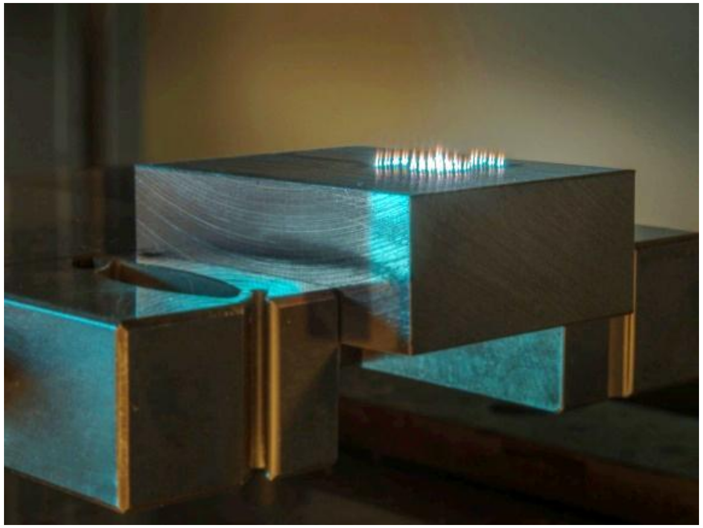
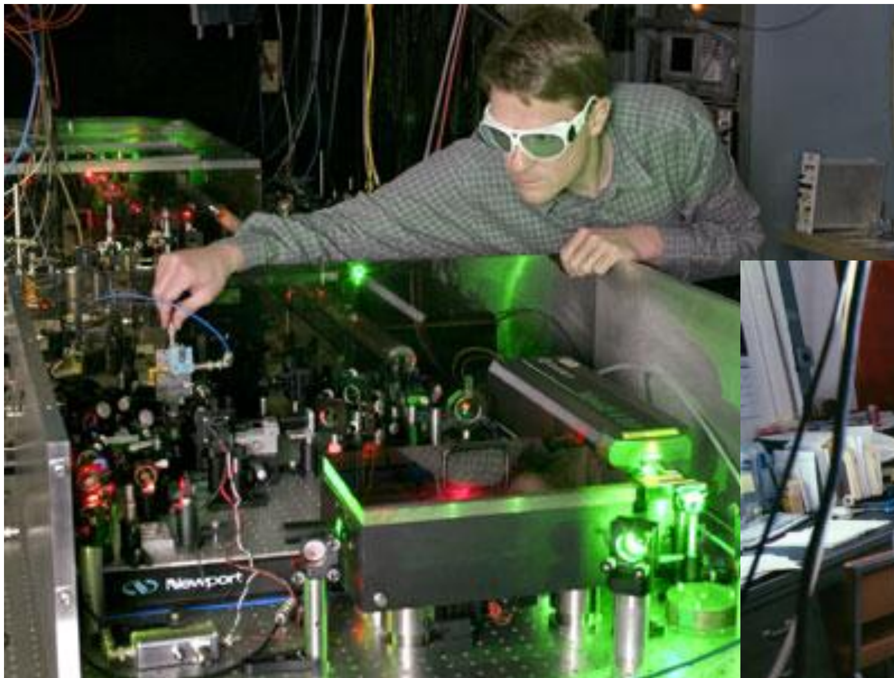
Verfahrens- und Systemtechnik zum präzisen Hochleistungsabtrag mit UKP-Lasern

Jens Holtkamp

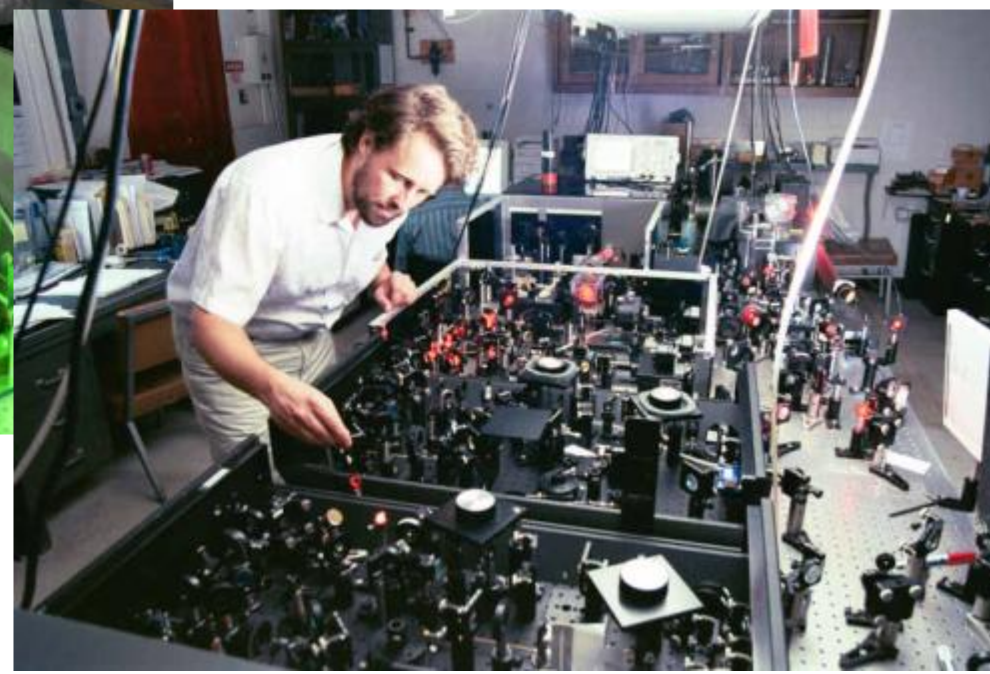


Fraunhofer
ILT

Motivation
Ultra short pulsed lasers



National Institute of Standards and Technology (NIST)



Regional Laser and Biomedical Technology Laboratories (RLBL) at the University of Pennsylvania

Motivation
High Power Ultra-short pulse laser sources

AMPHOS

TRUMPF

LIGHT CONVERSION

Amplitude TECHNOLOGIES

HIGH Q LASER
THINK ULTRAFAST!

Time-Bandwidth

JENOPTIK

LUMERA LASER

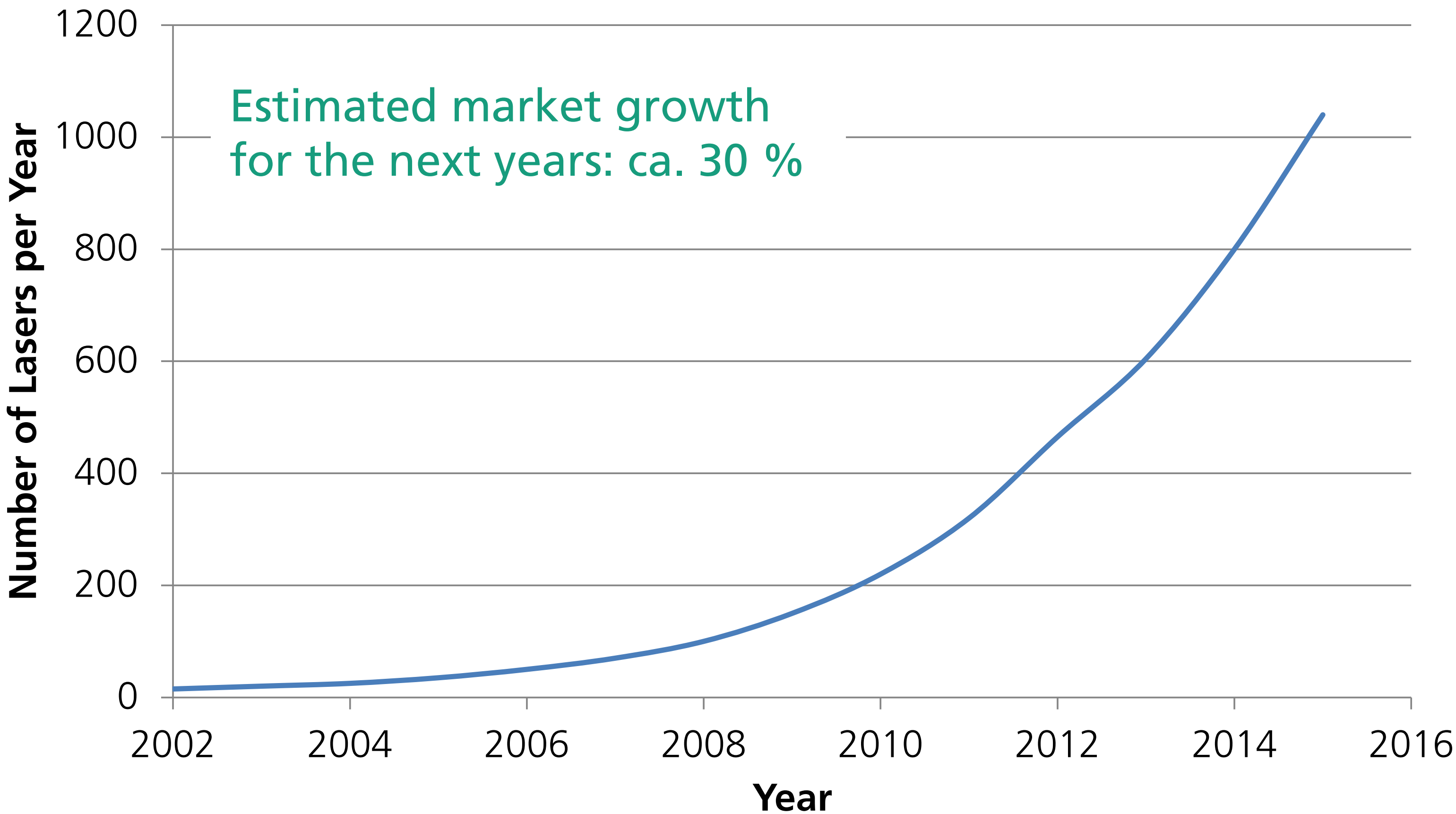
edgewave

rofin
ROFIN-SINAR INC

EKSPLA

Motivation

Number of ultrashort-pulsed Lasers for Material Processing



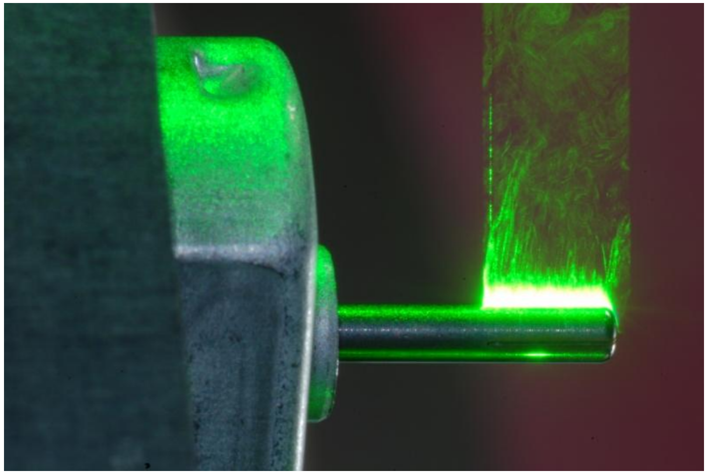
market estimation by Fraunhofer ILT

Fraunhofer ILT

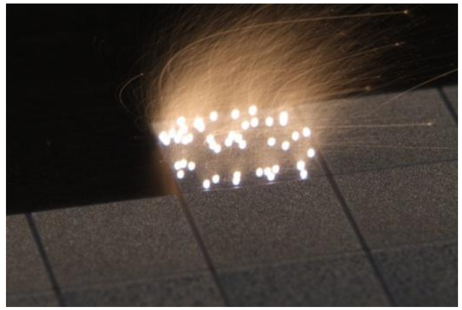
Motivation

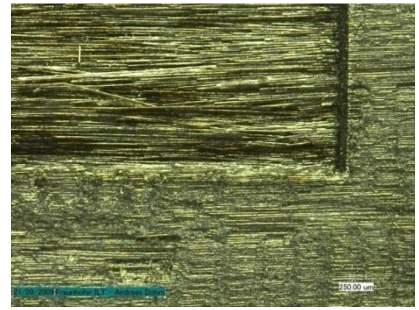
Potential of ultrashort-pulsed Lasers

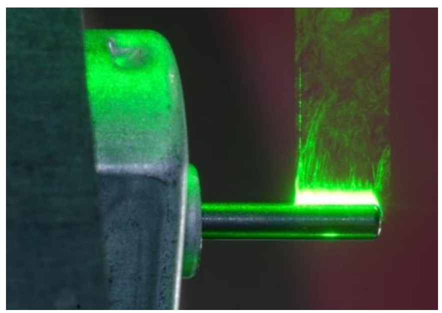
- Substitution of existing Technologies e.g. Etching, Erosion, Cutting
- Development of new Technologies e.g. Thin film ablation, Surface functionalisation
- Advantages of ultrashort-pulsed Lasers
  - (quasi) Material independant
  - (quasi) no thermal influence
  - Tool-free, wear-free and resource-efficient
  - Almost no lead-time (Digital Photonic Production)
  - Highest precision (lateral and vertical)
  - Universal application (due to high variety of parameters)

