

Micro and Nano Structuring with Ultra Short Pulsed Lasers for Tool Technology and Functional Surfaces

Mikro-und Nanostrukturierung mit
Ultrakurzpulslasern für Werkzeugtechnik und
funktionale Oberflächen



Arnold Gillner

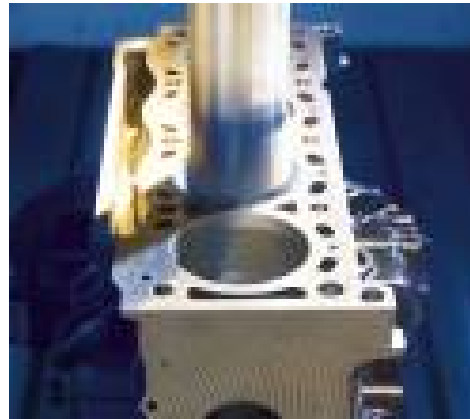
Fraunhofer-Institut für Lasertechnik Aachen

EPMT-Conference 14. Mai 2009



- Basics ultra short pulse laser processing
- Laser ablation with ns- and ps-Lasers
- Examples from tool technology
- Drilling with short pulsed lasers
- Nano structuring with short and ultra short pulsed lasers

Precision structuring – applications



Tools

- EDM machining
- High speed cutting

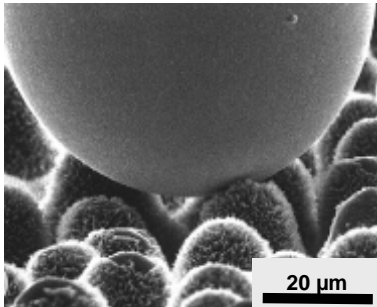
Parts

- Grinding
- Turning, milling

Surfaces

- EDM machining
- Etching

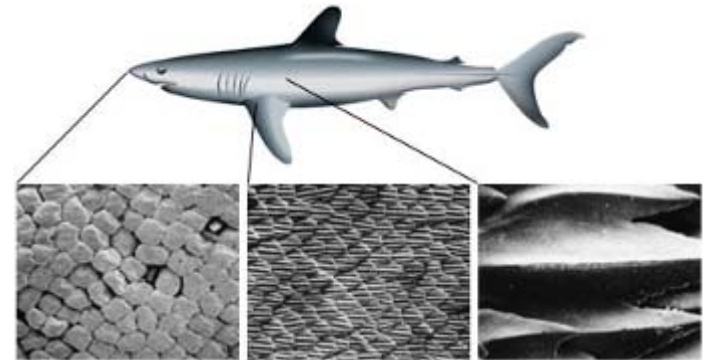
Functional structures – examples from nature



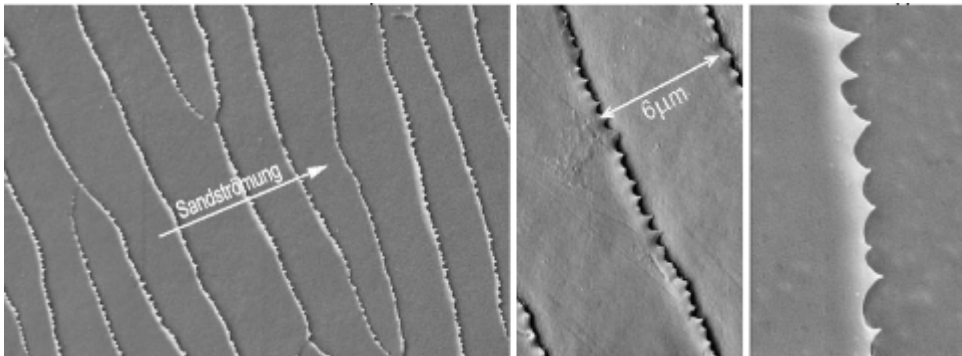
Lotus effect
Self cleaning,
water repellent



