High power ultra short pulse laser processing - a new approach for high precision manufacturing

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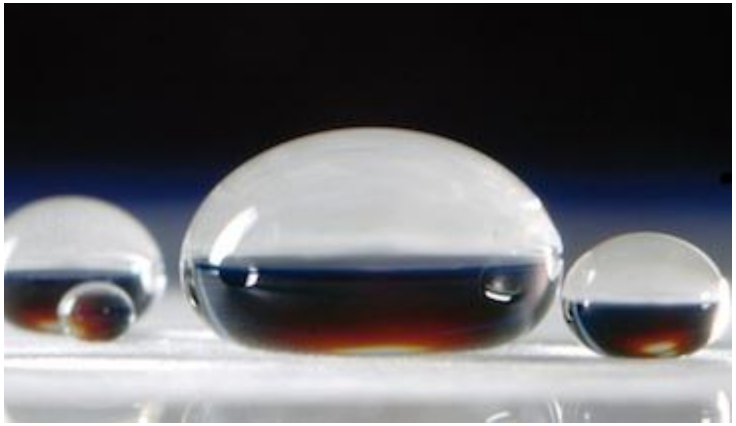
James Watt Institute –
Innovative Manufacturing
Research Center Conference 2012

Laser Based Production Processes

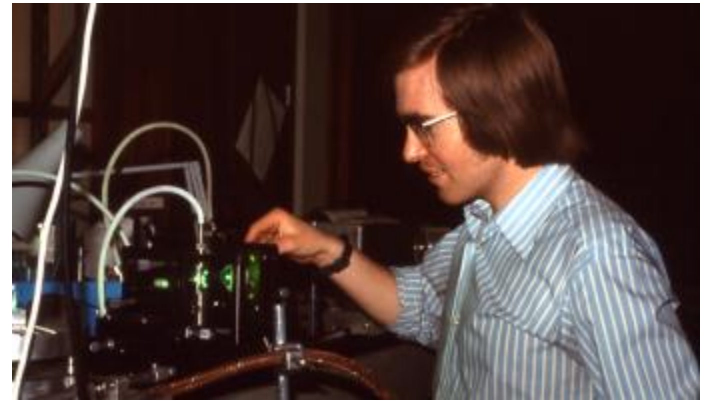
26th June 2012



Fraunhofer ILT

From Milliseconds to Femtoseconds

Theodore Maiman
(11.7.1927 – 5.5.2007)



Ivan Ruddock demonstrates the first Femtosecond-Dye-Laser.
Imperial College, London, 1970

Light
Amplification by
Stimulated
Emission of
Radiation

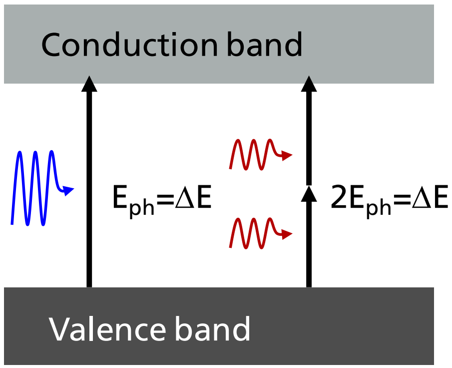
(Gordon Gould, 1957)

→

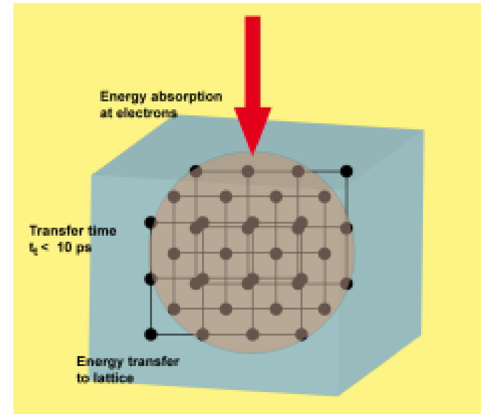
→

Limited
Application of
Sophisticated and
Expensive
Research

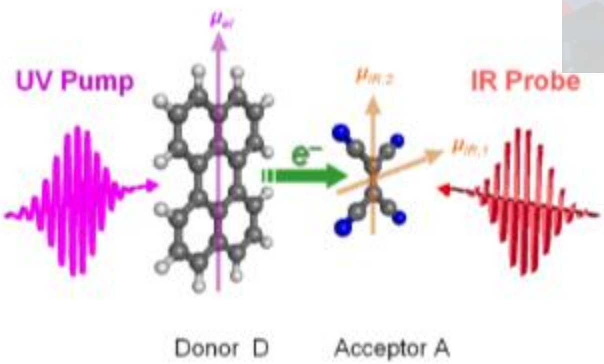
Ultra Short Pulse Lasers – A tool to overcome boundaries and explore new horizons



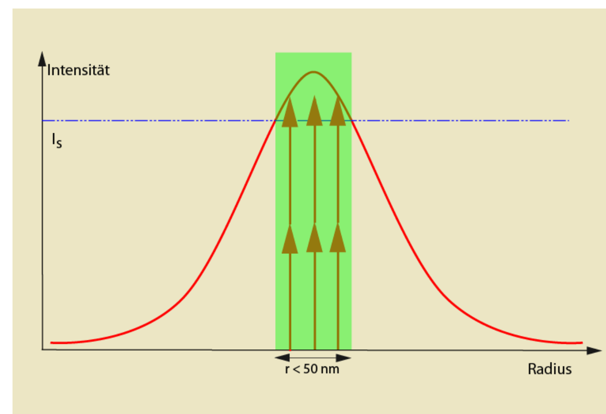
Absorption



Temperature

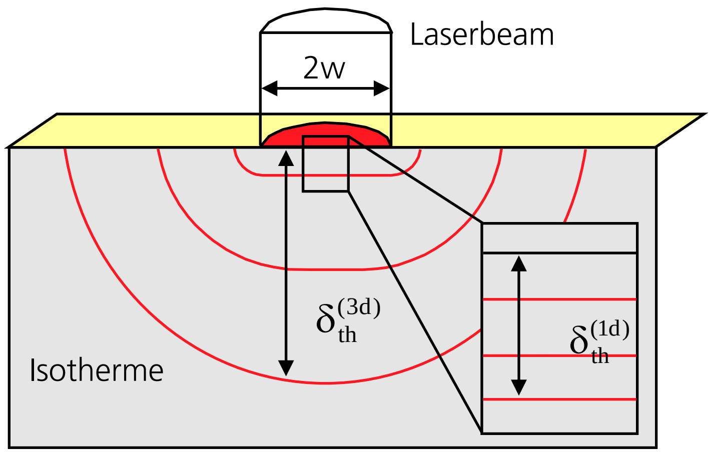


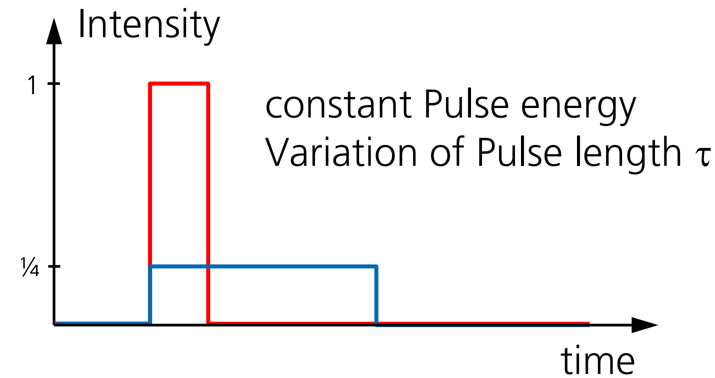
Time

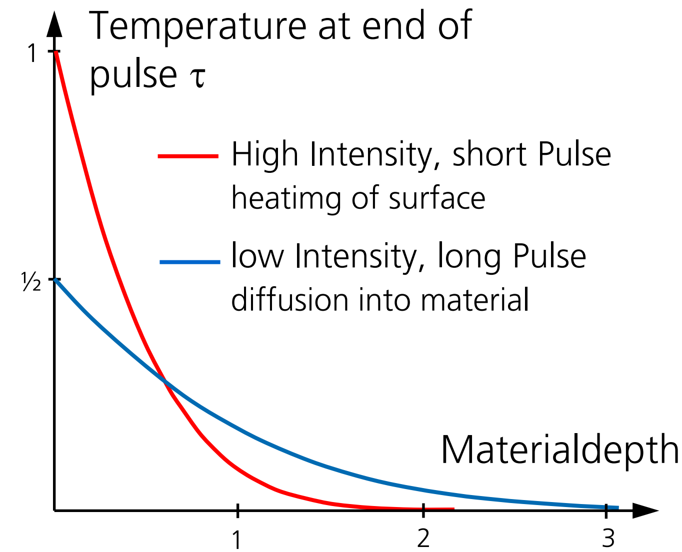


Space

Thermal processing







Solution of 1d- heat conduction problem:

$$T(z,\tau)-T_0=\frac{I\,A}{\lambda}\delta_{th}(\tau)\,ierfc\left(\frac{z}{\delta_{th}(\tau)}\right)$$

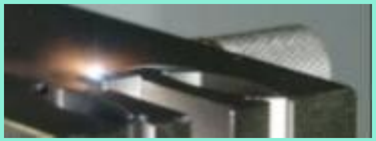
$$\delta_{th}(\tau)=\sqrt{4\kappa\tau}$$ **Thermal penetration depth**

$$\kappa=\frac{\lambda}{\rho c}$$ **Thermal conductivity [m²/s]**

Ultra short pulse lasers

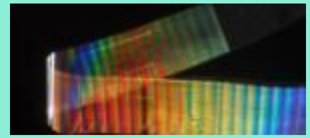
Application fields for ultra short pulse laser processing

Mechanical Engineering



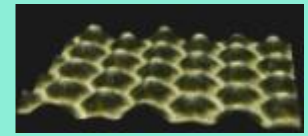
- Tool Technology
- Nozzle drilling
- Turbine blade structuring
- Glass processing

Nano Manufacturing



- Nano particle generation
- Multi photon polymerisation
- Functional surface processing
- Laser chemistry

Electronics



- Thin film processing
- Organic electronics
- Trimming
- Mask repair

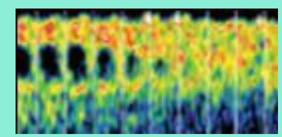
Photovoltaics

- Thin film processing
- Precision drilling
- Texturing
- Materials modification

Life Science

- Tissue ablation
- Ophtalmologic applications
- Bio fabrication
- Intra cell processing

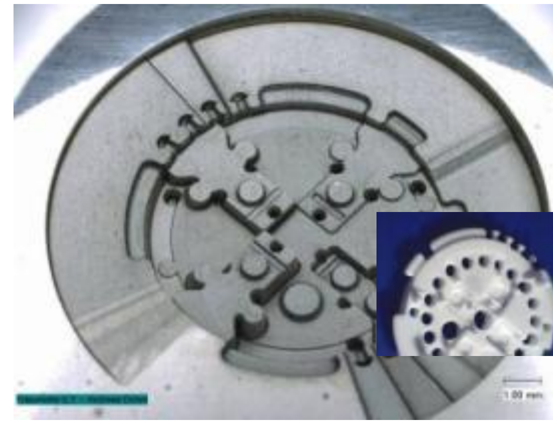
Metrology



- Optical coherence tomography
- Terahertz technology
- Materials analysis
- Bio diagnostics

Laser Tooling with Ultra Short Pulsed Laser

- Processing time10 Std.
- Ablated volume 100 mm^3
- Surface quality similar to EDM-Processing
  $R_a < 0.3$ µm
- No EDM-tools necessary



ns-Laser

ps-Laser

EDM

Precision structuring of embossing tools

3D-Structuring of embossing rolls

Material: Copper, chrome-plated
Roll: 250 mm diameter, 1 m length
Roller rotation speed: 1400 U/min
Line scan distance : 2 µm
-> surface speed: 15 m/s
-> spot distance @ 2 MHz: 7,5 µm
Laser power: 100 W
Spot size: 10 µm
Repetion rate: 3 MHz

- Clear replication of CAD-Data
- No melt and debris
- Surface roughness < 0.5 µm

