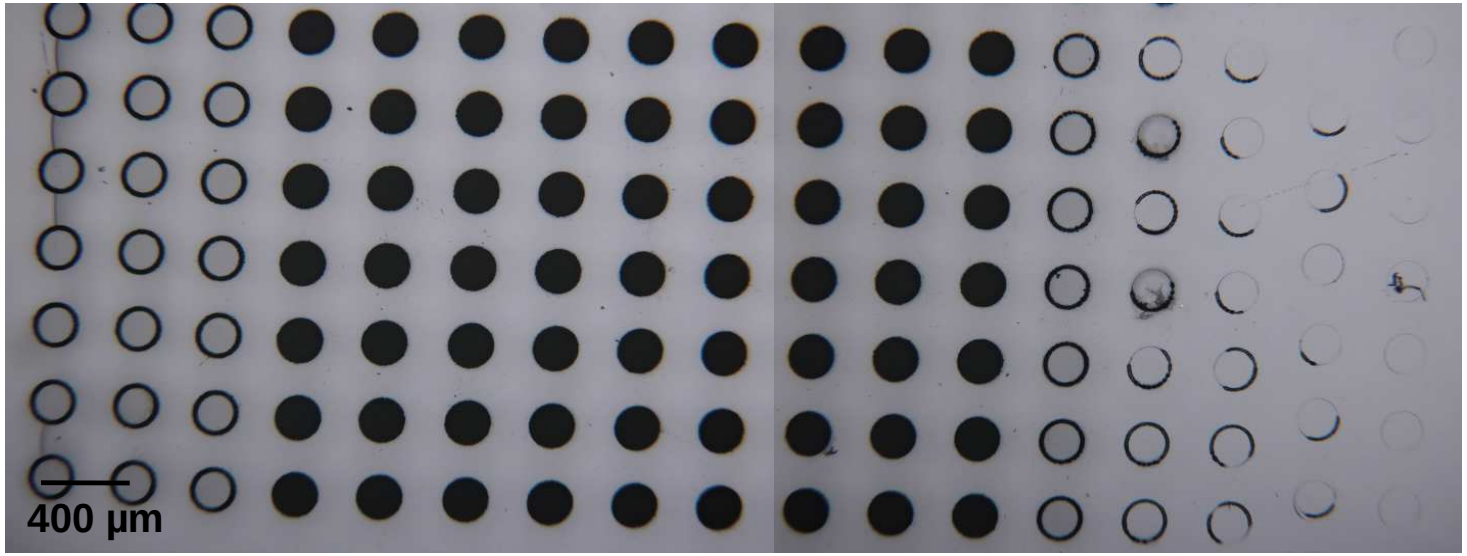
Gears made of fused silica

Material thickness, height: 1 mm
v=100 mm/s
P=200 mW
NA=0.3
Processing time: 400 seconds



Drilling of Glass with High Speed Micro Scanner

40W 30W 11.5W 5.4W



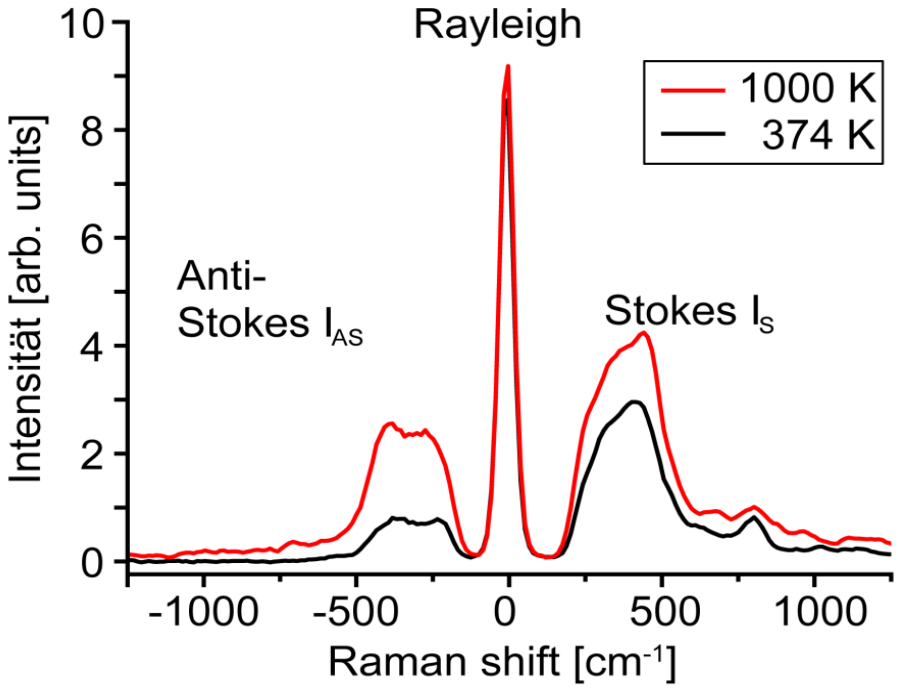
Drilling of 1 mm fused silica by ISLE with High Speed Micro Scanner:

- **Laser: Edgewave, 1064 nm, 10 ps, 80 W, 7 MHz**
- **Focus diameter: 2 µm**
- **Hole Diameter: 200 µm, Pitch: 400 µm, Depth: 1,000 µm**
- **Track velocity: 3 m/s, Processing time per hole: 9 ms**
- **Removal rate: 3.5 mm^3/s resp. 0.3 mm^3/Ws**

In-situ Measurement of Temperature

Institute of Applied Physics
Friedrich-Schiller-Universität Jena

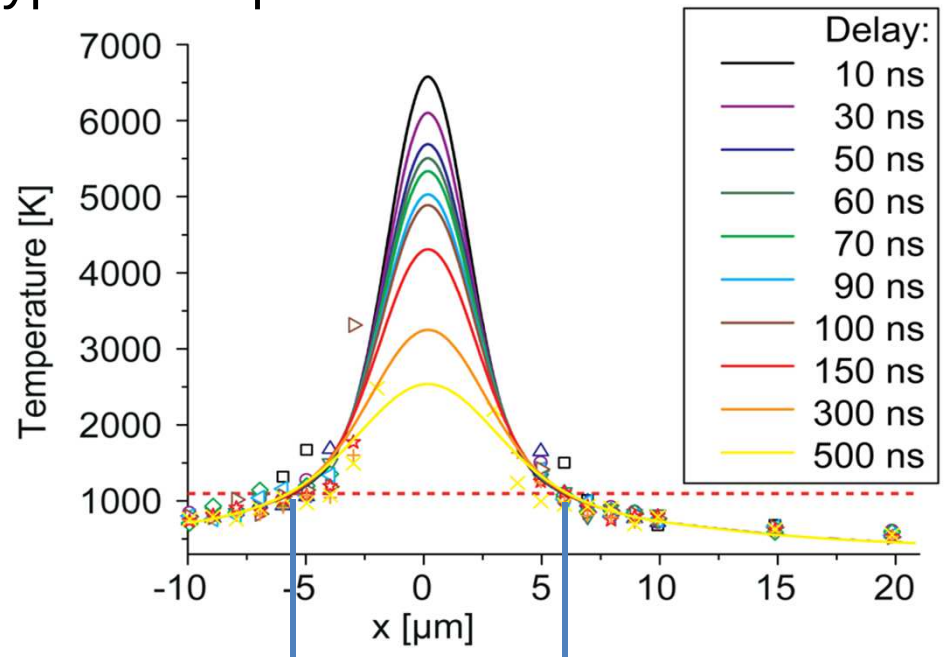
In-situ micro-Raman spectroscopy
(time- and space-resolved)