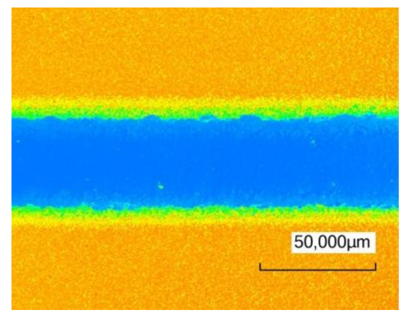


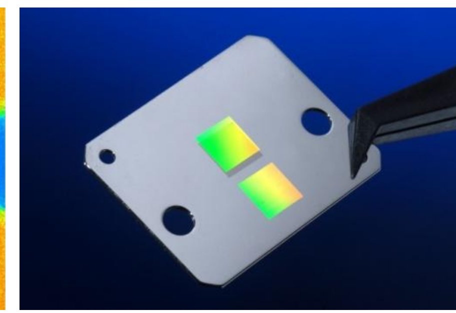
Motivation
Areas of Application

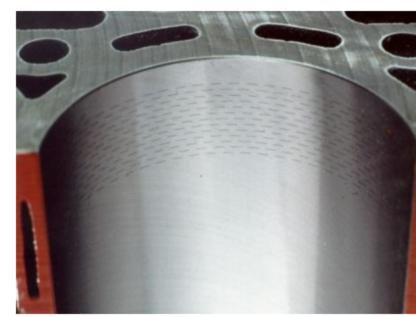










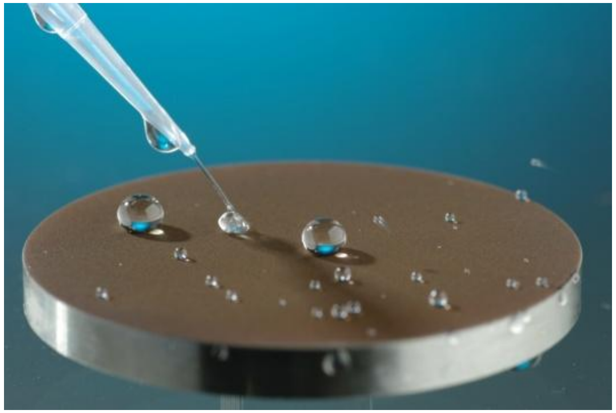


Fraunhofer
ILT

Motivation

Megatrends – Areas of Application

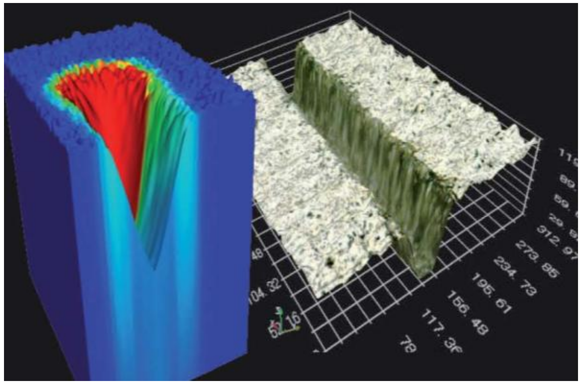
- **Display / Light**
  - (Thin-)Glass cutting
  - Thin film ablation
  - Mask production for coating technologies
- **Energy**
  - Photovoltaik: Texturing, Drilling, Doping
  - Wind: Surface structuring of rotor blades
- **Lightweight construction**
  - Cutting and Repair of Fiber reinforced plastics
- **Resource efficiency**
  - Functional surfaces (Wetting, Tribology)
  - Light guidance
  - Wafer Dicing
- **Environment**
  - Filter for Water treatment

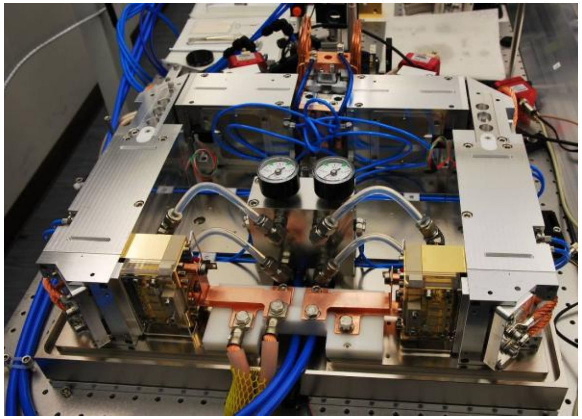


Basics

Tailored Light at Fraunhofer ILT

- Simulation
  - Interaction of laser radiation with material
  - Simulation of ablation processes
  - Development of ablation tools
- System Technology
  - New high power ps and fs Laser
  - Special Optics
  - Machine Technology
  - Deflection Systems
  - Process monitoring
- Process development
  - Use of different kind of laser systems and optics
  - Development of ablation strategies
  - Small batch production and Industrial validation

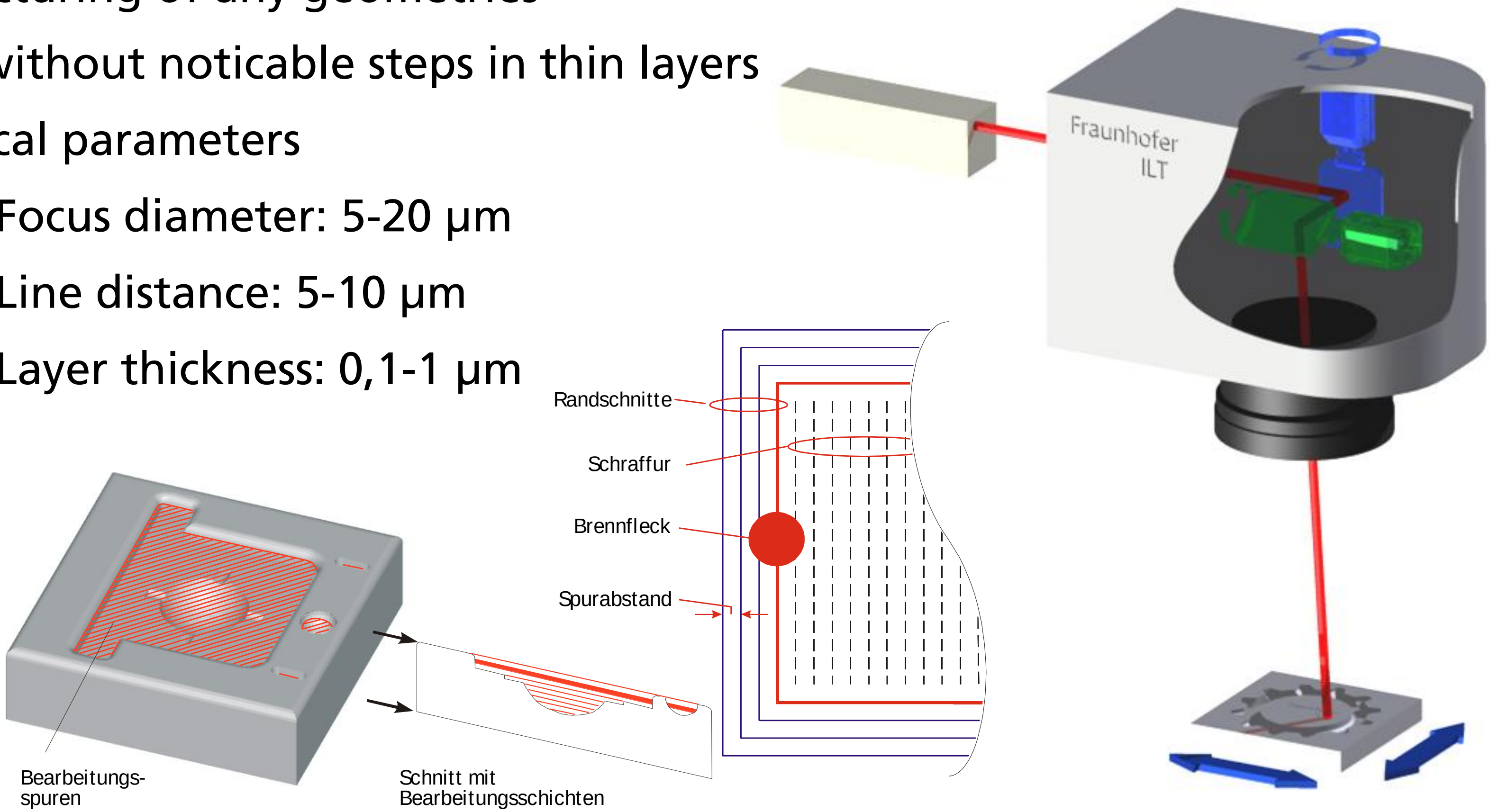




Basics

Process concept for laser micro ablation

- Structuring of any geometries
- 3D without noticable steps in thin layers
- Typical parameters
  - Focus diameter: 5-20 µm
  - Line distance: 5-10 µm
  - Layer thickness: 0,1-1 µm



Fraunhofer
ILT

Basics

Process concept for laser micro ablation

Average Power:	up to **1 kW** (Fa. Amphos)
Repetition Rate:	**kHz…MHz (typ. 500 kHz)**
Pulse Energy:	**µJ…mJ (typ. < 10 µJ)**
Pulse Power:	**100 MW**
Intensity:	100 TW/cm^2 = **10^{14} W/cm^2** @ (10 µm)^2
Ablation Rate:	up to **20 mm^3/min (typ. < 5 mm^3/min)**
Wavelength	**266 nm - 1064 nm**

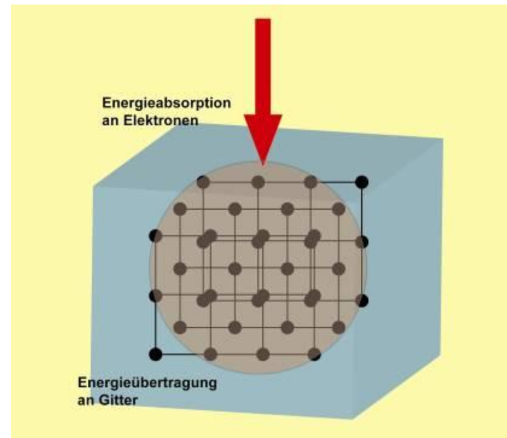
Ultra short laser pulse interaction with metals

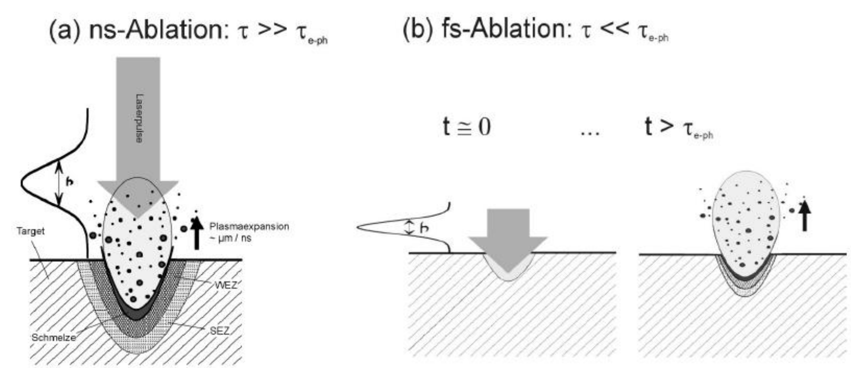
Time Ranges of Energy Transfer

- Photon – Electron: <10 fs
- Electron – Electron: <100 fs
- Electron – Lattice: 1-10 ps
- Lattice – Lattice: speed of sound