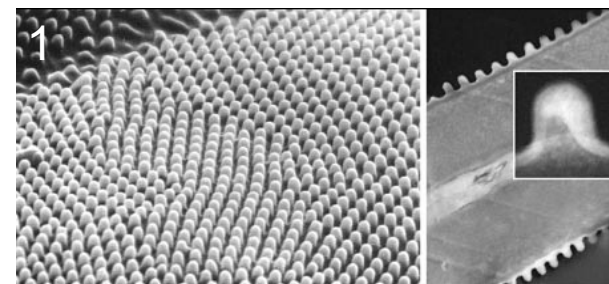
Gecko, self adhesive



Shark, low friction in fluidics



Sand fish, low friction with particles

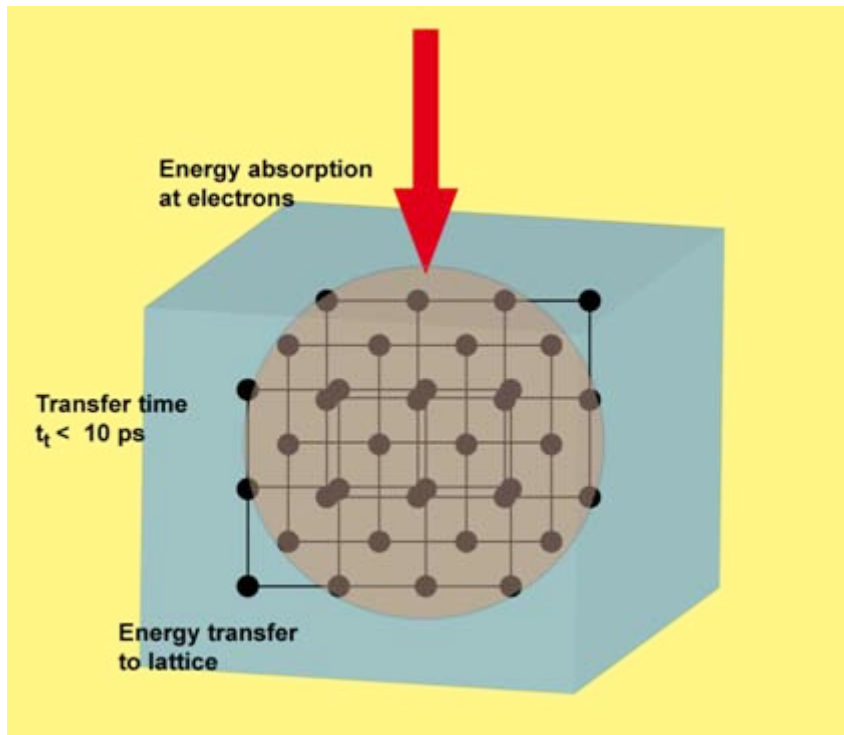


Moth eye

Moth wing

Moth eye, anti reflective

Ultra short laser pulse interaction with metals



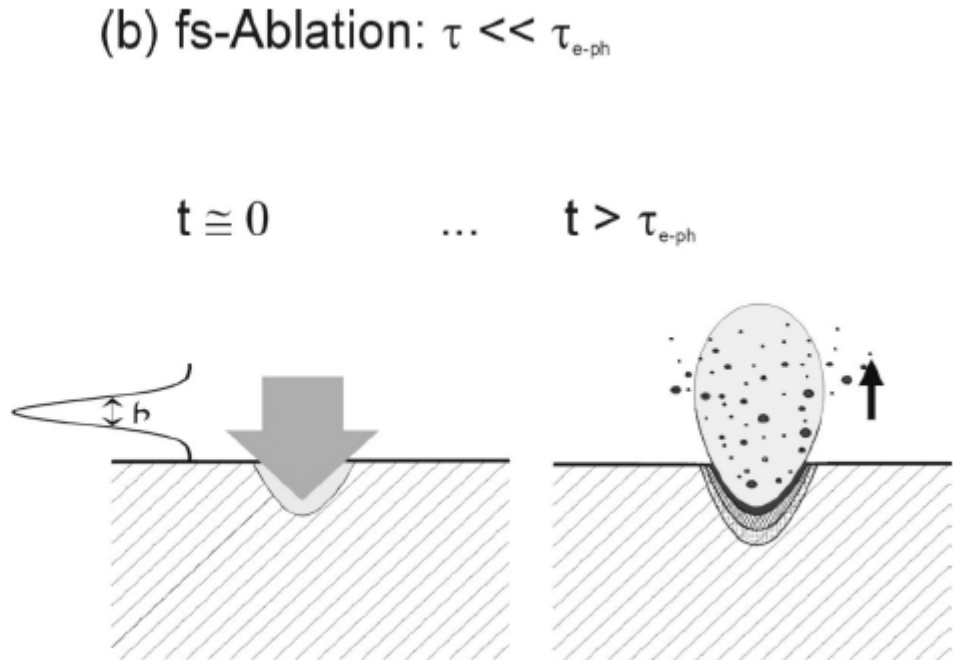
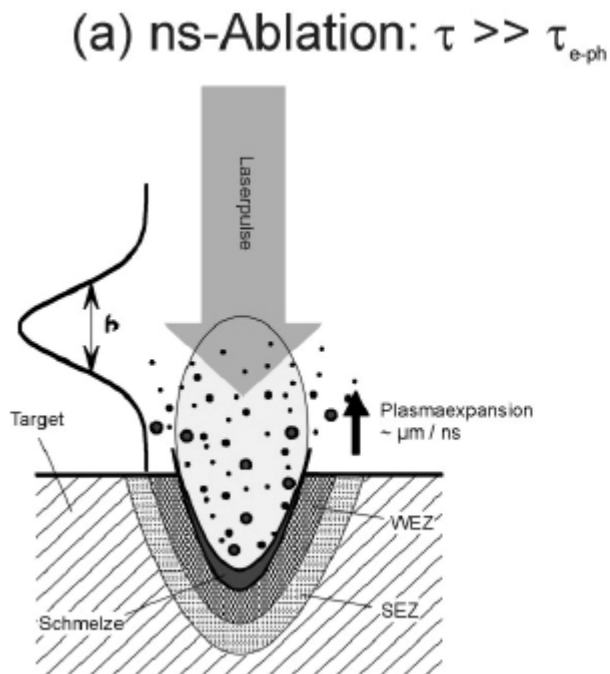
- Energy absorption at electrons
- Transfer of energy to lattice within typical 10 ps
- Heating and melting after end of laser pulse



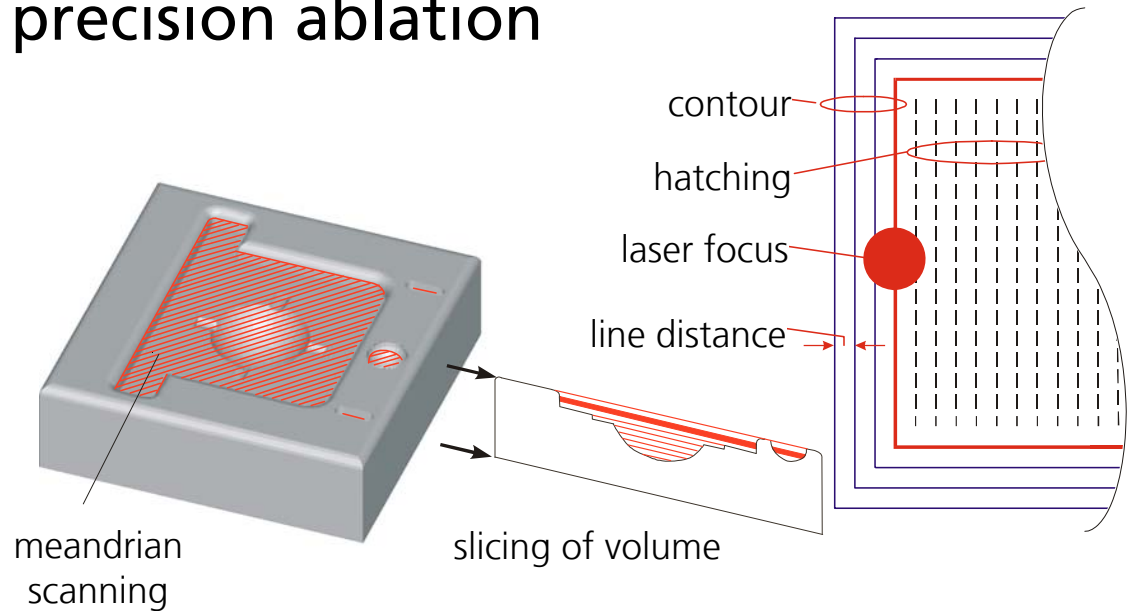
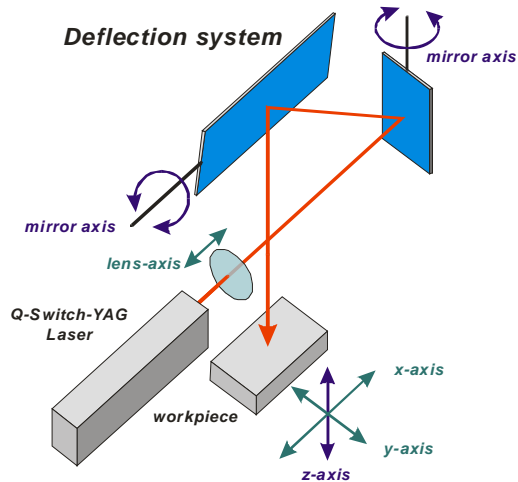
- No interaction of radiation with vapour and melt
- Ablation by vapourisation
- Minimal thermal influence

$$T(x) = \frac{2I_0}{K} \sqrt{kt} \cdot \text{ierfc} \frac{x}{\sqrt{4kt}}$$

Ultra short laser pulse interaction with metals



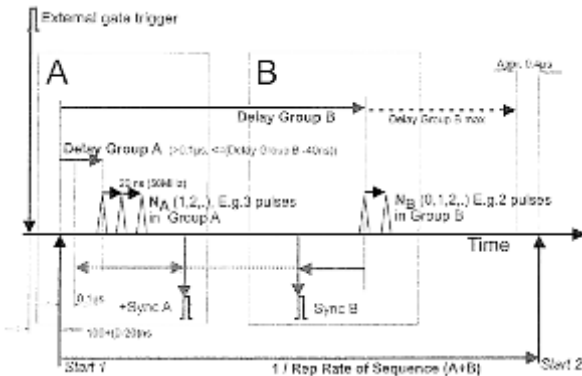
Process strategy for precision ablation



- Meandrian scanning of layers
- line overlap: ca. 70 %

Material ablation with ps-pulse-bursts

- Laser SuperRapid (Lumera Laser)
- Puls duration $t = 12$ ps
- Repetition rate $f \leq 500$ kHz
- Multi pulse option: yes
- Inter pulse-separation $\Delta t_n = 20$ ns
- Burst Energy EB max 200 μ J