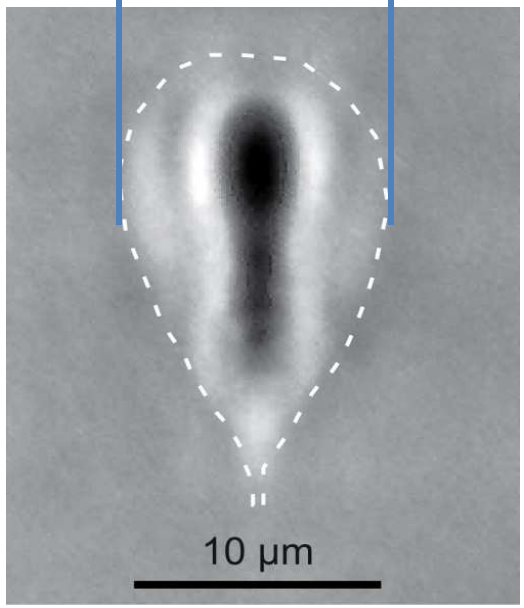


- increased Anti-Stokes scattering at higher temperature

$$\frac{I_{AS}}{I_S} \sim \exp\left(-\frac{h\nu_R}{k_B T}\right)$$

typical temperature evolution





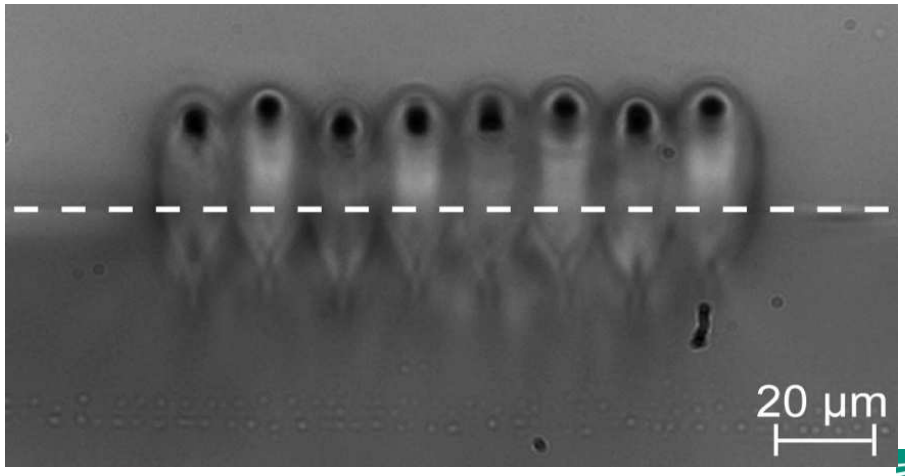
Laser Bonding Procedure

(1) Optical Contacting

(2) Adjustment of laser focus

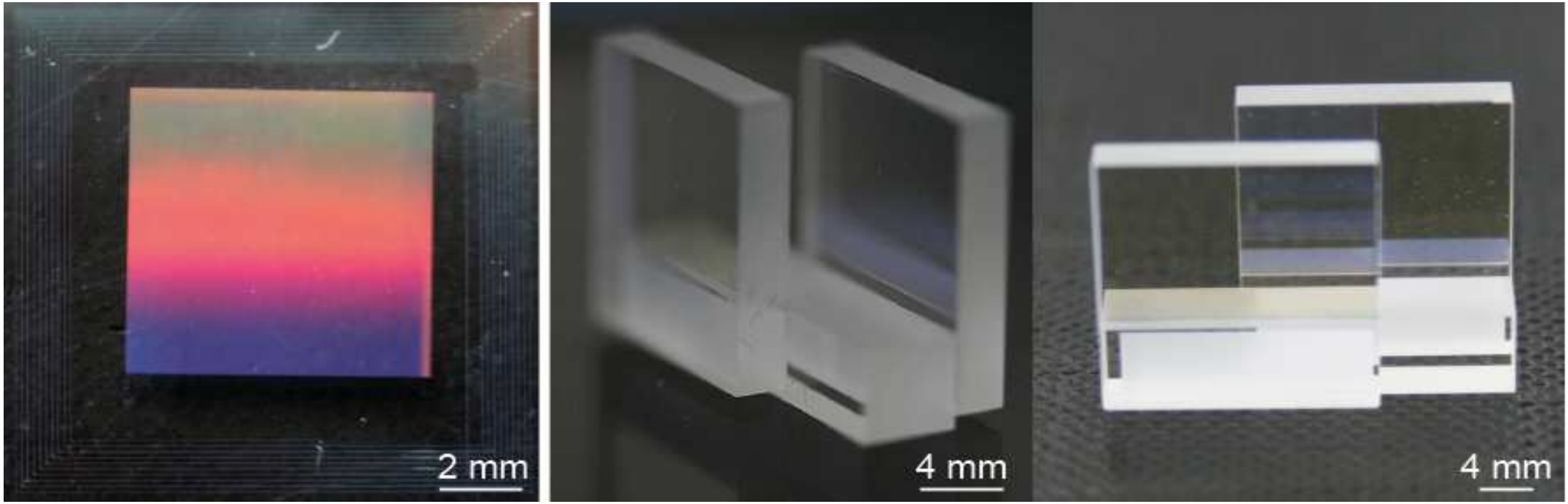
(3) Laser bonding process

- typical weld seam:



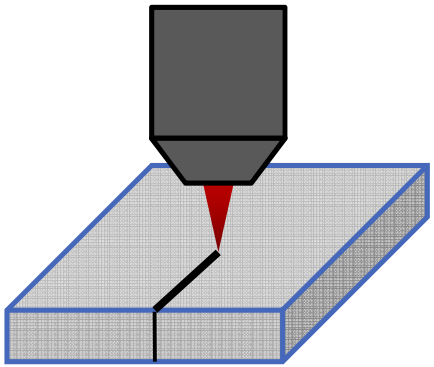
S. Richter, S. Döring et al., Appl. Phys. A 103, 257–261 (2011)

Application Potential