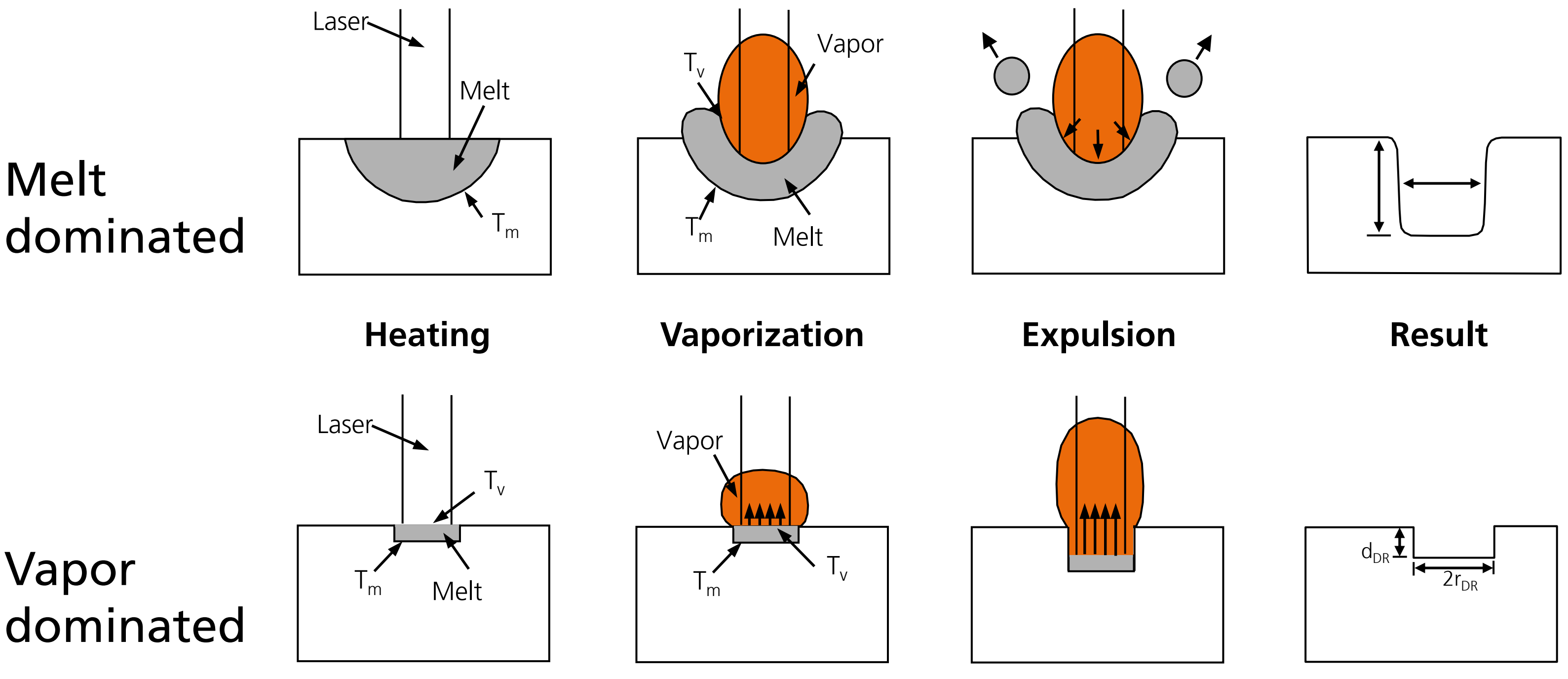
↓

- No interaction of radiation with vapour and melt (Heating after end of laser pulse)
- Ablation mainly by vapourisation
- Minimal thermal influence





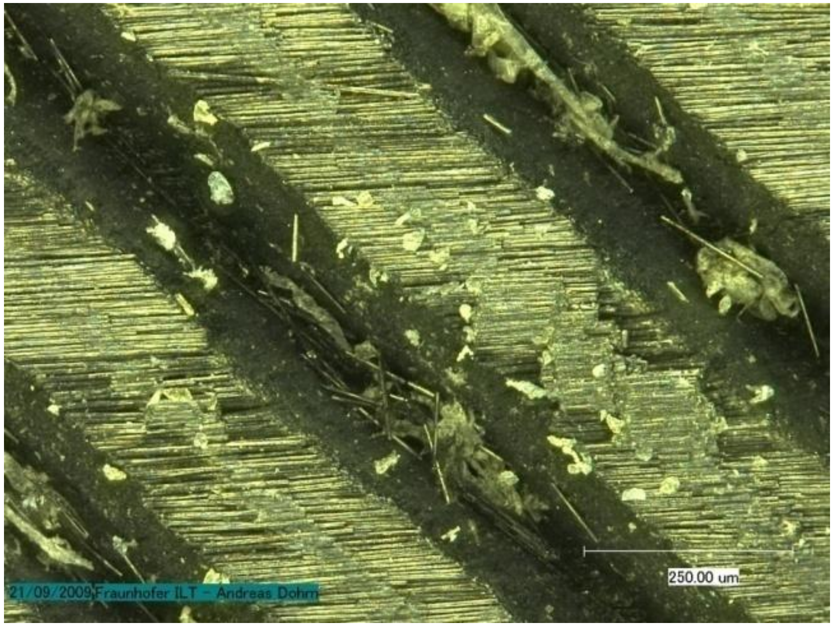
Ultra short laser pulse interaction with metals



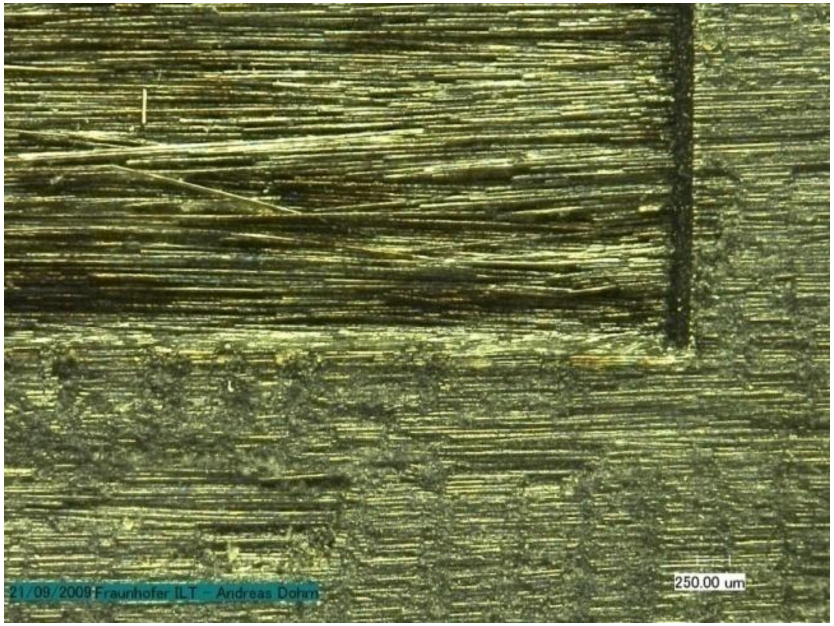
Fraunhofer ILT

Basics

Multipass-Ablation of Composite Materials



t_{Pulse} = 100 ns
Rep.-rate: 100 kHz
Pulse energy: 50µJ
V_{Scan}: 1m/s
Layer Thickness: 20 µm

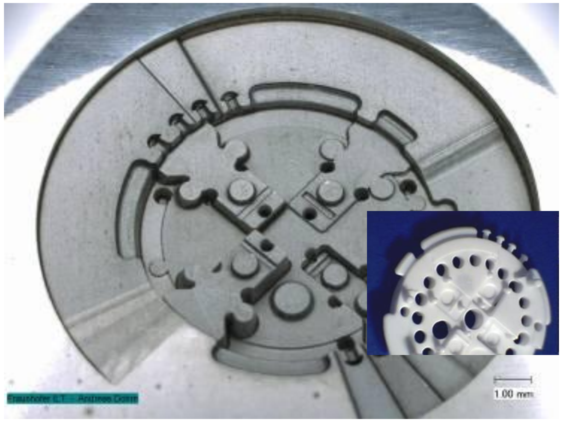


t_{Pulse} = 10ps
Rep.-rate: 100 kHz
Pulse Energy: 30µJ
V_{Scan}: 1m/s
Layer Thickness: 10 µm

Fraunhofer ILT

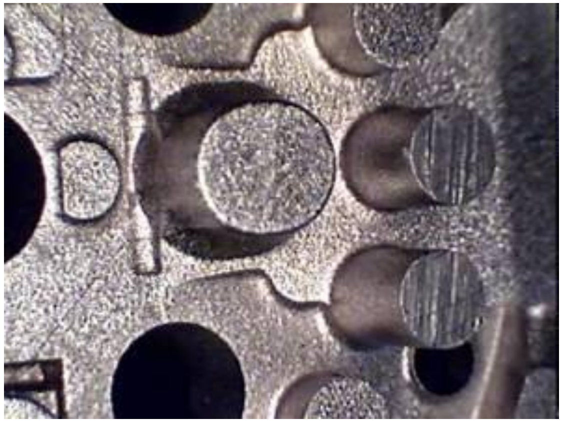
Laser Ablation with (Ultra-)short pulse Laser

- Time for manufacturing 10 hours
- Ablated volume 100 mm^3
- Quality of ablation comparable to EDM
- No tools needed