5 mm

Bundesministerium für Bildung und Forschung
Pikoflat
SAUERESSIG® SCHEPERS

RWTH
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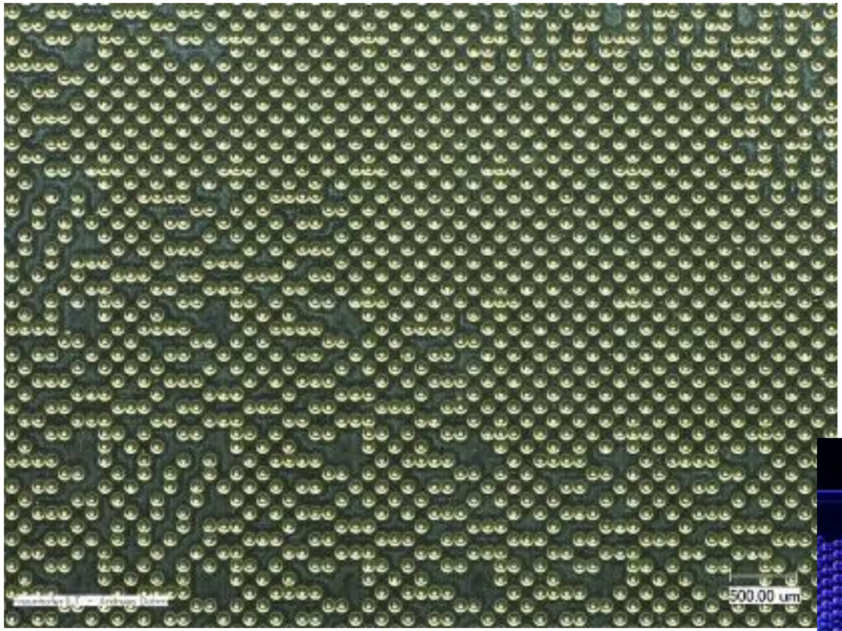
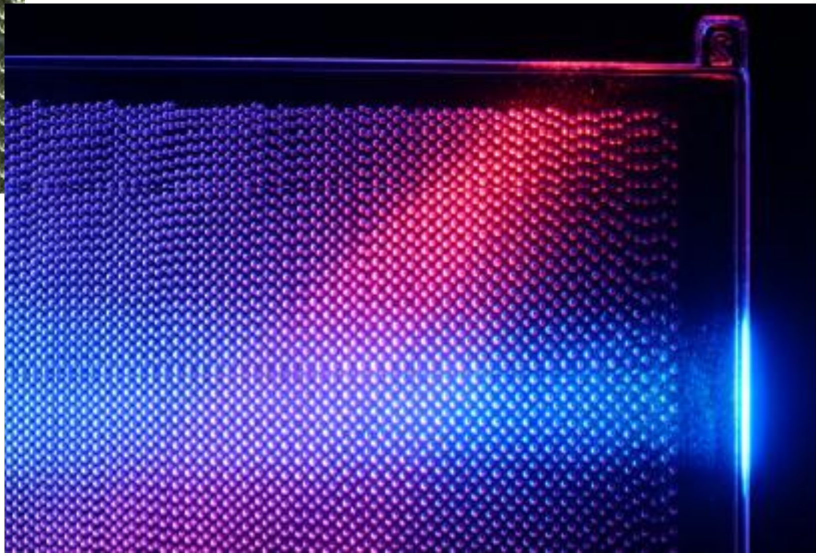
Precision structuring of embossing tools

SAUERESSIG® SCHEPERS

Micro injection moulding of lens arrays in PMMA



Micro moulding tool for surface structured parts

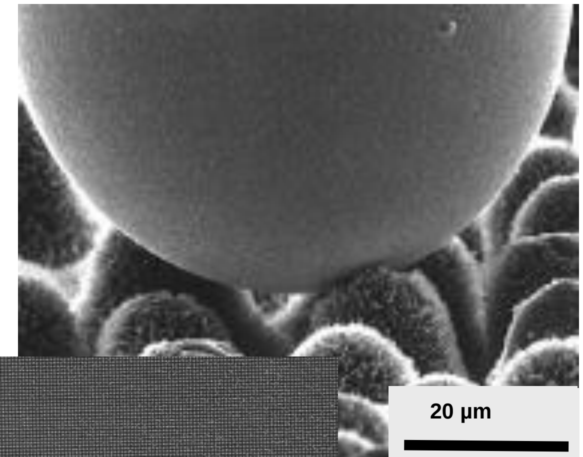


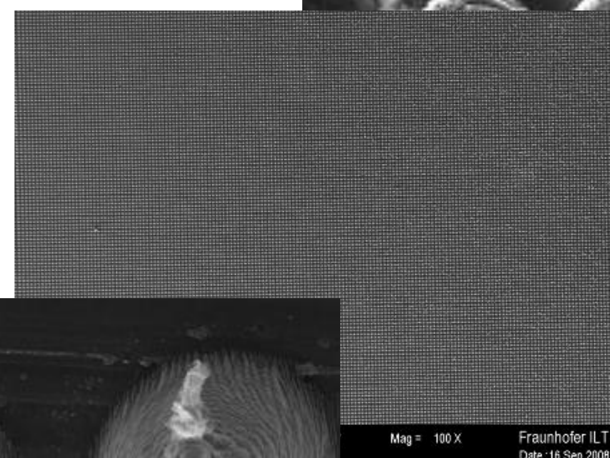
Laser structuring for functional surfaces

Structuring of injection moulding tool with Pikosecond lasers
Lumera Rapid, λ = 355 nm

Generation of multiple structures
Structure size: 10 µm
Sub structure: 2 µm
Sub-Sub structure: 100 nm

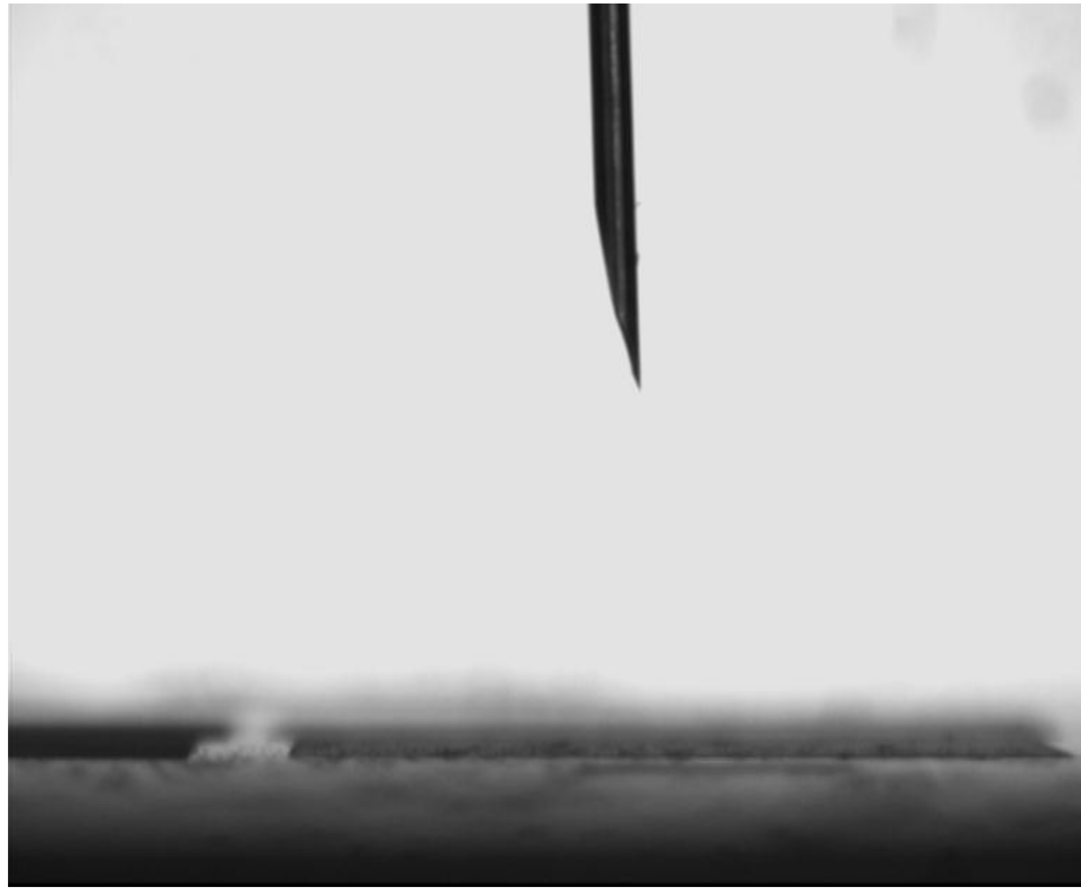
Replication by injection moulding
Material: Polypropylen





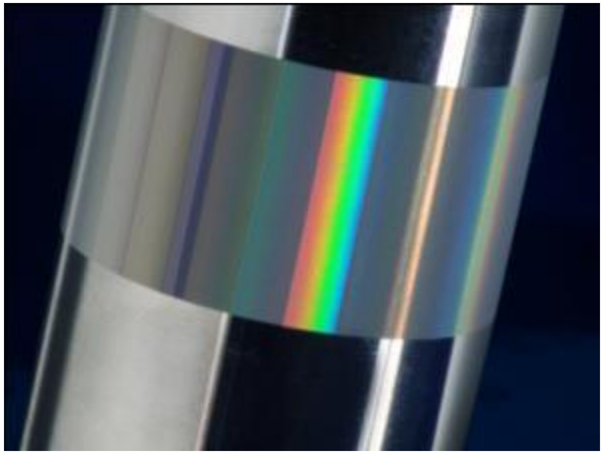
Laser structuring for functional surfaces

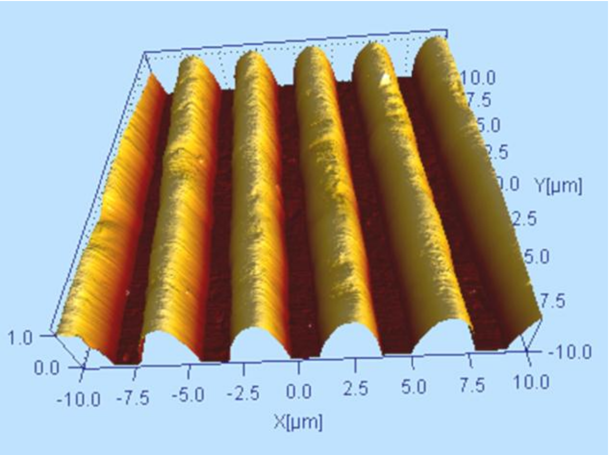
- Contact angle 174°
- Minimal Adhesion
- Rejection of capillary leads to removal of drop
- Drop is fixing on non structured surface



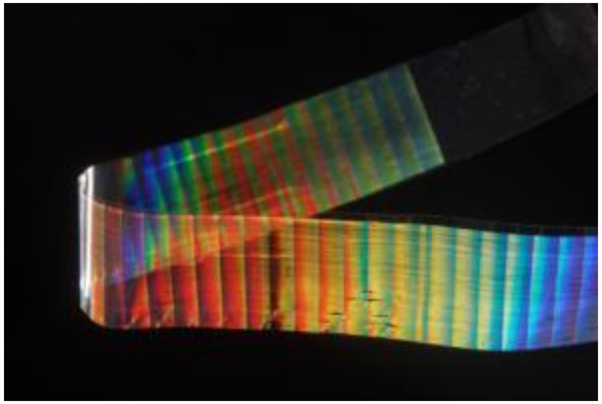
Surface modification with nanostructured tools

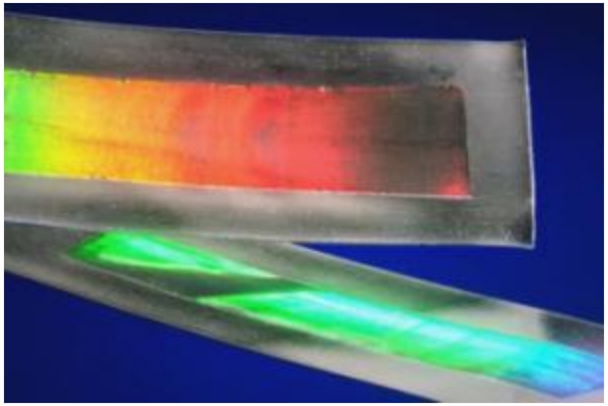
- Stainless-steel embossing tool
- Surface structuring with ps laser
- Structure size 800 nm





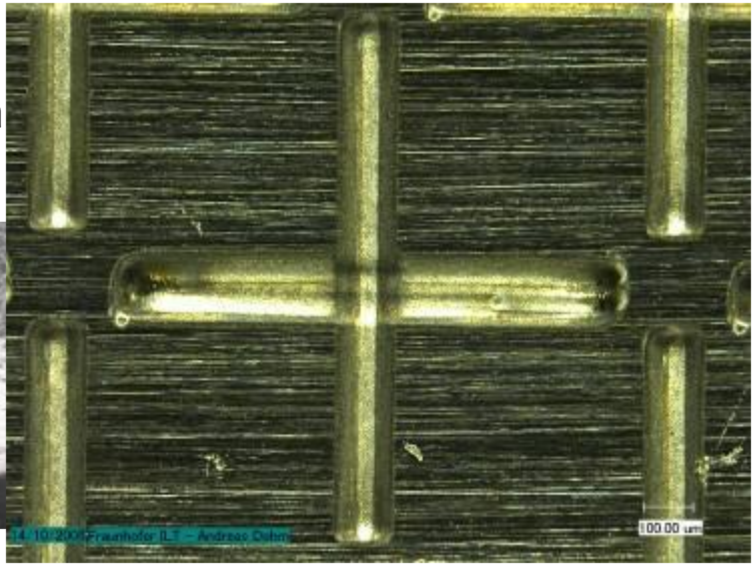
- Roll embossing of polymer and Aluminium
- Process speed 180 mm/min