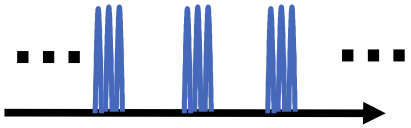


- encapsulation of optical components
- special bond-geometries without influence on functional areas
- stable joining of optical components without interface layer
- realization of gas-proof bonding

One-Pass Cutting of Transparent Substrate



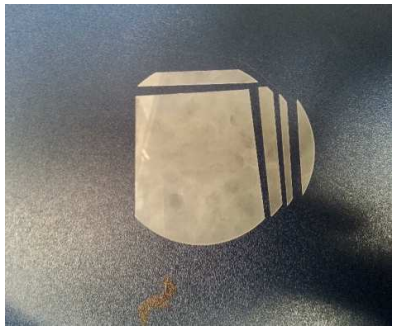
One pass cutting



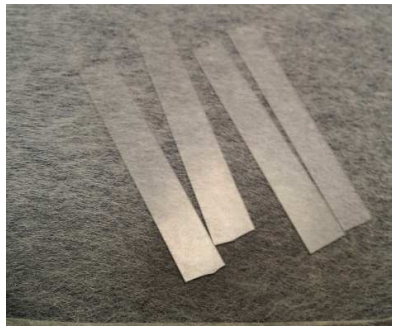
Pulse train

PX-series

- Picosecond pulse laser
- Burst pulse train mode
- One-pass and break
- Speed > 100 mm/s
- Tripping size < 20 µm
- Wall angle=0