ns-Laser

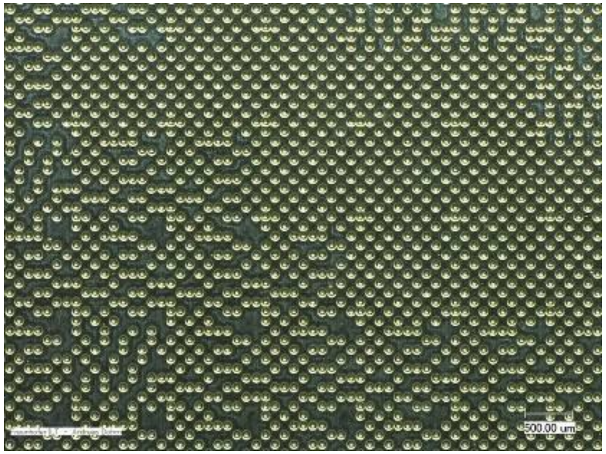
ps-Laser

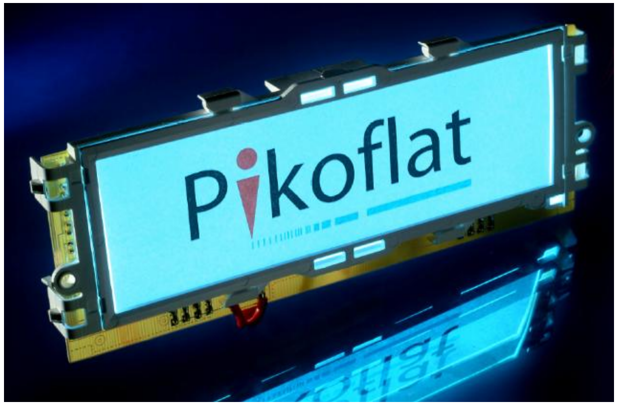


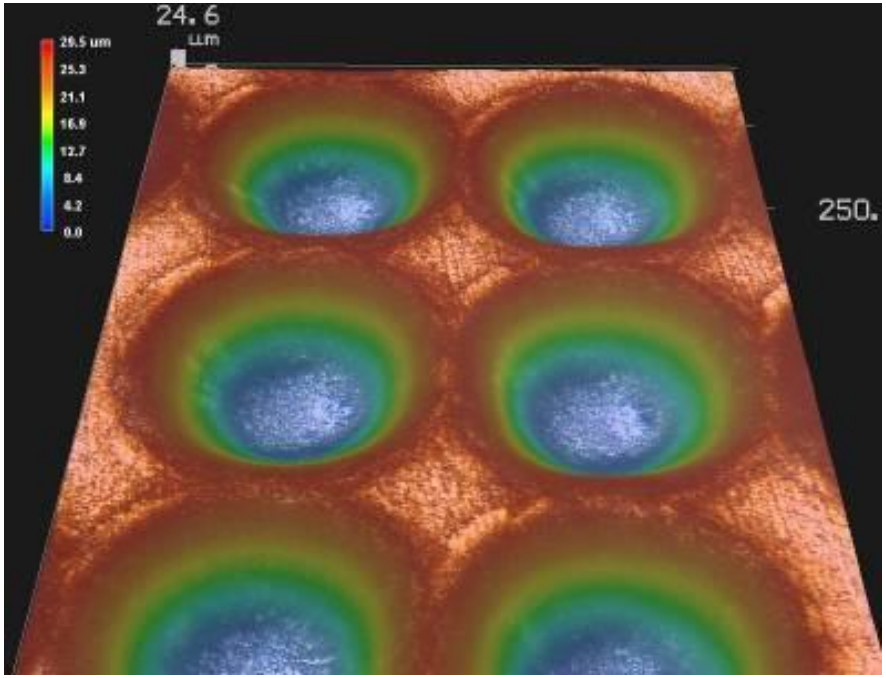
Eroded

Functional Surfaces

Micro injection moulding of lens arrays with ps-Laser





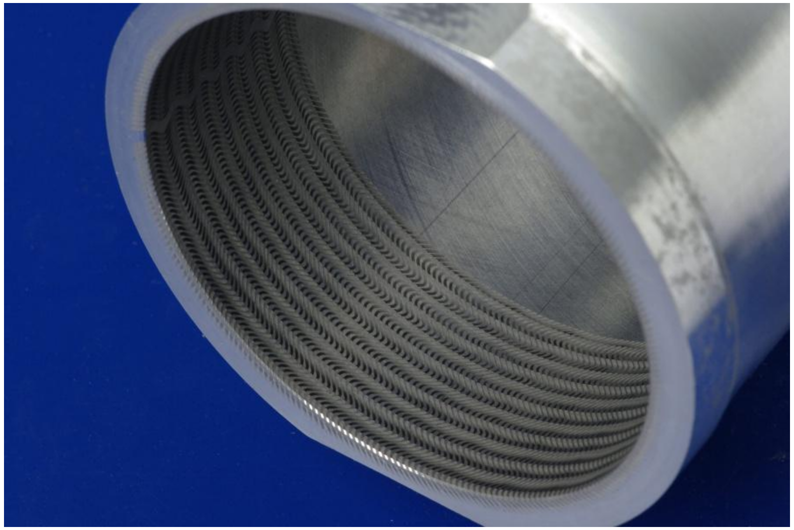


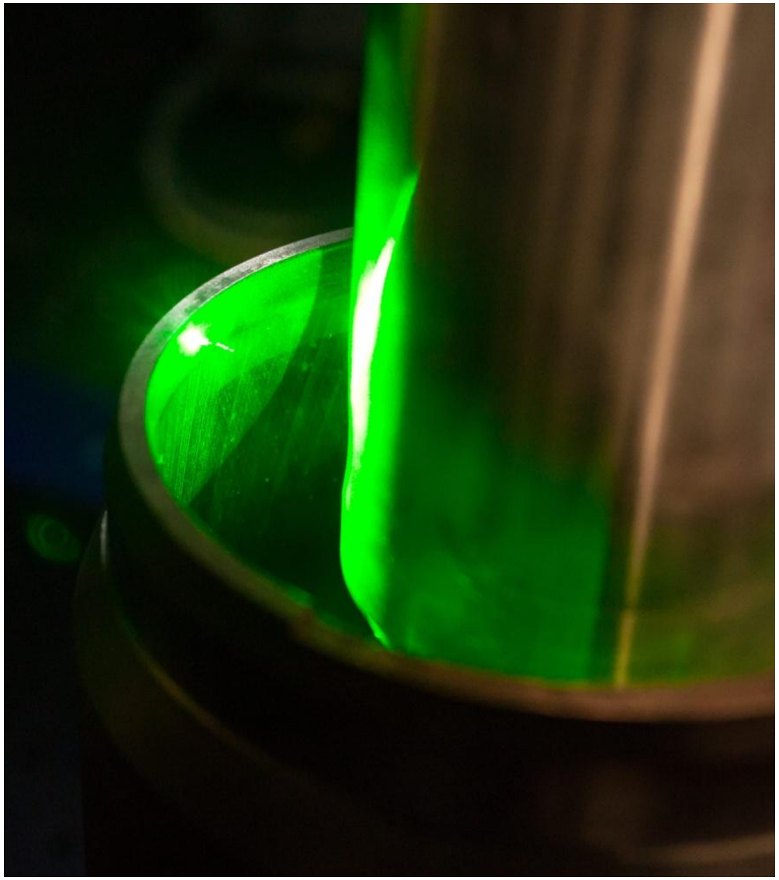
Surface quality

- After Laser ablation: R_a= 300nm
- After Laser polishing: R_a= 100nm

Functional Surfaces
Laser Structuring of Motor Components

- Aim: reduction of friction and wear
- Structures act as oil reservoir and a hydrodynamic bearing
- Compromise between efficiency and oil comsumption

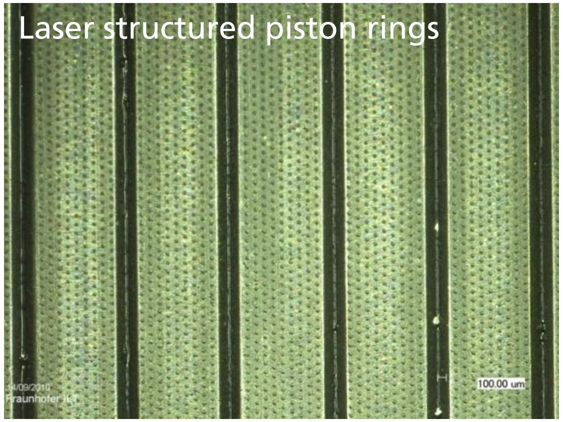


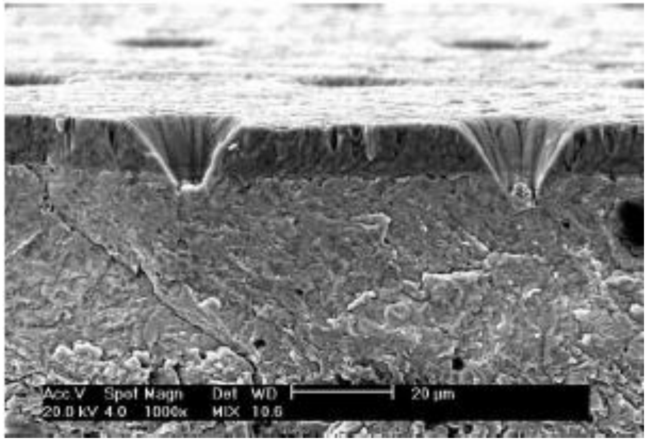


Functional Surfaces

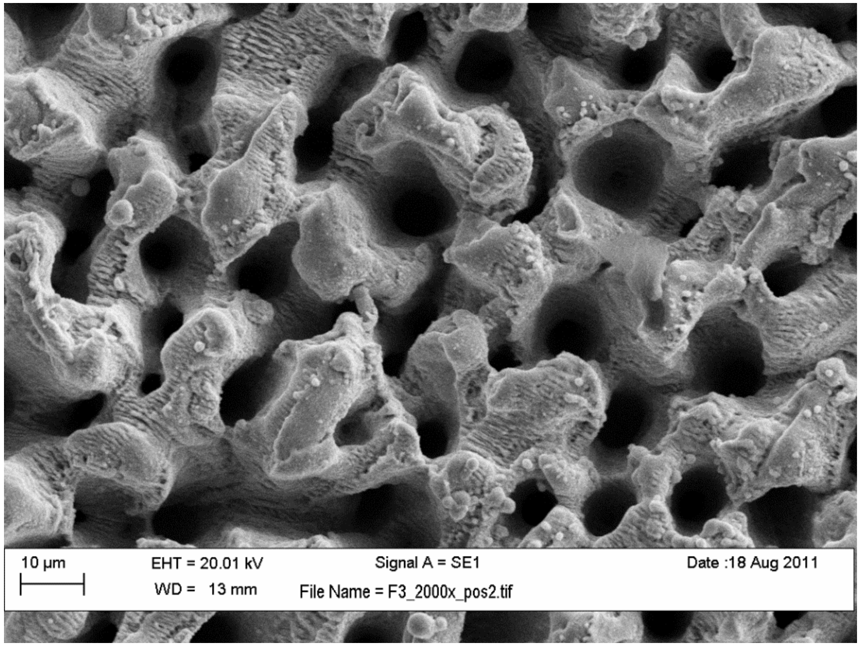
Laser Structuring of Motor Components

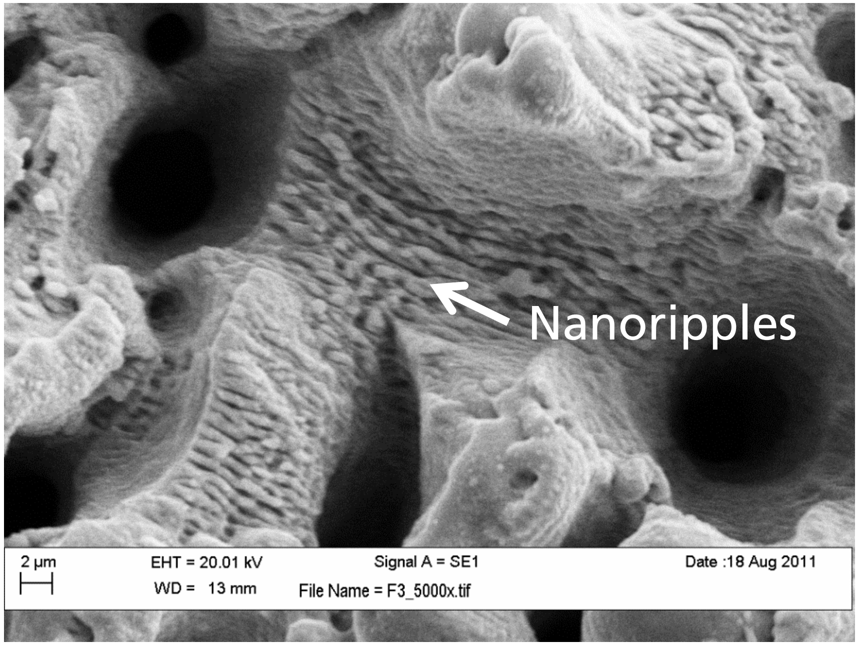
- Inserting of micro structures by ps laser ablation
  - No further treatment necessary
  - No thermal degradation of the adjoined material
- Applications in automotive industry under development
  - Piston rings
  - Cylinders
  - Sealing rings
  - Piston pumps





Functional Surfaces
Surface roughening





Cone-like-protrusions (CLPs)

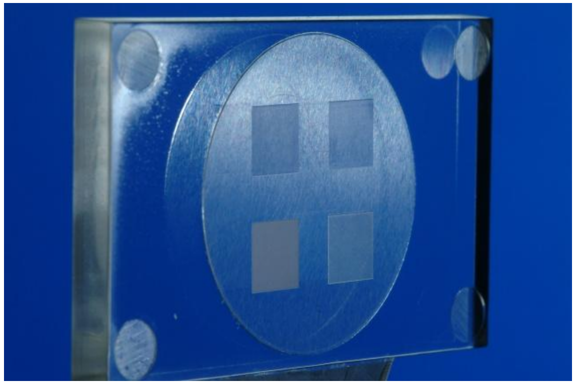
- Statistical structure effect that occurs by redistribution of melt during ablation with ultrashort laser pulses
- Structure sizes: 6-10µm

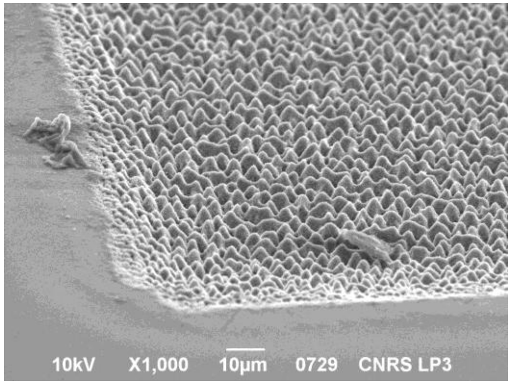
Nano ripples

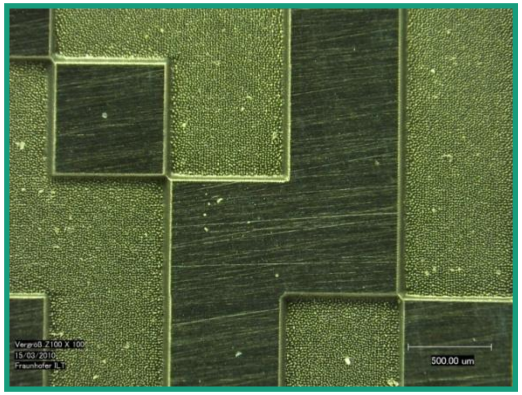
- Overlay of nanostructures
- Structure size: ~1µm