Materials processing with ultra short pulsed lasers

Laser ablation with ns-Laser



Complex injection moulding part with multiple holes

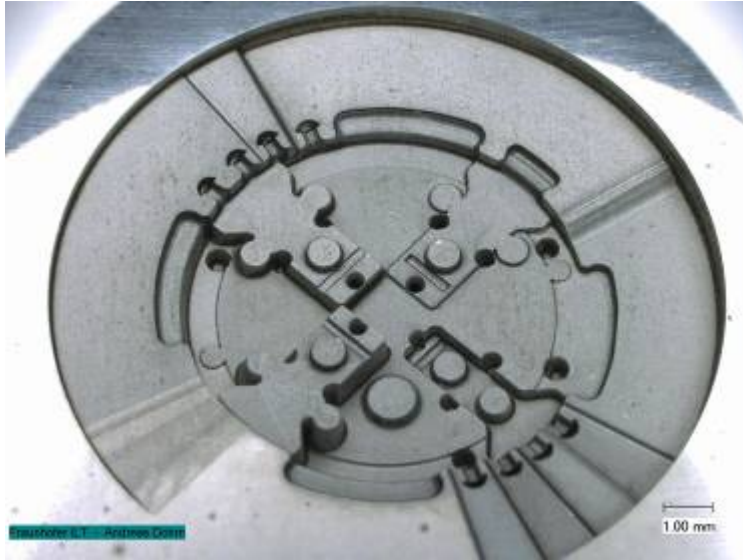


EDM machined



Laser ablation with ns-Laser

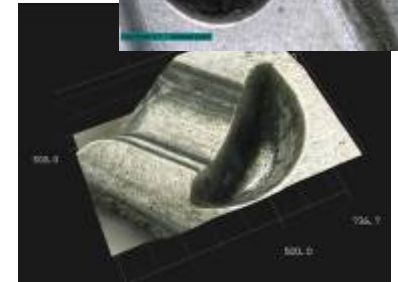
Laser ablation with ps-Laser



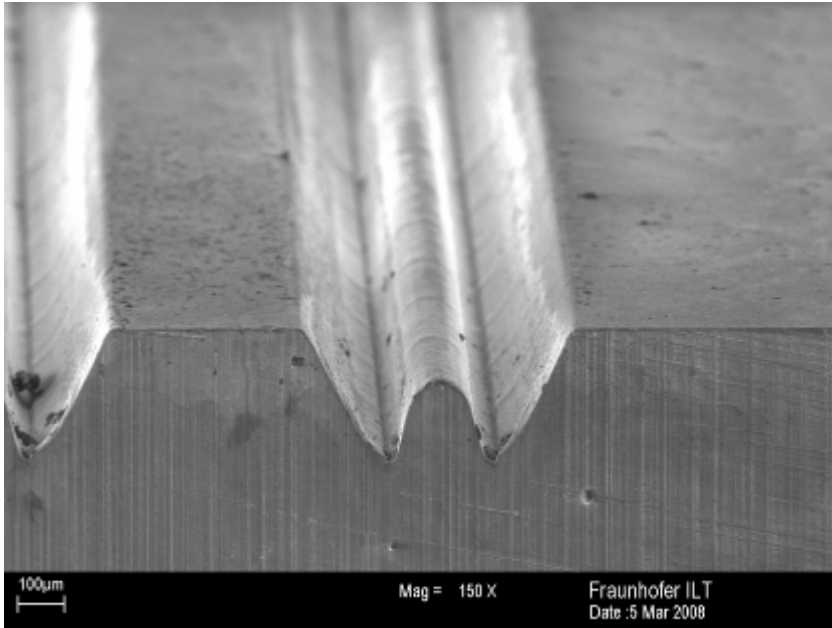
- Processing time: 10 h
- No tools
- Surface quality similar to EDM machining



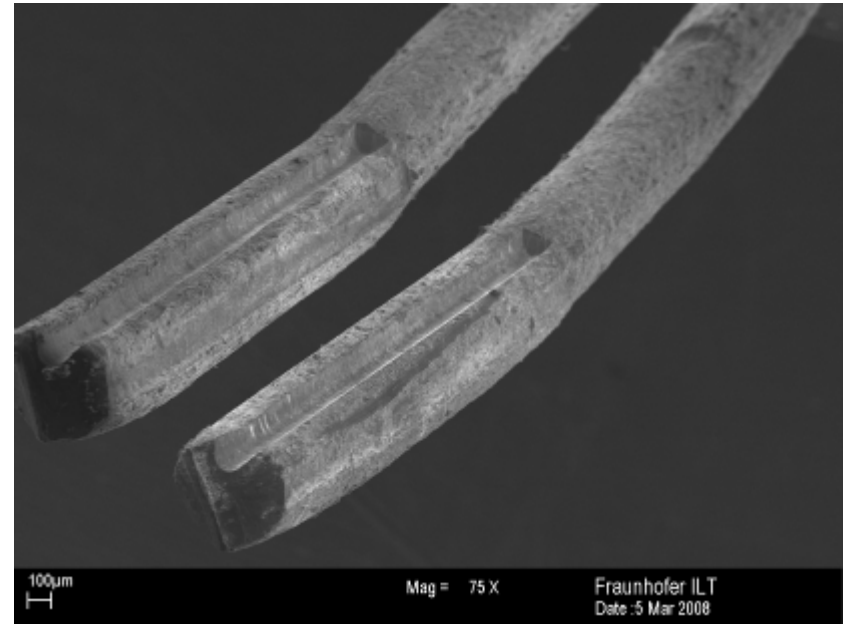
EDM machined



Laser ablation of embossing tools

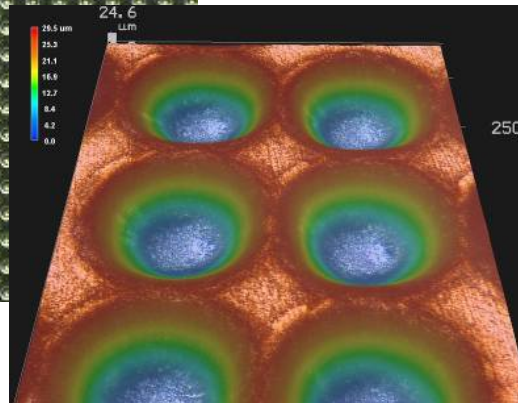


Embossing tool in tungsten carbide



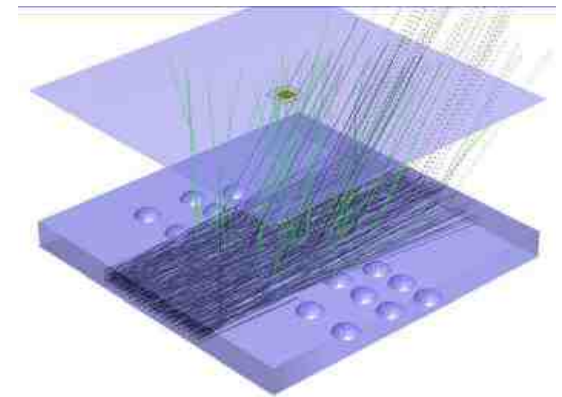
Embossing results in spring steel

Micro injection moulding of lens arrays in PMMA



Micro moulding tool for surface structured parts

After tool polishing sufficient part quality with surface accuracy better than 100 nm

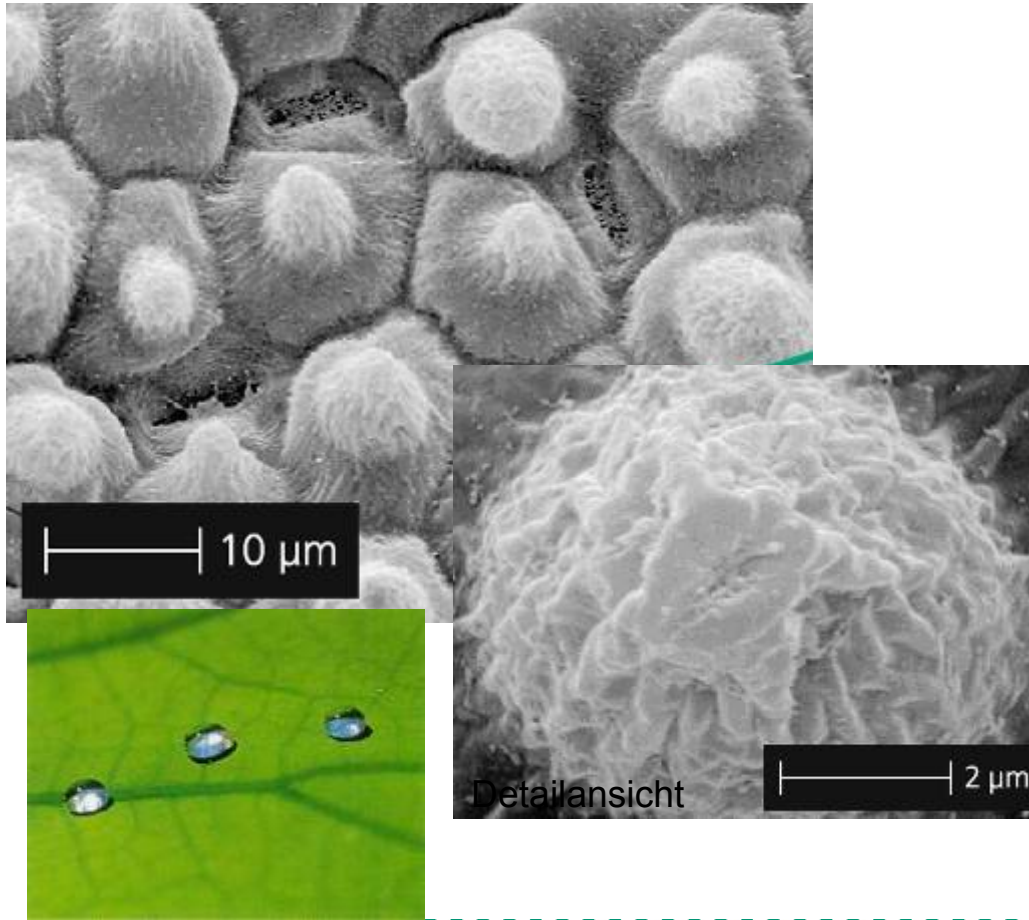


Materials processing with ultra short pulsed lasers

Light guiding element for LED illumination



Laser structuring for functional surfaces



Hydrophobic surfaces

Natural example:
Lotus leaf

Applications:

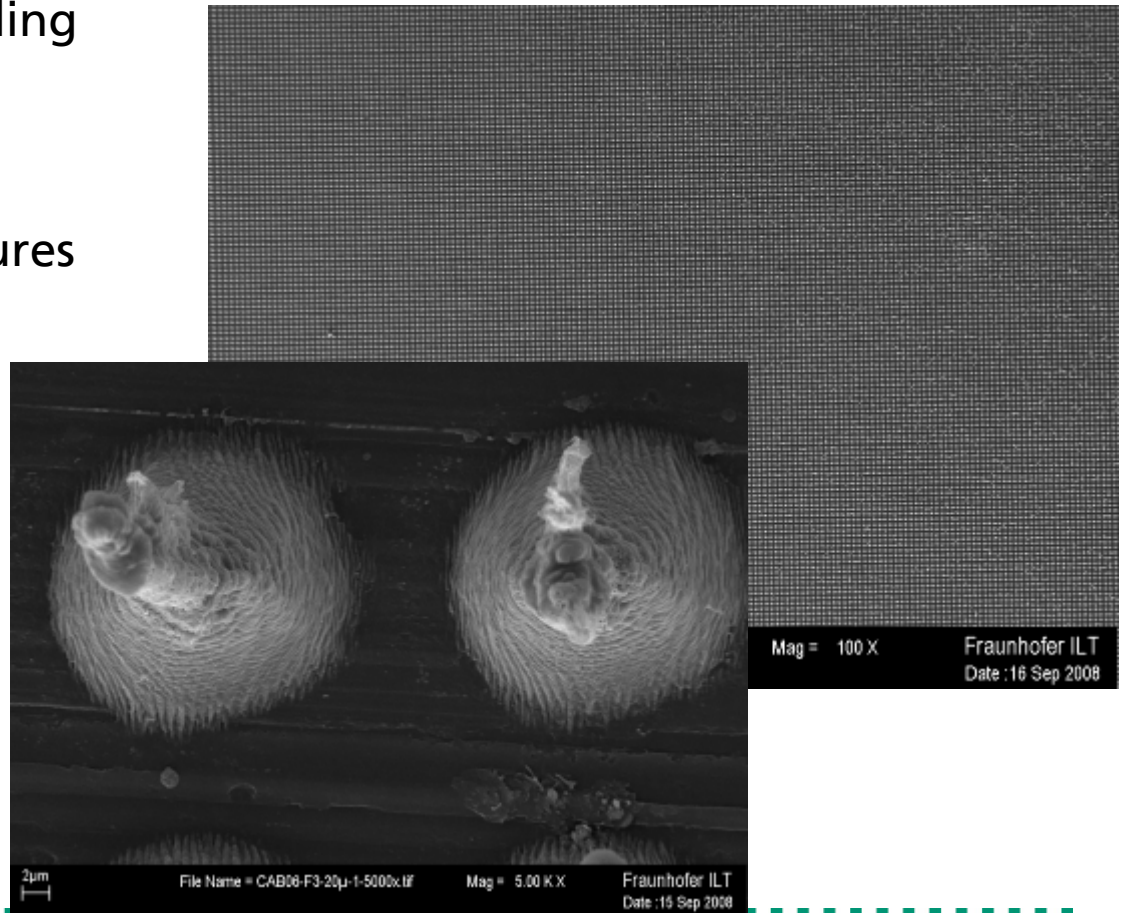
- Medical technology
- Bio analytics
- Micro chemistry
- ...

Laser structuring for functional surfaces

Structuring of injection moulding tool with Pikosecond lasers
Lumera Rapid, $\lambda = 355 \text{ nm}$

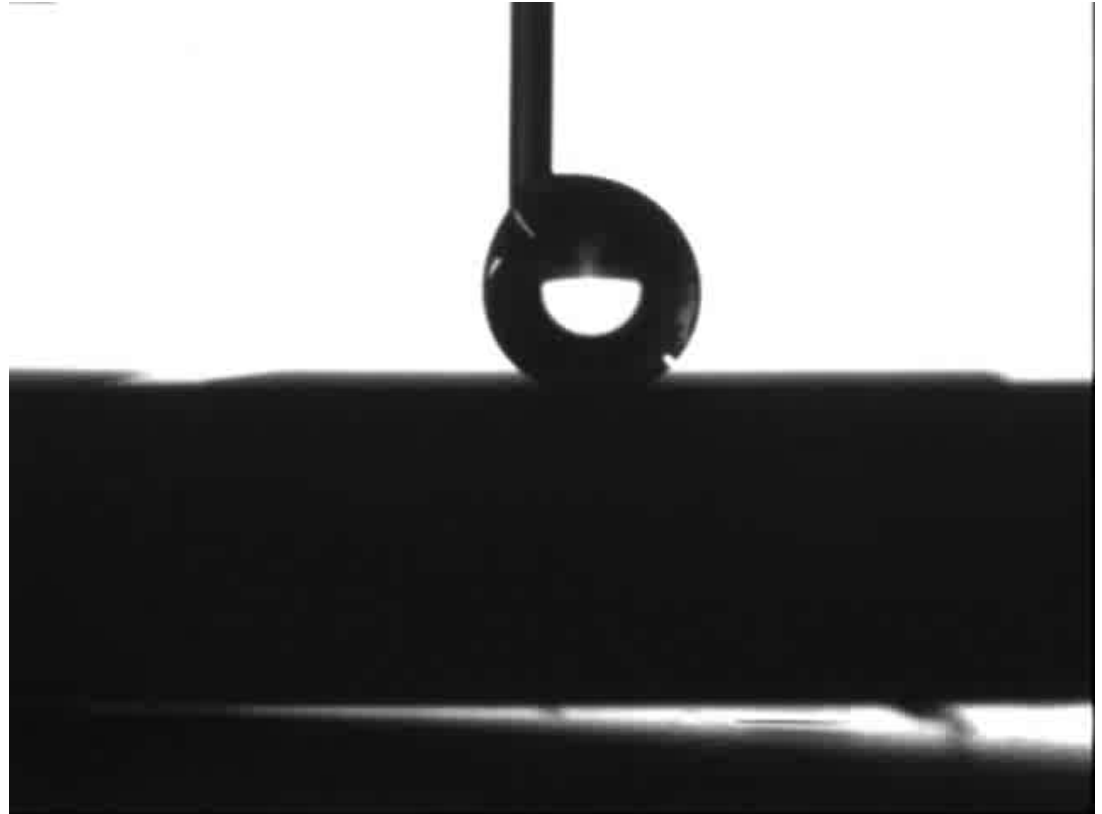
Generation of multiple structures
Structure size: $10 \mu\text{m}$
Sub structure: $2 \mu\text{m}$
Sub-Sub structure: 100 nm

Replication by injection moulding
Material: Polypropylen



Laser structuring for functional surfaces

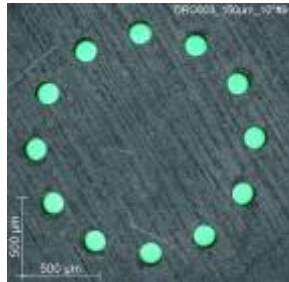
- Contact angle 174°
- Minimal Adhesion
- Rejection of capillary leads to removal of drop
- Drop is fixing on non structured surface



Drilling with ultra short pulsed lasers

Drilling with laser radiation

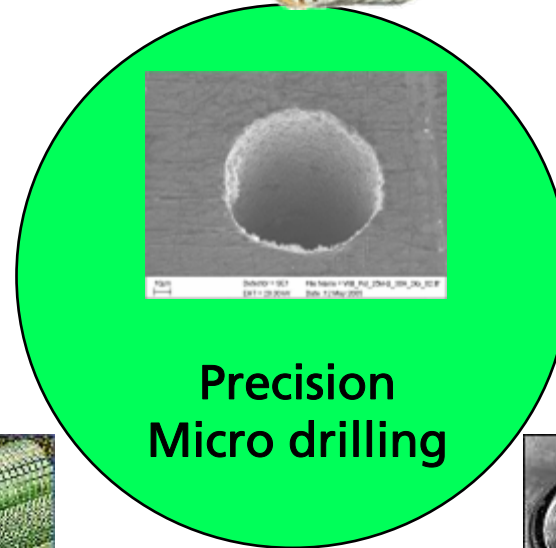
Einspritzdüsen
 $\varnothing = 50 - 100 \mu\text{m}$