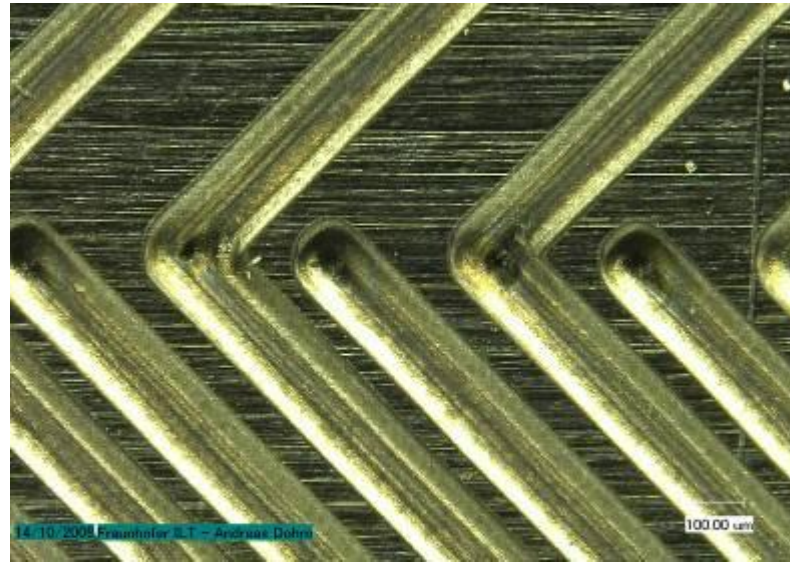




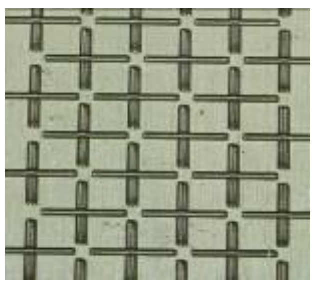
Laser structuring for functional surfaces

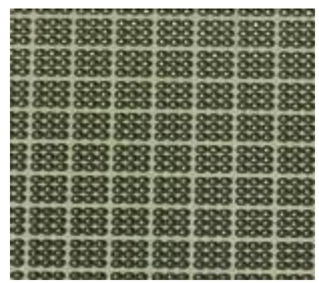
High
ultra

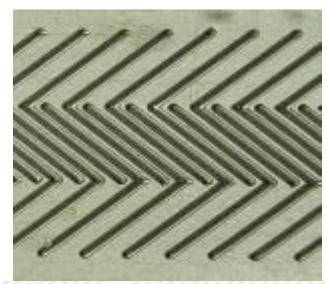




ns-Abla
- Melt
- Post
  nece
- Proc
  100 c
- Structure size > 50 µm



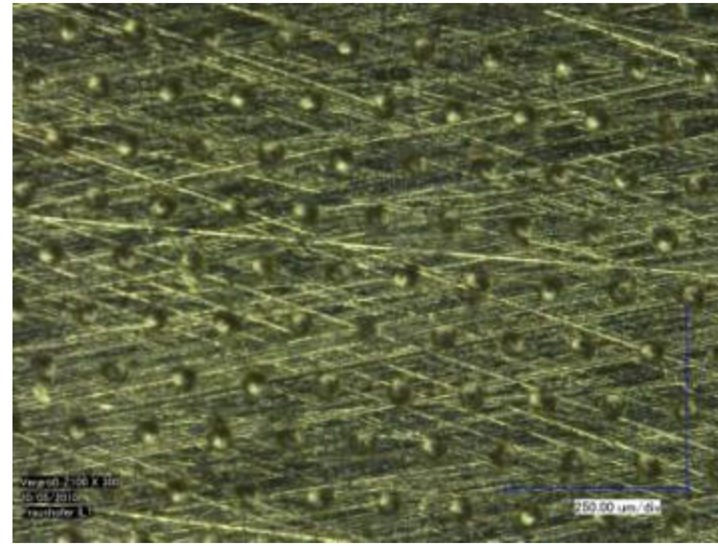




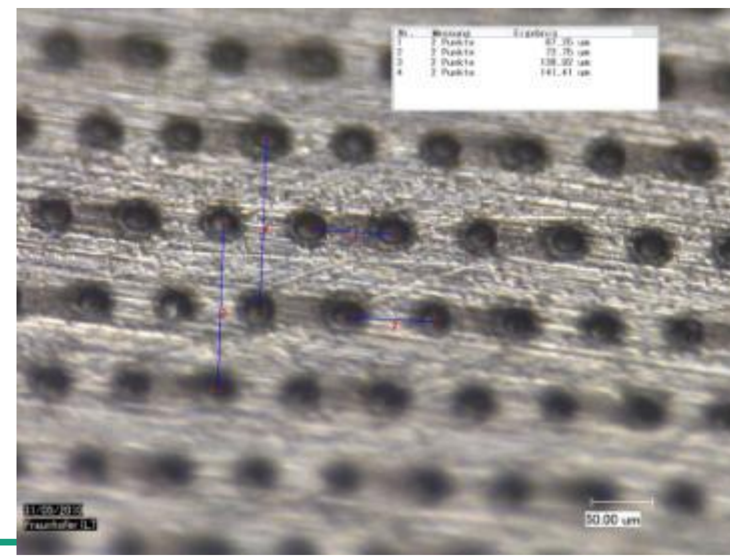
Laser structuring of motor components

- Aim: Reduction of friction and wear
- Approach: Micro and nano structuring of cylinder liners and piston rings
- Use of high power ultra short pulsed lasers

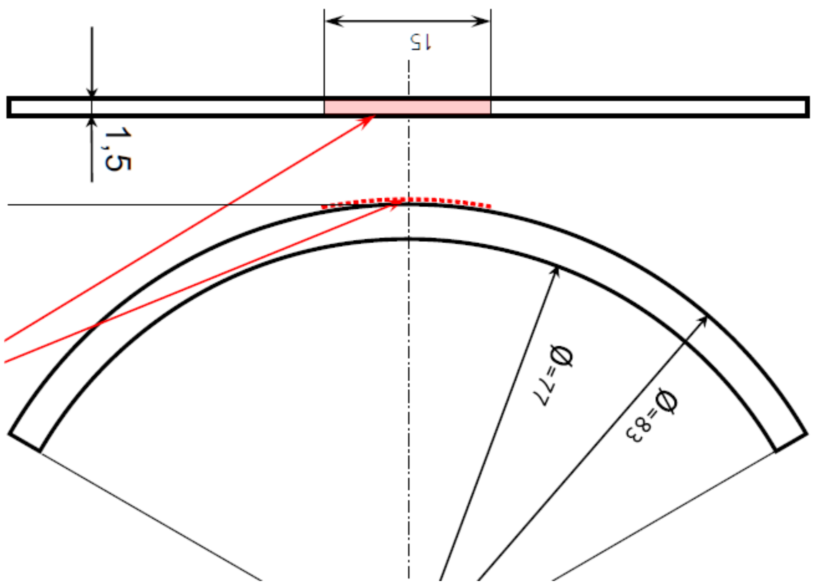
Cylinder liner



Piston ring

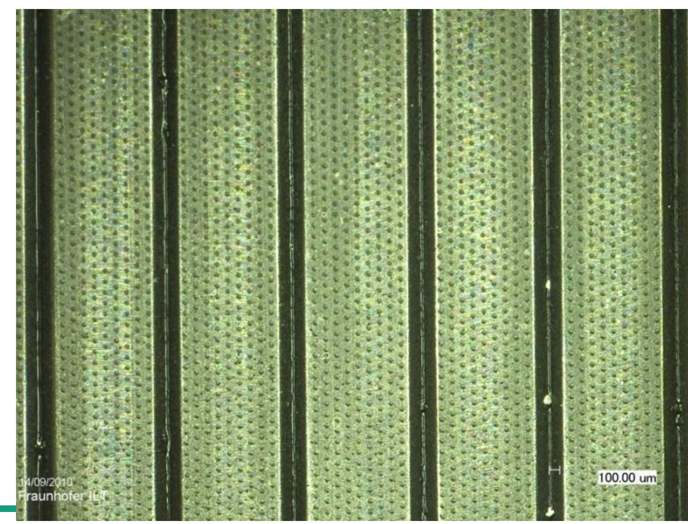


Strukturing of piston rings



Processing parameter:

- Lumera SuperRapid (1064nm, 10ps) on Deckel Maho Lasertec 40
- spot size 20µm
- Power: 0,2W
- Scan speed : 120mm/s
- Material: Chromium nitride (PVD) on steel (Stahl)

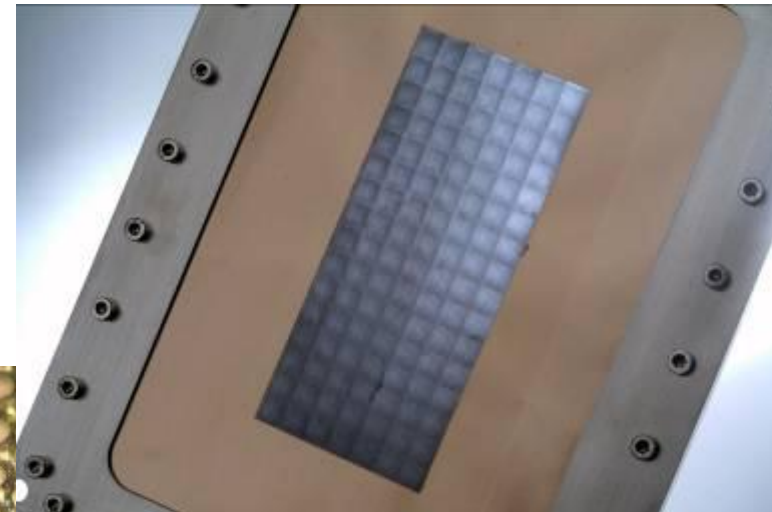


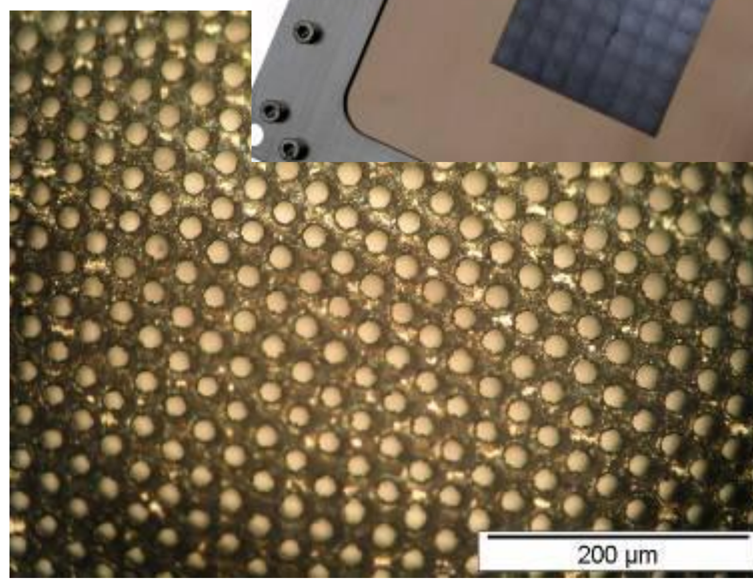
High speed percussion micro drilling

Foil:
- 50 mm x 160 mm
- Thickness: 50 µm

Hole dimensions:
- ∅ = 13 – 16 µm
- Distance 50 µm
- 4 Mio Holes

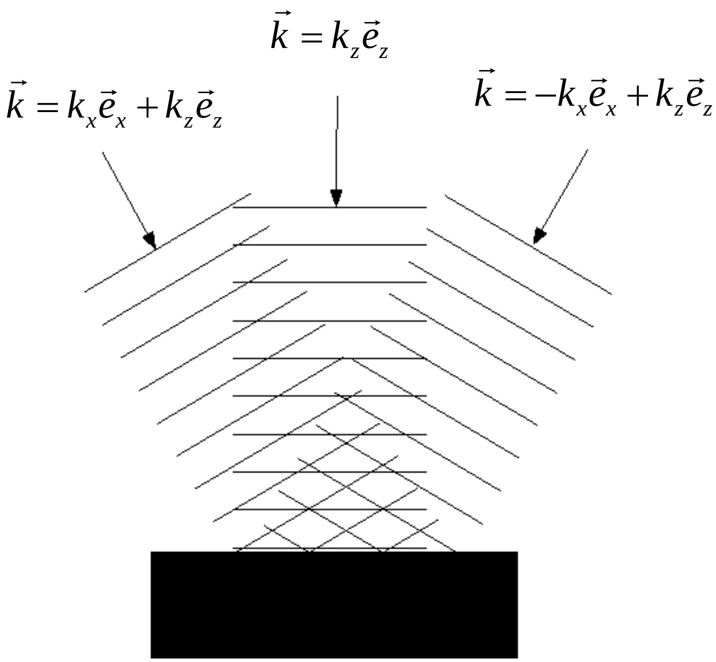
- Processing with Scanner
- Scanfield 10 mm x 10 mm
- Drilling Speed:
  1100 Löcher / s





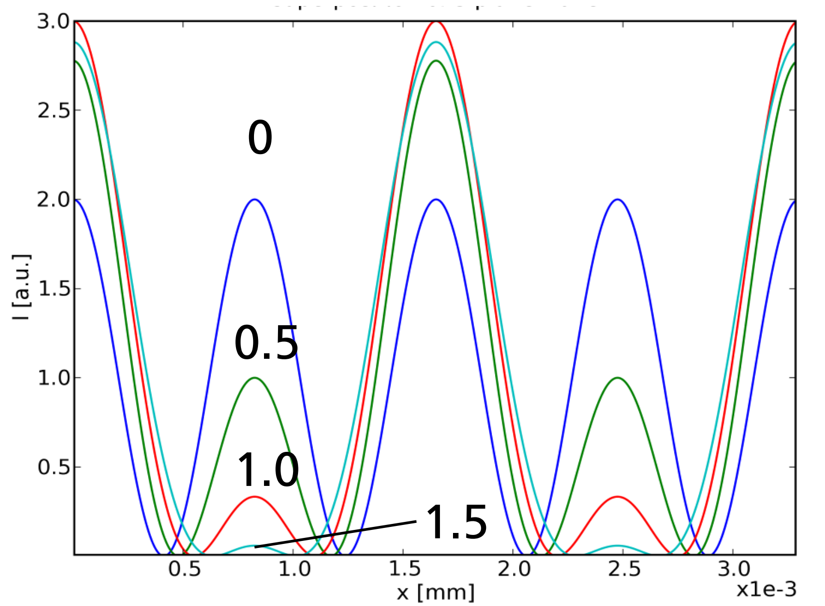
Three-Beam Interference Structuring:

Simulation: Three-Beam Interference in one Plane



$$E(x,z,t) = a\cos(\omega t - k_z z) + \cos(\omega t - k_z z - k_x x) + \cos(\omega t - k_z z + k_x x)$$

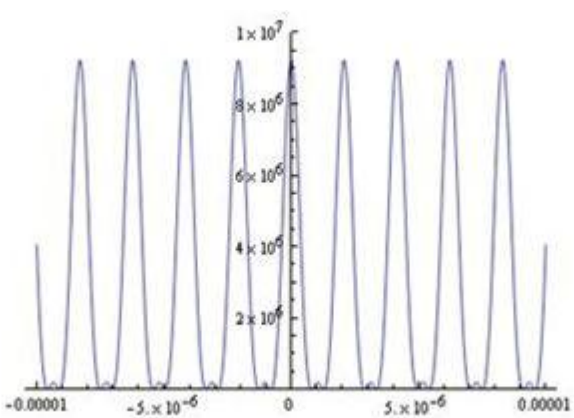
Superposition of 3 plane waves, coplanar arragement

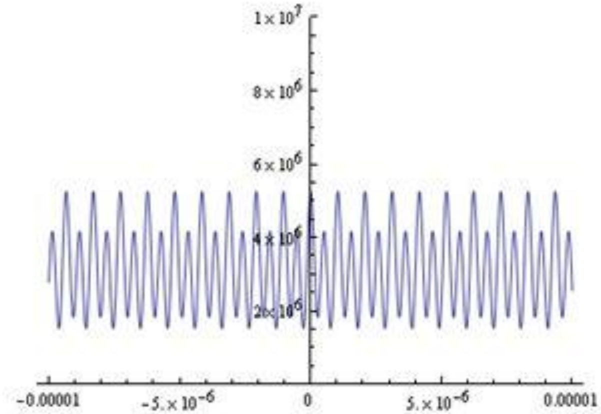


$$I(x,z) = \pi\left(2 + 2\cos(2k_x x) + a^2 + 4a\cos(k_x x)\right)$$

Three-Beam Interference Structuring:

Simulation: Three-Beam Interference in one Plane

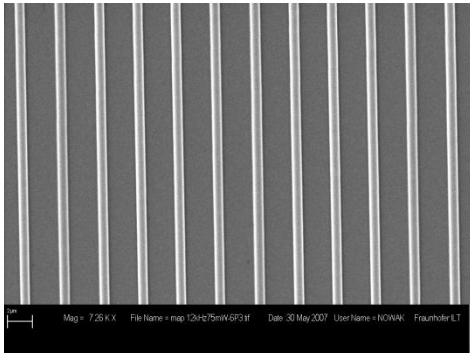


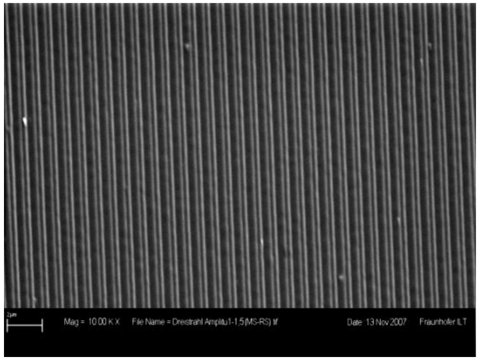


Intention:

Calculation of the sensitivity of the intensity-modulation depending on the alignment of the sample in z-direction

Linestructures in photoresist, periodicity: 2.8µm





optimal alignment **misalignment about : 84µm**

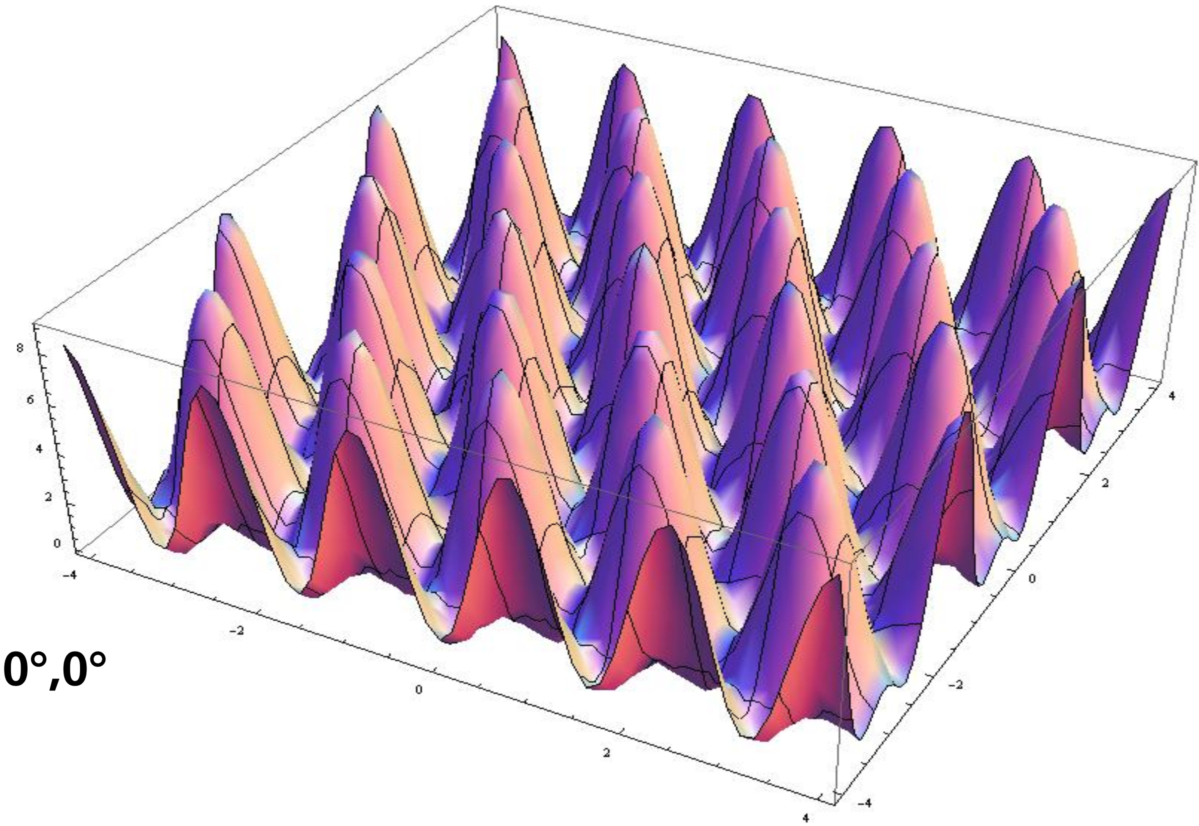
Three-Beam Interference Structuring:

Simulation of the

intensity-distribution

of the three coherent beams

Polarization constellation: 0°,0°,0°

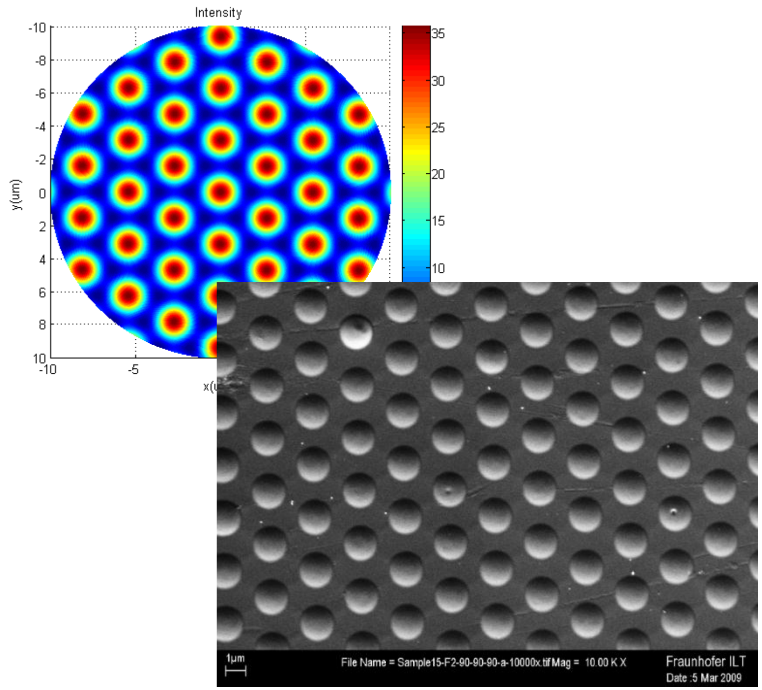


Software: Wolfram Mathematica 7

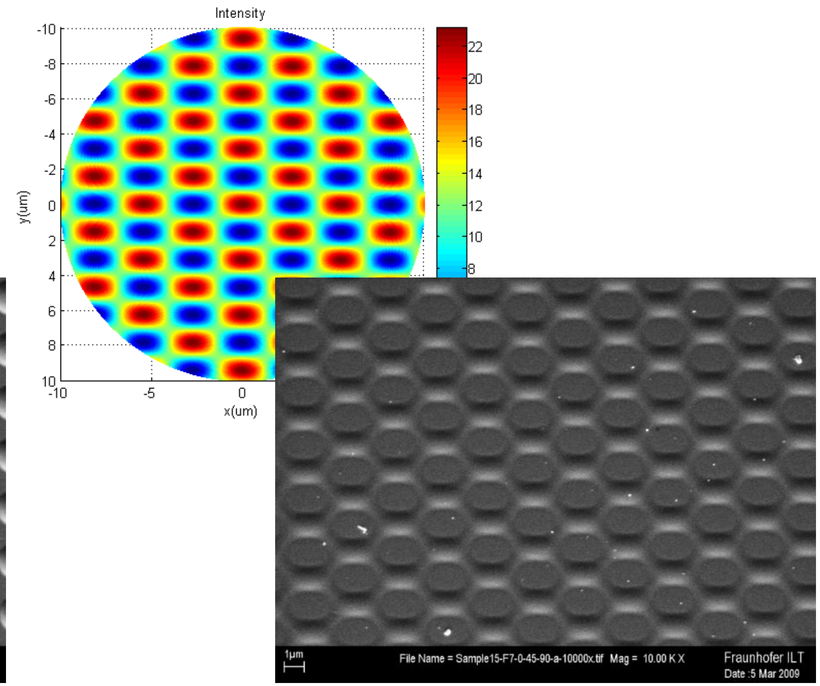
Three-Beam Interference Structuring:

Simulation: Polarization: 0°,0°,0°

Simulation: Polarization: 0°,45°,90°



SEM-Image:
Hole-structures in Pi*



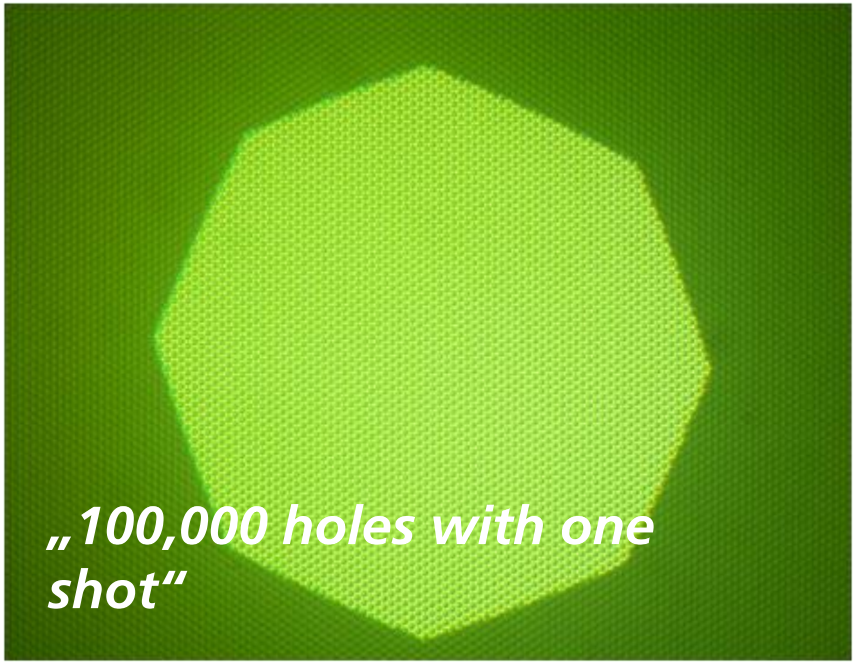
SEM-Image:
Rectangular-structures in PI*