Functional Surfaces
Surface roughening

- ablation of 10-30 layers with high laser intensity
- generation of structures with high aspect ratio (>10)
- Applications
  - anti-reflection surface
  - scattering area
  - Change of wetting behaviour



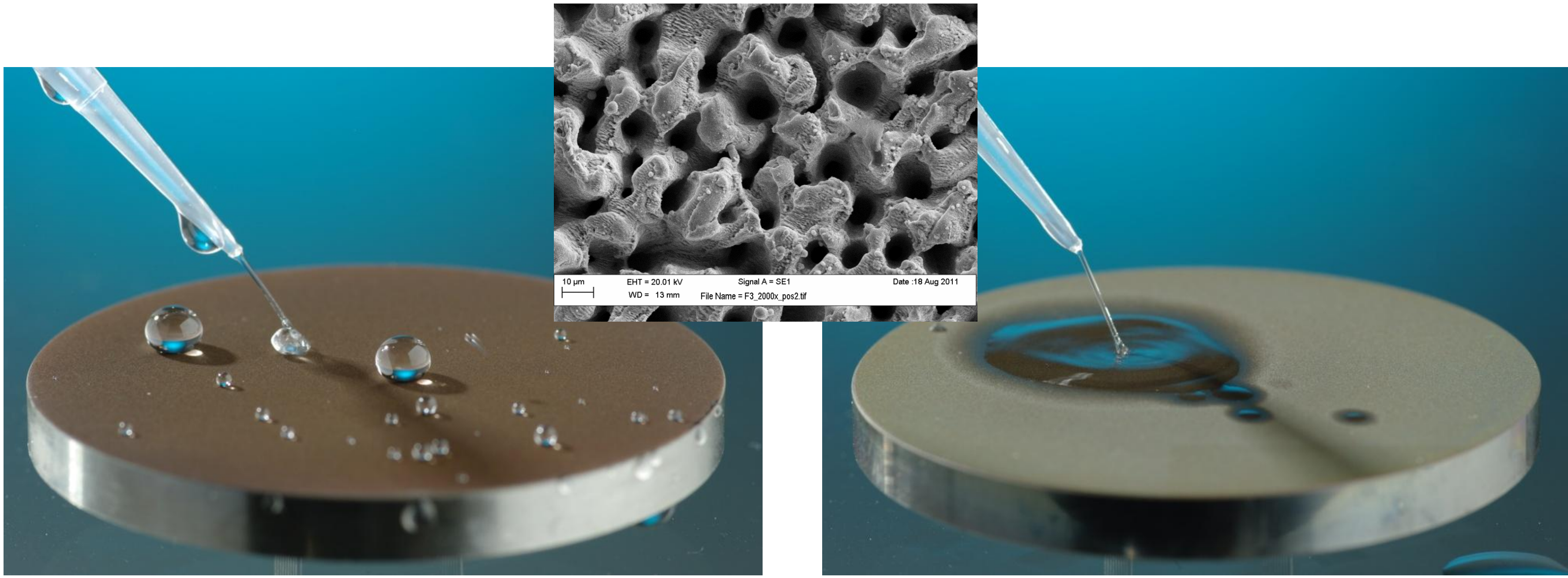




Fraunhofer ILT

Functional Surfaces

CLPs - Extreme enhancement of the surface area



Hydrophobic coating

- CLP (6-7µm)
- HMDSO Plasma Coating (300nm)
- Contact angle > 150°

Hydrophylic coating

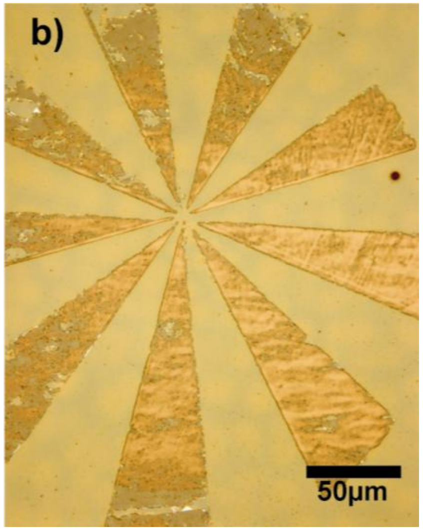
- CLP (6-7µm)
- HMDSO Plasma Coating with oxygen (300nm)

Fraunhofer ILT

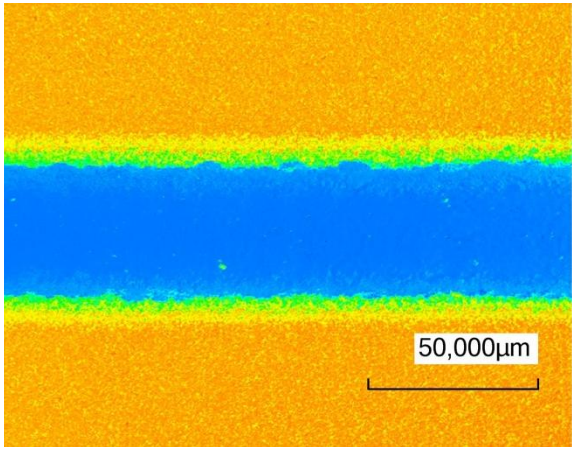
Functional Surfaces

Thin film processing

- Requirements for large area electronics:
  - Fast, High resolution
  - Shape independent
  - Different kind of layer materials and thicknesses (organic and anorganic)
  - No damage of the substrate
  - No delamination
- Used Laser
  - Excimer
    (193 nm, 248 nm, ns, mask projection)
  - Ultrafast laser
    (355, 532, 1064, fs…ps, Scanner deflection)
- Applications
  - OLED Lighting and Display
  - Thin film PV