Zerstäuber
 $\varnothing = 1-20 \mu\text{m}$

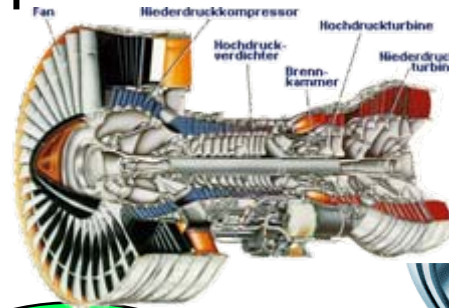


Mikrosiebe
 $\varnothing = 10-50 \mu\text{m}$



Precision
Micro drilling

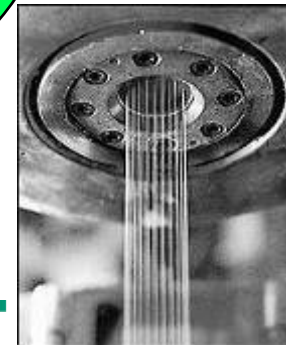
Kühlbohrungen
 $\varnothing = 100 - 800 \mu\text{m}$



Schmierbohrungen
 $\varnothing = 100 - 200 \mu\text{m}$

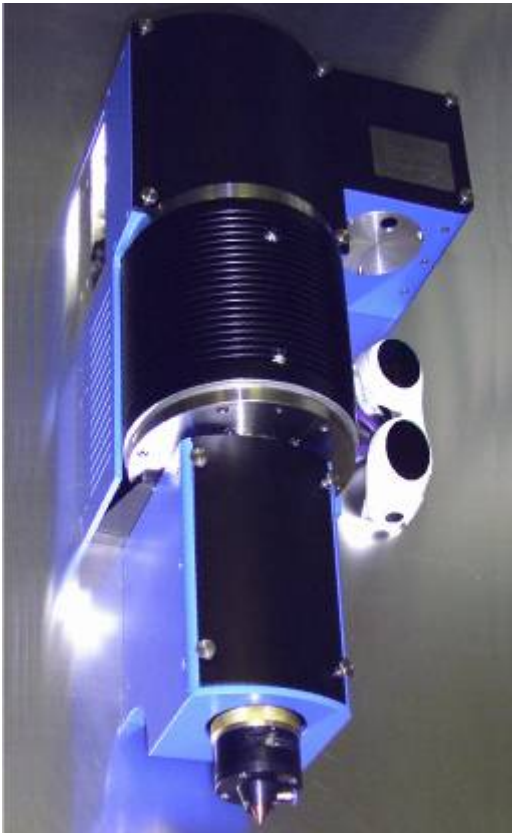


Düsenbohrungen
 $\varnothing = 10 - 100 \mu\text{m}$

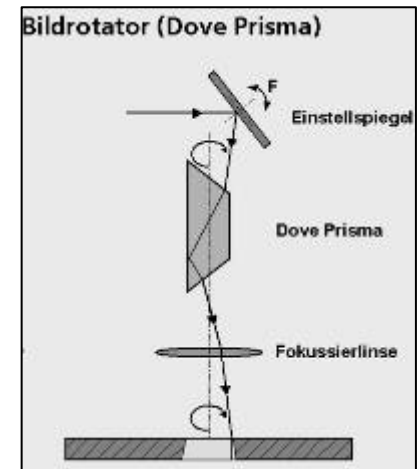


Spinddüsen
 $\varnothing = 10 - 100 \mu\text{m}$

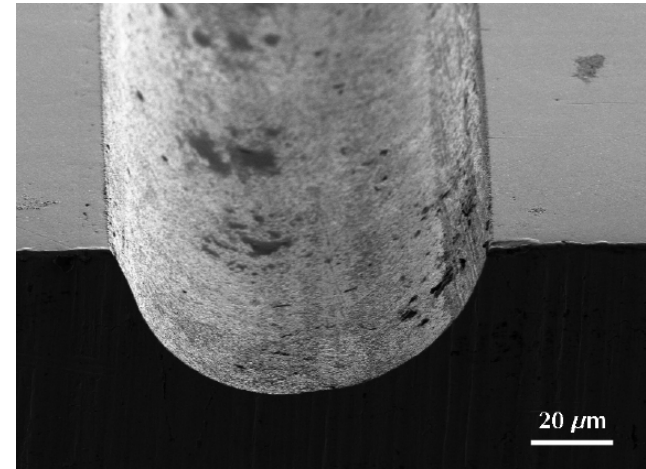
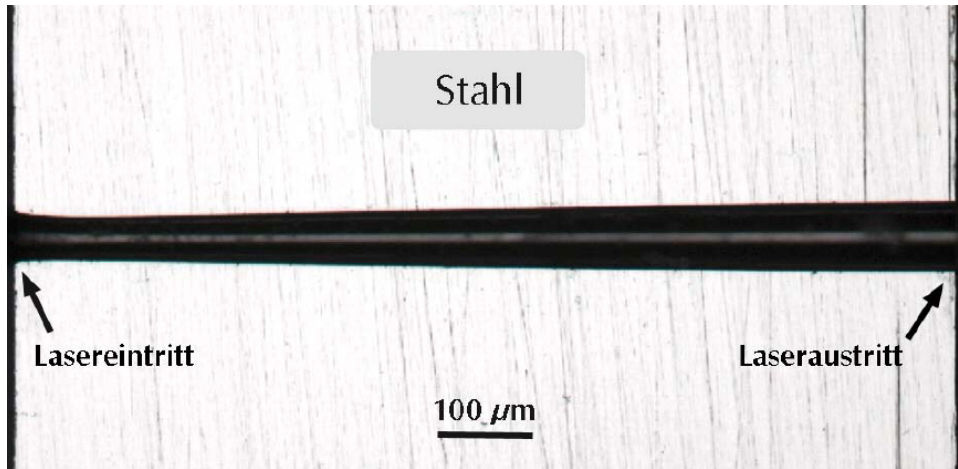
Drilling with laser radiation - trepanning



- Trepanning diameter 10 – 300 μm
- Conical drilling with aspect ratios from 1:2 to 2:1
- Laser beam rotation up to 40.000 min⁻¹
- Aspect ratios up to 1:40



Micro drilling with ps-laser radiation



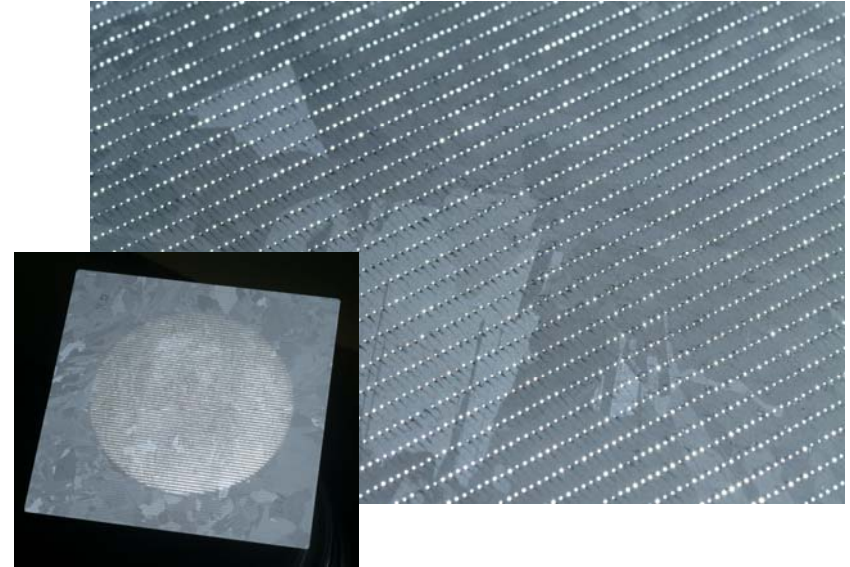
Cross section of injection nozzle
1 mm steel

High Quality hole
with roughness $< 1\ \mu\text{m}$

Multipass Drilling with Q-switch-Disc-Laser



Pulse energy: 3-6 mJ
Pulse duration: bis 1 μ s
Pulse frequency: 30000 Hz
Beam quality: $M^2 < 1,2$