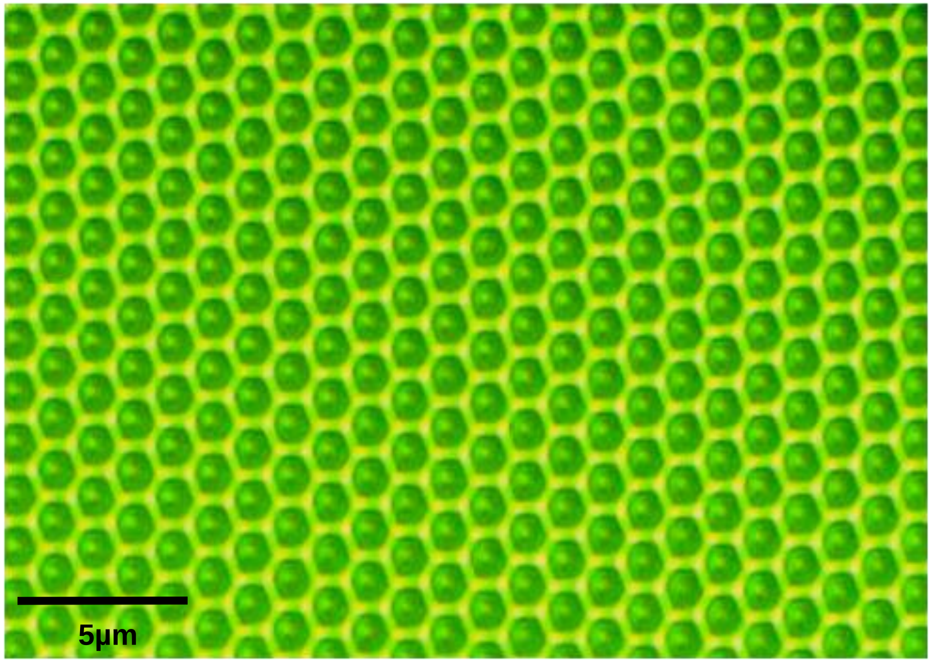
Software: Matlab

***Polyimid**

Three-Beam Interference Structuring:

Structures on Polyetheretherketone (PEEK):





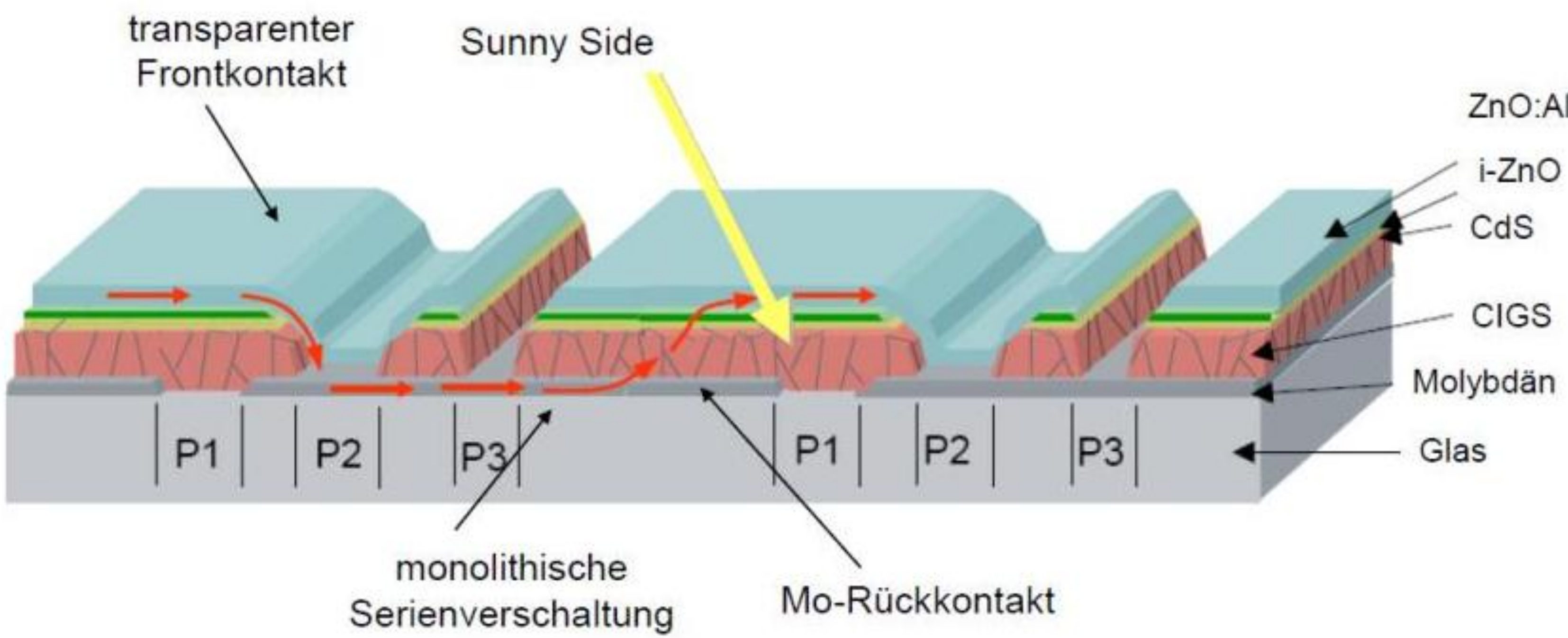
Homogeneous structures over the entire spot.

(Detail)

Diameter of the spot: 500µm

Diameter of the structure: 1µm
Depth of the micro-holes: 600nm

Thin film structuring in solar cell production



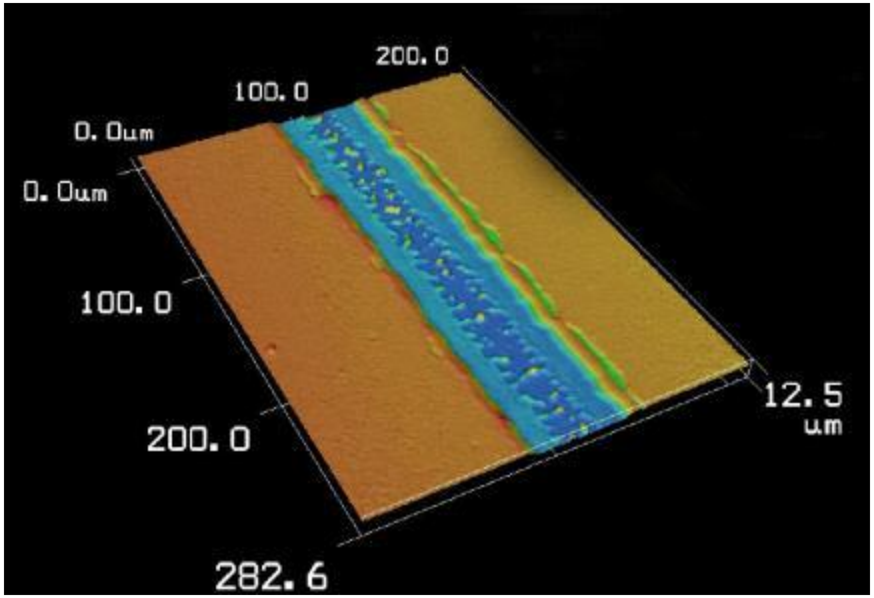
P1: Ablation of Molybdenium-Layer
P2: Ablation of CIGS-Absorber
P3: Ablation of CIGS and TCO-Layer

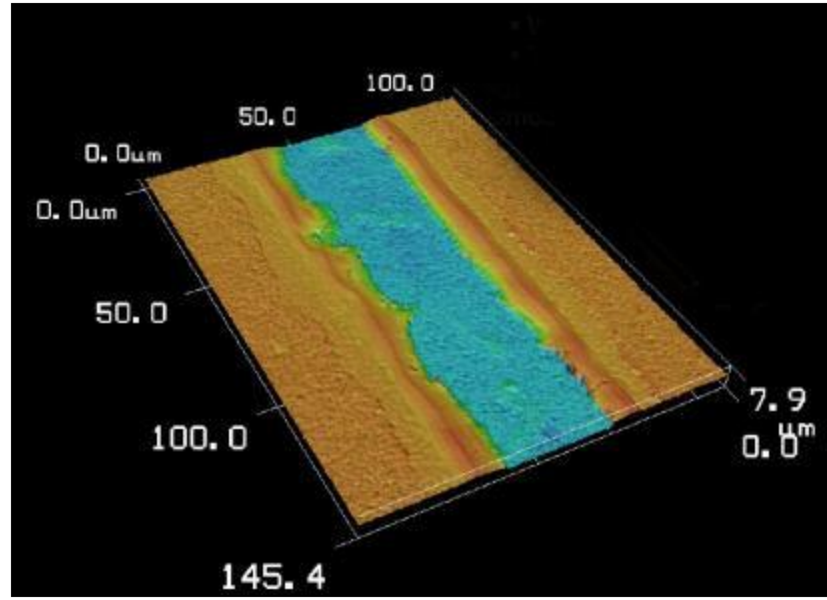
LPKF SolarQuipment

RWTH

Fraunhofer ILT

Thin film structuring in solar cell production





ns-Laser ablation of CIGS and TCO

- Molydenium deterioration
- CIGS-Melting

ps-Laser ablation of CIGS and TCO

- No Molydenium deterioration
- Low CIGS-Melting

LPKF SolarQuipment

RWTH

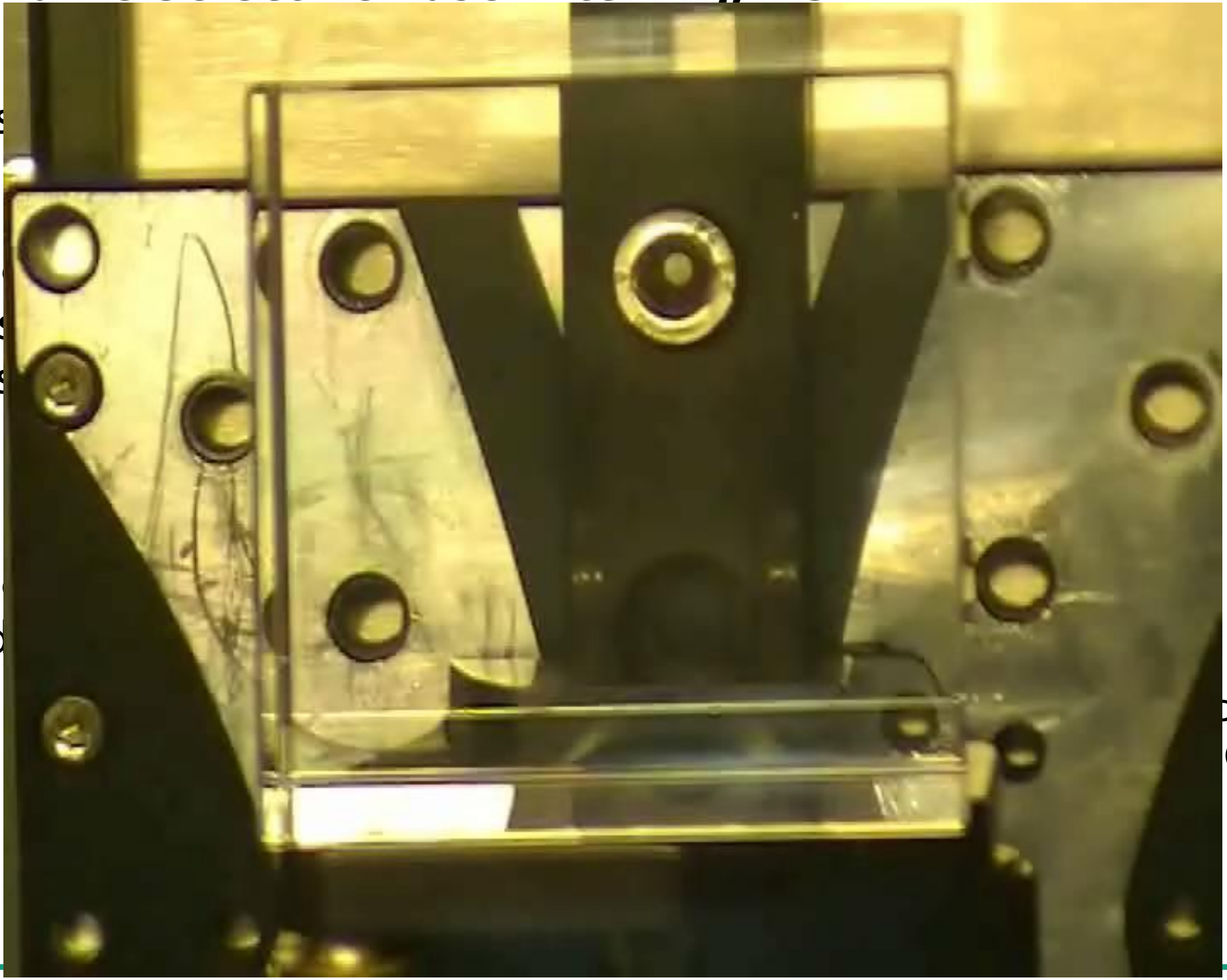
Fraunhofer ILT

In-volume Selective Laser Etching, "ISLE"