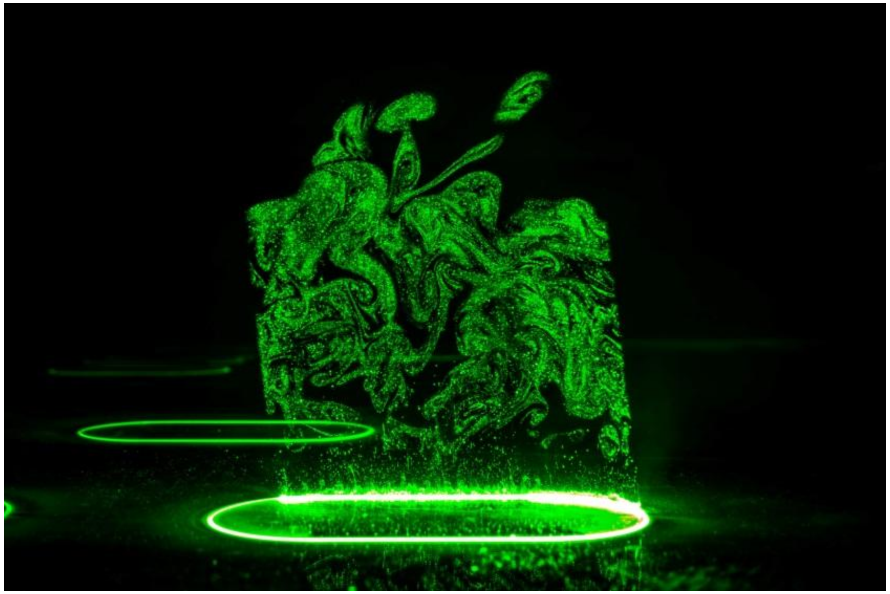
PEDOT:PSS
248nm
s= 1.6 ± 0.2 µm

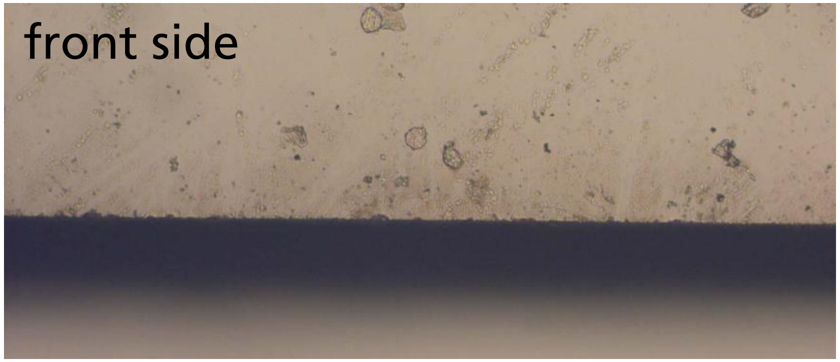


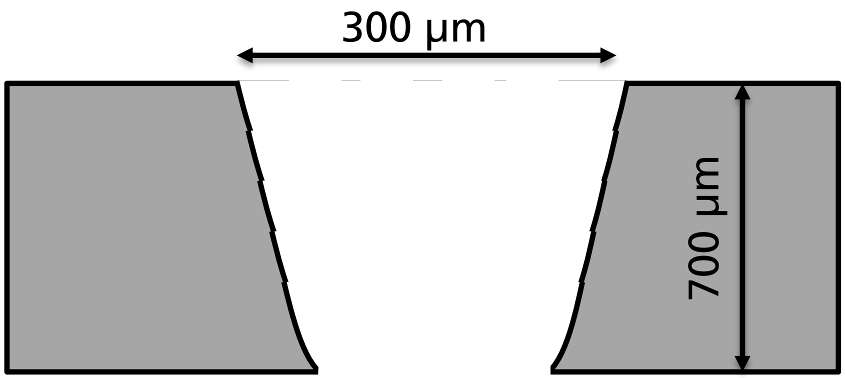
SnO on glass
10 ps, 355nm

Cutting
Thin glass processing

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



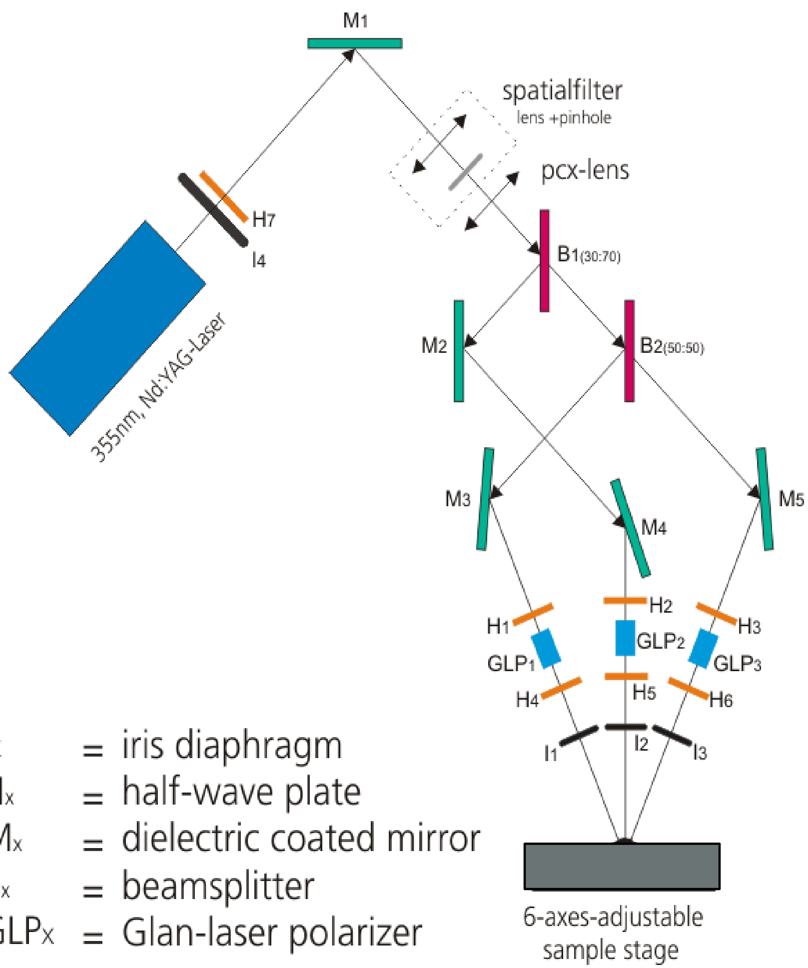




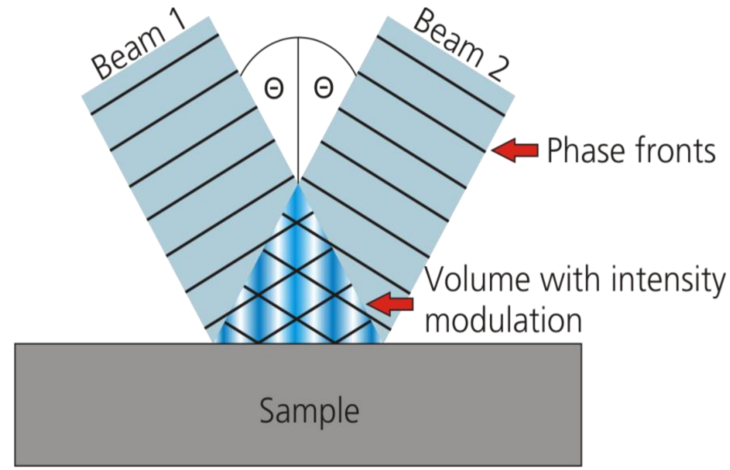
Fraunhofer ILT

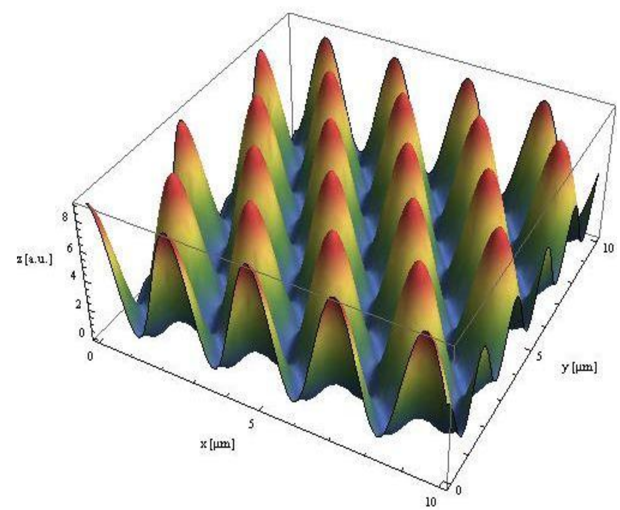
Periodic Nano Structuring

Interference Technique



Ix = iris diaphragm
Hx = half-wave plate
Mx = dielectric coated mirror
Bx = beamsplitter
GLPx = Glan-laser polarizer





Fraunhofer ILT

Periodic Nano Structuring

Interference Technique

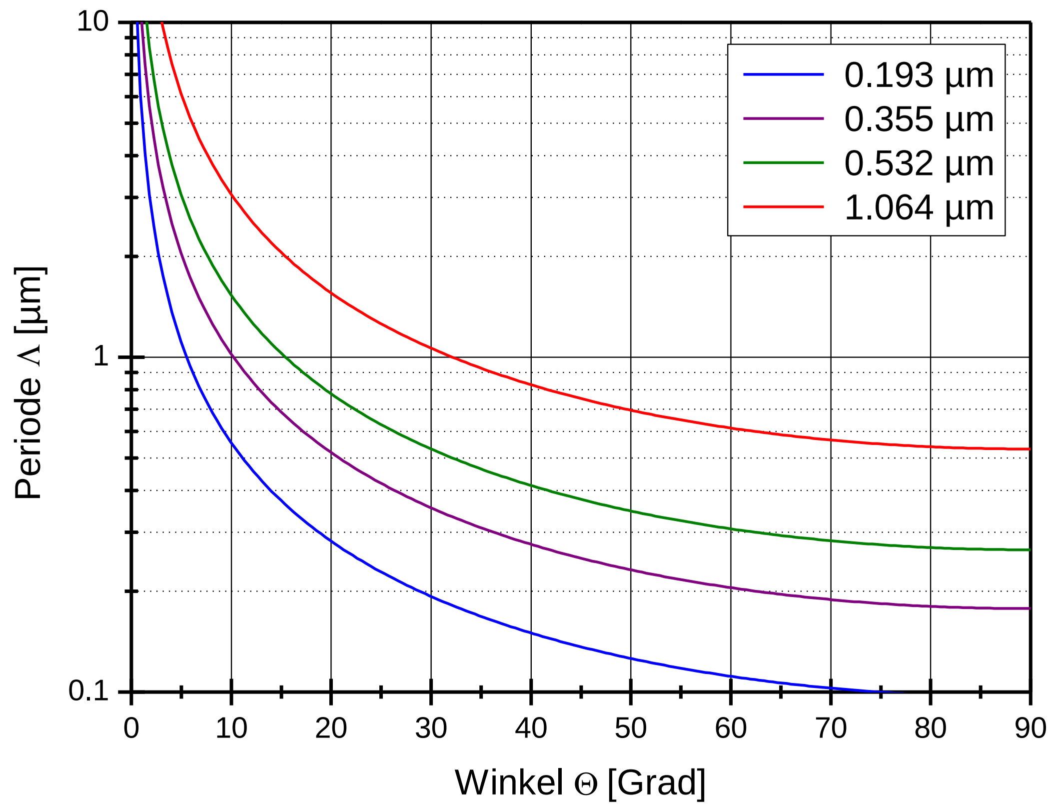
Periodicity controlled by:

- Laser wavelength
- Beam configuration
- Intersection angle

Formula:

$$\Lambda_{Periode} = \frac{\lambda_{Laser}}{2 \sin \Theta_{VW}}$$

Factor depends on beam configuration



Fraunhofer ILT

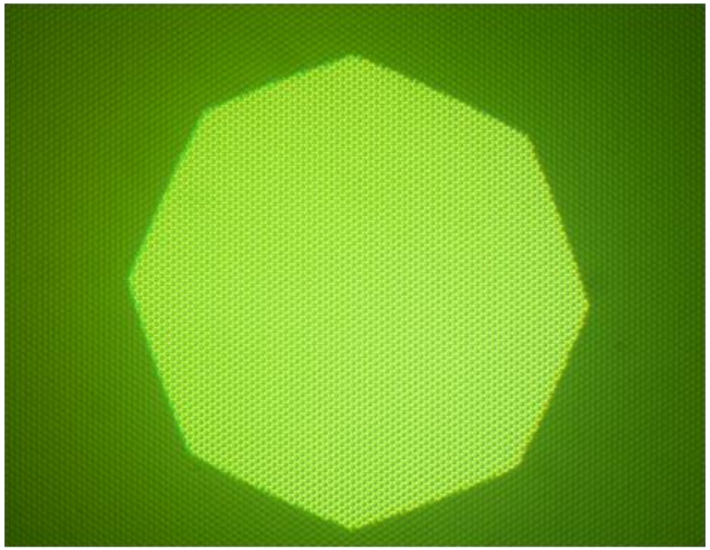
Periodic Nano Structuring
Interference Technique

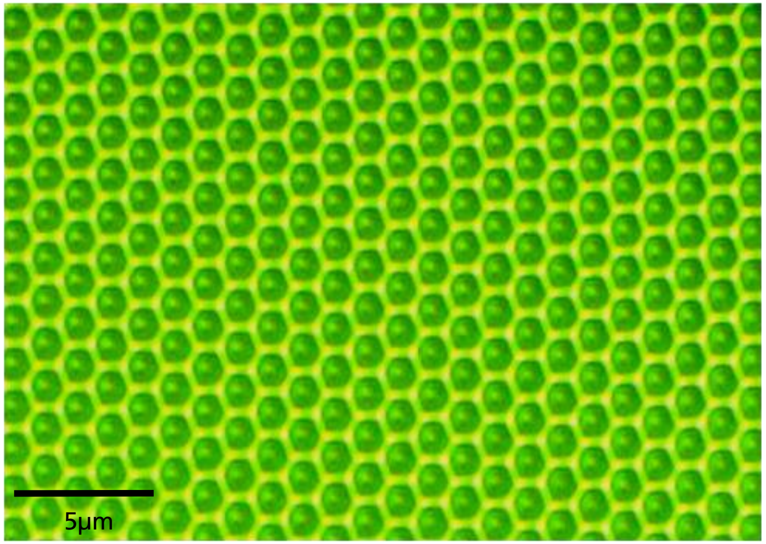
Potential
- Structures sizes: 100 nm - 5000 nm
- High uniformity of the created structures
- Whole beam diameter is structured simultaneously
- Non-flat surfaces can be processed
- Nearly material independent
- Only one process step

Challenges
- Gaussian beam profile leads to variations in structure size and depth over a spot
- Stitching necessary to structure area larger than the spot diameter
- Laboratory stage

Periodic Nano Structuring
Multi-Beam-Interference

- Structure geometry: Ø1 µm; depth: 600 nm
- Material: PEEK
- 100.000 holes with one shot
- Homogeneous structures over the entire spot (Ø500 µm)