Target: 10.000 holes/s @ 70 μ m diameter
Actual speed: 3000 Holes/s
Limited by pulse energy and Rep-Rate

Multipass Drilling with Q-switch-Disc-Laser

Q-switch disc laser

Pulse energy 3 mJ

Pulse length 1 μ s

Scanner field 200 x 200 cm²

Spot diameter \varnothing : 50 μ m

Drilling rate 3000 holes/s

Number of pulses 5



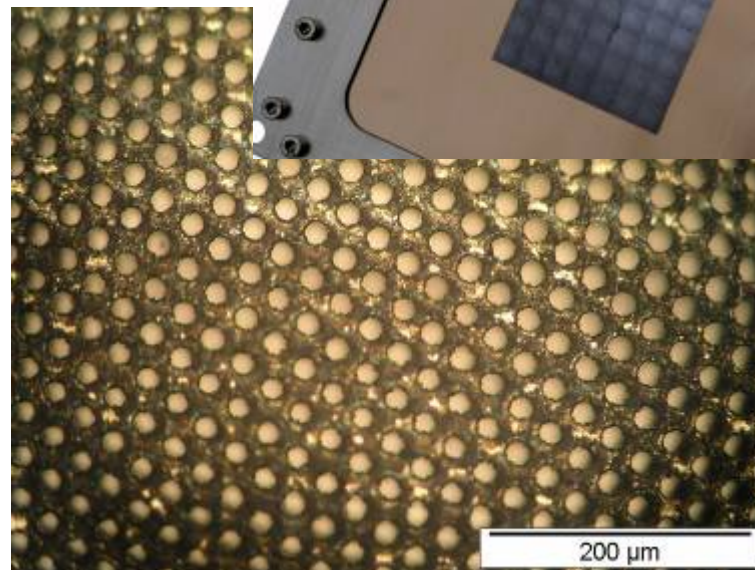
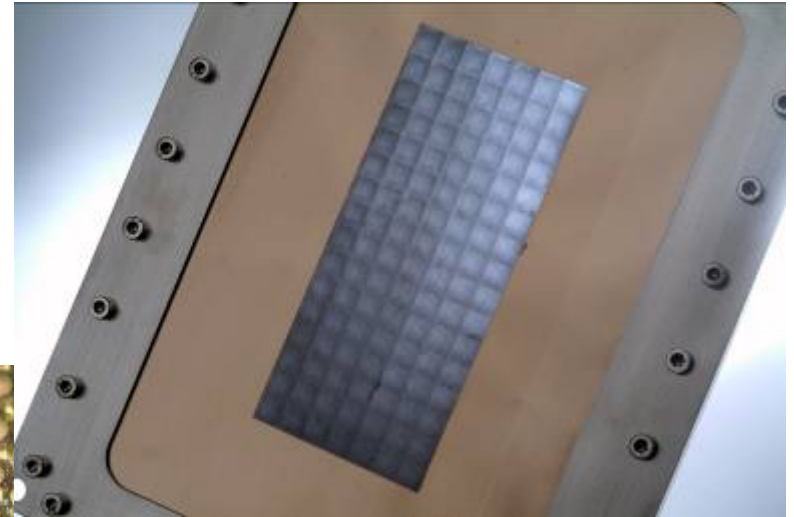
High speed drilling with laser radiation

Foil:

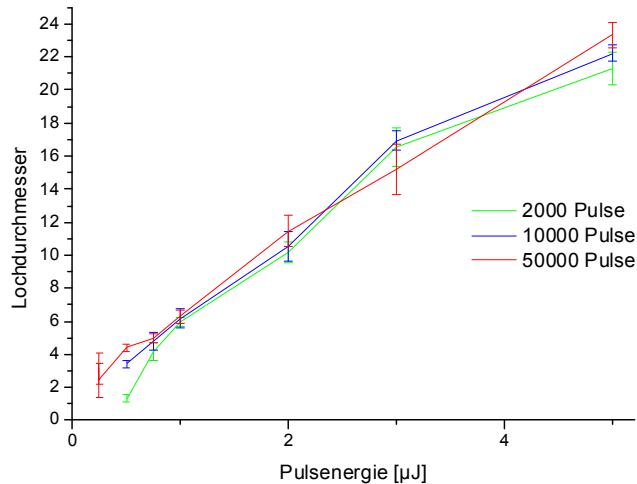
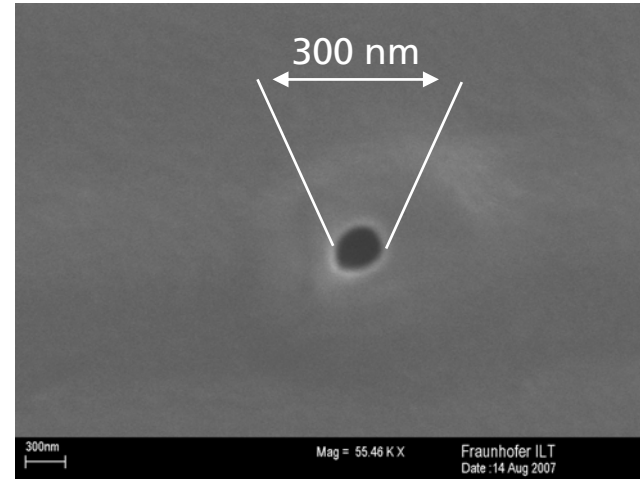
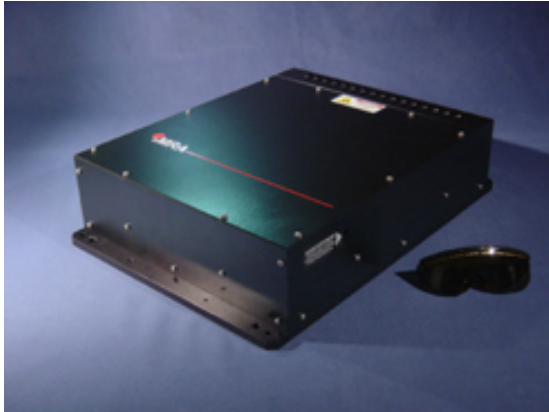
- 50 mm x 160 mm
- Thickness: 50 μm

Hole dimensions:

- $\varnothing = 13 - 16 \mu\text{m}$
 - Distance 50 μm
 - 4 Mio Holes
-
- Processing with Scanner
 - Scanfield 10 mm x 10 mm
 - Drilling Speed:
1100 Löcher / s