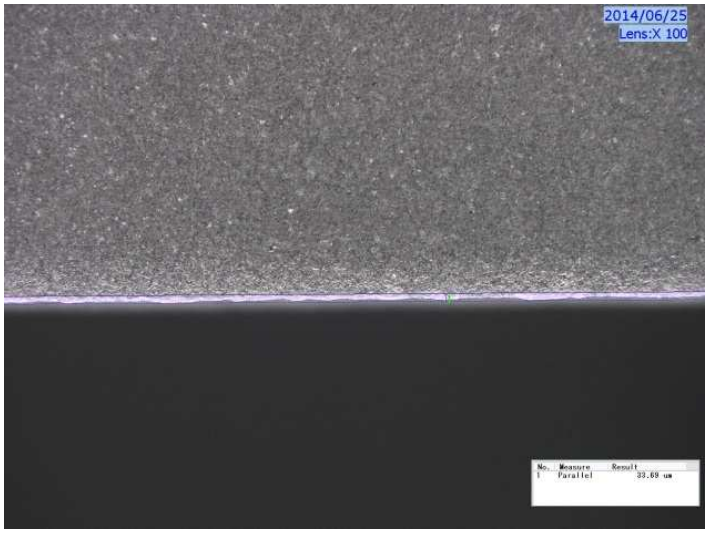
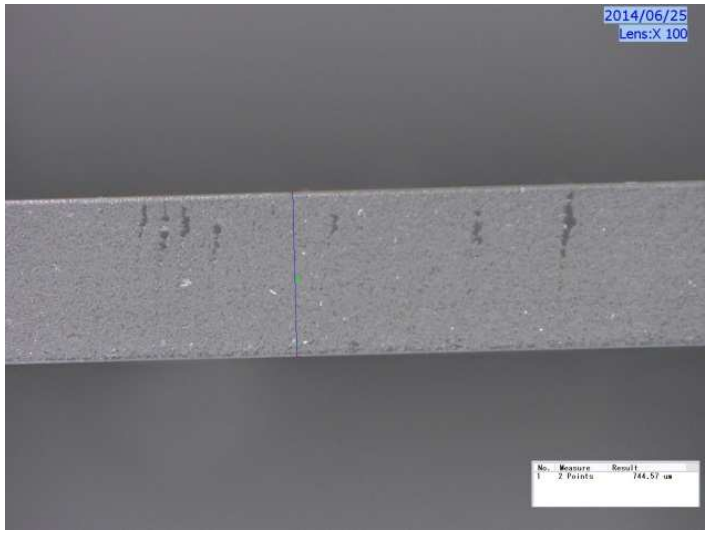
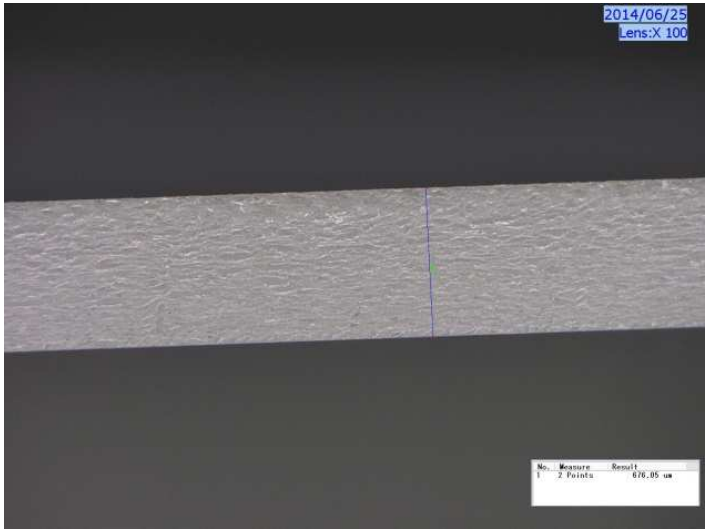


- Glass



- Sapphire

Cutting with high Power ps Laser Pulses

	Tempered Glass (Gorilla 2)	Sapphire
Top view		
Side view		

Application Fields of EdgeWave‘s Lasers

- Glass industry, e.g. micro drilling and high through put subsurface engraving
- Photovoltaic: e. g. scribing, drilling and cutting of Si-wafer, ablation of conduction or dielectric layers of thin film solar and crystalline Si solar cells
- Display, e.g. structuring of conduction layer, sequential lateral crystallization of Si
- Electronics industry, e.g. drilling and cutting of printed circuit boards
- Automobile industry, e.g. the manufacture of fuel injection valves
- Tool making and mechanical engineering, e.g. 3D rapid prototyping via ablation
- Scientific, e.g. pumping of dye laser, pumping of OPO, OPG or Ti:Saphire laser, particle imaging velocimetry

Conclusion

Multi 100 W ns lasers with tailored beam profiles for versatile applications

Multi 100 W ps lasers are available now.

kW class ps lasers and fs lasers are emerging

Ultra short pulse lasers are enabling high quality processing

- **Glass cutting**
- **Tool making**
- **Wafer dicing**
- **Embossing cylinder engraving, etc.**

Chellanges for closing the gap between micro processing and high through-put processing of macro parts:

- **High speed beam handling techniques**
- **Parallel processing**
- **Further power and energy scaling**

Thank for your attention!

EdgeWave GmbH

info@edge-wave.com
www.edge-wave.com