Process

1) Sele
the s
by fs

2) Sele
mod



thing
OH

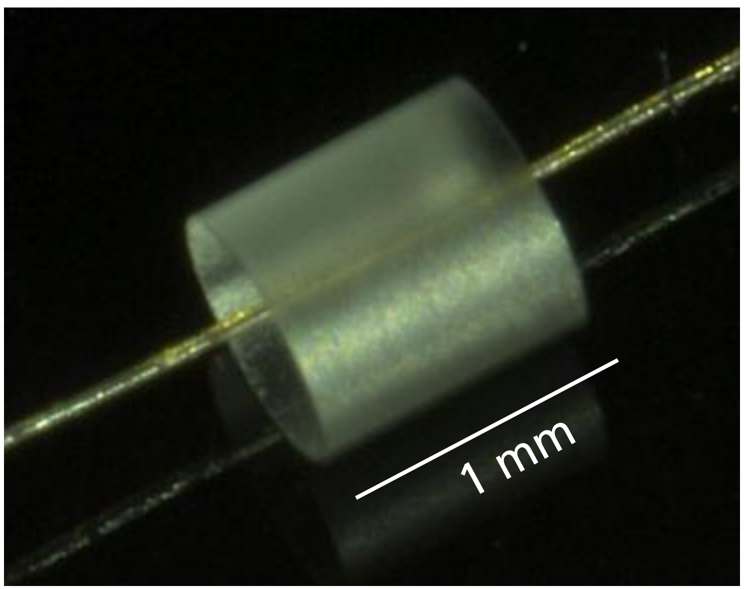
RWTH

Fraunhofer ILT

Examples for High Speed In-volume Micro Structuring

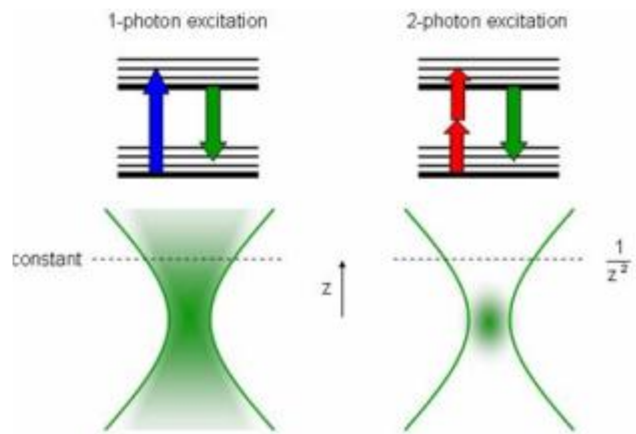
Tubes made of fused silica

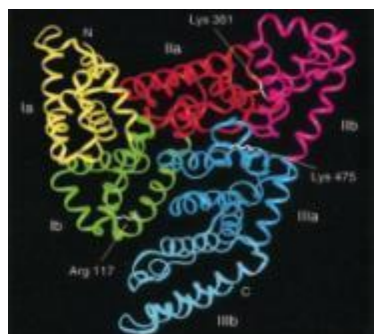
Diameter and height: 1 mm
v=25 mm/s
P=250 mW
NA=0.3
Processing time: 60 s



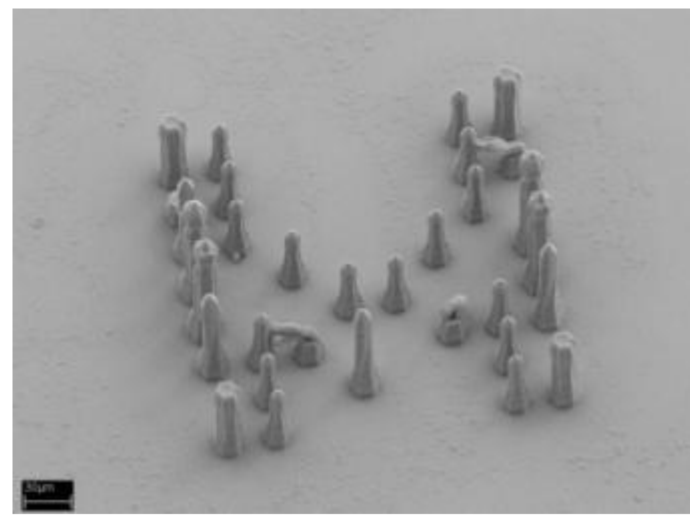
High Resolution Multiphoton Polymerisation

- Polymerisation initiated by absorption of two or more photons –
  requires high photon density
- Polymerized volume is restricted to the focus
- Direct 3D writing of micro-/nano Structures
- Large variety of materials:
  - Elastic polymers
  - Inelastic polymers
  - Biomolecules/proteins

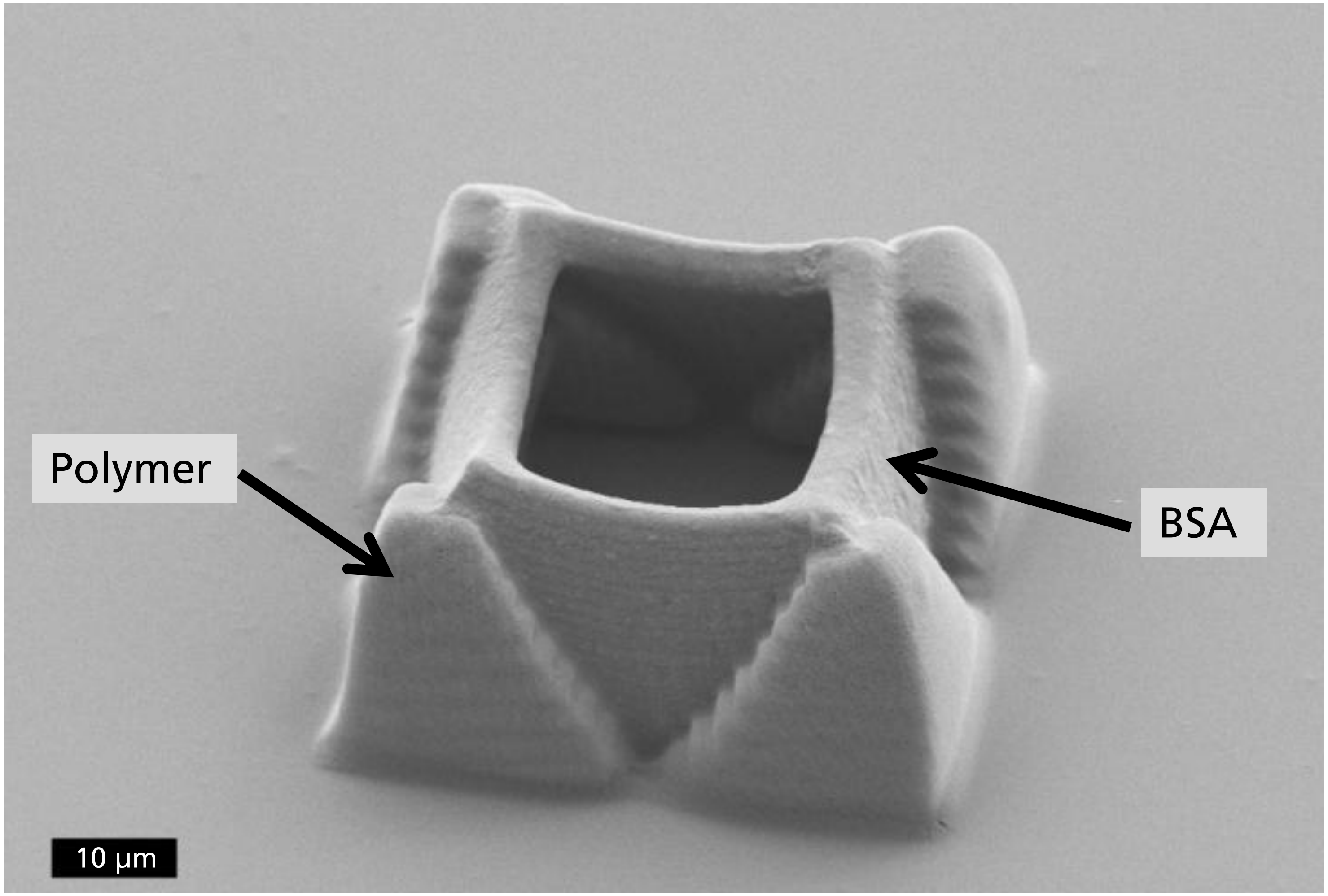




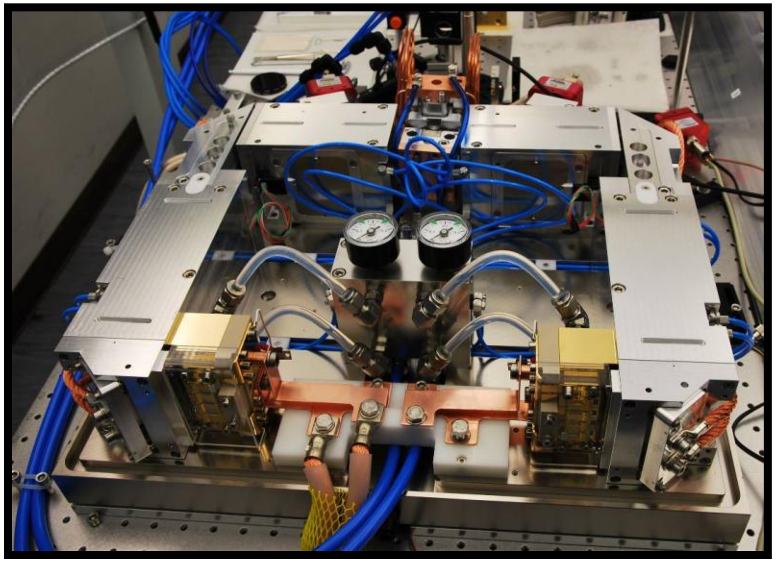
Sugio et al., 1999, Protein Engineering, 12, 6

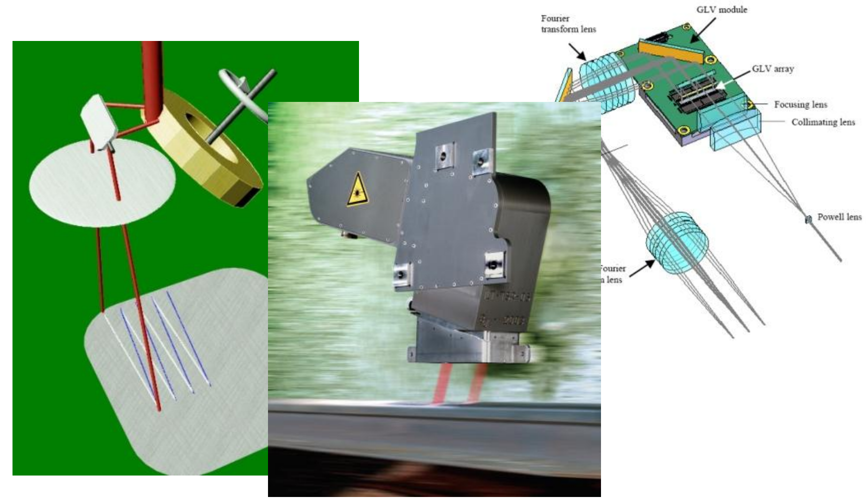


Polymer-Protein Hybrid Structures



High power ultra short pulsed lasers and fast scanners





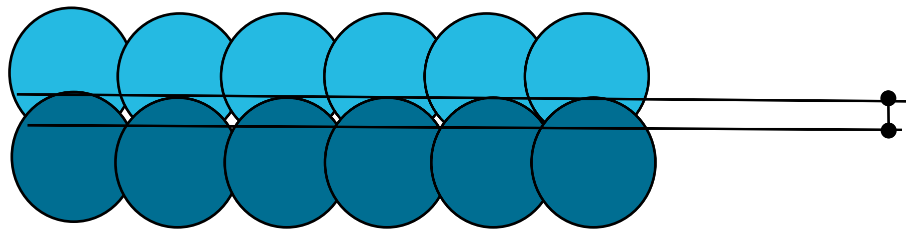
Development of high power ultrafast lasers

- 10 ps-Laser with 20 MHz Rep-Rate and P = 200 W
- 500 fs-Laser with 80 MHz Rep-Rate and P = 300 W

Development of process adapted high speed optical systems for ultrafast laser ablation

- High speed scanner systems
- Multiple beam optics for increase of ablation rate

Requirements on laser scanning for high repetition rate ultra fast lasers

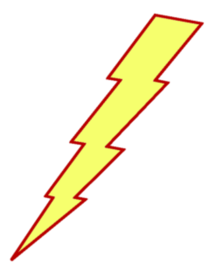


Pulse overlap 10 – 50 %

Line overlap 10 %

Scanner specifications for typical micro ablation technology

- D = 20 µm
- Pulse overlap = 10 µm
- f_{Laser} = 20 MHz
- **Scanning speed = 200 m/s**



Typical high precision Galvo-Scanner

v < 10 m/s

Structuring of embossing rolls

Material: Copper, chrome-plated
Roll: 250 mm diameter, 1 m length
Roller rotation speed: 1400 U/min
Line scan distance : 2 µm
-> surface speed: 15 m/s
-> **spot distance @ 2 MHz: 7,5 µm**
Laser power: 100 W
Spot size: 10 µm
Repetion rate: 3 MHz

5 mm

- Clear replication of CAD-Data
- No melt and debris
- Surface roughness < 0.5 µm