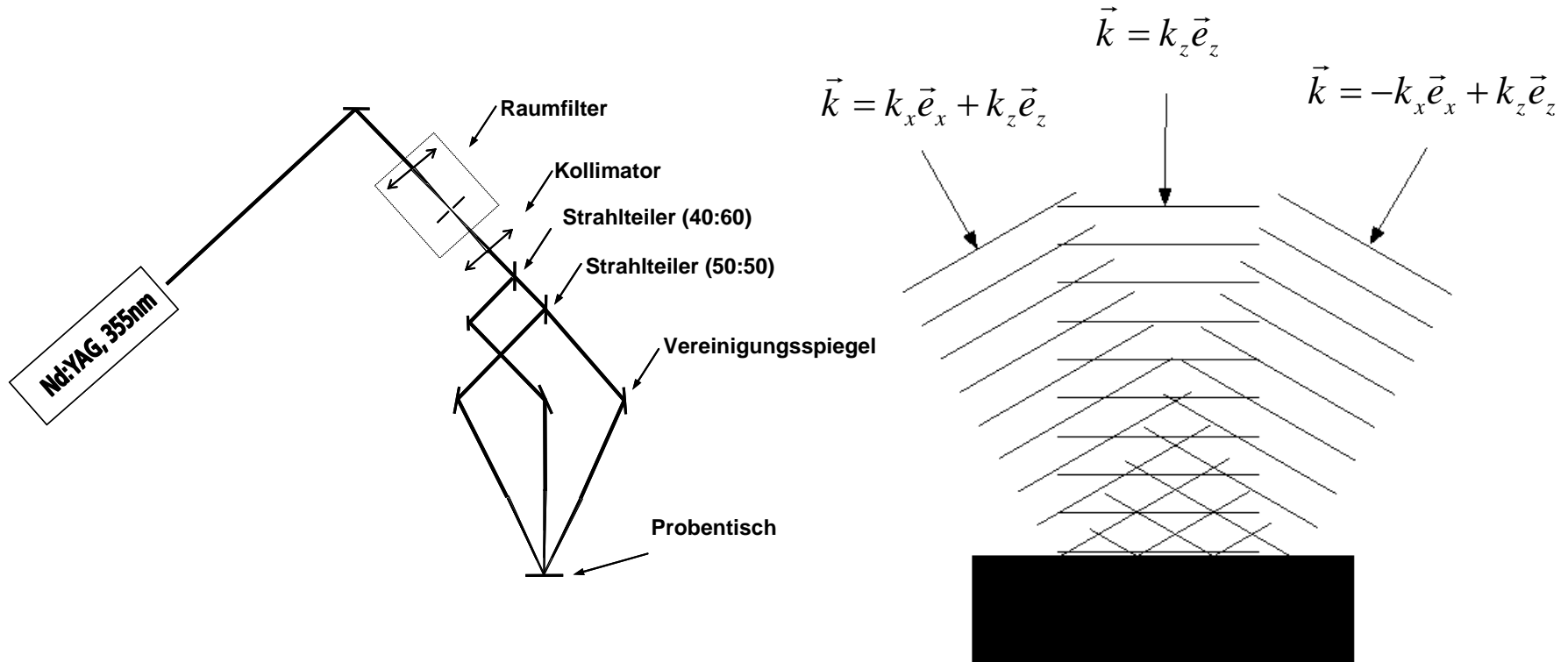


Nano drilling with Femtosecond pulses



IMRA FCPA μ Jewel D-400 series
Wavelength: 1045 nm
Pulse energy: 2 μJ
Pulse duration: < 500 fs
Frequency: 100 kHz

Interference structuring with laser radiation

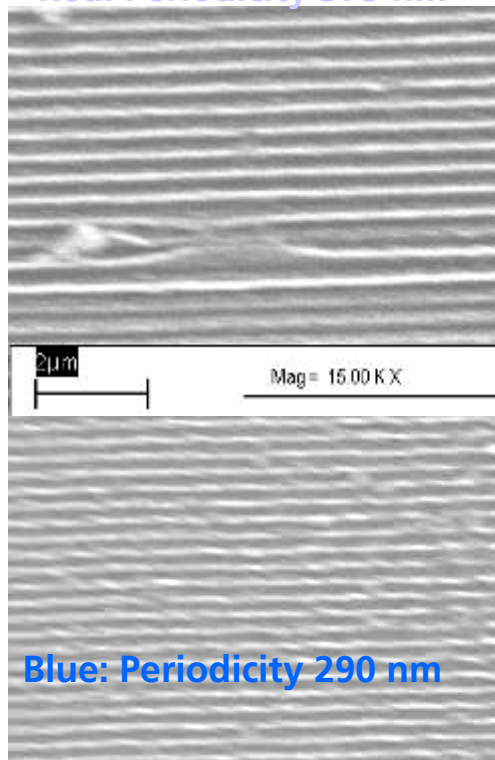


Three beam interference in a plane

Laser nano structuring for generation of diffractive optical structures

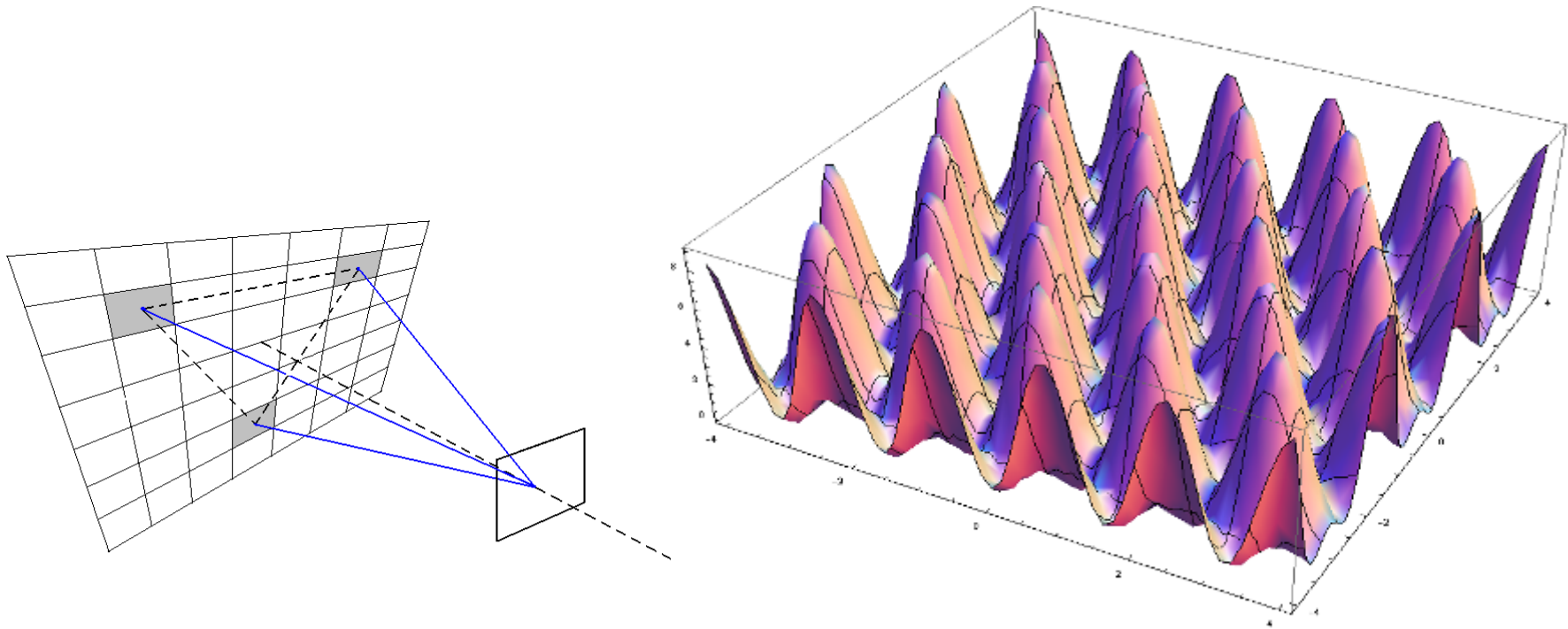
Two beam interference

Nd:YAG, 355nm, PI-Folie, $d = 50 \mu\text{m}$



Multi color effects with white light illumination

Interference structuring with laser radiation



Out of plane three beam interference

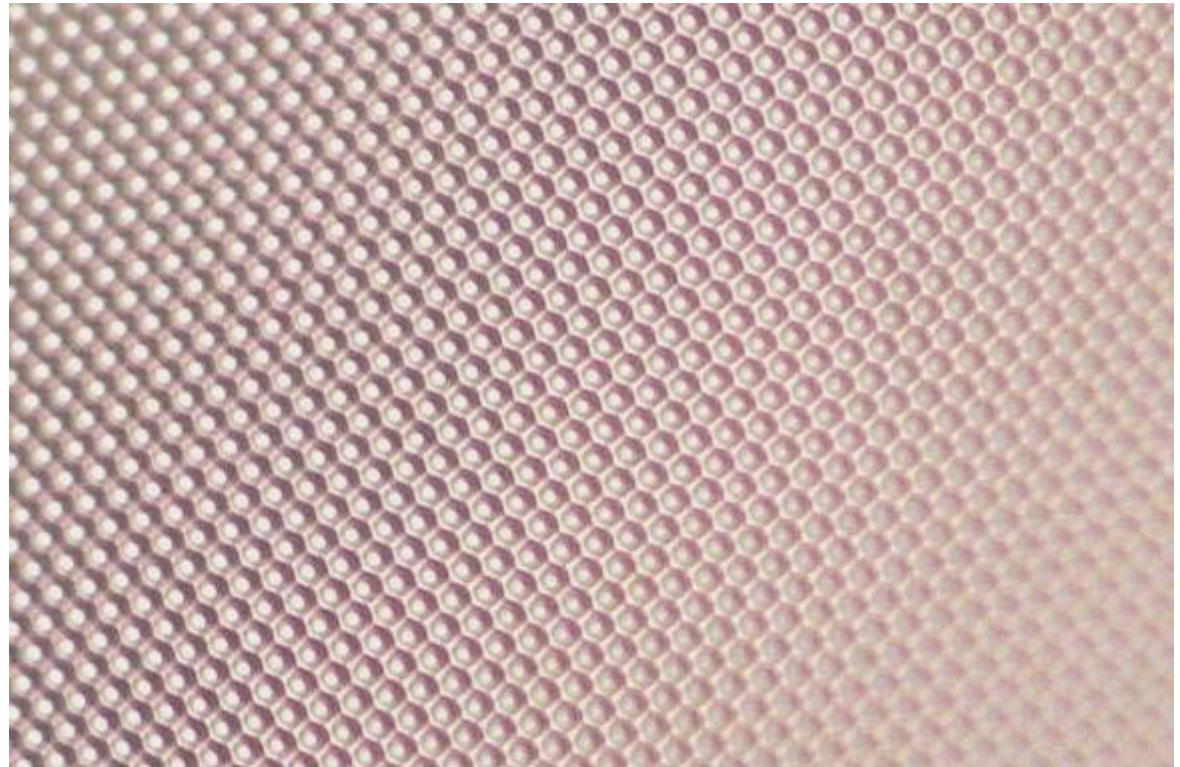


Interference structuring with laser radiation

Periodic structure
with negative
illumination
in photoresist

(AR-P 5350)