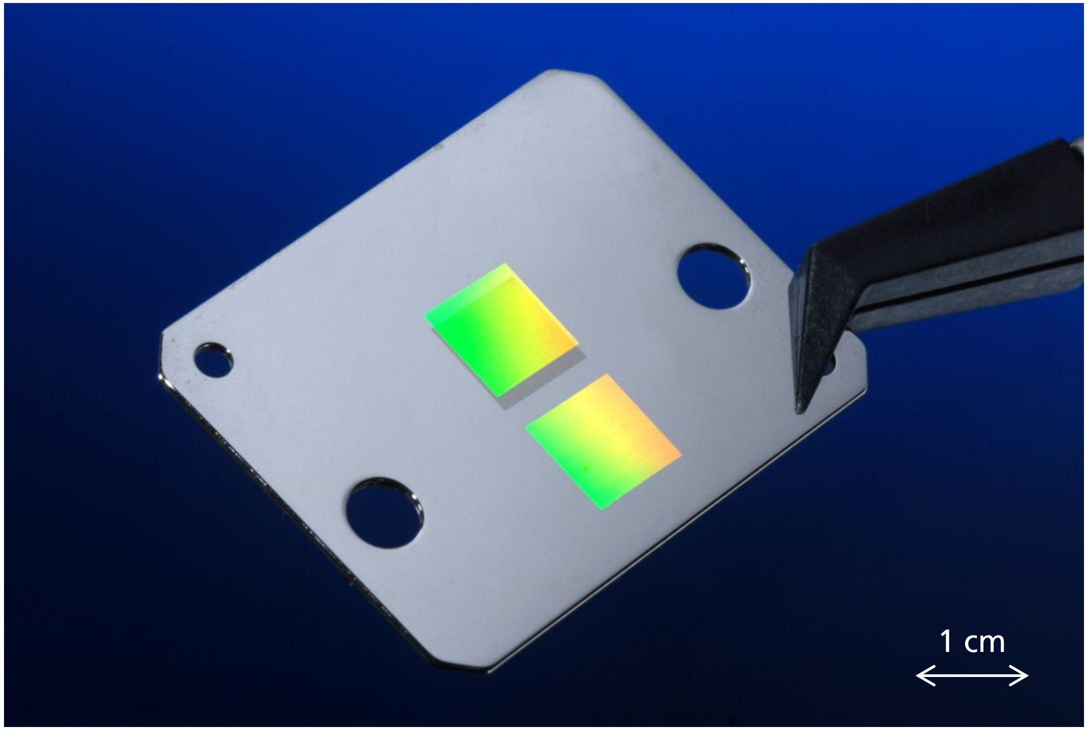




Periodic Nano Structuring

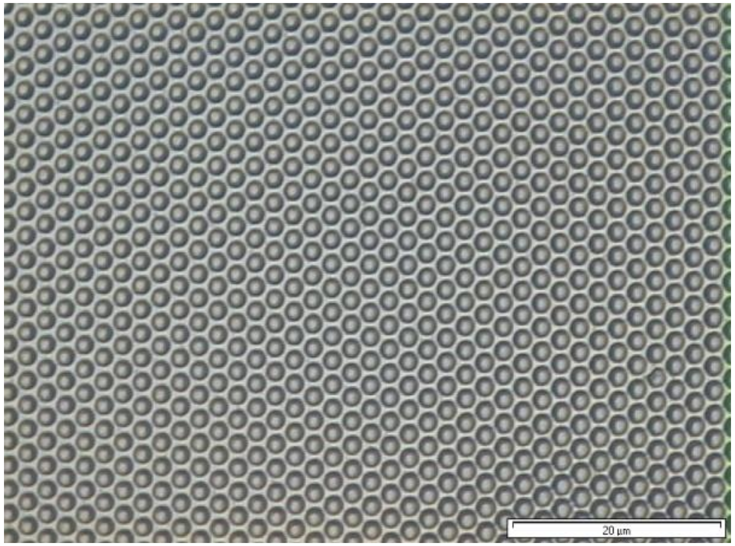
Multi-Beam-Interference

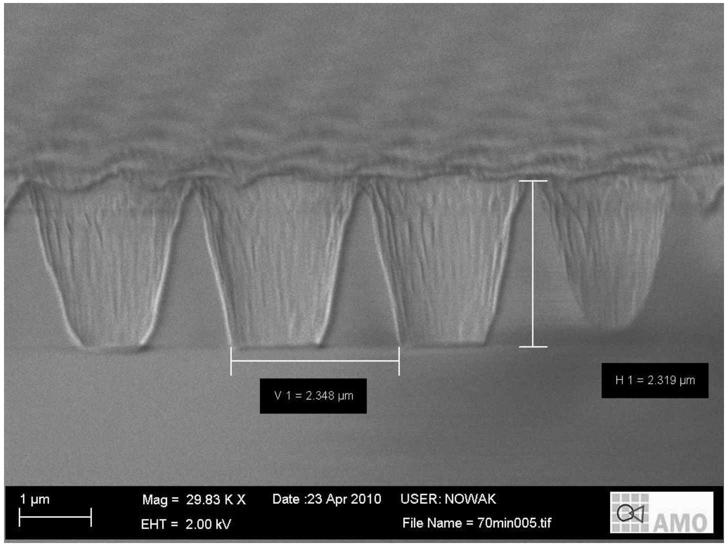
- Material: Stainless Steel
- Periodicity: 530 nm
- Focal diameter: 60 µm
- Wavelength: 355 nm
- 10 ps pulse duration



Periodic Nano Structuring
Multi-Beam-Interference

- Structure geometry: Ø1,6 µm; Depth: 2,3 µm
- Material: Quartz glass
- Structuring into Photoresist
- Subsequent Reactiv Ion Etching

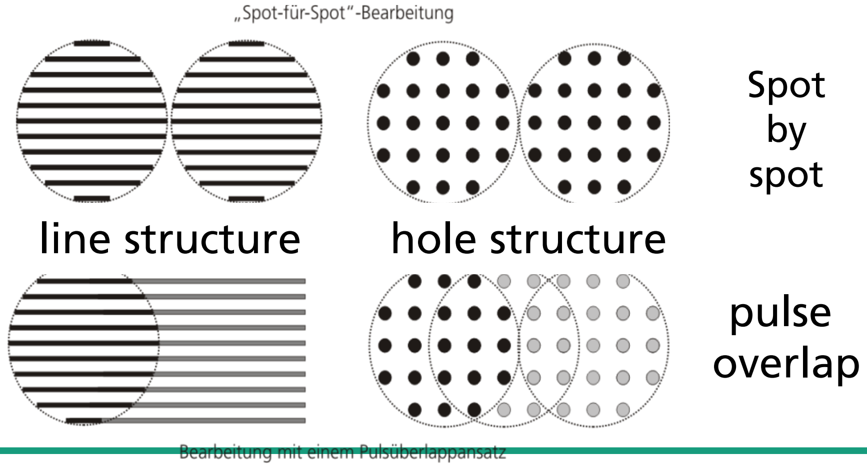


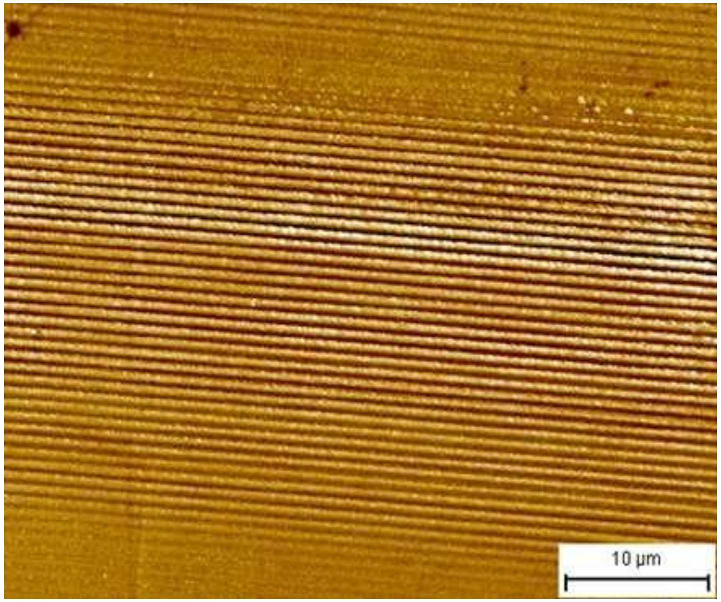


Periodic Nano Structuring
Interference Technique

Parameter

- Laser: 355nm, 400kHz, 10 ps
- Material: Brass
- Spot size: 30 – 50 µm
- Feed rate: 4500 mm/min
- Periodicty: 780 nm





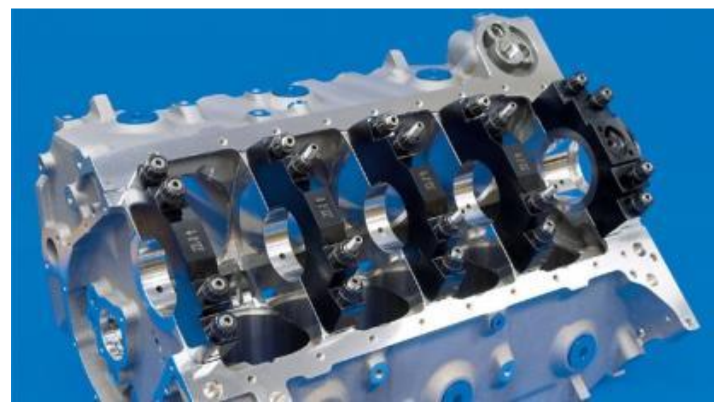
Future Developments

High Precision at Large Components

Cutting of fiber reinforced polymers

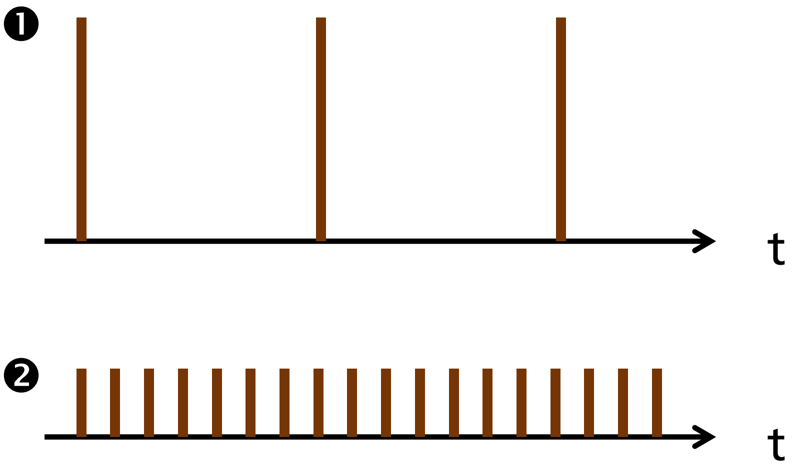
Large area processing

Surface structuring



Low friction surfaces

Large area processing
System strategies



high pulse energy / low reprate?

or

high reprate / low pulse energy?

Large area processing
Polygonic Mirror

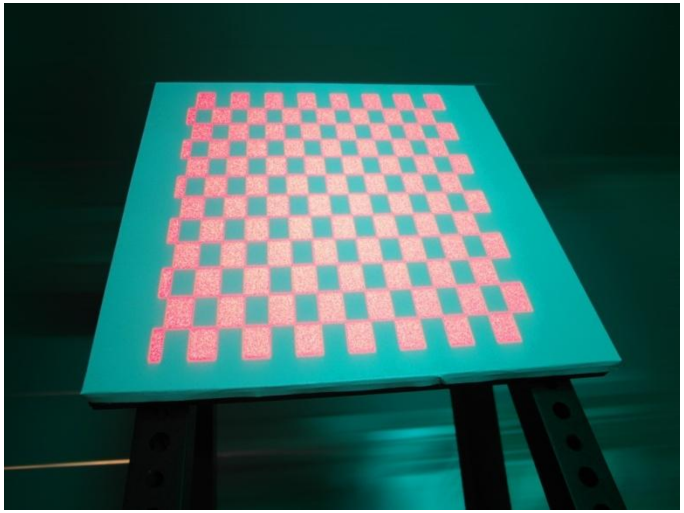
- Max. Scan velocity: 340 m/s (max. rpm: 12.000)
- Focal distance: 163 mm
- Focal diameter: 20-25 µm
- Scan-field: 100x100 mm^2
- Data import: Bitmap, PNG, 2D Array (Gray-scale value corresponds to number of Layers)
- Additional linear motor
- Number of mirrors: 11
- Max. Output Frequency: modulated 20 MHz; digital 40 MHz