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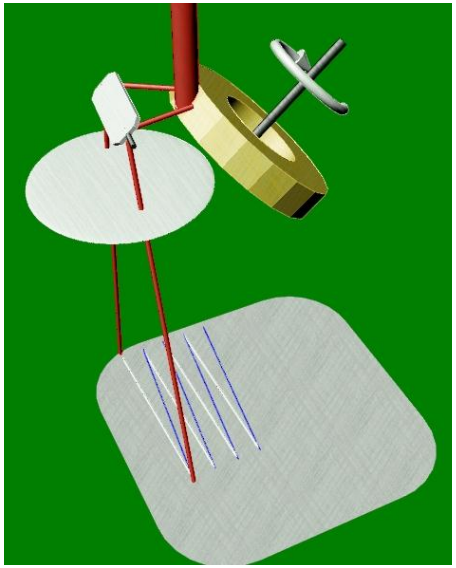
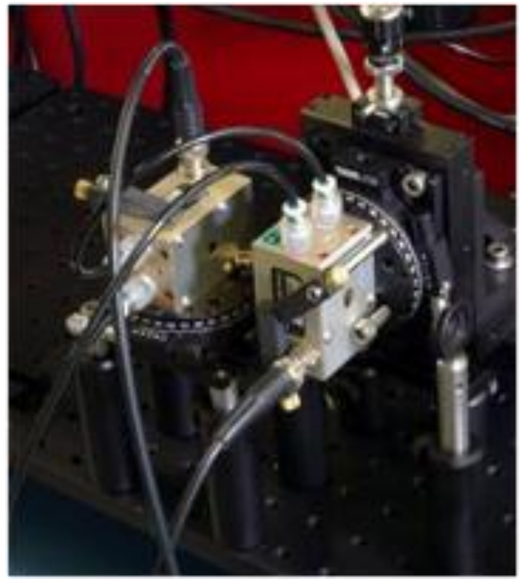
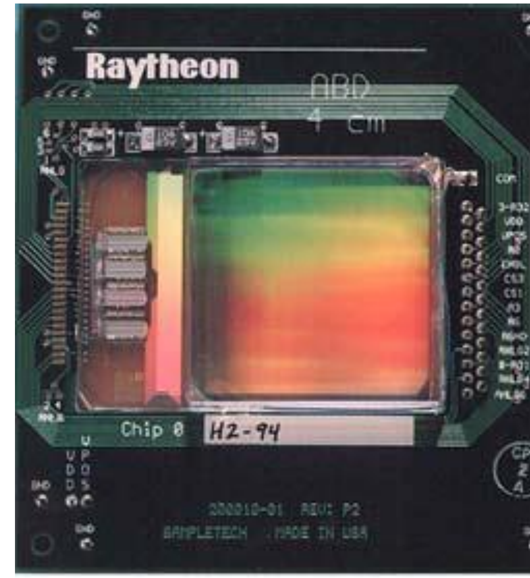
High speed scanning technologies



Polygonial mirror
Single line scan
Scanning angles > 20°
Scanning speed > 100 m/s



Acustooptic deflectors
x-y-scanning
Scanning angles < 2°
Scanning speed > 100 m/s

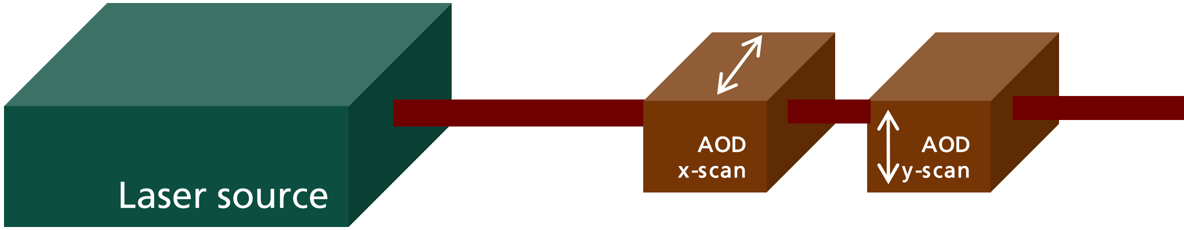


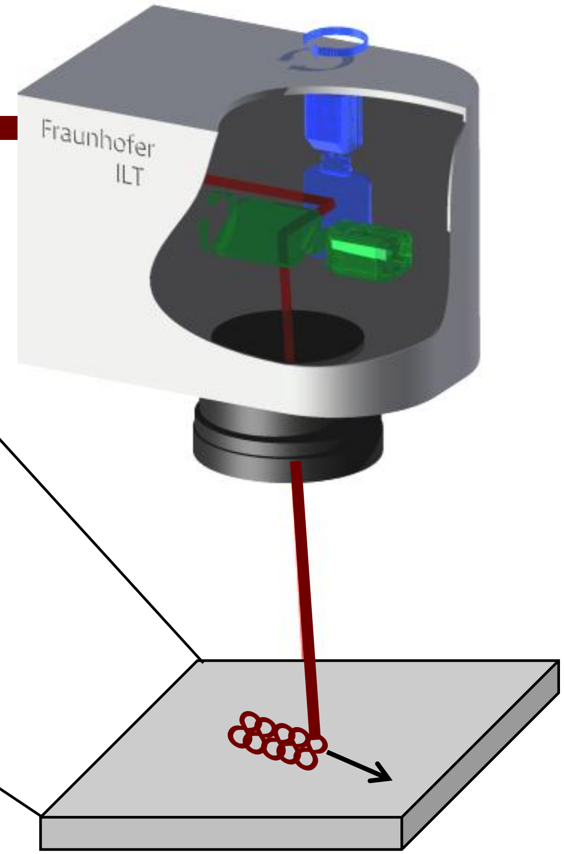
Phased array deflectors
Single line scanning
Scanning angles > 20°
Scanning speed > 500 m/s
for EO-devices

Requirement from ultrafast laser machining @ f = 50 MHz and d_{spot} = 20 µm

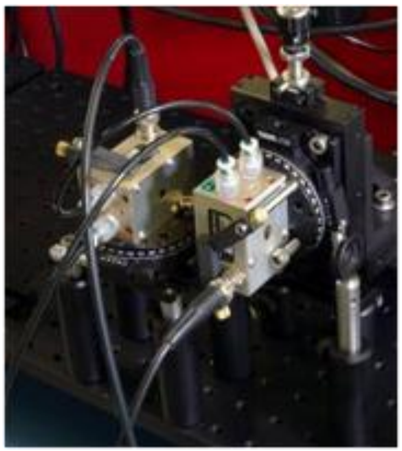
→ **Scanning speed v = 500 – 1000 m/s**

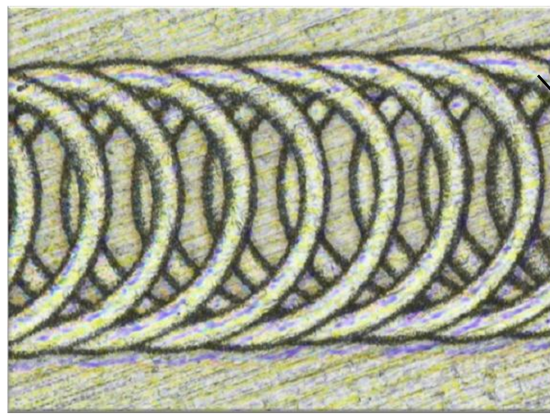
High speed ablation with superimposed AOD and Galvo

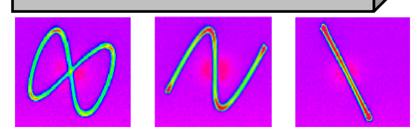




60% efficiency







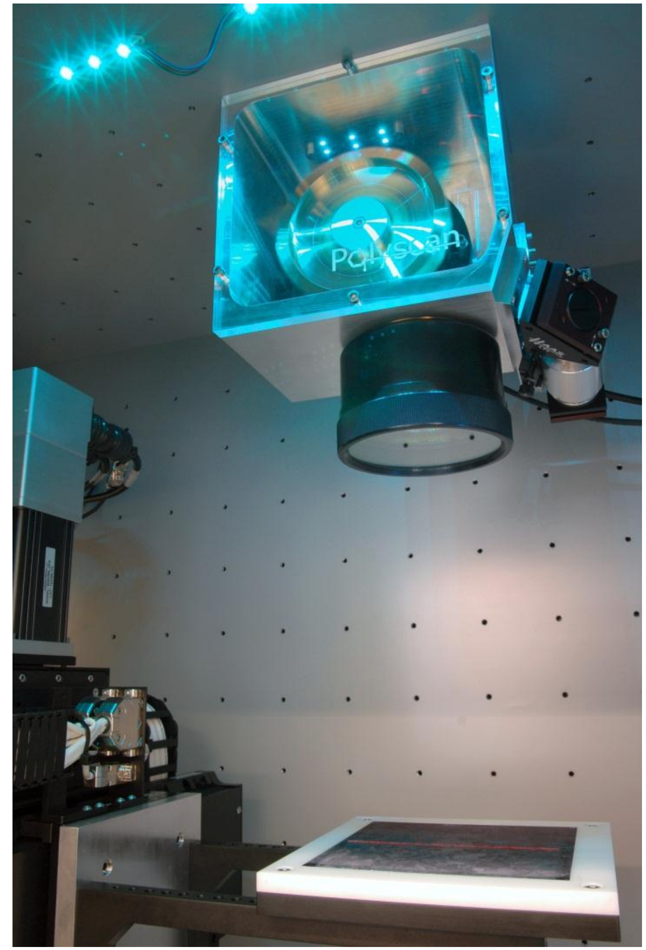
- Superposition of fast scan with small scan angle and slow scan with large scan angle

- Scan velocity up to 120m/s with arbitrary scan figures

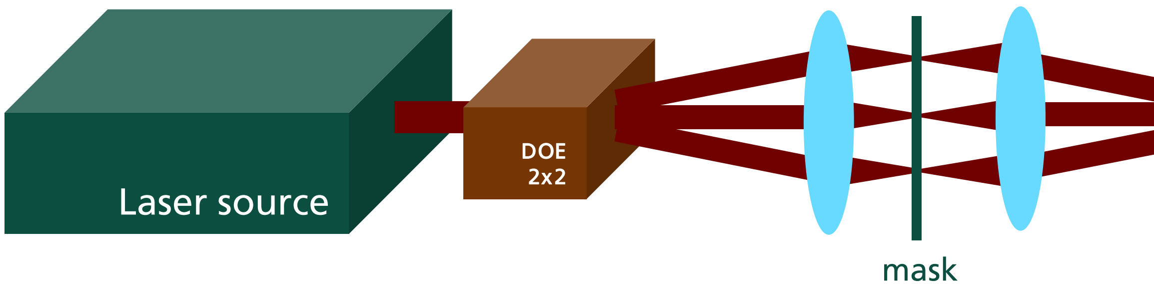
High speed polygon scanning system

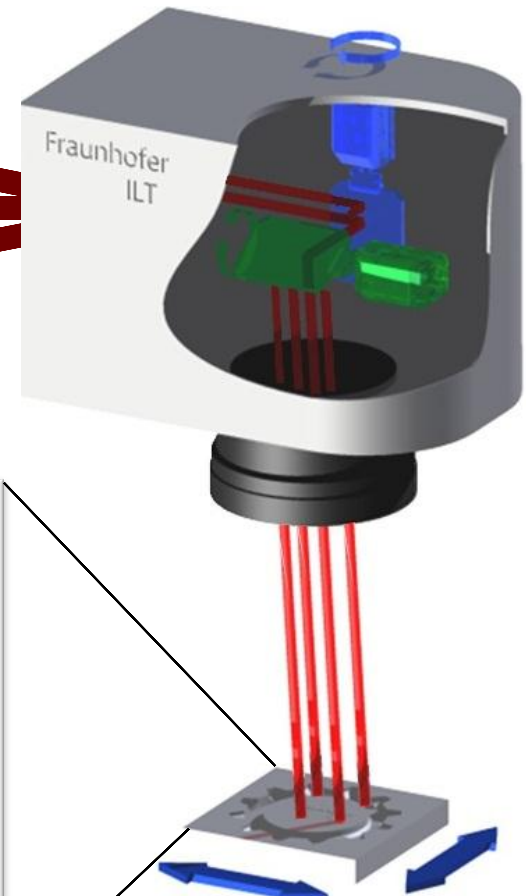
- Laser system: Slab-Amplifier with Lumera Oscillator
  - Pulse duration: 12ps
  - Reprate: 10.7 MHz
  - Max. power: 230W (21.5µJ)
- Polygon with 12 facets
- Scan speed: max. 320 m/s
- F-theta Linse f= 250 mm
- Fokusdurchmesser: 60µm

- Next step: Combination with Galvo Scanner



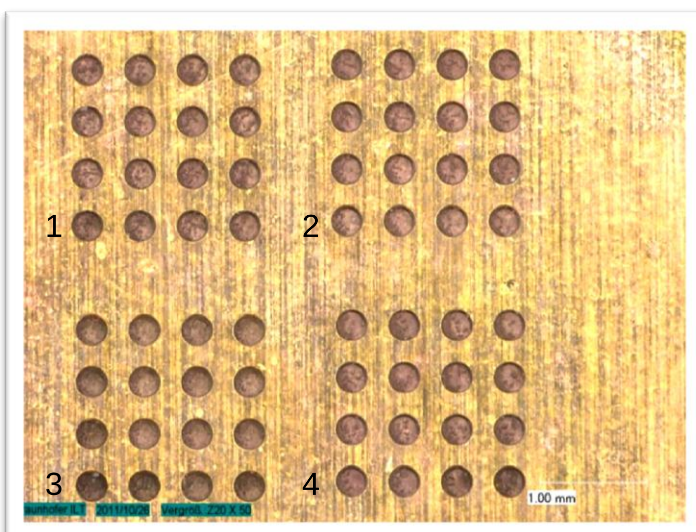
Multi parallel processing with diffractive optical elements