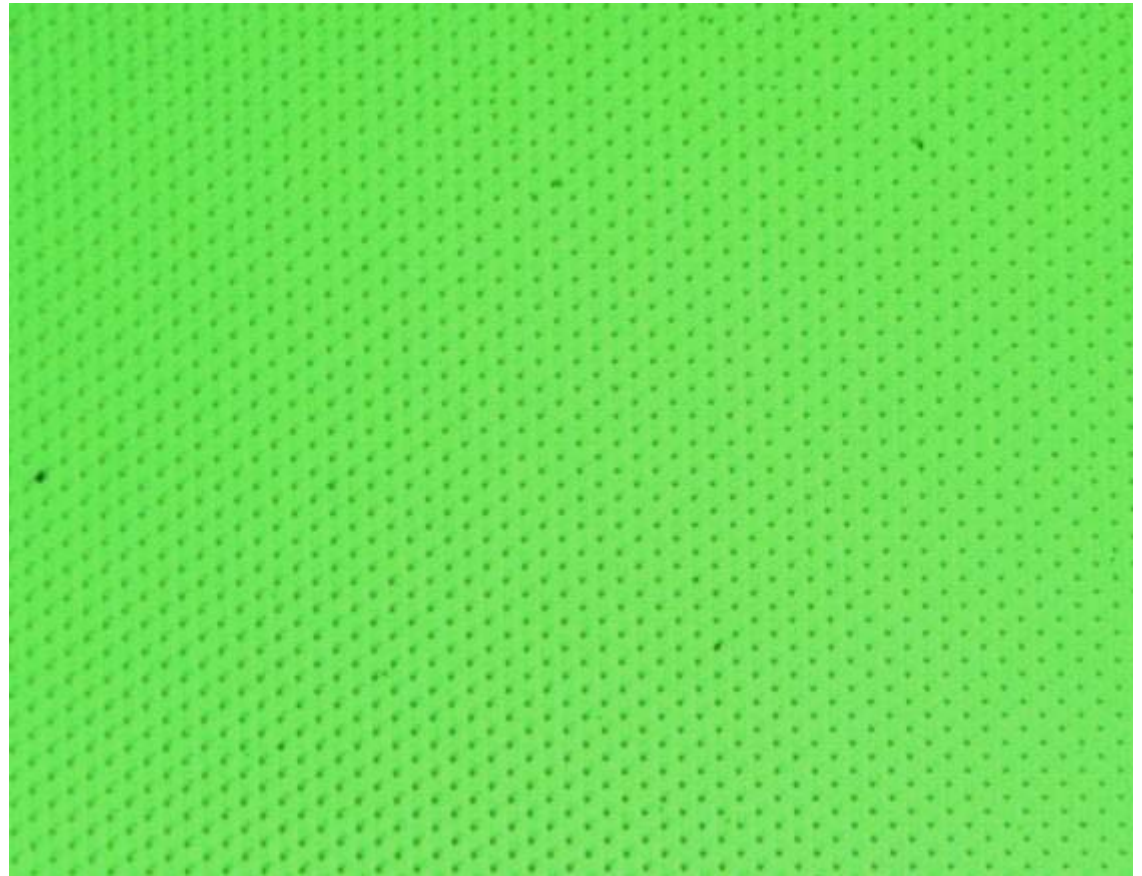
Periodicity $2\mu\text{m}$



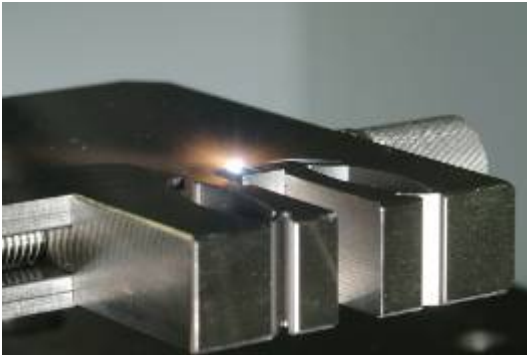
Interference structuring with laser radiation

Hexagonal
pattern
of 1 μ m holes in
Polyimide-Foil

(100.000 Holes with
one shot)



Laser structuring vs. conventional processing



Laser ablation

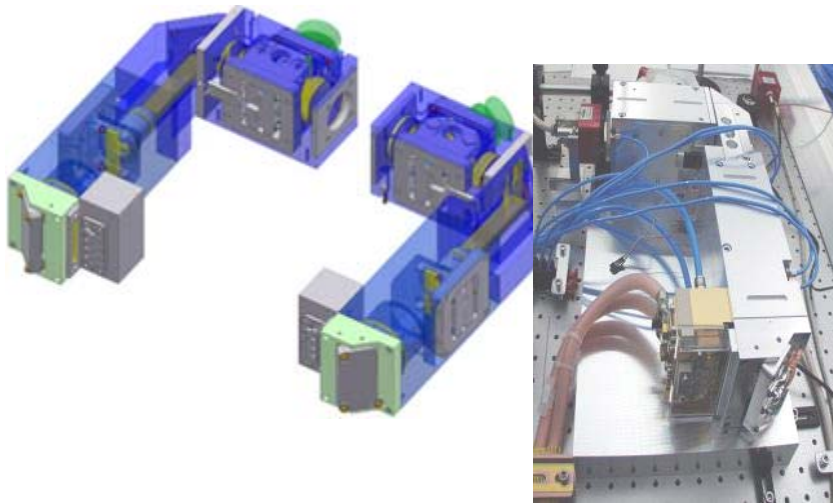
- Structure size 100 nm – 100 μ m
- No tool wear
- Material independent
- Dry process
- Large area processing
- High ablation rate possible



EDM processing

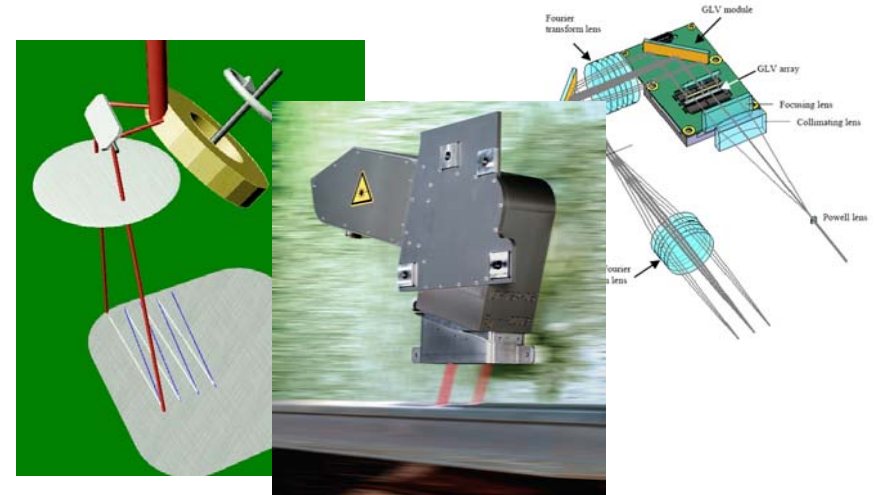
- Parallel processing
- Well known process
- High ablation rates

High power ultra short pulsed lasers and fast scanners



Development of high power ultrafast lasers

- 10 ps-Laser with 20 MHz Rep-Rate and $P = 200\text{ W}$
- 500 fs-Laser with 80 MHz Rep-Rate and $P = 300\text{ W}$



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

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

Thank you for your attention



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