Fraunhofer ILT

Large area processing
Polygonic Mirror

Chess pattern

- Calculation on FPGA
- 40 MHz Output Frequency
- Feed rate: 35 mm/s
- 9500 rpm

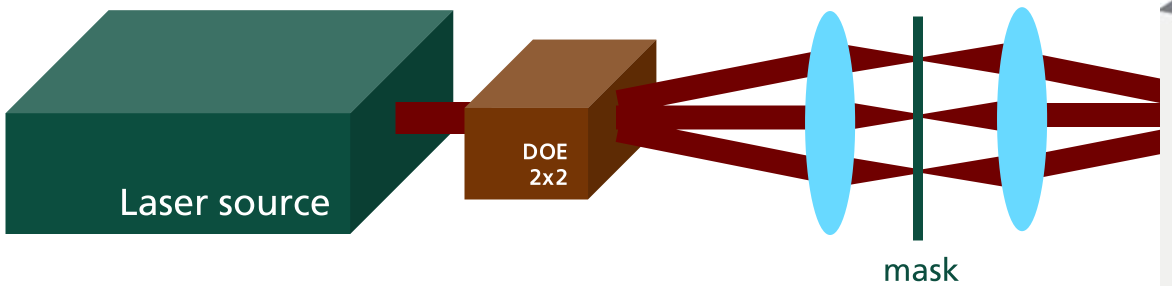


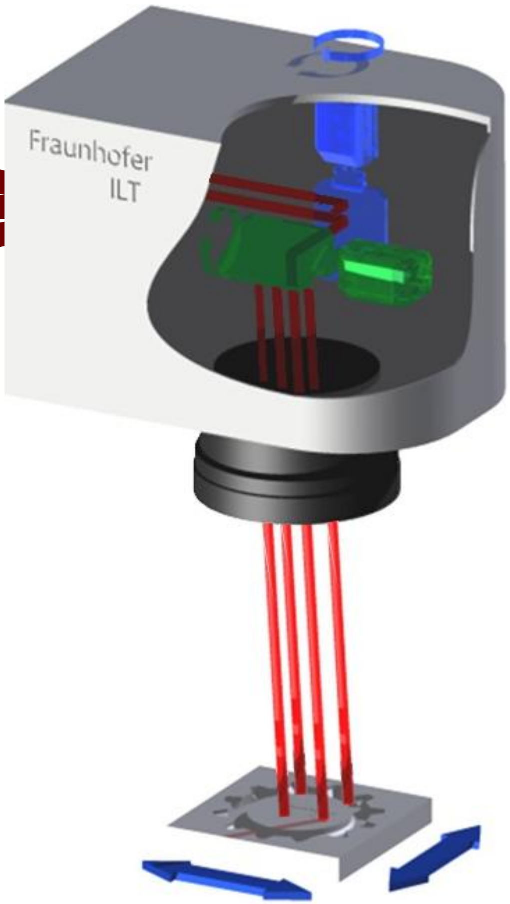
AC Dom, ILT + Polyscan Logo

- PNG-Import (25 MPix)
- 10 MHz Output Frequency
- Feed rate: 18 mm/s
- 2800 rpm

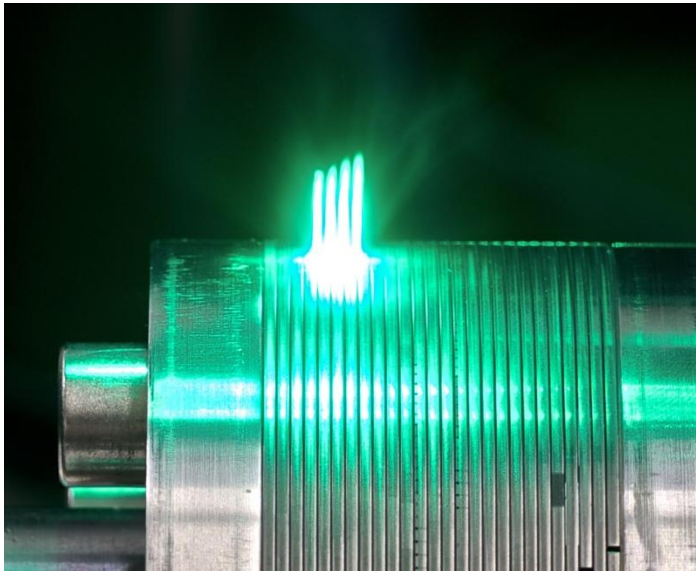
Large area processing

Multi-beam laser processing with DOEs





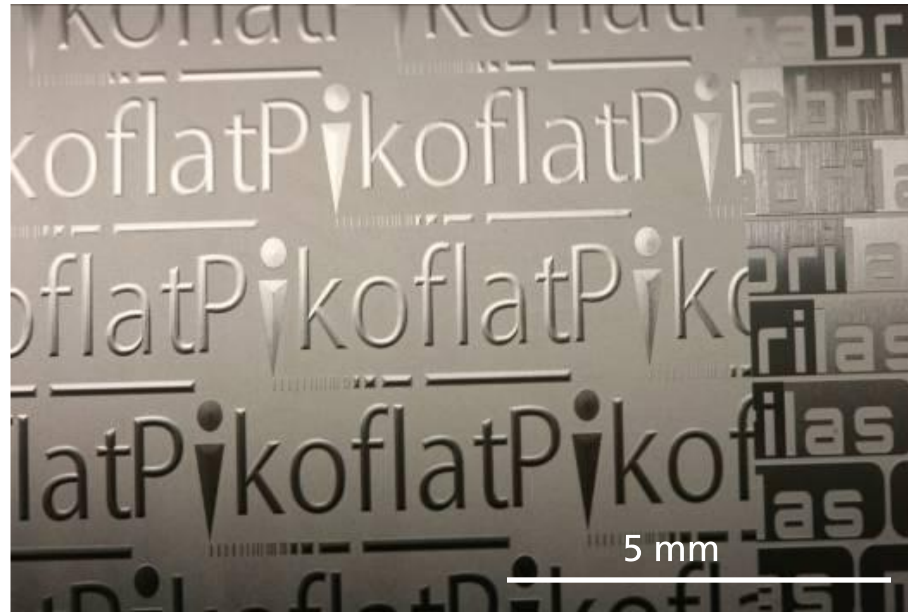
- Periodic structures
- Split high pulse energy into numerous partial beams



Large area processing

Micro structured Embossing rolls

- Material: chrome-plated Copper
- Dimensions:
  Ø250 mm; length 1 m
- Rotational speed:
  1400 rpm (v= 15 m/s)
- Line distance: 2 µm
- Focus diameter: 10 µm
- Laser power: 100 W



- Surface roughness <0,5 µm
- Min. structure size: 5 µm
- No burr

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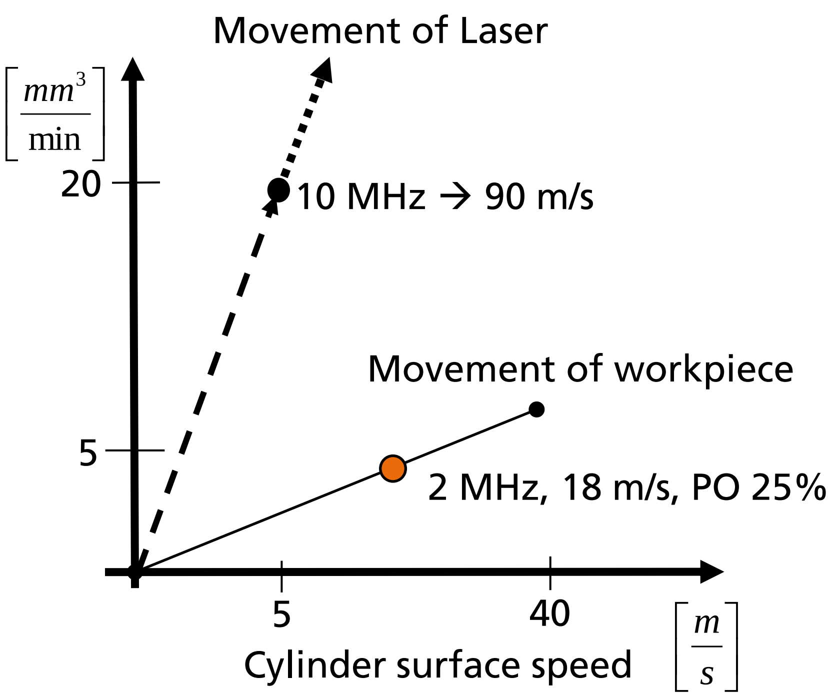
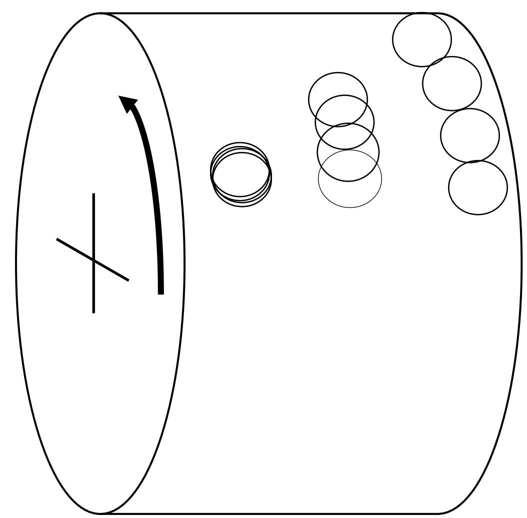
Large area processing
Micro structured Embossing rolls

- Higher ablation rate by additional scanning device



- Pulse overlap is controlled by rotational speed (fixed rep.rate)

Surface speed	1m/s	10m/s	20m/s
Pulse overlap (@ 2 MHz)	90%	50%	0%



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Future Developments

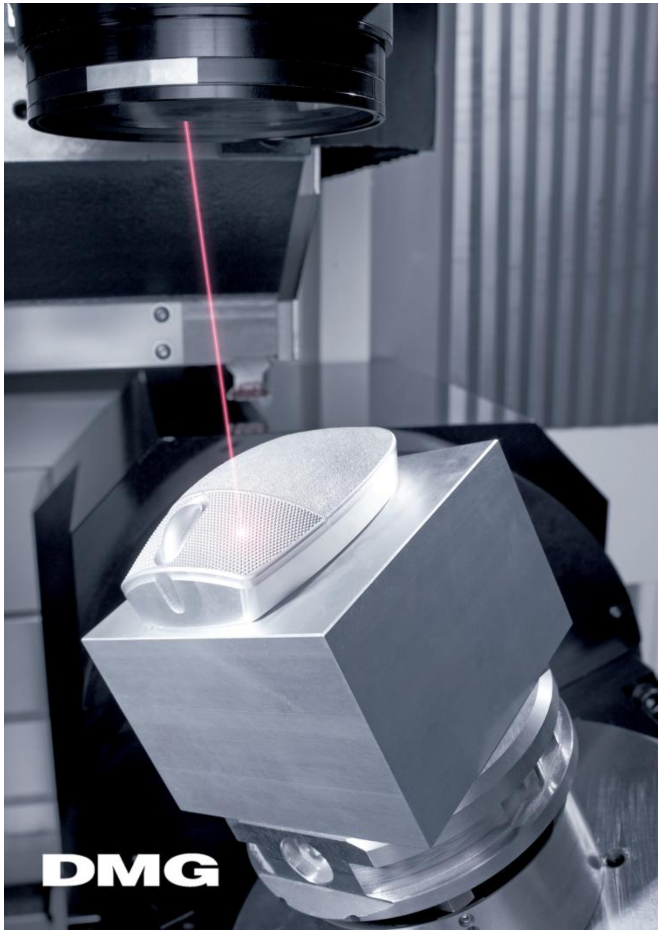
Ultrafast Manufacturing

Today:

- Typical ablation rates of e.g. Aluminum ca. 1 mm^3/min
- Limited by max. Laser power and Scanning speed

Future potential:

- Ablation rates of >5 mm^3/sec
- Use of fast deflection systems and >1 kW average Power
- Direct manufacturing of small components e.g. with specific surface features



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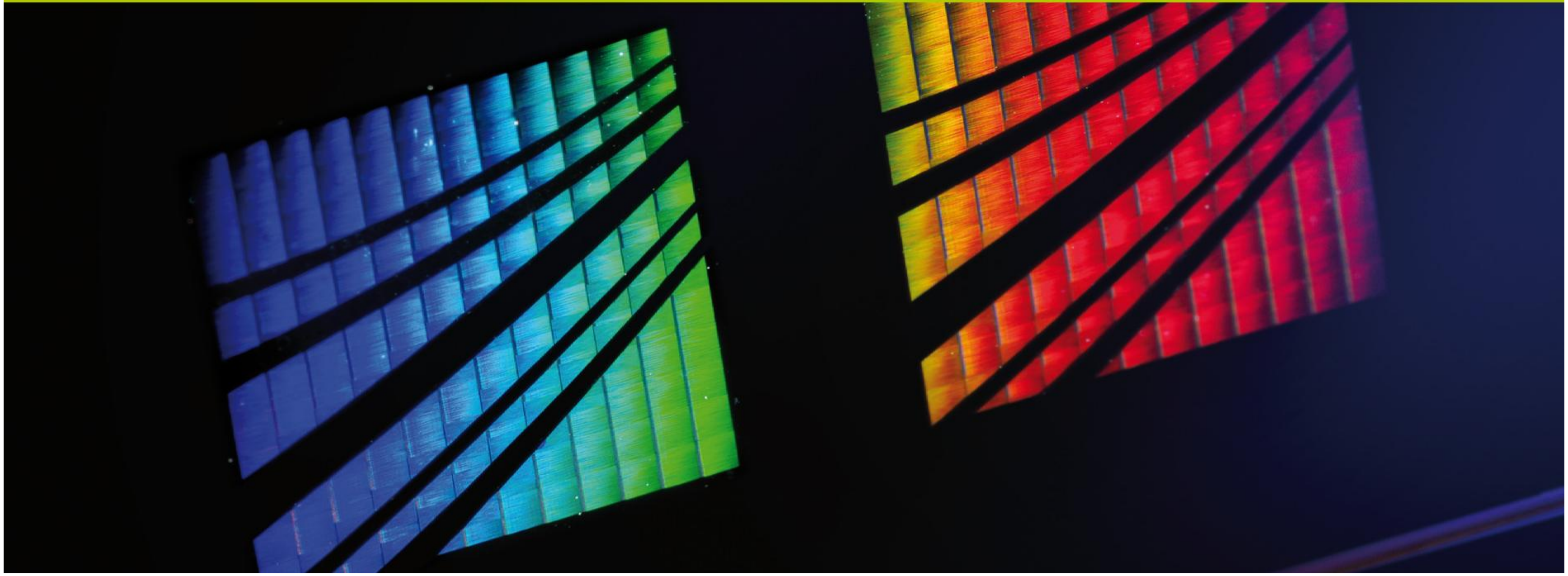
SAVE THE DATE

2. AACHENER ULTRAKURZPULSLASER-WORKSHOP

17./18. APRIL 2013



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