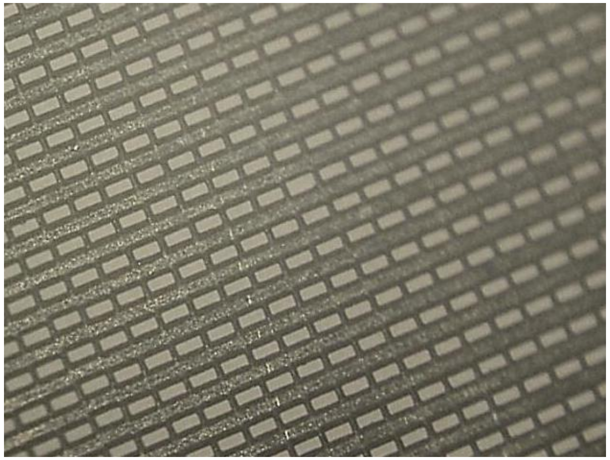
- suited for periodic structures

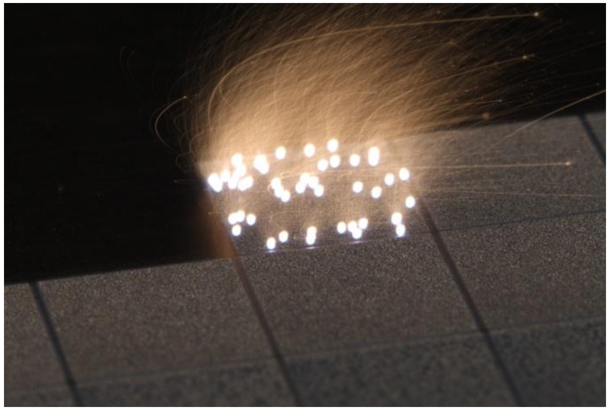
- split high average laser power into numerous partial beams



High speed processing with ultra short pulsed lasers

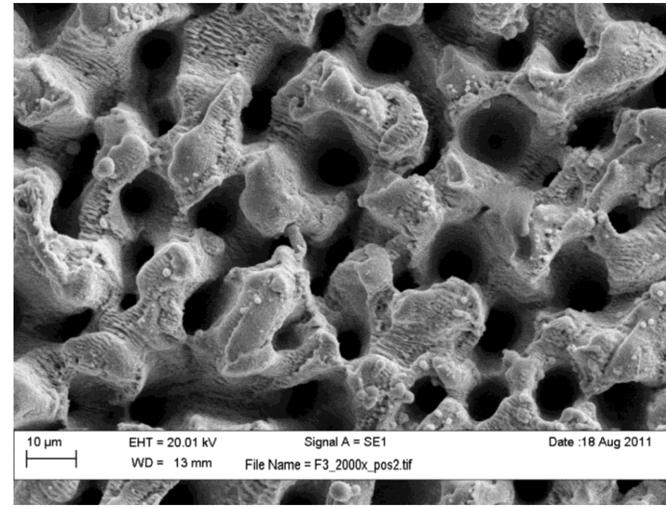
- Laser processes:
  - Drilling
  - Surface structuring
- Applications:
  - Production of large filters with micro holes for water treatment
  - Production of microscaled vaporization masks for thin film deposition
  - Functional surface structuring
- State of the art
  - Etching, mechanical drilling, lithography
- Challenges :
  - High ablation rates
  - Large areas

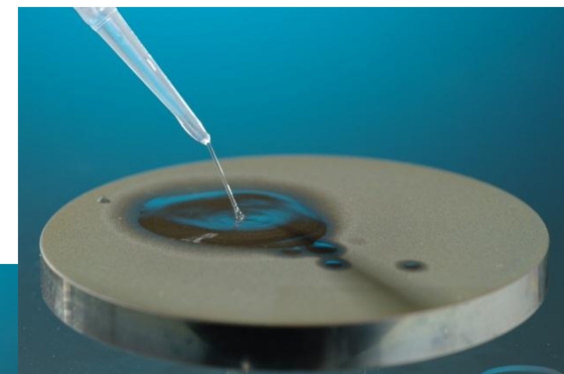




Functional Surfaces by selective Surface roughening

- Ablation of 10-30 layers with ultra short pulsed lasers and high laser intensity
- generation of structures with high structural aspect ratio (>10) and high absorbance of light (<95%)
- Applications
  - Optical absorber
  - scattering area on transparent parts
  - Change of wetting behaviour
  - Surface enlargement



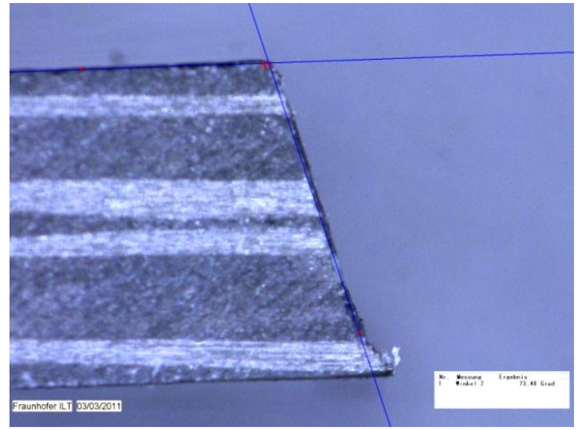


Cutting and ablation of fiber reinforces polymers

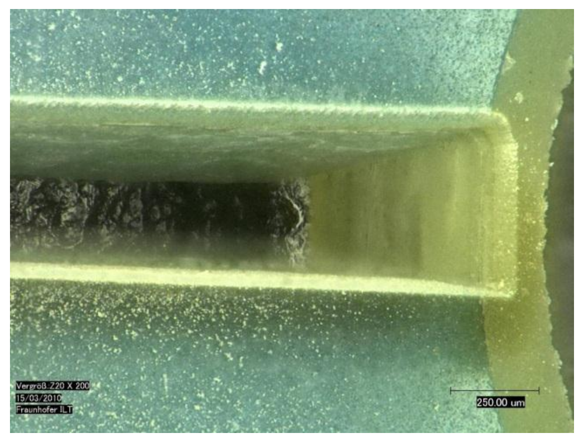
Low impact processing of CFRP

- Cutting
- Trimming
- Drilling
- Partial ablation
- Surface preparation

-> No delamination
-> No thermal degradation



Carbon FRP
t_{Pulse} = 500 fs
Rep.-rate: 5.9 MHz
Pulsenergie: 25 µJ
V_{Scan}: 100 m/s
Ablation rate: 120 mm³/s



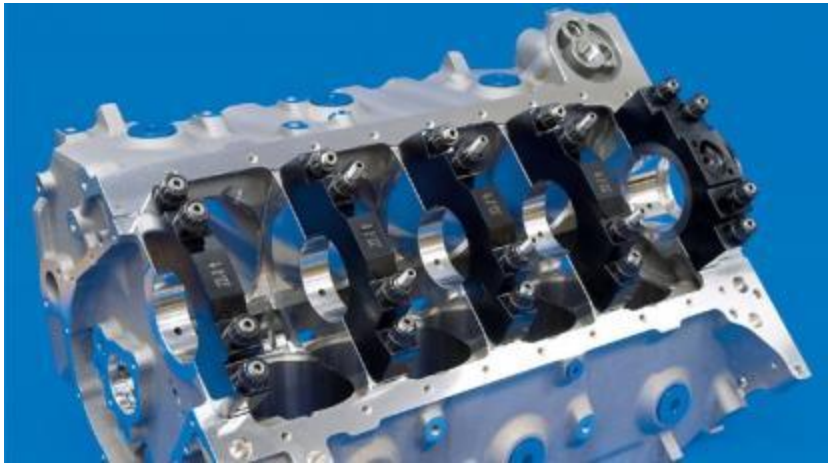
Glass FRP
t_{Pulse} = 10ps
Rep.-rate: 100 kHz
Pulsenergie: 30µJ
V_{Scan}: 1m/s
Ablation rate: 25µm

Future Developments – High Precision at Large Components

Cutting of fiber reinforced polymers

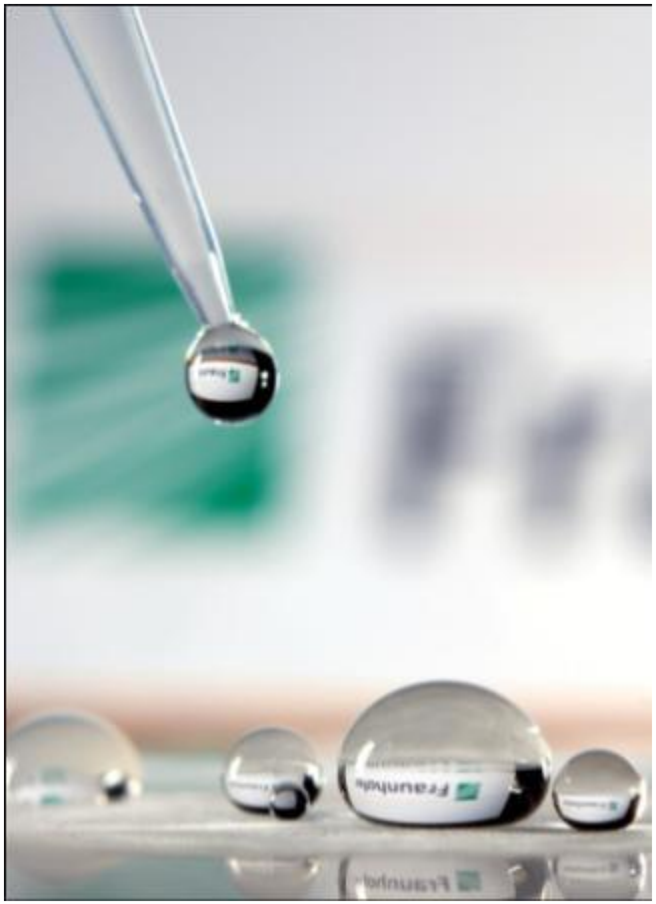
Large area processing

Surface structuring



Low friction surfaces

Thank you very much for attention



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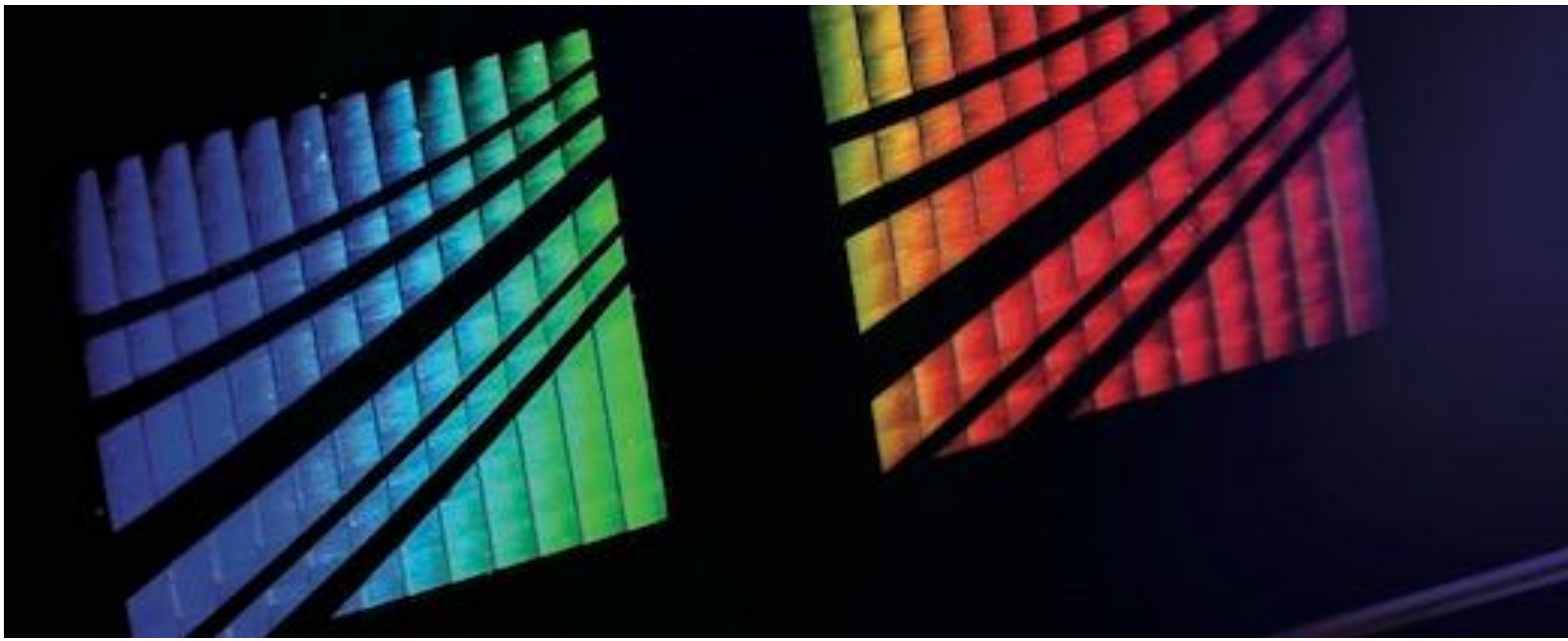
web.: www.ilt.fraunhofer.de

Save the Date

2. Aachener Ultrakurzpuls-Workshop
17. – 18. April 2013



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